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FOREWORD

Highway construction utilizes a wide variety of materials. Control of the quality of these materials and the methods by which they are used is a major concern of the highway practitioner throughout the planning, design, and construction stages of a project.

Requirements are set up in the form of specifications to govern both the quality of materials and their utilization. The Office of Materials has established procedures for determining whether the materials used and the end products meet the specified requirements. To assist the practitioner in making these determinations, this section has prepared a series of manuals as a guide to applying the standard control procedures.

The Supervising Engineers and their Inspectors accomplish the final control of the quality of materials and their use through on-the-job inspection. The ultimate responsibility rests with the Field Personnel to see that materials used meet the requirements of the Specification, the prescribed procedures are followed when so specified, and the required end results are obtained.

This Manual is intended primarily for use in the Field and is prepared from that point of view. We have endeavored to point out the fundamental principles involved in the different types of work and to describe standardized procedures for practical application by the inspection personnel on the job.

Adherence to these procedures will help ensure uniformity of requirements throughout the State on all projects, and will do much to make the inspection more effective in obtaining the best construction possible under the Specification.

The Manual has been revised and brought up-to-date to conform to the 2000 Edition of the Mn/DOT Standard Specifications for Construction.

In addition to this printed copy, we have stored, for your convenience, a copy (pdf format) of the Concrete Manual on the Mn/DOT Concrete Engineering website at www.mrr.dot.state.mn.us/pavement/concrete/manual.asp.

GENERAL
5-694.000

5-694.001 INTRODUCTION

This Manual is prepared to familiarize Engineering Personnel, Contractors, and Consultants with the fundamentals, principles, and better practices of concrete construction so that the best possible concrete pavements and structures, consistent with job specifications, are obtained. Particular emphasis is placed on test methods and inspection procedures for the control of concrete production and placement. Manual specifics are addressed to both the Contractor and the Engineer. However, the Engineer or Inspector should never adjust or otherwise operate the Contractor's equipment.

It includes a description of concrete materials, their uses and applications on concrete pavements, bases, bridges, culverts, curb and gutter, and other miscellaneous construction, construction procedures for the various types of work, items of concern to the Inspectors, duties of the Inspectors, typical design, adjustment of concrete mixes, useful tables, and required report forms.

Familiarity with the contents and instructions in this Manual will simplify the work of the Inspector and provide uniformity of control procedures. Where the instructions in this Manual differ from the Specifications and Plans on a project, the Specifications and Plans shall govern.

The Specifications are not repeated in their entirety herein; however, as an aid in locating the related material, a reference number sometimes is given.

5-694.002 PROCEDURE FOR ROUNDING-OFF NUMBERS

To “round-off” is to reduce to some predetermined point the number of places to which an observed or calculated figure is recorded. This is accomplished by either retaining the figure in the last place or point based upon the value of figures following this point. The general rules for rounding-off follow:

1. When the figure next beyond the last place retained is less than 5, retain unchanged the figure in the last place retained.
2. When the figure next beyond the last place retained is greater than 5, or a 5 followed by any figures other than zeros, increase by 1 in the figure in the last place retained.
3. When the figure next beyond the last place retained is exactly 5 (a 5 followed only by zeros), the figure in the last place retained shall remain unchanged if that figure is even (0, 2, 4, 6, 8) and increased by 1 if the figure in the last place retained is odd (1, 3, 5, 7, 9). This means: when the figure next beyond the last place retained is 5 and is followed only by zeros, round to nearest even number.
4. The rounded-off value of any number is performed by direct rounding of the most precise observed or calculated value available and not in two or more steps of successive roundings.
5. When it is desired to round-off a figure to the nearest 50, 5, 0.5, etc. proceed by doubling the observed or calculated value and round that value to the nearest 100, 10, 1.0, 0.1, etc. in accordance with the above procedures. Then, halve (divide by 2) the rounded figure to obtain the final rounded product. For example: To round-off the number 7075 to the nearest 50, double the number 7075 (14150) and round that number to the nearest 100 (becomes 14200). When 14200 is divided by 2, the resulting number 7100, is the rounded product of 7075. Some examples of rounding off are:

Observed or Calculated Value	To Be Rounded-Off to Nearest	Becomes Rounded Off Value
1.03497	1/100 or 0.01	1.03
1.03500	1/100 or 0.01	1.04
1.04500	1/100 or 0.01	1.04
1.03502	1/100 or 0.01	1.04
1.34999	1/10 or 0.1	1.3
1.35000	1/10 or 0.1	1.4
1.45000	1/10 or 0.1	1.4
1.35001	1/10 or 0.1	1.4
1.49999	Whole Unit or 1	1
1.50000	Whole Unit or 1	2
2.50000	Whole Unit or 1	2
1.50023	Whole Unit or 1	2
1.24987	1/2 or 0.5	1.0
1.25000	1/2 or 0.5	1.0
2.25000	1/2 or 0.5	2.0
2.25023	1/2 or 0.5	2.5

5-694.003 Mn/DOT CONCRETE SPECIFICATIONS

Below is a list of Specifications relating to concrete that are currently found in the Mn/DOT Standard Specifications for Construction, 2000 Edition.

DIVISION I - GENERAL REQUIREMENTS

DIVISION II - CONSTRUCTION DETAILS

2301 - CONCRETE PAVEMENT
2401 - CONCRETE BRIDGE CONSTRUCTION
2404 - CONCRETE WEARING COURSE FOR BRIDGES
2411 - MINOR CONCRETE STRUCTURES
2461 - STRUCTURAL CONCRETE
2514 - SLOPE PAVING
2521 - WALKS
2531 - CONCRETE CURBING
2533 - CONCRETE MEDIAN BARRIERS

DIVISION III - MATERIALS

3101 - PORTLAND CEMENT
3102 - GROUND GRANULATED BLAST FURNACE SLAG CEMENT
3103 - PORTLAND-POZZOLAN CEMENT
3105 - BAGGED PORTLAND CEMENT CONCRETE PATCHING MIX GRADE 3U18
3106 - HYDRATED LIME
3107 - MASONRY CEMENT
3113 - ADMIXTURES FOR CONCRETE
3115 - FLYASH FOR USE IN PORTLAND CEMENT CONCRETE
3126 - FINE AGGREGATE FOR PORTLAND CEMENT CONCRETE
3137 - COARSE AGGREGATE FOR PORTLAND CEMENT CONCRETE
3301 - REINFORCEMENT BARS
3702 - PREFORMED JOINT FILLERS
3721 - PREFORMED ELASTOMERIC COMPRESSION JOINT SEALS FOR CONCRETE
3723 - JOINT AND CRACK SEALER (HOT POURED ELASTIC TYPE)
3725 - JOINT AND CRACK SEALER (HOT POURED, EXTRA LOW MODULUS, ELASTIC TYPE)
3751 - BURLAP CURING BLANKETS
3754 - MEMBRANE CURING COMPOUND
3755 - EXTREME SERVICE MEMBRANE CURING COMPOUND
3902 - FORM COATING MATERIALS
3906 - WATER FOR CONCRETE AND MORTAR
3911 - CALCIUM CHLORIDE
3917 - CONCRETE TREATING OIL

5-694.004 METRIC EQUIVALENTS

Below is a list of different metric conversion factors commonly dealt with in the concrete industry.

A. METRIC CONVERSIONS

	MULTIPLY	BY	TO OBTAIN
LENGTH	inches (in.)	25.40	millimeters (mm)
	feet (ft.)	0.3048	meters (m)
	yards (yd.)	0.9144	meters (m)
	miles (mi.)	1.609 344	kilometers (km)
AREA	square inches (in^2)	645.16	square millimeters (mm^2)
	square feet (ft^2)	0.0929	square meters (m^2)
	square yards (yd^2)	0.8361	square meters (m^2)
VOLUME	cubic inches (in^3)	16387.064	cubic millimeters (mm^3)
	cubic foot (ft^3)	0.02832	cubic meters (m^3)
	cubic yards (yd^3)	0.76455	cubic meters (m^3)
MASS (WEIGHT)	ounces (oz.)	28.3495	grams (g)
	pounds (lb.)	0.4536	kilograms (kg)
	kips (k)	0.4536	tonnes (metric ton)
	tons (Tn)	0.9072	tonnes (metric tons)
	tonnes (metric ton)	1000.0	kilograms (kg)
	sack of cement	42.64	kilograms (kg)
STRESS	pounds/square inch (psi)	6.8948	kilopascal (kPa)
	pounds/square inch (psi)	0.006895	megapascal (MPa)
	kip/square inch (ksi)	6.8948	megapascal (MPa)
	kip/square foot (ksf)	47.8803	kilopascal (kPa)
	pascal (Pa)	1.0	N/m^2
FORCE	poundforce (lbf)	4.4482	newton (N)
	kip (k)	4.4482	kilonewton (kN)
	newton (N)	1.0	$kg \cdot m/sec^2$
MASS DENSITY	pounds/cubic foot (pcf)	16.0185	kilogram/cubic meter (kg/m^3)
	pounds/cubic yard (pcy)	0.5935	kilogram/cubic meter (kg/m^3)

	MULTIPLY	BY	TO OBTAIN
WATER	gallons (gal)	3.785	liters (L)
	liters (L)	1.0	kilograms (kg)
PROFILOGRAPH OR INERTIAL PROFILER	inches/mile (in/mi)	15.78	millimeters/kilometer (mm/km)
TEMPERATURE	Fahrenheit (ºF)	5/9(ºF – 32)	Celsius (ºC)
ADMIXTURE	ounces/cubic yard (oz./c.y.)	39	milliliters/cubic meter (mL/m^3)
	fluid ounces/100 lb. cement (fl.oz./cwt)	0.6519	milliliters/kilogram (mL/kg)
	gallons (gal)	0.0037831	cubic meter (m^3)

B. PROPERTIES OF CONCRETE

CONCRETE STRENGTHS (Not Exact Conversions)								
Metric (MPa)	**19**	**23**	**27**	**30**	**32**	**34**	**37**	**39**
English (psi)	**2700**	**3400**	**3900**	**4300**	**4700**	**5000**	**5300**	**5600**

UNIT WEIGHTS (Not Exact Conversions)		
	Metric	**English**
Steel	**7850 kg/m^3**	**490 pcf**
Concrete	**2400 kg/m^3**	**150 pcf**

REINFORCING BARS, M31M				
Grade		**Tensile and Yield Strengths**		
Metric	**English**	**Tensile Strength (MPa)**	**Min. Yield Strength (MPa)**	**Min. Yield Strength (ksi)**
300	**40**	**500**	**300**	**40**
400	**60**	**600**	**400**	**60**

COEFFICIENT OF THERMAL EXPANSION		
	Metric	**English**
Steel	**0.0000117/EC**	**0.0000065/EF**
Concrete	**0.0000108/EC**	**0.000006/EF**

C. SIEVE SIZES

The sieves used for portland cement concrete are noted below.

Metric	English
50 millimeter (mm)	2”
37.5 mm	1 1/2”
31.5 mm	1 1/4”
25.0 mm	1”
19.0 mm	3/4”
16.0 mm	5/8”
12.5 mm	1/2”
9.5 mm	3/8”
4.75 mm	#4
2.36 mm	#8
2.00 mm	#10
1.18 mm	#16
850 micrometer (µm)	#20
600 µm	#30
425 µm	#40
300 µm	#50
180 µm	#80
150 µm	#100
75 µm	#200

5-694.005 REINFORCING BARS AND HOOK DETAILS

Reproductions of Concrete Reinforcing Steel Institute (CRSI) Reinforcing Bar Specifications and Standard Metric Hook Details are reproduced in Figures A through C 5-694.005.

A 1997 publication from the CRSI indicates that ASTM has approved the soft converted bar sizes and that AASHTO is recommending the use of these revised ASTM specifications. The net result is that the bars are the same physical size as previous, with a new metric size designation.

Figure A 5-694.005 shows the approved standard bar markings for Mn/DOT projects. Soft metric reinforcing bars are identified with the Producer's mill designation, bar size, type of steel, and minimum yield strength or grade as shown in Figure B 5-694.005. Figure C 5-694.005 shows approved hook details.

METRIC BAR SIZE	DIAMETER (mm)	DIAMETER (in.)
#10	9.5	0.375
#13	12.7	0.500
#16	15.9	0.625
#19	19.1	0.750
#22	22.2	0.875
#25	25.4	1.000
#29	28.7	1.128
#32	32.3	1.270
#36	35.8	1.410
#43	43.0	1.693
#57	57.3	2.257

Figure A 5-694.005[1]

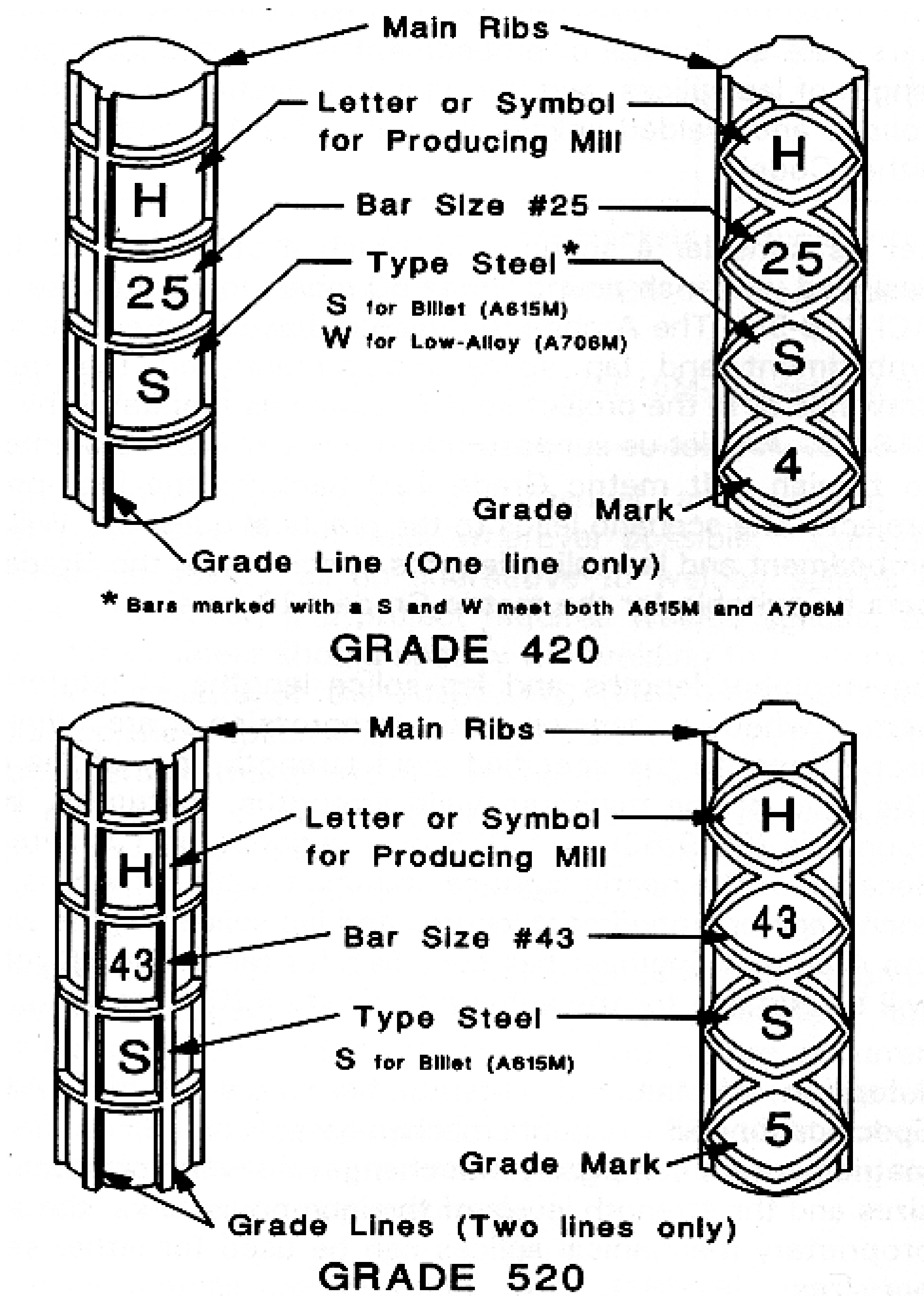
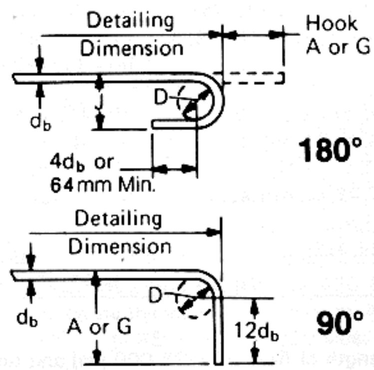


Figure B 5-694.005[2]



RECOMMENDED END HOOKS, ALL GRADES OF STEEL

BAR SIZE	D	180° HOOKS		90° HOOKS
		A or G	J	A or G
#10	60	125	80	150
#13	80	150	105	200
#16	95	175	130	250
#19	115	200	155	300
#22	135	250	180	375
#25	155	275	205	425
#29	240	375	300	475
#32	275	425	335	550
#36	305	475	375	600
#43	465	675	550	775
#57	610	925	725	1050

NOTE: All dimensions are in millimeters (mm).

ALL GRADES OF STEEL

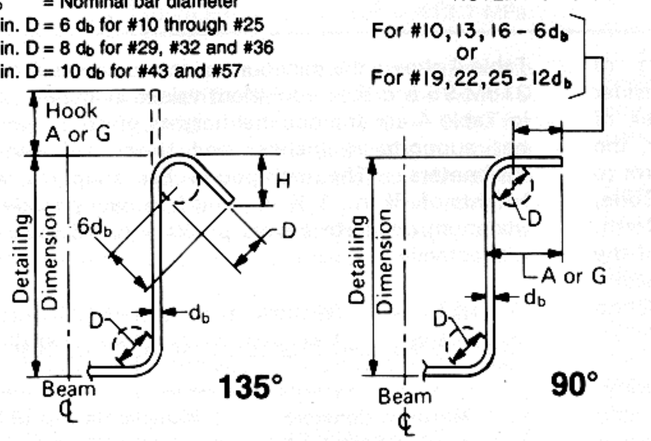
D = Finished inside bend diameter

d_b = Nominal bar diameter

Min. D = 6 d_b for #10 through #25

Min. D = 8 d_b for #29, #32 and #36

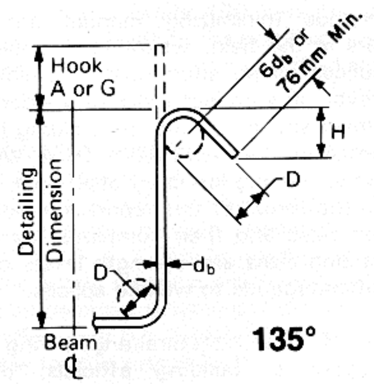
Min. D = 10 d_b for #43 and #57



STIRRUP HOOKS (Tie Bends Similar)

BAR SIZE	D	90°	135°	
		A or G	A or G	H*
#10	40	105	105	65
#13	50	115	115	80
#16	65	155	140	95
#19	115	305	205	115
#22	135	355	230	135
#25	155	410	270	155

*H dimension is approximate.
NOTE: All dimensions are in millimeters (mm).



SEISMIC STIRRUP / TIE

BAR SIZE	135° SEISMIC HOOK		
	D	A or G	H*
#10	40	110	80
#13	50	115	80
#16	65	140	95
#19	115	205	115
#22	135	230	135
#25	155	270	155

*H dimension is approximate.
NOTE: All dimensions are in millimeters (mm).

Figure C 5-694.005[3]

5-694.010 INSPECTOR'S CHECKLISTS

These checklists serve as a guide to new Inspectors, or refresh the memory of experienced Inspectors. While they are fairly complete, a good Inspector will modify and add to these checklists to meet the requirements of their particular job, taking into consideration the personnel and equipment used, and changes in the Specifications and the Special Provisions.

5-694.011 CHECKLIST FOR READY-MIX CONCRETE PLANT MONITOR - AGENCY

√ LIST FOR READY-MIX CONCRETE PLANT MONITOR	Specs.	Concrete Manual
1. Confirm that the ready-mix plant is authorized to produce certified concrete and that a *Contact Report* (signed by the Agency and Producer) is on file for the current year.	2461.4D7e	5-694.716
2. Become familiar with concrete batching and mixing equipment and the duties of the Producer.	2461.4B 2461.4C	5-694.012 5-694.430
3. Verify scale calibrations are complete and up-to-date.		5-694.401 -.440
4. Verify cement, fly ash, and admixtures are certified and approved. (www.mrr.dot.state.mn.us/pavement/concrete/products.asp)		5-694.114 -.116
5. Obtain cement and fly ash invoices (if available).		5-694.114
6. Verify the sources of the aggregates used in the mix.		
7. Check *Certificate of Compliance* for completeness and accuracy.	2461.4D7a	5-694.723
8. Verify the proper mix design weights.		5-694.143
9. Verify batch person is using current moisture results.		5-694.718
10. Take appropriate lab samples as required by the Schedule of Materials Control.		5-694.132
11. Fill out lab sample I.D. cards completely and enclose them with lab samples. Promptly submit to lab for testing.		5-694.751
12. Obtain fine and course aggregate verification samples as per Schedule of Materials Control and give a split sample to the Producer. **NOTE: Where problems of compliance with the Certified Ready-Mix Program occur, increase plant inspection and testing rates.**		5-694.132 -.135
13. Watch Certified Technician obtain and run moisture and gradation tests when possible.		5-694.141 -.148
14. Check to make sure the Producer completed the initial gradation and moisture tests prior to the start of concrete production each day.	2461.4D7c 2461.4D7d	
15. Check to make sure the Producer has run the required amount of gradation and moisture tests. Obtain companion to Producer's QC gradation sample as needed.	Schedule of Materials Control	
16. Review gradation results with respect to project specifications. Compare QC results to verification and companion sample results.	3126 3137	
17. Check Producer's aggregate QC charts for material consistency and verify charts and plant diary are accurate and up-to-date.	2461.4D7b - 2461.4D7d	5-694.735 5-694.736
18. Watch the batchperson weigh at least 1 load each time an audit gradation is collected. This includes observing the removal of wash water from the ready-mix truck by reversing the drum.	2461.4D7d	
19. Validate all water weights on the load watched and compare the total water with the design water. Record the results on the *Weekly Certified Ready-Mix Plant Report*.	2461.4D7d	5-694.725
20. Maintain daily diary which includes: time arrived and departed from plant, lab sample type and I.D. number, total cubic yards produced (estimate if necessary), materials with appropriate sources, any additional comments, and the signature of the Agency Inspector.	2461.4D7b	5-694.726
21. Submit *Weekly Certified Ready-Mix Plant Report* to Mn/DOT Concrete Engineering Unit on a weekly basis.	2461.4D7d	5-694.725

5-694.012 CHECKLIST FOR READY-MIX CONCRETE PLANT – PRODUCER

√ LIST FOR READY-MIX CONCRETE PLANT - PRODUCER	Specs.	Concrete Manual
1. Sample aggregates for gradation and moisture test. See Certified Ready-Mix Concrete Plant Specifications, Special Provisions, and Schedule of Materials Control.	3137 3126	5-694.127 5-694.128
2. Run fine and coarse aggregate gradations. If aggregates fail to meet Specifications, inform plant superintendent immediately.	2461.4D7d	5-694.141 5-694.144 - .148
3. Perform moisture test on all aggregate fractions and report results to the batch person.	2461.4D7c	5-694.142 - .143
4. If there is a definite indication of moisture change at any time, or prior to a high-early pour, run new moisture tests.		
5. Complete required reports: • *Concrete Batching Report - Form 2152* • Chart moisture on *Aggregate Moisture Content Chart* • *Concrete Aggregate Worksheet - Form 21763* • Chart gradations on *QC charts* • *Weekly Concrete Aggregate Report - Form 2449*		5-694.718 - .722
5. Make periodic checks during the day of the entire plant to see that it is functioning satisfactorily. Spot check the central plant mix timer for accuracy.	2461.4D	5-694.401 - .430
6. Check accuracy of scales and verify scale calibrations are complete and up-to-date.		5-694.431 - .435
7. Check the aggregate bins and piles. Assure that there is no contamination or interblending of the aggregates.		5-694.124
8. Check Certificate of Compliance for completeness and accuracy, or prepare a handwritten *Certificate of Compliance –Form 0042* if necessary.	2461.4D7a	5-694.723
9. Witness the actual batching of concrete to assure desired batch weights and tolerances are met.	2301.3F	
10. Check ready-mix trucks occasionally to see if revolution counters are working properly and the mixing drums are clean and blades are not worn.	2461.4D5	
11. Detain transit mix trucks on a level area until the minimum specified mixing time is accomplished.	2461.4D5c	
12. Maintain a daily plant diary that must remain at the plant site. The diary will document state project numbers, yards produced each day, tests performed, material problems, breakdowns, weather, etc., all to the approval of the Engineer.	2461.4D7b	5-694.724

5-694.013 CHECKLIST FOR MISCELLANEOUS CONCRETE INSPECTION

√ LIST FOR MISC. CONCRETE INSPECTION	Specs.	Concrete Manual
1. Become familiar with applicable specifications for the type of work performed. Check the plan and special provisions for details or changes.		
2. Prior to placement of concrete: • Review Contractor's equipment and forms for contract compliance and to ensure plan dimensions are met. • Make sure Contractor has made adequate arrangements for proper curing and protection of the concrete. • Obtain equipment for slump and air tests, cylinders, and temperatures.	2461.4A5	5-694.511 5-694.521 5-694.531 5-694.541
3. During placement of concrete: • Check vertical and horizontal alignment. Make sure forms are complete and adequately braced to correct line and grade. • Inspect grade for slope, adequate compaction, and proper moisture. • Review requirements for reinforcing steel, tie bars, expansion joints, and contraction joints. Check reinforcement to see if it is securely placed in the proper position. • Check location from offset stakes. Confirm handicap ramp and driveway locations. • Verify conduits, brackets or other openings or attachments are securely in place. • Ensure that proper drainage conditions are met. • Review backfilling procedures.	Standard Plans and Standard Plates	5-694.630 - .632 5-694.642 - .664
4. Check on placement of concrete throughout the pour to see that concrete is placed without segregation, and that vibration and consolidation are adequate. Visually check delivered concrete for load-to-load consistency.	See concrete item specified.	5-694.610 - .622
5. Collect, check and initial *Certificate of Compliance*: • Verify S.P. Number • Verify Mix Number • Verify delivery time is within Specifications • Verify Water – Total Actual Water vs. Mix Design Water • Record any additional water that was added at the jobsite	2461.4D6 2461.4D7	5-694.723
6. Monitor number and speed of revolutions and document any water added, if applicable.	2461.4D5c	
7. Air and Slump Testing: • Perform air content and slump tests at the point of placement. Check the Schedule of Materials Control for sampling rates. If testing is not possible at point of placement, correlation testing must be performed. • If there is any question about the consistency or the quality of the concrete, run additional tests as necessary. • Notify Contractor if air content or slump results are outside of Specifications.	2461.4A4a 2461.4A4b	5-694.530 - .541

8. Compressive Strength Testing (Cylinders): • Make and store cylinders where they are protected from vibration or disturbance until placed in the curing tank. • Provide protection from extreme variations in temperature from the time of casting cylinder until it is transported to the lab.	2461.4A5	5-694.510 - .511
9. Finishing: • Check allowable tolerances and review finishing procedures. • Check surfaces with straight edges for correct line and grade prior to initial set so that corrections are made while concrete is still workable.	See concrete item specified.	5-694.630 5-694.670
10. Curing: • Verify curing compound is approved. Take samples as required by the Schedule of Materials Control. • Check application rate of curing compound for uniformity, yield, and timely placement. • Check all concrete surfaces for adequate curing, immediately after pour and on subsequent days, until end of curing period. • If required, ensure proper cold weather protection is utilized.	See concrete item specified.	5-694.680 - .684
11. Maintain a daily diary that documents hours of production, equipment, concrete temperatures, air content, slump reading, cylinder data, location of work, yield, weather, air temperatures, any instructions directed to Contractor, and problems or unique circumstances encountered.		
12. Submit *Weekly Concrete Report* to Mn/DOT Concrete Engineering Unit on a weekly basis.	2461.4D7	5-694.727

5-694.014 CHECKLIST FOR CONCRETE PAVING BATCH PLANT INSPECTOR

√ LIST FOR CONCRETE PAVING BATCH PLANT INSPECTOR	Specs.	Concrete Manual
1. Verify the Contractor's aggregate sources and make sure preliminary testing has been done well in advance of the project start date.	See Special Provisions	
2. Make sure the Contractor submits mix designs to the Concrete Engineering Unit for review and approval a minimum of 21 days prior to the start of paving operations.		5-694.731
1. Complete a *Concrete Paving Contact Report*: • Check that scales and water meter are calibrated. • Verify cementitious materials and admixtures are approved. (www.mrr.dot.state.mn.us/pavement/concrete/products.asp)	2301.3F3	5-694.114 - .116 5-694.160 5-694.430 - .435 5-694.732
2. Batch trucks: • Check for mortar tightness • Check for properly operating box vibrators • Inspect box walls to insure they will not trap concrete in dents. • Check for cleanliness • Check for legal load limits	2301.3D	
3. Monitor stockpiling and loading of delivered aggregates: • 0.5 m (1 ft.) cushion • Driving of equipment over washed material • Proper drainage at least 12 hours prior to use in batching operations - observe truck boxes • Notice water at edges of pile	2461.4A1	5-694.124
4. Aggregate hopper and scales: • Check that batch weights are adjusted in accordance with moisture tests • Observe scale operation and loading of trucks at 2 hour intervals throughout the day • Check field hoppers for contamination. If contaminated, have Contractor empty storage and weigh hoppers and re-charge	2301.3F5 1901.8 2461.4B4	5-694.124 5-694.143
5. Cementitious hopper and scales: • Observe weighing operation at intervals throughout day • Collect invoices from foreman and assure that the cementitious materials are from certified sources • Complete *Cement Record* daily - *Form 2157* • Calculate the cementitious cut-offs appropriate to the volume of concrete produced	1901.8 2301.3F1-.3F4 2461.4B3 Schedule of Materials Control	5-694.112 5-694.115 5-694.431 - .435 5-694.740
6. Ensure the correct mix design weights are being used.		
7. Ensure compliance with minimum and maximum mixing times.	2301.3F1 2461.C2f	
8. Moisture Tests: • See Schedule of Materials Control and/or Special Provisions for testing rates • Run before every high early pour or whenever moisture appearance of delivered aggregate seems to vary • Complete *Concrete Batching Report - Form 2152* • Calculate water/cementitious ratio for compliance with project specifications and verify with microwave oven test		5-694.142 - .143 5-694.532 5-694.542 5-694.733 - .736

9. Gradations: • See Schedule of Materials Control and/or Special Provisions for testing rates • Review *Concrete Aggregate Worksheet JMF* and verify Contractor's tests for compliance		5-694.141 5-694.145 5-694.148 5-694.737
10. % Passing 75 µm (#200) Sieve: • Verify all fine aggregate gradations are washed to determine the mass passing the 75 µm (#200) sieve. • Verify the amount passing the 75 µm (#200) sieve for the coarse aggregate is run on the first four gradations during production.	3126.2F 3137.2D1	5-694.146 5-694.148
11. Take samples of cementitious materials, admixtures, etc. as required.	Schedule of Materials Control	5-694.112 5-694.115 5-694.751 - .753
12. Obtain the appropriate number of coarse aggregate QC/QA samples as required per project specifications for Coarse Aggregate Quality testing.	See Special Provisions	5-694.140
13. Review the Contractor's on-site QC records and charts for accuracy and completeness.		5-694.735 - .736 5-694.738
14. Maintain daily plant diary that includes hours of production, equipment, weather, air temperatures, concrete yardage totals, cement records, plant diary, water/cementitious ratio calculation worksheets, and problems or unique circumstances encountered.		5-694.726

5-694.015A CHECKLIST FOR PAVING INSPECTION – BEFORE START OF PAVING

√ LIST FOR PAVING INSPECTION – BEFORE START OF PAVING OPERATIONS	Specs.	Concrete Manual
1. Testing Equipment: • Obtain slump cones, air test units, rulers, pencils, necessary forms, etc., which are required for the job, and make sure all equipment is in good working order. • Check condition of beam boxes. • Make sure that air testing units, sieves, and scales were calibrated within the previous year.	2461.4A5	5-694.511 5-694.521 5-694.531 5-694.541
2. Obtain plans and special provisions and study them in detail.		
3. Become familiar with paving sequence and review field controls for line and grade.		5-694.600 Series
4. Paving Equipment: • Check paving equipment for proper adjustment and compliance with specifications. • Understand the function of each piece of equipment.	2301.3A1 2301.3H 2301.3J	5-694.645 - .648
5. Reinforcing Steel: • Check size, spacing, and placement of bridge approach panel rebars, and any other special reinforced panels. • Verify proper reinforcement size, grade, lap ties, depth and spacing. • Check size and length of centerline steel. Check if the required mechanical placer is placing it at the proper depth. • Check that the tie bars and supplemental steel set on chairs are properly placed.	2301.3E Standard Plans and Standard Plates	5-694.632
6. Check vibration equipment and verify vibration monitors are operating correctly. Computerized vibration monitors are required on slipform pavers.	2301.3H1 2301.3J Special Provisions	5-694.646
7. Verify the Contractor is prepared for inclement weather (rain or cold weather conditions).	2301.3M	
8. Verify string line is set sufficiently in advance to avoid delays.	2301.3J	5-694.643 - .644
9. Verify that utility work and conduits are complete. Pre-locate utility fixtures to be incorporated into the pavement.		5-694.630

5-694.015B CHECKLIST FOR PAVING INSPECTION – DURING SLIPFORM PAVING

√ LIST FOR PAVING INSPECTION – DURING SLIPFORM PAVING	Specs.	Concrete Manual
1. Base: • Check that the base (OGAB) material is maintained in a dampened condition ahead of the concrete placement. • Keep PASB thoroughly whitewashed to minimize its temperature. • Monitor trucks hauling concrete. Trucks hauling concrete should not be allowed on the finished grade.	2301.3G Special Provisions	5-694.631
2. Dowel Baskets: • Check dowel bar assemblies for proper placement to assure that they are parallel with the base and centerline of road, properly supported and staked. • Make sure the assembly ties are completely removed. • Make sure dowel baskets are securely anchored on the bottom rail using the correct number and length of anchors. • Check the placement of dowel assemblies at catch basins and manholes; keep joint at least 1 m (3 ft.) from structure. Refer to the Standard Plates for details. • Make sure form release agent has been applied to dowel bars. • Confirm joint locations are marked at the same location as the dowel baskets.	2301.3E3 2301.3G 2301.3K 3902 Standard Plans and Standard Plates	5-694.632 5-694.660 - .664
3. Monitor paving operation for continuous placement and consolidation of concrete.	2301.3J	5-694.645 - .649
4. Check if vibrating tubes are operating (indicated by localized open surface). Excessive vibration will cause segregation and bring lightweight aggregate to the surface (shale, etc.). Computerized vibration monitors are required on all slipform pavers.	2301.3J Special Provisions	5-694.646 - .647
5. Verify pavement width, thickness, crown, superelevation, edge slump, and joint match to ensure it meets plan requirements.	2301.3P	5-694.645
6. Check surface using a 3 m (10 ft.) straightedge to check for tolerance and then have surface dragged to remove straightedge marks.	2301.3P	5-694.645
7. Keyway Placement: • Assure location at proper elevation. • Make sure bars are the right size and length, and properly spaced. • Make sure keyway tie steel is not placed at a doweled joint.	Standard Plans and Standard Plates	5-694.632 5-694.664
8. Air and Slump Testing: • Observe Contractor perform air and slump tests. See Schedule of Materials Control Schedule and/or Special Provisions for testing rates. • Agency performs one air and slump test per day, run additional tests as necessary. • Agency performs correlation air tests behind and in front of paver daily and verifies air loss. Sample should be taken from upper half of pavement.	2461.4A4a 2461.4A4b	5-694.530 - .541

9. Flexural Strength Testing (Beams): • Observe Contractor make beams. See Schedule of Materials Control and/or Special Provisions for testing rates. • Contractor removes beams from boxes, cleans boxes, and reassembles boxes. • Agency cures and breaks beams. • Record beam break results on *Concrete Test Beam Data - Form 2162.*	2301.3A6 2461.4A5 Special Provisions	5-694.520 - .522 5-694.741
10. Collect, check, and initial *Certificate of Compliance* if used.		5-694.723
11. Make sure concrete is placed within time specification.	2461.4C5 2461.4D6	
12. Monitor number and speed of revolutions and water added while truck is mixing, if applicable.	2461.4D5c	
13. Concrete Appearance: • Check that the concrete is maintained at a uniform consistency. • Monitor the edge slump.	2461.4A4a	5-694.648 - .649
14. Check that no concrete is lost on the haul road or sticks in the truck after it dumps.	2301.3D	
15. Make sure concrete is spread evenly and uniformly.	2301.3G	
16. Make sure there is a uniform strike-off.	2301.3H1a 2301.3J	5-694.648
17. Check concrete placement on dowel bar assemblies to see that dowels are not displaced.	2301.3G	5-694.632
18. Check to see that paver is not over or under loaded, and that concrete is “rolling” not “sliding” in front of the screed.		5-694.648
19. Make sure the tamping bar is properly adjusted so large aggregate is tucked below the surface and not dragged.		5-694.647
20. Finishing: • Do not allow sprinkling of water on surface during the finishing operation. • Do not permit short smoothing floats as a constant part of the finishing operation.	2301.3H1d Special Provisions	5-694.648 5-694.671
21. Texturing: • Ensure texturing is properly performed at appropriate time. • Check that the texture marks are uniform and parallel to centerline. • Verify texture by observing Contractor sand patch testing. • Transverse tining is performed as required. Check that protection is provided to prevent tining marks at the transverse joint locations, if required. • Check that tines have proper random spacing, width, and are applied at the proper depth.	2301.3L Special Provisions	5-694.648
22. Stencil the stationing into the edge of the pavement every 200 m (500 ft.).		5-694.602

23. Headers: • Verify placement of construction header. • Be sure wet, sloppy concrete in front of the screed is wasted. • Check for right angles from longitudinal edge. • Check steel placement • Monitor vibration	2301.3G 2301.3H1b Standard Plates	5-694.630 5-694.660
24. Curing: • Verify an approved curing compound is used. • Check application rate of curing compound for uniformity, yield, and timely placement. • Take samples as required. • Ensure compliance with cold weather protection requirements.	2301.3M Schedule of Materials Control	5-694.680 - .683
25. Sawing Joints: • Check joint sawing operation. Check joint location adjustments at side streets, inlets, manholes, etc. • Check appearance, depth, and width of sawed joints. No raveling and no random cracking should occur at the time of initial sawing. • Widening of the joints shall not occur until the concrete is at least 24 hours old.	2301.3K Standard Plan 5-297.221	5-694.630 5-694.660 - .664
26. Sealing Joints: • Verify joints are clean and dry before approving. • Do not allow traffic on the slab until the joints are sealed.	2301.3N 2301.3A7 Standard Plan 5-297.221	5-694.665
27. Thickness Verification: • Determine the locations for cores using random numbers. • Observe the Contractor coring operation to verify authenticity.	2301.3P Special Provisions	5-694.691
28. Ride Quality and Smoothness: • Make sure California Profilograph or lightweight inertial profiler (LWP) is certified, calibrated and ready for use. • Check Ride Quality (2301.3P1c) and Smoothness (2301.3P1) of surface for contract compliance.	2301.3P Special Provisions	5-694.690
29. Maintain daily diary that documents hours of production, equipment, concrete temperatures, air content, slump reading, cylinder and beam data, stations paved, width, depth, yield, weather, air temperatures, and problems or unique circumstances encountered.		
30. Submit *Weekly Concrete Report* to Mn/DOT Concrete Engineering Unit on a weekly basis.	2461.4D7	5-694.744
31. Submit the following to the Mn/DOT Concrete Engineering Unit: • *Concrete Test Beam Data – Form 2162* • *Field Core Reports – Form 24327* • Ride Quality results • Incentive/Disincentive Information • Change Orders and Supplement Agreements		5-694.701 5-694.739 5-694.741 - .742

5-694.015C CHECKLIST FOR PAVING INSPECTION – FIXED FORM PAVING

In addition to this checklist, refer to 5-694.015A and 5-694.015B.

√ LIST FOR PAVING INSPECTION – FORMED PAVING	Specs.	Concrete Manual
1. Form Inspection: • Cleanliness • Check form tolerances – 15 mm (5/8") on face and 5 mm (3/16") on top.		
2. Form Placement: • Check for vertical face. • Check form locks are secure. • Use tape measure to check for alignment from offset tack line and visually inspect for final alignment. • Use carpenter's level to check for elevation from blue top to form line and visually inspect for final alignment. • Check forms for form release agent coating. • Recheck any forms removed from line for batch trucks. • Check proper grade to match bridge deck at least 50 mm (160 ft.) from bridge.		5-694.650 - .654
3. Check the placement of expansion joints to assure they are perpendicular to the subgrade, full width with no gaps at edges or center, and at the proper elevation. No daylight should show under the joint.	2301.3K	5-694.662
4. The first screed should carry a uniform roll of concrete 150-200 mm (6-8 in.) in diameter and leave concrete surface slightly high.		5-694.657
5. Second screed should carry a uniform roll of concrete 75-100 mm (3-4 in.) in diameter on the first board and 25-50 mm (1-2 in.) on the second board, and leave concrete slightly above the top of the forms.		
6. Make sure that the surface is tight with slight ripple marks after the finishing machine has passed.		
7. Check that the forward screed is slightly tilted up on the front face to provide compaction and surge. Never tilt the rear screed.	2301.3H1a	
8. Hand-operated straight edges are used to remove accumulated fine material and water and to correct minor discrepancies in elevation. They are pulled from the center to the forms. If much of this work is continually required, equipment and/or forms are out of adjustment.		5-694.654
9. Check that the longitudinal joint along the edge of the forms is made to the proper radius.		5-694.654
10. Within 24 hours of paving or form removal, check that the shoulders are tapered to provide surface water drainage.		5-694.654

5-694.015D CHECKLIST FOR PAVING INSPECTION – UNBONDED OVERLAYS

In addition to this checklist, refer to 5-694.015A and 5-694.015B.

√ LIST FOR PAVING INSPECTION – UNBONDED OVERLAYS	Specs.	Concrete Manual
1. Make sure dowel baskets are securely fastened through the PASSRC layer 25 mm (1”) into the concrete below.		5-694.631
2. Keep the PASSRC thoroughly whitewashed to minimize the temperatures and adequately damp prior to concrete placement.	Special Provisions	5-694.631
3. Mark concrete cores two feet from the outside edge of the pavement.	Special Provisions	5-694.631
4. Verify calculated pavement thickness using Contractor’s grade and line control string lines after pavement grades have been established from survey results and approved by the Engineer.	Special Provisions	5-694.631
5. If trucks are driving on PASSRC, ensure they are using plywood or similar material for turnaround points so the trucks don’t tear up the PASSRC.		5-694.631

5-694.016 CHECKLIST FOR CONCRETE PAVEMENT REHABILITATION INSPECTION

√ LIST FOR CONCRETE PAVEMENT REHABILITATION	Specs.	Concrete Manual
1. Review the Concrete Pavement Rehabilitation (CPR) Standards and the Special Provisions in the Plans and Proposal.	Special Provisions	5-694.900 Series
2. Prior to construction contact the Mn/DOT Concrete Engineering Unit to review the CPR video.		
3. Shut down the pavement at least 2 – 3 days in advance and mark sections for removal clearly with paint. Check soundness of concrete with hammer, sand, and/or chain drag.		
4. Ensure the Contractor is prepared for inclement weather.		
5. Verify all materials are approved. (www.mrr.dot.state.mn.us/pavement/concrete/products.asp)		
6. Make sure the Contractor keeps the pavement clean.		
7. Be sure the base is replaced with materials similar to the existing pavement and is level with the bottom of the pavement.		
8. Check for proper steel placement.		
9. Make sure all of the joints are clean – clear of laitance, incompressibles, and oils.		
10. Check the bonding grout, if the grout whitens, sand blast and regrout.		
11. Ensure proper consolidation of the concrete.		
12. Ensure the Contractor finishes patches from the middle to the outside of the patch.		
13. Straightedge the repair as often as necessary to ensure smoothness over the repair.		
14. Ensure concrete is properly cured. If a Hudson sprayer is used to apply curing compound, two applications are required.		
15. Perform air and slump tests as required by the Schedule of Materials Control or as directed by the Project Engineer. Run additional tests as necessary.	2461.4A4a 2461.4A4b	5-694.531 5-694.541
16. Collect, check, and initial *Certificate of Compliance*. Record any additional water that was added at the jobsite.		5-694.723
17. Be aware of allowable time limits for concrete placement.	2461.4D6	
18. Monitor the number and speed of revolutions and document any water added, if applicable.	2461.4D5c	
19. Prepare test cylinders as required. Make additional cylinders as required for high-early mixes.	2461.4A5	5-694.511
20. For retrofit dowel repairs: • Make sure the bottoms of the slots are flat. • Ensure caulking is filled to the edges of the slot so that no grout/cementitious material can fill the crack/joint and cause it to lock up.		
21. Maintain daily diary that includes hours, equipment, concrete temperatures, air content, slump reading, cylinder data, stations paved, width, depth, yield, weather, air temperatures, and problems or unique circumstances encountered.		
22. Submit *Weekly Concrete Report* to Mn/DOT Concrete Engineering Unit on a weekly basis.	2461.4D7	5-694.727

REFERENCES

1. Figure A 5-694.005, “Using Soft Metric Reinforcing Bars in Non-Metric Construction Projects”, Engineering Data Report Number 42, Concrete Steel Reinforcing Institute, 1997.
2. Figure B 5-694.005, “Using Soft Metric Reinforcing Bars in Non-Metric Construction Projects”, Engineering Data Report Number 42, Concrete Steel Reinforcing Institute, 1997.
3. Figure C 5-694.005, “Using Soft Metric Reinforcing Bars in Non-Metric Construction Projects”, Engineering Data Report Number 42, Concrete Steel Reinforcing Institute, 1997.

CONCRETE MATERIALS AND TESTING
5-694.100

5-694.101 GENERAL REQUIREMENTS

The Specifications contain requirements for all concrete materials. Inspect all materials used in the construction of concrete work at their source, on the job, or both. The Engineers and Inspectors must inspect all materials to assure they meet all requirements prior to incorporation into the work. Attention is called to Mn/DOT Standard Specifications for Construction References 1601 through 1607 and the sections of Division III (3000 Series) for the materials used.

5-694.110 CEMENTITIOUS MATERIALS

Cementitious material includes: portland cement, blended cements, ground granulated blast furnace slag, fly ash, silica fume, metakaolins and other materials having cementitious properties. Only portland cement, blended portland cement, ground granulated blast furnace slag, and fly ash are addressed in this section.

Cementitious material composed of portland cement, blended cements, ground granulated blast furnace slag, and fly ash are acceptable providing the material complies with 3101, 3102, 3103, 3115 and the substitution limits of 2461.3D. Only certified cementitious sources are allowed.

Do not use material of questionable quality (old, contaminated, wet, etc.) until approval is received from the Mn/DOT Office of Materials Laboratory.

Specification 1601 prohibits using more than one source of material without permission from the Engineer. It is generally preferable that for finished surfaces, such as bridge decks, walks and medians, as well as for retaining walls, a single brand is used throughout if possible. For portions of a structure below grade, limitations on brands for control are not necessary.

A list of certified cementitious material sources are available on the Mn/DOT Concrete Engineering website at www.mrr.dot.state.mn.us/pavement/concrete/products.asp.

A. Portland Cement

Portland cement is made from four basic compounds, tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrite (C_4AF). The cements used in Minnesota are made either from limestone and clay, limestone and shale, or limestone and slag. The manufacturing process known as the dry process is the most widely used at present. This consists of grinding the individual raw materials and feeding at controlled amounts into a rotary kiln and burning until they fuse into small lumps or balls called clinkers. In the wet process, a slurry of the blend is fed into the rotary kiln. The clinkers are cooled and then ground in two operations. Between the first and the final grind, a quantity of gypsum (usually 2 to 3% by mass (weight) of cement) is added to regulate the setting properties of the cement.

Cement companies make various other types of cement such as High-Early, Air-Entraining, White Portland, Low Heat, and Sulfate Resisting Cements on special order. These are not normally used in Agency work.

B. Blended Cements

These blended cements are composed of one of five classes of hydraulic cement for general and special applications, using slag, fly ash or other pozzolan with portland cement, or portland cement clinker with slag. Ternary blends are not allowed without the approval of the Mn/DOT Concrete Engineer.

C. Ground Granulated Blast Furnace Slag (GGBFS)

In the blast furnace, magnetic iron ore (Fe_3O_4) and haematic iron ore (Fe_2O_3) are fed along with limestone into a high temperature chamber containing coke. Coke is partially oxidized to carbon monoxide, which reduces the ores to iron. The other product that floats over the molten iron due to its relative lightness is called slag. Slag is composed of calcium oxide (CaO), silica (SiO_2) and alumina (Al_20_3). Slag is pulverized into a fine powder called ground granulated blast furnace slag and is used in this form as a cementitious component of concrete.

D. Fly Ash

Fly ash is the most widely used pozzolan in concrete. It is a fine residue resembling cement that is a by-product of burning coal in an electric power generating plant. Depending on the chemical consistency of the coal source, the material is identified as Class C (self-cementing) or Class F (non-cementing) fly ash.

5-694.111 CEMENTITIOUS MATERIAL HANDLING

The principal consideration in all operations involving the handling and sorting of cementitious material is to avoid damage or contamination of the product prior to its incorporation in the work.

Store cementitious material indefinitely if it is kept dry. Cement is usually improved and made more stable by a period of storage immediately subsequent to its manufacture since this permits stabilization of the free lime present in the freshly ground material.

Cementitious material is very susceptible to damage by contact with water or exposure to a moist atmosphere. When stored under such conditions for even comparatively short periods, cement takes up moisture and hydrates, making it unfit for use. Paper bags are somewhat resistant to atmospheric moisture, but do not provide adequate protection for long periods of storage. Material stored in bulk is less damaged by atmospheric moisture because the ratio of exposed surface to volume is much smaller than in sacked product. It is very important that lumps are screened out before use.

When bulk cementitious material is batched on the job by mass (weight), it is imperative that the specified amount is placed in each batch. This includes not only the accurate measurement, but also the prevention of loss of cementitious material during batching and in transit to the mixer.

On paving projects, Specification 2301.3F2 requires cut-offs for all cementitious materials. Make sure all shipments are received with seals intact. Make arrangements with the Contractor to document shipments received when the Agency is not present.

Make positive cementitious material cut-offs after the use of approximately 250 metric tons (500,000 pounds) and again prior to the use of 1000 metric tons (2 million pounds). Thereafter, a cementitious material cut-off is made at least every 1500 metric tons (3 million pounds) or once a week, whichever provides the longest time interval between cut-offs. The cementitious material cut-off is made at any time during the day. In making the cut-off, the Agency must know the exact amount of cementitious materials delivered to the plant. This quantity is determined from the invoices as specified in 2301.3F2.

An estimate of the amount of cementitious material used to date is made at the completion of the work each day and is determined from the amounts placed into the storage bins and silos, minus the amounts remaining in them. This estimate is compared with the total amount used based on the batch tickets.

The data for cementitious material received, unloaded, and used each day is recorded on the *Cement Record* (Form 2157). See Figure A 5-694.740 (1–3).

If using sacked material, the Inspector should assure that the entire contents of the bags are placed in the batch. Workers are often careless in this respect, and often leave several kilograms (pounds) in a bag. Workers should tie empty bags into bundles of 50 during each pour so that they may readily check the amount used. After counting the empty bags, remove them from the mixing site before the next pour begins.

5-694.112 CEMENTITIOUS MATERIAL INSPECTION

Give all cementitious material some form of visual inspection prior to use. For certified cementitious materials, inspection and testing at the source is required for compliance. See the Schedule of Materials Control for appropriate testing rates for the project.

Sampling occurs at the ready-mix or paving batch plant and is submitted to the Mn/DOT Office of Materials Laboratory for testing. Always take a sample when the condition of the cement is suspicious. No cementitious material is accepted at the project unless it is sealed and the seal is intact. The Producer/Contractor must either re-weigh or return to the shipping point transporters if they are without seals or have damaged seals.

When requested by the District Materials Engineer, the Ready-Mix Producer is required to obtain samples of cementitious materials for subsequent testing by the Agency. The samples shall weigh approximately 2 kg (5 lb.) and the Producer shall place them in an Agency provided container, sealed to prevent contamination. The Ready-Mix Producer shall identify the samples with a copy of the rail or transport invoice that identifies the brand, mill location and date sampled, and retain for the Agency Plant Monitor. The Agency Plant Monitor shall watch the material sampling process whenever possible.

The Producer/Contractor must handle and store cements shipped in paper bags (sacks) in a manner that will prevent the bags and cement from picking up moisture. Reject any sacks that take on moisture resulting in lumpy cement.

A *Cement Sample Identification Card* (Form 24300), Figure A 5-694.752 must accompany each sample.

5-694.113 CEMENTITIOUS MATERIAL COLOR

It is recognized that the color of a concrete surface is affected by other factors in addition to the color of the cementitious material. These may include water content, method and time of finishing, cement content, conditions of forms (in the case of formed surfaces), fly ash, and possibly others. Therefore, to ensure uniformity of concrete color, where it is considered important, take special care to assure all conditions, as well as the cementitious material color, are not modified.

5-694.114 CEMENT, GROUND GRANULATED BLAST FURNACE SLAG, AND BLENDED CEMENT CERTIFICATION

A list of certified cement and GGBFS sources are available on the Mn/DOT Concrete Engineering Unit website at www.mrr.dot.state.mn.us/pavement/concrete/products.asp.

I. General

Mn/DOT will only accept cementitious materials from certified sources.

Certification of any type of portland cement, blended cement, or GGBFS is based on testing of samples at the manufacturing plant, the distribution terminal, or at the port of entry with comparison sampling by Mn/DOT.

Only fly ash and GGBFS from certified sources are allowed for use in the manufacturing of blended cements. The Supplier shall provide proper documentation regarding each shipment of fly ash or GGBFS. See 5-694.116 for Fly Ash Certification. In manufacturing blended cement, the alkali content of the clinker shall not exceed the company's quality control criteria used for regular Type I cement. If the fly ash or GGBFS is blended or inter-ground with the cement, the cement shall comply with the Specifications and the requirements stated in this procedure.

Mixing of portland cement, blended cements, or GGBFS from different sources or of different types in one storage bin or silo is NOT PERMITTED.

The Supplier shall empty cement storage bins at ready-mix plants, batch plants, and pre-cast production plants, as far as practicable, prior to refilling from a different source. The Supplier shall store and dispense blended cement from separate storage bins.

The system for managing the documentation of the inspection of cementitious material was developed with four main objectives.

1. Mn/DOT projects must receive cementitious materials from certified sources only.
2. The certified source shall have a Mill Test Report Program that is approved by Mn/DOT to verify the quality of the cementitious material. The program must have an adequate testing schedule using standard procedures. As strength is a major factor in a uniform quality control program, Mn/DOT requires regular cube strength test results to evaluate trends in the cementitious materials.
3. Quality control testing is done by the Producer to assure that the material meets certain standards, whereas the owner does acceptance or verification testing. Therefore, the Agency may check cementitious material arriving at a ready-mix, batch, or pre-cast production plant for project verification by the construction project personnel so that unsuitable cementitious materials are not incorporated into projects.
4. Timely record keeping provides the ability to certify the product at the manufacturing plant or the distribution terminal, then track the product from the point of certification to the ready-mix plant, batch plant or pre-cast production plant. To make this system work, the manufacturer, distributor, and concrete producer must maintain records of dates that the product is manufactured, dates the product is shipped and received at various locations, and a Mill Test Report that corresponds to the quantity shipped.

Final acceptance is based upon the use of cementitious material from certified sources and upon satisfactory test results from field verification samples from the cementitious material at the time of incorporation into the concrete.

II. Certification Procedures

Cement specifications and testing shall comply with Specification 3101, AASHTO M 85, and ASTM C 150.

Ground granulated blast furnace slag (GGBFS) shall comply with Specification 3102, AASHTO M 302, and ASTM C 989.

Blended cements shall comply with Specification 3103, AASHTO M 240, ASTM C 595 and ASTM C 1157.

Acceptance is judged on the basis of time of set, false set, fineness, soundness, air content of the mortar, chemical analysis, and compressive strength. The slag activity index is also required for GGBFS.

Mn/DOT may require additional testing if these tests do not continuously meet the requirements. Mn/DOT may also require additional testing of the product prior to shipment due to special considerations on that project. When required, special testing provisions are stated in the Contract documentation for the project.

A. Cement, Ground Granulated Blast Furnace Slag, and Blended Cement Specifications and Testing

AASHTO	ASTM	TEST
T 106	C 109	Test Method for Compressive Strength of Hydraulic Cement Mortar
T 107	C 151	Test Method for Autoclave Expansion of Portland Cement
T 137	C 185	Test Method for Air Content of Hydraulic Cement Mortar
T 129	C 187	Test Method for Normal Consistency of Hydraulic Cement
T 131	C 191	Test Method for Time of Setting of Hydraulic Cement by Vicat Needle
T 153	C 204	Test Method for Fineness of Hydraulic Cement by Air Permeability Apparatus
T 154	C 266	Test Method for Time of Setting of Hydraulic Cement Paste by Gillmore Needles

B. Approved Laboratory

A laboratory is considered approved if it is properly equipped and staffed to perform the tests required for an acceptable quality control program. The Laboratory must participate in the Cement and Concrete Reference Laboratory (CCRL) or other program approved by the Mn/DOT Concrete Engineering Unit. A laboratory certification program is required.

C. Mill Test Report Program

The cement manufacturing plant or cement distribution terminal (certified source) shall submit to the Mn/DOT Concrete Engineer a copy of the proposed Mill Test Report Program. This program is submitted for approval, prior to certification, in writing to:

Mn/DOT Concrete Engineer
Mn/DOT Office of Materials
1400 Gervais Avenue
Maplewood, MN 55109

The Mill Test Report Program shall outline, as a minimum, the following:

- Sampling Procedures
- Testing Procedures
- Quantity of Cementitious for Mill Test
- Statement on Failing Test Procedures
- Proof of CCRL Laboratory participation or Mn/DOT Laboratory Approval
- The proposed (Mn/DOT - Certified Source) Companion Testing rate
- Laboratory Name and Location
- Source of GGBFS and Blast Furnace Plant Location

Address any variations from Mn/DOT Standard Specifications 3101, 3102, 3103, AASHTO, ASTM, or other standard methods or procedures.

The following minimum testing rates and procedures shall apply at the certified source:

1. Obtain a 2 kg (5 lb.) grab sample representing not more than 400 metric tons (tons) at the manufacturing plant or distribution terminal.
2. Obtain 1 composite sample representing not more than 4800 metric tons (tons) at the manufacturing plant or at the distribution center representing a given Mill Test Report to include, but not limited to soundness, air content, fineness, time of set, cube strength, and chemical analysis.

Make all certified source Mill Test Reports available for study by Mn/DOT personnel for at least 3 years after testing of the cement represented is completed. The Agency may require copies of these reports at any time.

D. ASTM C 917 Sampling and Documentation

The Supplier shall use an ongoing compressive strength sampling program for uniformity and take and test samples at the rate and by the procedures outlined in ASTM C 917.

The Supplier shall electronically furnish the Agency with a tabular report as outlined in ASTM C 917. Submit the report quarterly via email to MaterialsLab@dot.state.mn.us to the attention of the Mn/DOT Concrete Engineer.

E. Companion Sampling and Testing Program

The certified source and Mn/DOT shall agree on a rate and procedure for sampling and shipping a companion sample to the Mn/DOT Office of Materials Laboratory for comparison testing. The comparison sample is obtained at a minimum rate of once per month for every month of production or one sample per shipment, whichever is less.

At the manufacturing plant, port of entry, or distribution terminal, the sample for comparison testing is taken by host State personnel (if available) or plant personnel at the time of manufacture or time of discharge. Take samples in accordance with AASHTO T 127 or ASTM C 183 and split into two samples. Test one portion by an approved laboratory as outlined in section B and ship the other portion (comparison sample), at least 10 kg (20 lb.) in size, to:

Mn/DOT Office of Materials
Attn: Cementitious Comparison Sample
1400 Gervais Avenue
Maplewood, MN 55109

Ship the comparison sample to Mn/DOT within 10 days of the sample date and label as to:

- Date sampled
- Comparison sample number and mill sample number
- Lot number of the sample
- Name of Certified Source (Manufacturing Plant or Distribution Terminal)
- Available Mill Test result found at the quality control laboratory, including 3-day, ASTM C 109 test result.

Mn/DOT will report the result of the companion sampling to the Supplier of the Certified Source. If nonconformance is found, Mn/DOT will attempt to resolve the discrepancy as quickly as possible. Continued approval of the Laboratory will depend on the comparison of its test results with those of Mn/DOT's Laboratory. If major differences are found, a third party may arbitrate the difference.

F. Project Verification/Spot Check Sampling

Mn/DOT will take verification/spot check samples periodically at the ready-mix or batch plant and at precast production plants just before incorporation into the work. Test results, which do not comply with the Specifications, are subject to Mn/DOT Specification 1503 and continued out of tolerance results are considered sufficient cause to rescind cement or slag approval and for removal from the list of certified sources.

G. Basis of Removal from the List of Certified Sources

The Mn/DOT Concrete Engineer may remove a Manufacturer from the list of certified cementitious material sources based on the following:

1. If the Manufacturer does not supply Minnesota's state or county projects during a three consecutive year period.
2. If the project verification samples or companion samples fail and a review of the certified source's records indicate that there is cause for concern as to the quality of the cementitious material.
3. Failure to comply with the certification program approved by Mn/DOT.

H. Re-Certification of Certified Sources

The Mn/DOT Concrete Engineer will re-certify the cementitious material source upon satisfactory compliance with the area of concern as outlined in section G. This may require a re-submittal of all or a portion of sections C and D.

I. Documentation, Record Keeping and Tracking

Incorporation into Mn/DOT projects prior to Mn/DOT receiving certified Mill Test Data and any cementitious material that fails the above mentioned testing, is subject to Mn/DOT Specification 1503.

The certified source shall furnish with each shipment from the manufacturing plant (or the point of certification) to the distribution terminal and finally to the ready-mix plant, batch plant or pre-cast production plant, an invoice or bill-of-lading, and all available mill test data for the cement shipped. Each copy shall indicate the manufacturer of the cementitious material, manufacturing plant location; type of cementitious material, quantity, and approximate date the product arrived from manufacturing to the distribution terminal, and the state project number, if available.

It shall also bear the following certification statement with a signature of a responsible company representative (i.e. Manager of the Supplying Company or Quality Control Supervisor).

Cement Certification Statement

Insert Company Name **certifies that the cement produced at *insert plant and location* conforms to ASTM and Mn/DOT Specifications for Type *insert Type* portland cement.**

GGBFS Certification Statement

Insert Company Name **certifies that the slag produced at *insert plant and location* conforms to ASTM and Mn/DOT Specifications for Grade *insert Grade* GGBFS.**

For truck shipments, a copy of the bill-of-lading or invoice shall accompany each load, and the Project Engineer shall retain them at the project or ready-mix plant. For rail shipments, the Supplier shall mail these copies to the Project Engineer or the ready-mix plant.

When more than one project is supplied by a ready-mix plant, the plant shall furnish the Project Engineer, for each project, either a copy of each bill-of-lading or invoice, or a listing of the bills-of-lading or invoices representing the cementitious material incorporated into the project. This listing shall bear the signature of the plant representative.

Copies of all invoices, bill-of-lading and Mill Test Reports shall remain on file at the manufacturing plant, distribution terminal or ready-mix plant, batch plant or pre-cast production plant for a period of 3 years. Mn/DOT may require copies of these reports at any time. Storage of the certified mill test and ASTM C 917 data on a CD is encouraged.

J. Certification by Other States for Cement and Cement Blends

Mn/DOT will accept cement and cement blends certified in other States providing the process complies with the following agreement:

1. The host Agency requires that the portland cement plant within its boundaries have a laboratory compliant with ASTM C 1222 Standard Practice for Evaluation of Laboratories Testing Hydraulic Cement. This lab will perform testing on the applicable types of cement (ASTM C 150/AASHTO M 85*, ASTM C 595/AASHTO M 240, C 1157) produced and shipped for State Agencies consumption. AASHTO accreditation for hydraulic cement testing of the applicable cement types is acceptable. Agency laboratories used for verification testing must meet the same criteria. *NOTE: As modified by Spec. 3101.
2. The host State Agency requires that the portland cement plant within its boundaries have a printed, Agency acceptable quality control/quality assurance plan for the production of cements used by State Agencies. The plan must include commitments to comply with ASTM C 1222 and ASTM C 183 Standard Practice for Sampling and the Amount of Testing of Hydraulic Cement. The host State Agency verifies compliance with the quality control plan.

3. The host State Agency requires that the cement producer maintain and provide, for all lots of cement shipped, a compilation of mill reports in an electronic form. The host Agency will provide applicable data at least semiannually.
4. The host State Agency requires that the cement producer submit two samples of a regular portland cement (ASTM C 150/AASHTO M 85) and a blended portland cement (ASTM C 595/AASHTO M 240) or a performance specification cement (ASTM C 1157) if produced, semiannually for verification testing. The second sample is retained for independent analysis as needed.
5. The host State Agency requires that the cement producer submit reports for ASTM C 917 Standard Test Method for Evaluation of Cement Strength Uniformity from a Single Source for both regular portland cement and blended portland cement, if produced, at least semiannually. In lieu of ASTM C 917 sampling and testing, a report of production data analysis for the non-predominant cement manufactured at a cement plant is satisfactory.
6. The host State Agency requires that the cement producer maintains production and quality control/quality assurance records for at least seven years and make those records available if requested.
7. The host State Agency reviews submittals from the cement producer along with Agency test results. If deficiencies are discovered, the State Agency monitors corrective actions taken by the producer until the deficiencies are corrected. The reciprocal agreement State Agency is notified of the deficiencies and of each occurrence.
8. Any test results or submittals collected by the host State Agency are made available to the reciprocal agreement State Agency upon request.
9. All portland cement plant information and data is confidential within the limits of a public Agency and is for State Agencies information and inspection only.
10. Quality assurance test results of field samples, performed by a reciprocal State, are reported to the host Agency when non-compliance occurs. The reciprocal State Agency deals directly with the cement producer. The host State Agency takes action as described in Item 7. The host Agency notifies all reciprocal agreement State agencies when non-compliance occurs.
11. Portland cement tests or requirements beyond the standards stated above are provided to reciprocal State agencies by agreement between the host State and reciprocal State agencies.

5-694.115 FLY ASH

Fly ash is a pozzolan that meets the requirements of ASTM C 618 as modified by Specification 3115. Pozzolans are siliceous or siliceous and aluminous materials. Class F fly ash has little or no cementitious value. However, when in finely divided form and in the presence of moisture, it chemically reacts with the calcium hydroxide produced from the reaction of the portland cement and water to form compounds possessing cementitious properties. Class C fly ash has cementitious characteristics.

Two forms of fly ash are permitted for Agency work. Fly ash interground with cement and fly ash added separately to the mix. When the fly ash is interground with cement (Type IP cement), up to 20% by mass (weight) is permitted. Specification 2461 permits fly ash replacement as a cement substitute up to 15% by mass (weight) for Class C and Class F fly ash. Special provisions may allow higher percentages of fly ash substitutions.

In addition to being economical, fly ash tends to reduce map cracking and abnormal expansion. This is probably due to its lower heat of hydration.

Fly ash in concrete also:

- Reduces water requirements
- Reduces bleeding
- Retards time of set
- Increases the modulus of elasticity
- Reduces volume change
- Reduces permeability
- May increase resistance to sulfate reaction
- Improves the workability of the mix due to the spherical shape of the fly ash particles

It also results in a higher ultimate tensile strength and a higher ultimate compressive strength; however, its 28-day strength is lower.

When fly ash or blended cements are substituted, the batch masses (weights) of the coarse aggregates are adjusted to compensate for the volume change due to the substitution. The use of fly ash or blends usually requires more air-entraining agent than plain concrete.

Fly ash added separately to the mix requires additional handling facilities; i.e., silos, etc., similar to those required for regular cement.

5-694.116 FLY ASH CERTIFICATION

A list of certified fly ash sources is available on the Mn/DOT Concrete Engineering Unit website at www.mrr.dot.state.mn.us/pavement/concrete/products.asp.

A. General

Mn/DOT will only accept fly ash from certified sources.

Fly ash shall meet the requirements of Specification 3115 for the class specified. Certification of any source of fly ash is based on the Supplier testing samples at the plant, with comparison sampling by Mn/DOT.

Acceptances of fly ash is judged on the basis of certified sources and upon satisfactory test results from verification/spot check samples from the fly ash at the time of incorporation into the concrete.

Approval is based upon fly ash production while a power plant is utilizing specific materials, equipment, and processes. Approval requires identification of the specific sources of the coal from which the ash is derived. Any changes in materials, equipment and processes will void any source approval and requires a new approval.

Fly ash produced immediately prior to shutdown and after start up is possibly quite different from the fly ash obtained during normal operation of the plant. This fly ash may not meet specifications. Companion samples tested by Mn/DOT that do not meet Specifications may result in voiding the source approval.

The system for managing the documentation of the inspection of fly ash was developed with four main objectives.

1. Mn/DOT projects must receive only certified fly ash.
2. The Fly Ash Supplier shall have a quality control program that is approved by Mn/DOT to verify the quality of the fly ash. This quality control program shall include a schedule of testing and procedures to discontinue the use of fly ash that does not meet Mn/DOT Specifications.
3. Record keeping must provide supporting evidence to certify the product at the power plant, and then track the fly ash from the point of certification to the ultimate destination. To make this system work, the Supplier must maintain records of fly ash quality tests, quantity and type of product certified, date of manufacture, date of shipment, and destination of fly ash. The Supplier shall provide up-to-date records and submit copies to Mn/DOT project staff prior to use.
4. The Producer's Certified Technician and Agency Plant Monitor shall check and sample fly ash arriving at ready-mix or batch plants for verification to ensure that unsuitable fly ash is not incorporated into projects.

B. Fly Ash Power Plant Certification Procedures

The Supplier at the power plant where the fly ash is manufactured (certified source) shall submit to the Mn/DOT Concrete Engineer a copy of the proposed Quality Control program. The Supplier shall submit a request for prior approval of this certification program in writing to:

Mn/DOT Concrete Engineer
Mn/DOT Office of Materials
1400 Gervais Avenue
Maplewood, MN 55109

The Quality Control Program shall outline, as a minimum, the following:

- Sampling Procedures
- Testing Procedures
- Quantity of fly ash for each lot
- Testing Frequency per lot
- Normal Testing or Reduced Testing Rates
- Noncompliance Procedures for Failing Materials
- Type of equipment used to manufacture the fly ash
- Raw Coal Source Location
- Layout of Power Plant and Process
- Production schedule of the power plant

- The Target Specific Gravity representing the fly ash at the Power Plant (this value is used for Verification testing)
- A Mn/DOT - Certified Source Companion Testing rate

Address any discrepancies from AASHTO, ASTM, or other standard methods or procedures. The program shall also outline what steps to take when samples tested fall outside the Specifications.

The Supplier shall specify the quantity of fly ash that they consider a "lot" sample. One bin or one day's production are suggested quantities.

The following minimum testing rates and procedures shall apply:

1. Test one sample representing not more than 4 hours production at the power plant for the loss of ignition (LOI).
2. Test two samples representing not more than 48 hours production at the power plant for the specific gravity and percent retained on the 45µm (No. 325) mesh sieve.

The Mn/DOT Concrete Engineer may require an inspection of the plant to verify the equipment and the manufacturing process prior to certification or at any time during the manufacturing of fly ash.

All Suppliers at the power plants that manufacture fly ash shall have test records available for study by Mn/DOT personnel for at least three years following production of a fly ash lot.

C. Companion Sampling and Testing Program

The certified source and Mn/DOT shall agree on a rate and procedure for sampling and shipping a companion sample to the Mn/DOT Office of Materials Laboratory for companion testing. The minimum sampling rate is once per week for every week of production. The Supplier's personnel shall take the sample for companion testing during manufacture in accordance with AASHTO T 127 or ASTM C 183 and retain those samples for a maximum of 6 months. The Supplier shall randomly select one weekly sample per month, split the sample and test one portion ("mill test") by an approved laboratory as outlined in section E. Submit the other portion of the split sample (companion sample) within 10 days of date sampled to:

Mn/DOT Office of Materials
Attn: Fly Ash Comparison Sample
1400 Gervais Avenue
Maplewood, MN 55109

Include the following information with the companion sample:

- Date sampled
- Comparison sample number and mill sample number
- Lot number of the sample
- Power plant
- Supplier

- Class of fly ash
- Mill sample test result found at the quality control laboratory.

Mn/DOT will report the results of the Companion Sampling to the Supplier. If nonconformance is found, Mn/DOT will attempt to resolve the discrepancy as quickly as possible. Continued approval of the Laboratory will depend on the comparison of its test results with those of Mn/DOT's Laboratory. If major differences are found, a third party may arbitrate the difference.

D. Fly Ash Specifications and Testing

Fly ash specifications and testing shall comply with Mn/DOT Standard Specification 3115, AASHTO, ASTM, and the following:

AASHTO	ASTM	TEST
T 106	C 109	Test Method for Compressive Strength of Hydraulic Cement Mortar
T 105	C 114	Methods for Chemical Analysis of Hydraulic Cement
T 98	C 115	Test Method for fineness of Portland Cement by Turbidimeter
T 107	C 151	Test Method for Autoclave Expansion of Portland Cement
-	C 157	Test Method for Length Change of Hardened Cement Mortar and Concrete
T 137	C 185	Test Methods for Air Content of Hydraulic Cement
-	C 186	Test Method for Heat of Hydration of Portland Cement
T 131	C 191	Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle
T 153	C 204	Test Method for Fineness of Portland Cement by Air Permeability Apparatus
-	C 265	Test Method for Calcium Sulfate in Hydrated Portland Cement
T 154	C 266	Test Method for Time of Setting of Hydraulic Cement by Gillmore Needles
T 186	C 451	Test Method for Early Stiffening of Portland Cement (Paste Method)
-	C 452	Test Method for Potential Expansion of Portland Cement Mortars Exposed to Sulfate
-	C 465	Specifications for Processing Additions for Use in Manufacture of Hydraulic Cement
-	C 563	Test Method for Optimum SO_3 in Portland Cement

Acceptance is judged on the basis of time of set, false set, fineness, soundness, air content of the mortar, chemical analysis, and compressive strength. Mn/DOT may require additional testing if these tests do not continuously meet the requirements. They may also require additional testing of the product prior to shipment due to special considerations on that project. When required, special testing provisions are stated in the Contract documentation for the project.

Fly ash incorporated into Mn/DOT projects which fail the above-mentioned tests, is subject to Mn/DOT Specification 1503.

E. Approved Laboratory
A laboratory is considered approved if:

1. It is properly equipped and staffed to perform the tests required for an accepted quality control program and is accredited by a national laboratory certification program approved by Mn/DOT, or
2. Comparison samples with the Cement and Concrete Reference Laboratory (CCRL) are within acceptable tolerances.

Continued approval of the Laboratory depends on the comparison of its test results with those of Mn/DOT's Office of Materials Laboratory. If major differences are found, it is imperative that they are resolved as quickly as possible. Continued unresolved differences in test results are considered a basis for discontinuing laboratory approval.

F. Co-mingling of Fly Ash
Mixing of fly ash from different sources or of different classes in one storage bin or silo is not acceptable. At ready-mix plants and paving batch plants, empty the fly ash storage bin, as far as practical, prior to refilling from a different source.

G. Project Verification/Spot Check Sampling
Mn/DOT will take verification/spot check samples periodically at the ready-mix plant or at the batch plant. Test results that do not comply with the Specifications are subject to Mn/DOT Specification 1503, and continued out of tolerance results is considered sufficient cause to rescind approval to furnish fly ash and removal from the list of certified sources. See Figure A 5-694.116 for sampling of material from a truck.

Figure A 5-694.116

H. Basis of Removal from the List of Certified Sources of Fly Ash.
The Mn/DOT Concrete Engineer may remove a Supplier of fly ash from the list of certified fly ash sources based on the following:

1. If the project verification samples or companion samples fail and a review of the Supplier's records indicate that there is a cause for concern as to the quality of the fly ash.
2. If a Supplier does not supply Minnesota's state or county projects during a three consecutive year period.
3. If the power plant changes sources of coal or equipment for use in the manufacturing fly ash or the power plant changes its operation that may cause the consistency of the fly ash to change without notifying Mn/DOT.

I. Re-Certification of Certified Sources of Fly Ash
The Mn/DOT Concrete Engineer will re-certify the fly ash source upon written documentation from the Supplier that the area of concern as outlined in section H is corrected. This may require a re-submittal of all or a portion of section B requirements.

J. Documentation, Record Keeping and Tracking
The Producer/Supplier of certified fly ash shall furnish with each shipment an invoice or bill-of-lading for the project records. Each copy shall indicate the class of fly ash, quantity, date of shipment, a project number if available, and a means of tracking the fly ash shipment to the corresponding test data. It shall also bear the following certification statement with a signature of a responsible company representative (i.e. Manager of the Supplying Company or Quality Control Supervisor).

Fly Ash Certification Statement

Insert Company Name **certifies that the fly ash produced at** ***insert plant and location*** **conforms to ASTM and Mn/DOT Specifications for Class** ***insert Class*** **fly ash.**

For truck shipments, these copies of the bills-of-lading or invoice shall accompany each load, and the Project Engineer shall retain them at the project or ready-mix plant. For rail shipments, the Supplier shall mail these copies to the Project Engineer or ready-mix plant.

When more than one project is supplied by a ready-mix plant, the plant shall furnish the Project Engineer, for each project, either a copy of each bill-of-lading or invoice, or a listing of the bills-of-lading or invoices representing the fly ash incorporated in the project. This listing shall bear the signature of the plant representative.

Copies of all invoices, bills-of-lading and Mill Test Reports shall remain on file at the manufacturing plant, distribution terminal or ready-mix plant, batch plant or pre-cast production plant for a period of 3 years. Mn/DOT may require copies of these reports at any time. Storage of the certified Mill Test Data on a CD is encouraged.

5-694.120 AGGREGATES

Aggregates used in concrete are obtained from either natural gravel deposits or are manufactured by crushing quarried rock.

Natural deposits of sand and gravel may contain large amounts of deleterious aggregates such as shale and iron oxides. Therefore, some of these deposits do not meet concrete aggregate specifications. Beneficiating equipment can sometimes remove these undesirable materials during production. During processing, oversized material is either eliminated or reduced to usable size by crushing.

Crushed rock is generally obtained from quarried granite, quartzite, limestone, or trap rock. Trap rock is a general classification given to fine-grained, dark colored igneous rock. Crushed rock of the type classified as Class A, per Specification 3137.2B1, is not generally washed but is merely crushed and screened. Limestone can vary considerably in quality even in the same formation and careful selection by ledges is often necessary.

Fine aggregate (sand) produced by crushing quarried rock is not permitted.

5-694.121 AGGREGATE SIZE

Aggregates are divided into two general group sizes, fine and coarse. In many instances more than two actual sizes of material are used, due to a further subdivision by size of material within one or both of the groups. Figure A 5-694.121 shows an illustration of aggregate size from fine to coarse.

A. Fine Aggregate (Spec. 3126)
Fine aggregate is normally considered material that will pass through a sieve having 4.75 mm (No.4) mesh. Specifications require washed, natural sand, unless otherwise provided by the Special Provisions. In some instances, fine aggregate of two or three different sizes or from more than one deposit are used.

Figure A 5-694.121

B. Coarse Aggregates (Spec. 3137)
Coarse aggregate is considered the material that is retained on a 4.75 mm (No.4) sieve. Two sizes of coarse aggregate are required whenever the maximum size of the aggregate is 25 mm (1 in.) or larger.

5-694.122 CLASSES OF COARSE AGGREGATE

Coarse aggregate as used in concrete is classified into five groups per Specification 3137.2B.

- Class A is quarried granite, trap rock, or quartzite. The Engineer may also designate aggregate consisting of 100% crushed oversized gravel or boulders as Class A aggregate.
- Class B is all other quarried rock such as limestone and dolostone.
- Class C is natural or partially crushed gravel obtained from natural deposits.
- Class D is an approved mixture of two or more of the other classes.
- Class R is aggregate obtained from crushing and recycling concrete.

The Contractor must wash all coarse aggregate with the exception of Class A aggregate. The intermixing of aggregates of different classes is allowed only with approved blending belts or by batching operations.

5-694.123 AGGREGATE PROPERTIES

Determine aggregate properties prior to their use in concrete. The actual test procedures for fine and coarse aggregate may vary slightly but the purpose is the same.

NOTE: The accepted National Standard assumes calculations are based on a water temperature of 4ºC (39ºF) where 1 m^3 of water has a mass of 1 kg (1 ft^3 of water weighs 62.4 pounds). Mn/DOT calculates mix designs based on unit weight of water of 62.3 lb/ft^3 that is more representative of the water at actual concrete temperatures.

A. Specific Gravity

Specific gravity is the ratio of the mass of a solid or liquid to the mass of an equal volume of distilled water at 4ºC (39ºF). In the specific gravity determinations for aggregates, the average water temperature is 21ºC (70ºF). Water at 21ºC (70ºF) weighs 998 kg/m^3 (62.3 lb/ft^3). However, for ease of calculation, the mass (weight) of water used for metric concrete mix designs is 1000 kg/m^3.

For the fine aggregate, the specific gravity is computed by dividing the mass (weight) of oven-dry sand in grams by the volume of water displaced by the saturated surface dry sand in milliliters. For the coarse aggregate, the specific gravity is computed by dividing the mass (weight) of oven-dry material by the difference in mass (weight) of saturated surface dry aggregate in air and the mass (weight) of the same material immersed in water.

The specific gravity of aggregates that are predominantly limestone will vary from 2.58 to 2.65. The specific gravity of aggregates that have a high percentage of trap rock, granite, or quartzite will vary from 2.65 to 2.75.

B. Absorption

All aggregate particles contain small pores that vary in size and number from particle to particle. Oven-dry aggregate particles exposed to water absorb water into the pores. The rate and extent of absorption into the particles depends on the size of the pores and the amount of water available for absorption.

For test purposes, the material is considered to have absorbed its maximum quantity of water when it has remained submerged in water at approximately 21ºC (70ºF) for 48 hours. The absorption factor of a test sample of material is determined by dividing the difference in mass (weight) between the saturated surface dry material and the oven-dry material by the oven-dry mass (weight).

C. Gradation and Fineness Modulus

The range in size and quantity of an aggregate is referred to as the gradation. To produce a uniform quality concrete, limitations are placed on the proportions of aggregate of the different sizes. The production of aggregate may require the removal of some material of one size or blending in material of another size so that the combined materials result in a gradation meeting requirements. The gradation is determined by sieving representative samples of the material through a series of different size sieves (largest size on top and in descending order) and recording the amount passing each sieve.

Sieves of selected sizes are designated as standard sieves used in determining a numerical gauge that indicate to some extent the relative gradation of a material. The gauge is referred to as "Fineness Modulus". The selected sieves are called the Fineness Modulus (F.M.) sieve series and consist of the following coarse aggregate sizes: 75 mm, 37.5 mm, 19 mm, 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, and 150 µm (3 in., 1-1/2 in., 3/4 in., 3/8 in., No.4, 8, 16, 30, 50, and 100). The numerical value for F.M. is obtained by adding the percentage passing each of the sieves in the fineness modulus series, dividing this result by 100, and subtracting from 10. There are 10 sieves used for this analysis.

Generally, the F.M. is only calculated for the fine aggregate and the 75 mm, 37.5 mm, and 19 mm (3 in., 1-1/2 in., and 3/4 in.) sieves are not used for the gradation. Therefore, when calculating the F.M. for the fine aggregate the percent passing the remaining sieves is added up, divided by 100, and subtracted from 7. A greater F.M. represents a coarser sand. See 5-694.148 for a F.M. calculation.

Specification 3126.2G requires the F.M. determination on the fine aggregate. They permit a maximum variation of 0.2 from the established value for that source. The Mn/DOT Concrete Engineer will change the established value only when there are changes in plant operation or changes in the gradation of material in the deposit.

D. Absolute Volume

The absolute volume of a quantity of mixed particles is the summation of the solid volumes represented by each of the individual particles. All materials vary in their characteristics and have different specific gravities. It is necessary to know the average value of the specific gravity of the type of material in question to determine the absolute volume. The mass of 1 m^3 of the solid material (absolute volume) is equal to the specific gravity of the material multiplied by 1000 (1000 kilogram equals the mass of 1 m^3 of water). (The weight of 1 ft^3 of the solid material (absolute volume) is equal to specific gravity of the material multiplied by 62.3 (62.3

pounds equals the weight of 1 ft^3 of water at 70ºF)). The absolute volume (A.V.), expressed in m^3 (ft^3), of a given mass (weight) of material is equal to the dry mass (weight) of the material divided by the product of 1000 (62.3) and the specific gravity.

$$A.V. = \frac{Mass(kg)}{1000\, {}^{kg}\!/\!_{m^3} \times Sp.G} = \frac{Weight(lb.)}{62.3\, {}^{lb.}\!/\!_{ft^3} \times Sp.G}$$

E. Void Content

The void content of aggregate is that part of the bulk volume of the dry material that is occupied by air or void space.

In the void content test, 0.02832 m^3 (1 ft^3) of the dry aggregate is weighed and the absolute volume of solid material is determined. The void factor is equal to one minus the absolute volume of the aggregate in the unit volume. The void content will vary with the degree of consolidation.

To calculate the void content:

$$\text{Voids in m}^3 = \frac{1}{0.02832 m^3} \times \left\{1 - \left(\frac{\text{Unit Dry Mass (kg)}}{1000\, {}^{kg}\!/\!_{m^3} \times Sp.G}\right)\right\}$$

$$\text{Voids in ft}^3 = 1 - \left(\frac{\text{Unit Dry Weight (lb.)}}{62.3\, {}^{lb}\!/\!_{ft^3} \times Sp.G}\right)$$

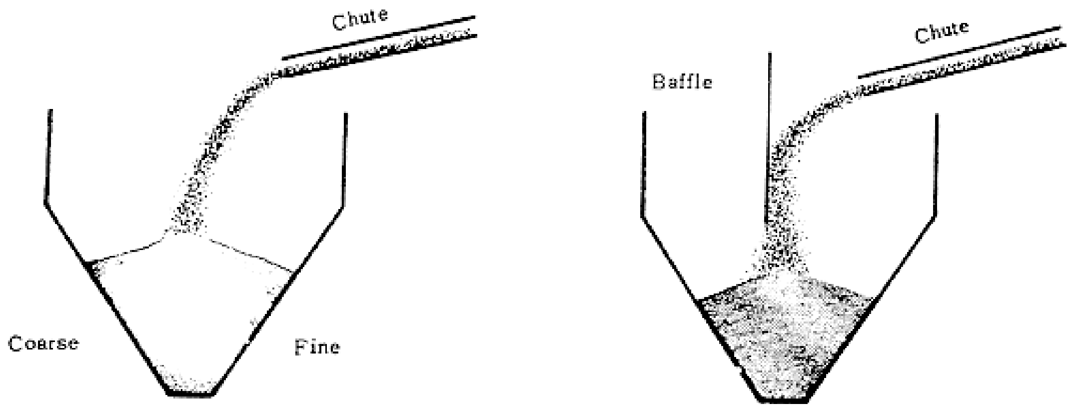
5-694.124 AGGREGATE HANDLING

See Figures A, B, and C 5-694.124.

Handle aggregates, from the time they are produced until they go into the mixer, in a manner to avoid:

- Alteration of the gradation due to segregation
- Contamination by deleterious foreign materials
- Non-uniformity in moisture content

The Inspector must keep these points in mind during observations of routine operations, and correct without delay any operation that is conducive to the development of these conditions. Non-uniform materials cannot produce uniform quality concrete during batching operations regardless of the number of quality control tests. The best form of control is a uniform procedure in handling the aggregates to reduce the risk of the three conditions mentioned previously. Specification 2461.4A1 contains a number of detailed requirements which are designed as aids in securing more uniform materials. Review these requirements for compliance.



INCORRECT CORRECT

Figure A 5-694.124

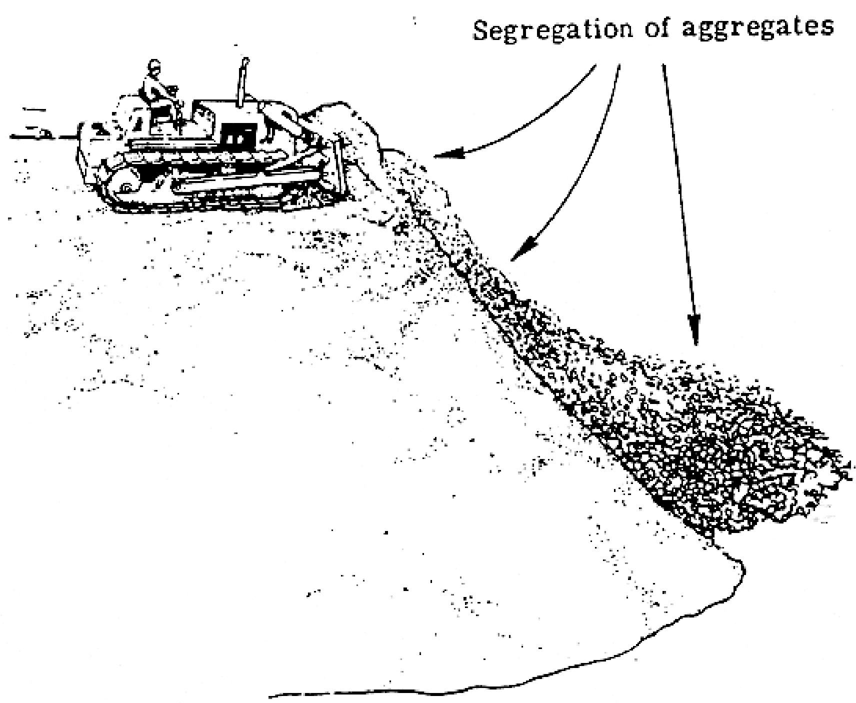


Figure B 5-694.124

STOCKPILING METHODS

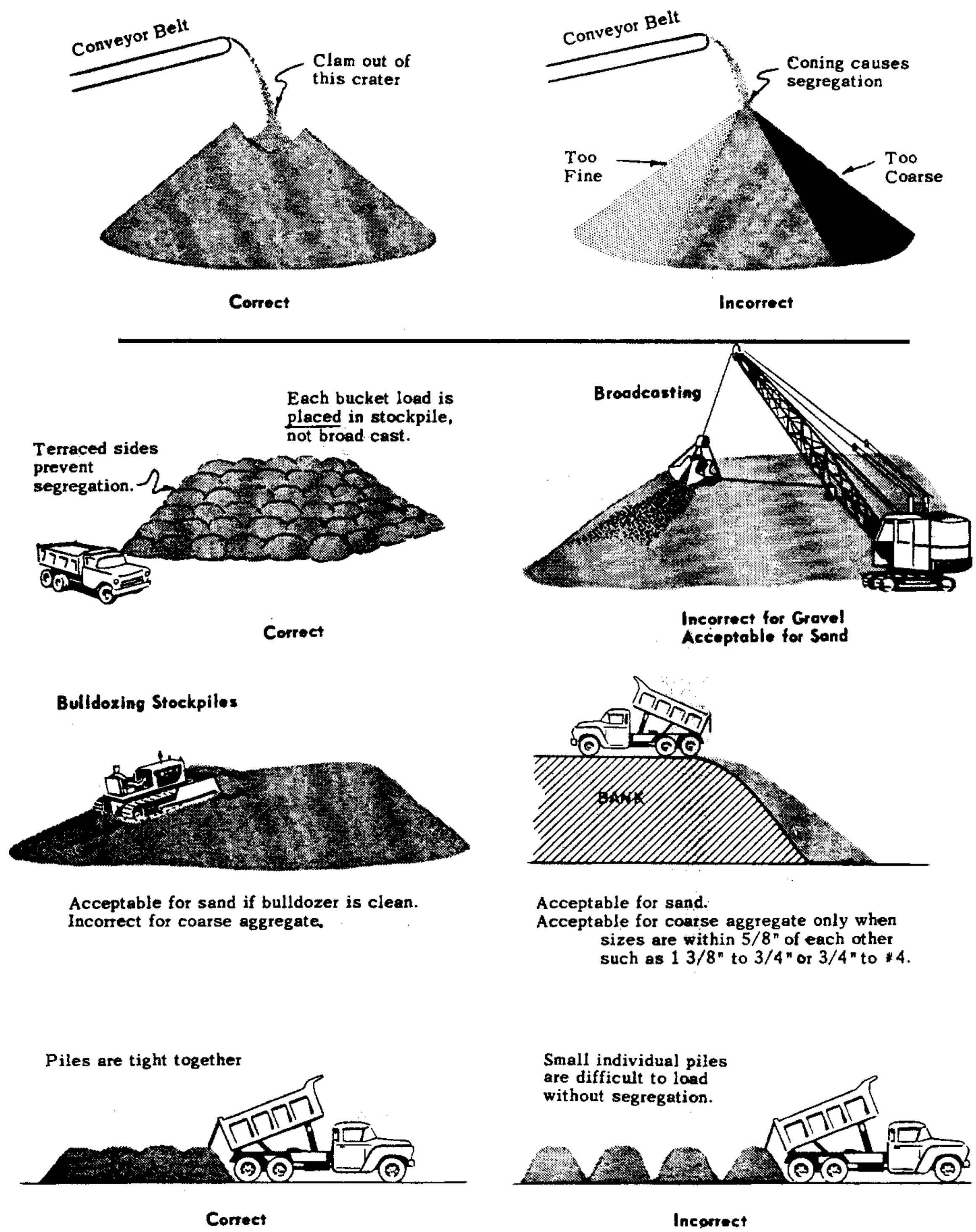


Figure C 5-694.124

5-694.125 AGGREGATE INSPECTION

Extensive inspection may occur at the producing plant during production. Such inspection, however, does not assure that the material is acceptable at the time of use. Make the final inspection and approval of the material when it is used.

Aggregates are generally hauled by either truck or rail from the producing plant to the job site. The cars commonly used are either hopper bottom cars that are normally unloaded with the use of belt conveyors under the tracks, or gondola cars that are unloaded with the use of a clam.

5-694.130 AGGREGATE SAMPLING

The Schedule of Materials Control defines the minimum number of tests required. When gradations or quality tests are running close to the tolerance limits, additional tests are required (process and acceptance verification (audit) tests) to assure that only materials meeting the Specifications are used.

At least one month prior to use of material from any new source or from new areas of old sources; the Agency shall coordinate with the Contractor in submitting samples to the Mn/DOT Office of Materials Laboratory for complete quality tests and design constants. Prior to submitting the required samples, the Agency shall obtain at least ten representative samples from stockpiles or the belt. Submit at least ten gradations of each coarse aggregate and fine aggregate fractions. Submit these gradings with the samples and include the 25 mm (1 in.) and 12.5 mm (1/2 in.) sieves in addition to the Specification sieves for the coarse aggregates.

The size of the coarse aggregate samples required is 135 kg (300 pounds) for each fraction. The proportions of each fraction is determined by the Producer/Contractor and approved by the Engineer. Seventy kilograms (150 pounds) of sand is usually sufficient for a complete analysis.

5-694.131 SAMPLING COARSE AGGREGATE AT A PRODUCING PLANT

A. Sampling from a Discharge Belt, Vibrating Screen, or Chute

1. Make a rapid pass back and forth across the entire discharge area with a pail or other sampling device. The pail should have a perforated bottom to allow water to drain out.
2. **TAKE EXTREME CARE TO INTERCEPT THE FULL CROSS SECTION OF THE FLOW**. The mass (weight) of the individual particles determine the distance beyond the chute or belt that each particle travels; therefore, catch the sample as near to the discharge point as possible. This will assure that the sampled material is representative of the material produced for it includes fines nearest the conveyor that are easily missed.
3. If the material is not running uniformly, combine several samples obtained at equal time intervals and then reduce to the desired mass (weight) by quartering. An alternate procedure is running two or more tests and averaging the percentages.

B. Sampling from a Loading Hopper

1. When it is impractical to sample the material before it enters the loading hopper, it is possible to get a representative sample from the discharge gate of the hopper. The best method is to obtain the sample while the bin is empty. The steps usually followed are to:
   a) Empty the bin into a truck.
   b) Pound the bin sides to make sure no material is left in the corners of the bin.
   c) Close the discharge gate just enough to direct but not restrict the flow of material.
2. The bin then serves as a chute, therefore, sample according to the chute method.
3. Any method of sampling from a bin other than that suggested above must have specific approval of the Engineer due to the difficulty in getting representative samples.

5-694.132 SAMPLING COARSE AGGREGATE AT A BATCHING PLANT

Whether the aggregate is previously inspected or not, it is necessary to test the material for final approval just prior to mixing. Obtain these samples by any of the following methods listed in order of preference. Take separate samples for gradation and moisture tests.

A. Sampling from a Conveyer Belt
When the aggregates are carried to the storage hoppers by a conveyer belt, obtain a sample by stopping the belt and completely removing all the material in a short section. See Figures A and B 5-694.132.

B. Sampling from a Goose-neck Conveyer
During filling of the storage bins from a conveyer belt, secure the samples from the end of the gooseneck conveyer. Use the method described previously under 5-694.131A.

C. Sampling from the Discharge Gates of the Storage or Batching Hopper
This method of sampling shows the gradation of material at time of use, however, segregation may occur within the bin.

Take samples by either leaning into the weigh bin with the container in hand or by suspending the container from a pipe or bar that rests on both sides of the weigh bin. Pass the container back and forth through the entire stream during charging of the weigh hopper. When using the latter sampling method, take care not to let the supporting devices deflect any of the material. See Figure C 5-694.132.

D. Sampling from a Stockpile
Coarse material has a marked tendency to segregate when allowed to fall freely from any height resulting in a pile of material much coarser at the outside of the pile. For this reason, it is very difficult to obtain a truly representative sample from large stockpiles of coarse aggregate. Stockpile sampling is the least reliable of methods and therefore is the least preferable method. If power equipment is available for use, secure several samples from a stockpile by taking portions from several areas of the pile. Combine the samples and quarter to provide a representative sample. See Figure C 5-694.134.

When power equipment is not available, take samples by hand shoveling. Take samples near the top of the pile, at or near the base of the pile, and at an intermediate point. To provide a representative sample, mix the individual samples, reduce to a single sample size by quartering and test the sample. When information on variations within the stockpile are desired in addition to the average condition, test the individual samples.

E. Sampling from Sumps

The sampling method used is the same as listed above for sampling a stockpile, except that sampling is from the sump.

F. Sampling from Railroad Cars

Take samples from railroad cars by digging three or more trenches across the car at points that appear representative of the material. Trench to at least 300 mm (1 ft.) below the surface of the aggregate and approximately 0.3 m (1 ft.) wide until the bottom of the trench is practically level. Take equal portions at nine equally spaced points along the bottom of the trench by pushing a shovel downward into the materials and not by scraping horizontally. The locations of two of the nine points are directly against the side of the car.

Combine the separate samples and reduce by quartering. If information on variation is desired, test the samples separately.

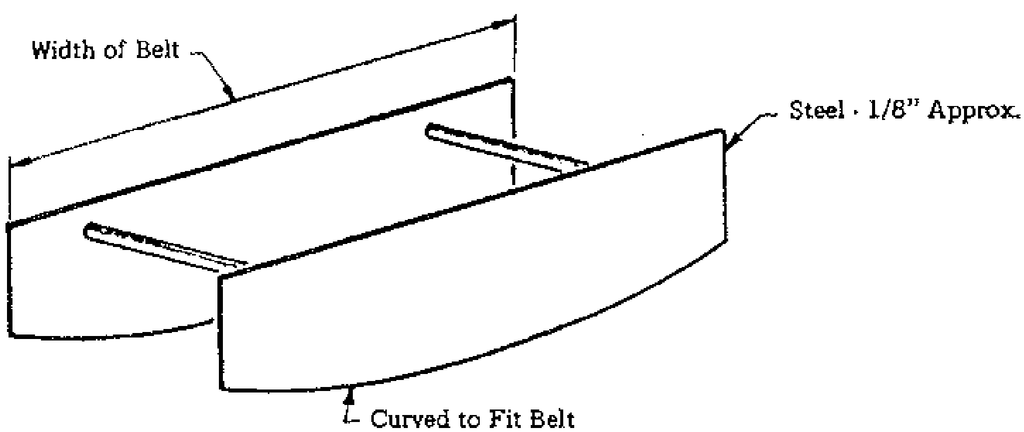


Figure A 5-694.132

Figure B 5-694.132

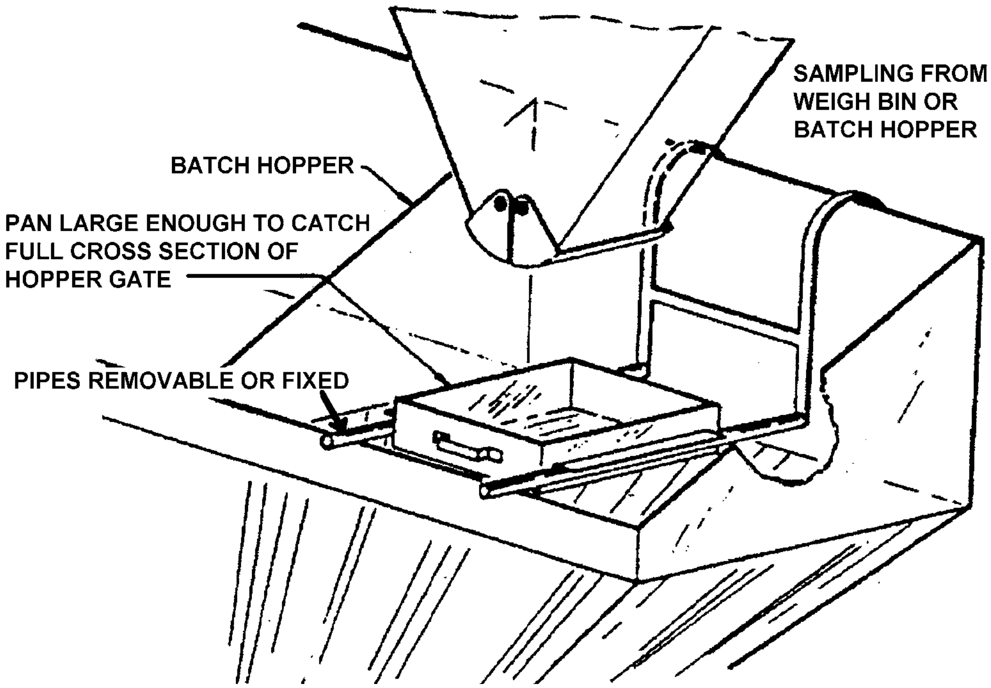


Figure C 5-694.132

5-694.133 SAMPLING FINE AGGREGATE (SAND)

Unlike coarse aggregate, damp sand does not segregate easily. However, the gradation varies considerably as it comes from the dehydrator during production. For this reason, do not sample sand during production from the dehydrator, the belt carrying material from the dehydrator, nor a bin that is supplied by either one. Take samples after re-handling of the sand to get a more representative sample. Sample sand with either a sampling tube or hand shoveling. Figures A and B 5-694.133 show a sampling tube and the procedure for sampling from trucks. Figure C 5-694.133 show sampling methods from coned and bulldozed sand stockpiles.

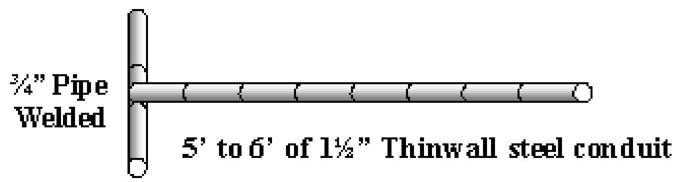
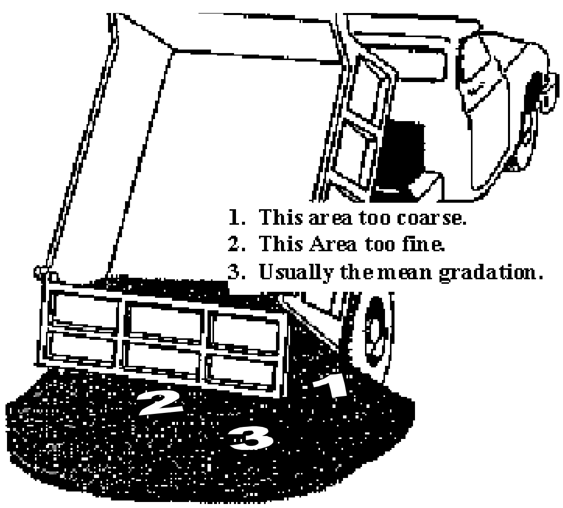


Figure A 5-694.133



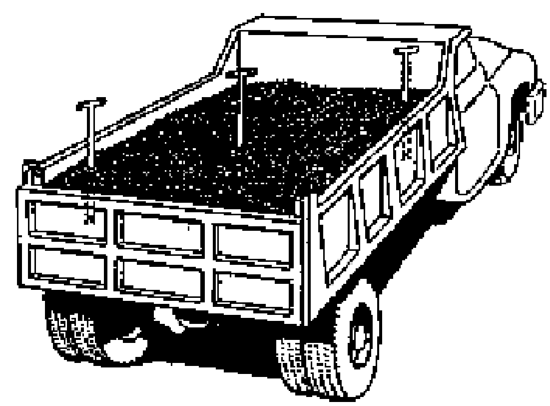
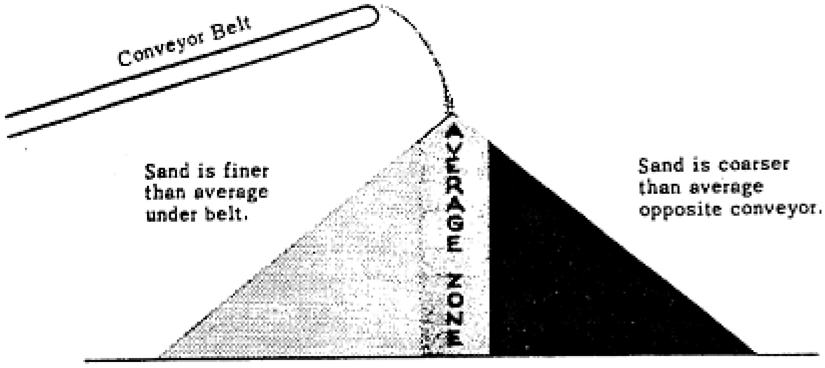
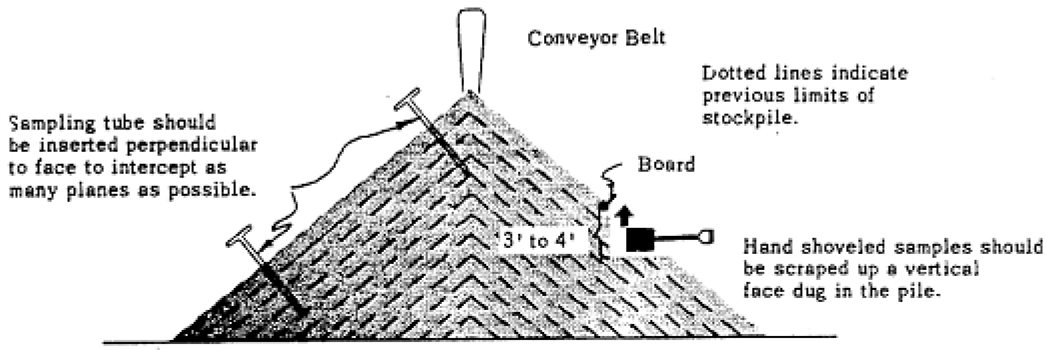


Figure B 5-694.133

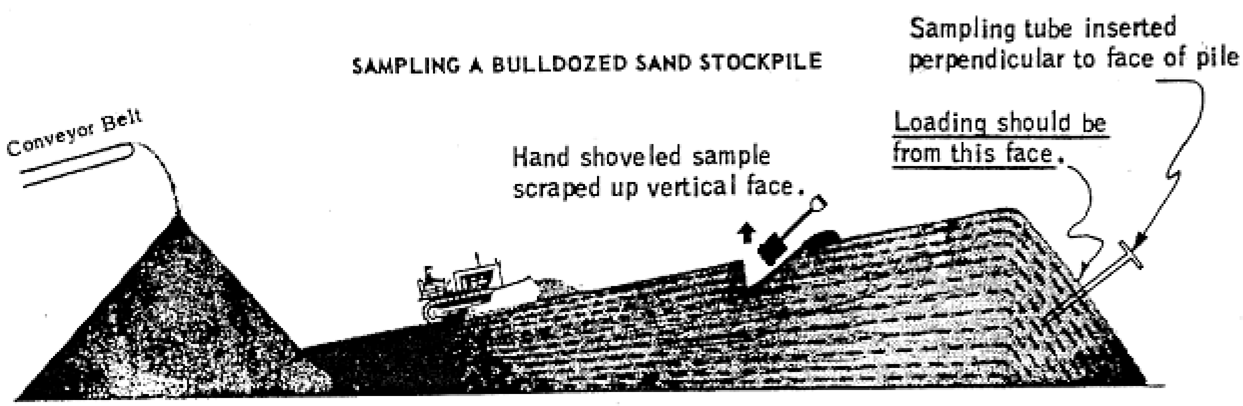


Side view of pile



End view of pile

SAMPLING A BULLDOZED SAND STOCKPILE



Dotted lines indicate previous surfaces.

Figure C 5-694.133

When using a sampling tube, brush the dry sand aside and sample only the moist sand beneath. (Dry sand segregates easily.) Ram the tube into the pile perpendicular to the surface of the pile. Discard this sample. The tube is then lined with fine sand and the actual sample is not robbed of this fine sand. Ram the tube into the pile again to obtain the actual sample. Take samples from a number of locations and combine to get the proper sample size.

When using a hand shovel to secure samples, dig a 1 m (3 to 4 ft.) vertical face in the side of the pile and then scrape the shovel up the vertical face. A board shoved into the pile above the point of sampling will prevent the dry sand from running down and contaminating the sample. Take the samples from the sand stockpile near the top, near the base and at intermediate points. Either combine or run separately, depending on the information desired. Because samples near the base are normally “dirtier”, it is good practice to run a “Percent Passing the 75 µm (No.200) Sieve” test on a sample representing this area.

Whether the aggregate has been previously inspected or not, it is necessary to test the material for final approval just prior to mixing. Take these samples at any of the sampling points listed in 5-694.133.

5-694.134 SAMPLE SIZE

Blend the individual samples and reduce to the approximate sample size by use of a riffle splitter or by quartering. Keep in mind that the sample size is doubled for samples requiring companions.

Aggregate Size	Mass
CA-1, 2, 3	10 to 15 kg (25 lb.)
CA-5, 50	5 to 7 kg (10 to 15 lb.)
CA-60, 70, 80 and Sand	5 kg (10 lb.)

A. Riffle Splitter Method
See Figure A and B 5-694.134

1. Place the sample splitter on a flat surface.
2. Place two sample pans under the discharge chutes so that no material is lost.
3. Pour the sample into the splitter, moving back and forth over all the chutes to distribute the flow of material evenly. Continuously clear away material flowing into the pans to prevent clogging of discharge chutes. Repeat procedure at least four times to ensure the sample is thoroughly blended.
4. After the material has been blended it is then split in consecutive operations to the desired sample size. The last two pans should contain well-blended companions of the approximate sample size.

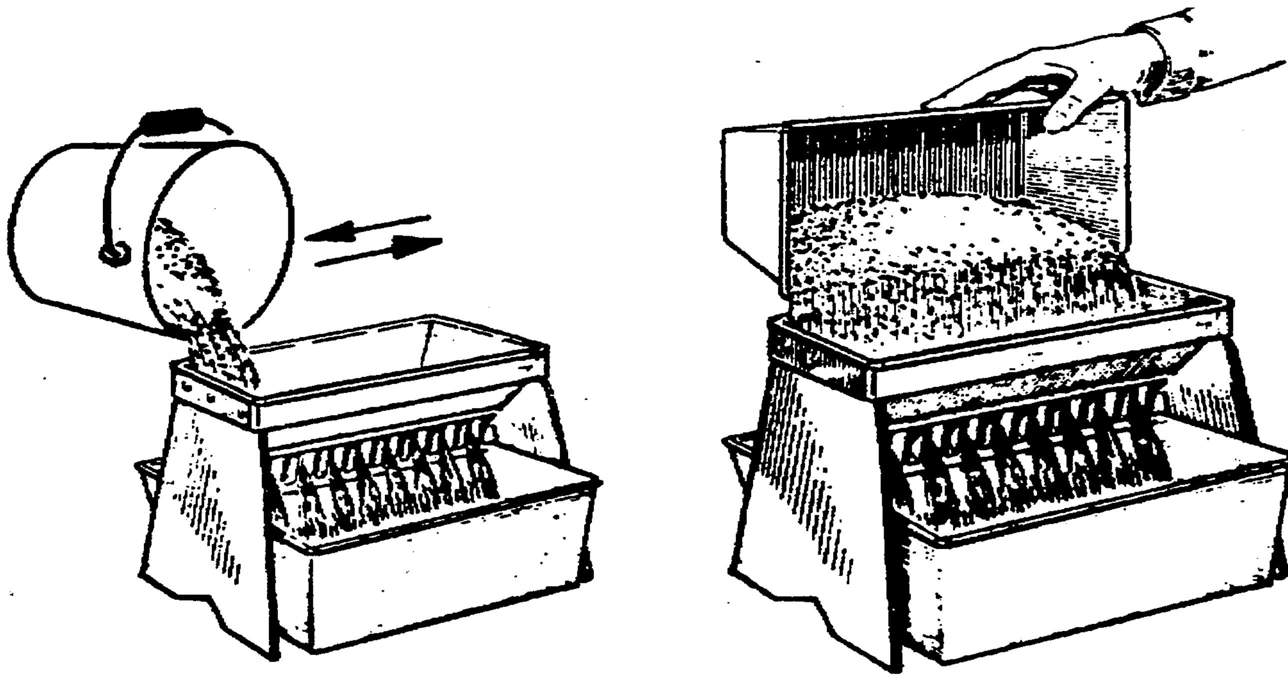


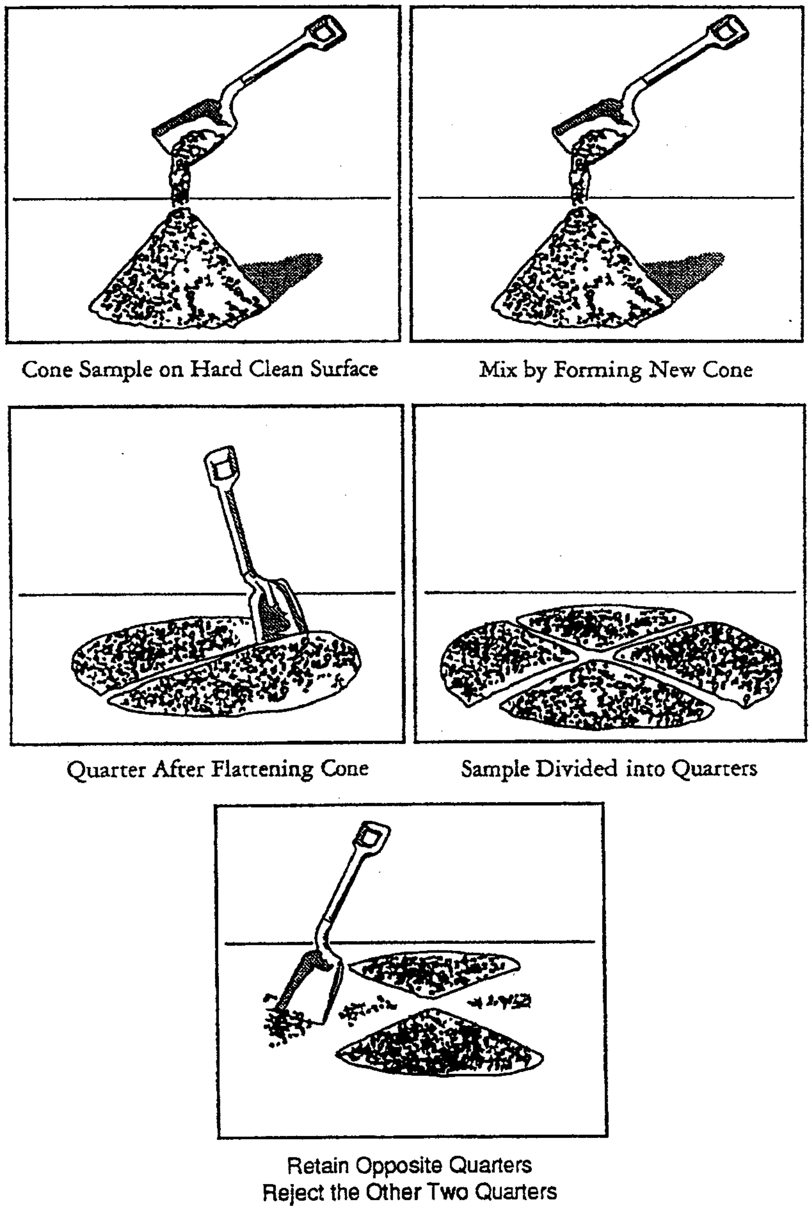
Figure A 5-694.134

Figure B 5-694.134

B. Quartering Method

See Figure C 5-694.134

1. Place the aggregate on a clean flat smooth surface and mix well.
2. Form a low flat pile.
3. Cut the pile into four pie-shaped parts with a trowel.
4. Remove and discard two opposite quarters.
5. Remix the remainder of the aggregate. Take care to include the fines and dust
6. Continue to reduce the sample to a size that is satisfactory for testing by repeating the process. For samples requiring a companion, save both portions remaining in the last reduction process.



Cone Sample on Hard Clean Surface

Mix by Forming New Cone

Quarter After Flattening Cone

Sample Divided into Quarters

Retain Opposite Quarters
Reject the Other Two Quarters

Figure C 5-694.134

5-694.135 SUBMITTING SAMPLES TO THE LABORATORY

Take samples on the day the material is used unless they are considered preliminary samples.

As shown in the Schedule of Materials Control, it is very important that these samples are accurately and completely identified. When more than one fraction of coarse aggregate is used, separation of bags for each size is required. Indicate on the *Sample ID Card* (Form 2410) that there is more than one fraction. Use a pencil to fill in the data on the cards since moisture in the sample may smear ink and make the writing illegible. See 5-694.751.

If a split sample is run in the field for paving either by the Contractor or by the Agency, record the results on the back of the sample card. This is done to check the accuracy of the field testing. Obtain all of these samples by splitting or quartering.

5-694.136 INDEPENDENT ASSURANCE SAMPLING AND TESTING

Independent Assurance sampling and testing is required on all Federal Aid, State Funds and County Federal Aid Projects. Assurance sampling is the direct responsibility of the District Materials Engineer. The District Materials Office will notify each project engineer on the *Project Summary of Independent Assurance Sampling and Testing* (Form IAT 24121) of the items and number of Independent Assurance samples required.

The purpose of this sampling is to verify the Inspector's sampling and testing procedures. The testing equipment used is also checked during Independent Assurance sampling. The project personnel are required to notify the District Materials Section when beginning any work requiring Independent Assurance sampling. It is necessary for scheduling to provide early notification. It is the responsibility of the project personnel to keep a record of Independent Assurance contacts to assure a sufficient number and timely contacts are made. Independent Assurance sampling is not a paper requirement; it is for the benefit of the Project Engineer that equipment and procedures meet requirements so that quality control testing is accurate.

5-694.140 AGGREGATE QUALITY

Before mixing operations begin, the Inspector should make it a standard practice to examine the concrete materials for general quality. The point of final inspection and approval of any material is at the time the material is placed in the work. For this final approval, the Project Engineer is responsible. Even though material was previously inspected and tentatively approved at the source, it may become altered or contaminated before it is used, or was shipped prior to inspection and testing without the knowledge of the Agency Inspector.

Physical properties of the material relative to aggregate class and gradation are readily checked, but factors affecting the general quality of the material are sometimes given slight attention or ignored entirely by the Agency. These factors include cleanliness and the presence of various kinds of deleterious materials. Inspect the aggregates for presence of soil lumps and clay balls. Before any material is actually used in concrete, the Project Engineer must assure that it meets all specification requirements relative to general quality.

5-694.141 AGGREGATE GRADATION TESTING

Both Plant Monitors and Certified Plant Technicians monitor the gradation of the aggregate as the work progresses.

A. Preliminary Tests

Because of the possible differences between the gradation furnished and the gradation used in the mix design, preliminary checks on gradation may indicate the necessity for a redesign of the mix before the work begins. If field test results are available, record them on the back of the *Sample ID Card* (Form 2410).

Samples of both fine and coarse aggregate confirm the conformance to the Specifications as well as insuring that the aggregate represents gradations that were used in past mix designs. Since there is practically no segregation of the fine aggregate in the normal handling of this material, secure average gradations by taking a few samples midway up the slope and around the outside of the pile. A much larger number of small individual samples are required for the coarse aggregate. Take these from the base to the top of the stockpile and about 0.3 m (1 ft.) below the exposed surface. Combine all of the small samples for any particular size of aggregate into one large sample and then quarter down to a sample of the desired size for testing. It is best to obtain preliminary samples by periodic sampling of the material at the producing plant.

B. Production Tests

Fine aggregate gradations usually do not vary much from the time of production. The coarse aggregate is subject to considerable change, due to abrasion and breakage of the particles and segregation of the materials in the handling operations. Check the percent passing the 75 µm (No.200) sieve if the aggregate looks dirty. Check the gradation of all sizes of coarse aggregate. Keeping the combined gradation at the desired value may require adjustment in the ratio between the sizes but consider that the proportion changes may affect the combined aggregate quality.

Running averages indicate the trends of aggregate gradation as incorporated in the work and are used as the basis for mix adjustments when necessary.

- Aggregate gradation testing is performed both in the field and in the laboratory. Process control (QC) testing is sampling and testing performed by the Producer/Contractor and acceptance (QA) testing is sampling and testing performed by the Agency.
- The Contractor and Agency Certified Technicians shall take samples of materials adequate in size to provide companion samples for both Contractor and Agency testing.
- Split the sample using a splitter.
- Test the QC companion sample when necessary and the QA verification samples in either the field or the laboratory. The Inspector must use a different sieve nest than the Contractor. If the test fails, recheck as soon as possible.
- The Contractor and the Agency shall report test results to one another to provide information for re-sampling and corrective action if required. Price reductions for

gradation failures are based on the Agency verification QA samples and not on Contractor QC tests in accordance with the Schedule of Price Reductions for Failing Materials unless an acceptance schedule is already included in the Contract.

5-694.142 AGGREGATE MOISTURE CONTENT

AGGREGATE MOISTURE TESTS FOR CERTIFIED READY-MIX PLANTS ARE PERFORMED BY THE PRODUCER'S CERTIFIED TECHNICIANS. AGGREGATE MOISTURE TESTS FOR LARGE CONCRETE PAVING PROJECTS ARE PERFORMED BY AGENCY CERTIFIED TECHNICIANS.

To ensure the incorporation of the design masses (weights) of oven-dry materials into the batch, it is necessary to determine how much moisture the aggregates carry. The results are used to make the proper allowances for this moisture in the weighing of the material. Figure A 5-694.142 shows different moisture states of aggregates. Mn/DOT bases all of the mix designs and testing on oven-dry aggregates.

The average concrete has total water content that occupies about 15% of the batch volume. Free water in the aggregates supplies about 25% of this total water. It is evident that the free water in the aggregates makes up from 3 to 4% of the batch volume.

The moisture content of the sand is determined more rapidly and accurately than for the coarse aggregate. Take care in securing these samples so they are representative of the moisture content and gradation of the materials. Variations in gradations of the coarse aggregate can result in excessive variation in the moisture content since a large number of small particles have a greater total surface area and therefore a higher moisture content than one large particle of the same mass (weight).

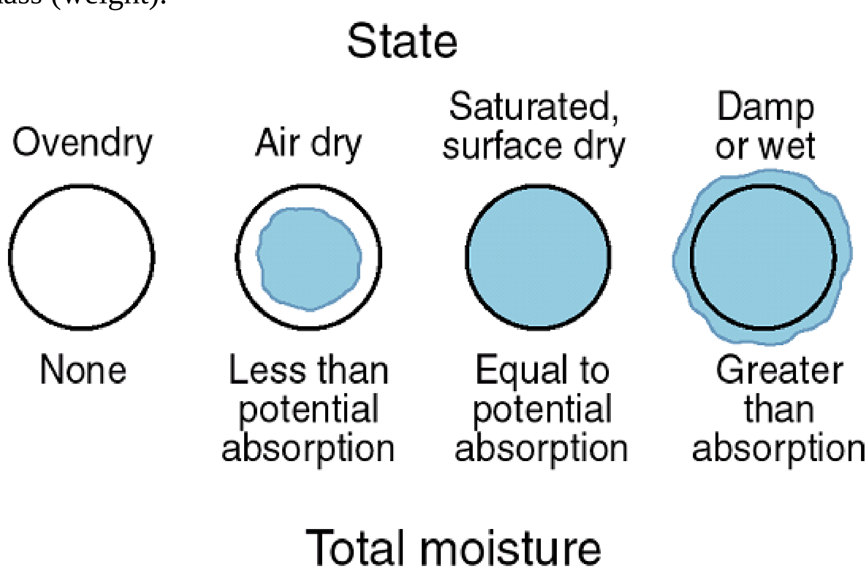


Figure A 5-694.142

A. Certified Ready-Mix

The Producer's Certified Technician must test the aggregates for moisture, and give the results to the batch person prior to the start of Agency production each day. The Technician may take moisture samples the night before the pour for aggregates representative of materials used the next day. The Agency Monitor should observe the Technician perform the test if possible. The Monitor should check the Technician's calculations and verify that the results are reasonable for the condition of the aggregates and the recent and current weather conditions.

B. Concrete Paving

On paving work where batching is continuous day after day and new material is likewise received every day, continuous moisture testing is essential. The Agency Monitor should study the sequence of the material handling operations, and try near the end of each day, to secure tests of the materials in the condition that will exist the following morning. In this way the scales are correct at the beginning of the day. Proper control consists not only in the number of moisture tests made in a day, but also in the ability to observe and analyze the whole sequence of the handling operations and the timing of the tests made with these handling operations. The Contractor and Agency should recognize the critical periods in the handling cycle and anticipate probable changes in moisture content and then time tests accordingly.

C. Oven Dry Moisture Test Procedure

Record all test results on the *Concrete Batching Report* (Form 2152). See Figure A 5-694.718.

1. Obtain a representative sample of each aggregate. To minimize moisture loss, limit handling of sample.
2. Weigh approximately 500 g of fine aggregate and 2000 g of coarse aggregate.
3. Determine wet masses (weights) of samples immediately after sampling to minimize the moisture loss by evaporation. See Figure B 5-694.142.
4. After the wet mass (weight) is determined, dry the aggregate until all moisture is removed. Take care in the drying process so that none of the aggregate particles are lost. Extreme heat may cause some of the materials to explode. If any of the particles are lost, the resultant dry mass (weight) will indicate higher moisture content than the material actually contained.
5. Dry the aggregates to a constant mass (weight) and determine the dry mass (weight). See Figure C 5-694.142. Constant weight is determined by alternately weighing and drying the material until there is no significant weight loss.
6. Total moisture is determined by dividing the weight lost in drying by the dry weight of the sample.

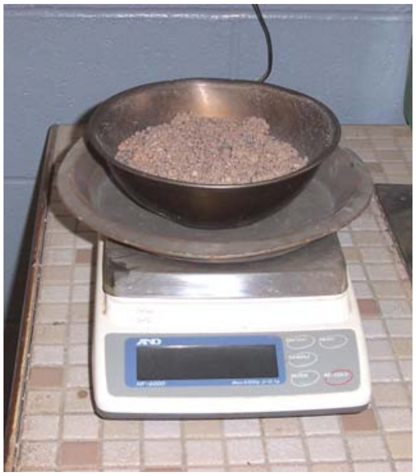


Figure B 5-694.142

Figure C 5-694.142

D. Moisture Probes and Calibration

In addition to the standard moisture test, the Producer may choose to determine moisture content in the fine aggregate by use of an Agency approved moisture probe. See Figure D 5-694.142. For Agency approval of a moisture probe, calibration is required before each construction season.

To calibrate a moisture probe, follow the procedures outlined below:

1. Note the reading on the moisture probe.
2. Obtain a fine aggregate sample as it passes the probe.
3. Note the reading on the moisture probe again. Confirm the two readings are within 0.5% of each other. Average the two readings.
4. Divide the sample into thirds, and determine the moisture content of each of the three portions by the oven-dry method described in 5-694.142C. Confirm the readings are within 0.5% of each other. Average the three results.
5. Compare the results of the moisture probe average (Step 3) and the oven-dry method average (Step 4).
   a. If the results are within 0.5%, document the results in the plant diary for Agency approval.
   b. If the results are not within 0.5%, wait at least one hour or a minimum of two loads and repeat Steps 1 - 5.
6. If neither of the tests is within 0.5%, recalibrate the probe according to the manufacturer's recommendation.

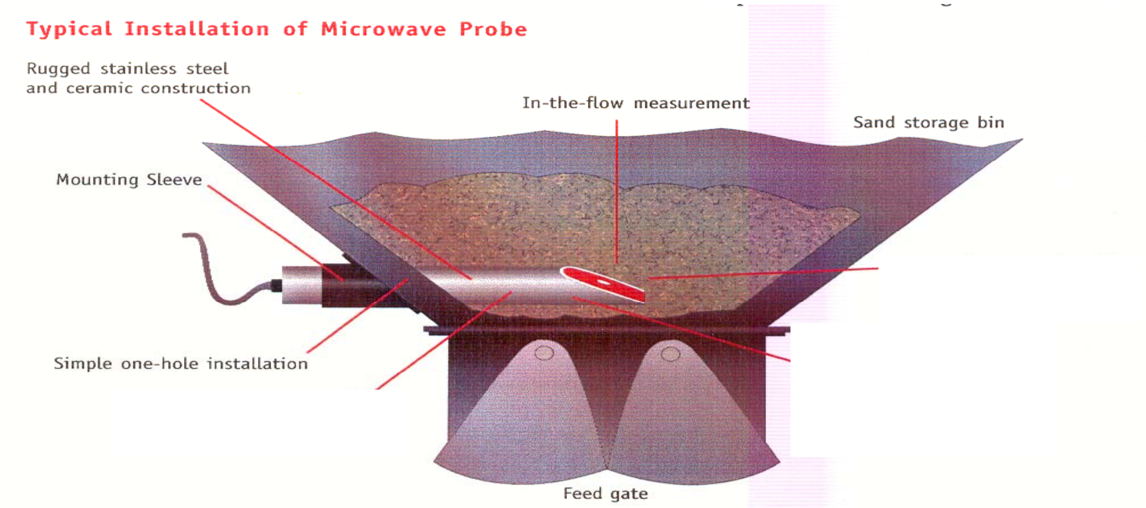


Figure D 5-694.142

5-694.143 COMPUTATION OF SCALE SETTING

The cementitious content in the batch shall conform to the quantity shown in the design.

The Producer shall adjust the dry aggregate batch masses (weights) shown in the design based on the amount of moisture they carry. See the *Concrete Batching Report* (Form 2152) in 5-694.718.

The water indicated in the design is the maximum total water. Design water content is an estimate based on previous experience with materials from the same source or on established rules of design. The total water in a concrete batch consists of the combined free water carried by all of the aggregates and the actual water added to the concrete batch at the mixer.

In normal operations, less mixer water than indicated by the moisture test is added to the first batch and the consistency is observed during the mixing period. If the batch appears too dry in the mixer, additional water is added until the specified consistency is obtained. The mixer water for the second batch is increased by the amount added during the adjustment process for the batch. Subsequent batches are controlled by the consistency obtained with the water content maintained as constant as possible. If the mixing water, allowing for changes in aggregate moisture content, consistently varies from tolerances, the Producer shall run another moisture test, check and repair the equipment, and/or request a revision of the mix design. Contact the Mn/DOT Concrete Engineering Unit at 651-779-5573 if the total actual water exceeds the design water by more than 4 percent.

Sometimes the aggregate is so dry that its total moisture factor is less than its absorption factor. In this case the free water factor is a negative number and the material will actually absorb water from the mix.

5-694.144 AGGREGATE GRADATION TESTING PROCEDURES

NOTE: FOR AGENCY AND CONTRACTOR TESTING, MECHANICAL SHAKERS ARE REQUIRED.

The Specifications provide that the aggregates meet certain requirements. Standard test methods are used to determine whether the materials meet these requirements.

Procedures in the Central and District Laboratories are in accordance with procedures found in the Mn/DOT Laboratory Manual. The field procedure is outlined below:

Check or calibrate the following equipment each year:
- Mechanical shaker
- 25 kg (60 lb.) capacity electronic balance, dairy scale, or beam balance with weights
- Necessary sieves and bottom
- Necessary pails and containers

If any of these pieces of equipment do not bear a date of calibration within the past year, exchange it for one that does.

5-694.145 COARSE AGGREGATE SIEVE ANALYSIS

Record all results on the *Concrete Aggregate Worksheet* (Form 21763) for ready-mix or the *Concrete Aggregate Worksheet – JMF* (Form 21764) for paving. See Figure A 5-694.720 and Figure A 5-694.737.

A. Equipment
- Mechanical shaker
- 25 kg (60 lb.) capacity electronic balance, dairy scale, or beam balance with weights
- Necessary sieves and bottom
- Necessary pails and containers

B. Samples
1. Secure a representative sample.
2. Reduce the sample to the required size.
3. Allow excess water to drain prior to the test.

C. Procedure
1. Set-up nest of required sieves in a mechanical shaker. The use of a 25.0 mm (1 in.) and a 12.5 mm (1/2 in.) filler sieve is recommended to lighten the load on the 19.0 mm (3/4 in.) and the 9.5 mm (3/8 in.) sieves, respectively. See Figure B 5-694.145 for the *Maximum Allowable Quantity of Material Retained on a Sieve*.
2. Place empty pail on scale and tare to zero. See Figure A 5-694.145.

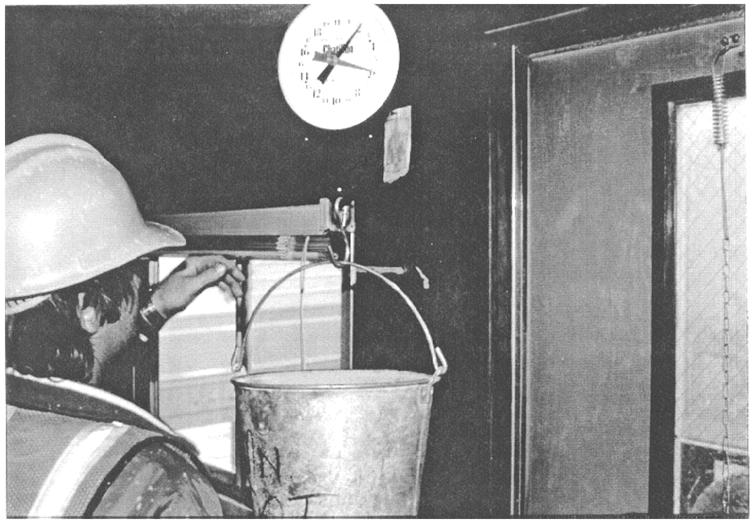


Figure A 5-694.145

3. Weigh the sample and record mass (weight) to nearest 1 g (0.1 lb.).
4. Pour the sample into the nest of sieves and shake for a minimum of 7 minutes. DO NOT hand fit rock through a sieve.

   NOTE: CRUSHED ROCK SUCH AS LIMESTONE, GRANITE, ETC., WILL REQUIRE ADDITIONAL SIEVING TIME.

5. Examine material on each sieve for clay balls; if present, run a separate test for clay balls in coarse aggregate. See 5-694.147.
6. Weigh and record the amount retained on each individual sieve. Total the amount retained on each sieve and the bottom pan. This check total must weigh within ± 0.3% of the original mass (weight). When weighing the sample with a dairy scale, the check total must be within ±0.2 lbs.
7. Calculate and record the amount passing each sieve. The mass (weight) passing any sieve is the cumulative mass (weight) of all materials retained on each individual smaller sieve and the bottom.
8. Calculate and record the percent passing each sieve by dividing the amount passing each sieve by the check total mass (weight). Report percentages for each of the sieves to the nearest whole number. Refer to Figure A 5-694.720.

Example:

Amount passing 9.5 mm (3/8 in.) sieve = 1.5 lb.

Check Total = 13.4 lb.

$$\%\ \text{Passing } 9.5\ \text{mm } (3/8\ \text{in.})\ \text{sieve} = \frac{1.5\ \text{lb.}}{13.4\ \text{lb.}} = 11\%$$

9. Calculate the composite gradation of the materials when more than one fraction is required. The proportion of each fraction of coarse aggregate will vary for different sources of aggregate, since the proportions are dependent upon the actual gradations of the individual fractions.
   a. Determine the proportions (percentages) of each fraction of the aggregates required to meet the specification.

$$\begin{aligned}&\textit{Example}:\\&70\%\ \text{of 19 mm - (3/4-) material}\\&\underline{30\%}\ \text{of 9.5 mm - (3/8-) material}\\&100\%\ \text{of CA - 50}\end{aligned}$$

   b. The composite percent passing any particular sieve is found by multiplying the percentage of the material required (Step 9a.) by the percentage passing each sieve (Step 8) and adding these values together. Record percentages for each of the sieves to the nearest whole number.

Use the 9.5 mm (3/8 in.) sieve as an example. Refer to Figure A 5-694.720.

$$\begin{aligned}&\textit{Example:}\\&70\%\ \text{ of }\ 11 = 8\\&30\%\ \text{ of }\ 13.3 = 28\\&\text{Total Composite of 9.5 mm (3/8 in.) sieve} = 36\%\end{aligned}$$

Consult the Aggregate Producer or Contractor regarding the proposed proportions before the job starts. It is the Contractor's responsibility to determine aggregate proportions, not the Agency's.

For process control testing (QC), the percent passing each sieve size for each of the aggregate fractions for all samples tested are recorded on the *Weekly Concrete Aggregate Report* (Form 2449). See 5-694.721.

For acceptance testing, the verification (QA) sample test results are reported by the Agency on the *Weekly Certified Ready-Mix Plant Report* (Form 24143). See 5-694.725.

MAXIMUM ALLOWABLE QUANTITY OF MATERIAL RETAINED ON A SIEVE
References from ASSHTO T 27 - 97[1] and/or Mn/DOT Standards
{+ #4 Sieve Quantities interpolated by this formula = [(2.5) x (Sieve opening, mm) x (Sieving Area, M2)] }

Nominal Dimensions of Sieve			203mm	8"	305mm	12"	305mm x 305mm	12"x12"	360mm x 360mm	14"x14"	400mm x 400mm	16"x16"	368mm x 572mm	14.5 x 22.5
		Sieving Area m^2	* .02850		* .06701		.09290		.12645		.16516		.21048	
			kg	lbs	kg	lbs	kg	lbs	kg	lbs	kg	lbs	kg	lbs
In.	Mm													
4	100		-	-	-	-	23.23	-	-	-	-	-	-	-
3 ½	88		-	-	15.08	33.2	20.90	-	-	-	-	-	-	-
3	75		-	-	12.56	27.7	17.42	-	-	-	-	-	39.47	87.0
2 ½	63		-	-	10.55	23.3	14.63	-	-	-	-	-	31.15	69.4
2	50		1.56	7.8	8.38	18.5	11.61	25.5	15.79	34.8	20.59	45.4	26.31	58.0
1 ½	37.5		2.67	5.9	6.28	13.8	8.71	19.2	11.84	26.1	15.47	34.1	19.73	43.5
1 ¼	31.5		2.24	5.6	5.28	12.6	7.32	16.1	9.96	21.9	13.01	28.6	16.58	36.5
1	25		1.78	3.9	4.19	9.2	5.81	12.8	7.89	17.4	10.30	22.7	13.15	29.0
¾	19		1.35	3.0	3.18	7.0	4.41	9.7	5.99	13.2	7.85	17.3	10.00	22.0
5/8	16		1.14	2.5	2.68	5.9	3.72	8.2	5.06	11.2	6.61	14.6	8.42	18.6
½	12.5		0.89	2.0	2.09	4.6	2.90	6.4	3.95	8.7	5.17	11.4	6.57	14.5
3/8	9.5		0.67	1.5	1.59	3.5	2.21	4.9	2.99	6.6	3.90	8.6	5.00	11.0
3	6.3		0.45	1.0	1.06	2.3	1.46	3.2	1.99	4.4	2.60	5.7	3.32	7.3
4	4.75		0.33	0.7	0.80	1.8	1.10	2.4	1.50	3.3	1.95	4.3	2.50	5.5

{- #4 Sieve Quantities interpolated by this formula = [(7kg/m^2) x (Sieving Area in m^2)] **Mn/DOT Lab Manual**

8" round sieves with openings smaller than the #4 (4.75mm) sieve	**= [7000 g x 0.02850] = 199.5 g**	**200 grams**
12" round sieves with openings smaller than the #4 (4.75mm) sieve	**= [7000 g x 0.06700] = 469.0 g**	**450 grams**

Figure B 5-694.145

5-694.146 COARSE AGGREGATE PERCENT PASSING 75 µm (No.200) SIEVE TEST

Record all results on the *Concrete Aggregate Worksheet* (Form 21763) or the *Concrete Aggregate Worksheet – JMF* (Form 21764) for paving. See Figure A 5-694.720 and Figure A 5-694.737.

A. Apparatus

- Electronic scale or beam balance with weights (sensitive to 0.1 g).
- Standard 200 mm (8 in.) diameter, 1.18 mm (No.16), and 75 µm (No.200) sieves with necessary brushes for cleaning sieves and pans.
- Pans or bowls of a sufficient size to contain the sample covered with water and to permit vigorous agitation without loss of any part of the sample or water, and a spatula for stirring the sample.
- Stove or oven of sufficient size capable of maintaining a uniform temperature for drying samples at 110ºC ± 5ºC (230ºF ± 9ºF).
- A detergent, dispersing agent, or other wetting solution.

NOTE: The use of a mechanical apparatus to perform the washing operation is not precluded provided the results are consistent with those obtained using manual operations. The use of some mechanical washing equipment with some samples may cause degradation of the sample.

B. Sampling

Secure a representative sample of the aggregate for testing. Reduce the sample obtained to a mass (weight) after drying of not less than:

Aggregate Size	Minimum Mass
CA-5 through CA-8	2500 g (6 lb.)
CA-1 through CA-4M	5000 g (10 lb.)

The test sample is the end result of the reduction. Reduction to an exact predetermined mass (weight) is not permitted.

B. Procedure

1. Place balance on a firm level base. Check for zero balance.
2. Dry the test sample to constant mass (weight) at a temperature of 110ºC ± 5ºC (230ºF ± 9ºF) and weigh to the nearest 0.1 g of the mass (weight).
3. Add sufficient water to cover the sample. If necessary, add a detergent, dispersing agent or other wetting solution to the water to assure a thorough separation of the material finer than the 75µm (No.200) sieve from the coarser particles.
4. Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the 75 µm (No.200) sieve from the coarser particles, and to bring the fine material into suspension.
5. Pour the wash water slowly over the nested sieves, arranged with the coarser sieve on top; save the material retained on the sieves. Take care to avoid, as much as possible, pouring the coarser particles onto the sieves. See Figure A 5-694.146.

6. Repeat the washing process until the wash water becomes clear.
7. Wash the material retained on the sieves back into the sample, pour off the excess water, then dry sample to constant mass (weight) at 110ºC ± 5ºC (230ºF ± 9ºF) and measure to the nearest 0.1 g of the sample mass (weight).

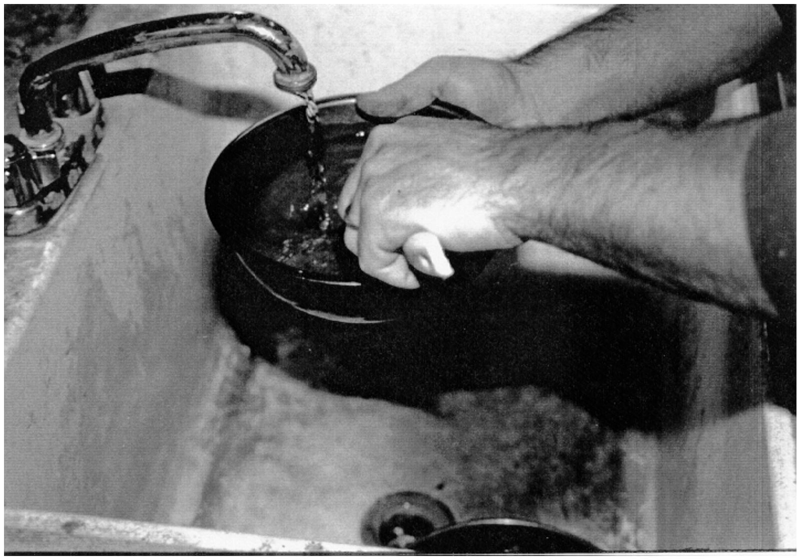


Figure A 5-694.146

The difference between the original sample mass (weight) and the washed sample mass (weight) is the loss in washing of the material passing the 75 µm (No.200) sieve.

NOTE: The sample was dried, weighed, washed, re-dried, and re-weighed without leaving the original pan. This is done to prevent inadvertent loss of material.

D. Calculation

Calculate the percent of material passing a 75 µm (No.200) sieve by washing as follows:

$$\text{Matl. Passing } 75\ \mu\text{m } (\#200) = \left(\begin{array}{r} \text{Original Dry Wt. of Sample} \\ - \text{Wt. of Dry Washed Sample} \end{array} \right)$$

$$\%\ \text{Passing } 75\ \mu\text{m } (\#200) = \frac{\text{Matl. Passing } 75\ \mu\text{m}(\#200) \times 100}{\text{Original Wt. of Sample}}$$

Report to the nearest 0.1%.

5-694.147 COARSE AGGREGATE CLAY BALLS

If clay balls are present in the material, determine the quantity of clay balls by mass (weight) of the material by taking a sample of 10 to 15 kg (25 to 40 lb.) of representative aggregate. Remove all clay balls and clay ball conglomerates from the sample, dry to a constant mass (weight), and weigh to the nearest 0.1 g.

The percent of clay balls is calculated as follows:

$$\%\ of\ Clay\ Balls = \frac{Dry\ Qty.of\ Clay\ Balls \times 100}{Original\ Dry\ Qty.of\ Sample}$$

Report to the nearest 0.1%.

5-694.148 FINE AGGREGATE SIEVE ANALYSIS

Record all results on the *Concrete Aggregate Worksheet* (Form 21763) for ready-mix or the *Concrete Aggregate Worksheet – JMF* (Form 21764) for paving. See Figure A 5-694.720 and Figure A 5-694.737.

A. Apparatus

- Standard 200 mm (8 in.) diameter fine sieves with cover and bottom: 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, 75 µm (3/8 in., No.4, 8, 16, 30, 50, 100, 200) sieves
- Brushes for cleaning pans and sieves
- Mechanical shaker
- Necessary bowls, pans, or pails
- Stove for drying samples

B. Samples

- Secure a representative sample of the sand.
- Reduce the sample to the wet mass (weight) of approximately 500 g.

Use a filler sieve or reduce the sample size if more than 200 g is retained on any sieve.

C. Procedure

1. Place balance on a firm base. Check for zero balance.
2. Dry the sample to a constant mass (weight). Cool, weigh, and record mass (weight) to the nearest 0.1 g.
3. Wash the sample, in the same pan, over the 75 µm (No.200) sieve by adding water to the sample, stirring the sample with a spoon or spatula and pouring the cloudy water on to the 75 µm (No.200) sieve, being careful not to lose any of the material or allow the 75 µm (No.200) sieve to overflow. Repeat this procedure until the water is fairly clean.

4. Rinse the 75 µm (No.200) sieve back into the pan taking care not to lose any of the material. Lightly tap the outside of the pan and let stand until the fines have settled out of the water. Carefully pour off excess water, again taking care not to lose any material.
5. Dry the sample to a constant mass (weight), cool, weigh and record to the nearest 0.1 g. Subtract this dry washed weight from the initial dry weight (Step 3) to obtain the weight loss by washing.
6. Pour entire sample into the nest of required sieves. Check each sieve carefully each day to make sure the sieve cloth is not damaged.
7. Shake sieves for a minimum of 7 minutes.
8. Weigh and record the amount retained on each individual sieve to the nearest 0.1 g. Total the amount retained on each sieve, the amount passing the 75 µm (No.200), and the loss by washing amount. This number must check to within ±0.3% of the initial dry weight of sample.
9. Calculate and record the amount passing each sieve to the nearest 0.1 g. The mass (weight) passing any sieve is the cumulative mass (weight) of all materials retained on each individual smaller sieve and the bottom.
10. Calculate and record the percent passing each sieve by dividing the amount passing each sieve by the check total mass (weight). Report percentages to the nearest whole number. Refer to Figure A 5-694.720.

$$\textit{Example}:$$
$$\text{Amount passing 600 } \mu\text{m (No.30) sieve} = 207.2\text{g}$$
$$\text{Check Total} = 509.9\text{ g}$$
$$\%\text{ Passing 600 } \mu\text{m (No.30) sieve} = \frac{207.2\text{ g}}{509.9\text{g}} = 41\%$$

11. Calculate the Fineness Modulus (F.M.). Add % Passing 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, and 150 µm (3/8 in., No. 4, 8, 16, 30, 50, and 100) sieves, divide by 100 and subtract from 7. Report the fineness modulus to the nearest 0.01.

Refer to Figure A 5-694.720.

$$\text{Example}:$$
$$\text{F.M.} = 7 - ((100 + 100 + 91 + 70 + 41 + 12 + 2) \div 100)$$
$$\text{F.M.} = 7 - 4.16 = 2.84$$

5-694.150 INSPECTION OF WATER (Specification 3906)

Water used in mixing concrete shall not contain salt, oil, acid, injurious alkali, vegetable matter, or other deleterious substances. Generally, if the water is clear and palatable, it is satisfactory for use in concrete.

If the source of water that the Contractor intends to use appears questionable, take a 1 L (1 qt.) sample and send in to the Mn/DOT Office of Materials Laboratory for testing.

5-694.160 ADMIXTURES (Specification 3113)

A list of approved admixtures is available on the Mn/DOT Concrete Engineering Unit Website at www.mrr.dot.state.mn.us/pavement/concrete/products.asp.

5-694.170 APPROVED PRODUCTS

A list of approved products is available on the Mn/DOT Concrete Engineering Unit Website at www.mrr.dot.state.mn.us/pavement/concrete/products.asp.S

PROPERTIES AND MIX DESIGNATIONS
5-694.200

5-694.210 PROPERTIES OF CONCRETE

Inspectors should familiarize themselves with the most important properties of concrete:
- workability
- durability
- strength
- volume change
- air entrainment
- density

All of these affect the finished product and knowledge of these properties is essential to produce a quality final product. Each property is explained below.

5-694.211 WORKABILITY

Workability is one of the most important of these properties. The degree of workability necessary in a concrete mix depends entirely upon the purpose for which it is used and the methods and equipment used in handling and placing it in the work. Inspectors must use their best judgement in determining the workability of the concrete and must make any adjustments to the mix that is necessary to improve the workability in accordance with instructions in this Manual and the Specifications. Indicate any adjustment in the mix (such as the addition of water, cement, or admixtures at the job site) on the *Weekly Concrete Report* (Form 2448) to provide information for possible mix design adjustments by the Mn/DOT Concrete Engineering Unit.

The factors that affect the workability of concrete are size distribution of the aggregate, shape of the aggregate particles, gradation and relative proportions of the fine and coarse aggregate, plasticity, cohesiveness, and consistency of the mix. These factors were all given careful study and investigation at the time the design procedure now in use was established. The proportions of the fine and coarse aggregate are determined from the shape of the aggregates and the gradation. For instance, a large rock size coarse aggregate that is mainly crushed will permit the use of larger size sand particles and maintain good workability. Well-rounded gravel will have better workability with finer sand, which is needed to fill the smaller void areas. These ideal conditions are seldom found and the mix design requires adjustments to compensate for variations from the ideal conditions. The consistency of the mix, relative to the wetness or dryness, will affect the workability to a large degree. Do not increase the water content beyond the tolerance allowed in Specification 2461.3J without adjustment in the mix design. Adding water in any amount with no control will produce poorer concrete, lowering its strength and durability.

The finest materials contribute to the plasticity and cohesiveness of the mix, mainly the cementitious portion of the concrete (cement, fly ash, ground granulated blast furnace slag, and silica fume). The cementitious content, however, is usually fixed by other considerations. Air entrainment greatly improves plasticity and cohesiveness. The entrained air in the form of small air bubbles acts as a lubricant or ball bearings between the aggregate particles making the mass more workable.

5-694.212 DURABILITY

The ultimate durability is the most important property of concrete. To ensure a high degree of durability, it is essential that clean, sound materials and the lowest possible water content are used in the concrete, together with thorough mixing. Good consolidation during placement of the concrete is important, as are proper curing and protection of the concrete during the early hardening period, which assure favorable conditions of temperature and moisture. Cure concrete properly for a minimum of three days in order to develop good durability.

Another property that helps ensure durability is the water to cementitious ratio (w/c). The term w/c in this publication refers to weight of water divided by the weight of cementitious material. Cementitious materials include portland cement, slag, silica fume, fly ash, and any other material having cementitious properties as approved by the Engineer.

While strength is always an indicator of quality concrete, it does not necessarily correlate to durable concrete. A low w/c ratio is a good indicator of durable concrete. A general characteristic of a low w/c ratio is that an acceptable strength is usually inherent. The overall voids left in the concrete by excess water are kept to a minimum by keeping the batch water and any add water to a minimum. This gives a more dense concrete along with a more durable and stronger mix.

A good air void system is also essential to having a durable concrete when the concrete is exposed to freeze-thaw conditions. Concrete having a total air void content of about 6.5% seems optimal. A mix having 6.5% total air voids will have approximately 1.5% entrapped air voids and 5.0% entrained air voids. Entrapped air is the larger bubbles formed in the mixing process and does not provide much protection against freeze-thaw action. The entrained air bubbles are smaller and more closely spaced. These small bubbles give protection against freeze-thaw. Concrete with entrained air will have a lower strength than the same mix without entrained air, but the concrete can attain strengths required for most purposes by an increase in the cementitious factor of the mix or by reducing the water content.

5-694.213 STRENGTH

The strength of concrete is the next important property to consider. With a fixed amount of cement in a unit volume of concrete, the strongest and most impermeable concrete is one that has the greatest density, i.e., which in a given unit volume has the largest percentage of solid materials. The use of the absolute minimum quantity of water required for proper placement ensures the greatest strength from the concrete.

It is essential that freshly mixed concrete be thoroughly consolidated to eliminate air pockets and secure maximum density in the structure. The Engineer must prevent the occurrence of loosely textured or porous concrete matrix called “honeycombing” to achieve maximum strength and density.

The degree of curing and protection afforded after placement is highly important to the final strength attained by the concrete. It is known that the strength increases rapidly at early ages and the rate of strength gain gradually decreases. Concrete will continue to gain strength indefinitely if conditions are favorable. It is therefore, very important that curing is provided at the correct time and for the proper duration of time. Effects of varying curing conditions are shown in graphical form in Figure A 5-694.213.

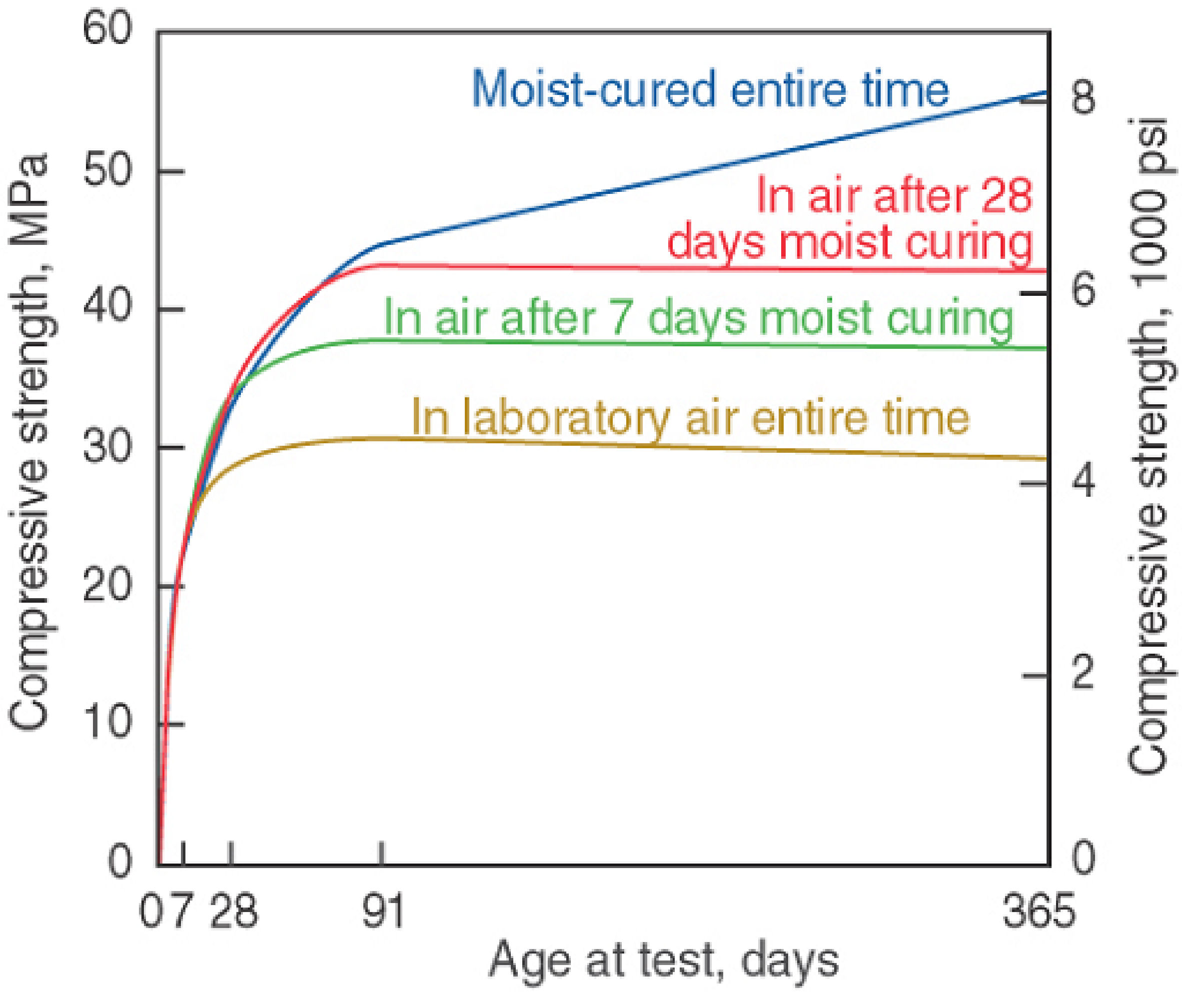


Figure A 5-694.213[1]

Concrete strength increases in an approximately constant direct relation to the increase in cement content of the concrete. The strength also decreases in a somewhat direct proportion to the increase of the water or void content of the concrete. By dividing the cement content of the concrete by the void content of the concrete (the sum of air and water), when both are expressed in absolute volumes, a numerical value, the cement-voids ratio, is obtained that is related to the strength. For a constant void content, the concrete strength will increase or decrease in proportion to the change in cement content. A chart showing the relation of concrete strength to the cement-voids ratio and water-cementitious ratio is shown in Figure B 5-694.213.

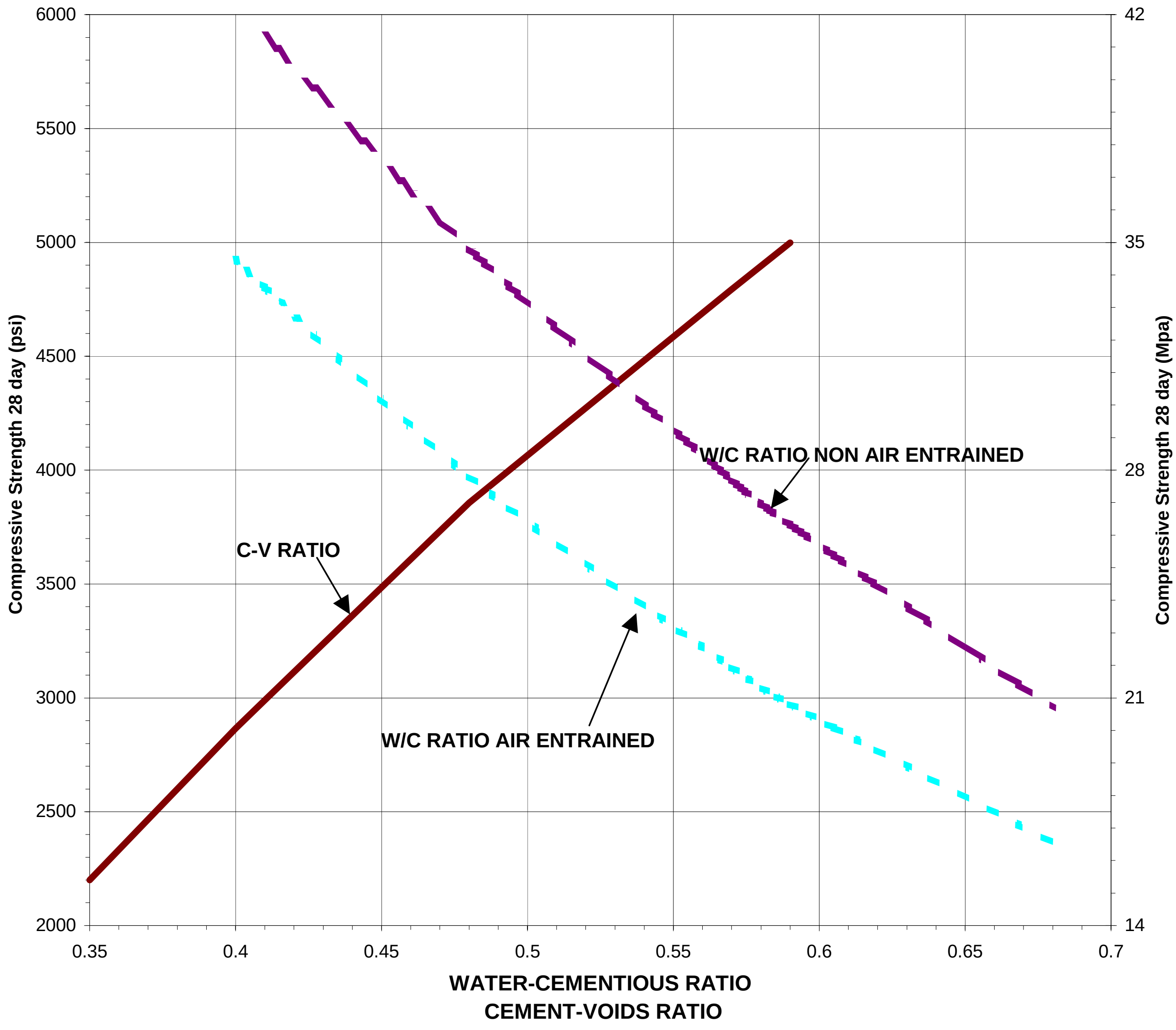


Figure B 5-694.213

5-694.214 HIGH-EARLY STRENGTH

There are three methods Mn/DOT makes adjustments to obtain high-early strength.

1. Adding 30% more cement by weight to the normal cement content (the fine aggregate is reduced) while the water and air contents remain unchanged.
2. Adding chemical admixtures to the standard mix.
3. A combination of 1 and 2.

The additional 30% cement or addition of a water reducer increases the cement-voids ratio of the mix and thereby strength is increased. Accelerating admixtures added to a standard mix, without changing the cement or water content, increase the rate of hydration thereby increasing the early strength but reducing the ultimate strength. **Use of chloride based admixtures for reinforced concrete is not recommended.**

Increasing the cement content 30% produces high-early strength concrete. Do not increase the water content more than 5% over that used with the normal cement content. There is a tendency to increase the water content to the extent that the same slump is obtained. The addition of excess water will nullify the benefits of the increased cement content and produce a lower early and lower ultimate strength than anticipated. The actual slump value is less in a higher cement content mix due to the increased workability of the mixture that is a result of the high cement content. The lower slump concrete with the additional cement is just as workable as the normal concrete.

5-694.215 VOLUME CHANGE

Concrete continually undergoes changes in its volume from one cause or another throughout its service life. These constant changes are the principal causes of the ultimate failure or deterioration of the concrete.

Plastic shrinkage is the first change to occur. Plastic shrinkage is caused by volume loss due to the hydration reaction and by evaporation. Volume change due to hydration is called autogenous shrinkage. This volume change is controlled to some extent in the original mix design by using low sand and low water contents.

After the concrete has changed from the plastic to the hardened state, it is subject to changes in its volume and dimensions due to changes in temperature as well as creep. Creep is deformation under sustained loading. Expansion or contraction of the concrete due to temperature change may produce irregular cracking in the structure. This cracking is controlled by the use of contraction joints in pavements, sidewalks, curbs and structures, by permitting and providing for cracks to occur at predetermined locations. Temperature differentials in a section of concrete will change the volume and as a result will change the normal stresses within the section. The normal stress is reduced, increased, or modified by deformation or warp of the concrete section.

Hardened concrete is also subject to volume change due to changes in its moisture content. All concrete is porous and absorbent, and will take up or lose moisture if given the opportunity. This action tends to induce internal stresses in the concrete structure if the change in volume is restrained to any degree. For example, a concrete pavement resting on a wet subgrade and exposed to drying surface conditions will tend to curl or warp upward around the outside edges. This warp is resisted by the weight of the slab and also by interlocking features of the joints in the pavement and results in tensile stresses in the lower portion of the pavement.

5-694.216 AIR ENTRAINMENT

All concrete contains some entrapped air bubbles. Large entrapped air bubbles are undesirable. Air-entrained concrete has air, in a finely divided and dispersed form, purposely induced at the time of mixing. The air is produced in the concrete by the addition of an approved air-entraining admixture. The entrained air in the concrete, in the form of a large number of very small air bubbles in the mortar portion of the mix, is the result of the foaming action of the admixture. <u>Take care when placing concrete to consolidate the concrete without driving out the entrained air</u>.

The principal reason for entraining air in concrete is to increase resistance to the destructive effects of freezing and thawing and deicing salts. The entrainment of air also increases the workability of the concrete for placement purposes and permits a reduction in the sand and water contents of the mix. The bubbles exist in the mortar the same as an equal number of fine grains of sand, and in that sense, they are considered a distinct component of the mortar in addition to the cement, water, and sand.

The large number of fine bubbles increases the cohesiveness and fatness of the mix that not only improves the workability of the concrete, but also eliminates, to a large extent, the undesirable properties of ordinary concrete, namely segregation and bleeding.

The entrained air is not removed to any appreciable degree from the concrete mass during placement operations, even when high frequency vibration is employed, unless the concrete is over vibrated or over worked.

The increased resistance of air entrained concrete to the action of destructive salts and to ordinary freezing and thawing is especially valuable in the case of pavements because of the common use of chlorides for ice removal. It is also beneficial in the case of bridge piers and other structures where the concrete is exposed to severe freezing and thawing conditions. Late fall concrete is particularly susceptible to scaling caused by salts and freezing and thawing.

The strength of concrete is lowered by the addition of air. Maintain the air content of Type 3 Concrete at 6.5% ± 1.5%. Do not exceed this value and hold the air content in the range of 6 to 7%. This provides the desired durability and limits the loss of strength. The limits of 5 to 8% are allowed for unavoidable variations in materials and job conditions. Specification 2461.4A4b allows for some inadvertently placed concrete outside these limits to remain in place. The key word is “inadvertent”. **It is not an option to place concrete which falls outside of any specified range.**

5-694.217 DENSITY

The value of high density was addressed indirectly in connection with other related properties in concrete.

The factors that contribute to high density for all types of concrete are:

- Use of well-graded aggregate of the largest possible maximum size.
- Minimum water content consistent with good workability.
- Minimum air content consistent with adequate durability.
- Thorough consolidation during placement.

5-694.220 MIX DESIGNATION

Each mix is designed for a specific type of work, method of placement, and finishing. Varying the amount of sand, rock, or water in a mix will produce different placing and finishing characteristics and may also affect the quality of the finished product. Cement and air contents will affect the strength and durability of the concrete.

5-694.221 CLASSIFICATION OF CONCRETE

All concrete is classified by Type, Grade, Mix Designation, and Coarse Aggregate Designation as outlined in Specification 2461.3. A mix number identifies these requirements. The Engineer must determine from the Plans or Specifications the proper mix number for each phase of the work.

A. Types of Concrete

Concrete is classified as either Type 1 or Type 3. The type of concrete required, or the use of either type when permitted, is shown in the detailed Specification or in the Special Provisions for the items of work in the Contract.

Type 1 Concrete: This is concrete used without the addition of an air-entraining admixture.
Type 3 Concrete: This is concrete that has an approved air-entraining admixture to produce a specified target air content of 6.5%. See 5-694.540 for air content test method.

Do not confuse these designations with cement types. Cement is also defined by various type designations. For example, Type I cement is for general use and Type III cement is for high-early strength.

B. Grades of Concrete

Eight grades of concrete are provided in Specification 2461.3B2 for use as specified for different construction items. The basis of this classification is the relative strength and general quality, as governed by the cement-voids (C/V) ratio law.

Reference to Table 2461-1 in the Specifications indicates that for a given grade of concrete, the C/V ratio and strength for Type 3 Concrete is less than for Type 1 Concrete. The reason for this is that it is considered desirable to maintain the cement factors for concrete of the same grade at approximately the same level regardless of the type of concrete. In the few instances where either Type 1 or Type 3 Concrete of the same grade is permitted, it was determined that the reduced strength obtained from Type 3 Concrete was adequate and was more than offset by the increased durability provided by the entrained air.

C. Mix Designation

The slump range designations are identified in Table 2461-2 in the Specifications. The slump is normally controlled in a 25 mm (1 in.) range, the maximum of which is shown in the mix designation. This number is the maximum slump in 25 mm (1 in.) increments. For example, a 3Y36 has a maximum slump of 75 mm (3 in.) with a range of 50 to 75 mm (2 to 3 in.). Mixes such as 3Y16 and 3U17 where 25 mm (1 in.) is the designated maximum slump are normally controlled in a 12.5 mm (1/2 in.) range.

Carefully monitor this slump range. Too high a slump may result in concrete of low strength or poor durability. Too low a slump may result in cold joints or honeycombed areas due to poor placement characteristics.

D. Coarse Aggregate Designation

Table 2461-3 in the Specifications identifies the gradation ranges as shown below:

Range	Optional CA Designations
0	CA-00 only (Recycled concrete)
1	CA-15 to 50, inclusive
2	CA-15 to 50, inclusive
3	CA-35 to 50, inclusive
4	CA-35 to 60, inclusive
5	CA-45 to 60, inclusive
6	CA-50 to 70, inclusive
7	CA-70 only
8	CA-80 only

These gradation ranges indicate the gradation of the coarse aggregate that the Contractor may select for use in a particular mix. Generally, the selection of a coarser gradation will require lower cement content than the same mix with a finer gradation. However, availability of material may justify a finer gradation. Where hand methods of placement and finishing are used, a finer gradation provides more mortar in the concrete making it somewhat easier to consolidate and finish.

The aggregate shall conform to one of the classifications defined in Specification 3137. If a letter is shown as the last figure in the mix number, the Contractor is required to use an aggregate conforming to the same class as the letter. If no letter is shown the class of aggregate is optional with the Contractor. Normally, only certain items of bridge construction will have a class of aggregate specified.

The first digit of the mix number designates the type of concrete. The following letter designates the grade (design strength). The two mix designation digits following the letter indicate the maximum permissible slump and the range of coarse aggregate gradations permitted. A letter following the latter two numbers designate the class of coarse aggregates required. When high-early strength concrete is used, the letters “HE” are added after the normal mix number. There are two examples shown below as to how concrete is classified according to mix designations.

Example 1 - Mix number 3A41
“3” designates the type of concrete (Air-entrained)
“A” designates the grade of concrete (Grade A – 27 MPa (3900 psi) anticipated strength)
“4” designates the upper slump limit (75 to 100 mm (3 to 4 in.))
“1” designates the gradation range (CA-15 through CA-50)

Example 2 - Mix number 3Y46A
“3” designates the type of concrete (Air-entrained)
“Y” designates the grade of concrete (Grade Y – 30 MPa (4300 psi) anticipated strength)
“4” designates the upper slump limit (75 to 100 mm (3 to 4 in.))
“6” designates the gradation range (CA-50 through CA-70)
“A” designates the coarse aggregate group (Class A aggregate)

REFERENCES

1. Figure A 5-694.213, Design and Control of Concrete Mixtures, 14th Edition, Portland Cement Association, 2002.

MIX DESIGN
5-694.300

NOTE: FOR PROJECTS REQUIRING CONTRACTOR MIX DESIGN, THE DESIGN PROCEDURES ARE SPECIFIED IN THE SPECIAL PROVISIONS OF THE CONTRACT.

5-694.301 ESTIMATED MIX PROPORTIONS

It is the standard procedure at Mn/DOT to furnish estimated mix proportions, prior to starting the work, for the purposes stated below:

1. If a prospective bidder desires such information, estimated mix proportions for materials from specific sources are furnished as an aid in estimating the approximate cost of concrete.
2. The Mn/DOT Concrete Engineering Unit furnishes the Project Engineer with the estimated proportions as an aid in starting the work. For this purpose it is considered a trial mix. The estimated mix proportions are furnished as soon as essential information is received from the Project Engineer covering source and other pertinent data relative to the materials.

Trial mixes are adjusted in the field when necessary to meet specification requirements and to compensate for changes that may occur in the materials.

When materials come from aggregate sources not previously used, the materials must be tested at a certified laboratory to determine if the aggregates meet the requirements of Specification 3126 and 3137 prior to completion of a mix design. These tests require 30 days and are made on samples of representative materials.

5-694.302 REQUESTING MIXES

The Engineer shall submit information for concrete mix designs to the Mn/DOT Concrete Engineering Unit as soon as possible prior to the start of concrete operations. A minimum of two weeks is required when the aggregate sources have been previously used, four weeks for new aggregate sources. Obtain this information from the Contractor and submit on the *Concrete Mix Design Request* (Form 2416). See 5-694.711 for an explanation on completing this request form and an example of a completed form.

Upon receipt of Form 2416 from the Engineer, the Mn/DOT Concrete Engineering Unit issues *Estimated Composition of Concrete Mixes* (Form 2406). See Figure A 5-694.712. Delays may occur if all data needed for the design is not available.

5-694.311 MATERIAL TERMS

NOTE: The accepted national standard assumes calculations are based on a water temperature of 4°C (39°F) where 1 m^3 of water has a mass of 1000 kg (1 ft^3 of water weighs 62.4 pounds). Mn/DOT has historically calculated mix designs based on unit weight of water of 62.3 lb/ft^3 that is more representative of the water at actual concrete temperatures.

A. Specific Gravity

Specific gravity of a material is the ratio of the mass (weight) of a given volume to the mass (weight) of an equal volume of water. Water is used as a standard because of its uniformity. See 5-694.123A.

B. Absolute Volume

See 5-694.123D.

C. Total Moisture Factor

This term refers to the total amount of water carried by a given wet aggregate. It is expressed as a decimal of the oven-dry mass (weight) of the aggregate that carried it. It consists of the sum of the free moisture carried on the surface of the aggregate and the absorbed water within the pores of the aggregate.

D. Free Moisture Factor

The free moisture of an aggregate is the water that is carried on the surface of the aggregate particles and becomes a part of the total mixing water of the concrete. The free moisture is expressed as a decimal and is the ratio of the mass (weight) of this water to the oven-dry mass (weight) of the aggregate.

E. Absorption Factor

The absorbed water of an aggregate is the water contained within the pores of the aggregate and is held within the particles by capillary force. The absorption factor is expressed as a decimal and is the ratio of the mass (weight) of water for 100% saturation of the aggregate to the oven-dry mass (weight) of the aggregate. When the total moisture factor of an aggregate is less than its absorption factor, the aggregate absorbs some of the batch water from the concrete mix. See 5-694.123B.

F. Fineness Modulus of Aggregate

The Fineness Modulus (F.M.) of an aggregate is a numerical index of the relative fineness or coarseness of the aggregate. It is based on the summation of the percentages of material passing the fineness modulus sieves and is determined by dividing this result by 100, and subtracting from 10. The coarse aggregate fineness modulus sieves are the: 75 mm, 37.5 mm, 19 mm, 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, and 150 µm (3 inch, 1 1/2 inch, 3/4 inch, 3/8 inch, No.4, 8, 16, 30, 50, and 100). Generally, the F.M. is only calculated for the fine aggregate. The fine aggregate fineness modulus sieves are the: 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, and 150 µm (3/8 inch, No.4, 8, 16, 30, 50, and 100). Therefore, when calculating the F.M. for the fine aggregate the percent passing the sieves is added up, divided by 100, and subtracted from 7.

G. Void Content of Aggregate

See 5-694.123E.

5-694.312 MIX TERMS

A. Water Content

The water content of a concrete mix consists of the free moisture carried by the aggregate plus the batch water added at the mixer. Water contained within or absorbed by the aggregates is not included as a part of the water content. The water content is expressed in kilograms (pounds) or by the decimal part of mixing water contained in a unit volume of concrete. The term, kilograms per cubic meter (pounds per cubic yard), is used most often and is used in future reference in this Manual.

B. Cement Content

The cement content of a concrete mix is expressed as the kilograms (pounds) of cement contained in a cubic meter (cubic yard) of concrete. Minimum cement contents for various grades and consistencies of concrete are given in Specification 2461.3C.

C. Air Content

The air content of a concrete mix is expressed as the percent of air contained in a given volume of concrete. In concrete mix designs it is used as a decimal part of the concrete mix.

D. Unit Content Factors

At times it is convenient or necessary to express the quantity of cement, aggregate, water, and air in a concrete mix in terms of the decimal part by absolute volume that each occupy in a unit volume of concrete. Then the unit content factor for each material is some decimal value less than one that is obtained by dividing the absolute volume of each material by the total absolute volume of concrete. The sum of all the content factors in the concrete mix (including the air content) must always equal one.

E. Cement-Voids Ratio

This is a numerical ratio obtained by dividing the absolute volume of the cementitious materials in a concrete mix by the sum of the absolute volumes of water and air in the mix. The cement-voids ratio may measure, in a general way, the relative quality of concrete.

F. Gradation Index

The gradation index is a numerical value assigned to each mix number and determines the relative amounts of fine and coarse aggregate in the mix. Experience and extensive testing have found that for maximum density, economy, and workability, a definite relationship should exist between the maximum particle size of the coarse aggregate and the part of the combined (fine and coarse) aggregate that is finer than 1/10 the maximum size of the coarse aggregate.

A gradation index of 1.00 requires that the decimal part of the combined aggregate that is finer than 1/10 the maximum size of the coarse aggregate represents the void content of the coarse aggregate. For instance, if the void content of a coarse aggregate is 40%, then 40% of the combined fine and coarse aggregate is finer than 1/10 the maximum size particles for a gradation index of 1.00. For this purpose, the maximum size of the coarse aggregate is considered the opening through which 95% of the material will pass. The maximum size of the coarse aggregate and the fractions of the coarse and fine material which are 1/10 the maximum size, is determined graphically by plotting the sieve analysis on the semi-logarithmic chart. See Figure A 5-694.312.

Because air-entrained concrete is more workable than standard concrete and because the entrained air can substitute as a replacement for some of the fine aggregate, the gradation indexes for air-entrained concrete are less than those for corresponding standard non air-entrained concrete. The actual index values used for the different kinds of work and placement conditions as established by experiences on Agency work are shown in Table A 5-694.312.

G. Consistency

The term "Consistency" as used in this Manual refers to the relative wetness of concrete mixes. For a given mix, the relative wetness or consistency is measured by means of the slump test that is described in 5-694.530 and 5-694.531. For a given mix, workability increases directly with increases in wetness, or millimeters (inches) of slump, so long as the mix remains plastic and cohesive and provided that segregation does not occur. Consistency, therefore, is primarily related to and dependent upon the amount of water used per unit volume of concrete.

H. Water Requirements of Concrete Mixes

The water requirement of a concrete mix for a given consistency is primarily dependent upon the overall gradation and shape of the aggregate. Sufficient water is needed in a mix to wet and lubricate the surfaces of the cement and aggregate particles. Water fills voids and gives the particle dispersion necessary for the desired workability.

The water requirement for a given workability is not affected to any appreciable degree by the cement content.

A general relationship exists between the water requirements and the fineness modulus of the combined aggregate. This general relationship is shown in graphical form for Type 1 and Type 3 Concrete, respectively, in Figure B 5-694.312 and C 5-694.312.

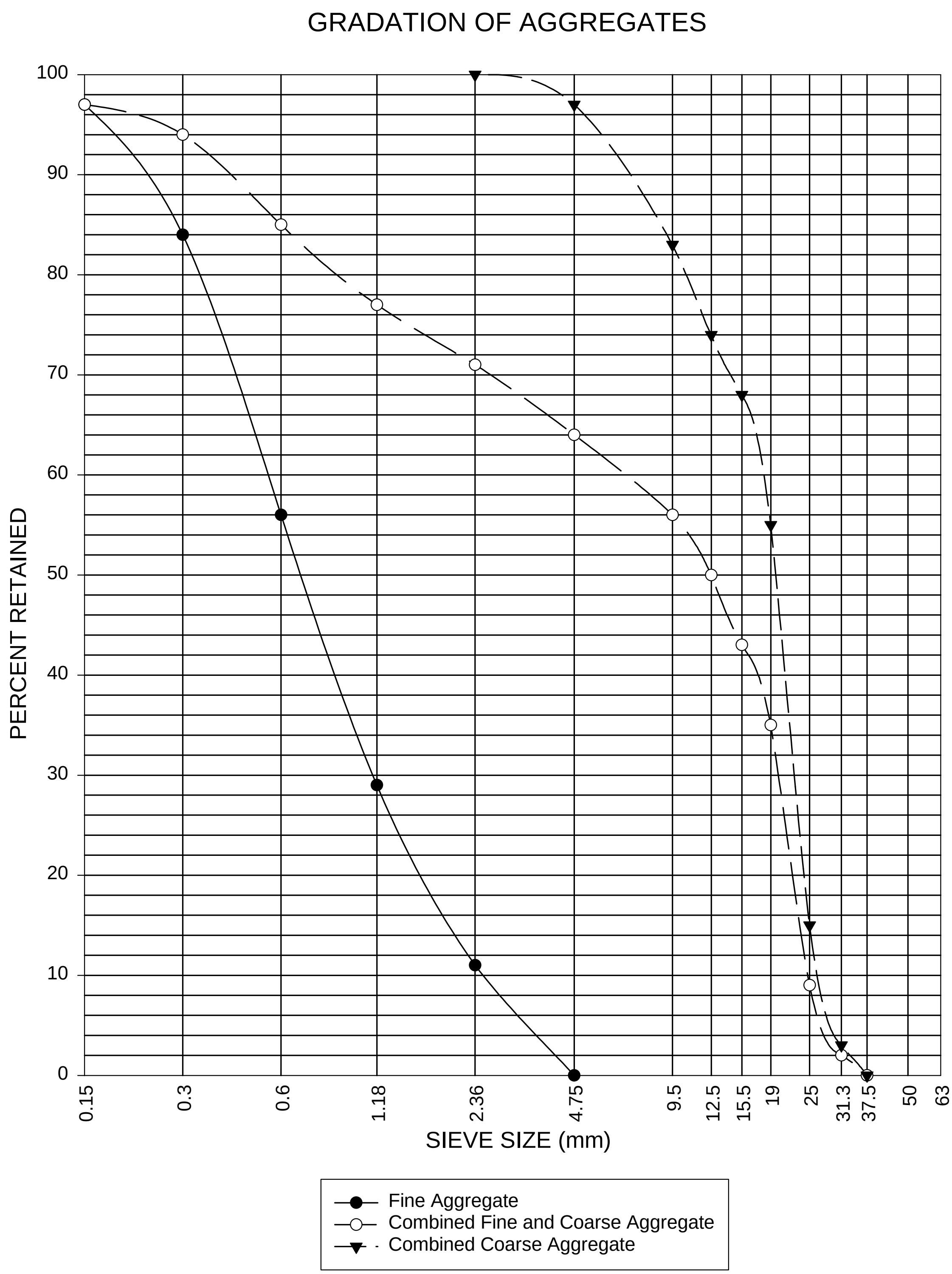


Figure A 5-694.312

Kind of Work	Method of Placement	Type	Grade	Slump mm (in.)	Gradation Index	Gradation Range	Optional Gradations of C Agg.	Mix No.	Remarks
Spec. 2201 **PAVEMENT BASES**	Manual Std. Machine Vibratory	3 3 3	B B B	75-100 (3-4) 50-75 (2-3) 25-50 (1-2)	1.00 1.00 1.00	2 2 2	15-50 Incl. 15-50 Incl. 15-50 Incl.	3B42 3B32 3B22	
Spec. 2301 **CONCRETE PAVEMENT**	Manual Std. Machine Vibratory	3 3 3	A A A	75-100 (3-4) 50-75 (2-3) 25-50(1-2)	1.00 1.00 1.00	1 1 1	15-50 Incl. 15-50 Incl. 15-50 Incl.	3A41 3A31 3A21	
RECYCLED CONCRETE PAVEMENT	Manual Std. Machine Vibratory	3 3 3	A A A	75-100 (3-4) 50-75 (2-3) 25-50 (1-2)	1.00 1.00 1.00	0 0 0	00-Only 00-Only 00-Only	3A40R 3A30R 3A20R	Recycled aggregate must be crushed to 19 mm-(3/4"-). A virgin 19 mm+(3/4"+) material may be added at the Contractor's option.
PAVEMENT REPAIR	3U18 and 3A32HE are the Standard Mixes. See Pavement Rehabilitation Standards for Details.								
Spec. 2401 **BRIDGES**									
Cofferdam Seals Hand Railings Slipform Railings Curbs & S.W. Etc. General Reinf. Structural General Reinf. Structural Bridge Slabs	Tremie Vib + Manual Vibratory Vib + Manual Vib + Manual Vib + Manual Vibratory	1 3 3 3 1 3 3	X Y Y Y A Y Y	125-150 (5-6) 75-100 (3-4) 12-25 (1/2-1) 75-100 (3-4) 75-100 (3-4) 75-100 (3-4) 50-75 (2-3)	1.10 1.10 1.00 1.00	2 6 6 6 3 3 3	15-50 Incl. 50-70 Incl. 50-70 Incl. 50-70 Incl. 35, 45, 50 35, 45, 50 35, 45, 50	1X62 3Y46 3Y16 3Y46 1A43 3Y43 3Y33	 3Y46A may be required 3Y16A may be required 3Y46A may be required 3Y33A may be required
End Diaphragms Interior Diaphragms	Vib + Manual Vib + Manual	3 3	Y Y	75-100 (3-4) 75-100 (3-4)	1.00 1.00	3 3	35, 45, 50 35, 45, 50	3Y43 3Y43	
Low Slump Bridge Deck Overlays Precast Piles Cast-in-Place Piles	Vibratory Vib + Manual Manual*	3 3 1	U W C	12-25 (1/2-1) 25-75 (1-3) 125-150 (5-6)	 1.00	7 6 2	70 50-70 Incl. 15-50 Incl.	3U17A 3W36 1C62	*Vibration required if reinforcing cages are called for.
Slope Protection	Manual	3	A	*50-75 (2-3)	1.10	4	35-60 Incl.	3A34	*Slump may be adjusted as approved by Engineer.
Prestressed Conc. Girders Prestressed Conc. Girders Precast Conc. Channels Bridge Approach Panels Precast Box Culvert Precast Conc. End Section	Vib + Manual Vib + Manual Vib + Manual Vib + Manual Vib + Manual Vib + Manual	1 3 3 3 3 3	W W W X W W	50-75 (2-3) 50-75 (2-3) 25-50 (1-2) 75-100 (3-4) 75-100 (3-4) 75-100 (3-4)	 1.00 	6 6 6 2 6 6	50-70 Incl. 50-70 Incl. 50-70 Incl. 15-50 Incl. 50-70 Incl. 50-70 Incl.	1W36 3W36 3W26 3X42 3W46 3W46	
Spec. 2411 **MONOLITHIC CULVERTS**									
Sidewalls and Wing Walls Top and Bottom Slabs	Vib + Manual Vib + Manual	3 3	Y Y	75-100 (3-4) 50-75 (2-3)	1.00 1.00	3 3	35, 45, 50 35, 45, 50	3Y43 3Y33	

Table A 5-694.312

Kind of Work	Method of Placement	Type	Grade	Slump mm (in.)	Gradation Index	Gradation Range	Optional Gradations of C Agg.	Mix No.	Remarks
Spec. 2411 RETAINING WALLS									
Reinforced Type Walls Gravity Type Walls Concrete Sub-Foundation	Manual + Vib Manual + Vib Manual + Vib	3 3 1	Y B A	75-100 (3-4) 50-75 (2-3) 75-100 (3-4)	1.00 1.00 1.00	3 2 3	35, 45, 50 15-50 Incl. 35, 45, 50	3Y43 3B32 1A43	
Spec. 2506 MANHOLES AND CATCH BASINS									
Structures of Design A, C, E, F, or G, Drop Inlet, and Surface Block All Other	Manual Manual	3 3	B Y	75-100 (3-4) 75-100 (3-4)	1.00 1.00	2 3	15-50 Incl. 35, 45, 50	3B42 3Y43	
EROSION CONTROL STRUCTURES									
Culvert Headwalls Reinforced Type Dams Gravity Type Dams Flumes, Aprons, Spillways, Etc.	Manual Manual Manual Manual	3 3 3 3	A Y B A	75-100 (3-4) 75-100 (3-4) 50-75 (2-3) 50-75 (2-3)	1.00 1.00 1.00 1.00	2 3 2 4	15-50 Incl. 35, 45, 50 15-50 Incl. 35-60 Incl.	3A42 3Y43 3B32 3A34	
Spec. 2521 SIDEWALKS									
Plain Exposed Aggregate	Manual Manual	3 3	A A	50-75 (2-3) 50-75 (2-3)	1.00 1.00	2 6	15-50 Incl. 50-70 Incl.	3A32 3A36	
Spec. 2531 CURB AND GUTTER									
Slipform Curb & Gutter Hand Curb & Gutter	Vibratory Vibratory	3 3	A A	25-50 (1-2) 50-75 (2-3)	1.00 1.00	2 2	15-50 Incl. 15-50 Incl.	3A22 3A32	
Spec. 2533 MEDIAN BARRIERS									
Cast-in-Place Barriers Slipform Barriers Precast Barriers	Manual + Vib Manual + Vib Manual + Vib	3 3 3	Y Y Y	50-75 (2-3) 12-25 (1/2-1) 50-75 (2-3)	1.00 1.00 1.00	2 2 2	15-50 Incl. 15-50 Incl. 15-50 Incl.	3Y32 3Y12 3Y32	
PRESTRESSED CONCRETE NOISE BARRIERS									
Wall Panels Concrete Posts	Manual + Vib Manual + Vib	3 3	W W	50-75 (2-3) 50-75 (2-3)		6 6	50-70 Incl. 50-70 Incl.	3W36 3W36	41 MPa (6000 psi) required

Table A 5-694.312

WATER REQUIREMENTS FOR TYPE 1 CONCRETE

Approximate Equation
(Based on the use of a natural gravel aggregate of average gradation)

For 1 1/2" Slump	**W = 553.08 - 53.24 M**	**Note: For Crushed Aggregate add 16.0 pounds of water per cubic yard.**
For 2 1/2" Slump	**W = 571.70 - 55.00 M**	
For 3 1/2" Slump	**W = 595.30 - 57.30 M**	

Where: W = Pounds of Water per Cubic Yard
M = Fineness Modulus of Mixed Aggregates

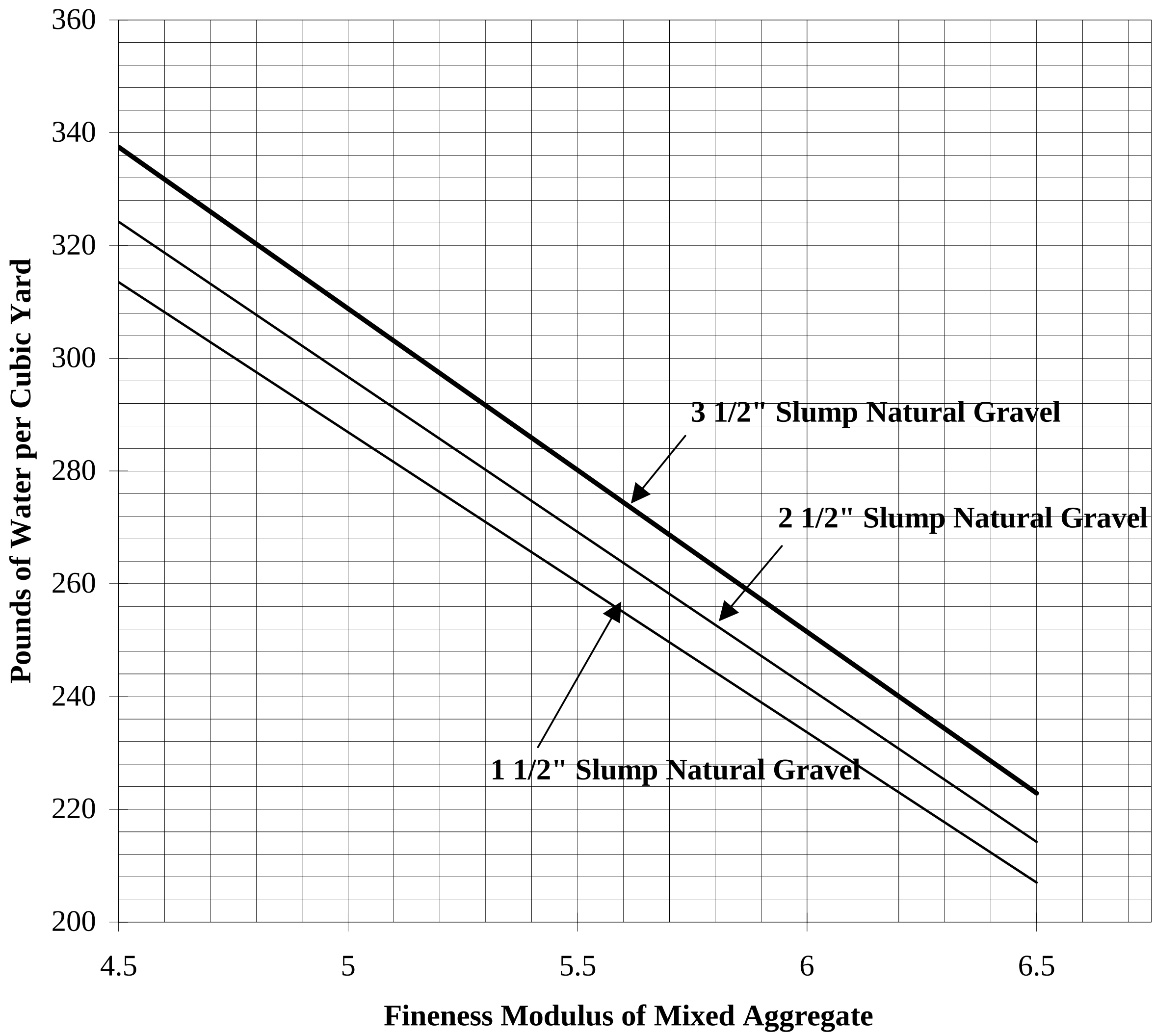


Figure B 5-694.312

WATER REQUIREMENTS FOR TYPE 3 CONCRETE

Approximate Equations

	Natural Gravel Aggregate (Dashed Line)	Crushed Rock Aggregate (Solid Line)
1 1/2" Slump	W = 591.60 - 61.10 M	W = 582.70 - 56.60 M
2 1/2" Slump	W = 619.45 - 63.97 M	W = 610.15 - 59.32 M
3 1/2" Slump	W = 639.30 - 66.00 M	W = 629.60 - 61.20 M

Where: W = Pounds of Water per Cubic Yard
M = Fineness Modulus of Mixed Aggregate

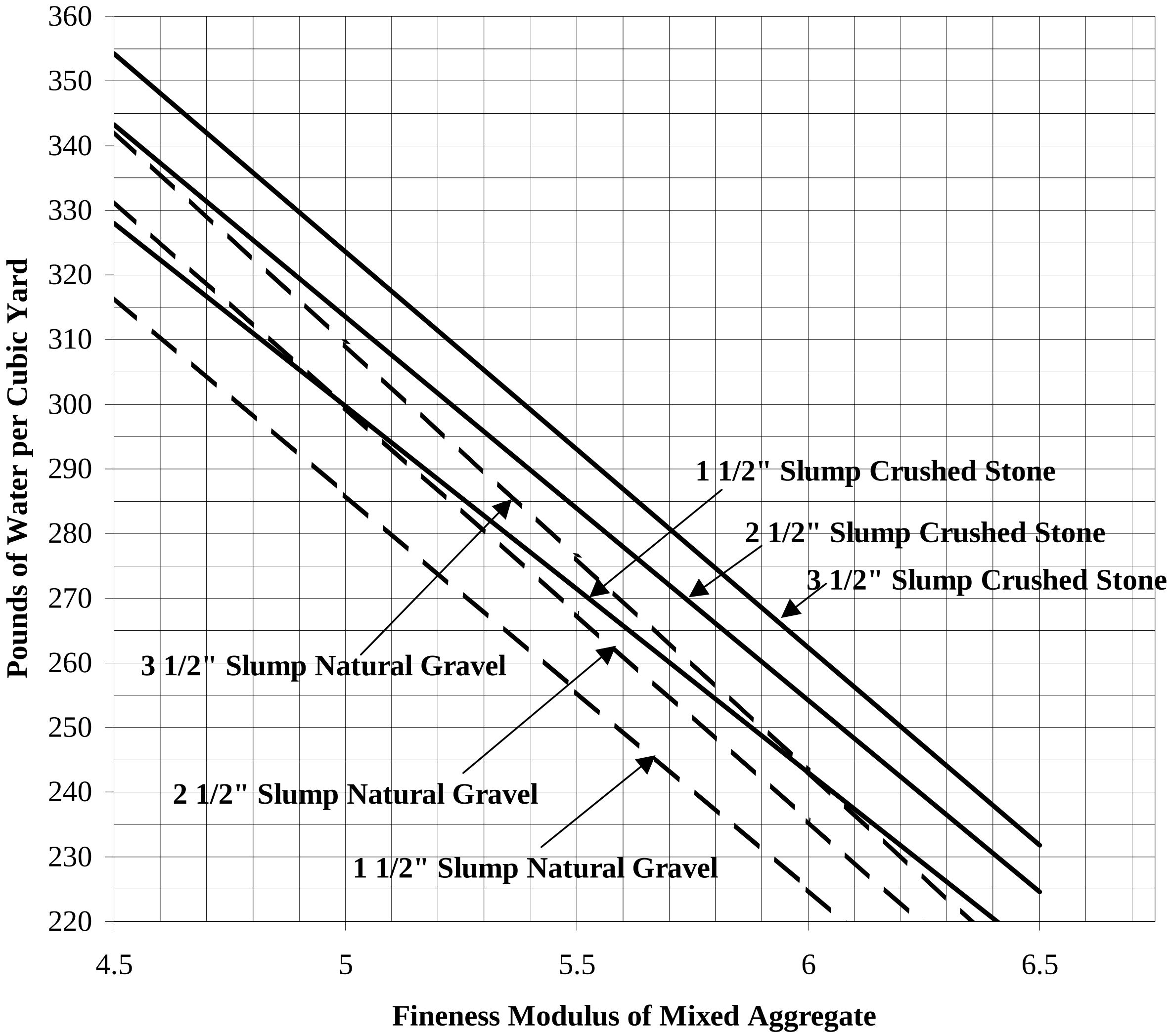


Figure C 5-694.312

5-694.330 ANALYZING THE MIX

Upon completion of each day's pour, transfer the mix data to the *Weekly Concrete Report* (Form 2448). See 5-694.727 for instructions. Analyze the results by comparing the data with the requirements of the Specifications. Check for compliance with the water ratio and the w/c ratio. Contact the Mn/DOT Concrete Engineering Unit if the mixture needs adjustment to comply with the Specifications. **Promptly, send the report to the Mn/DOT Concrete Engineering Unit.**

5-694.331 ROUTINE MIX ADJUSTMENTS

Whenever it is found that the mix does not comply with one or more of the Specification requirements, establish a new job mix. If there is a decided change in the aggregate gradations or concrete characteristics, a new design is required. In each case, contact the Mn/DOT Concrete Engineering Unit at 651-779-5573 for a new mix design or advice.

5-694.340 PROPORTIONING BY VOLUME

This section covers volumetric proportioning when the mixing unit is not calibrated for the particular aggregates and as covered in Section 5-694.450 of the Manual.

5-694.341 BASIS OF MIX PROPORTIONS

When batching by bulk volume is employed by the Contractor, as provided in 2461.4B1 of the Specifications, the proportions are issued in the terms of normal mass (weight) proportions. Convert all mass (weight) proportions to volumetric measure prior to use on the project. Adjust the batch proportions by mass (weight) by reducing the numerical values for fine and coarse aggregates and water by 9%. This results in an approximately 10% increase in cement content as required by specifications when volumetric batching is employed. See 5-694.450 for the exception to the 10% additional cement requirement.

Since one sack of cement is considered as one cubic foot of bulk material, it is easy to change the batch masses (weights) per sack of cement to relative values in terms of bulk proportions. A ratio of 1:2.5:4.0 means there are 2.5 parts of bulk sand and 4.0 parts of bulk coarse aggregate per unit volume of cement. The values are based on the same loose, moist conditions that occur on the project.

5-694.342 VOLUMETRIC MEASUREMENT OF MATERIALS

Only use cement in whole sacks as furnished by the Manufacturer. The use of fractional sacks is not permitted unless the cement is weighed and the bulk volume of other materials adjusted for the quantity of cement used.

It is satisfactory to proportion the aggregates by the use of standard size boxes or by determining the desired volume in a wheelbarrow box with a strike off to leave the correct amount of material in the wheelbarrow.

Water is measured at the mixer in the conventional manner or by use of calibrated containers, but the water contained in the aggregates is not measured except at the time the bulk proportions are determined. Keep the amount of water at a minimum for the consistency required.

5-694.343 CONVERTING PROPORTIONS FROM MASS (WEIGHT) TO BULK VOLUME

Use the following method to convert mass (weight) proportions to bulk proportions.

Use two or three cylinder molds to determine the unit weight of each of the aggregates. Fill one of the molds with moist fine aggregate in the same state of compaction as measured later from the bulk material. Strike-off the fine aggregate above the top of the mold leaving the mold level full. Exercise care not to compact the sand. Obtain the net mass (weight) of the moist fine aggregate and determine the moisture content. Knowing the volume, the moist mass (weight) and the moisture content, determine the dry mass (weight) of a unit volume of the moist material. Follow the same procedure for each size of coarse aggregate used.

The following is an example of converting proportions from mass (weight) to bulk volume.

Assume the following Dry Batch Masses (Weights) issued:

Cement	42.7 kg (94 lb.)
Fine Aggregate	95.5 kg (210 lb.)
Coarse Aggregate	136.4 kg (300 lb.)
Water	21.8 kg (48 lb.)

Unit Volume Determination (Moist)	Fine Aggregate	Coarse Aggregate
Volume of mold	0.00556 m^3 (0.1965 ft^3)	0.00556 m^3 (0.1965 ft^3)
Moisture Content	0.050	0.020
Net Wet Mass (Weight) of Sample	7.5 kg (16.5 lb.)	9.2 kg (20.3 lb.)
Dry Mass (Weight)	7.1 kg (15.7 lb.)	9.0 kg (19.9 lb.)
Dry Mass/Cubic Meter of Wet Material (Dry Weight/Cubic Yard of Wet Material)	36.4 kg (80.0 lb.)	45.9 kg (101.0 lb.)

The adjustment in proportions (Items reduced by 9% as explained in 5-694.341.)

	Metric	English		Bulk Volume Ratios
Cement	42.7/42.7	94/94	=	1.0
F.A.	$\frac{95.5 \times (1-0.09)}{36.4}$	$\frac{210 \times (1-0.09)}{80}$	=	2.4
C.A.	$\frac{136.4 \times (1-0.09)}{45.9}$	$\frac{300 \times (1-0.09)}{101}$	=	2.7
Water	21.8 x (1-0.09) = 19.8 kg	$\frac{48 \times (1-0.09)}{8.33}$	=	5.24 gal. or 19.8 L

BATCHING AND MIXING
5-694.400

5-694.401 CHECKING BATCH PLANT OPERATION

Check to ensure accuracy and dependable operation of the proposed equipment and methods prior to the start of concreting operations and after making any changes in the location or arrangement of the batching plant. Plant calibration is the responsibility of the Producer/Contractor.

Check the general layout of the plant before the equipment is erected to ensure efficient operation and adequate space for stockpiling and handling materials in compliance with specification requirements. Whenever possible, avoid the arrangement and erection of batching plants in congested locations which are not conducive to proper handling of materials. Small stockpiles result in segregation and non-uniformity of materials and very poor control of the concrete. Once a batching plant is erected in such a location, it is difficult to improve conditions. Experience has demonstrated that the most uniform concrete is produced when the batching plant is favored by adequate space for the maintenance of large stockpiles of materials.

When draining aggregates at the batch plant site, provide provisions for disposal of drainage water and for clear-cut separation of drained from undrained materials. Keep materials of different sources/classes or gradations separated. Sometimes, timber bulkheads are erected to save space in the Producer's storage yard. These are satisfactory if built properly.

Erect the weighing bins and hoppers on firm foundations to avoid settlement, which might affect the accuracy of the equipment.

At concrete batching sites, check that there is enough material in stockpiles to complete the concrete pour or the rate of aggregate delivery is sufficient to keep up with the required rate of concrete delivery. When using a collecting hopper for handling more than one size aggregate, empty entirely of one size material before placing another size material within. Check to assure that the conveyor and reflector chute used with the collecting hopper are clear of any accumulated materials. The discharge chute for deflecting the material into the various storage compartments must center over the correct compartment while it is charged with aggregate.

5-694.410 BATCHING EQUIPMENT

Check batching equipment before the operation begins. Inspect the equipment and review the procedures the Producer/Contractor will follow during batching. The batching apparatus and progress must meet specification requirements and produce uniform high quality concrete. The following information will aid the Inspector in evaluation of the equipment.

The batching equipment generally consists of a weigh hopper loaded from overhead bins by gravity, that discharges either into the truck below or onto a belt that goes to the mixer. Weigh the cementitious materials independently of aggregates either on separate scales or in separate compartments.

The gates controlling charging and discharging of the weigh hopper must tightly close and have operating interlocks when producing concrete. See Figure A 5-694.410. The charging device shall provide the capability of stopping the flow within the specified weighing tolerance and controlling the rate of flow of the material. The manner of attachment of vibration equipment or other aids to charging or discharging shall not interfere with the accuracy of the weighing.

Figure A 5-694.410

The Contractor should avoid overloading the weigh hopper or exceeding the scale capacity. The batches shall not overflow the weigh hopper or exceed the scale capacity. Sufficient clearance must exist above batching hoppers to permit removal of any overload. When fully batched into the hopper, the top of the material must not touch the charging bin above.

Cement weigh hoppers must have an access port to facilitate inspection of the interior. The installation of the dust seal between the storage bin and the weighing hopper must not affect the weighing accuracy. The weigh hopper shall have a coned bottom and a vibrator to ensure complete discharge.

Prior to mixing, carefully examine the mixer to assure that all requirements of Specification 2461.4C2 regarding blade wear, drum speed, timing, etc. are met. The mixer shall produce concrete at a rate applicable to the size of the pour and the type of operation. Mixers having capacities of 0.3 m^3 (10 ft^3) or more require automatic timers set in accordance with Specification 2461.4C2 or 2301.3F prior to any mixing operations. Figure B 5-694.410 shows a mixer dumping a load.

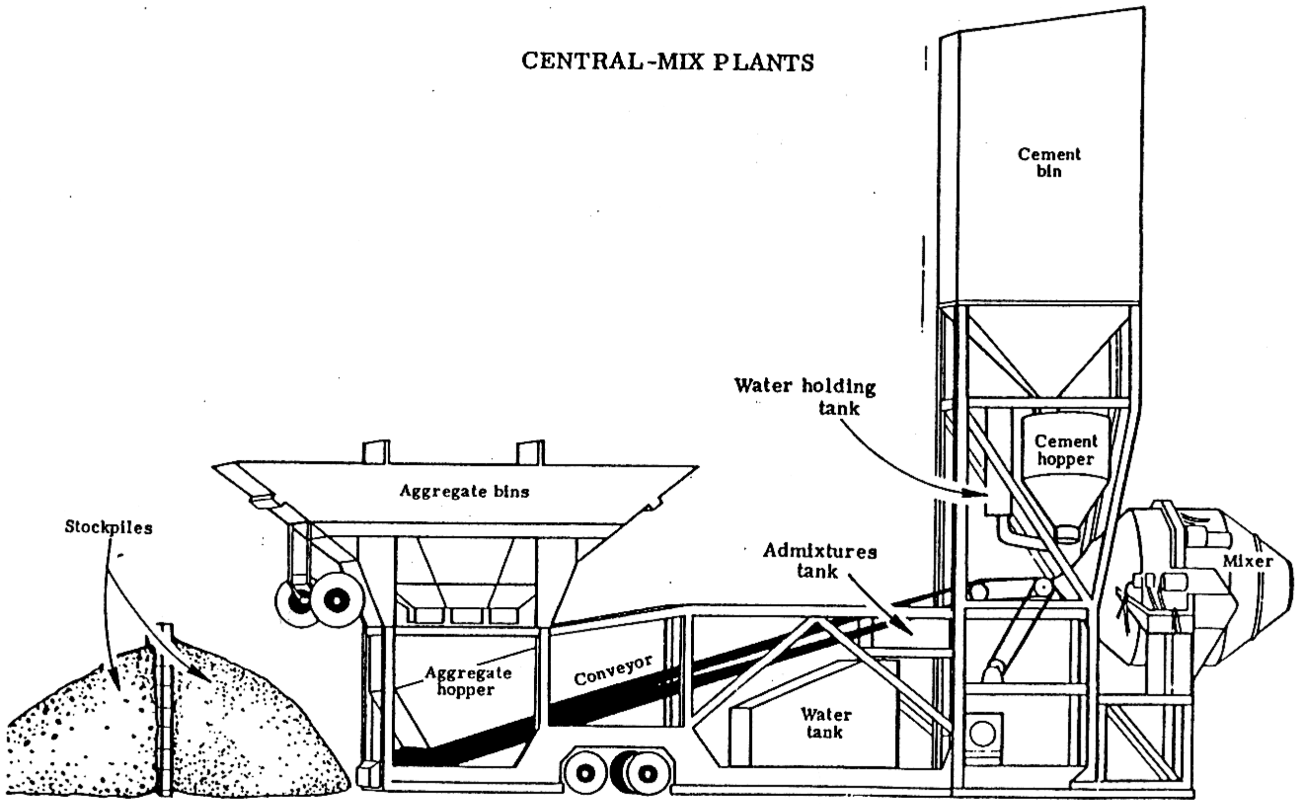


Figure B 5-694.410

Specification 2461.4C2f states that the mixing period begins when the last of the materials enter the mixer drum and ends when the discharge of the batch begins. Paving mixers, 0.75 m^3 (1 yd^3) or larger, are required to have a mixing time of 60 seconds. To attain this mixing time, consider other factors such as charging and discharging time in the total operating cycle. Specification 2301.3F1 states that when mixing operations are first started on a project, set the timing device to produce an operating cycle of 75 seconds for single drum and 55 seconds for dual drum mixers. See Figure C 5-694.410 for an example of a single drum mixer and Figure D 5-694.410 for an example of a dual drum mixer. This operating cycle is the time period between successive occurrences at some fixed point in the operation, for example, from bell to bell. Reduce the cycle time if, after the operating constants are determined, the Inspector is certain that each batch will have a full 60 seconds of mixing time during the operating cycle.

Special points to observe regarding batching are the following:

- For both single and dual-drum mixers, the water should start into the drum in advance of the solid materials and it should continue to flow into the drum until after all of the solid materials have entered.
- The drum must empty of the preceding batch before the solid materials of a new batch enter the drum.
- For dual-drum mixers, the first drum must empty completely and the transfer chute must close before the solid materials of a new batch enter the drum. Likewise, the second drum must empty and the discharge chute close before the transfer of the following batch from the first drum begins.
- The number of revolutions at mixing speed shall not exceed 150.

Figure C 5-694.410

Figure D 5-694.410

5-694.411 TYPES OF BATCHING EQUIPMENT

Batching equipment is designated as Manual, Semi-Automatic, and Automatic as defined below:

A. Manual
Batching equipment is charged by devices that are actuated manually, with the accuracy of the weighing operation being dependent upon the operator's visual observation of the scale. The charging device is actuated by either hand or by power assists. The weighing accuracy shall comply with tolerances per Specification 1901 and 2301.3F.

B. Semi-Automatic
Batching equipment is charged by devices, which are separately actuated manually for each material to allow weighing of the material. They are actuated automatically when reaching the designated mass (weight) of each material. The weighing accuracy shall comply with tolerances per Specification 1901 and 2301.3F.

C. Automatic
Batching equipment is charged by devices which when actuated by a single starter switch, will automatically start the weighing operation of all materials consecutively and stop automatically when reaching the designated mass (weight) of each material. Automatic batching equipment shall have suitable delivery interlocks per Specification 1901 & 2301.3F. See Figure A 5-694.411.

Figure A 5-694.411

5-694.412 REQUIREMENTS FOR PAVING BATCHING EQUIPMENT

Batching equipment used in conjunction with paving operations have further requirements in addition to those specified for other types of concreting operations.

The Contractor shall provide:

- Computerized batching is required.
- A computer-generated batch ticket showing the target and actual masses (weights) of all components. This shall serve as the materials recorder along with cementitious cut-offs.
- The water added to the mix by an electronic meter, approved by the Engineer, which records the amount of total water, including temper water, as part of each batch ticket.

5-694.430 CHECKING BATCHING AND MIXING EQUIPMENT

There are two items of equipment to closely observe at all times. These are the scales used for weighing the batch materials and the water measuring equipment. Check to make sure that this equipment meets accuracy requirements before the work begins. An approved scale company must check and calibrate the scales that have not received an approved inspection within six months prior to starting production. Thereafter, scales are checked and calibrated once each year. Additional calibrations are made at three-month intervals using the procedure described in 5-694.431 and 5-694.433. The Producer's Plant Personnel may perform these if observed by an Agency Inspector. If more than 45 days have elapsed since the full-scale check by a scale company, the first such check is made before operations begin. Spot-check the scale calibrations at least once each month. The Producer should check the scales for zero balance and the effectiveness of the interlocking controls for the cement and aggregates at least twice each day and for sensitivity at least once each day. The Producer shall report defective controls in the plant diary.

The most accurate weighing systems include load cells. A load cell uses a strain gauge to measure the direct stress that is introduced into a metal element when it is subjected to a tensile or compressive force.

Load cells are attached to digital displays for easy reading and zeroing. They also feature programmable high/low set points. Signals for the load cells are sent electronically to the computer for accurate documentation. See Figure A 5-694.430.

Figure A 5-694.430

When weighing or measuring equipment is moved from one setup to another, the Producer/Contractor shall completely recalibrate it after erection at the new site. Erratic and inaccurate operation of the measuring equipment due to maladjustment or damage may result from impact and shock during the move.

Sluggishness of the working parts or a marked change in the level of material in the weighing hoppers may indicate inaccurate operation of the scales. Providing the batch composition and other conditions remain constant, the water setting at the mixer should also remain relatively constant. A decided change in the required mixer setting following an extended period of uniform operation indicates that something is wrong with the equipment and that an immediate check is required. In such cases, a thorough checking of the equipment is required in addition to re-calibration. Investigate the cause of the trouble and eliminate it.

In order to determine whether or not the concrete meets specification requirements for cement content, water-cement ratio, etc. the Inspector must know the exact amount of materials used in mixing the concrete.

The equipment used for proportioning the various materials in the batching operations shall comply with Specifications 1901.8 and 2461.4B. Specification 2461.4D for ready-mix work and 2301.3F for concrete paving projects also apply. The Producer/Contractor is required to furnish personnel and accessories needed to check the accuracy of the equipment. An Agency Monitor records the results, while offering other reasonable assistance to facilitate this calibration. The equipment must meet accuracy and sensitivity requirements within the specified tolerances at all times.

If water measuring equipment is inactive for any extended period of time, as over winter, the Producer/Contractor should dismantle and thoroughly clean and adjust before it is calibrated. Problems are frequently encountered with this type of equipment due to formation of scale and rust. This condition is aggravated considerably by long periods of inactivity or storage. The presence of scale or other foreign material in the system is invariably indicated by erratic operation. Erratic or inaccurate operation may also result from wear or maladjustment of the equipment, leaky valves, etc. When such inaccurate operation is encountered, immediate correction is required before mixing is allowed to start.

5-694.431 CALIBRATING WEIGHING EQUIPMENT

When a scale servicing company performs the required calibration they should generally follow the procedures outlined below:

A. Visual Inspection Prior to Test

- Clearance around hopper and lever system
- Dust curtain for slack - freedom
- Balance of scale
- Correct problems noted above, before proceeding on

B. Test Procedure

1. Balance Indicator: Check for repeatability. Note the hangers, materials used to hold weights, and the correction weights are included in the balance.
2. Sensitiveness: Check on non-automatic indicating scales. Twice the value of the minimum graduated interval on the beam allowed.
3. Fractional Poise: Check to capacity by 50 kg (100 lb.) increments; tolerance 0.5%.
4. Balance Check: Remove test weights and recheck balance device. This action should not change balance by more than one of the minimum graduations (plus or minus).
5. Empty Test: Apply test weight to empty scale, minimum load of 500 kg (1000 lb.), 1000 kg (2000 lb.) desirable (or to capacity of device, whichever is greater); tolerance 0.5%.
6. Balance Check: Remove test weights and re-check balance. The device should not change balance by more than one of the minimum graduations (plus or minus).
7. Half Normal Batch Capacity Test: Fill the hopper to about one-half the capacity of the device with batching materials, take reading, then apply test weights. Tolerance is applied only to the

total of the test weights used; tolerance 0.5%.

8. Balance Check: Remove test weights and recheck reading with materials. Reading should not change by more than one of the minimum graduations (plus or minus).
9. Full Normal Batch Capacity Test: Fill the hopper with batching material to as near capacity that will still allow the test weights to be applied without exceeding the capacity and take reading. The test weights tolerance of 0.5% is applied only to the total of the test weights used.
10. Balance Check: Remove test weights and recheck reading with materials. Reading should not change by more than one of the minimum graduations (plus or minus).
11. Electronic Indicators: Check for environmental factors such as R.F.I. interference from other electronic elements in the environment. Interference must not affect the device by more than two of the minimum graduations (plus or minus).

C. Spot Check Procedure

The usual procedure in making a spot check is to assure that the equipment is generally in good operating condition. The knife-edges or other working parts of the equipment shall have no binding or cramping. The Producer must have a sufficient number of test weights. Fully load the storage hoppers prior to the spot check.

The first step is to balance the scale at a load of zero with the weighing hopper clean and empty. On single beam scales, obtain the zero balance with the adjustable counter weight provided. For multiple beam scales, obtain zero balance first with the tare beam and then with each and all of the weight beams free to act with the tare beam. To prevent use with other beams, securely fasten in a zero position any of the multiple beams actually not required in the weighing operations when multiple beam scales are used. After zero balance is satisfied, one or more of the test weights is applied by means of a suitable hanger furnished by the Producer/Contractor. Knowing the mass (weight) of the hanger accessories is required because it is included as part of the applied load.

If the scale is to operate with a normal working load of about 250 kg (500 lb.), apply the test weights in 50 kg (100 lb.) increments until the calibration is carried up to 350 kg (700 or 800 lb.), including the mass (weight) of the hanger. For larger scales, fill the bins to within approximately 100 kg (200 lb.) of the expected operating point, then test weights in 50 kg (100 lb.) increments are applied until a point approximately 100 kg (200 lb.) over the operating point is reached. Each time a weight increment is applied, balance the scales and record a reading opposite the known applied load.

While carrying the spot check over the expected operating range, check the sensitivity of the equipment by temporarily applying an additional load equivalent to 0.2% of the load at that time. The additional load should throw the equipment out of balance.

If the equipment fails to meet requirements in any respect, a report should indicate the discrepancy. After the scales are repaired or otherwise rendered satisfactory, re-calibrate the scales and send a copy of the reports to the Project Engineer to document that the equipment complies with the specifications. A sample of the *Test of Weighing Equipment* (Form 2124) is shown in Figure A 5-694.717.

For paving projects over 750 m^3 (1000 yd^3), check the various interlocking devices to assure proper function. Check that the hopper inlet gate and the discharge gate cannot open at the same time. If one gate is open, the other gate is interlocked in the closed position. The cementitious scales shall have these same features, but in addition, the discharge gate is not capable of opening until the scale is in balance at full load. Once the discharge gate is open, it is not capable of closing until the tare beam or dial comes back to zero balance. The discharge gate of the cementitious hopper is always locked in the closed position during the weighing operation when the cementitious in the weighing hopper is outside the specified tolerance of 1%. Check this feature during the spot check by resetting the scale at balanced loads by an amount equivalent to (both plus and minus) slightly more than the 1% tolerance in mass (weight) permitted. If the discharge gate can open, the discharge-locking device is not functioning properly.

Do not use equipment for paving which does not have the required interlocking devices for controlling the batching operations as provided in Specification 2301.3F4.

5-694.432 AUTHORIZED SERVICE COMPANIES FOR SCALE CALIBRATIONS

A list of authorized service companies for scale calibrations is available on the Mn/DOT Concrete Engineering Unit website at www.mrr.dot.state.mn.us/pavement/concrete/concrete.asp.

5-694.433 CALIBRATING WATER MEASURING EQUIPMENT

Calibrate and spot check water weighing equipment in accordance with the following sections. Carefully calibrate water-measuring equipment before mixing operations begin, but after the mixer is in its operating position. See Figure A 5-694.433 for an example of a water meter and a water scale.

Figure A 5-694.433

Measure the mixing water on approved scales or by volume using an approved water-metering device. For approval, the water meter shall comply with the following:

1. It shall have a discharge indicator capable of setting to within 5 L (1 gal.) of a predetermined amount.

2. It shall have a positive automatic shutoff valve that stops the flow of water when the indicated amount of water is delivered.
3. It shall operate within a maximum delivery tolerance of 1% of the required water setting at the time of batching.
4. It shall bear an approved inspection seal displaying the date of the previous calibration and adjustment within 6 months of the date of use.

Unless evidence is furnished indicating that the water meter was calibrated and adjusted within the previous six months by an authorized service agency as listed on the Mn/DOT Concrete Engineering Unit website, recalibrate and adjust prior to use in accordance with the weighing procedures given in this Manual. Spot check the water meter for accuracy at least once each month as the work progresses. Any platform scale used in the calibration of water meters is subject to the requirements for scale accuracy and calibration and adjustment provisions set forth in Specification 2461.4D4.

Report all calibrations of water-measuring equipment on the *Test of Weighing Equipment* (Form 2124). See 5-694.717.

An authorized service agency or the Producer/Contractor under the supervision of the Engineer may perform the meter calibration.

5-694.434 WATER METER CALIBRATION

A. Visual Inspection Prior to Test

1. Check for partially collapsed lines, leaks, or restrictions that would divert or otherwise hamper the flow of water to the meter.
2. Inspect gears, pivots, etc., for excessive wear.
3. Check legibility of dials, numerals, and pointers.
4. Correct any problems noted above before proceeding.

B. Test Procedure
(NOTE: Disregard Temperature Corrections)

1. Obtain a good quality platform scale and calibrate it in accordance with 5-694.431.
2. Place clean 220 L (55 gal.) drum or other suitable container on scale and record tare mass (weight). Run approximately 50 L (15 gal.) of water into drum, record mass (weight) of water (total mass (weight) less tare) and record water meter reading. Repeat 3 times.
3. Dump out water, re-tare drum and follow procedure in B2 above for the 100 and 150 L (30 and 45 gal.) levels.
4. Compare meter measurements with computed volume, based on 1 L = 1 kg (1 gal. = 8.33 lb.). The comparison shall agree with the Specifications for the work. If they are not in agreement, do not batch concrete until the equipment meets the requirements. This will usually require repair or replacement of the meter and re-calibration.
5. The quantity of water discharged may not agree exactly with any of the indicator settings. While it is desirable that the settings and the discharged volume agree, such agreement is not

absolutely essential for practical operation. If exact agreement is not found and shifting of the indicator cannot provide agreement, the Inspector may prepare a calibration chart by plotting the actual discharges against their corresponding indicator settings and drawing a smooth curve through these points. Do this only when the discrepancies between indicator settings and actual discharges are all in the same direction. If the opposite condition is found where the actual discharges run alternately or erratically plus or minus with respect to the indicator settings, the equipment is mechanically defective and unsatisfactory. The Producer/Contractor must repair the equipment and put in proper working condition before the mixing operations begin.

5-694.435 SPOT CHECKING OF WATER MEASURING EQUIPMENT

Once a month or whenever the mixer is moved to a new location, perform a spot check for comparison with the previous calibration. If there is disagreement between the spot check and the calibration, the Producer/Contractor needs to make a complete re-calibration.

Conduct the spot check as outlined in calibration procedure 5-694.434, item B1 - B5, except check only at the 150 L (45 gal.) level and do not send the information to the Mn/DOT Concrete Engineering Unit.

5-694.440 CERTIFIED READY-MIX CONCRETE

Mn/DOT has developed a certification program for the quality control of concrete production for ready-mix concrete plants. **It is the Prime Contractor's responsibility to make certain that a certified ready-mix plant produces all ready-mix concrete used on the Contract.** Other than small quantities as defined in the Schedule of Materials Control, concrete supplied from ready-mix is certified by the Producer to meet Mn/DOT Specifications. Ready-mix concrete is addressed in Specification 2461.4D.

Ready-mix concrete shall meet the same general requirements as job mix concrete. Since commercial plants supply other users during the same general period as they furnish the Agency with certified ready-mix concrete, the problem of good inspection is considerably more complicated than when using job mixed concrete. At the ready-mix concrete plant, the concrete aggregates may vary to a greater degree, both in moisture content and in gradation.

5-694.441 STEPS IN CERTIFYING A READY-MIX PLANT

Prior to the beginning of the project or once per calendar year, an Agency Representative shall perform a thorough on-site inspection of the concrete plant and complete a *Concrete Plant Contact Report* (Form 2163). The *Contact Report* (See 5-694.716) contains the necessary information to assure that the plant can produce concrete meeting Specifications, and has a signature block for the Ready-Mix Producer Representative certifying that the Producer will maintain the plant in that condition.

1. An Agency Representative will meet at the ready-mix plant with the Producer's Level II Technician. Together they will do a complete walk-through inspection of the plant.

2. Completely fill-out the *Contact Report*. The Producer's Level II Technician should help with operation and equipment questions.
3. The plant must have its scales calibrated by an approved scale company within the last six months (Specification 1901, 2461.4D, and 2301.3F for concrete paving shall apply). Enter results on scale company forms or Mn/DOT *Test of Weighing Equipment* (Form 2124). See 5-694.717.
4. Lab scales and equipment are calibrated annually before the Agency project begins. Equipment and scales meeting the tolerances are dated using tape or other marking methods.
5. The aggregate testing is done by Mn/DOT Certified Level I or II Technician. Their names, certification numbers, and a cell phone number for the Level II Technician are posted at the plant site at all times.
6. The plant must use certified cements, fly ash, slag, and Mn/DOT approved admixtures. Check the Mn/DOT Concrete Engineering Unit website for a list of approved materials at www.mrr.dot.state.mn.us/pavement/concrete/products.asp.
7. Observe/discuss materials handling operations with the Producer/Contractor to ensure that stockpiles are not segregated, contaminated, or have non-uniform moisture contents. Refer to 5-694.124 and Specification 2461.4A1.
8. Watch aggregate handling closely. Discontinue operations that result in segregation. The Inspector should see that baffles are in place and working properly where they are needed to reduce and control coarse aggregate segregation.
9. Assure that the plant is using aggregate sources that have a history of meeting Mn/DOT quality requirements. For aggregate quality information, contact the District Materials Engineer or the Mn/DOT Concrete Engineering Unit at 651-779-5573.
10. In the Metro District, generation of a completely computerized Certificate of Compliance is required. Out-state Districts, under certain conditions, are allowed the option of a handwritten *Certificate of Compliance* (Form 0042). See Figure B 5-694.723.
11. Mechanical shakers are required for both fine and coarse aggregate gradations.
12. A copy of Mn/DOT's Concrete Manual is required at the plant site.
13. A sitemap identifying the contents of all stockpiles, bins, and silos must be posted at the plant site.

5-694.442 CONTRACTOR RESPONSIBILITY

The Contractor shall obtain all of the ready-mix concrete used on the Contract from a Certified Ready-Mix Concrete Plant meeting all of the pertinent requirements of Specifications 1604 and 2461 and the following. See 5-694.012 for a checklist for Ready-Mix Producers.

A. Certificate of Compliance

It is the Contractor's responsibility to ensure that the Ready-Mix Concrete Producer adheres to all of the following requirements.

With each truckload of concrete, supply a signed Certificate of Compliance that the concrete complies with the Contract requirements. See Figure B 5-694.723 for an example of a handwritten *Certificate of Compliance*.

The Certificate of Compliance shall include:

1. Name of the Ready-Mix Concrete Plant
2. Name of the Contractor
3. Date
4. State Project Number (S.P.)
5. Bridge Number (when applicable)
6. Time concrete was batched/discharged
7. Truck number
8. Quantity of concrete in this load
9. Running total quantity of this concrete mix batched on this day for this project
10. Type of concrete (Mn/DOT Mix Designation Number)
11. Cement brand and production mill
12. Fly ash brand and production power plant
13. Admixture brand and product name
14. Pit number for each aggregate source
15. Admixture quantity per 100 wt. or ml/ m^3 (oz/yd^3) for:
    - air-entraining admixtures
    - water reducing admixtures
    - other admixtures
16. Design masses (weights) per m^3 (yd^3) for:
    - cement
    - fly ash
    - each coarse aggregate fraction
    - fine aggregate (sand)
17. Design water mass (weight)
18. Target and Actual batched masses (weights) for:
    - cement
    - fly ash
    - each coarse aggregate fraction
    - fine aggregate (sand)
    - actual water added
    - any temper water added
    - total water
19. The ticket shall also include the following information printed with enough room beside each item to allow the Agency Field Inspector to record the appropriate test results: air content, air temperature, concrete temperature, slump, cylinder number, and location/part of structure

Items 11, 12, 13, 14, and 16 are needed only on the first Certificate per day per mix designation or when one of these items changes.

NOTE: The Certificate of Compliance shall consist of a single sheet maximum. Projects administered by the Metro District require a computerized Certificate of Compliance. If the computer that generates the Certificate of Compliance malfunctions, the Producer may finish any pours that are in progress provided the plant issues handwritten Certificates of Compliance on the most current version of Mn/DOT's *Certificate of Compliance* (Form 0042). New pours are not permitted to begin without a working computerized Certificate of Compliance.

As an option for Out-state Districts, the Ready-Mix Producer may use handwritten Certificates of Compliance, which are the most current version of Mn/DOT's *Certificate of Compliance* (Form 0042). The form must contain all of the information required above including water measurements.

B. Contractor Sampling and Testing Requirements

The Certified Ready-Mix Concrete Plant will provide testing as outlined below.

1. All testing and plant operations are overseen by a Mn/DOT Certified Plant Level II Quality Control Supervisor who is on site, or accessible by cellular phone to reach the site within an hour.
2. The Quality Control Supervisor will maintain or oversee the maintenance of a plant diary. The diary documents quantities produced each day, tests performed, material problems, breakdowns, weather, etc., all to the approval of the Engineer. See 5-694.726.
3. All testing is performed at the plant site by Mn/DOT Certified Technicians.
4. Mechanical shakers are required for sieve analysis of fine and coarse aggregates.
5. Testing shall comply with Mn/DOT Specifications and procedures and according to the following list of tests and standards.

AASHTO T 27	Sieve Analysis of Fine and Coarse Aggregates
AASHTO T 255	Total Moisture Content of Aggregate by Drying
AASHTO M 92	Wire-Cloth Sieves for Testing Purposes. The sieves shall comply with the requirements of 5-693.420B of the Department's Bituminous Manual "Equipment Calibration and Verification Policies and Procedures for Laboratory Certification".
AASHTO M 231	Weighing Devices used in the Testing of Materials

6. The Certified Technician furnishes cement and fly ash samples on request. Only certified cement and fly ash are allowed. When sampling is required, the Agency should monitor whenever possible.
7. The Producer/Contractor provides a minimum of one moisture test and one gradation test per day when more than 20 m^3 (yd^3) are produced each day.
   a. Perform moisture tests on all aggregates at the rate of 1 per 200 m^3 (yd^3).
   b. Run gradations on fine (sand) aggregate at the rate of 1 per 200 m^3 (yd^3).
   c. Run gradations on coarse fractions at the rate of 1 per 100 m^3 (yd^3).
   d. Complete initial tests prior to concrete production each day.
   e. Provide additional tests when the condition of the material substantially changes.
   f. Provide a split companion sample of aggregate gradations and retain for one week for Agency gradation testing.
   g. Chart and display the data at the plant for:
      1) Moisture content (including weekly moisture probe checks, if applicable)
      2) Coarse aggregate and the 2.36 mm (#8), 600 µm (#30), and 300 µm (#50) sieves

3) Agency companion and verification (audit) gradations on the same chart as the Ready-Mix Producer.

h. Document the results of all gradations on the *Weekly Concrete Aggregate Report* (Form 2449) and keep supporting documentation for all testing on file at the plant site. See 5-694.721.

NOTE: The Producer may choose to determine moisture content in the fine aggregate by use of an approved moisture probe. See 5-694.142D for approval requirements.

5-694.443 AGENCY RESPONSIBILITY

For Certified Concrete Ready-Mix Plants, the following summarizes the Agency's responsibilities.

A. Plant Responsibilities for Certified Ready-Mix Plants

See 5-694.011 for a checklist for Ready-Mix Concrete Plant inspection.

B. Office Responsibilities for Certified Ready-Mix Plants

1. At the end of each week of production, the Producer's Level II Technician must fax or deliver a completed copy of the *Weekly Concrete Aggregate Report* (Form 2449) to the Agency. See 5-694.721. The Producer must leave a space between each gradation test for the Agency to record companion gradation results. The Agency records all companion results and sends a copy back to the Producer for charting. If allowable variations are exceeded (as described in the Specifications), the conflicting results are circled and the Producer's Level II Technician is notified.
2. Send the Contractor a completed copy of the "*Weekly Certified Ready-Mix Plant Report*" (Form 24143). See 5-694.724. Circle any failing verification results. The Agency Lab should run companion and verification samples, preferably the same day the concrete is placed but not later than the following day. **Report any failing tests to the Contractor's Level II Technician as soon as possible so corrective action can prevent further failures.**
3. Report failing verification samples to the Project Engineer. Discuss repeated verification failures with the Mn/DOT Concrete Engineering Unit for possible de-certification of the concrete plant, technician or source of aggregate. Contact the Mn/DOT Concrete Engineering Unit regarding questions on price reductions or refer to the current Schedule of Price Reductions.
4. Each week, Project Engineers should receive copies of Form 24143 and Form 2449.

5-694.444 MITIGATING TESTING VERIFICATION PROBLEMS

It is imperative that all parties are notified when testing compliance problems occur to provide for corrective action. If the gradation tests on split samples from quality control or verification samples result in a variation between the Producer and the Agency greater than that set forth below, the 2 parties will cooperatively take and split a new sample. The Producer's representative will test the sample while witnessed by the Agency Plant Monitor. This will serve as a check on the process to correct deviations from the standard testing procedure. If this problem continues, the Project Engineer, District Materials Engineer and the Mn/DOT Concrete Engineer will make a total review of the plant. If results still do not agree, the parties should resolve the dispute by third party resolution according to procedures described in Section 5-691.350 of the Mn/DOT Contract Administration Manual.

Allowable variations on percent passing any sieve:

Sieve	% Allowed
50 mm - 9.5 mm (2 in. - 3/8 in.)	+ or - 6
4.75 mm - 600 µm (#4 - #30)	+ or - 4
300 µm (#50)	+ or - 3
150 µm (#100)	+ or - 2
75 µm (#200)	+ or - 0.6

The Agency and Producer must test all verification samples. The Producer has the option to use the companion to the verification sample as part of the process control testing.

It is important to review test data to assure that the verification test results are in the same statistical family of data as the Producer's QC tests. It is not expected that the comparison between verification sample test results and process control tests will correlate as well as split samples from verification or the Producer's process control tests. If in the judgement of the Engineer these tests do not correlate, investigate the problem. Inconsistencies in test results should trigger additional visits to the plant and additional sampling and testing. Possible causes for variations may include: dirty or defective screens, not thoroughly sieving samples, segregated samples, improper sampling or splitting techniques, etc.

The Ready-Mix Producer, after an acceptable time period, may request a reduction in testing rates if past results warrant. Only the Mn/DOT Concrete Engineer can approve this request. This approval is based only on extraordinary procedures performed by the Aggregate Supplier and Ready-Mix Producer to insure consistency and quality control. Extra fractions and bins are an example of such a procedure.

5-694.445 AGENCY RESPONSE TO NON-COMPLIANCE WITH THE CERTIFIED PLANT REQUIREMENTS

If a proposed plant cannot produce concrete, perform testing, or report information as required during completion of the Concrete Plant Contact Report, concrete is not acceptable from this plant.

DO NOT ACCEPT concrete on the Project if:

1. Companion samples or verification acceptance samples fail to meet requirements.
2. A review of the plant indicates that there is cause for concern in the quality of the concrete.
3. A plant fails to comply with any part of the certification program.

If concrete is inadvertently placed in the work, it is subject to Mn/DOT Specification 1512, Unacceptable and Unauthorized Work. Price Reductions are determined according to the Schedule of Price Reductions for Failing Materials for Concrete, Bituminous, and Grading & Base Construction based on Agency verification samples.

The project may begin after review and approval of the Concrete Plant Contact Report. Any procedural changes that cause non-compliance with this program will result in decertification of the plant and cessation of further production of concrete for this Project. Decertification will also occur at any plant that continually produces concrete that is noncompliant as detailed above. Complete disregard of this specification or fraudulent test reports are grounds for immediate Decertification.

Decertification could include any or all, but is not limited to, the following actions:

1. Revocation of Plant Certification.
2. Revocation of Technician Certification for individual(s) involved.
3. Loss of bidding privileges as determined by the State Construction Engineer.
4. Criminal prosecution for fraud as determined by the Attorney General.

The Mn/DOT Concrete Engineer determines any Decertification actions.

5-694.446 FIELD INSPECTION OF CERTIFIED READY-MIX CONCRETE

Close coordination is required between the Plant Operator, Plant Monitor, and Project Inspectors to assure satisfactory concrete placement at the job site.

It is satisfactory to add water to the ready-mix truck on the project whenever the slump of the concrete is below the minimum required for the specific mix, provided the Inspector checks the Certificate of Compliance to determine if adding the proposed amount does not exceed the tolerances permitted. When water is added, the measured quantity is handwritten on the Certificate of Compliance. The Inspector must include this added water with the total water on the Certificate of Compliance when making out the *Weekly Concrete Report* (Form 2448). See 5-694.727. Do not use water to re-temper old concrete.

On bridge deck concrete, the water/cementitious ratio shall not exceed 0.44.

5-694.450 LOW SLUMP CONCRETE OVERLAYS

Mn/DOT has developed a report for documenting low slump concrete for bridge deck overlays. This form is called the *Weekly Report of "Low Slump Concrete"* (Form 21412). See 5-694.762.

The batch quantities for the fine aggregate are based on a specific gravity of 2.65. Normally, the specific gravity of concrete sand is close enough to 2.65 so that the batch quantity of sand only needs correction for moisture content. However, the specific gravity of Class A coarse aggregates vary significantly with each source.

Always adjust the 3U17A concrete mix design weights based on the specific gravity of the coarse aggregate. Obtain the specific gravity of Class A material from sources other than listed on the back of the *Weekly Report of "Low Slump Concrete"* (Form 21412) and the corresponding batch quantities from the Mn/DOT Concrete Engineering Unit. Use only Mn/DOT approved water reducers and air-entraining agents. Compatibility of admixtures is critical.

There is not a requirement to determine the moisture content of the aggregates. Run a minimum of one gradation of stockpiled aggregates prior to commencing operations and each time aggregate is delivered to the site. Monthly, submit one laboratory sample for gradation of both fine and coarse aggregate during operations. Visually inspect the aggregates for correct class of aggregate, segregation, and excessive moisture. For calibration purposes, assume arbitrary moisture content of 3% for the fine aggregate, but no moisture for the coarse aggregate.

NOTE: Concrete mixes for patching (3U37A) or other uses are available by contacting the Mn/DOT Concrete Engineering Unit, at 651-779-5573.

5-694.451 LOW SLUMP CONCRETE BATCHING REQUIREMENTS

Continuous mixers at the job site produce grade 3U17A concrete for low slump bridge deck overlays. If the 3U17A mix for purposes other than an overlay is required by the proposal, use either a paddle type or a continuous mixer. When using a paddle type mixer, batch the materials by mass (weight). The 3% moisture assumption for the fine aggregate is used only to adjust the batched quantity. Continuous mixers used for low slump concrete overlays in Minnesota are called Concrete-Mobiles and they require calibration.

5-694.452 LOW SLUMP CONCRETE OVERLAY PROCESS

The process of performing a low slump overlay begins with surface preparation. Surface preparation includes sand blasting the existing surface and placement of concrete around the joints. Inspectors are advised to visually inspect the surface and drag a chain to detect defective areas. When defects are observed, take conventional corrective actions, such as chipping off loose concrete prior to the overlay. The “dry-run” is the process of moving the paver over the structural deck and spot-checking for minimum overlay thickness. Application of a bonding grout facilitates an adequate bond with the overlay.

Concrete is conveyed by buggies from the Concrete-Mobile to the paver. The paver trims and consolidates the concrete to the prescribed elevation. For surface texturing, an astroturf drag is usually attached to a finishing bridge that runs behind the paver.

The following pictures illustrate some activities in a low slump overlay process.

Figure A 5-694.452 shows batching on site using a Concrete-Mobile. The Contractor shall calibrate the Concrete-Mobile prior to commencement of any project, and whenever there is a observed discrepancy in yield or a change in conditions.

Figure B 5-694.452 shows the preparation of the finishing bridge. The astroturf is attached to the bridge, but tentatively folded.

In Figure C 5-694.452 the existing joint over an abutment has been removed prior to replacement. This step does not occur in new construction.

Figure D 5-694.452 shows the E8S joint placed prior to the overlay activity. Sufficient strength gain is required to carry loaded buggies across the E8S joint prior to low slump overlay placement. A low slump mix is shown in Figure E 5-694.452. The bonding grout is placed a few minutes ahead of the low slump overlay.

The Contractor is placing the low slump concrete overlay in Figure F 5-694.452. Arrows indicate direction of motion of parts of the paver.

Figure G 5-694.452 shows the view from behind the paver. The finishing tool is modified with a cutting tool for joint re-establishment.

The final finish using astroturf drag is shown in Figure H 5-694.452. The chain provides constant pressure for uniform texturing. Joint establishment must precede the texturing.

Figure A 5-694.452

Figure B 5-694.452

Figure C 5-694.452

Figure D 5-694.452

Figure E 5-694.452

Figure F 5-694.452

Figure G 5-694.452

Figure H 5-694.452

5-694.453 OPERATING PRINCIPLE OF "CONCRETE-MOBILES" (Continuous Mixers)

The heart of the Concrete-Mobile is a device called a "Cement Meter Feeder" which provides a uniform flow of cement to the concrete mix. All of the other ingredients including aggregates, water reducer, air-entraining admixture, water, etc., are proportioned to this uniform flow of cement.

- The cement meter feeder is a rotary vane type.
- The cement in the cement bin is in an unpacked condition and flows into the meter pockets or sections similar to water flow.
- The cement is brought to the space immediately over the cement meter feeder wheel by a cross-auger. It is next dislodged as the wheel revolves at the bottom by gravity and the two hammers striking the pocket by spring action. These two hammers ride on the bottom of the cement meter feeder.
- As the cement meter feeder revolves, the ramps or wedges on the cement meter feeder cock the hammer springs.
- After the ramp or wedge clears the hammers, the spring causes the hammers to strike the pocket sharply and this dislodges the cement.
- The Inspector hears the sounds of the hammers striking the cement meter feeder and the springs are observed from the rear of the Concrete-Mobile.
- The cement then drops on the aggregates previously placed on the main conveyor belt.
- Since an aggregate proportioning device is not as accurate as batching by mass (weight), an additional 2% of cement is automatically added to the mix.
- The fine aggregate and the coarse aggregate are stored in separate bins. Each aggregate bin is controlled by a positive gate that allows selection of the correct proportion of fine and coarse aggregate by the Operator.
- The admixtures are forced into the mix by air pressure on each tank. There are two tanks provided using a HiFlo (large) tank for water reducer and LoFlo (small) tank for air-entraining agent. It is extremely important that both admixtures are diluted and thoroughly mixed before placement in the tanks. The admixtures are selected from the Mn/DOT Approved products list at www.mrr.dot.state.mn.us/pavement/concrete/products.asp.

5-694.454 PROJECT CALIBRATION OF CONCRETE MOBILE

See 5-694.761 for the Concrete Mobile Calibration Worksheet.

This calibration procedure is applicable to mechanical and all-hydraulic Concrete Mobiles. It also applies to the Magnum Concrete Mobile with certain exceptions. **Calibrations are based on 45 kg (100 lb.) quantities. These values are not exactly equal but these quantities are used for convenience.** Exceptions are identified where they occur. Each Concrete Mobile Model has a unique number of revolutions and length of time to deliver 45 kg (100 lb.) of cement for state work.

A. Cement Check Calibration

The list of items required by the Contractor are:

- A scale with a capacity of 225 kg (500 lb.). Check the accuracy of the scale by weighing a known quantity of about 135 kg (300 lb.). Adjust the scale as necessary.
- A box or other container to catch the discharged material on the scale.
- A suitable deflector (sheet metal, etc.) to deflect the falling material into the container.

Project personnel verify the cement output. The cement check procedure is as follows:

1. Check to see that the aggregate bins and the main conveyor belts are empty and clean.
2. Clean and free-up cement deposits from the cement meter feeder.
3. Check the spring hammers and the cement meter register for proper operation.
4. Check all bin vibrators for operation (two for cement bin, two for sand bin).
5. Ensure that the cement bin aeration system is operating properly and that the air breather hole is open to atmospheric pressure.
6. Ensure the Concrete Mobile is properly grounded. (Each truck has two ground straps. If the truck is not grounded, the cement has a tendency to develop a static charge and may bridge.)
7. Place the mix-conveyor in the travel position and fix the piece of sheet metal into the bottom end of the mix conveyor as a deflector for material falling off the main conveyor belt.
8. With the cement meter register engaged, run out sufficient cement for charging the belt and ensuring that uniform discharge is occurring.
9. Zero the meter, place the box or other container on the scale, and position so all the discharged cement is caught.
10. Engage the main conveyor and allow the equipment to run until the meter register reaches 45 kg (100 lb.) of cement. Record the number of revolutions and the time in seconds.
11. Engage the main conveyor and allow the equipment to run until the meter register reaches 3 times the known number of revolutions required for 45 kg (100 lb.) of cement.
12. Stop the main conveyor. Weigh the material and record the net mass (weight). The cement should weigh between 135 and 138 kg (300 and 306 lb.).
13. If the net mass (weight) does not fall between 135 and 138 kg (300 and 306 lb.) of cement, empty the box and repeat the test 2 more times. If the average of the 3 tests falls between 135 and 138 kg (300 and 306 lb.), accept the established meter count and proceed to Sand and Stone Dial Check.

If the meter count does not fall within 135 and 138 kg (300 and 306 lb.), correct the meter count as follows:

Example:
Original meter count = 70 revolutions
Original cement weight = 46 kg (102 lb.)
Original time constant = 30 seconds
Average mass (weight) for 3 times the number of revolutions = 150 kg (331 lb.)

Determine the new meter count:

$$\text{New Meter Count} = \frac{\text{3 x Original Cement Mass (Wt.) x Original Meter Count}}{\text{Average Cement Mass (Wt.) from 3 Tests}}$$

$$\text{New Meter Count} = \frac{3 \times 46\text{ kg (102 lb.)} \times 70\text{ Revs}}{150\text{ kg (331 lb.)}}$$

$$\text{New Meter Count} = 64.4\text{ Revs}$$

To carry the correction further, correct the time required to measure 46 kg (102 lb.) of cement. Use the time constant later when calculating the HiFlo and LoFlo admixture settings. Determine the new Meter Count first.

Determine the new time constant:

$$\text{New Time Constant} = \frac{\text{New Meter Count x Original Time Constant}}{\text{Original Meter Count}}$$

$$\text{New Time Constant} = \frac{64.4\text{ Revs} \times 30\text{ seconds}}{70\text{ Revs}}$$

$$\text{New Time Constant} = 27.6\text{ sec}$$

The "time constant" is the time required to produce 45 kg (100 lb.) of cement.
The "meter count" is the number of revolutions to produce 45 kg (100 lb.) of cement.

Use the new Meter Count and Time Constant instead of the previous meter count for calibration purposes and for producing all concrete for the project. The terms "Meter Count" and "Time Constant" used hereinafter means the corrected version if re-calibration was required.

B. Sand and Stone Dial Checks for Fine and Coarse Aggregate
Check the dial indicators for the sand and stone gates annually to ensure the pointers have not slipped on the shafts and that wear on the bottom of the gates is not excessive. The calibration procedures are identical for both the sand and stone gate. The standard Concrete Mobile uses a 76.2 mm x 76.2 mm x 203.2 mm (3 in. x 3 in. x 8 in.) hardwood block as a calibration device that

is placed on the belt lengthwise. The gate is lowered until it just touches the block and is then tightened by the hand-wheel as shown on the dial. The pointer should read between 6.2 and 6.6. (Note that the dial is a reference point and does not measure the gate opening in millimeters (inches) or other dimension.) If the dial reading is not within tolerance, loosen the setscrews and adjust the pointer to 6.4. (The Magnum Concrete Mobile uses a 42.86 mm (1-11/16 in.) hardwood block and the same procedure except the sand dial pointer should read between 7.8 and 8.0 and the stone dial pointer should read between 7.4 and 7.6.)

C. Aggregate Calibration

The aggregates are proportioned per 45 kg (100 lb.) of cement. For the 3U17A concrete mix using 815 kg/m^3 (1374 lb/yd^3) of concrete sand and 914 kg (1540 lb.) of Concrete Trap Rock, the amount of each aggregate is determined by dividing by 11, which is equal to 496 kg of cement divided by 45 kg. This results in 74 kg of sand and 83 kg of stone required per 45 kg (100 lb.) of cement for the mix. Note that the moisture content of the sand is assumed to be 3%. The corrected quantities therefore are as follows:

Proportions per 45 kg (100 lb.) of cement:

Sand (adjusted for 3% MC)	1.03 x 74 kg (164 lb.)	=	76 kg (169 lb.)
Stone (Concrete Trap Rock)		=	83 kg (184 lb.)

Empty the cement bin before proceeding to the next step. Retain this cement in a clean drum or other container for use in the slurry if the Contractor so desires.

D. Procedure for Sand Gate Calibration (Cement and Stone Bins empty)

The equipment required is the same as that required for the cement check.

1. After inspecting the bins for cleanliness, fill the sand bin with the sand used for the project.
2. Make sure none of the sand overflows into the stone bin.
3. Set the sand dial pointer at 2.0 (6.0 Magnum) and run out sufficient material to load the belt and ensure uniform discharge.
4. Zero the cement meter and place the box and scale under the raised mix-conveyor and allow it to run until the meter-register reading equals the reading for 45 kg (100 lb.) of cement.
5. Stop the conveyor, weigh the box and record the result.

Perform the same test with the sand dial pointer set at 3.0 and then 4.0 (7.5 and 9.0-Magnum). Run out sufficient material to pre-load the belt, etc. for each new setting. Obtain the net mass (weight) of the sand and plot the 3 results as shown in the example, Figure D 5-694.454. The results should plot in a reasonably straight line. If they do not, rerun the gate settings that appear out of line. Empty the sand bin.

E. Procedure for Stone Gate Calibration (cement and sand bins empty)

Equipment needed is the same as for Sand Gate Calibration.

1. Fill the stone bin with care to prevent the coarse aggregate from spilling over into the sand bin.
2. Set the stone dial pointer at 3.0 (7.0 - Magnum) and run out sufficient material to load the belt and ensure uniform discharge.

3. Zero the cement meter and place the box and scale under the raised mix conveyor to catch all the material that is discharged.
4. Engage the main conveyor and allow it to run until the meter-register reading equals the reading for 45 kg (100 lb.) of cement.
5. Stop the conveyor and weigh the box, recording the results.

Perform the same test with the stone dial pointer at 4.0 and then 5.0 (9.0 and 11.0-Magnum). Run out sufficient material to pre-load the belt, etc. for each new setting. Obtain the net mass (weight) of the stone for the stone dial settings by subtracting the mass (weight) of the box. Plot as shown in Figure D 5-694.454. Again, the results should plot in a reasonably straight line; if it does not, run additional tests as required.

F. Calibration of the HiFlo and LoFlo Systems

In the interest of uniformity, prepare the Water Reducer as follows:

- Place 22.7 L (6 gal.) of approved water reducer in a clean 208.2 L (55 gal.) drum.
- Fill the drum with water and agitate to thoroughly mix. This is a 1:7 solution (8 total parts to the solution) with sufficient accuracy for calculating the HiFlo setting to an accuracy of 97% or more.

1. HiFlo Setting Calculations

For illustrative purposes, assume the maximum dosage is 118 ml/45 kg (4 oz./100 lb.) of cement and that the particular Concrete Mobile delivers 45 kg (100 lb.) of cement every 70 revolutions in 30 seconds).

The HiFlo system is calibrated in L/min. (qts./min.):

Delivers 90 kg (200 lb.) of cement in one minute =

$90/45 \times 118 \text{ mL} = 236 \text{ mL}$ OR $2 \times 4 \text{ oz.} = 8 \text{ oz.}$ of water reducer required per minute

1:7 solution = 8 parts of solution:

$8 \times 236 \text{ mL} = 1888 \text{ mL}$ solution per minute OR $8 \times 8 \text{ oz.} = 64 \text{ oz.}$ solution per minute

Approximately 1.9 L/min. OR $\frac{64 \text{ oz.}}{32 \text{ oz. per quart}} = 2 \text{ qts.}$ of solution per minute

From the HiFlo diagram Fig. A 5 - 694.454 - setting = 2.2

(Use Fig. B 5 - 694.454 for Magnum Concrete Mobile)

Air Entraining Agent (AEA) - Place 18.9 L (5 gal.) of an approved air-entraining agent in a clean 208.2 L (55 gal.) drum. Fill the drum with water and agitate to thoroughly mix. This is a 1:10 solution (11 parts to the solution).

2. LoFlo Setting Calculations

For illustrative purposes, assume 22 ml/45 kg (0.75 oz./100 lb.) of cement will result in 6.5% of entrained air in the mix. (Actual requirement is determined by actual air tests since temperature and other factors affect the dosage.) Also assume the particular Concrete Mobile delivers 45 kg (100 lb.) of cement in 30 seconds.

The LoFlo system is calibrated in L/min. (oz./min.):

Delivers 90 kg (200 lb.) of cement in one minute =

$2 \times 22 \text{ mL} = 44 \text{ mL}$ OR $2 \times 0.75 \text{ oz.} = 1.5 \text{ oz.}$ of AEA required per minute

1:10 solution = 11 parts of solution:

$11 \times 44 \text{ mL} = 484 \text{ mL}$ solution per minute OR $11 \times 1.5 \text{ oz.} = 16.5 \text{ oz.}$ solution per minute

From the LoFlo diagram Fig. A 5-694.454 - setting = 0.8

(Use Fig. B 5-694.454 for Magnum Concrete Mobile)

NOTE: The floats for the HiFlo and LoFlo systems will only operate when the Concrete Mobile is mixing concrete. The cleanliness and proper operation of both systems is shown if the floats return to zero when mixing is stopped. Likewise if the floats do not return to the zero position, it is an indication the system is not functioning properly and corrective action is necessary.

3. HiFlo Setting Procedure for Non-Standard Float Valves

Equipment Required:

- Clean plastic or metal pail (provided by Contractor)
- Scale used for calibration (provided by Contractor
- Stop watch (provided by Department)

Fill the HiFlo tank with water. Empty or shut off the LoFlo system. Assure that the air system is in operation and the Air Pressure Regulator - Pressure Gauge is at the prescribed pressure of 100 kPa or 175 kPa Magnum (15 psi standard, 25 psi Magnum).

The calibration procedures consist of operating the HiFlo system by passing the main conveyor (belt) control during a time interval for 2 or more HiFlo float settings. This procedure eliminates actuation of the belt, cement meter and the quick-acting water valves so that only liquid from the HiFlo tank drops into the mixing chamber. Initial step: weigh and record the tare mass (weight) of the pail.

Run 1. Actuate the HiFlo system as described above and set the float at a reading of 1.0. Stop the HiFlo system; place the pail under the pipes to catch the water; simultaneously actuate the HiFlo system and the stopwatch. After 60 seconds, release the HiFlo valve. Remove the pail and weigh the pail and liquid. Record the results.

Run 2. Follow the same procedure as for Run 1 except with a float setting of 2.0.

Upon completion of Runs 1 and 2, convert the mass of the liquid to liters (quarts). (NOTE: One liter of water has a mass of 1 kg (1 gal. of water weighs 8.33 lb. and there are 4 qts. per gal.).

On graph paper, plot the results of the two runs as shown in the example. The required liters (quarts) of solution per minute are calculated, as prescribed in paragraph A above, and the correct setting is selected from the graph.

Example:

Assume the constants for a particular truck (Magnum):

- 29.5 revolutions at 20.7 seconds (second gear)
- Tare of pail = 0.7 kg (1.5 lb.)
- 18 mL (4 oz.) water reducer dosage per 45 kg (100 lb.) of cement

$$\frac{60\,\text{sec.}}{20.7\,\text{sec.}} \times 45\,\text{kg}\,(100\,\text{lb.}) = 130\,\text{kg}\,(290\,\text{lb.})\,{}^{\text{cement}}\!/_{\text{min.}}$$

$$\frac{130\,\text{kg}\,{}^{\text{cement}}\!/_{\text{min.}}}{45\,\text{kg cement}} \quad or \quad \frac{290\,\text{lb.}\,{}^{\text{cement}}\!/_{\text{min.}}}{100\,\text{lb. cement}} = {}^{2.90}\!/_{\text{min.}}$$

$${}^{2.90}\!/_{\text{min.}} \times 18\,\text{mL} \times 8\,\text{parts of solution} = 2738\,\text{mL}\,(2.75\,\text{L})\,\text{per min. of solution required} \quad \text{OR}$$

$${}^{2.90}\!/_{\text{min.}} \times 4\,\text{oz.} \times \frac{1\,\text{qt.}}{32\,\text{oz.}} \times 8\,\text{parts of solution} = 2.90\,\text{qts. per min. of solution required}$$

Run 1. HiFlo Setting 1.0

Mass of Pail and Liquid	*3.2 kg (7.0 lb.)*
Tare	*- 0.7 kg (1.5 lb.)*
Mass of Liquid	*2.5 kg (5.5 lb.)*

$$2.5\,kg = 2.5\,L/min. \quad OR \quad 5.5\,lb. \times \frac{1\,lb.}{8.33\,gal.} = 2.64\,qts./min.$$

Run 2. HiFlo Setting 1.0

Mass of Pail and Liquid	*5.7 kg (12.5 lb.)*
Tare	*- 0.7 kg (1.5 lb.)*
Mass of Liquid	*5.0 kg (11.0 lb.)*

$$5.0\,kg = 5.0\,L/min. \quad OR \quad 11.0\,lb. \times \frac{1\,lb.}{8.33\,gal.} = 5.28\,qts./min.$$

From Figure C 5 - 694.555, the HiFlo setting is 1.1.

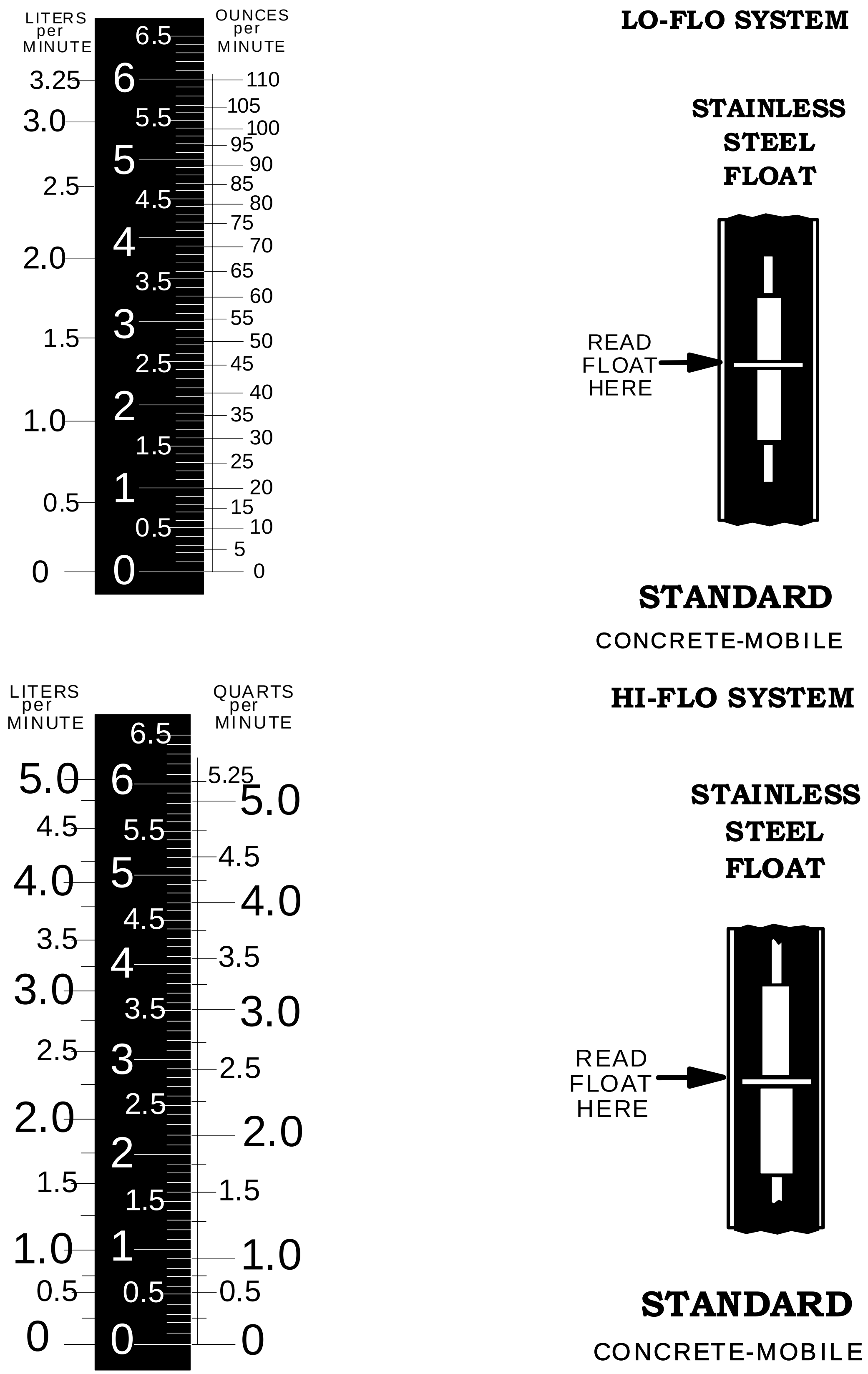


Figure A 5-694.454

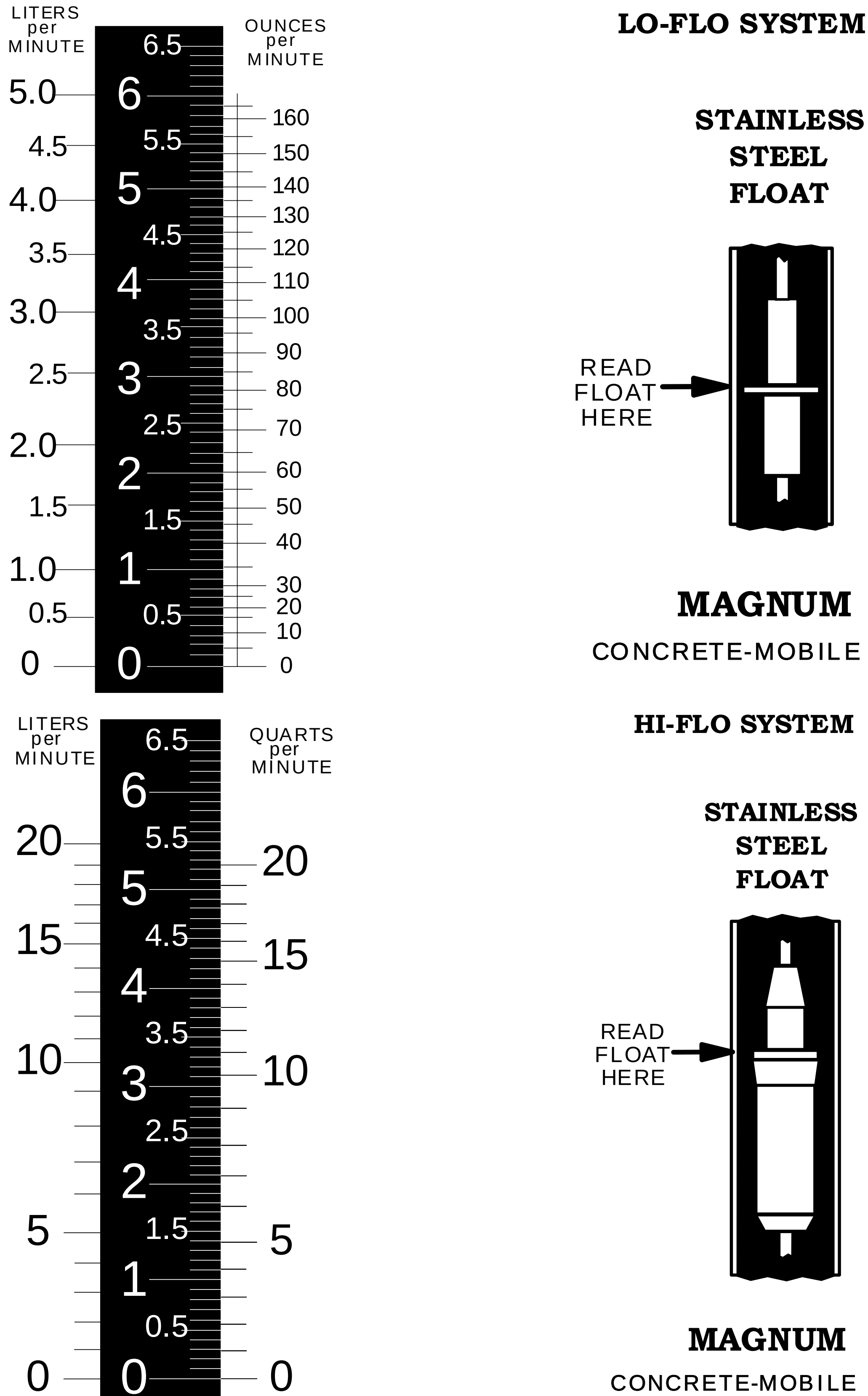


Figure B 5-694.454

HI-FLO CALIBRATION EXAMPLE

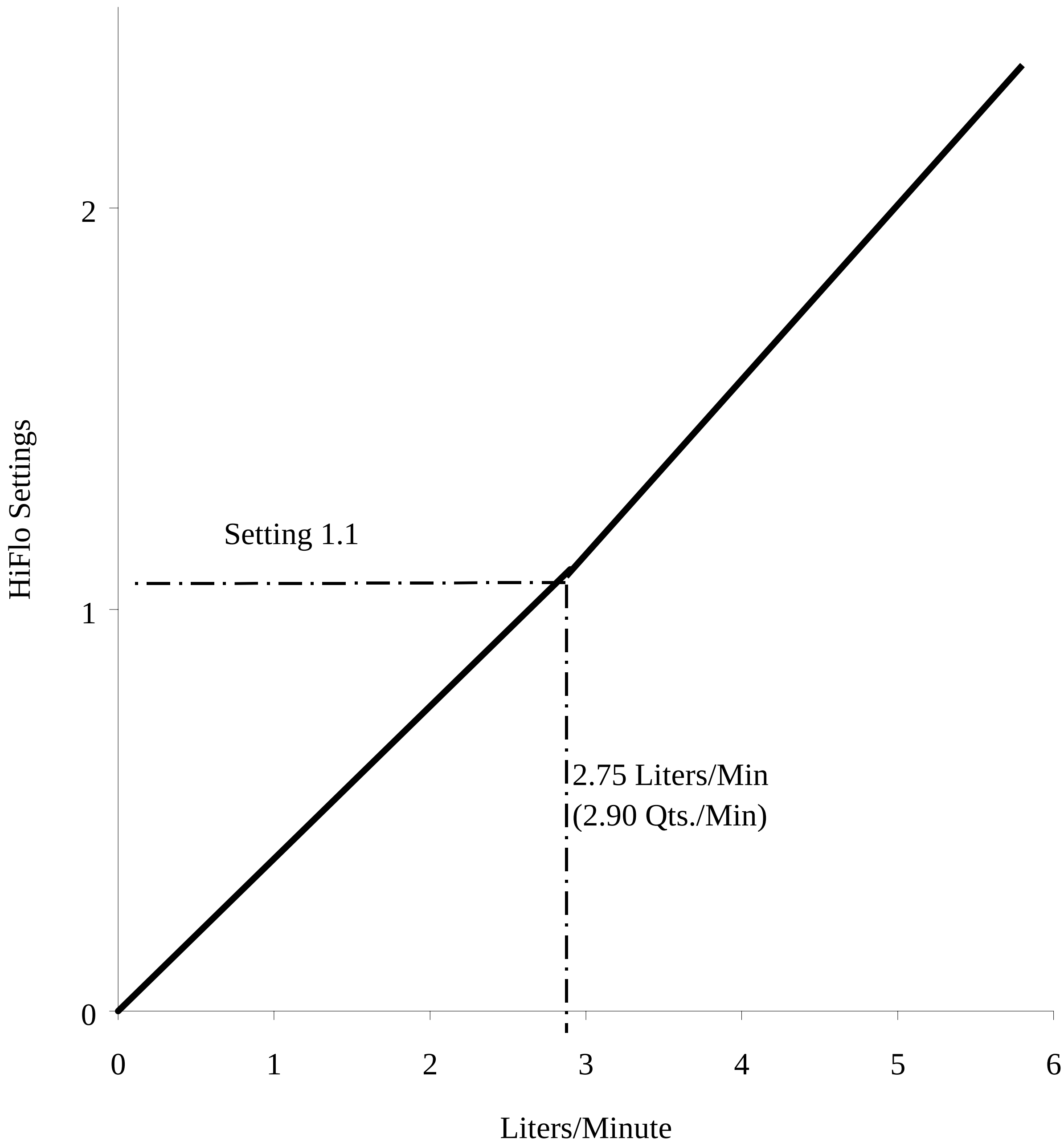


Figure C 5-694.454

Real Good Concrete Co. 1
Constants: 72.5 Rev. @ 31.0 Seconds (Corrected)
Aggregates: FA Concrete S & G
CA Concrete Trap Rock

Mn/DOT 3U17A Concrete Mix
Calibrated by D.A. Caswell

Materials/C.M. (C.Y.)	**3U17A**
Cement	**496 kg (836 lb.)**
Air	**6 1/2%**
FA	**815 kg (1374 lb.)**
CA	**914 kg (1540 lb.)**
WR	**1.95 mL/kg (3 oz./cwt.)**

Sand and Stone Dial Settings vs. Quantity of Sand/Stone

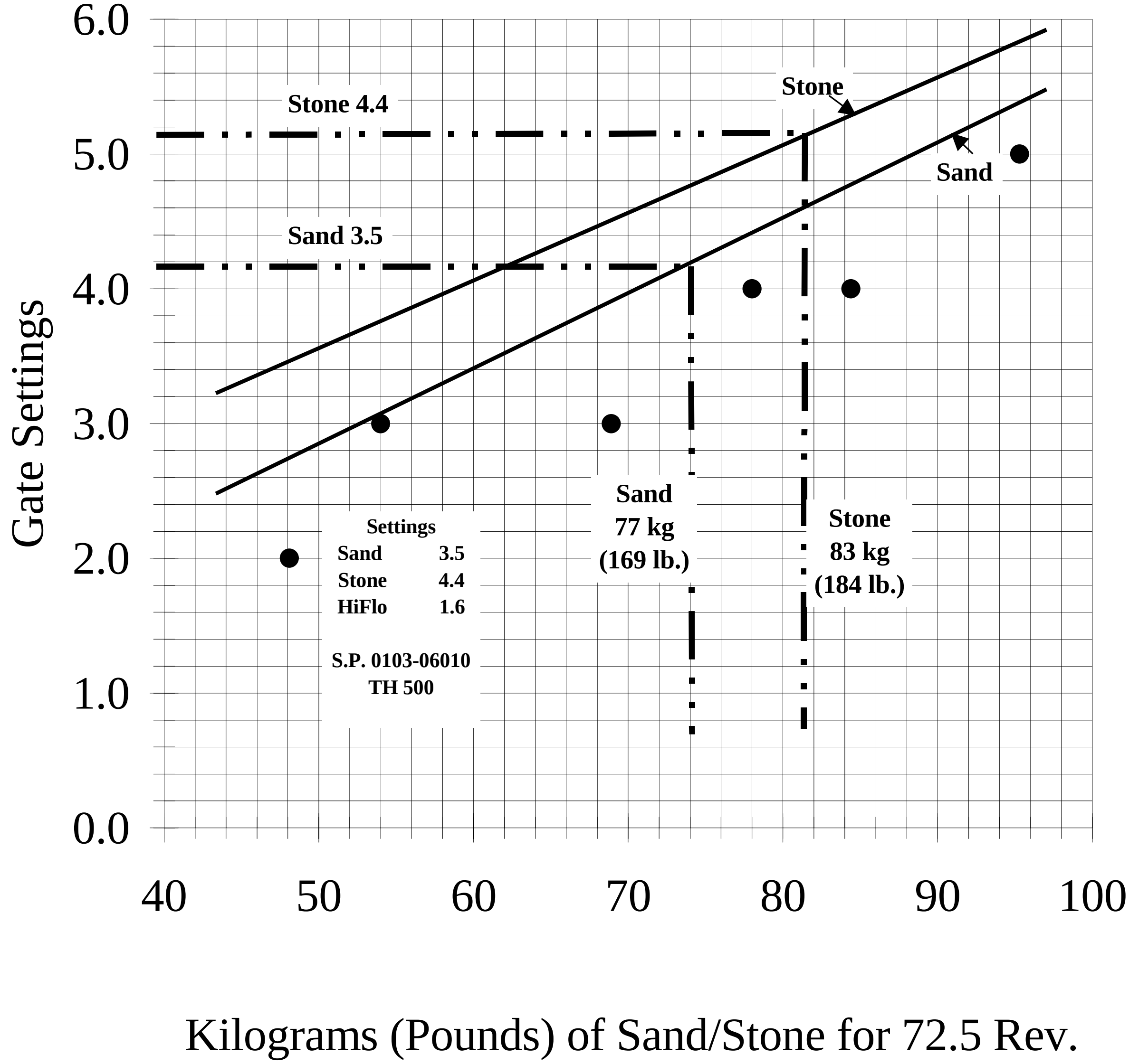


Figure D 5-694.454

5-694.455 LOW SLUMP CONCRETE OVERLAY USING TYPE IP CEMENT

Upon completion of calculations and the subsequent data plot, include a copy of both the calculations and the plot for project files.

Type IP cement (Portland-Pozzolan) is authorized for Low Slump Concrete Bridge Deck Overlays. If the Contractor elects to use Type IP cement, place the entire overlay on a bridge using Type IP cement. In other words, paving portions of the overlay on a particular bridge with Type IP cement is not permitted. The overlay must have either all Type I cement or all Type IP. The concrete mix for low slump overlays using Type IP cement is 3U17A (IP) to differentiate from the regular mix.

The design is as follows:

Low Slump Concrete Mix Design 3U17A (IP)
Mix Design Based on kg/m^3 (lb/yd^3)

Strength:	39 MPa (5600 psi) concrete at 28 days	
Water:	160 kg (270 lb.),	0.1602 m^3 (4.334 ft^3)
Air:	6.5%,	0.0650 m^3 (1.755 ft^3)
Type IP Cement (Sp.G – 2.97):	496 kg (836 lb.),	0.1278 m^3 (4.518 ft^3)
FA (Specification 3126):	803 kg (1353 lb.),	827 kg damp (1394 lb. damp)
CA* Class A (Specification 3137):		
152003 New Ulm Quartzite	(Sp.G - 2.63)	614 kg (1364 lb.)
173006 St Cloud Granite	(Sp.G - 2.72)	634 kg (1411 lb.)
194009 Dresser Trap Rock	(Sp.G - 2.97)	693 kg (1540 lb.)
106002 Ortonville Stone	(Sp.G - 2.64)	616 kg (1369 lb.)
117001 Sioux Quartzite	(Sp.G - 2.65)	618 kg (1374 lb.)
187002 Granite Falls Granite	(Sp.G - 2.67)	623 kg (1385 lb.)

Water Reducer: Maximum amount according to Manufacturer's recommendations.
Slump: 20 mm ± 5 mm (3/4 in. ± 1/4 in.)

* If a coarse aggregate other than listed is used, obtain the concrete mix design from the Mn/DOT Concrete Engineering Unit.

CONCRETE TESTS
5-694.500

5-694.501 SAMPLING OF CONCRETE

Taking concrete samples at the point-of-placement rather than the point-of-delivery is always preferable. Special situations may occur which create difficulties in sampling and transporting samples taken from the point-of-placement. When this occurs, sampling at the point-of-delivery is satisfactory but only after running correlation tests between the 2 sampling locations. **(Caution: The correction factors developed between the 2 sampling locations may vary due to changing conditions such as air and concrete temperature changes, pumping distances, etc. Perform correlation tests several times throughout the day.)**

If necessary, modify sampling procedures to fit a specific situation. If the slump test result is outside of the slump range, correct before placing the concrete in the work. Make corrections as follows:

<u>Slump too low</u>: Add water in measured amounts to bring the slump within the specified range. Record the added water on the Certificate of Compliance.

<u>Slump too high</u>: Add additional cement by full bag to bring the slump within the specified range. Provide cement from the same manufacturer as the original batch. Record the added bags of cement on the Certificate of Compliance.

After the addition of water, cement, or air-entraining admixture, remix the batch for 50 revolutions at mixing speed to insure adequate dispersion of the materials throughout the batch. Retest to verify compliance with the Specifications. If the concrete is placed in the work, report both tests on the *Weekly Concrete Report* (Form 2448) with a notation of the amount of water, cement or air-entraining admixture added. The number of revolutions at mixing speed shall not exceed 150 per Specification 2461.4C. Mix the concrete at agitating speed for all revolutions over 150.

Obtain samples for strength tests by the same procedure as for slump or air test, except obtain the sample from the middle half of the load whenever possible. If the sample is transported to a different location for specimen fabrication, remix the sample to ensure uniformity. The following sections provide procedures for sampling from various mixers.

Start slump, temperature, and air content tests within 5 minutes after obtaining the sample of fresh concrete. Start strength tests within 15 minutes of obtaining the sample.

5-694.503 SAMPLING FROM STATIONARY MIXERS

Sample the concrete by either passing a container through the discharge stream of the mixer or by diverting a portion, or the entire discharge stream into a sampling container. When a container is passed through the discharge stream, sample the entire stream to reduce segregation that may occur as the material leaves the mixer. When sampling by diverting the discharge, diversion of one-half the discharge is satisfactory provided it is full-depth.

5-694.504 SAMPLING FROM READY-MIX CONCRETE TRUCKS

Normally, take samples during the discharging operation. Obtain samples by collecting the full width of the discharge stream of the chute into a sampling container. Control the rate of discharge from the truck at a satisfactory rate for sampling. Do not reduce the rate of discharge by closing or reducing the size of the discharge opening of the truck. You may need to stop the discharge from the drum to collect the full width and depth of the discharge stream on the chute into the sampling container. Provide a sample of sufficient size to perform the tests without reusing the same concrete for subsequent tests.

Usually samples are not taken from the first one-quarter or last one-quarter of a cubic meter (cubic yard) of truck discharge. Should these or other portions of the discharge indicate improper mixing, reject the concrete. It is recommended that after sampling; stop further discharge from the mixer until the tests are completed. If the slump and air content meet requirements, complete the discharge. This delay in placing concrete is extremely important when the test is on the first load of concrete of the day.

5-694.505 CONCRETE AGE-STRENGTH RELATIONSHIP

Concrete strength varies with age. Under continuous favorable conditions, concrete continues to gain strength indefinitely. Samples of concrete taken from old pavements and tested in compression indicate higher strengths after 25 years than when the pavement was 1 to 3 years old. Tests for concrete strength are made shortly after it has been placed (7 to 90 days). It is always tested for acceptance at fairly early ages with respect to the concrete life and for this reason the strength obtained is less than the ultimate strength the concrete will attain.

Flexural strength and compressive strength develop at different rates within the concrete. Except for the first few days, the rate of strength gain is greater in compression than in tension (flexural).

5-694.510 COMPRESSIVE STRENGTH TESTS

Strength tests are required for one or both of the following purposes:

1. To check the potential strength of the concrete under controlled conditions against the desired strength; and
2. To establish a strength-age relationship for the concrete under job conditions as a control for construction operations or the opening of the work.

Tests made for the first purpose are referred to as standard tests and those for the second purpose are referred to as control tests.

For uniform and comparable results, follow a standard and consistent procedure in making all of the test specimens whether they are used either for standard or for control tests.

Twenty-four hours after casting, place the cylinders in water at a temperature of 15 to 25°C (60 to 80°F) for a period of 12 to 14 days. You do not need to remove plastic molds when curing cylinders in water however, remove the caps during the curing period. Transport the cylinder, in a capped plastic mold to prevent moisture loss, to the laboratory for further curing and testing. Adequately protect the specimens to avoid shipping damage. Completely fill out the *Concrete Cylinder ID card* (Form 2409) so that the cylinder is positively identified when it reaches the Mn/DOT Office of Materials Laboratory. Number cylinders made on each contract in consecutive order, beginning with number 1. Show the cylinder numbers on both the identification card and on the *Weekly Concrete Report* (Form 2448) for the concrete mix used.

Cylinders that have the suffix “C” after the numbers are considered control cylinders and are cured the same as the structure.

The standard cylinders are tested at 28 days, unless for special reasons, tests at different ages are desired. Control cylinders should indicate the desired test age. If the test age is not given, they will be tested at 28 days.

When sending samples, address shipping tags to:

Office of Materials
1400 Gervais Avenue
Maplewood, MN 55109

Some of the factors that can result in failures are listed below. Take precautions so none of these occur on the project. The first 3 factors do not affect the strength of the concrete in the structure, but cylinder test results do indicate lower strengths than the actual structure. The last 5 conditions affect the quality of the concrete in both the structure and in the specimens.

1. Improper molding of the specimens may result in honeycombed sections in specimens. Honeycombing indicates improper molding methods, segregation of the coarse aggregate or a batching error resulting in excessively high rock content of the mix.
2. Towards the end of each construction season, cylinders that broke below 80% of anticipated strength are checked to determine whether casting procedures were proper. In many cases the tops were poorly finished with open texture and projections. Identifications scribed in the tops are also observed as well as “nibs” on the bottom caused by striking the bottom of the mold with the rounded, semi-hemispherical rod. All cause reduced strength.
3. Inadequate curing of the cylinders may result in low strengths. Concrete subjected to poor curing conditions in the first 48 hours may never develop its potential strength. Cylinders that are exposed to frost, direct rays of the sun on warm days, and to adverse dry conditions during

early age are also affected. Low temperatures and lack of moisture retard strength gain, yielding 28-day strength values lower than expected; however, the concrete will eventually develop its full strength.

4. Rough handling of cylinders, particularly during early ages, will cause fractures or planes of weakness in the cylinders. Disturbance of any nature during the setting period may reduce the concrete strength.
5. A decrease in the cement content of the mix by either withholding part of the cement per batch or by increasing the quantity of aggregates per batch reduces the concrete strength. During the proportioning operations, assure that the proper quantities are measured out. Where sacked cement is furnished, assure the full content of each sack is placed in the mixer.
6. The use of dirty or contaminated aggregates results in a lower bond strength between the cement paste and the aggregates, thus producing a poorer quality cement paste, thereby reducing concrete strength.
7. Increasing the water content of the mix for easier workability without increasing the cement content to compensate for the additional water results in a weakened cement paste. Use sufficient water to give the desired consistency; additional water will shorten the life of the concrete structure. Water above the amount in the batch design results in a weaker cement paste along with a decrease in strength.
8. Decreasing mix time, either intentional or otherwise, may leave portions of both sand and gravel that are uncoated with cement paste. Worn mixing blades can also result in reduced mixing action.

5-694.511 CASTING CYLINDERS

In making the test specimens, place molds on a level, firm foundation in a sheltered place where they can remain undisturbed and protected from direct sunlight and from temperatures below 15°C (60°F) for at least 24 hours. If metal molds are used, lightly oil the inside before placing concrete in them. If a suitable casting site is not available in the immediate proximity of the work, transport the concrete and cast specimens to a location where they are kept undisturbed for the initial 24-hour period. If sampling has caused segregation, re-mix by hand shoveling prior to casting the test cylinder.

Mn/DOT standard cylinder mold size is 100 x 200 mm (4 x 8 in.). If aggregate has a maximum size greater than 31.5 mm (1 1/4 in.), use 150 x 300 mm (6 x 12 in.) molds.

White is Mn/DOT's standard color for concrete cylinder molds. Mn/DOT also recommends using domed lids instead of flat lids. This is to discourage the practice of stacking cylinder molds containing plastic concrete on top of one another. This is to eliminate one possible cause for low cylinder strengths. White cylinder molds do not attract nearly as much heat from the sun as the black ones do. Standard cylinders must be kept in a protected area, out of the sun and protected from temperatures below 15°C (60°F), and undisturbed for the initial 24-hour period.

Cylinder Casting Procedure

1. Use steel, fiber, or plastic molds.
2. Cast on flat surface.
3. Start casting cylinder within 15 minutes of taking a representative sample of concrete.
4. Place the concrete in the mold and rod each layer 25 times per layer in 2 equal layers for 100 x 200 mm (4 x 8 in.) cylinders using a 9.5 mm (3/8 in.) diameter hemispheric-nosed steel rod. For 150 x 300 mm (6 x 12 in.) cylinders, rod concrete 25 times per layer in 3 equal layers with a 16 mm (5/8 in.) diameter, hemispheric-nosed steel rod. Uniformly distribute the rodding over the cylinder area and penetrate slightly into the previous layer when tamping the second and/or third layers.
5. Tap the sides of fiber and plastic molds after each layer lightly with the hand prior to the strike-off to remove entrapped air bubbles on the sides of the mold. When using steel molds, tap the mold lightly with the mallet.
6. After rodding the top layer, strike-off the surface evenly using a wood float or other suitable object. Do not use the cap as a finishing tool.
7. When casting cylinders in plastic molds, place the cylinder cap on the mold immediately after finishing the cylinder. Place adequate curing medium on other molds. Do not disturb for 24 hours.
8. Place SP and Field ID on cylinder mold, not on cylinder surface. Do not mark caps since they are reused. Do not etch identification into the surface of the cylinders. When using metal molds, transfer the ID to the top surface of cylinder and strip metal molds.
9. Place in curing tank. Cylinders in plastic molds may cure in water tank with caps off.
10. Fill out *Concrete Test Cylinder ID* card (Form 2409). See 5-694.754.
11. Protect cylinder from moisture loss and shipping damage. Ship sufficiently prior to testing date. Ship cylinders in plastic molds if the tops are sealed.

Protect the cylinder from moisture loss and extreme temperature change after casting. Control moisture loss by:

- Placing the specimen in an insulated box containing moisture
- Covering with polyethylene sheeting or bags
- Covering with a minimum of 4 thicknesses of wet burlap
- Covering with waterproof paper
- Placing caps on plastic cylinder molds

Protect specimens from the direct heat of the sun and from extreme changes in temperature. In cold weather, keep specimens in a heated enclosure and do not allow specimens to freeze.

Fill out the sample card completely, including the source of concrete when ready-mix concrete is used. See 5-694.754. Enter the full name of the concrete source each time a card is made out.

5-694.520 FLEXURAL STRENGTH TESTS

These routine tests are usually made only on paving jobs and are tested at the job site. Rehabilitation projects requiring early openings may also utilize flexural tests.

As with all testing practices, the value of the standard flexural test results depend entirely on uniform adherence to the standard procedure outlined below. Tests are normally made at the standard ages of 7 and 28 days. High early strength concrete may require additional beams to verify opening strengths.

Record the test data for all beams on *Concrete Test Beam Data* (Form 2162) and submit to the Mn/DOT Concrete Engineering Unit every week after the 28-day specimens are tested. Whenever there is a change in the mix or in the source of any of the materials, report this data so that only one set of conditions are on a sheet. A sample of Form 2162 is shown in Figure A 5-694.741.

5-694.521 CASTING BEAMS

Carefully make the beams of representative concrete as follows:

1. Obtain enough concrete to cast 7 and 28-day specimens. Casting should occur within 15 minutes of obtaining the representative concrete sample.
2. Clean and oil molds.
3. Cast on a flat surface.
4. Place concrete and rod 65 times per layer in 2 equal layers with a 16 mm (5/8 in.) rod. Spade along edges after each layer. Tap lightly along inside and outside edges after each layer.
5. Strike off surface with a straight edge and finish with a trowel or wood float.
6. Impress ID into the surface within 150 mm (6 in.) from outside edge. (If placed near the third point, the impressions of the numbers might adversely affect the test results.)
7. Adequately cure and do not disturb for 24 hours.
8. Place in curing tank.
9. Test beams according to the procedure described in 5-694.522.

NOTE: Control beams are intended to verify opening strengths and therefore cure them in a similar manner as the pavement. In cases of late season paving, you may cure control beams in water tanks to avoid freezing and assume there is an equal trade off between the moist cure of the sample and the additional heat generated by the slab. In any case, ACI requires moist curing beams for at least 24 hours immediately before testing in water saturated with calcium hydroxide at $23 \pm 2°C$ ($73 \pm 3°F$).

Number the beams in consecutive order for each contract, beginning with number 1. Where more than one project is included in one contract, DO NOT use separate series of numbers. The numbers of the beams made each day and the station where they were cast are entered on the *Weekly Concrete Report* (Form 2448).

After casting, the specimens are left uncovered only until the identification numbers are inscribed and then covered with wet burlap, impermeable paper, or polyethylene plastic and left undisturbed for 24 hours. Protect these test specimens from direct sun and extreme temperatures.

When 24 hours old, carefully move the specimens in the molds to the testing locations. Exercise care in this operation to avoid damage to the beams. DO NOT throw or drop at any time. Upon arrival at the testing site, remove the beams from the molds and store the specimens in saturated limewater at 15 to 25EC (60 to 80EF) until the 7 or 28-day testing date has arrived. DO NOT subject the specimens to water temperatures lower than 15°C (60°F).

5-694.522 TESTING BEAMS FOR FLEXURAL STRENGTH

Nearly all State Departments of Transportation use third point beam breakers for flexural testing of concrete pavement. By using third point beam breakers, Mn/DOT can share its test results with other states and adapt the test results for use with AASHTO pavement design equations.

A. Before the First Use of the Beam Breaker After Transportation or Storage

1. Release all four case latches and lift the cover straight up.
2. Place the cover at the desired operating location and set the apparatus squarely on the top of the cover. See Figure A 5-694.522.
3. Remove any ties from the recorder or other components.

Figure A 5-694.522

B. Recording Charts

Third point loading recording charts are used to determine the Modulus of Rupture for each specimen. Proper use of the testing machine will apply a rate of loading between 861 and 1207 kPa (125 and 175 psi) per minute for any beam whose cross section dimensions are 150 x 150 mm (6 x 6 in.), ±8 mm (±5/16 in.). Four different spirals labeled A, B, C, and H are indicated on each recording chart. See Figure B 5-694.522. The chart in Figure E 5-694.522 is a guide to use in determining which spiral to use in testing each specimen. Note the exact dimensions of the specimen to determine which spiral to use. The chart is also used to correct the Modulus of Rupture values for specimens that do not have an exact 150 x 150 mm (6 x 6 in.) cross section. The spiral labeled H, is used for loading specimens at a rate of 861 kPa (125 psi) per minute, and is not used by Mn/DOT.

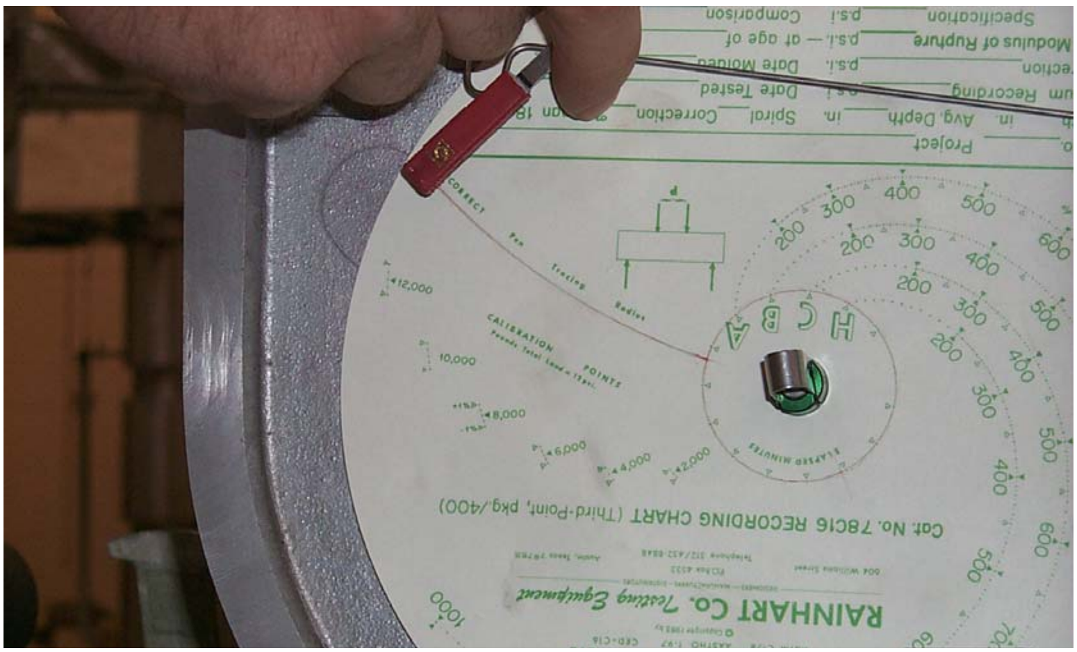


Figure B 5-694.522

C. Test Procedures

1. Remove the plastic dust cover.
2. Close the control valve and pump the loading head approximately 6 mm (1/4 in.) until the piston floats.
3. Open the recorder door and install a recording chart: slip the edge of the selected chart under the pen lifter and over the open chart hub. See Figure C 5-694.522. Do <u>not</u> clamp (in order to rotate the chart manually for checking).
   a. Adjust Zero - Adjust the cam as necessary until the pen traces the zero circle, turn the cam with your fingers: clockwise to raise the pen and vice versa. The piston must float under no load.
   b. Check the friction - Move the pen arm up the chart approximately 25 mm (1 in.) and release it. It must return to zero without help.
   c. Correct pen adjustment occurs when:
      - The pen arm assembly is fully inserted and clamped in the pen arm holder. Check that

the two pen arm fingers are under both rivets and clamped with the screw.

- The pen point trough is at approximately right angles to the chart both vertically and horizontally; flexing the pen arm and holding it close to the pen point adjust this.
- The pen point just makes contact with the chart. Too much pressure will cause skipping. Pressure is adjusted by flexing the pen arm.
- The length of the pen arm radius will trace a minute arc or a pen tracking arc on the chart. This length is important because an incorrect pen arm radius will generate an error directly proportional to the error in its length. To check this adjustment: swing the pen point to the maximum travel; rotate the chart and hand clamp it so that the pen point rests precisely on an arc at maximum reading; allow the pen to draw its own arc as it returns to the zero circle. Examine the coincidence of two arcs. If the two arcs vary more than 1 mm (1/32 in.) and are not corrected by adjustments as described in 1 and 2 above, the recorder needs calibration. You can also test the arc by tracing the radius shown in Figure B 5-694.522.

Figure C 5-694.522

4. With the beam on its side in relation to its position as molded, measure the width (b) and depth (d) at the center of the specimen. Take measurements to nearest 0.5 mm (0.02 in.). Use good outside calipers and a steel machinist's rule. See Figure D 5-694.522. Using these measurements turn to Figure E 5-694.522 to determine which spiral you should trace.

Figure D 5-694.522

Example:

If the depth (d) is 149.0 mm (5.87 in.) and the width (b) is 147.5 mm (5.80 in.), the convergence of these points in Figure E 5-694.522 is in the shaded area labeled C. Therefore you should trace spiral "C" during the testing.

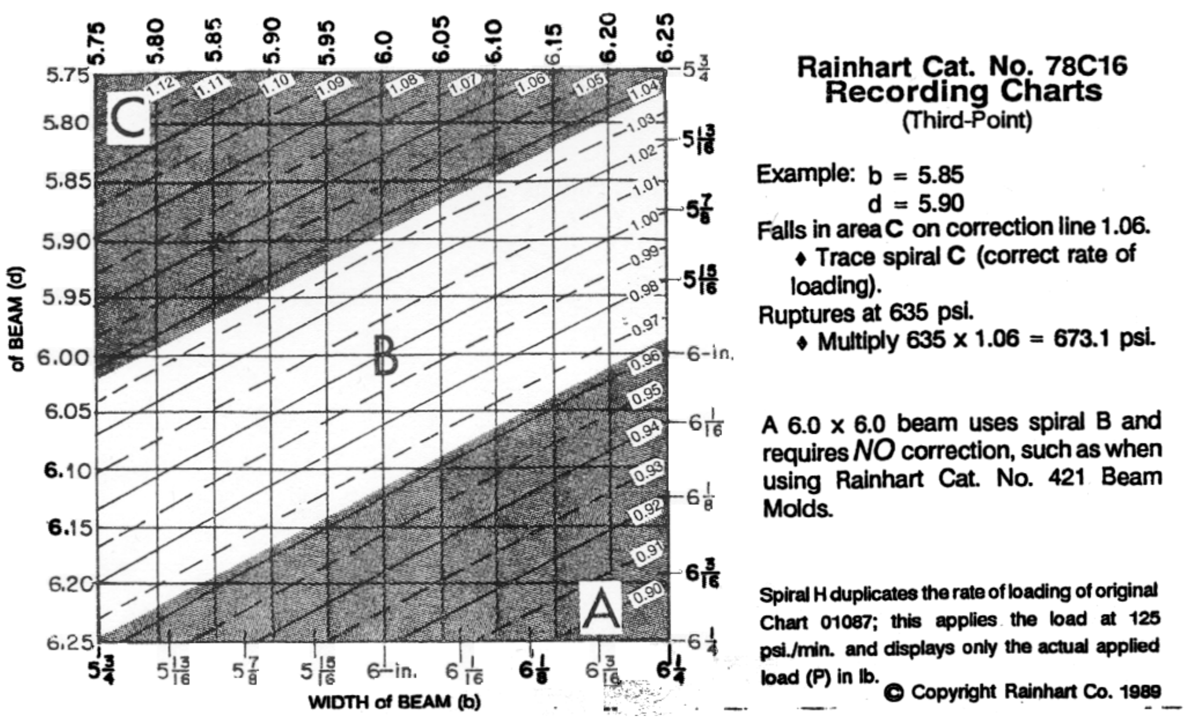


Figure E 5-694.522

5. Use the key and wind the chart drive clockwise approximately one full turn. See Figure F 5-694.522. Rotate the chart to its starting position, and then clamp the recording chart.

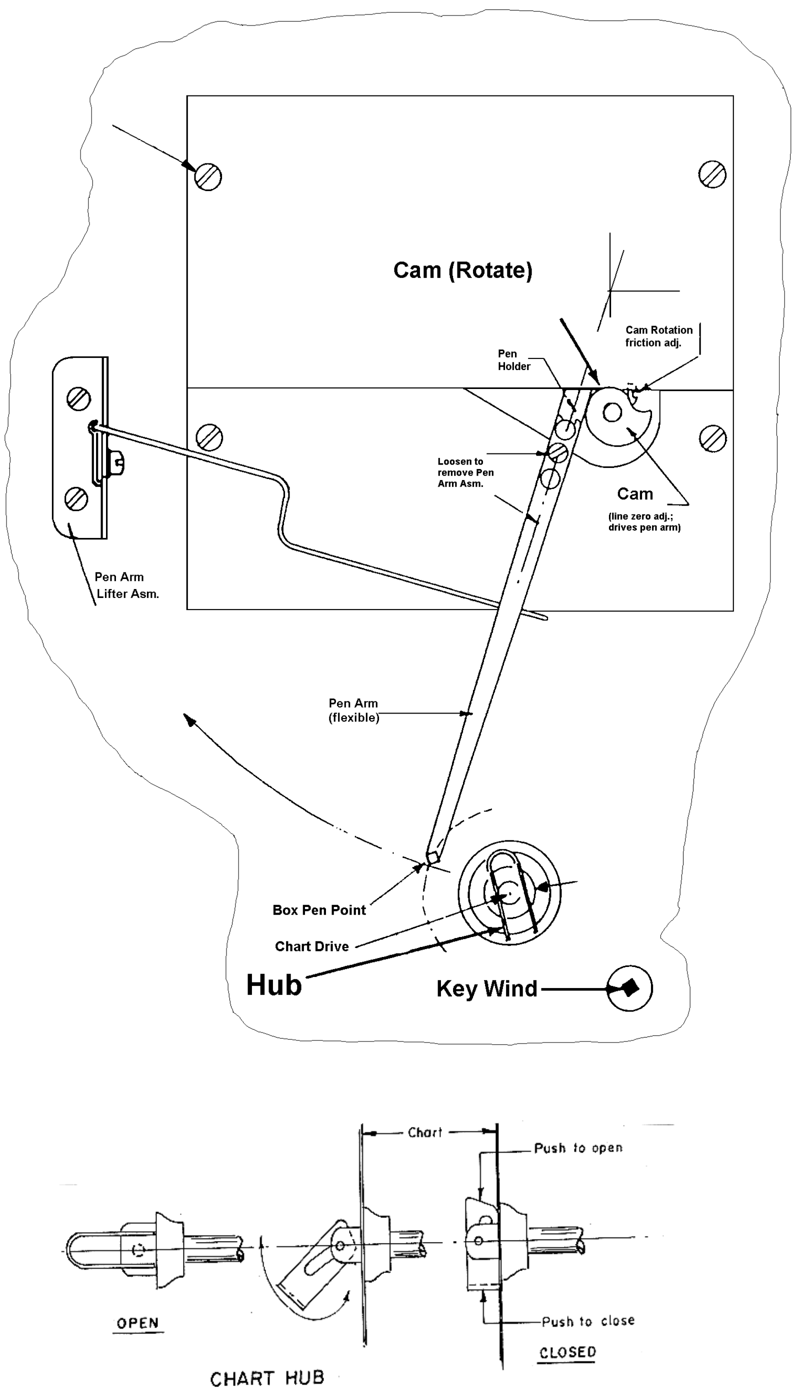


Figure F 5-694.522

6. With the beam **on its side** in relation to its position as molded (same position as used for taking the previous measurements), insert the beam from either end of the apparatus between the tie rods. Center the beam in relation to the four tie rods and have at least 25 mm (1 in.) of concrete protrude outside of each of the two cross-head bearing blocks. See Figures G and H 5-694.522.

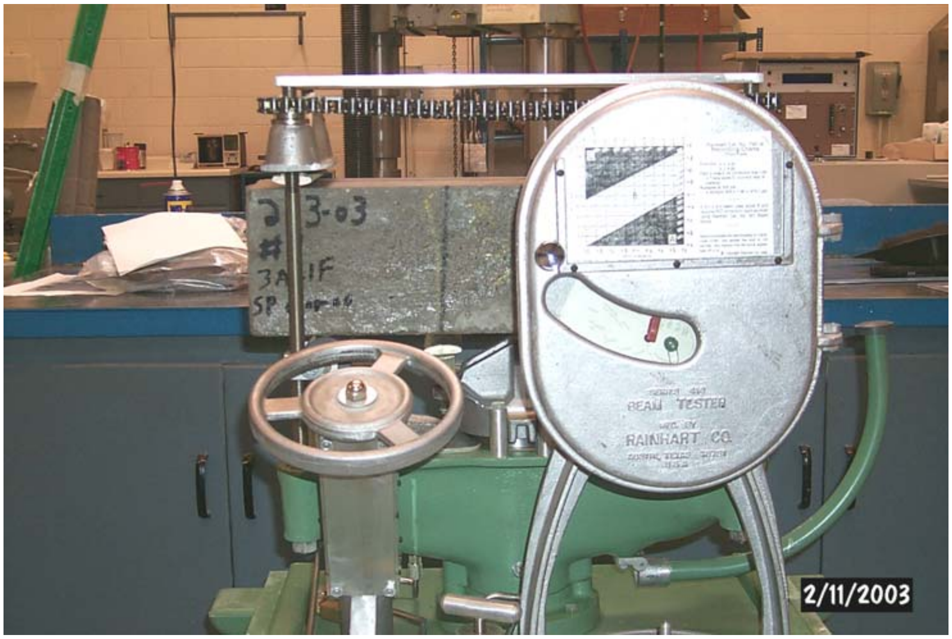


Figure G 5-694.522

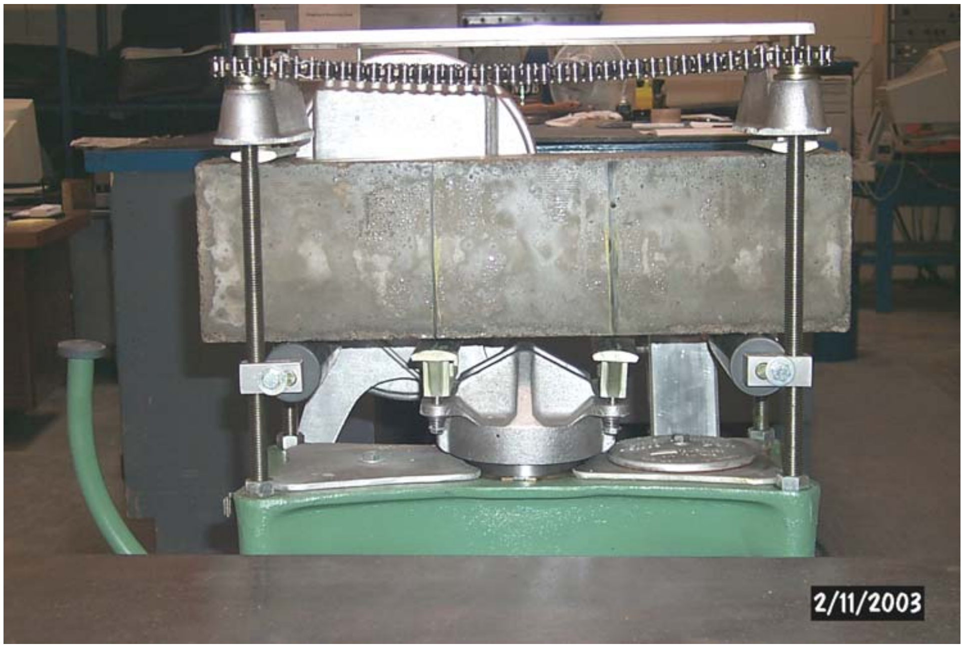


Figure H 5-694.522

7. The chain drive provides a quick method of adjusting the crossheads synchronized in height so that the load is applied normal to the beam. To operate, grasp opposite sides and move simultaneously clockwise to bring them down into contact with the beam, and counterclockwise to raise them. Stop as soon as they touch the beam; further loading is hydraulic.
8. Close the Control Valve clockwise. Counterclockwise rotation of the pump handwheel will fill the pump with oil and clockwise rotation will introduce it into the main hydraulic system to apply load. The centerhead is quickly raised to establish initial contact with the beam by rapidly spinning the hand wheel clockwise. As soon as contact is established and the loading block(s) seated (the recorder pen will show a small load), refill the pump.
9. Carefully trace the spiral of the rotating chart and load the beam until failure.
10. Open the control valve (counterclockwise two turns only), to allow the piston to retract by gravity, raise the crossheads and remove the beam sections.
11. Unclamp and remove the chart. After the end of the test, the chart drive will tick away until run down (clamp loop inverted). **NOTE**: You can rewind the chart drive at any time.
12. Fill in all pertinent test result data. Measure the average width and average depth of the specimen at the section of failure, and record. If the beam does not measure exactly 152.5 x 152.5 mm (6 x 6 in.), refer to the chart in Figure E 5-694.522. This chart is stored in the plastic holder on the front of the recorder door. Specimens must break in the middle one-third or 228.5 mm (9 in.) of the beam or they are not acceptable.

Example:

Beam Dimensions:
151.0 mm (5.95 in.) depth = d
152.0 mm (5.98 in.) width = b

From Figure E 5-694.522, use spiral B. If beam breaks at 3585 kPa (520 psi), check dimensions, follow line to upper right of chart, chart indicates that 1.02 (+2%) should be subtracted.

Final Strength

$$(1.02 \times 3585\, kPa) = 3657 \text{ kPa} = 3.66 \text{ MPa} \quad \underline{\text{or}}$$
$$(1.02 \times 520\ psi) = 530\ psi$$

D. After Each Day's Operation

1. Close the recorder door.
2. Open the control valve until the head bottoms and close the control valve.
3. Using a damp rag or brush, clean the top of the loading head and the base casting being careful to move all particles away from the hydraulic cylinder. DO NOT clean by flushing with water because some might find its way into the hydraulic system and cause disastrous rusting.
4. Position the dust cover over the machine.

E. Hydraulic Fluid

The most important item of maintenance on the Beam Tester is controlling the quality and quantity of the hydraulic fluid. Check this yearly during calibration, or whenever leakage is found, and after periods of extended storage.

Below are guidelines for checking the hydraulic fluid in the Beam Tester:

- **Fluid Specification** - All Rainhart Beam testers are furnished with factory installed Automatic Transmission Fluid with Dexron (GM type); an extra quart can is tied inside the case cover. This fluid is readily available from any quality petroleum products distributor.
- **Quantity** - With the piston fully retracted, remove the left hand cover of the base casting. Add if the fluid is more than 40 mm (1 1/2 in.) from the top undersurface of the base casting. Full is 12 mm (1/2 in.) from the top undersurface. A can is packed in the cover of every Beam Tester when shipped from the factory.
  - The capacity of the entire system is 1.6 L (1 1/2 qt.).
  - The right hand cavity of the Beam Tester base casting is dry and has no hydraulic function.
- **Quality** - With the piston fully retracted, remove the left hand cover of the base casting and check the condition of the oil in the reservoir at its deepest point next to the main cylinder.
  - Inspect for sludge, color, smell and water. **Do not use** automobile brake fluid. If the oil is extremely dark or has heavy viscosity, replace it. Since the hydraulic oil circulates in one direction only, all grit or impurities are transported to the reservoir where they can settle harmlessly to the bottom. The filter prevents foreign matter from entering through the pump.

5-694.530 CONSISTENCY (SLUMP) TESTS

Check and control the consistency of the concrete during each pour. According to Specification 2461.4A4a, the slump test is a measure of the consistency of the concrete. The consistency therefore is a measure of the water content of the concrete. The water content controls and affects the cement content of the concrete. Since the slump test is important, do not substitute a guess for an actual test.

The minimum tests required according to the Schedule of Materials Control may not provide a sufficient number of tests to assure quality. An individual slump test may not indicate the true consistency of the concrete because of unavoidable variations in the composition of the concrete and because of variations in the manipulation of the concrete. For this reason, take several tests to obtain a true average value. On small pours, one test may not provide sufficient information to assure quality.

Enter the results of slump tests on the *Weekly Concrete Report* (Form 2448). See Figure B 5-694.727.

The consistency of concrete mixes, in terms of millimeters (inches) of slump, is determined by their relative water contents. Thus, a given change in the water content of a mix will result in a corresponding change in slump. The percentage change in water content per millimeters (inches) of slump change is not constant over the whole range of consistency. It is greater at the dry end of the range and less at the wet end. Only use this procedure when the plant has held back water from the design mix and the slump is less than required by the mix design. The added water to increase the slump cannot exceed the design water by more than 4% per Specification 2461.3J(2).

Guidelines for the approximate changes in water content, in percent, for various changes in slump are shown in Table A 5-694.530.

To illustrate the use of the table, assume the water for a given mix will produce a 50 mm (2 in.) slump. If a 100 mm (4 in.) slump is desired with this mix, increase the water content 7.9%. In another illustration, the water content is decreased 10.3% to reduce the slump from 125 to 50 mm (5 to 2 in.).

Guidelines for Slump Adjustment

From a slump of:	To a slump of:					
	25 mm (1 in.)	50 mm (2 in.)	75 mm (3 in.)	100 mm (4 in.)	125 mm (5 in.)	150 mm (6 in.)
25 mm (1 in.)		+6.5%	+11.3%	+14.9%	+17.5%	+19.9%
50 mm (2 in.)			+4.5%	+7.9%	+10.3%	+12.6%
75 mm (3 in.)				+3.2%	+5.6%	+7.7%
100 mm (4 in.)					+2.3%	+4.4%
125 mm (5 in.)						+2.0%

Table A 5-694.530

5-694.531 CONSISTENCY (SLUMP) TEST PROCEDURE

Equipment needed:

- Slump cone in clean and good condition
- Smooth, rounded 16.0 mm (5/8 in.) diameter steel rod with a rounded tip

Consistency (Slump) Test Procedure:

1. Obtain a representative concrete sample. Start test within 5 minutes of when sample was taken.
2. Dampen the slump cone and place on a flat, moist, non-absorbent and rigid surface; hold the cone firmly in place by standing on the foot pieces.
3. Immediately fill the cone in 3 layers, each layer approximately one-third the volume of the mold or about 67 mm (2 5/8 in.) for the first layer and 155 mm (6 1/8 in.) for the middle layer.
4. Rod each layer with 25 strokes of the tamping rod. Uniformly distribute the strokes over the cross-sections of each layer making approximately half of the strokes near the perimeter, then progress with vertical strokes spirally toward the center, slightly penetrating into the underlying layer. In rodding the top layer, an excess of concrete is maintained above the top of the cone. After the top layer is rodded, the surface of the concrete is struck off even with the top of the cone.

5. Remove any excess spillage of concrete from around the base of the cone and lift the cone clear of the concrete allowing the concrete to settle or slump under its own weight. Slowly lift the cone vertically and carefully to secure a proper result, with the lifting operation taking approximately 3 to 7 seconds.
6. The amount of slump is measured immediately after the mold is lifted by placing the rodding bar across the inverted mold and measuring from the top of the mold to the displaced original center of the top of the concrete. Record the slump as measured to the nearest 5 mm (1/4 in.).
7. If the slump test shows results higher than the maximum of the 25 mm (1 in.) slump range specified in 2461.3B3, notify the Contractor of the results and test the next load. When testing the next load, do not allow the placing of any concrete until the test shows acceptable slump.

Notes:

- Specification 2461.4A4a allows an additional 25% above or 50% below the upper end of the specified range on an occasional basis. This does not change the slump range. This is intended to give the Contractor some time to correct any problems they may have and get the slump back within the range as soon as possible. If any load's Certificate of Compliance shows the water used (including any added on site) is greater than mix design water subject to 2461.3J(2), reject the load and do not place into the work.
- Water reducers are currently more frequently used. According to Mn/DOT Specifications, water reducers must have the Engineer's approval for use. If approval is granted, investigate any slump failures to verify if the high slump is due to the water or admixture. The price reductions listed in the Schedule of Price Reductions for high slumps, especially bridge deck concrete, were originally based on high slumps due to high water. High slumps caused by admixture may not warrant the price reduction imposed similar to that caused by water. In any case, the slump of the concrete should remain constant.

Figures A and B 5-694.531 illustrate the slump test for consistency. Figure A shows a low slump and Figure B a high slump.

Figure A 5-694.531[1]

Figure B 5-694.531[2]

5-694.532 VERIFICATION OF WATER IN FRESH CONCRETE BY USE OF A MICROWAVE OVEN

Mn/DOT has incorporated the use of AASHTO TP23-93 to verify the Contractor's water in concrete pavements. This test uses a microwave oven to drive the water out of fresh concrete. Mn/DOT has an incentive/disincentive program for the water-cementitious (w/c) ratio. This incentive is based on the Contractor's actual batch weights and is verified using the microwave.

Knowing the weight of the fresh concrete and the weight of the dried concrete, the total water content can be calculated. This total water content is not the same as the total batch water content because the total water content includes all absorbed moisture in the aggregates. The water content used to determine the w/c ratio is the batch water added by the Contractor plus any free moisture; this does not include the absorbed moisture.

There are many variables in this procedure. The most significant are the absorption and moisture of the aggregates. For this reason, Mn/DOT will run new absorption tests on all aggregate sources before paving begins. The Paving Contractor will also need this information since they will be designing their own mixes. Together with the Agency, the Contractor will have to submit samples to the Mn/DOT Office of Materials when they decide which aggregates they are going to use.

Moisture tests and microwave oven testing are performed by the Agency. Testing rates are found in the special provisions.

A. Verification of Water in Fresh Concrete Test Procedure

See 5-694.734 for instructions and the worksheet for performing the microwave oven test procedure.

Figure A 5-694.532 shows an example of a dried microwave oven sample.

Figure A 5-694.532

B. Definition of Lots and Sublots Involving Water/Cementitious Ratios

For determination of water/cementitious ratio incentive/disincentive, a lot represents one day of paving. Paving includes integrant curb and gutter and curb and gutter placed with the same mixture as paving. A change in mix design requires beginning a new lot. Changes in mix design for small quantities such as hand work and high early mixes greater than 356 kg/m^3 (600 lbs/yd^3) cementitious are not included as part of a lot or sublot for incentive/disincentive determinations.

All samples for testing are taken in a random manner according to the prescribed sampling rate. A minimum of 2 tests and a maximum of 4 tests are required per day. The minimum sublot size is 250 cubic meters (cubic yards). Gradation testing is not required when production is less than 250 cubic meters (cubic yards) per day.

If less than 3 sublots are produced in a day before the new mix design is initiated, the sublots shall be averaged with the previous lot and included as part of that lot. On the first day of production or whenever the mix design is changed prior to the production of 3 sublots, this production is hereby defined as a lot. If production is less than 3 sublots, the sublots are included in the next day's production. On the last day of paving or on the last day of using a specific mix design, the concrete involved shall constitute a separate lot/sublot unless the above applies regarding less than 3 sublots.

5-694.540 AIR CONTENT TESTS

The general statements made in an earlier section with reference to consistency apply as well to testing of the air content of the concrete.

Accurate determination of the air content is essential in computations of cement content and yields, as well as a check for compliance with Specification 2461.4A4b limitations on the air content itself.

For all air-entrained concrete the Specification limits for air content is in the range of 5 to 8%. The target air content for all concrete is 6.5%.

Perform enough tests during the pour to accurately determine the average air content of the concrete.

The air test is subject to the variations and limitations of each batch; therefore, spread the tests out over the entire period of the placement operation. When the tests are taken at proper intervals, a relatively accurate average value for air content is obtained. On large pours, many tests are required. On small pours a minimum of two tests is desirable. Check a current Schedule of Materials Control for minimum testing rates. Send a sample of each lot of air-entraining admixture to the Laboratory for infrared scan and percent of solids tests.

It is the duty of the Inspector to inform the Contractor of the air content test results. It is then the responsibility of the Contractor to determine and adjust the air-entraining agent dosage rate to maintain the air content within the specified range. Concrete which is placed in the work before air test results are known is subject to reduced payment if the air content is outside of the Specifications.

In making the test, it is very important to use concrete of representative composition in filling the testing apparatus container. This is necessary since the air contained in the concrete is all in the mortar portion of the concrete. If the sample used in the test contains either too much or too little mortar with respect to the amount of coarse aggregate, the test will indicate an incorrect air content. Another factor that may contribute to erroneous test results is the use of water in the test that contains a considerable amount of small air bubbles. Water that is freshly drawn from a pressurized line or a valve on the mixer possibly may contain some entrained air. When water is taken from such sources, allow it to stand for 10 to 15 minutes before using it in the test. This will permit the air contained in the water to escape.

It is important to complete the test without interruption and as quickly as possible once it is started. Make the test on freshly mixed concrete, since there is a loss of workability if the sample is allowed to stand for some time after mixing.

5-694.541 AIR CONTENT TEST PROCEDURE

A. Operation of the Pressure Meter (Type B Meter)

Figure A 5-694.541

1. Obtain a representative sample. Begin air content testing within 5 minutes of obtaining the representative sample.
2. Dampen bowl. On a level surface, fill container in 3 equal layers, slightly overfilling the last layer.
3. Rod each layer 25 times with a 16 mm (5/8 in.) rounded tip rod, uniformly distributing strokes.
4. Rod bottom layer throughout its depth without forcibly striking bottom of container.
5. Rod the middle and top layer throughout their depths and penetrating 25 mm (1 in.) into the underlying layer.
6. Tap the sides of the container smartly 10 to 15 times with the mallet after rodding each layer.
7. Strike off concrete level with top of container using the bar and clean off rim.
8. Clean and moisten inside of cover before clamping to base.
9. Open both petcocks.
10. Close air valve between air chamber and the bowl.
11. Inject water through petcock until it flows out the other petcock.
12. Continue injecting water into the petcock while jarring and tapping the meter to insure all air is expelled.
13. Close air bleeder valve and pump air up to initial pressure line.
14. Allow a few seconds for the compressed air to stabilize.
15. Adjust the gage to the initial pressure.
16. Close both petcocks. **DO NOT TILT THE METER AT ANY TIME**.
17. Open air valve between chamber and bowl.
18. Read the air percentage after lightly tapping the gage to stabilize the dial.
19. Close the air valve and then open petcocks to release pressure before removing the cover.
20. Calculate air content:

$$Air\ Content = (meter\ reading - aggregate\ correction\ \ factor\ if\ \ requred)$$

21. Properly report (record) the results.
22. Clean up the base, cover, and petcock openings.

When the test indicates an air content outside the limits specified in Specification 2461.4A4b, run recheck test immediately. Record the results of the air tests on the *Weekly Concrete Report* (Form 2448). See 5-694.727.

5-694.542 UNIT WEIGHT (DENSITY) TEST

The unit weight (density) test is a measure of the weight per cubic meter (cubic foot) of freshly mixed concrete. By knowing the unit weight of the concrete, other information can be determined such as the concrete yield and water content for microwave oven testing. See 5-694.734 for the unit weight test procedure.

5-694.550 TEMPERATURE TEST

The Inspector should determine and record the concrete temperature at time of placement. Unless the Special Provisions for the Contract provide otherwise, the concrete temperature requirement is in the range of 10 to 30°C (50 to 90°F) per Mn/DOT Specification 2461.4A3. The Certificate of Compliance provides a space for the concrete temperature and air temperature.

On most work, take the temperature with issued thermometers that have been checked for accuracy. On massive pours in large bridge piers or abutments, special installations of electrical thermocouples are sometimes needed to secure data on the rate of temperature change as produced by the heat of hydration of the cement. Such data is very important in determining how long protective coverings, forms, etc. shall remain in place before exposing the concrete to atmospheric conditions.

REFERENCES

1. Figure A 5-694.531, Design and Control of Concrete Mixtures, 14th Edition, Portland Cement Association, 2002.
2. Figure B 5-694.531, Design and Control of Concrete Mixtures, 14th Edition, Portland Cement Association, 2002.

PLACEMENT OPERATIONS
5-694.600

5-694.601 GENERAL

Concrete placing, finishing, and curing operations are just as important in obtaining quality in the completed structure as the inspection of the materials and the mixing operations. It is essential that the Inspector observe these operations to assure that they comply with good construction procedures. This section provides guidance for both the Contractor and the Agency.

Form construction and inspection for bridge construction is addressed in the Mn/DOT Bridge Construction Manual and Inspectors should refer to that manual for further information. See the Bridge Manual 5-391 for additional items pertaining to structures.

5-694.602 PAVEMENT STATION NUMERALS

Imprint station numbers in the surface by using steel stencils after finishing and texturing (and tining if required) the concrete, but prior to the application of any curing material. Place the numerals along the right-hand edge of the pavement, in the direction of traffic, so that a driver can read while traveling on the shoulder. See Figures A and B 5-694.602 for examples of concrete pavement stationing. The beginning station is marked, to the nearest meter (foot), at the start of paving. Centerline stations are marked at all 200 m (500 ft.) station intervals thereafter. All equations of one meter (foot) or more are stenciled so that the equality sign is at the point of the equation. Finally, the stationing of all header joints are marked to the closest meter (foot) reading in the direction of paving.

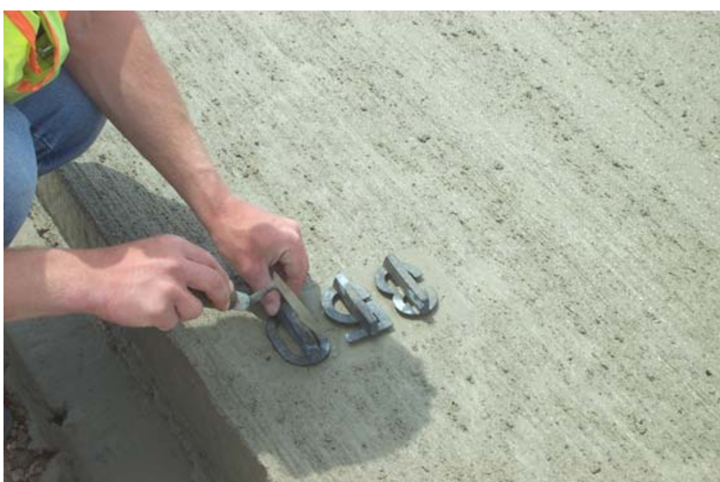


Figure A 5-694.602

Figure B 5-694.602

5-694.603 TEMPERATURE LIMITATIONS

DO NOT expose concrete to temperature extremes. Concrete shall have a temperature of 10 to 30°C (50 to 90°F) at the time of placement, except a temperature of not less than 5°C (45°F) is allowed with the use of an approved accelerator. If the materials used in the production of concrete will not produce concrete in this temperature range, heat or cool one or more of the materials as necessary. If the temperature of all the concrete materials is above 10EC (50EF), it is not necessary to heat any of the materials.

Water is the easiest of the materials to adjust for temperature control. When the average temperature of the cement and aggregate is between 2 and 10EC (35 and 50EF), control the concrete temperature by heating only the water. By using hot or cold mixing water (whichever is necessary), you can maintain the temperature within the above range. Mixing water must never exceed 80EC (180EF) since there is danger of flash set at these high temperatures. This method is not acceptable in cold weather when the aggregates contain frost. The aggregates then require heating as specified in 2461.4A3.

Overheated dry aggregates may result in cement dusting or dry coating of cement on the particles with a partial or complete loss in bond. Heat the material sufficiently to remove the frost lumps.

Figure A 5-694.603 indicates the temperature of freshly mixed concrete as affected by the temperature of its ingredients in hot weather concreting. The chart in Figure B 5-694.603 indicates the approximate temperature expected in the concrete for various temperatures of mixing water and solids. This chart is based on an average mix and is sufficiently close for estimating temperature of mixing water when knowing the average temperature of the solids.

DO NOT place concrete when there is danger of damage from frost in the first 24 hours after the pour. DO NOT place when the air temperature is below 2°C (36°F) except when the structure is enclosed and heated or when sufficient cover is provided to protect the concrete from freezing. See Specification 2461.4A2.

In the late spring, summer, and early fall the normal temperatures that prevail are not detrimental to the concrete, provided moisture control is maintained. When the temperature during the night approaches or falls below 0°C (32°F), protect the concrete from freezing. The extent of protection depends on the expected temperature. Protection may require several layers of curing paper or plastic blankets and, if needed, placing of straw hay between the blankets to improve the insulating value. In the fall of the year it is good practice to use a double layer of paper or plastic, or a combination thereof, to retain the heat of hydration and increase strength gain. Remove and replace concrete that is frozen within the first 24 hours since concrete frozen during early stages of hydration will never produce durable concrete. See 5-694.680 for additional information on concrete curing.

Additional heat can aid in production of early strength in concrete when it is accompanied by adequate moisture. Heat without applied moisture will dry out the concrete. When heat and steam are applied for accelerated cure, the operation should not begin until one or two hours after the initial set. Heat applied early is detrimental.

TEMPERATURE OF FRESHLY MIXED CONCRETE AS AFFECTED BY TEMPERATURE OF ITS INGREDIENTS IN HOT WEATHER CONCRETING

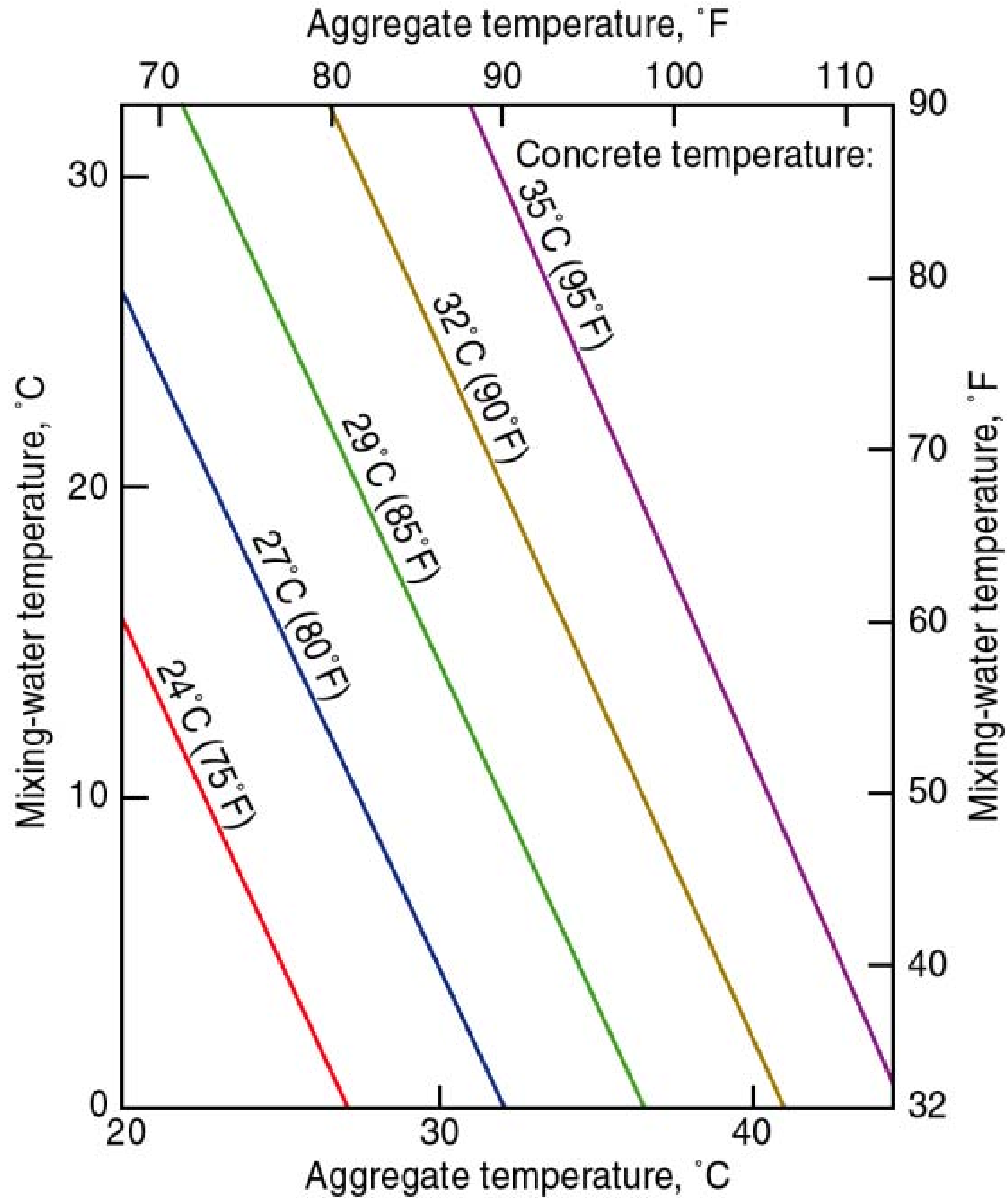


Figure A 5-694.603[1]

TEMPERATURE OF MIXING WATER NEEDED TO PRODUCE HEATED CONCRETE OF REQUIRED TEMPERATURES IN COLD WEATHER CONCRETING

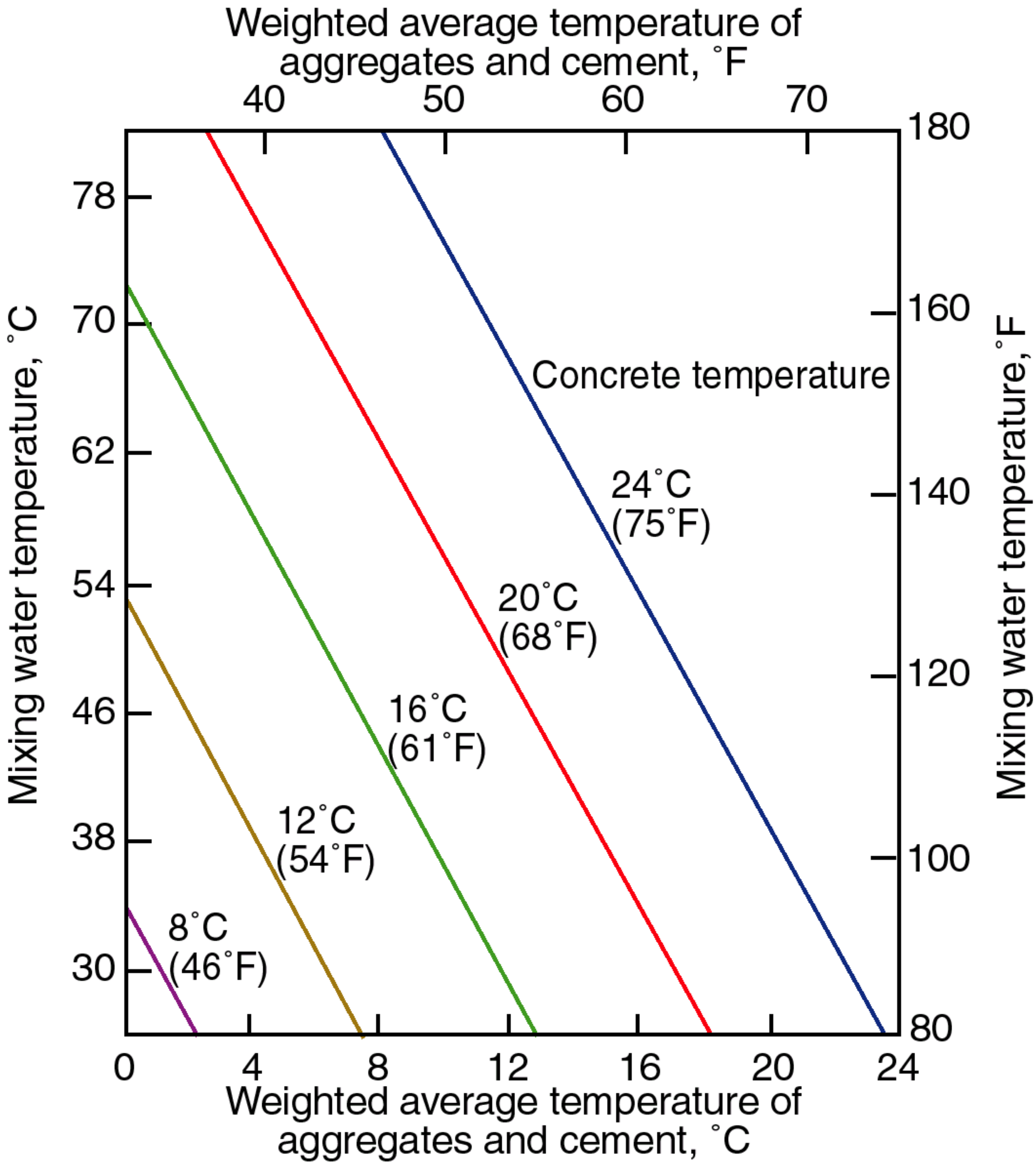


Figure B 5-694.603[2]

5-694.610 PLACING CONCRETE

Properly mixed concrete having good workability at the time of placement may lose some or all of its desirable characteristics due to mishandling at the job site. Concrete can segregate in the same way coarse aggregate could segregate during stockpiling operations. The "free fall" of concrete (outside the limits of a spout or chute) should not exceed 1.2 m (4 ft.). Always place concrete as near as possible to its final position in the completed structure.

5-694.611 BUCKETS

Check concrete buckets for accumulation of dry and hardened concrete and have the material removed prior to use. Control segregation by minimizing the fall of concrete when charging the concrete bucket. Move the bucket during discharge into the forms to prevent the formation of concrete piles. See Figure A 5-694.611 for an example of placing concrete with a bucket.

Figure A 5-694.611

5-694.612 CHUTES AND BELTS

Divert the fall of concrete discharged from the ends of chutes and belts by a baffle. Unrestricted fall permits the coarse portion of the batch to separate and carry to the front end of the discharge while the soft or mortar portion of the batch flows under and to the back of the discharge.

When concrete is discharged from a ready-mix concrete truck, move the chute back and forth to reduce segregation. Do not permit the concrete to build up in piles if the concrete is spouted onto the ground as in curb and gutter or pavement construction. Spread by moving the chute in as large an arc as possible within the form area. Once the concrete is slightly above the form elevation, move the truck to a new location and repeat the operation. Move concrete from high to low areas by shoveling; never move concrete with a vibrator. See Figure A 5-694.612 for an example of placing concrete from the end of a chute.

Figure A 5-694.612

5-694.613 BUGGIES

Concrete placement should start at the far end of the section whenever concrete buggies are used on flat slab construction. Always place concrete from buggies toward the top edge of the previously deposited concrete. Shovel out concrete that appears segregated and spread over the bottom of the pour. Fill any depressions left by the removal of the segregated material by placing fresh concrete in the cavity and not by vibrating the concrete from the edges of the cavity.

5-694.614 PUMPING CONCRETE

The Contractor may elect to place concrete by pumping. See Figure A 5-694.614 for an example of concrete pumping on a bridge deck. Concrete has a tendency to become stiffer or lose more slump and entrained air from pumping than with other placement methods. This is partly due to additional heat caused by friction as the concrete is forced through the pipe. You may need to increase the slump and entrained air content of the concrete from the specified range for this reason to assure that it meets Specification 2461.4A4a and 2461.4A4b at the point-of-placement. Discharge of concrete from the end of the pump is controlled similar to that for chutes or buggies, since concrete discharged from the pump has the same tendency to segregate. Make sure both air and slump tests are measured at the discharge end of pump. Establish a correlation of slump and air between the ready-mix truck discharge and the pump outlet if it is not practical to take slump and air tests at the point-of-placement. Pumping concrete through aluminum pipes causes some of the pipe walls to wear away and become mixed with the concrete. The aluminum has a deleterious effect on the concrete; therefore, Contractors are not permitted to use aluminum pipes.

Ensure that a restrictor is provided near the outlet of the pipe in order to minimize uneven discharge (spitting).

Figure A 5-694.614

5-694.615 SPREADERS OR BELT PLACERS

Concrete spreaders are used on all large paving projects to aid in the distribution of concrete over the entire area. They are also used on bridge decks and some large slab work.

The purpose of the spreader is to move large quantities of concrete short distances with minimum segregation and deposit the concrete within the forms or on the grade as near as possible to its final position. The spreader will even out the irregularities by moving the concrete from high areas to low areas when sufficient concrete is placed.

The placer/spreader generally involves any combination of the following: unloading belts, augers, plow systems, or strike offs. Sensors may control steering, grade, or both. See Figures A and B 5-694.615 for examples of a belt placer and spreader.

Figure A 5-694.615

Figure B 5-694.615

5-694.620 CONSOLIDATION OF CONCRETE

All concrete, regardless of workability and consistency, needs some consolidation to remove air pockets and settle the concrete into place. The degree or extent of such consolidation depends on the consistency of the concrete, placement method, and the shape of the section into which the concrete is placed.

Specifications require filling cavities, evident when the forms are removed, with mortar. Proper consolidation techniques will reduce the number of patched areas.

5-694.621 HAND TAMPING AND SPADING

Tamp or spade the concrete by hand along forms and headers whenever other methods of consolidation are not used.

Work the area within the mass of concrete by tamping with either a sharp object such as a shovel, or with a blunt object such as a base tamper, or even a piece of wood. The purpose of this tamping is to cause slight movement of the concrete that forces the air and water to the surface and helps consolidate the concrete. Concrete will settle during the tamping to the extent that air and water are removed. The desirable entrained air is not removed by tamping, but tamping works out the objectionable entrapped air and consolidates the concrete mass.

Consolidate areas along forms and headers with a smooth flat blade. In most cases, the backside of a flat shovel or a long concrete finishing trowel will do a very good job of spading. The object of spading is to work the mortar around the coarse aggregate next to the forms and also to permit the escape of the entrapped air that builds up next to the forms.

Areas at the intersection of the forms and the divider plates, such as in concrete curb and gutter work, is a place where honeycombing often occurs.

Proper concrete placement, spading and tamping in these critical areas reduces honeycombing. The same is true near the bottom of the forms where they rest on the base. The Inspector should see that proper consolidation is practiced in these areas.

When constructing deeper structures (retaining walls, footings, etc.), place the concrete in multiple layers and consolidate each layer if there is trouble consolidating the full depth of concrete.

Tamping the outside of the forms with a solid object will decrease entrapped air and reduce the voids in the finished surface. When this procedure is used, tamp with care so that the forms retain their desired alignment and shape.

5-694.622 INTERNAL VIBRATION

Vibration of concrete makes it more workable and will make relatively dry concrete behave like concrete having a higher slump. Internal vibration is performed using a long, slender, vibrating cylinder that is projected into the concrete. The ratio of diameter to length of the head, the weight and speed of vibration for internal vibrations, will vary with the workability of the concrete and the type of section constructed. In the construction of large heavy sections, the concrete used may appear harsh and stiff. The vibrating head for this work is shorter with a larger diameter up to 75 mm (3 in.).

On thin sections, the concrete is more plastic (having both a lower coarse aggregate content and a smaller size aggregate), and a vibrator with a longer head and a smaller diameter of 19 to 32 mm (3/4 to 1 1/4 in.) is used. See Figure A 5-694.622 for an example of a hand vibrator.

Figure A 5-694.622

Instructions for Proper Internal Vibration:

1. Insert the vibrator head vertically into the concrete for the full depth of the lift and extend down into the previous lift 50 to 75 mm (2 to 3 in.) to blend the two lifts together.
2. Withdraw the device in a smooth vertical motion while the unit is vibrating.
3. Never over vibrate by leaving the vibrator head in one location too long.
4. Vibration shall continue by lowering and raising the vibrator in different areas until the concrete is completely consolidated.
5. The distance between points of vibration will vary with the concrete workability, consistency, quantity of steel, and the shape of the section, but distance between the insertions of the vibrator head along the form shall never exceed 0.5 m (2 ft.).

Pulling the vibrator head laterally along the concrete promotes segregation and is not allowed. Vibration is not allowed as a method of moving concrete from high areas to low areas or along forms.

5-694.630 PLACING OPERATIONS[3]

A. Reinforcement

Install reinforcement and anchor in place to prevent movement during concrete placement operations.

Baskets are placed so dowels are parallel to the grade and the centerline. Anchor in place at the proper alignment and grade within a 3 mm (1/8 in.) tolerance, and mark location for sawing joint.

Headers require care in setting. Place permanent terminal headers or temporary terminal headers at the beginning and end of the job. Install construction headers during the day's operation for delivery interruptions or equipment breakdowns if necessary.

B. Utilities and Drainage Structures

Urban projects involving storm sewer inlets, junction boxes, water valves, sanitary sewer manholes, natural gas facilities, electrical vaults, and cables of all kinds may require prior adjustments to proposed grade of various cast iron items or boxing-out.

Proper compaction over and around these facilities is necessary to provide uniformity in subgrade support. This includes controlling the moisture content of the material to near optimum.

All types of utility and drainage structures, depending on size and location, may require special jointing of the slab to avoid random cracking. The plans should indicate the joint layouts of street intersections, alleys, etc. Make this information available to the saw crew.

C. Delivery of Concrete

- Designate a haul route for concrete delivery trucks and communicate to all drivers.
- Make sure trucks do not disturb the forms or grade near the forms.
- Ensure that the delivery of concrete is consistent and sufficient in quantity to keep forward progress of paving operations at a rate compatible with placement and finishing operations.
- Check the slump and air content of the concrete to assure that it is consistent and within the specified mix design requirements.
- Safety is to be enforced at all times. Consider backup alarms, dumping procedures, following dumper's directions, traffic patterns, etc.
- Remember, a controlled uniform delivery rate is one of the first steps to construction of a quality pavement. A uniform process in the quality of concrete, head of material, rate of delivery, placement, creating uniform forces in front of and under the machine produces a good pavement. Pavers are finishers, not bulldozers.
- The distance from batch plant to the grade operation is a governing factor in obtaining timely delivery of concrete to the paver. The travel time to and from the paving spreader is also governed by the haul road conditions. A paved surface and minimal traffic friction would allow usage of a more distant plant site, conversely a dirt surface for the entire round trip would increase the haul time and require an increase in the number of haul units.
- Numerous variables enter into supplying concrete to the paver in consistent volumes. Close coordination involving the plant foreman, truck foreman, and concrete foreman is a necessity. The Contractor must coordinate the number of trucks needed to keep the paver speed uniform.

When truck mixed concrete is used the Contractor and the Concrete Producer must establish a realistic rate of delivery. Calculate the rate of production and delivery on a desired cycle time for each truck mixer for loading, mixing, delivery, discharging, and return to the plant.

The placement rate is defined as the paver speed in meters (feet) per minute times the material needed per meter (foot) of length. The following is an example of concrete truck unloading times to assure the paver continues to move at a constant speed.

- Paver speed of 2 m (6.6 ft.) per minute,
- Grade yield loss of 5%,
- Pavement section 7.2 m (24 ft.) wide and 200 mm (8 in.) thick,

$$2\,m/\text{min.} \times 7.2m \times 0.20m \times 1.05 = 3.024\,m^3/\text{min.}$$

$$\left(6.6\ ft./\text{min.} \times 24\,ft. \times 8in. \times 1\,ft./12in. \times 1.05 = 4\,yd^3/\text{min.}\right)$$

Unloading time is a small part of the overall cycle time. However, anticipate that concrete mixes having varying slumps have different unloading characteristics.

An important factor in an urban area is the anticipated congestion that is encountered by the concrete delivery vehicles. Determine estimated delivery and return times based on speed limits, anticipated congestions, and distance to the project. The project itself will likely cause some lane closures and/or detours in the area.

D. Paving Operations

Regardless of the paving method used, it is essential that the concrete is discharged, consolidated, and finished in a uniform manner to eliminate segregation or non-uniform density. Non-uniform placement creates differences in density, allows variance in shrinkage and may result in a rough riding pavement.

UNIFORMITY is the key to placing, consolidating, and finishing concrete pavement with any paving equipment or method.

Maintain a consistent and uniform head of concrete in front of the strike-off screed. A head of concrete that does not run over forms or the screed works best. This applies to equipment of all types and sizes.

E. Small Screeds and Hand Placement

For small machines or hand placement, screeding is accomplished in numerous ways, including clary screeds, revolving triple tubes, single tube (drum) finishers, hand-operated and self-propelled vibratory screeds, and hand-operated bull floats. The roller screeds and vibratory screeds are commonplace for small machine and hand placement operations.

Perform small machine or hand placement with care. On handwork sections and some short mainline sections, the vibration is generally limited to hand-operated spud vibrators working in the concrete ahead of the screed and along the forms.

The following are the key elements in placement:

- Check that the concrete is placed and spread uniformly. Move concrete with shovels, not rakes or hand spud vibrators, which can segregate the mix.
- See that vibration is adequate over the total concrete area to obtain proper consolidation.
- Check that the workers keep the vibrating screed moving forward on the forms. If hand screeding and consolidation is required, assure that it is performed in a vigorous manner.
- Two people operating hand floats and straightedges usually float the surface. Again, assure that the work is done thoroughly so the pavement is finished to the proper grade and cross section.
- Successive passes of the screed, if required, should overlap the previous passes. Waste any natural laitance over the sides.
- Small irregular areas are often finished with straightedges and hand floats, following consolidation with a hand spud vibrator.

F. Curb Placement

The finishing process in the gutter line is critical to maintain water flow, especially on flat grades, high or low points of vertical curves and near storm water intakes. Establish and finish the top edge and face of the curb, or the acceptability of the pavement is visually in question.

5-694.631 AGGREGATE BASE LAYERS

A. Dense-Graded Aggregate Base[3]

Dense-graded aggregate bases are used as either a filter layer beneath an open-graded base or in the case of granular subgrade soils, the sole base layer. In either case, confirm that the base is well compacted and damp enough to prevent absorption of moisture from the concrete during placement. In the case of a dense-graded aggregate base filter layer assure that there are no areas of insufficient thickness that may cause subgrade soils to pump into the overlying OGAB thereby contaminating it.

B. Open Graded Aggregate Base (OGAB)

Many paving projects use OGAB to facilitate drainage under the pavement. See Figure A 5-694.631 for an example of OGAB prepared for concrete paving. The base is constructed of coarse aggregate meeting the gradation in the Special Provisions of the contract. The OGAB is often treated with asphalt to stabilize the material, this is referred to as permeable asphalt stabilized base (PASB).

In any case, check the cross-section of the OGAB just like the dense graded base. Again, the Inspector should record base elevation checks at least every 0.8 kilometers (0.5 mile).

If PASB is used, treat the surface with a lime solution before paving. This lime solution helps keep the temperature of the base low so the concrete mixture does not “flash-set”. This is important for base stability and for proper curing of the concrete.

No construction traffic, including loaded or unloaded haul trucks, is allowed on either the OGAB or the PASB unless the Contractor can demonstrate that it will not contaminate, rut or tear the base. The major concern is to verify that the base is not contaminated and will still allow drainage.

Figure A 5-694.631

C. Permeable Aggregate Stabilized Stress Relief Course (PASSRC)

PASSRC is a stabilized, permeable aggregate base layer that serves both as an interlayer and drainage layer for an unbonded concrete overlay.

After placement and compaction, the inspector should check the PASSRC layer to ensure that there is no displacement or rutting occurring. A curing period may be needed to allow the PASSRC to "firm up" before the overlaying concrete is placed.

Although concrete hauling units are permitted on the PASSRC, it is the Contractor’s responsibility to maintain the surface. If contamination, rutting or other damage occurs to the PASSRC or underlying structure, the affected areas must be cleaned and/or repaired and leveled, or removed and replaced prior to placement of the concrete overlay/pavement to assure drainage capacity as designed.

If concrete hauling units turn around on the PASSRC, the Contractor shall protect the PASSRC from deformation by any method acceptable to the Engineer. See Figure B 5-694.631 for an example of using plywood as a turnaround point on the PASSRC.

Within two hours prior to constructing the concrete overlay, the PASSRC layer shall be coated with a whitewash of hydrated lime and water. The proportions used in the whitewash mixture and the rate of application shall be such that a uniform color, not darker than uncoated concrete after curing, will be produced on the surface of the PASSRC layer. The purpose of the whitewash is to reduce the heat generated from the black surface of the PASSRC, and thus give an even curing temperature within the pavement depth. If the whitewash should wear off due to construction operations, it shall be replaced or the surface cooled with water prior to paving. Damage to the PASSRC layer shall be repaired promptly by the Contractor, as directed by the Engineer, at no expense to the Agency.

Figure B 5-694.631

5-694.632 PAVEMENT STEEL AND PLACEMENT[3]

Dowel bars are designed to provide effective load transfer across joints. Reinforcing steel is not used in pavements as reinforcement in the traditional sense. Reinforcing steel in pavements is designed to hold random cracks together and facilitate aggregate interlock load transfer.

The Contractor can set imbedded steel items ahead of the placement of concrete, or insert them into the plastic concrete. When steel is set ahead of paving operations, the Contractor must secure the steel firmly in place so that it cannot move during the placement, vibration and finishing of concrete.

A. Dowel Bars

Only dowel bar assemblies pre-approved by the Mn/DOT Concrete Engineering Unit are allowed. Remove and replace assemblies that become bent or damaged prior to or during concrete placement. Currently Mn/DOT allows epoxy coated, solid stainless steel, and stainless steel clad dowel bars based upon the specifications for each project. See Figure A 5-694.632 for an example of epoxy coated dowels and Figure B 5-694.632 for an example of solid stainless steel dowels.

Figure A 5-694.632

Figure B 5-694.632

Dowels are installed at contraction joints to provide load transfer from slab to slab without faulting of the joint. They are generally installed in a heavy wire assembly staked to the base. **The staking must prevent movement of the dowel basket assembly during concrete coverage. Failure to satisfactorily anchor these baskets in the past has resulted in joint failures on many projects. This issue is especially critical on unbonded concrete overlays where it is difficult to anchor the baskets through the bituminous stress relief layer (PASSRC) and into the underlying in-place concrete.** Cutting the tie wires on the dowel bar assembly prior to paving is required.

No greater than 30 minutes prior to concrete placement, lubricate the entire dowel with a form release agent meeting Specification 3902 to allow movement as the slabs expand or contract. The key is to provide a thin film of lubricant to assist the movement of the concrete at the dowel. A thick film of grease can react with the concrete and allow voids, which can lead to socketing at the dowel and contribute to premature faulting of the joint.

When placing doweled transverse expansion joints a dowel cap is needed over the end of the dowel to permit movement into the cap as the expansion material is compressed.

Place dowels parallel to the centerline of the pavement that allow the concrete pavement to expand and contract. The lubricated dowel accommodates this movement. When dowels are misaligned the joint can lock and cause cracking near the contraction joint.

The Mn/DOT Concrete Engineer may approve the use of dowel bar inserters (DBI) as an alternative to dowel bar assemblies on a case-by-case basis. The approval is made on a performance basis. There are two common types of DBI's in use. One system is called the mid-mount inserter in which the inserter is an integral part of the paver. Another system utilizes a separate paver for inserting the bars and is followed by another paver for final finishing operations.

When using a DBI, the dowel basket assembly is not needed since the dowel bars are mechanically inserted into the fresh concrete. The elimination of the basket assemblies also provides an open paving lane for hauling and dumping concrete ahead of the paver. The bars are sprayed with a form release agent prior to placement. Vibrating forks are used to insert the oiled dowels into the concrete at the correct depth. See Figure C 5-694.632 for an example of a DBI. Correction of the concrete surface is necessary after the dowel bars are inserted. Contractor personnel should perform periodic probing for proper dowel alignment and depth and Agency personnel should perform spot checks. The Contractor must mark doweled joints carefully for joint sawing.

Figure C 5-694.632

B. Tie Bars

Tie bars are installed in most longitudinal joints. The purpose of tie bars at the centerline longitudinal joint is to prevent lane separation. In the case of centerline joints, the bars are installed at mid-slab depth in a “hinged joint”. In slipform operations, these bars are pre-placed on bar chairs in front of the paver or placed in the plastic concrete with a wheel or stabbed into the slab with an automatic inserter. See Figure D 5-694.632 for an example of inserting tie bars using a wheel.

Figure D 5-694.632

The tie bars involved in longitudinal joints constructed for additional lanes are generally installed with either air, hydraulic, or manual side bar inserters. Bent tie bars are normally installed by placing them on a horizontal plate, attached to the side form, prior to installation. There is a slit in the traveling side form, also known as "keyway steel", to accommodate these bars. See Figure E 5-694.632 for an example of installed keyway steel. These bars require straightening prior to placing the added lane or shoulder. If the bars being installed are straight they are normally placed on a guide, attached to the side form, prior to installation.

Figure E 5-694.632

Epoxy-coated tie bars are required for concrete pavement construction. It is of the utmost importance that these bars are placed at least 450 mm (18 in.) from any contraction or expansion joint to avoid tying up the joint. Many of today's joint spalls were caused by tie bars crossing a joint and tying the joint together.

C. Supplemental Steel

Inspect the reinforcing steel to assure it is sufficiently cross-tied to retain the steel in its planned position and that the steel is free of foreign matter and scaly rust. The Contractor must place the steel on chairs to ensure it is at the correct height. See Figure F 5-694.632 for an example of supplemental steel over a culvert.

There are four instances where supplemental steel may be required.

1. Reinforced Panel over Culverts - Standard Plate 1070L

- Use when height of fill (H_f) < 3 m (10 ft.). This is regardless of the pipe diameter.
- Use No.13 bars for pavement thickness < 305 mm (12 in.). Use No.16 bars for thicknesses ≥ 305 mm (12 in.). Placement depth shall be t/2 ± 25 mm (t/2 ± 1 in.).

- Assumed definition of a culvert – pipe open on one or both ends. If a pipe is closed on both ends, it is unlikely to have the outside cold air flow that could cause settlement/heaving problems and would reduce the need for reinforced panels as long as pipe H_f is 1.2 m (4 ft.) or greater below grade.

Figure F 5-694.632

2. **Concrete Mainline Pavement - Standard Plan 5-297.217**
   - Place in panels where pavement width exceeds 4.6 m (15 ft.) without a longitudinal joint, and in the middle lanes where tied pavement width exceeds 4 lanes.
   - Use No.13 bars for pavement thickness 255 mm (10 in.) or less. Use No.16 bars for thickness over 255 mm (10 in.). Placement depth shall be t/2 ± 25 mm (t/2 ± 1 in).

3. **Concrete Ramp Pavement – Standard Plan 5-297.219 – See Note 1**
   - Place in panels where pavement widths exceed 4.6 m (15 ft.) without a longitudinal joint.
   - Use No.13 bars for pavement thickness 255 mm (10 in.) or less. Use No.16 bars for thickness over 255 mm (10 in.). Placement depth shall be t/2 ± 25 mm (t/2 ± 1 in.).

4. **Storm Sewers and Water Mains – No standard**
   - If height of fill (H_f) < 1.2 m (4 ft.), no matter what diameter, supplemental steel is needed.

5-694.633 PAVEMENT PRE-CONSTRUCTION MEETING[3]

There are numerous critical factors involved in the construction of a typical concrete pavement project. An important beginning step is the implementation of a communication network between the Paving Contractor, Concrete Producer/Supplier, Agency and Testing Personnel.

Everyone involved must have the information available in a timely manner to perform his or her functions, starting with the pre-construction meeting to final project acceptance. They need to discuss all project elements related to slipform paving with special emphasis on communication, safety, paving access, traffic control, scheduling and interpretation of project specifications.

5-694.640 SLIPFORM PAVING APPLICATIONS[3]

This section covers the construction of a typical concrete pavement using the slipform paving method of construction. The practices presented represent "good practice" and are not meant to limit innovation of any kind.

Slipform when applied to concrete pavement construction means to consolidate, form into geometric shape, and surface finish a concrete mass (vertical or horizontal) by "slipping" or pulling the forms continuously through and surrounding the plastic concrete mass. In slipform paving of a roadway the forms for shaping the mass, the tools for consolidation, and the tools for surface smoothing are firmly mounted into a self-propelled machine.

Slipform is used in almost every type of paving operation. This technique has broad application for highway and street construction. Contractors have identified the following common construction advantages:

- Uses lower slump concrete
- Permits high production paving
- Capable of producing a very smooth riding surface

High quality slipform concrete pavement is achieved with:

- Accurate line and grade control
- Uniform, well compacted grade
- Consistent concrete production and delivery
- Consistent, uninterrupted forward motion of paver
- Adequate internal vibration
- Timely texturing and curing

5-694.641 SLIPFORM PAVING OPERATIONS[3]

All slipform pavers in the world market are of the "extrusion-type process". The extrusion process is simply defined as forcing, pressing or pushing a material through a die or mold to create the desired shape. The concrete is squeezed through the mold to form and shape the pavement in the slipform paver. See Figures A and B 5-694.641 for examples of concrete going through a slipform paver.

Concrete mixtures have many unique elements. More importantly, its behavior as a fluid is a critical factor during paving operations. Fluids are incompressible. Energy applied to a fluid results in equal and opposite transmittal throughout the confined area. A change in delivery or constituents of the mixture (mainly water) changes the hydraulic forces imparted by the concrete. These changes require a variation in the applied energy (pressure and vibration).

Figure A 5-694.641

Figure B 5-694.641

Uniformity is a critical issue; in design (mix and geometrics), in logistics (supply and delivery), and in energy levels (vibration, head pressure, and movement) are vital for machine performance and paving results. Any change in these variables can produce a rough-riding pavement.

The slipform paver contains the mold components. These components consist of the bottom of the "profile pan" or "forming plate" and the side forms. This system confines the concrete and provides the die or mold for the desired shape. The base is the bottom of the mold.

The pressure to the concrete comes from the mass weight of the machine upon the forming plate and the taper adjustment, if present, of the side forms confining the concrete. The pressure also comes from the power of the vibrators as they pressurize the area under the paving form and between the side forms.

Tools are utilized during the paving process to perform the functions of filling the forms and creating a uniform shape. These tools are an auger spreader, spreader plow, strike-off, tamper bar, or any combination of these items. There is also a secondary finishing process of some kind to remove slight irregularities from the surface finish.

The extrusion pressure comes from the continuous movement of the slipform mold through the confined mass of concrete. The energy is also applied by continuous vibration that changes particle distribution and lowers face-to-face and particle-to-steel friction by fluidizing the concrete.

The result desired is a uniform geometric shape and uniform exact surface in the horizontal and vertical dimension. This is best accomplished by a constant mixture and uniform movement of the paver.

Placing operations must include the following elements:

- Uniform particle content
- Uniform fluid (water) content
- Constant pressure and vibration
- Uniform machine movement

5-694.642 SUBGRADE[3]

The construction of a quality concrete pavement begins with a good subgrade. A uniform grade must sustain hauling units to place the base material and provide a platform that will support the compactive effort necessary to densify the base material. This requires a subgrade well compacted to profile with tolerances within the specified limits.

There are instances where the grade is in place for a lengthy period prior to commencing final grade preparations for paving. There are also cases where the grading is not finished to the required tolerances. When these conditions are encountered it becomes necessary to make some parallel grade adjustments rather than move large quantities of earth to match the original plan profile. This is accomplished by lowering or raising the existing profile to meet the existing grade. Always balance cut and fill whenever practical. Adequate transitions within acceptable geometric tolerances are provided to meet the adjusted profiles. Any profile adjustments must match the existing structures.

Accurate grade trimming is necessary to construct a smooth pavement of uniform thickness.

In most instances of subgrade trimming, windrows of cut material are deposited on the embankment edges. Cutting slots through the berms establish drainage for the trimmed grade at adequate intervals to prevent ponding of water. This is especially critical on the low side of super-elevated sections. Proper drainage planning will pay off during all subsequent construction activities including paving.

Full-width trimmers are commonly used on highway projects. The accuracy of these machines is very good when they are controlled from string lines.

5-694.643 LINE AND GRADE[3]

The Survey Crew and Paving Contractor must coordinate surveying to ensure complete understanding concerning the elevations and offset distances established for grade reference points. The elevations and offsets provide the basis for establishing the string line. The string line is used to provide an accurate reference for elevation and alignment control of the subgrade trimming, base placement and trimming, and paving operations.

A. Setting Reference Hubs

Hubs are placed with the use of a total station, Electronic Distance Measuring (EDM) equipment or transit and have a tack or punch hole in the top to provide a line exactly referenced to centerline and normal (at a right angle). The tops of the hubs are shot for elevations that relate to plan profiles.

The Contractor determines the offsets of the hubs for the particular equipment and operations. These offset distances may differ on each side of the slab. At times the Contractor must adjust the location normally selected for hubs to accommodate specific project staging and phasing.

When setting the hub offset, the Contractor must consider all elements of the construction and grading operations including width of equipment, windrows of material, drainage trenches, and other site-specific variables.

B. Establishing the String Line

Wire, cable, woven nylon, polyethylene rope, or other similar materials are all acceptable as string line sensor line. The stake must have sufficient length to maintain rigidity when driven into the grade. The stake must have an adequate length exposed above grade to allow adjustment of the string line to the desired height above the profile grade.

The string line stake is placed in a vertical position outside the hub line. The line is inserted into the holder arm slot and adjusted to a point directly over the hub tack point.

The string line supports are located at approximately 7 m (25 ft.) intervals unless horizontal or vertical curves are encountered. In those cases, place the string line supports at closer intervals. Occasionally, in very uniform conditions, string line supports with a 14 m (50 ft.) interval are used. See Figure A 5-694.643 for an example of string line staking.

Many Contractors prefer to run a string line on each side of the paver. A smoother ride is usually obtained with this dual string line system. The decision to run two string lines is made based on the Contractor's experience. Dual string lines are required on unbonded overlays in Minnesota.

Figure A 5-694.643

Prior to beginning paving, check the string line several times to ensure it is correct. Several factors that could affect the string line are as follows:

- Air temperature and relative humidity variations during the day affect the length of line. Check line tension and periodically tighten the winches.
- Equipment bumping the line and personnel stumbling into or tripping over the line will require immediate checking and corrective action. All personnel should exercise caution while working in the vicinity of the string line.
- In many instances the haul road is located parallel to the string line. This requires periodic eyeballing of the string line to determine if any heaving of the grade has occurred that could disturb the hubs and/or line stakes.
- Replace string lines that have broken rather than tying knots in the line. A break generally is an indication that weather and use have taken their toll.
- Check the string line stake arms and adjust bolt sets during installation to make sure that thread wear or mis-threading does not allow arm movement.

Projected grades are extensions of an imaginary line connecting the top of the proposed edges of the pavement slab. They are located in line with the offset reference hubs. To construct a super-elevated curve, rotation of this imaginary line about a point on the slab centerline results in one edge being lowered accompanied by a corresponding rise on the opposite edge. This is the fundamental concept in establishing grades and utilization of elevated string lines for grade control of automated trimming of grade, laying bases, and placing concrete pavement.

The paving equipment accommodates the paving crown, super-elevated transitions, and super-elevated sections. The various shapes are created by adjustments in the paving equipment.

The survey party will calculate the top of both edges of the slab from the plan profiles and cross-sections. The imaginary line, previously discussed, is connected through the edges of slab and extended to a point over the hubs. The determination of the elevation of this imaginary line at the hub location enables the calculation of the difference in elevation between the point on line and the top of the hub.

At this point, communication about proper interpretation of the information shown on the grade stakes is absolutely critical. Miscommunication about how the grades were established could result in constructing the improper super-elevation.

The grade information generally includes the following:

- Centerline stationing
- Curve information
- Offset distance from edge of slab
- Cut (C) or Fill (F) to within 3 mm (0.125 in.)

See Figure B 5-694.643 for an example of hub information.

Figure B 5-694.643

Generally, grade information is referenced to the top edge of slab. On tangent sections of alignment where both edges of slab are the same elevation, offset and projected grade information are identical.

Proper communication during the setting of these hubs and recording of the information on the grade stakes is absolutely essential. All parties must meet to reach agreement for this activity to avoid confusion between the paving crew, the trimming crew, and the survey crew.

The staking system normally includes hand winches placed at approximate intervals, not more than 300 m (1000 ft.), to tighten the line to the extent necessary to avoid any perceptible sag between stakes. Use caution when tensioning the string line. A sudden break in the string line could cause severe injuries. Increase the visibility of string lines by placing ribbons on them.

To ensure even tension in the string, pull it out of the rod holders before applying force to tighten the line. Use a small triangular file to remove all nicks or projections in the string slots to prevent tearing of the string.

The machine elevation-sensing wand rides beneath the string, and the alignment-sensing wand rides against the inside of the string. See Figure C 5-694.643 for an example of elevation and alignment sensing wands. Neither of these wands should deflect the line a measurable amount.

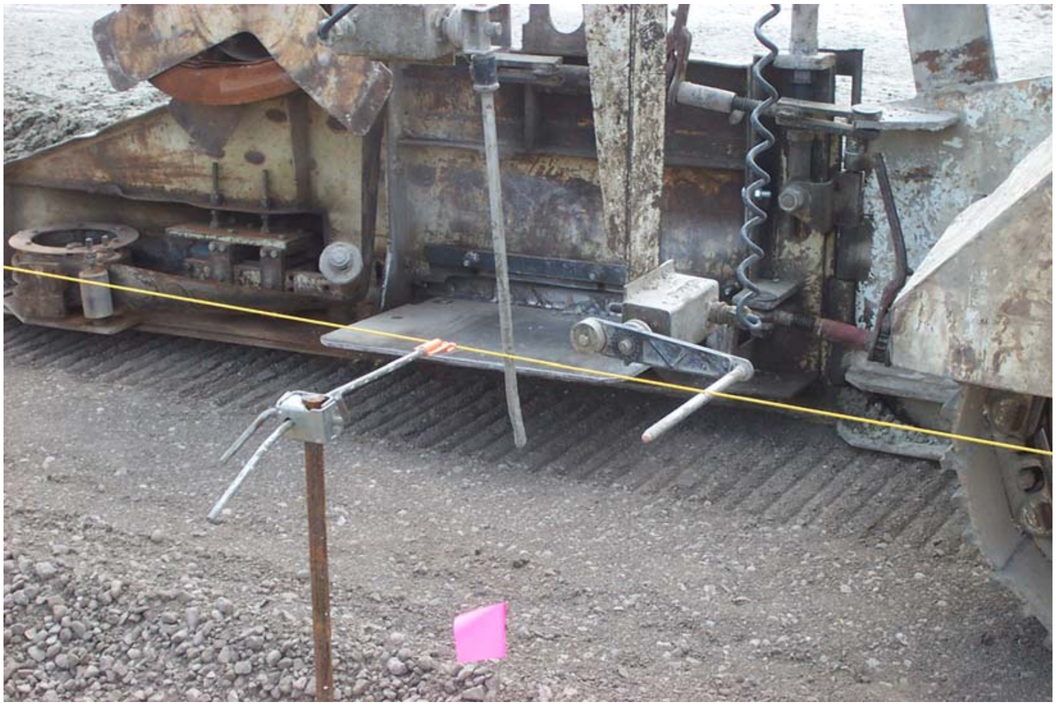


Figure C 5-694.643

Check the completed line installation by eye. This check will help detect mistakes in setting the line and any survey staking errors. Communicate with surveyors and ask them to re-survey any areas in question before making changes.

Correcting surveying mistakes by eyeballing is a poor substitute for accurate surveying. Resolve all questions, prior to pavement placement.

In some situations the stringline elevation is set as a low-line. This will enable unloading belts to extend it without disturbing the line.

To cross the string line with hauling units or other equipment, remove the string line for about 30 m (100 ft.) and place it securely on the ground. Check for any damage before re-tensioning and using for paving operations.

C. Adjustments of the Sensor System

Check the sensor system thoroughly following paver set up. Many types of sensing systems exist including electric, hydraulic, laser, or sonic. Installation and operation of these sensors according to the manufacturer's recommendations or the Contractor’s experience is imperative.

Set the sensor wands as near horizontal as possible and at the same distance from the unit to the string line. Adjust the pressure of the wand against the string line as needed during paving.

Set the sensor wands at the same distance, approximately 200 to 250 mm (8 to 10 in.) from the unit to the string line. Adjustment of the counterbalances will determine the pressure against the lines during operation and will probably require some experimentation. Adjust the dampening setscrew on each unit to lessen continual seeking movement and rapid changes.

When setting the sensors on the same side of the paver, take into account the location of the string line stakes. Set the sensors at different spacing than the string line stakes. When the sensor is set at a different distance, the wands are not at the sag point between the string line stakes at the same time. This minimizes the chance of building a uniformly occurring sag in the pavement.

5-694.644 PLACING BASE TO SPECIFICATION AND TOLERANCE[3]

In the language of pavement design, the word *base* represents the layer of a selected material placed immediately beneath the pavement surfacing. Any selected course of material placed beneath the base is referred to as a *subbase*. The earth grade at the bottom of the pavement structure, whether modified by special treatment or not, is referred to as the *subgrade*.

Good construction practices provide that all of these bases, regardless of placement methods, are built to acceptable tolerances and provide the working platform necessary to:

- Enhance the quality of performance of the finished product
- Minimize loss of concrete
- Eliminate short core penalties
- Contribute to incentives such as smoothness

Perform the trimming in a manner that accommodates the slipform paving operation. The trimming must coordinate with the paving operation.

Grades are trimmed using electronically controlled trimmers to a specified tolerance prior to any pavement construction.

Pad line, track line, or form line are terms often used to describe the area outside the edge of the proposed pavement which provides the foundation for all of the paving equipment operations.

Most Contractors believe that this line is one of the major keys to smooth pavement and should encompass the following characteristics.

- Extend the base itself to a point at least 1 m (3 ft.) beyond the outside edge of the pavement. Figure A 5-694.644 illustrates an extended track line.
- Construct the base or trim parallel to the projected cross slope of the base. The creation of parallel planes is essential in minimizing the yield loss. In addition, parallel planes ensure that the proper thickness of pavement is placed over the entire roadbed.
- Build a base durable enough to provide a relatively smooth passage for the entire paving train, including the texturing and curing equipment. Avoid placing edge drains beneath the track

lines (longitudinally) prior to paving. The weight of the paving equipment can crush the drainage pipes. Place these drains after placement of the pavement.

- Keep the pad line clean of dirt, debris, and surplus concrete during the pavement operations.

Figure A 5-694.644

5-694.645 BEGINNING PAVING OPERATIONS[3]

Prior to beginning paving there are some critical elements in the process that need extra attention and understanding. These include but are not limited to paver set up and vibration.

A review of safety measures and cautions for everyone concerned, including Agency personnel, is a necessary starting point.

Getting started properly includes the following elements:

- Check all of the equipment in the paving train to verify its operational readiness
- Verify that an acceptable distance of grade is approved for concrete placement
- Check that approved test reports are available for all materials presently in storage on the job site and the plant site
- Verify that back-up testing equipment is available
- Verify that all the necessary concrete placement tools are available, such as hand tools, straight edges, hand floats, edgers, and hand vibrators
- Determine that radio/telephone communication with the plant is operational
- Verify that equipment is available to water the grade
- Check the stringline again
- Verify that the day's work header is in place
- Check weather forecast
- Make sure polycure plastic is available in case of rain

The paving train consists of a number of pieces of equipment. Many paving operations utilize a placer/spreader as the first piece of equipment. Second in line is the paver that consolidates and places the materials to final line and grade. This is followed by texturing equipment. The pavement is then transversely tined if required for final friction needs. Many times the texturing machine and the curing machine are the same piece of equipment. After texturing (and tining if required), the pavement is sprayed with a curing compound. The track line must have adequate stability to support all of the above pieces of equipment.

A. Paver Set-up

Check the various components of the paver prior to commencing paving operations.

- The Contractor must provide a “square” paving kit. This is not a problem with two track pavers, but more likely a problem with four track machines. The paving frame must parallel the line control. If not, the machine is skewed in forward motion even though the tracks appear in line. A straightforward approach to adjust the paving kit to “square” is use of the “3-4-5” right triangle technique.
- Following paver set up, string line the pan or forming plate. Check both edges and centerline for trueness. Adjust the proposed crown in the pan and any following float.
- Set the pan parallel to the string line and in accordance with the Manufacturer's recommendations or the Contractor's experience. Many operators state that operating the pan as close to parallel with the string line will provide the best results. This is called adjusting the machine attitude, draft, or angle of attack.

B. Start-up Operations

The day’s paving operations should begin with the production of two batches. Check the two batches for slump and air at the plant. Acceptance or rejection is at that point. Upon determination that the batches produced are acceptable, delivery and dumping/spreading begins for paving operations. All additional paving operations can now begin. Delivery of additional batches to load up the machines in the paving train begins at this time. Loading and developing proper spacing normally takes about one-half hour. Paving operations are considered fully underway at this point.

Start-up operations also include construction of the day's header or matching the in-place pavement. The finishers are in charge of this operation.

After coming off the header, other general concerns are addressed as follows:

- Check for proper alignment and elevation of dowels
- Plan ahead for placement of tie steel and supplemental steel
- Mix workability
- Staying within allowable water/cementitious ratio
- Adjustments in delivery of concrete and paving train forward progress to concrete supply
- Check for proper internal vibration at paver
- Probe for depth
- Surface condition behind the paver
- Control slump between 25 and 50 mm (1 and 2 in.)
- Coordinate slump with plant and provide concrete with a consistent slump to the paver
- Begin grade yield checks

C. Yield Checks
Check yield often to verify proper machine adjustments and grade preparation. Yield is the actual amount of concrete placed at the field project site based on the production of a given volume. Slightly more material is needed to compensate for job variations. Calculation of the grade yield allows the Contractor and the Agency to determine the actual amount of material placed. The Contractor will probably check the yield every 1 or 2 hours and the Agency will check yield as needed.

To determine the yield, calculate the difference between the theoretical volume required and the actual volume placed.

Example:

Theoretical volume required for pavement (Length x Width x Depth):

$$\left(328\,ft.\times 24\,ft.\times 10 in.\times 1\,ft. \big/ 12 in.\times 1 yd^3 \big/ 27\,ft^3\right) = 243 yd^3$$

Actual volume placed was 246 yd^3:

$$YieldLoss = \left(1-(243/246)\right)\times 100\% = 1.2\%$$

The most critical factor in controlling yield loss is constructing the pavement to the proper depth. Contractor personnel will continually probe to assure correct slab depth and that there are no short cores. A simple way to measure thickness is to set a plate on an unstablized base and probe for thickness at that location. Log these results and compare them with yield loss during the day's paving. Also compare these results with core results.

5-694.646 PAVER INTERNAL VIBRATION

Internal vibration is the vibrator-applied energy (centrifugal force) within and internal to the mass of concrete (vertically or horizontally).

The purpose of vibration in the paving process is two-fold:
- To consolidate the concrete mass or remove undesirable voids
- To fluidize the mass to aid the "flow-through" of the concrete in the slipform process

Cores are taken after paving to verify if good vibration techniques were used. The cores should indicate good aggregate distribution and very little entrapped air voids.

A. Metering
Some slipform pavers have an area between the auger-strike off and the pan called the "meter box" or "grout box". This area contains the vibrators and tamper bars, if applicable. Other slipform pavers do not have this box, but have an area where there is a static head above the vibrators. This area is adjacent to the vibrator eccentrics or the zone of influence. The concrete becomes energized (particles in motion), water bubbles exploding, entrapped air rising to escape, and the volume of the mix is reduced.

B. Static Head

There is another important characteristic of the internal vibrator. An increase of height of the static head developed during the paving process causes an increase in vibrator efficiency.

The vibrators are mounted on equipment with what is known as an "isolation mounting". Vibrators will work and have equal characteristics in the vertical or horizontal position. They are mounted ahead of the extrusion meter. The energy transmitted by the vibrator is directly proportional to the size of the weight, and the speed of rotation (RPM). The weight is fixed, as is the back and forth distance (amplitude) that the head of the vibrator moves.

Speed is the only variable that is controllable. This is done by varying or controlling the volume of hydraulic fluid to the hydraulic motor. This controls the speed of rotation, and is measured in vibrations per minute (VPM). The amount of the energy and the energy influence change as VPM varies. On electric vibrators, varying the speed of the generator or alternator controls VPM.

The energy level (vibration) required to consolidate and fluidize the concrete mass during paving operations is different for each mix design and depth of concrete. Specification 2301.3H1c requires vibrators to operate at a frequency of not less than 3600 nor more than 6000 impulses per minute in concrete. When checked in air, the appropriate VPM is 4150 minimum and 6900 maximum. A hand-held tachometer (Vibro-tach) can be used to check the VPM of vibrators. This process is an important step in vibrator maintenance. Regular checks can reduce the unwanted results of malfunctioning units. Vibrator manufacturers have developed monitoring systems that give the paver operator continuous readouts of vibrator activity. Electronic vibration monitors are required on all slip-form paving equipment.

The energy transmitted by the vibrator is transmitted in a circle and is cone-shaped. The transmitted energy is equal to 360E surrounding the rotating weight is known as the "zone of influence". See Figure A 5-694.646 for an illustration of the zone of influence.

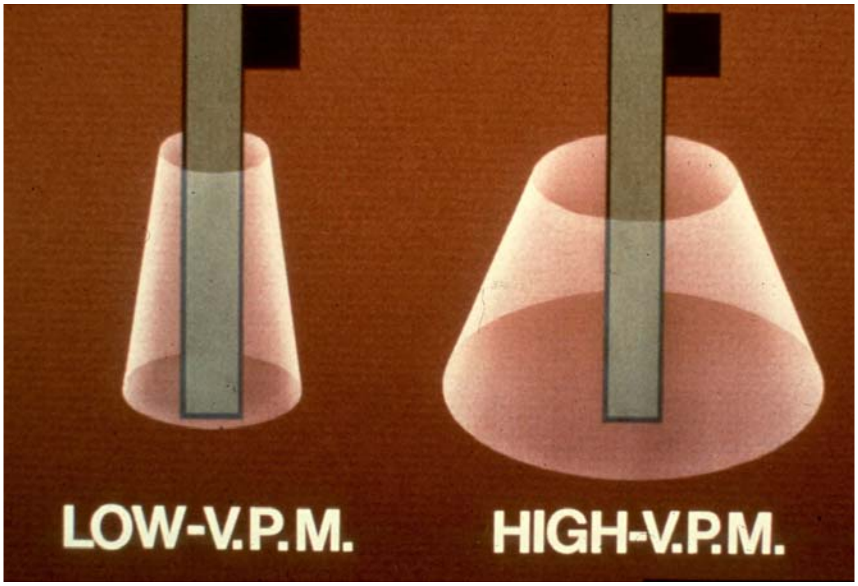


Figure A 5-694.646

The zone of influence will vary with:

- Paver speed
- The distance of the weight from the driving motor and shaft
- The care and cleanliness of the isolator mount

C. Location

The Contractor should adjust the position of the vibrators according to the Manufacturer's recommendations or experience with the specific mix. Depending on the appearance of the concrete reaction behind the paver, the energy level is adjusted to a uniform level of VPM to begin paving and readjusted to appropriate levels.

Vibrators in a paver are mounted to take advantage of the zone of influence. Each vibrator is adjustable for position and energy level. Position is a mechanical adjustment performed prior to the paving operation.

The horizontal spacing is set to have a slight overlap of the zone of influence. This overlap normally ranges between 50 to 75 mm (2 to 3 in.). This is done to eliminate segregation, as is the case if the zones were apart. Many Contractors prefer a closer spacing because the zone of influence overlap is increased. This closer spacing allows the operator to better control the slab texture.

At a constant forward speed of the paver, the zones of influence change as the VPM change. Increased VPM widen the zones; decreased VPM narrow the zones. The energy level required for a particular mix design, at a given paver speed and depth of placement may require more or less vibrators operating at higher or lower energy levels.

Vibrators, while necessary for the paving process, are NOT a cure-all for other problems. The vibrator may identify and exacerbate a concrete mix (design) problem, but not cause the problem. The vibrator will not overcome poor paver adjustment, improper paving technique, or mix design. Proper vibration will produce a well-consolidated concrete mass and leave a uniform surface behind the paver. Control vibration to prevent vibrator trails. Too much vibration can segregate the concrete and drive out entrained air. Too little vibration results in a high volume of entrapped air reducing the strength.

Significant improvement in mix uniformity is noted at a lower paver speed with the vibrators located at the finished surface of the pavement. There is a small amount of entrapped air.

Tuning the vibration to the concrete mix is very important. Particular attention paid to this phase of the operation pays off in a sound durable pavement.

D. Operations

Most vibrators used in slipform paving are hydraulic; therefore check them for any evidence of oil leakage. Have a supply of replacements readily available during paving operations. Do not mix sizes of vibrators on a paver. Check the performance of vibrators again near the end of the day's paving. Any deficiency is evident when the oil is the hottest.

During paving operations, observing the vibrator gangs is necessary at frequent intervals. Any failure of an individual vibrator is readily apparent. The appearance of the concrete within the grout box area changes if there is a problem with a vibrator. Notice how the top of the static head changes from a uniform to non-uniform appearance.

5-694.647 TAMPER BAR[3]

The tamper bar is located just in front of the pan of a slipform paver. It oscillates in a vertical direction to "tamp" the concrete as it moves under the paving pan. The tamper bar is a feature found on some slipform pavers. Operate in accordance with the manufacturer's instructions. The tamper bar performs several functions. It helps "tamp" the large aggregate below the surface of the paving pan so none of the large aggregate are dragged as the concrete moves through the paver. It also helps keep material moving at the meter point so as not to accumulate on the meter. See Figure A 5-694.647 for an illustration of the extrusion process and Figure B 5-694.647 for an example of the auger screw and vibrators.

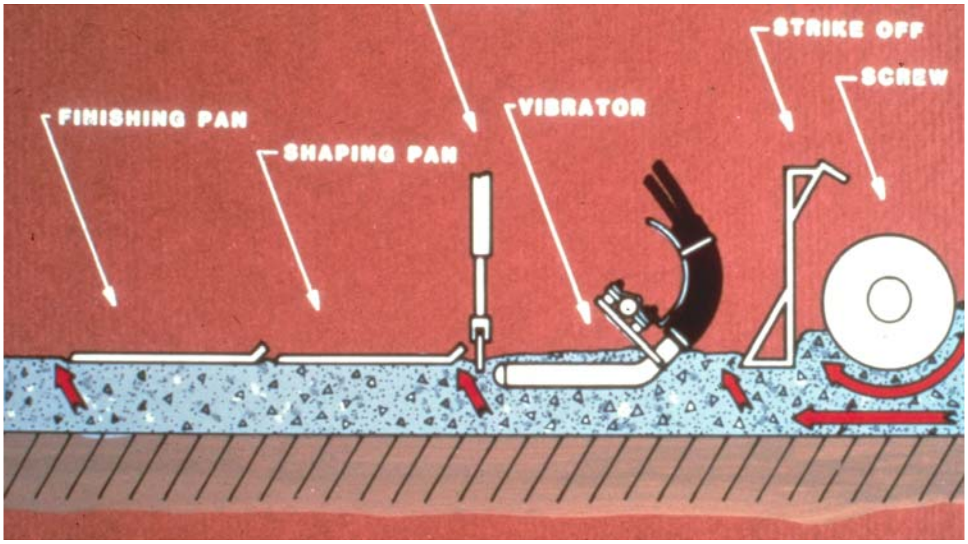


Figure A 5-694.647

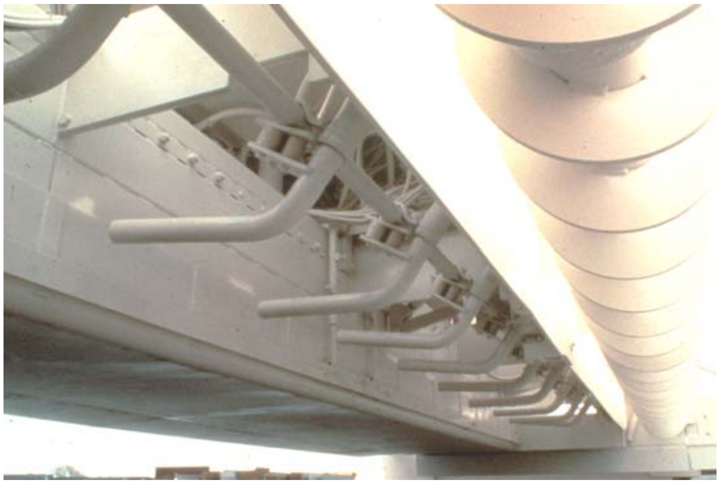


Figure B 5-694.647

5-694.648 PAVER OPERATION[3]

A. Paving Speed

Normal paving speeds are in the range of 0.5 to 3 m (2 to 10 ft.) per minute. The volume of concrete delivered to the paver should ensure a continuous paving speed. When delivery does not permit a constant speed, vary the speed to match a decrease in delivery and vice-versa. Speeds of 3 m (10 ft.) per minute or greater may require a change in the number and spacing of the vibrators.

B. Concrete Head

Concrete head is a constant concern of the paver operator, spreader operator, and truck dump operator. Coordinating their efforts can result in a nominal depth of concrete being pushed ahead by the machine and at the same time avoid having to fill holes at the edges. The goal is to keep the depth of static head about the same thickness as the concrete pavement placed. Operators use a variety of techniques to keep just enough excess material for dispersal if a shortage develops.

C. Finishing

When everything (mix, equipment, timing, delivery, etc.) is substantially correct, no finishing other than texturing (and tining if required) is necessary. However, many things can happen to this outdoor assembly line process requiring correction in the final phase. Do not undertake finishing while any bleed water is present. Bleed water is significant under some weather conditions or with some mix peculiarities.

The Contractor may utilize several pieces of equipment to correct minor variations and help seal any small imperfections in the finished slab surface. Floats will not remove any significant bumps. The Contractor may use any combination of these machines on the same slab for finishing:

- A tube float is a round tube or tubes that operate in a diagonal direction in relation to the slab centerline. The tube does not rotate but rests on its own mass on the slab surface. The tube float is normally a self-propelled machine and is not attached to the paver.
- A longitudinal float, attached to the paver or self-propelled, is a float that is up to 0.3 m (1 ft.) wide and 4.5 m (14 to 15 ft.) long. See Figure A 5-694.648 for an example of a longitudinal float. This float is placed parallel or close to parallel with the centerline of the slab. The float is carried from one side of the slab to the other while oscillating front to rear. This is commonly termed the final finisher.

Checking the surface behind the paver with a 3 m (10 ft.) straight edge is a normal procedure. For any surface imperfections, correct with a hand-operated float. See Figure B 5-694.648 for an example of a hand-operated float. Periodically check the trueness of the straightedge with a string line.

Figure A 5-694.648

Figure B 5-694.648

Excess water, if worked into the surface, can cause plastic shrinkage, excessive water cementitious ratio at the surface, and eventual spalling of the surface. If there isn't any daylight under the bull float and there are no major holes or tears, move on. It is also important to remember that it is not necessary to seal every small dimple or hole in the pavement surface. Over-finishing can lead to problems such as scaling and premature deterioration of the surface.

D. Texturing

Plastic concrete is textured to increase skid resistance of its natural finished surface. Texture is defined in terms of "macro" and "micro". Engineers feel both micro texture and macro texture are necessary to ensure the maintenance of acceptable friction numbers throughout the surface life of the pavement. Macro texture on concrete paving is generally achieved by astroturf or broom drag. See Figures C and D 5-694.648 for examples of astroturf and broom drag. Typically broom texturing is performed on bridge decks.

Figure C 5-694.648

Figure D 5-694.648

E. Tining

In addition to and immediately following the texturing, provide the pavement surface with a transverse metal-tine surface if required. This operation requires a mechanized device providing a randomized spacing of 16 to 26 mm (approximately 5/8 to 1 in.). See Figure E 5-694.648 for a mechanized tining device. The required tine width is 2 to 3 mm (approximately 1/12 to 1/8 in.) and the required tine depth is 3 to 8 mm (approximately 1/8 to 5/16 in.). Take care not to dislodge coarse aggregate particles. Manual methods are used for ramps, etc., but are subject to the approval of the Engineer.

Make sure the tining machine is parallel to the pavement surface. If the tining bar is not parallel to the pavement surface an uneven pressure is exerted on the pavement surface, resulting in a non-uniform texture.

At each transverse joint location, a 100 to 150 mm (4 to 6 in.) wide strip of the pavement surface is protected from the tining operation to provide a transverse tineless surface centered over the joint saw cut. The Engineer may eliminate this requirement for right-angle joints.

Figure E 5-694.648

5-694.649 TROUBLESHOOTING CHECKLISTS[3]

During paving, certain situations occur that require particular attention. The following are possible circumstances that might arise and a list of some of the factors to consider when trouble shooting the problem.

A. Tearing of the Mix

- Speed of the paver
- “Square” of paving kit to string line
- Vibration frequency

- Draft of the pan
- Mix proportions
- Air content
- W/C ratio

B. Bleed Water
- Wait until bleed water evaporates before tining (if required) and curing
- Air content

C. Too Much Grout on Surface
- Too much water applied to surface
- Over vibration (vibration speed too high)
- Machine moving too slow for vibration
- Rain

D. Crawdaddy Holes
- Check air content
- Check W/C ratio and adjust if necessary
- Check vibrators that align with the holes
- Check for proper paver travel speed

E. Trackline and Stringline
- Clean trackline
- Protect the stringline from displacement
- Avoid knots in the stringline

F. Equipment Maintenance
- Repair hydraulic leaks
- Use proper replacement parts
- Clean up after each use – don’t create soft spots in base

G. Vibrator Streaking (Vibrator Trails Visible Behind the Paver)
- Head above vibrators
- Materials and mixtures
- Frequency
- Paver speed
- Vibrator positions and spacing
- Blown vibrator

H. Edge Slump
- Consistency of concrete
- Air content
- Gradation
- Position of edge vibrators

- Vibrator frequency
- W/C ratio
- Mix design (some are more prone to caving edges)

I. Wide Variances in Texturing

- Inconsistent concrete (review mixing operation, placing, and finishing process)
- Placing and finishing process
- Adjustment of the final finisher
- Observe operation of texturing equipment
- Condition and cleanliness of texturing equipment (astroturf or brooms)
- Vibrator positioning
- Speed of paver

5-694.650 FIXED FORM PAVING OPERATIONS[3]

Fixed form paving has many uses, ranging from placing mainline pavements to constructing city streets. Setting forms for irregularly shaped areas is a generally accepted technique. However, Contractors are continually devising methods to reduce the areas that require forms.

Form paving is used for streets, local roads, airports, and complicated, short length and variable-width pavements. Ramp tapers and similar variable-width areas are generally constructed using fixed form equipment.

A conventional form riding train of equipment includes a spreader that has a gang of interval vibrators embedded in the struck-off concrete prior to the finishing machines.

The finishing machine has twin-oscillating screeds, which assist the consolidation process and strike off the concrete to the proper shape. Some trains include two finishing machines. Some finishing machines have a cantilevered pan float mounted on the rear of the machine that adds a compressive force as the final machine shaping.

On some smaller projects, only the finishing machine is used, and internal vibrators are mounted near the form on each side.

Automatic machines, utilizing a heavy duty paving carriage to vibrate, strike off, and longitudinally smooth, seal, and texture the concrete are also used. These machines ride on the forms or on pipe laid outside the forms, with or without string line leveling.

5-694.651 TRIM GRADE AND COMPACTION[3]

Establishing the correct grade is the first critical step in constructing a smooth, high quality pavement. Grades that are trimmed following form placement are either trimmed with a fine grade machine that cuts to the proper depth or by motor patrols and a tail planer that ride on the forms. A flat steel roller is used following final shaping. Check the form alignment and profiles following these operations on grade.

When granular bases are used, the Contractor may do the final trimming after the forms are in place. The cut material is normally hauled ahead and incorporated into the base being laid. Moisture is usually added, the base is re-compacted (if necessary), and final steel rolling is then accomplished prior to any steel being set.

5-694.652 SETTING THE STRING LINE[3]

If form-line grading is done by machine, set the string line twice. First, set the string line at an offset height to meet the requirements of the mechanical grader, and then set the string line for form setting.

For form setting, the string line is set at the face and top elevation of the form (pavement). The string line is installed on form pins located with the outside edge of the pins on the proposed edge of slab alignment as measured from the reference hub. Set a string line pin opposite each reference hub. A carpenter's level is generally used to transfer the grade from the hub to the string line pin. Hubs are normally set on 10 m (25 ft.) intervals for tangent sections and closer for curves. The string line is then put up, fastened securely on each pin, and drawn as taut as is necessary to prevent string line sags between pins.

Generally, the opposite reference hubs are not tacked for exact alignment control and are used for elevation reference only. Therefore, the alignment for the opposite side of slab string line is obtained by measuring across the proposed width of slab.

After the string lines are set, the subbase elevation check at the form line is made. Deviations must be addressed before forms can be set. Make certain the line did not slide up or down during the tightening process.

5-694.653 FORMS[3]

The key ingredient in a fixed form paving operation is the form. The form is the mold that determines the pavement depth, width, and ride.

A typical paving form is made of interlocking steel sections. The face of the form is the same height as the proposed pavement thickness. The form has a wide, flat base to give the form stability and an upper rail to carry the paving equipment. Provisions are also made for fastening the form to the base and grade with form "pins" (stakes).

Typical Specifications may place the following requirements on paving forms:

- Each form section is usually made of metal at least 5.6 mm (1/4 in.) thick and 3 m (10 ft.) long
- Form depths should equal the edge thickness of the pavement
- Buildup permitted on form bottom, bolted on to provide proper depth, with 50 mm (2 in.) maximum thickness
- Sometimes wood boards are bolted on to the bottom of the forms to provide proper depth, with 50 mm (2 in.) maximum thickness
- The base width of the forms should provide stability
- Flange braces should extend outward on the base not less than 2/3 the depth of the form

Specifications will differ, but generally the top of the forms must not vary from a true plane (perfectly flat surface) by more than 3 mm (1/8 in.) in 3 m (10 ft.). The face of the forms should not vary from a true plane by more than 6 mm (1/4 in.) in 3 m (10 ft.). Detect any variances with a straightedge or string line.

Before the forms are set, individually inspect them to determine if they meet the specified requirements. Check that the pin keys are straight and free moving in the pockets and capable of holding forms tight against the pins. Check that joint locks are not bent or worn and are capable of holding the ends of the form in true alignment. This criterion is an absolute must if the forms are to serve as rails for paving equipment.

Drive pins of sufficient length to securely hold the forms in place during placing and finishing the concrete in all pinholes, and drive all keys and form locks tight. As the key or form locks are driven in, they stabilize the form against the pin, preventing it from moving. Check these pins regularly to prevent any form movements caused by equipment moving over the forms.

The top of the inside edge of the form shall match the previously set string line. Make minor alignment corrections utilizing the twin point keys located on the inside and outside of each pin pocket.

If any form sits above the string line, remove the form and tamp or trim the base to the proper grade. If the form sits below the string line, remove the form and scarify the base. This will prevent separation or peeling of the additional material that the Contractor must add to bring the form to the proper grade line. A firm bed of fine crushed aggregate works well to fill in the low spots.

5-694.654 SETTING FORMS[3]

The proof of a good form-setting job is the absence of form rocking during equipment passage.

A. Forming Curves

Provide flexible forms (steel or wood) used on street returns and other curves of specified radii equal in depth to the pavement thickness and staked or braced to prevent movement during concrete placement.

Metal forms are most efficient for straight-line work. When curves are needed, you can use metal forms if the radius of the curve is greater than 30 m (100 ft.). On a curve, set 3 m (10 ft.) straight metal forms as arc tangents. Paving equipment can “track” a curve set as described. The final decision regarding form use is based on equipment and the appearance of the finished pavement.

If a curve has a radius less than 30 m (100 ft.), use flexible form sections to shape the curve. Curved metal forms are used, but it is not always practical to order these metal forms to fit only one radius. However, if the radius is too small, metal forms may not achieve a smooth curve. In these situations the Contractor could attach wood to metal forms. However, this creates a new problem: form-paving equipment cannot ride on these wood forms. Hence, the Contractor must use approved equipment for hand placement, consolidation and strike off. You may need extra form-pins to hold the wooden forms. Making a smooth curve may require form-pins both inside and outside the forms. Pull any extra form pins placed inside the forms before the concrete is consolidated and before final finishing.

After a curve is formed, notify the Survey Crew to check it. Compare the findings with the curve data shown in the plans.

B. Curbs

Make sure the correct curb type is used. If integral curbs are constructed following the placement of the pavement, by either hand forming or use of a curb mule, clamp or pin a curb depth form to the top of the slab form. The curb mules (right and left hand required) are winch propelled. Some machines include integral curb placement as part of one process.

Form setting is a critical construction step. You must assure that the forms are accurately set to line and grade and are supported uniformly by a firm foundation.

The finished smoothness of the pavement depends on the care with which the forms are set and maintained, since the finishing equipment generally rides on the forms. Proper alignment and elevation of the forms will contribute to a smooth pavement.

Because the majority of subgrades and bases are now trimmed full width with string line controlled equipment, the form lines are compacted and are at plan grade. Some Contractors still use form-line graders that operate with a string line to trim the form grade lines. A firm and level foundation under all forms is required. The forms must not rest on pedestals of dirt or rock; a uniform base is required for support.

Set the forms to proper grade and line. Once the forms have been set, check them for overall alignment and tolerance before any paving occurs. The quickest and simplest way of checking is to use the "eyeball" method. Sight along each form line to see that the forms are straight (alignment) and the tops are smooth (tolerance). Most deviations are obvious. However, you can use a level, a 3 m (10 ft.) straightedge, or string line to check minor errors. Check horizontal alignment against the offset hubs. Check the width of the roadway between the forms to assure it conforms to the plans. Immediately reset any form section that is out of line.

Check that the joints between forms are tight and smooth.

When keyway strips are specified, attach them to the faces of the forms after the forms are in place. Keyways are grooves formed in the vertical edge of one lane of concrete to facilitate tie steel installation, which later become filled with concrete of the adjacent lane. This provides for load transfer between adjacent lanes.

Run forms beyond headers for proper grades and to allow placing and finishing equipment a platform on grade line to work beyond the pavement's end.

C. Preparing Forms for Paving

Start with clean forms, oil them inside and out prior to keyway, tie bar, and concrete placement, and handle them with care. Oiling the outside of the form prior to use makes removal of concrete spilled over the forms during finishing much easier. Oil forms before installation of tie bars to avoid oiling tie bars.

Check the ends of the form sections to see that they are flush and securely attached to one another. If the adjoining ends are not flush, the paving equipment is forced up and down, resulting in a bumpy, uneven surface.

All forms should allow for tightly locking the ends of adjacent form sections. When in position, the forms must match-up in a flush condition.

For a secure setting, stake forms with a minimum of three iron pins for every 3 m (10 ft.). When in place, the forms should not spring or settle due to the mass and vibration of equipment. Any up-and-down movement of the forms will result in rough pavement.

Sometimes the adjacent pavement lanes or curb and gutter section act as the side form. Make certain there are no irregularities at the edge or the top of pavement.

5-694.655 FORM REMOVAL[3]

In most instances, remove the forms within 6 to 8 hours if extreme care is taken during the pin pulling and unlocking of the forms. Pull pins first with pin extractor (mechanical or hydraulic), and then remove forms without prying between the edge of the forms and the concrete. A light tap followed by hand removal is preferred.

After removing the forms, check to see that there was adequate vibration to produce dense concrete along the form line. Honeycombing indicates insufficient vibration. If necessary, adjust the vibration process when paving resumes.

Cure the edges of the pavement as soon as possible after form removal.

5-694.656 FORM MANAGEMENT[3]

If possible, clean forms immediately after removal otherwise they are difficult to clean. Dirty forms are difficult to check with straightedges, and make concrete placement difficult. Treat the forms with care so they are ready for the next day or job. Properly handled, the forms will last for years.

5-694.657 FACTORS OF FIXED FORM CONCRETE PAVING AFFECTING PAVEMENT SMOOTHNESS[3]

Producing a good ride with forms is dependent upon numerous factors, including the following, exclusive of design considerations:

- Uniform grade - properly compacted and moistened ahead of concrete placement
- Good form line compaction, properly graded
- Forms that meet the Specifications
- Proper string line erection and form placement, including oiling
- Proper construction and grading of boxouts and fixture adjustments
- Proper placement of dowel baskets and pre-placed reinforcement, including keyway
- Consistent mix, slump, and timely delivery
- Proper timing and placement of the mix on the grade. Cover grade, avoid excessive piles.
- Adequate vibration and consolidation. If hand puddling, do not use rakes, move surplus concrete with shovels. Use extra care in placing concrete over the basket assemblies and in vibrating that area.
- Proper machine adjustments and operation. Steady machine progress enhances smoothness. Avoid excessive finishing. No water buckets or paste brushes. Straightedge check of slab. Use float to fill any surface voids that show up behind finishing machine.
- Use edger on slab edges, top of curb if placed, and around boxouts and expansion joints if included. Use minimum radius edger compatible with mix being used, especially where future placement of slab will abut.
- Wait for sheen to disappear before texturing
- Adequate and timely application of cure
- Cure sides of slab after form removal

5-694.660 JOINTS

Since concrete is a material of low tensile strength and since concrete construction may require staging in operations, the construction of joints is necessary to alleviate problems due to random cracking. See Standard Plan 5-297.221 for joint details.

5-694.661 CONSTRUCTION JOINTS

A construction joint is needed wherever the concrete placement operation is terminated prior to completion of the structure and concrete placement is resumed later. The locations of these joints are generally known in advance and are indicated on the plans for reinforced structures. These joints are substituted for either a contraction or expansion joint since there is no problem of stress on curb and sidewalk work.

A construction joint, normally called a “header joint” or “header”, is placed at the beginning and completion of each day of paving operations. The header joint is formed by using a “board” shaped to the desired cross-section of the pavement. See Figure A 5-694.661 for an example of a completed header joint.

Headers are considered a perpetual problem to concrete foremen, finishers, and are a continuing challenge. Headers are placed at mid-panel. Install side forms, approximately 3 m (10 ft.) in length, to provide proper edge alignment and confine the area for consolidation. Set the side forms to match the width of the pavement.

Figure A 5-694.661

Tie bars, 1.5 m (5 ft.) long, are inserted 0.75 m (2.5 ft.) into the fresh concrete. Concrete around the header joint is thoroughly consolidated by vibration to give strong, dense concrete. A point of weakness may develop at the joint if poor construction practices are followed. The "cream" carried along in the paver is not allowed in the header. Take care not to damage the in-place pavement when paving resumes.

Provide fresh concrete for the final few meters. Do not use the slurry that may have collected in the spreader rolls. Provide thorough but not excessive patterned hand consolidation.

Use a straightedge of sufficient length that laps back onto the existing concrete that has the proper shape. String lining is also recommended.

Near the end of large placements, carefully measure the remaining volume to adjust the amount in the last two or three trucks to provide the required concrete. Aim high, this can prevent waiting for a short load after the plant has closed or the concrete truck is scheduled for other jobs. Do not use concrete spilled or disposed of on the ground to make up any deficiency in material. The material placed at the end of the day's placement should have the same quality consistent with the other material used.

Edge tool the side form edges and the header itself. Use an edging tool with only a minimal radius. Texture and apply cure in a timely manner. Many times this operation at the header is performed by hand. When starting operations the next day, repeat the process of straight edging and string lining across the joint.

5-694.662 EXPANSION JOINTS

Concrete is subject to expansion and contraction due to temperature and moisture changes. In some instances, it is necessary to construct expansion joints in the structure to provide for relief of the stresses that occur. Expansion joints are always used at bridges.

In curb, gutter, and sidewalk work, expansion joints are required as explained in Specification 2531.3C. The joint used is a plain butt joint with non-extruding preformed joint filler. The Contractor must place the joint filler absolutely vertical; otherwise (since it is a plain butt joint), one section will tend to slide up on the other when the concrete expansion becomes large enough. Follow good consolidation methods at these joints.

Expansion joints are rarely used in concrete pavements. If used, the size and spacing of dowel bars are indicated in the plans. Place non-extruding pre-molded joint filler vertically and straight across the pavement. Check to make sure the dowel bars are parallel. Obtain good consolidation around the dowels, joint filler, and protection angles to obtain a strong joint. The use of preformed expansion baskets tends to cause problems when they are used in pavements. The preformed expansion material acts as a dam, catching the progressing concrete during normal operation, and can either tip the basket or prevent consolidation. Either situation can cause early deterioration of the joint.

If the joint filler is tipped during the construction, remove the concrete around the joint, straighten or replace the filler, and then replace the concrete. If a tipped joint is discovered after the concrete has hardened, a standard full-depth concrete repair is necessary. In this case, remove approximately 1.5 m (5 ft.) of concrete on each side of the joint (excluding bridges) to properly repair the defect. Use the newest concrete pavement rehabilitation standards available to replace the joint.

5-694.663 CONTRACTION JOINTS

There are several types of contraction joints used in concrete construction. The purpose of a contraction joint is to induce a crack to occur at a predetermined location rather than allow the inevitable random cracks.

In some types of construction, divider plates are used to help hold the forms during concrete placement. This is a practice used in curb, gutter, and sidewalk construction. When the divider plate is removed, there is a small opening, which then acts as a contraction joint. It will open up slightly when the concrete contracts, but provides little if any space for expansion. Obtain good consolidation around the divider plates. More commonly, hand tooling forms the joints.

The contraction joints for concrete paving are divided into two main classes; doweled and undoweled joints. Standard practice in Minnesota, in almost every case, is using doweled joints since undoweled joints will fault over time. Dowel bars provide for load of the vehicles to transfer across the joint from one pavement slab to the next. The minimum dowel bar size is 32 mm (1 1/4 in.) in diameter by 380 mm (15 in.) long. Joints without dowel bars provide for only partial load transfer through aggregate interlock.

The joints are normally constructed by sawing a groove in the concrete after it has hardened. Contraction joints in pavement usually have a depth of t/4 (thickness of the pavement divided by 4). The exception is on unbonded concrete overlays that have a joint depth of t/3.

Only pre-approved dowel bar assemblies are permitted. Saw the joint directly over the center of the dowel bars. It is very probable that a secondary crack will occur near the joint if the plane of weakness is 50 mm (2 in.) or more off center. The section of concrete between the crack and groove will soon spall out. The crack may occur outside the limits of the dowel bars resulting in no load transfer if the joint is 100 to 125 mm (4 to 5 in.) off center of the dowel assembly.

Flush all debris left on the pavement surface and in the joints after the saw cut is completed. Check to assure saw cut depth meets Specifications.

Joints that are over 13 mm (1/2 in.) in an uncracked condition will require oversized sealers. Contact the Mn/DOT Concrete Engineering Unit for specific recommendations.

The Contractor must assure that the construction sequence is performed in a timely manner so that no random cracks occur. Usually sawing is done about 8 to 12 hours after placement, but each situation is unique due to mix design, temperature, thickness, etc.

5-694.664 LONGITUDINAL JOINTS

Three types of longitudinal joints are predominately used.

- L1T or L1 joint - This is a sawed joint down the center of a roadway or section, either tied or untied.
- L3 joint - This is a construction joint between two concreting operations, which are not tied to one another, essentially a butt joint.
- L2KT joint - This is similar to the L3 joint except the two operations are tied together. This joint calls for placing the first pavement with an indented keyway and bent tie steel installed and tucked into the keyway. The tie steel is straightened before the second operation is begun allowing the tying of the two together.

The sawed longitudinal joint is often used as a traffic marker for two lanes of traffic and is used on double lane pavement construction. Most of these joints contain steel tie bars placed approximately at the mid-depth of the pavement. The size, length, and spacing will vary and this data is obtained from the plans. This steel is inserted into the concrete while it is plastic. A mechanical placing device is used. This is usually located on the front of the paver and automatically spaces and places the steel.

All other longitudinal joints are considered a type of construction joint. These joints may or may not contain tie steel. Check the plans for this feature. Make sure good consolidation is obtained around and under any keyways. Remove the concrete that is spilled on the previously constructed portion the same day the work is performed.

5-694.665 JOINT SEALING

The Contractor shall fill the joints with an approved sealing compound prior to allowing any traffic on the roadway. The sealant type is specified in plans. All approved joint sealants are available on the Office of Materials website at www.mrr.dot.state.mn.us/pavements/concrete/products.asp.

Assure that the joints are cleaned of all debris and dust and **completely dry** just prior to the sealing operation otherwise it is possible the joints could have adhesion failure. The other type of failure that may occur is cohesion failure that is generally contributed to the wrong type of sealant, a poor shape factor, or the joint spacing frequency. See Figure A 5-694.665 for an example of these types of failures.

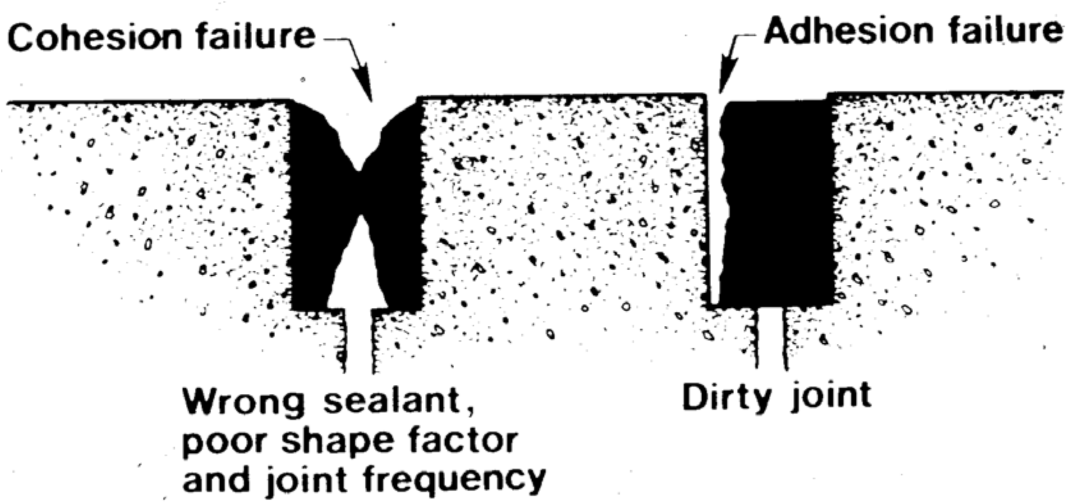


Figure A 5-694.665

A. Hot Pour Sealants

The Contractor shall handle the joint material as prescribed by the Manufacturer and also as required by the Specifications. All material is pre-approved by the Mn/DOT Office of Materials. Call 651-779-5617 if a material needs verification. Fill longitudinal joints to a slightly under-filled to flush level. An operating tolerance from level to 3 mm (1/8 in.) under the pavement surface is allowed. If any areas of the sealant have settled more than 3 mm (1/8 in.) below the surface of the pavement during the first 24 to 48 hours, the Contractor shall refill to the previously mentioned tolerance.

Rubber asphalt is a material that requires good temperature control during the heating cycle. A slight increase in temperature above the normal operating temperature can change the characteristics of the material and render it unfit for use. For this reason, the Inspector must make sure that the material is heated at the temperature recommended by the Manufacturer. See Specification 3719, 3723, or 3725.

B. Silicone Sealants

Confirm that the joint is completely clean and dry and also free of all incompressibles prior to sealing. An oversized backer rod is placed before silicone is added to the joint. See Figure B 5-694.665 for an example of backer rod installation. Some of the sealants are tooled into the joint with an approved device to ensure the correct shape factor and performance; other silicones are self-leveling. All of the sealants are installed according to Manufacturer's recommendations unless modified by the Mn/DOT Concrete Engineering Unit. The Contractor shall clean excess sealant from the upper face of the joint and salvage and reuse if in an acceptable condition. See Specification 3722 in the Special Provisions for silicone joint sealant requirements. See Figure C 5-694.665 for an example of sealing contraction joints with silicone.

Figure B 5-694.665

Figure C 5-694.665

C. Preformed Joint Sealant

Preformed sealants are commonly used in Minnesota. They are used in areas where there are problems with other sealants bonding to the sawed faces of the pavement joint and in areas where high performance concrete is specified. If these sealants are specified, they are installed according to the Manufacturer's recommendations unless modified by the Mn/DOT Concrete Engineering Unit. See Specification 3721. See Figure D 5-694.665 for installation of preformed compression joint sealants.

Figure D 5-694.665

5-694.670 FINISHING

A final finish is applied to all surfaces exposed during concrete consolidation. The extent of such finishing depends on the type of work. The Inspector should refer to the Specifications for the specific requirements on the type and degree of finishing required.

5-694.671 FINISHING CONCRETE PAVEMENTS

The Contractor should not add water to the surface of the concrete to aid in finishing without the approval of the Engineer. The Engineer will only give this approval to replace evaporated surface water directly behind the paver caused by a halt in forward progress from a short-term breakdown in equipment or supply of concrete. The Contractor should supply sufficient trucks to assure a steady forward progress of the paver. **Pavement sections where water is added without the approval of the Engineer are not eligible for incentive payment for w/c or ride and are subject to the provisions of Mn/DOT 1503 and 1512.**

5-694.672 FINISHING CONCRETE BRIDGE DECKS

The Contractor shall perform the operations to finish the bridge deck to meet the criteria for acceptable placement rate, concrete density, and surface finish. This process consists of the use of mechanical-leveling plates attached to the finisher and/or the use of manual levels and floats or other approved hand finishing tools as well as the finishing broom from the work bridge. See Figure A 5-694.674 for an example of this process. Rails have to be set to the proper grade and elevation for an approved power operated finishing machine to travel on. Contractor should ensure that work bridges are stiff enough to minimize sagging unto the finished surface.

Figure A 5-694.674

Certain high strength concrete and low slump overlays are characterized by low bleed water. After finishing, the Contractor should continuously fog-spray in order to reduce evaporation. In micro silica decks, soaker-hoses produce the same effect. The Contractor should not use this process as a finishing tool but should use it along with similar evaporation control measures such as windbreaks.

5-694.673 FINISHING SMALL AREAS

Hand methods are usually used for spreading and screeding concrete in small areas. Repeat the screeding action, which in some instances is performed with a timber set on edge, until there are no open textured areas in the surface. If necessary, supplement the screeding operation with a long handle wood or magnesium float. The float will help iron out isolated high spots and will do a better job of filling in the open textured areas. Floating and screeding should stop when a smooth, closed surface is obtained.

Do all edging as soon as possible after the screeding. Work large aggregate particles that are near the edge into the concrete. Repeat the edging when the concrete is starting to obtain its initial set. **Concrete reworked will produce defective surfaces**.

Surfaces of sections such as culvert walls and columns require very little finishing. Float the surface and remove any laitance accumulating at the surface. Properly finish the surface to provide for the next section placed on it.

5-694.674 CHECKING THE FINISHED WORK

After each operation or section of work is completed, inspect it and have the Contractor correct the defects to the satisfaction of the Engineer. The Contractor shall correct the defects that reflect poor workmanship by improved operations.

5-694.680 CURING CONCRETE

One of the most important steps in concrete paving is the method used to prevent loss of mix water. Moisture is maintained in the concrete for the following reasons:

- Facilitate hydration
- Prevent surface (map) cracking
- Allow the concrete to reach its design strength

The cure is applied when the finishing of an area is complete. If the texturing went well, it is time to cure. Begin cure application when the original sheen has nearly disappeared. When weather conditions exist that make the decision when to spray difficult, it is better to spray too early rather than too late.

A minimum curing period of at least 3 days at about 15 to 20°C (60 to 70°F) is necessary to give the concrete an ability to attain its potential strength. For adequate curing, the concrete must remain moist and have favorable temperature conditions. Standard practice includes several methods of moisture and temperature control. Check the Specification 2301.3M to determine the specific requirements.

There are several methods of curing:

- Water
    - Wet Burlap
    - Fogging (See Figure A 5-694.680)
    - Ponding
    - Others
- Polyethylene sheeting (Plastic)
- Liquid Membrane

Figure A 5-694.680

5-694.681 WET BURLAP

Burlap is often used for curing culverts and bridges. It is required to pre-wet burlap and maintain in a moist condition; otherwise, it will tend to remove moisture from the concrete. Evaporation of water from the burlap has a cooling effect, which is desirable in hot weather but is objectionable when air temperatures are below 10°C (50°F). Confirm that the burlap is securely tied or weighted down so the concrete will remain covered at all times.

5-694.682 POLYETHYLENE SHEETS (PLASTIC)

These materials are generally used as an alternate to curing membranes or to protect the surface from rain or frost. No tears and holes are allowed in the material at the time of use. The Contractor must place the material at the correct time and place continuously with the phase of concrete placement. If the material is placed too soon, it will mar the surface. When it is placed after final set has occurred, too much moisture is lost from the concrete. Make sure the sheets are securely placed. See Figure A 5-694.682 for an example of curing with plastic on a bridge deck.

Figure A 5-694.682

5-694.683 CURING MEMBRANES

This is the most widely used form of cure. Curing membranes are pre-approved by the Mn/DOT Office of Materials Laboratory. Verify the membrane-curing compound is approved for use by contacting the Mn/DOT Cement and Soils Lab at 651-779-5556. Review the Specifications and Special Provisions to determine which curing compound is required for the particular construction and the time of year. Specification changes preclude the use of water-based curing compounds.

The surface is sprayed with curing compounds to prevent evaporation of mix water. Standard curing materials used include both white-pigmented cure and plastic sheets (in case of rain). Curing compounds are visible when applied and provide an opportunity to determine uniformity of placement.

Thoroughly mix and continually agitate curing compounds. Larger projects utilize bulk delivery and storage. The bulk storage is normally air agitated, and the spray machine tank is stirred with electrically driven paddles. Smaller deliveries are usually in barrels.

Preparing and maintaining the cure-spraying machine includes flushing the nozzles before operating. Most texturing machines have shields or hoods that shelter the nozzle application operation to prevent spray drift, especially in windy conditions. See Figure A 5-694.683 for an example of a curing cart on a concrete paving project.

Figure A 5-694.683

Specifications require that the concrete is covered with at least the minimum quantity of membrane, normally specified as m^2/L ($ft.^2/gal.$) of compound. Inspectors should verify the rate of application and record the test data. It is desirable to spray in both directions so the membrane will get into all depressions and around all particles. Be sure to apply the cure to the vertical slab edges. Re-spray any damaged areas and check that no areas are left uncoated. Cure the edges of the pavement as soon as possible after form removal.

5-694.684 SURFACE TREATMENTS

Certain items of work require that the concrete is given a coating of material to further protect it. Normally this material is a concrete treating oil, but other materials are also specified. Use only the material listed in the Specifications or Special Provisions. The treatment is used to provide additional protection to the surface from scaling. Concrete scaling is caused by freezing and thawing, by the application of salts, or by a combination of both.

Only apply the concrete treating oil when the concrete is dry so it will penetrate as far as possible into the concrete. It is preferable to apply it on a clear, warm day. Apply in two separate applications, the second application is delayed until the first completely absorbs into the concrete.

5-694.690 CONCRETE PAVEMENT SMOOTHNESS

After completion of the initial curing period and prior to the opening of the roadway to traffic, the Contractor shall test the pavement surface for surface smoothness and ride quality. The profile index is used for measurement of pavement smoothness and for acceptance and payment on most concrete paving projects. Profile Index is calculated according to California Test Method 526.

A. Surface Smoothness

Surface Smoothness shall be measured with a 7.62 m (25 foot) California type profilograph, or a Lightweight Inertial Profiler (IP), which produces a profilogram (profile trace of the surface tested). See Figure A 5-694.690 for an example of a California Profilograph and Figure B 5-694.690 for an example of a Lightweight Inertial Profiler. The Contractor shall furnish a properly calibrated, documented and certified 7.62 m (25 foot) wheel base, California type, computerized profilograph or Lightweight Inertial Profiler (IP) and competent operator to measure pavement surface deviations in the longitudinal direction. The computer shall generate a profile index, using a 5.08 mm (0.2 inch) blanking band and the required bump threshold based upon the speed limit of the segment, to identify "must grind" locations.

In the longitudinal direction, determine deviations according to California Test Method 526. In the transverse direction, determine deviations using a 0.9144 m (3 foot) straightedge. See Figure C 5-694.690 for an example of a 3 foot straightedge.

Figure A 5-694.690

Figure B 5-694.690

Figure C 5-694.690

B. Ride Quality

The Engineer will determine the final ride quality based on the results of the California profilograph or Lightweight Inertial Profiler data.

Only bridge surfaces, bridge approach panels, and pavements within 75 m (250 feet) of a terminal header, not adjacent to a paved surface, are exempt from ride quality requirements.

C. Smoothness Measuring Device Certifications

Certified smoothness-measuring devices are required by Contract, for evaluating final mainline smoothness on Agency concrete paving projects. The procedure for certification of smoothness measuring devices is on file in the Mn/DOT Concrete Engineering Unit. Regardless of when a smoothness device is certified, the certification is only valid for the remainder of the same calendar year. A decal is issued to each smoothness device and is displayed on the device in an obvious location at all times the device is present on an Agency construction project.

Certification does not eliminate the need for daily calibration of the smoothness device on the project site.

5-694.691 ROUTINE CORE DRILLING

It is standard practice to drill and test cores from finished concrete pavements. Concrete base, curb and gutter work, sidewalks, and bridge construction may also require coring. These cores are taken to determine the thickness of the pavement and the concrete strength. They are sent to the Mn/DOT Office of Materials to determine their height. This verifies the thickness of the pavement for compliance with Specification 2301.3P2.
Cores are tested for compressive strengths at an age of 60 days. In specialized cases, cores are tested for durability by measuring their resistance to freezing and thawing. The Project Engineer is responsible for determining coring locations for paving. The Project Engineer arranges to have the core locations marked on the pavement for the guidance of the Contractor's core driller. The locations are determined using a random number table. See Figure A 5-694.691 for a random number table. Mainline pavement is divided into 1500 m (5000 ft.) sections as specified in 2301.3P2. Each section requires 1 core every 300 m (1000 ft.) per lane. Therefore, a standard 8.2 m (27 ft.) wide roadway requires 10 cores per 1500 m (5000 ft.), 5 in each lane. Turn lanes, bypass lanes, tied shoulders and third lanes are separated into their own sections.

The steps for core layout are:
See Figure B 5-694.691 (English)

1. Divide project into 1500 m (5000 ft.) sections.
2. Divide sections into 300 m (1000 ft.) subsections.
3. Calculate the number of cores required in each subsection.
4. Use a random number system to choose the station and location of each core. Stay 0.5 m (2 ft.) away from edges and centerline.
5. List the core locations on the *Field Core Report* (Form 24327). See Figure A 5-694.742.

It frequently happens that the list location of a core coincides with that of a joint or manhole. In these cases, the Engineer is to shift the core location so that it is not drilled closer than 1.5 m (5 ft.) from the joint or manhole. The Engineer then records the revised location on the list.

Mark core locations by painting a 150 mm (6 in.) circle. The station location is painted alongside the circle. After the core is drilled, the drill operator will mark the core number on the top and the station number on the side.

The Agency shall field measure the core thickness and compare to the required thickness. If any core thickness is short by more than the tolerances allowed in Specification 2301.3P2, the Contractor shall take additional cores to find the extent of the thin pavement. It is best to measure the core thickness soon after it is taken so any additional cores, if required, are taken while the equipment is still at the project.

The Agency should check the cores against the list and see that all cores are properly marked before the driller leaves the project. Results of the tests obtained from the cores are furnished to the Project Engineer.

RANDOM NUMBERS TABLE

.53 .74 .23 .99 .67	.61 .32 .28 .69 .84	.94 .62 .67 .86 .24	.98 .33 .74 .19 .95	.47 .53 .53 .38 .09
.63 .38 .06 .86 .54	.99 .00 .65 .26 .94	.02 .72 .90 .23 .07	.79 .62 .67 .80 .60	.75 .91 .12 .81 .19
.35 .30 .58 .21 .46	.06 .72 .17 .10 .94	.25 .21 .31 .75 .96	.49 .28 .24 .00 .49	.55 .65 .79 .78 .07
.63 .43 .36 .82 .69	.65 .51 .18 .37 .88	.61 .38 .44 .12 .45	.32 .92 .85 .88 .65	.54 .34 .81 .85 .35
.98 .25 .37 .55 .26	.01 .91 .82 .81 .46	.74 .71 .12 .94 .97	.24 .02 .71 .37 .07	.03 .92 .18 .66 .75
.02 .63 .21 .17 .69	.71 .50 .80 .89 .56	.38 .15 .70 .11 .48	.43 .40 .45 .86 .98	.00 .83 .26 .91 .03
.64 .55 .22 .21 .82	.48 .22 .28 .06 .00	.61 .54 .13 .43 .91	.82 .78 .12 .23 .29	.06 .66 .24 .12 .27
.85 .07 .26 .13 .89	.01 .10 .07 .82 .04	.59 .63 .69 .36 .03	.69 .11 .15 .83 .80	.13 .29 .54 .19 .28
.58 .54 .16 .24 .15	.51 .54 .44 .82 .00	.62 .61 .65 .04 .69	.38 .18 .65 .18 .97	.85 .72 .13 .49 .21
.34 .85 .27 .84 .87	.61 .48 .64 .56 .26	.90 .18 .48 .13 .26	.37 .70 .15 .42 .57	.65 .65 .80 .39 .07
.03 .92 .18 .27 .46	.57 .99 .16 .96 .56	.30 .33 .72 .85 .22	.84 .64 .38 .56 .98	.99 .01 .30 .98 .64
.62 .95 .30 .27 .59	.37 .75 .41 .66 .48	.86 .97 .80 .61 .45	.23 .53 .04 .01 .63	.45 .76 .08 .64 .27
.08 .45 .93 .15 .22	.60 .21 .75 .46 .91	.98 .77 .27 .85 .42	.28 .88 .61 .08 .84	.69 .62 .03 .42 .73
.07 .08 .55 .18 .40	.45 .44 .75 .13 .90	.24 .94 .96 .61 .02	.57 .55 .66 .83 .15	.73 .42 .37 .11 .16
.01 .85 .89 .95 .66	.51 .10 .19 .34 .88	.15 .84 .97 .19 .75	.12 .76 .39 .43 .78	.64 .63 .91 .08 .25
.72 .84 .71 .14 .35	.19 .11 .58 .49 .26	.50 .11 .17 .17 .76	.86 .31 .57 .20 .18	.95 .60 .78 .46 .75
.88 .78 .28 .16 .84	.13 .52 .53 .94 .53	.75 .45 .69 .30 .96	.73 .89 .65 .70 .31	.99 .17 .43 .48 .76
.45 .17 .75 .65 .57	.28 .40 .19 .72 .12	.25 .12 .74 .75 .67	.60 .40 .60 .81 .19	.24 .62 .01 .61 .16
.96 .76 .28 .12 .54	.22 .01 .11 .94 .25	.71 .96 .16 .16 .88	.68 .64 .36 .74 .45	.19 .59 .50 .88 .92
.43 .31 .67 .72 .30	.24 .02 .94 .08 .63	.38 .32 .36 .66 .02	.69 .36 .38 .25 .39	.48 .03 .45 .15 .22
.50 .44 .66 .44 .21	.66 .06 .58 .05 .62	.68 .15 .54 .35 .02	.42 .35 .48 .96 .32	.14 .52 .41 .52 .48
.22 .55 .22 .15 .86	.26 .63 .75 .41 .99	.58 .42 .36 .72 .24	.58 .37 .62 .18 .51	.03 .37 .18 .39 .11
.96 .24 .40 .14 .51	.23 .22 .30 .88 .57	.95 .67 .47 .29 .83	.94 .69 .40 .06 .07	.18 .16 .36 .78 .86
.31 .73 .91 .61 .19	.60 .20 .72 .93 .48	.98 .57 .07 .23 .69	.65 .95 .39 .69 .58	.56 .80 .30 .19 .44
.78 .60 .73 .99 .34	.43 .89 .94 .36 .45	.56 .69 .47 .07 .41	.90 .22 .91 .07 .12	.78 .35 .34 .08 .72
.84 .37 .90 .61 .56	.70 .10 .23 .98 .05	.85 .11 .34 .76 .60	.76 .48 .45 .34 .60	.01 .64 .18 .39 .96
.36 .67 .10 .08 .23	.98 .93 .35 .08 .86	.99 .29 .76 .29 .81	.33 .34 .91 .58 .93	.63 .14 .52 .32 .52
.07 .28 .59 .07 .48	.89 .64 .58 .89 .75	.83 .85 .62 .27 .89	.30 .14 .78 .56 .27	.86 .63 .59 .80 .02
.10 .15 .83 .87 .60	.79 .24 .31 .66 .56	.21 .48 .24 .06 .93	.91 .98 .94 .05 .49	.01 .47 .59 .38 .00
.55 .19 .68 .97 .65	.03 .73 .52 .16 .56	.00 .53 .55 .90 .27	.33 .52 .29 .38 .87	.22 .13 .88 .83 .34
.53 .81 .29 .13 .29	.35 .01 .20 .71 .34	★ .62 .33 .74 .82 .14	.53 .73 .19 .09 .03	.56 .54 .29 .56 .93
.51 .86 .32 .68 .92	.33 .98 .74 .66 .99	.40 .14 .71 .94 .58	.45 .94 .19 .38 .81	.14 .44 .99 .81 .07
.35 .91 .70 .29 .13	.80 .03 .54 .07 .27	.96 .94 .78 .32 .66	.50 .95 .52 .74 .33	.13 .80 .55 .62 .54
.37 .71 .67 .95 .13	.20 .02 .44 .95 .94	.64 .85 .04 .05 .72	.01 .32 .90 .76 .14	.53 .89 .74 .60 .41
.93 .66 .13 .83 .27	.92 .79 .64 .64 .72	.28 .54 .96 .53 .84	.48 .14 .52 .98 .94	.56 .07 .93 .89 .30
.02 .96 .08 .45 .65	.13 .05 .00 .41 .84	.93 .07 .54 .72 .59	.21 .45 .57 .09 .77	.19 .48 .56 .27 .44
.49 .83 .43 .48 .35	.82 .88 .33 .69 .96	.72 .36 .04 .19 .76	.47 .45 .15 .18 .60	.82 .11 .08 .95 .97
.84 .60 .71 .62 .46	.40 .80 .81 .30 .37	.34 .39 .23 .05 .38	.25 .15 .35 .71 .30	.88 .12 .57 .21 .77
.18 .17 .30 .88 .71	.44 .91 .14 .88 .47	.89 .23 .30 .63 .15	.56 .34 .20 .47 .89	.99 .82 .93 .24 .98
.79 .69 .10 .61 .78	.71 .32 .76 .95 .62	.87 .00 .22 .58 .40	.92 .54 .01 .75 .25	.43 .11 .71 .99 .31
.75 .93 .36 .57. 83	.56 .20 .14 .82 .11	.74 .21 .97 .90 .65	.96 .42 .68 .63 .86	.74 .54 .13 .26 .94
.38 .30 .92 .29 .03	.06 .28 .81 .39 .38	.62 .25 .06 .84 .63	.61 .29 .08 .93 .67	.04 .32 .92 .08 .09
.51 .28 .50 .10 .34	.31 .57 .75 .95 .80	.51 .97 .02 .74 .77	.76 .15 .48 .49 .44	.18 .55 .63 .77 .09
.21 .31 .38 .86 .24	.37 .79 .81 .53 .74	.73 .24 .16 .10 .33	.52 .83 .90 .94 .76	.70 .47 .14 .54 .36
.29 .01 .23 .87 .88	.58 .02 .39 .37 .67	.42 .10 .14 .20 .92	.16 .55 .23 .42 .45	.54 .96 .09 .11 .06
.95 .33 .96 .22 .00	.18 .74 .72 .00 .18	.38 .79 .58 .69 .32	.81 .76 .80 .26 .92	.82 .80 .84 .25 .39
.90 .84 .60 .79 .80	.24 .36 .59 .87 .38	.82 .07 .53 .89 .35	.96 .35 .23 .79 .18	.05 .98 .90 .07 .35
.46 .40 .62 .98 .82	.54 .97 .20 .56 .95	.15 .74 .80 .08 .32	.16 .46 .70 .50 .80	.67 .72 .16 .42 .79
.20 .31 .89 .03 .43	.38 .46 .82 .68 .72	.32 .14 .82 .99 .70	.80 .60 .47 .18 .97	.63 .49 .30 .21 .30
.71 .59 .73 .05 .50	.08 .22 .23 .71 .77	.91 .01 .93 .20 .49	.82 .96 .59 .26 .94	.66 .39 .67 .98 .60

Figure A 5-694.691

THIS IS AN EXAMPLE OF A TYPICAL CORE LAYOUT. (English)

Step 1- Divide project into 1500 m (5000 ft.) sections.
Step 2- Divide project into 300 m (1000 ft.) sections.
Step 3- Calculate the number of cores required in each subsection.

BEGIN		1000 ft.		1000 ft.		1000 ft.		1000 ft.		END
3958+00	2	3968+00	2	3978+00	2	3988+00	2	3998+00	2	4008+00
4008+00	2	4018+00	2	4028+00	2	4038+00	2	4048+00	2	4058+00
4058+00	2	4068+00	2	4078+00	2	4088+00	2	4098+00	2	4108+00
4108+00	2	4118+00	2	4128+00	2	4138+00	2	4148+00	2	4158+00
4158+00	2	4168+00	2	4178+00	2	4188+00	2	4198+00	2	4208+00
4208+00	2	4218+00	2	4228+00	2	4238+00	2	4248+00	2	4258+00
4258+00	2	4268+00	2	4278+00	2	4288+00	2	4298+00	2	4308+00
4308+00	2	4318+00	2	4325+86						

Where 2 = Number of Cores Required in this case.

Total cores required is 74 - 7 full sections with 10 per section and 4 for the remaining section.

Step 4- Use a random number system to choose the station and location of each core. Alternate Left and Right.

Started with 0.62 and 0.33 on random number chart. Use numbers as decimal (i.e. 6.2 and 3.3). The first number is added for stations and the second is position from centerline.

3958+00 plus 6.2 6 Stations = 3964+20
3.3 rounds to 3 feet

Stay 0.5 m (2 feet) away from edges and centerline.

Section	Station	Position	Section	Station	Position
Sec. 1	3964+20	3R	Sec. 3	4087+20	9R
	3968+20	2L		4096+20	2L
	3977+80	9R		4099+30	8R
	3984+20	8L		4103+70	2L
	3987+00	5R		4104+90	9R
	3996+30	2L		4111+90	2L
	4003+50	4R		4113+20	4R
	4006+90	4L		4120+10	4L
	4015+80	2R		4126+60	2R
	4024+50	2L		4131+40	2L
Sec. 2	4031+90	2R	Sec. 4	4138+60	8R
	4038+10	2L		4146+60	6L
	4043+20	10R		4149+30	8R
	4050+50	2L		4158+90	6L
	4054+70	2R		4168+60	2R
	4058+50	8L		4170+30	2L
	4066+70	2R		4177+20	3R
	4068+20	7L		4184+60	8L
	4071+40	2R		4186+20	2R
	4080+50	2L		4189+80	7L

Continue on with the remaining sections.

Figure B 5-694.691

REFERENCES

1. Figure A 5-694.603, Design and Control of Concrete Mixtures, 14th Edition, Portland Cement Association, 2002.
2. Figure B 5-694.603, Design and Control of Concrete Mixtures, 14th Edition, Portland Cement Association, 2002.
3. Section 5-694.630 through 5-694.657, FHWA HI-02-018, NHI Course 13133 - Construction of Portland Cement Concrete Pavements, American Concrete Pavement Association, 2000.

REPORTS AND WORK SHEETS
5-694.700

5-694.701 GENERAL

A summation of data on inspection items is required at periodic intervals. The data is collected on report forms. Some forms are submitted to the Mn/DOT Concrete Engineering Unit and all other forms are filed in the Project file for internal use only. The reports submitted to the Mn/DOT Concrete Engineering Unit provide information regarding the progress of the work and become a part of the construction history of the Project. They are also used to track source history to verify changes in sources. All forms used on concrete work other than for miscellaneous materials are shown. Examples of forms not previously illustrated are contained in this section.

Submit the following forms to the Mn/DOT Concrete Engineering Unit:

A. Field Reports

1. Weekly Concrete Report (Form 2448)
2. Weekly Certified Ready-Mix Plant Report (Form 24143)
3. For **Concrete Paving Projects Only**, send copies of all Agency and Contractor tests results including control charts. These include but are not limited to:
   a. Field Core Reports (Form 24327)
   b. Concrete Test Beam Data (Form 2162)
   c. Ride Quality Results
   d. Incentive/Disincentive Information
   e. All change orders and supplemental agreements regarding concrete issues

B. Laboratory Reports

1. Cylinder Reports
2. Aggregate Test Reports
3. Other reports that indicate failing concrete related materials

NOTE: All other forms are for Project internal documentation only. DO NOT send them to the Mn/DOT Concrete Engineering Unit.

A large number of forms were developed for use in the field to aid the Inspector in recording data and tests. Some forms are used as inspection notices. Do not confuse these forms with the report forms. Do not submit them to the Mn/DOT Concrete Engineering Unit, but retain them in the Project File.

5-694.710 PRELIMINARY WORKSHEETS

5-694.711 CONCRETE MIX DESIGN REQUEST (Form 2416)

The Project Engineer submits this form to the Mn/DOT Concrete Engineering Unit to initiate the concrete mix design process. Submit one form for each source or combination of sources of aggregates used. If the source was not previously used, at least **one month's notice** is necessary. For sources previously used, **two week's notice** is required.

Instructions for Completing the Concrete Mix Design Request (Form 2416)

Complete all items on the Mix Design Request. Any items left blank may delay receiving a mix design.

Item numbers listed below correspond to the numbers in Figure A 5-694.711. See Figure B 5-694.711 for a completed example.

Item 1: Project Number
List the low project number.

Item 2: From
Identify the name of the person requesting the mix design and the Project Engineer, if different.

Item 3: Telephone Number
List the telephone number of the person requesting the mix design.

Item 4: Type of Work
List the part of structure for which the concrete is intended. For example, if the concrete is for a bridge pier, don't just write "Bridge", write "Bridge - Pier".

Item 5: Mix Number
Indicate the Mn/DOT mix design requested.

Item 6: Gradation Number
Indicate the gradation specification. Contact the Concrete Supplier to determine what gradation specification is selected (if there is a choice).

Items 7 and 8: % of ¾"+ and % of ¾"-

If more than one size of aggregate is used, indicate the percent of each of the materials used in the composite. Contact the Concrete Supplier to obtain this information.

Item 9: Class of Coarse Aggregate (A, B, C, etc.)
Indicate the class of the coarse aggregate. If unsure, refer to Spec. 3137.2B or ask the Concrete Supplier.

Item 10: Fly Ash? (Y/N)
Indicate whether or not fly ash is included in the mix design.

Item 11: Other Admixtures (Type & Mfr.)
Indicate type and manufacturer of admixture if expected to use.

Item 12: Source of Fine Aggregate Pit Number
List the pit number for the fine aggregate source.

Item 13: Fineness Modulus
List the Fineness Modulus of the fine aggregate. The Supplier provides this number.

Item 14: Source of Coarse Aggregate Pit Number
List the pit number for the coarse aggregate sources.

Item 15: Source of Fly Ash, Power Plant (If Used)
Identify the fly ash power plant, not the distributor of the fly ash.

Item 16: Class
Designate the class of the fly ash, it is either "C" or "F".

Item 17: If Ready-Mix, Name and Location
Indicate the name of the ready-mix plant and specify the location. For example, list Cemstone #28, Minneapolis, not just Cemstone.

Item 18: Date
Indicate the date the mix design is requested.

Item 19: Signed
Handwritten signature of the Project Engineer.

Item 20: Date of First Pour
Indicate the earliest possible date of the first pour.

5-694.712 ESTIMATED COMPOSITION OF CONCRETE MIXES (Form 2406)

After receiving a completed *Concrete Mix Design Request* (Form 2416), the Mn/DOT Concrete Engineering Unit issues the Composition of Concrete Mixes.

Commonly referred to as the Mix Design, the Composition of Concrete Mixes provides the estimated mix proportions. See Figure A 5-694.712 for a completed example.

Mn/DOT TP-02416-03 (10-2002)

PROJECT NO: 1

TO: Concrete Engineering Unit

FROM: 2

TELEPHONE NUMBER: 3

SUBJECT: Concrete Mix Design Request

Please submit the following information as soon as it can be definitely ascertained. This information is necessary before the concrete proportions can be designed for your project. Submit one form for each source or combination of sources of aggregates to be used. If the source has not been previously used, at least **ONE MONTH'S notice** will be necessary. For sources that have been used, **TWO WEEK'S notice** will be required.

Type of Work	Mix No.	Gradation No.	% of 3/4"+	% of 3/4"-	Class of Coarse Aggregate (A, B, C, etc.)	Fly Ash? (Y / N)	Other Admixtures (Type & Mfr.)
4	5	6	7	8	9	10	11

Source of Fine Aggregate Pit No.: 12 FINENESS MODULUS 13

Source of Coarse Aggregate Pit No.: 14

Source of Fly Ash, Power Plant (If Used): 15 Class: 16

If Ready-Mix, Name and Location: 17

DATE 18 SIGNED 19 Date of First Pour 20

CONCRETE PROPORTIONS WILL NOT BE ISSUED UNTIL THIS FORM HAS BEEN RECEIVED AT THE CONCRETE ENGINEERING UNIT. SUBMIT ONE COPY EITHER BY MAIL OR FAX AT 651-779-5580. PLEASE INCLUDE A COVER SHEET.

Mn/DOT TP-02416-03 (10-2002)

PROJECT NO: 1020-30

TO: Concrete Engineering Unit

FROM: Clay Pitts

TELEPHONE NUMBER: 651-654-8739

SUBJECT: Concrete Mix Design Request

Please submit the following information as soon as it can be definitely ascertained. This information is necessary before the concrete proportions can be designed for your project. Submit one form for each source or combination of sources of aggregates to be used. If the source has not been previously used, at least **ONE MONTH'S notice** will be necessary. For sources that have been used, **TWO WEEK'S notice** will be required.

Type of Work	Mix No.	Gradation No.	% of 3/4"+	% of 3/4"-	Class of Coarse Aggregate (A, B, C, etc.)	Fly Ash? (Y / N)	Other Admixtures (Type & Mfr.)
MISC	1A43	50		70/30	C	Y	
PILES	1C62	50		70/30	C	Y	
MISC	3Y43	50		70/30	C	Y	
C & G	3A22	50		70/30	C	Y	
C & G	3A32	50		70/30	C	Y	
SLOPE PAVING	3A34	50		70/30	C	Y	

Source of Fine Aggregate Pit No.: 123456 FINENESS MODULUS 2.70

Source of Coarse Aggregate Pit No.: 70% 123456 (3/4-) 30% 134567 (3/8-)

Source of Fly Ash, Power Plant (If Used): NSP-EAGAN Class: C

If Ready-Mix, Name and Location: QUICKMIX, MILL CITY, MN

DATE 2/3/03 SIGNED CLAY PITTS Date of First Pour 3/4/03

CONCRETE PROPORTIONS WILL NOT BE ISSUED UNTIL THIS FORM HAS BEEN RECEIVED AT THE CONCRETE ENGINEERING UNIT. SUBMIT ONE COPY EITHER BY MAIL OR FAX AT 651-779-5580. PLEASE INCLUDE A COVER SHEET.

MN/DOT TP-02406-02 (12-92)

Minnesota Department of Transportation
Estimated Composition of Concrete Mixes

To: Clay Pitts Title: Project Engineer S.P. No. 1020-30
Address: P.O. Box 325, Mill City, MN 55101

MATERIAL	Pit Number	CEMENT MANUFACTURER, FLYASH GENERATING PLANT, OR AGGREGATE SOURCE			TYPE OR CLASS	GRAD. NO.	SPG.	ABSORP.	F.M.
Cement	------	(Any Certified)			I	----	3.15	----	----
Fly Ash	------	(Any Certified)			C	----	2.58	----	----
Fine Agg.	123456	SALINGER, LAKELAND			---	----	2.64	.008	2.70
Coarse Agg. No.1	123456	SALINGER, LAKELAND	CA - 50	70	C	3/4-	2.70	.014	----
Coarse Agg. No.2	134567	ROCK ISLAND, FALLS CITY		30	C	3/8-	2.65	.016	----
Coarse Agg. No.3									----
Coarse Agg. No.4									----

Admixtures: A.E.A. (Type 3 Concrete) Water Reducers or Retarder (M1 and M2)

COMPUTED ON TAPE NO.	MIX NO.	BATCH VOLUME CU. FT.	C/V RATIO	SLUMP RANGE (INCHES)	% AIR	PORT. CEMENT	FLY ASH	WATER	Estimated Batch Weights- Pounds(dry) Fine Agg.	Coarse Aggregate No.1	No.2	No.3	No.4
	1A43	RM	.56	3-4	1.5	507	89	276	1372	1296	556		
	1C62	"	.44	5-6	"	404	71	290	1302	1393	597		
	3Y43	"	.54	3-4	6.5	549	97	271	1193	1276	547		
	3A22	"	.50	1-2	"	455	80	245	1256	1345	576		
	3A32	"	.50	2-3	"	481	85	262	1229	1316	564		
	3A34	"	.50	2-3	"	485	86	269	1312	1241	532		

NOTICE:
ALL TESTS AND SAMPLE RATES MUST COMPLY WITH THE MATERIALS CONTROL SCHEDULE

Copy To:

Note: Adjust above dry weights for moisture contained in the aggregates
Ready-mix batches are based on 27.00 cubic feet +1%

Dist M Materials

Extra 4

Date 2/17/03 Mica Schist
Concrete Engineering Specialist

5-694.715 CERTIFIED READY-MIX REPORTS AND WORKSHEETS

All of the reports and worksheets in sections 5-694.716 through 5-694.727 are required for documentation on all projects requiring Certified Ready-Mix. These sections include descriptions and examples of each form. **To obtain a blank form, download a copy of the form from the Mn/DOT Concrete Engineering website at www.mrr.dot.state.mn.us/pavement/concrete/forms.asp.**

5-694.716 CONTACT REPORT (Form 2163)

Prior to the beginning of a project, or once per calendar year, an Agency Plant Monitor shall perform a thorough on-site inspection of the concrete plant in order to complete a *Concrete Plant Contact Report*. This Contact Report contains the information necessary to assure that the plant is able to produce concrete meeting specifications, and has a signature block for the Ready-Mix Producer certifying that the Producer will maintain the plant in that condition. See Figure A 5-694.716 (1-4).

5-694.717 TEST OF WEIGHING EQUIPMENT (Form 2124)

This form is for reporting a complete calibration of the weighing equipment at the plant. Reports on spot checks are not required. This form is applicable to either ready-mix or paving. See Figure A 5-694.717.

5-694.718 CONCRETE BATCHING REPORT (Form 2152)

This form is for calculating and documenting moisture results and proportioning aggregates by Producer Technicians. It is intended as a worksheet and must remain at the plant for the entire season. The spaces on the backside do not require completion for ready-mix production. See Figure A 5-694.718.

5-694.719 AGGREGATE MOISTURE CONTENT CHART

This chart is produced and maintained by the Producer's Technician and is used as an aid for Plant and Field Personnel to track the total aggregate moisture content. If the plant has moisture probes, the moisture probe correlations are also plotted on this chart. It must remain at the plant for the entire season. See Figure A 5-694.719.

5-694.720 CONCRETE AGGREGATE WORKSHEET (Form 21763)

This worksheet is for calculating the Producer's quality control (QC) gradations. Each coarse and fine aggregate gradation must be independently numbered consecutively, beginning with number one each year. It must remain at the plant for the entire season. See Figure A 5-694.720.

TP-2163-02 (1/2002) dual

Minnesota Department of Transportation

Contact Report – Ready Mix 2003

Plant Name: Quickmix Date: 3/4/03

Address: 1221 Industrial Street Phone: 651-555-1235

Mill City, Mn 55101 Fax: 651-555-1236

Prior to the production of Agency concrete **each construction season**, an Agency Representative shall perform a thorough on-site inspection of the concrete plant to assure that the plant can produce concrete meeting Mn/DOT Specifications.

In addition, the Concrete Producer must also provide the following copies of documentation:

[X] **Lab Equipment Calibrations** Producer must check and calibrate the sieves prior to starting production. The date of calibration should be clearly marked on the equipment using the procedures described in the Mn/DOT Lab Manual 2001, 2002, 2008, and 2009.

T.S.

[X] **Scale and/or Meter Calibrations** An approved scale company or the Minnesota Department of Public Service must check and calibrate the scales. Thereafter, they are checked and calibrated once each year. Additional calibrations are made at three-month intervals using the procedures described in the Mn/DOT Concrete Manual 5-694.431 and 5-694.433.

[X] **Certificate of Compliance** A batch ticket that includes all Mn/DOT Specifications, and the supporting oven dried mix design and moisture test results.

[X] **Technicians**

MN/Dot Certified Plant 1 Technician John Stone Cert # 10000

MN/Dot Certified Plant 1 Technician David Rock Cert # 10001

MN/Dot Certified Plant 2 Technician Mike Boulder Cert # 10002

MN/Dot Certified Plant 2 Technician Cell Phone # 651-555-6789

Agency Representative: Tom Sands

[ ] Approved for Agency production in 2003

[ ] Approved for limited Agency production in 2003 (500 yd^3 for general concrete; 200 yd^3 for bridge concrete)

[X] Re-inspected and approved on 3/20/03 by Tom Sands

[X] Not approved for the following reason/s:

Scales have not been calibrated

The Concrete Producer agrees to maintain all plant and laboratory equipment within allowable tolerances as set forth in the MN/DOT Specifications, to have all moisture and gradation tests run by a Plant Level I Technician certified by MN/DOT, and to have the Plant Level II Technician certified by MN/DOT on site at all times or available at the plant site in a reasonable time frame when called.

After completing the Concrete Plant Contact Report, any procedural changes that cause non-compliance with this program will result in de-certification of the plant and cessation of further production of Agency concrete.

Certified by: Jim Granite

Plant Representative

Plant

Type of Mixer:

Type of Plant: Ready Mix __X__ Transit Mix _____

Batching Equipment: Make: Selectron

Model: CB500

Condition: good

Tilting Drum (60 sec) __X__ Turbine (45 sec) ____ Rotary (30 sec) ____

Max. mixer batch size __7.5__ yd^3

Dry Batch Truck Mixing (5 min or 50 revs.) _______

Plant has Mixer and Truck Mixing capability ______

Certificate of Compliance:

Computerized Batch Printout (y/n): __Y__ English/Metric Conversion: ______

NOTE: All of the following items are required (Specification 2461.4D7a)

__X__ **a**. Name of Plant
__X__ **b**. Contractor
__X__ **c**. Date
__X__ **d**. State Project Number
__X__ **e**. Bridge Number
__X__ **f**. Batch Time
__X__ **g**. Truck Number
__X__ **h**. Yd^3/load
__X__ **i**. Yd^3/Cum
__X__ **j**. Mix Design
__X__ **k**. Cement Brand & Mill
__X__ **l**. Fly Ash Power Plant
__X__ **m**. Admix Product Name
__X__ **n**. Pit Number
__X__ **o**. Admix Qty
__X__ **p**. Design Wts
__X__ **q**. Design Water
__X__ **r**. Target and Actual Batched Wts of all components; and Trim and Total Water Wts
__X__ **s**. Labeled Spaces for Field Test Results (air content, air temp, concrete temp, slump, cylinder #, and part of structure)

Aggregate Moisture Meters:

Material	Plant Equipped with Meter (y/n)	Make	Model	Sensor Location	Does meter automatically adjust computer weights
Sand	YES	HYDRONICS	HV02	12"-18" ABOVE GATE	YES
3/4"+ (19mm+)	NO				
3/4"- or (19mm-)	NO				
1/2"- or 3/8"- (12.5mm or 9.5mm)	NO				
Class A	NO				

Scale and Meter Information:

Material	Type	Make	Capacity	Graduation
Cement	DIGITAL	SELTEC	5,000 LB	5 LB
Fly Ash	"		5,000 LB	5 LB
Slag				
Aggregate	"		25,000 LB	20 LB
Water Scale				
Water Meter	VALVE	BADGER	2 ½"	1 GA

Materials

Cementitious Materials:

Material	Supplier w/Mill	# of Silos	Capacity (tons)	Delivered By (truck, rail)	Delivered To Silo By (blower, elevator)	Delivered To Hopper By (gravity, auger)	Sampled At (truck, rail, hopper valve)
Cement	HOLCIM - MASON CITY	2	100 &60	TRUCK	BLOWER	AUGER	TRUCK
Cement							
Fly Ash	NSP - EAGAN	1	25	TRUCK	BLOWER	GRAVITY	TRUCK
Slag							
Other							

Admixtures:

Type	Supplier	Name of Product	Sampled At (dispensing tubes recommended)
A.E.A.	EUCLID	AEA92	STORAGE TANK
Water Reducer	EUCLID	WR-91	"
Retarder	EUCLID	RETARDER 100	"
Super Plasticizer	EUCLID	EUCON 37	"
Calcium Chloride	VAN WATERS & ROGERS	CACL2	"

Aggregates:

Material	Supplier	Pit Location	Pit Number	Delivered By	In Plant storage (tons)
Sand	SALINGER	LAKELAND	123456	TRUCK	60
3/4"+ (19mm+)	"	"	"	"	60
3/4"- (19mm-)	"	"	"	"	60
1/2"- or 3/8"- (12.5mm or 9.5mm)	ROCK ISLAND	FALLS CITY	134567	"	60
Class A	MERIDIAN	ST. CLOUD	173006	"	60

Plant is fed by: Drive over hoppers 4 How many compartments 4

Field hoppers _____ How many _____

Number of storage bins 4

Are stockpiles separated (y/n) Y

How many belts feed plant working bins 4

Is turn head used (y/n) N

Aggregate sampled at: Batch Hopper _____ Belt X Stockpile _____

Water:

Source:

X City Water

____ Well Water

____ Both

Proportioned by:

X Meter

____ Scale

Can water be heated with a boiler (y/n) Y

Temperature gauge location: ON RECIRCULATION LINE

Lab and Equipment

Inspection Quarters:

__X_ Area (120 ft^2)
__X_ Adequate Lighting
__X_ Heating System
__X_ Air Conditioning
__X_ Ventilation
__X_ Concrete Manual

__X_ Suitable Desk
__X_ Chair
__X_ Stool
__X_ Fire Extinguisher
__X_ Running Water

Posted Information
__X_ Current Site Map
__X_ Tech I & II Names & Cert #
__X_ Tech II Cell Phone #

Equipment:

Mechanical Shakers, Screens and Sieves

Box Screens: **Must have all screens listed below** **Calibrated on 1/2/03**

____ 2" (50mm)*
____ 1 1/2" (37.5mm)*
____ 1 1/4" (31.5mm)*
__X_ 1" (25mm)
__X_ 3/4" (19.0mm)
__X_ 5/8" (16mm)
__X_ 1/2" (12.5mm)
__X_ 3/8" (9.5mm)
__X_ #4 (4.75mm)
__X_ Bottom Pan
__X_ Mechanical Shaker

*Required when using 3/4"+ (19.0mm) aggregate

NOTE: Plants producing CA-50 with two fractions will need to use a 1/4" (6.3mm) sieve as a filler between the 3/8" (9.5mm) and the #4 (4.75mm) sieves.

Brass Sieves: **Must have all sieves listed below** **Calibrated on 1/17/03**

__X_ 3/8" (9.5mm)
__X_ #4 (4.75mm)
__X_ #8 (2.36mm)
__X_ #16 (1.18mm)
__X_ #30 (600µm)
__X_ #50 (300µm)
__X_ #100 (150µm)
__X_ 2 - #200 (75µm)
__X_ Bottom Pan
__X_ Mechanical Shaker

NOTE: Two #200 (75µm) sieves are needed, one is for shaking the gradation and the second is for washing the sample during the final steps of the gradation process.

Scales and Miscellaneous

Scales:

__X_ Dairy Scale Calibrated on 2/2/03 **MINIMUM 55 lb CAPACITY**

Must have one of the two scales listed below.

____ Triple Beam Balance including the needed Hanging Weights (1 - 500g and 2 - 1000g) Calibrated on________________ **MINIMUM 2600g CAPACITY**

__X_ Electronic Scale Calibrated on 1/30/03 **MINIMUM 2600g CAPACITY**

Miscellaneous:

YES 2" (50mm) Sample Splitter with 3 Pans
ELECTRIC 3 Burners: Natural Gas or Electric
NYLON Sample Bags: Nylon or Paper-lined Burlap **MINIMUM 33 lb CAPACITY**

STATE OF MINNESOTA DEPT. OF TRANSPORTATION
Office of Maintenance

TEST OF WEIGHING EQUIPMENT

Owner: Quickmix - Location: Mill City S.P. VARIOUS

Type of Scale: DIGITAL Make: Seltec Fed. No. -

Date of Test: 4-30-2003 Tested by: Tom Sands Bridge No. -

Scale used for weighing: AGGREGATE CAP 25,000 # GRAD 20#

Standard Weight Applied	Wt. Of Added Material	Wt. of Hanger Rods and Platform	Total Applied Load	Scale Reading at Balance	Diff. in Lbs. (+) or (-)	Sensitivity in Lbs.	REMARKS
0	0	0	0	0	0	0	
100			100	100	0		AVERAGE BATCH
200			200	200	0		
300			300	300	0		SIZE 4 ½ CY
400			400	400	0		
500	0	0	500	500	0	0	
0	0	0	0	0	0	0	
0	14000	0	14000	14000	0	0	
100			14100	14100	0		
200			14200	14200	0		
300			14300	14300	0		
400			14400	14400	0		
500		0	14500	14500	0	20#	
							SPOT CHECK CONSOLE
							AGAINST MASTER SCALE
							@ 0.500, FINAL BALANCE
							CONSOLE MUST FOLLOW
							MASTER SCALE WITHIN
							2 GRADUATION OF LESS

General Conditions of Scales: GOOD

Is the equipment protected from wind and weather? YES

Signed Clay Pitts
Project Engineer

Mn/DOT TP-02124-02 (7/80)

TP 2152-03 (3/2001)

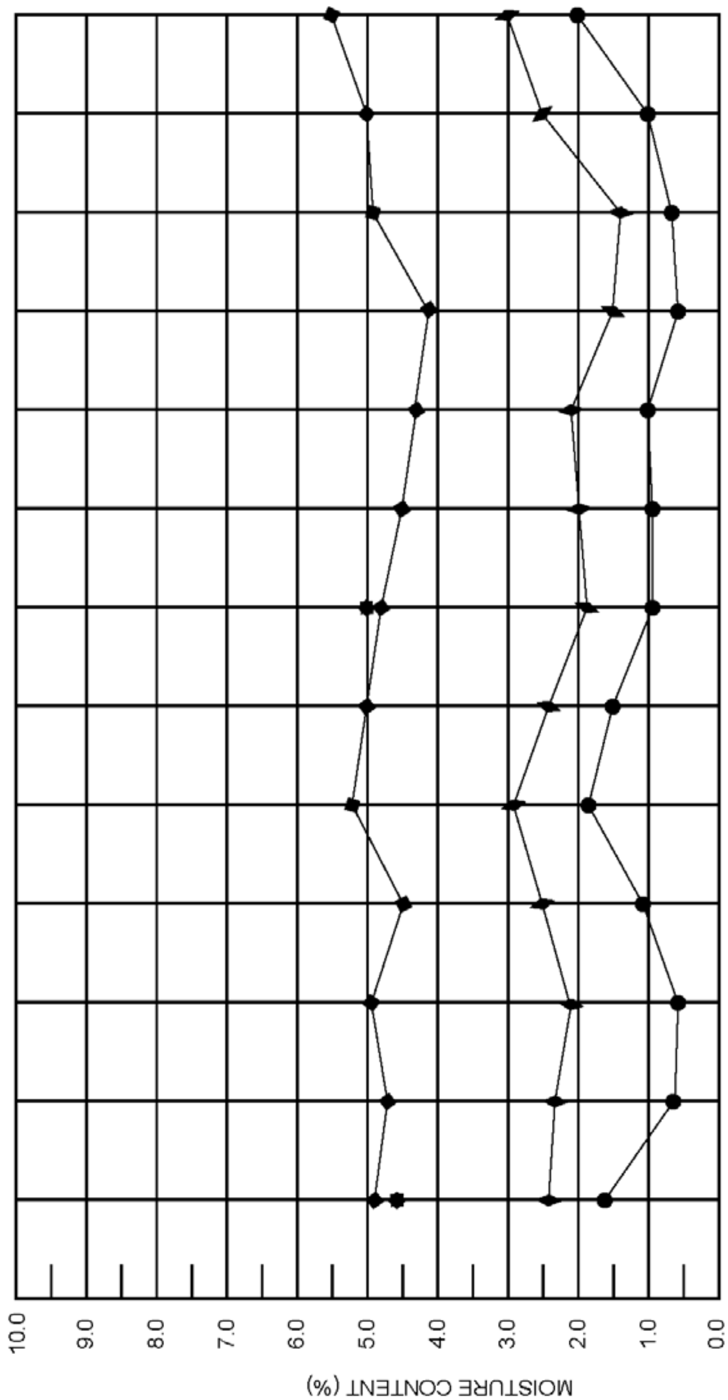
Minnesota Department of Transportation

Concrete Batching Report

Batch Plant Quickmix – Mill City Date 4/1/03

Material		Sand	3/4-	3/8-		Sand	3/4-	3/8-		Sand	3/4-	3/8-		Average Free Water (Not Weighted)
A. Wt. Sample + Pan	Wet	718	2338	2345		705	2330	2356		700	2321	2313		
B. Wt. Sample + Pan	Dry	692	2306	2298		680	2316	2310		674	2308	2271		
C. Moisture Loss	A–B	26	32	47		25	14	46		26	13	42		
D. Tare Wt, Pan	-	145	300	300		145	300	300		145	300	300		
E. Dry Wt. Sample	B–D	547	2006	1998		535	2016	2010		529	2008	1971		
F. Total Moisture Factor	C/E	.048	.016	.024		.047	.007	.023		.049	.006	.021		
G. Absorb. Factor	-	.008	.014	.016		.008	.014	.016		.008	.014	.016		
H. Free Moisture Factor	F–G	.040	.002	.008		.039	-.007	.007		.041	-.008	.005		
I. Time Scales Set				7:15a				10:05a				1:10p		
		Mix No. 3Y43		**Cement Wt.** 549			**Fly Ash Wt.** 97			**Design Water** 271				
J. Design Wt.	-	1193	1276	547		1193	1276	547		1193	1276	547		
K. Total Moisture	FxJ	57	20	13		56	9	13		58	8	11		
L. Scale Setting	J+K	1250	1296	560		1249	1285	560		1251	1284	558		
M. Free Moisture	HxJ	48	3	4		47	-9	4		49	-10	3		
Total Free Moisture				55				42				42		
		Mix No.			**Cement Wt.**			**Fly Ash Wt.**			**Design Water**			
J. Design Wt.	-													
K. Total Moisture	FxJ													
L. Scale Setting	J+K													
M. Free Moisture	HxJ													
Total Free Moisture														
		Mix No.			**Cement Wt.**			**Fly Ash Wt.**			**Design Water**			
J. Design Wt.	-													
K. Total Moisture	FxJ													
L. Scale Setting	J+K													
M. Free Moisture	HxJ													
Total Free Moisture														
		Mix No.			**Cement Wt.**			**Fly Ash Wt.**			**Design Water**			
J. Design Wt.	-													
K. Total Moisture	FxJ													
L. Scale Setting	J+K													
M. Free Moisture	HxJ													
Total Free Moisture														

AGGREGATE MOISTURE CONTENT



DATE	TIME	FINE AGGREGATE	MOISTURE METER	CA- 3/4-	CA- 3/8-
4/1	7:15a	4.8	4.6	1.6	2.4
4/1	10:05a	4.7		0.7	2.3
4/1	1:10p	4.9		0.6	2.1
4/2	6:30a	4.5		1.1	2.5
4/3	10:00a	5.2		1.8	2.9
4/3	2:00p	5.0		1.5	2.4
4/7	7:10a	4.8	5.0	0.9	1.8
4/7	9:50a	4.5		0.9	2.0
4/7	1:00p	4.3		1.0	2.1
4/7	3:00p	4.1		0.6	1.5
4/8	6:50a	4.9		0.7	1.4
4/8	9:30a	5.0		1.0	2.5
4/9	8:00a	5.5		2.0	3.0

CA-

TP-21763-04 (5/2002)

Minnesota Department of Transportation

Concrete Aggregate Worksheet

S.P. 1020-30	Plant: Quickmix-Mill City	Date: 4/1/03	Agg. Source(s) #: FA – 123456 CA – 50 3/4- 123456
Engineer: Clay Pitts	Tester: John Stone	Time: 6:30a	CA – 50 3/8- 134567 CA -

Sieve Analysis of Coarse Aggregate

Agg. Fract.	CA - 3/4- Mix Prop. 70 %				CA - 3/8- Mix Prop. 30 %				CA - ____ Mix Prop. ____ %			
	Test No. CA20 13.4 Sample Wt.		Quality Sample Submitted. By JS Date 4/1		Test No. CA20 14.4 Sample Wt.		Quality Sample Submitted. By JS Date 4/1		Test No. Sample Wt.		Quality Sample Submitted. By ____ Date	
Sieve Sizes	Weights		%	Grad.	Weights		%	Grad.	Weights		%	Grad.
Pass – Ret.	Ind.	Cum.	Pass	Req.	Ind.	Cum.	Pass	Req.	Ind.	Cum.	Pass	Req.
2" – 1 1/2"												
1 1/2" – 1 1/4"												
1 1/4" – 1"	0											
1" – 3/4"	.9	13.4	100									
3/4" – 5/8"	2.7	12.5	93									
5/8" – 1/2"	5.0	9.8	73		0	14.4	100					
1/2" – 3/8"	3.3	4.8	36		1.1	14.4	100					
3/8" - #4	1.3	1.5	11		9.2	13.3	92					
#4 – Btm	.2	.2	1		4.1	4.1	28					
Check Total	13.4	± 0.3% or 0.2 lb of Sample Wt.			14.4	± 0.3% or 0.2 lb of Sample Wt.				± 0.3% or 0.2 lb of Sample Wt.		

Coarse Aggregate Percent Passing #200 Sieve Test

	(CA -)		(CA -)		(CA -)
(A) Dry weight of original sample					
(B) Dry weight of washed sample					
(C) Loss by washing (A – B)					
(D) % Passing #200 (C ÷ A) × 100					

Composite Gradation for (CA - 50)

Agg. Fract.	CA – 3/4-	CA – 3/8-	CA -	Composite	Grad. Req.
Proportions	70 %	30 %	____ %	100%	
2"					
1 1/2"					
1 1/4"					
1"	70	30		100	100
3/4"	65	30		95	85-100
3/8"	8	28		36	30-60
#4	1	8		9	0-12

Washing Data for Sieve Analysis of Fine Aggregate

(A) Dry sample and record weight	510.3
(B) Wash and dry sample, record weight	506.6
(C) Loss by washing (A – B)	3.7
Enter (C) to the right, for fine sieve analysis	

Sieve Analysis of Fine Aggregate

Quality Sample Submitted. By: J.S. Date : 4/1

Test No. FA12 Sample Wt. 510.3

Sieve Size Pass Ret.	Weights Ind.	Weights Cum.	% Pass	Grad. Req.
3/8" - #4	0		100	100
#4 - #6	0	509.9	100	95 – 100
*#6 - #8	47.4	509.9		**
#8 - #16	105.7	462.5	91	80 – 100
#16 - #30	149.6	356.8	70	55 – 85
#30 - #50	146.3	207.2	41	30 – 60
#50 - #100	49.7	60.9	12	5 – 30
#100 - #200	7.0	11.2	2	0 – 10
*#200 - Btm	.5	4.2	.8	0 – 2.5
Loss by washing	3.7			
Check Total	509.9	± 0.3% of Sample Wt.		
Fineness Modulus	Within ± 0.20		2.84	2.70

* #6 and #200 not included in Fineness Modulus

** #6 is recommended as filler sieve

5-694.721 WEEKLY CONCRETE AGGREGATE REPORT (Form 2449)

The Certified Concrete Ready-Mix Producer records the fine aggregate (sand) and coarse aggregate gradation results on this report. A column between the Producer's quality control tests is left blank for the Agency to record comparison test results. This report is submitted to the Agency weekly. See Figure A 5-694.721 (1-2) for an example that has been completed by the Producer and is ready for submission to the Agency.

5-694.722 QUALITY CONTROL CHARTS

Quality Control charts are a visual and statistical method of tracking gradations in order to achieve better quality control of concrete aggregates. This method is helpful in visualizing the consistency of the material and aiding the Producer in making sound aggregate decisions and adjustments. These charts are produced and maintained by the Producer's Technician. They must remain at the plant for the entire season.

Quality Control Charts are made-up of an Upper Limit (UL), Lower Limit (LL), the midpoint of the range or Target Value (TV), and the Quality Control Band (QCB). The QCB is defined as a band on either side of the TV where the material is considered uniform. The width of the QCB is dependent on the gradation range.

Gradation Range	Width of the QCB
<9	+/- 1
9 - 21	+/- 3
>21	+/- 5

Each test result is labeled with the gradation sample number, date and time, and is plotted on the Quality Control Chart in the appropriate place. Using a different color or symbol, the average of the last four tests is plotted on the same vertical line.

The objective of the aggregate supplier is to have the running average values inside the QCB and to not have an individual test below the LL or above the UL. Mn/DOT uses the LL and the UL values for individual tests as acceptance for projects; however, the running average may provide input for deciding any penalties.

The results of the Agency's verification gradation and the Producer's companion gradations are charted on the same chart to compare results. The Agency results are not included in the running average calculations.

See Figures A and B 5-694.722 for examples of Sand and CA-50 Quality Control Charts.

TP 2449-04 (1/2002)

Minnesota Department of Transportation

Weekly Concrete Aggregate Report

Ready-Mix Plant Quickmix - Mill City Week Ending 4/5/03

S. P. Nos. 1020-30

Sand Source/Location Salinger-Lakeland Pit # 123456

Date	4/1		4/2		4/3				Sand Specs. Sampled @ Belt
Time	6:30a		6:00a		9:00a				
Gradation #	FA12		FA13		FA14				
3/8"	100		100		100				100
#4	100		100		99				95 - 100
#6									-
#8	91		91		90				80 - 100
#16	70		71		73				55 - 85
#30	41		43		43				30 - 60
#50	12		14		12				5 - 30
#100	2		2		2				0 - 10
F.M.	2.84		2.83		2.81				2.70 ± 0.2
#200	.8		1.1		1.3				0 - 2.5
Lab I.D. #	2								
Inspector	J.S.		D.R.		D.R.				

CA-Size 50 Source/Location Composite Pit # 123456 / 134567

Date	4/1		4/1		4/2		4/3		Specs. CA - 50 Sampled @ Belt
Time	6:30a		12:00p		6:00a		9:00a		
Gradation #	CA20		CA21		CA22		CA23		
2"									
1 1/2"									
1 1/4"									
1"	100		100		100		100		100
3/4"	95		90		97		85		85 - 100
1/2"									-
3/8"	36		39		45		36		30 - 60
#4	9		11		12		11		0 - 12
Lab I.D. #	2								
Inspector	J.S.		D.R.		D.R.		D.R.		

CA-Size 3/4- Mix Prop. 70 % Source/Location Salinger-Lakeland Pit # 123456

Date	4/1		4/1		4/2		4/3		Specs. CA - Sampled @ Belt
Time	6:30a		12:00p		6:00a		9:00a		
Gradation #	CA20		CA21		CA22		CA23		
2"									
1 1/2"									
1 1/4"									
1"	100		100		100		100		
3/4"	93		85		96		79		
1/2"	36		35		54		26		
3/8"	11		13		21		9		
#4	1		1		1		3		
Lab I.D. #	2								
Inspector	J.S.		D.R.		D.R.		D.R.		

CA-Size 3/8- Mix Prop. 30 % Source/Location Rock Island-Falls City Pit # 134567

Date	4/1		4/1		4/2		4/3		Specs. CA - Sampled @ Belt
Time	6:30a		12:00p		6:00a		9:00a		
Gradation #	CA20		CA21		CA22		CA23		
2"									
1 1/2"									
1 1/4"									
1"									
3/4"									
1/2"	100		100		100		100		
3/8"	92		100		100		100		
#4	28		35		38		29		
Lab I.D. #	2								
Inspector	J.S.		D.R.		D.R.		D.R.		

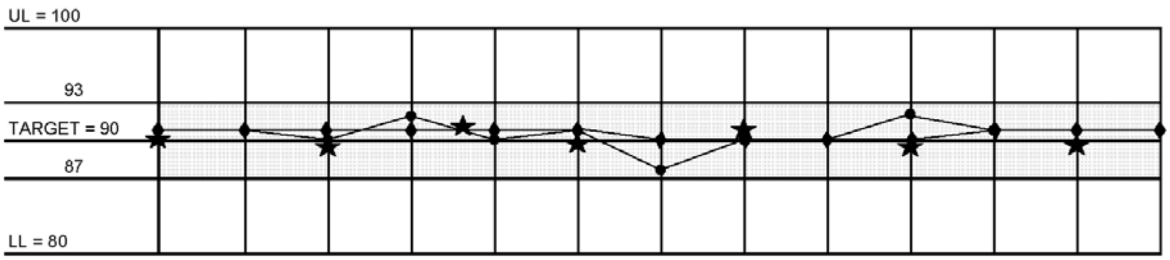
Remarks:

SAND QUALITY CONTROL CHART

Plant Quickmix - Mill City

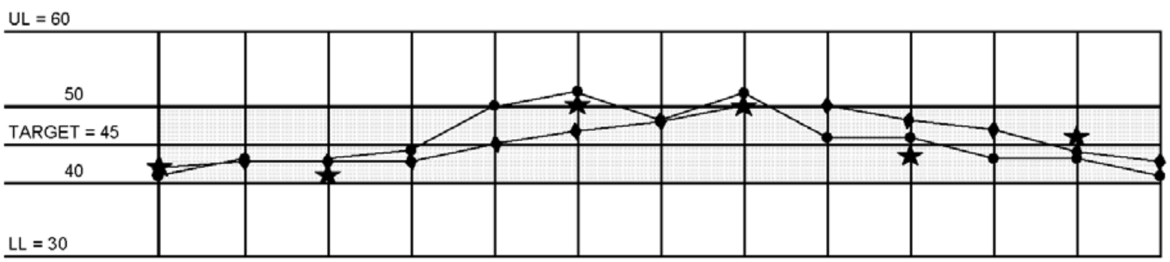
SAMPLE #	12	13	14	15	16	17	18	19	20	21	22	23	24
DATE	4/1	4/2	4/3	4/3	4/7	4/7	4/8	4/9	4/24	4/25	4/25	4/28	4/29
TIME	6:30a	6:00a	9:00a	1:00p	6:30a	2:30p	6:00a	7:00a	6:00a	6:00a	12:00p	6:00a	6:00a

SIEVE: ***#8*** **RANGE:** ***80-100***



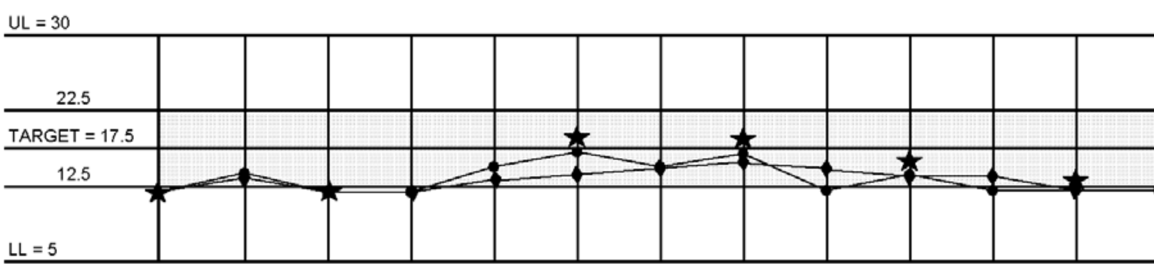
RESULTS	91	91	90	92	90	91	88	90	90	92	91	91	91
RUNNING AVG	91	91	91	91	91	91	90	90	90	90	91	91	91

SIEVE: ***#30*** **RANGE:** ***30-60***



RESULTS	41	43	43	44	50	52	48	52	46	46	43	43	41
RUNNING AVG	42	43	43	43	45	47	48	50	50	48	47	44	43

SIEVE: ***#50*** **RANGE:** ***5-30***



RESULTS	12	14	12	12	15	17	15	17	12	14	12	12	12
RUNNING AVG	12	13	12	12	13	14	15	16	15	14	14	12	12

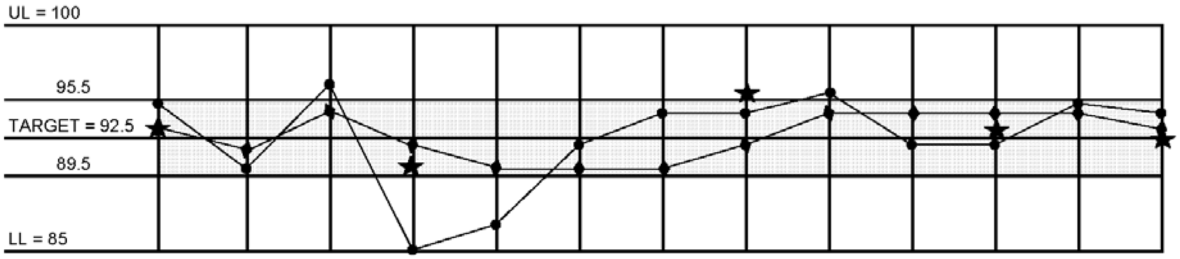
★ STATE RESULTS

CA-50 QUALITY CONTROL CHART

Plant Quickmix - Mill City

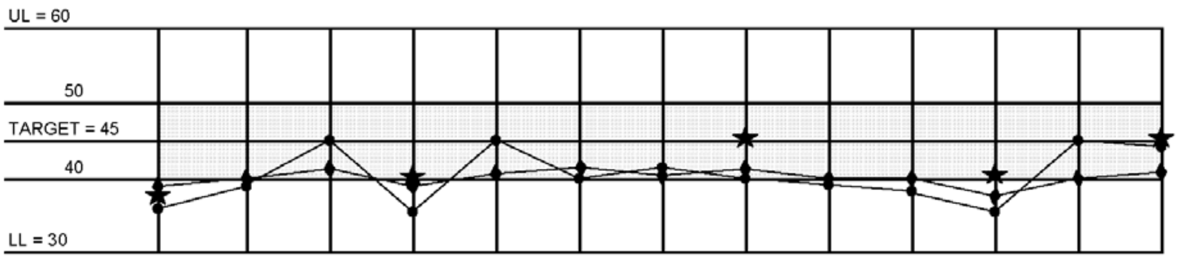
SAMPLE #	20	21	22	23	24	25	26	27	28	29	30	31	32
DATE	4/1	4/1	4/2	4/3	4/3	4/7	4/7	4/7	4/8	4/8	4/9	4/24	4/25
TIME	6:30a	12:00p	6:00a	9:00a	1:00p	6:30a	9:15a	2:30p	6:00a	9:00a	7:00a	6:00a	6:00a

SIEVE: ***3/4"*** **RANGE:** ***85-100***



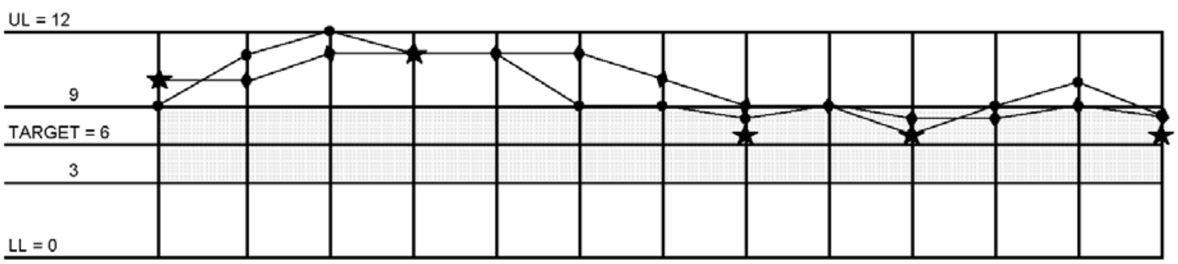
RESULTS	95	90	97	85	87	92	94	94	96	92	92	95	94
RUNNING AVG	93	91	94	92	90	90	90	92	94	94	94	94	93

SIEVE: ***3/8"*** **RANGE:** ***30-60***



RESULTS	36	39	45	36	45	40	42	40	39	38	36	45	44
RUNNING AVG	39	40	42	39	41	42	41	42	40	40	38	40	41

SIEVE: ***#4*** **RANGE:** ***0-12***



RESULTS	9	11	12	11	11	9	9	8	9	7	9	10	8
RUNNING AVG	10	10	11	11	11	11	10	9	9	8	8	9	8

★ STATE RESULTS

5-694.723 CERTIFICATE OF COMPLIANCE (Form 0042)

This form is filled out by the Ready-Mix Plant Producer for all loads of concrete produced for the Agency. The Certificate of Compliance (batch ticket) shall include all the data specified in the latest version of the requirements for "Certified Ready-Mix Concrete Plants". The ticket must accompany the load to the jobsite where it is handed to the Agency Representative.

The Inspector at the job site must obtain the Certificate of Compliance prior to accepting the load of concrete. Reject any load that arrives on the job without a Certificate of Compliance. Report any job site modification in the batch contents on this ticket. Examples of such changes are – "added 5 gallons of water," "12 oz. of air entraining admixture (A.E.A.) (show brand) added with 4 gallons of water," or "10 lb. of calcium chloride in solution totaling 4 gallons added." Place all field test results for slump, air, air temperature, concrete temperature, cylinder numbers and location on the ticket and sign it.

The Certificate of Compliance shall consist of a single sheet maximum. If the computer that generates the Certificate of Compliance malfunctions, the Producer may finish any pours that are in progress provided the plant issues handwritten Certificates of Compliance on the most current version of Mn/DOT Form 0042. New pours are not permitted to begin without a working computerized Certificate of Compliance. See Figure B 5-694.723 for a completed example.

See Figure A 5-694.723 for an example that corresponds to the numbers below. The Certificate of Compliance shall include:

1. Name of the ready-mix concrete plant and location
2. Name of the Contractor
3. Date
4. State Project Number (S.P.)
5. Bridge Number (when applicable)
6. Time concrete was batched/discharged
7. Truck number
8. Quantity of concrete in this load
9. Running total quantity of this concrete mix batched on this day for this project
10. Type of concrete (Mn/DOT Mix Designation Number)
11. Cement brand and production mill
12. Fly ash brand and production power plant
13. Admixture brand and product name
14. Pit number for each aggregate source
15. Admixture quantity per 100 wt. cementitious and/or ml/m^3 (oz/yd^3) for:
    - air entraining admixtures
    - water reducing admixtures
    - other admixtures
16. Design weights (Oven Dry) per m^3 (yd^3) for:
    - cement
    - fly ash
    - each coarse aggregate

- fine aggregate (sand)

17. Design water weight
18. Target and Actual batched weights for:
    - cement
    - fly ash
    - each coarse aggregate fraction
    - fine aggregate (sand)
    - actual water added
    - any trim water added
19. Total water (Batch Water + Free Moisture) (kg. or lb.)
20. The ticket shall also include the following information printed with enough room beside each item to allow the Field Inspector to record the appropriate test results: air content, air temperature, concrete temperature, slump, cylinder number, and location/part of structure.

Items 11, 12, 13, 14, and 16 are needed only on the first Certificate per day per mix designation or when one of these items changes.

21. Producer's signature
    a. Metro District

    All concrete batched in the Metro District requires a computerized Certificate of Compliance.

    The signature of a Certified Technician is required on the first Certificate of Compliance of each Agency pour. The Technician must verify the following when signing the first Certificate of Compliance:

    1. The mix designation and all required specification information are correct.
    2. The 1 cubic meter (1 cubic yard) oven dry batch weights are correct.
    3. The current moisture data on aggregates have been entered in the batching system.
    4. The batching system is weighing accurately.

    b. Out-state Districts

    Computerized Certificates of Compliance are required when Contract quantities exceed 385 cubic meters (500 cubic yards) for general concrete work and 155 cubic meters (200 cubic yards) for bridge concrete.

    For Contracts that do not exceed the limits addressed above, the Ready-Mix Producer may use handwritten *Certificates of Compliance* (Form TP00042). See Figure A 5-694.723.

    The Producer must sign the Certificate of Compliance for each individual truckload of ready-mixed concrete at the time of delivery. The Producer must verify the following when signing the first Certificate of Compliance:

    1. The mix designation and all required specification information are correct.
    2. The 1 cubic meter (1 cubic yard) oven dry batch weights are correct.
    3. The current moisture data on aggregates have been entered in the batching system.
    4. The batching system is weighing accurately.

TP 0042-02 (3/2000)

Minnesota Department of Transportation

Certificate of Compliance

Ready-Mix Plant		Contractor		S. P.	Date
1		2		4	3
Bridge 5	Mix # 10	Truck # 7	Time Batched 6	Quantity this load 8 yd^3	Cumulative quantity 9 yd^3

	Design Wt. (C.Y.)	Total Moisture	Free Water	Target Batch (C.Y.)	Target Batch Weight	Actual Batch Weight	Manufacturer & Mill or Power Plant/Aggregate Source & Pit #
Cement	16				18	18	11
Fly Ash	16				18	18	12
Sand	16				18	18	14
CA 3/4+	16				18	18	14
CA 3/4-	16				18	18	14
CA	16				18	18	14
Water	17				18	18	
Total Water (Free Plus Batched)						19	

Total Water Available to Add at Jobsite	Gal.	Total Water Added at Jobsite	Gal.	Total Water	Lbs.
	(Target – Actual)/8.33				Water Added at Jobsite*8.33 + Total Water (Actual)

Admixture	Dose		Manufacturer/Type
Air Entraining Agent	15	oz/c.y.	13
Admixture # 1	15	oz./cwt.	13
Admixture # 2	15	oz./cwt.	13

Plant Representative Comments and Signature

21

Field Tests				Field Comments
Location (Station, etc.) 20				
Air Temp. 20	Conc. Temp. 20		Cyl. # 20	
Air Content (%) 20		Slump 20		

TP 0042-02 (3/2000)

Minnesota Department of Transportation

Certificate of Compliance

Ready-Mix Plant		Contractor		S. P.	Date
Quickmix - Mill City		Pebble Brothers		1020-30	4/1/2003
Bridge # 89006	Mix # 3Y43F	Truck # 10	Time Batched 8:55a	Quantity this load 10 yd³	Cumulative quantity 10 yd³

	Design Wt. (C.Y.)	Total Moisture	Free Water	Target Batch (C.Y.)	Target Batch Weight	Actual Batch Weight	Manufacturer & Mill or Power Plant/Aggregate Source & Pit #
Cement	549			549	5490	5480	Holcim - Mason City, IA
Fly Ash	97			97	970	980	NSP - Eagan, MN
Sand	1193	57	48	1250	12500	12520	123456 Salinger - Lakeland
CA 3/4+							
CA 3/4-	1276	20	3	1296	12960	12920	123456 Salinger - Lakeland
CA- 3/8-	547	13	4	560	5600	5640	134567 Rock Island - Falls City
Water	271		(55)	215	2150	2000	
Total Water (Free Plus Batched)					2710	2550	

Total Water Available to Add at Jobsite	19 Gal.	Total Water Added at Jobsite	5 Gal.	Total Water	2592 Lbs.
	(Target – Actual)/8.33				Water Added at Jobsite*8.33 + Total Water (Actual)

Admixture	Dose	Manufacturer/Type
Air Entraining Agent	14 oz/c.y.	Euclid - AEA 92
Admixture # 1	oz./cwt.	
Admixture # 2	oz./cwt.	

Plant Representative Comments and Signature

Mike Boulder

Field Tests				Field Comments
Location (Station, etc.) End Diaphragm, South				
Air Temp. 54°F	Conc. Temp. 70°F		Cyl. # 3	
Air Content (%) 6.2%		Slump 3.5		

5-694.724 CERTIFIED READY-MIX PLANT DAILY DIARY

Producer's Technicians are required to maintain a daily plant diary that includes the following information: State Project number, yards produced each day, tests performed, material problems, breakdowns, weather, etc., all to the approval of the Engineer.

CERTIFIED READY MIX PLANT DIARY

Plant Quickmix - Mill City **Date** 4/1/2003

Technician John Stone **Weather Conditions** Cloudy 60°

SP	MIX	QTY (m^3,y^3)
1020-30	3Y43	185

	Gradation Test ID Numbers					
Fine	12					
Coarse	20	21				

	Time Scales Set					
Moisture	7:15A	10:05A	1:10P			

Remarks 3/4- ran on the fine side for two consecutive tests. I informed Plant 2 Technician Mike Boulder and called Bill Dozer of Salinger Aggregates.

CERTIFIED READY MIX PLANT DIARY

Plant Quickmix - Mill City **Date** 4/2/03

Technician John Stone **Weather Conditions** Sunny 70°

SP	MIX	QTY (m^3,y^3)
1020-30	3Y43	72

	Gradation Test ID Numbers					
Fine	13					
Coarse	22					

	Time Scales Set					
Moisture	6:30A					

Remarks Met with Bill Dozer. He feels Salinger has identified the aggregate problem and it is corrected.

5-694.725 WEEKLY CERTIFIED READY-MIX PLANT REPORT (Form 24143)

This form is required for Certified Ready-Mix. The Agency Plant Monitor fills out this form. It contains a summary of each week's verification (audit) samples and documents the water content of the observed loads. The original stays with the job file and a copy is sent to the Mn/DOT Concrete Engineering Unit. See Figure A 5-694.725.

5-694.726 AGENCY PLANT MONITOR DAILY DIARY

Agency Plant Monitors are required to maintain a daily plant diary that includes the following information: Time arrived at plant; State Project number; quantity (estimate if necessary) of each mix produced; materials and sources; ID number and type of samples taken; time of departure; additional observations and comments; and the Monitor's signature.

QUICKMIX – MILL CITY 4/1/03

INSP: TOM SANDS
ARR: 8:30 a.m.
DEP: 10:35 a.m.
LAB SAMPLES: #2 CEMENT, #2 FLYASH,
#6A SAND, 3/8- & 3/4-
#12C SAND & #20C 3/8- AND 3/4-
MATERIALS:
SAND & 3/4- = SALINGER - LAKELAND PIT #123456
3/8- = ROCK ISLAND - FALLS CITY PIT 134567
CEMENT = HOLCIM – MASON CITY, IA
FLY ASH = NSP - EAGAN, MN
COMMENTS: JOHN STONE, QUICKMIX'S LEVEL I TECHNICIAN COMPLETED QC TESTING @ 7:15 a.m. FOR TODAY'S SCHEDULED POUR @ 8:00 a.m. THE 3/4- GRADATION (#20C) WAS ON THE FINE SIDE TODAY. JOHN CONTACTED THE PIT TO SEE IF ADJUSTMENTS COULD BE MADE. NO OTHER PROBLEMS.

PROJECTED PRODUCTION:
S.P. 1020-30 3Y43F 160 CY

Tom Sands

TP-24143-04 (2/2003)

Minnesota Department of Transportation

Weekly Certified Ready-Mix Plant Report

Plant: Quickmix – Mill City   Week Ending: 4/5/03

List all S.P.'s used during the week: 1020-30

Source Fine Aggregate: Salinger - Lakeland   Pit # 123456

Source Coarse Aggregate: Salinger - Lakeland   Pit # 123456

Source Coarse Aggregate: Rock Island – Falls City   Pit # 134567

Source Coarse Aggregate: ____   Pit # ____

Source Coarse Aggregate: ____   Pit # ____

Source Cement: Holcim Mason City   Source Fly Ash: NSP - Eagan

Source AEA: Euclid – AEA92   Source Other (Slag, etc) ____

Source Admixtures: ____

	SUN		MON		TUE		WED		THUR		FRI		SAT	
Date					4/1		4/2		4/3					
Yd³ Produced					185		72		196					
	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse
Producer Gradations					1	2	1	1	1	2				
Companion Gradations Run														
S.P.					1020-30		1020-30		1020-30					
Mix Designation					3Y43F		3Y43F		3A22F					
Time of Batch					8:55a		10:00a		10:45a					
Total Free Water lb/yd³					56		43		39					
Batch Water lb/yd³					200		202		183					
Total Water lb/yd³					256		245		222					
Design Water lb/yd³					271		271		245					
Inspector					T.S.		T.S.		T.S.					

Fine Aggregate Verification Samples

Date	4/1	4/3			
FA#	6	7			
3/8"	100	100			
#4	100	99			
#8	90	89			
#16	73	73			
#30	42	41			
#50	12	12			
#100	2	1			
FM	2.81	2.85			
#200	1.0	.8			
INSP	T.S.	T.S.			

Coarse Aggregate Verification Samples

Date	4/1	4/3						
CA#	6	7						
2"								
1 1/2"								
1 1/4"								
1"	100	100						
3/4"	93	90						
5/8"	83	79						
1/2"	58	53						
3/8"	38	40						
#4	10	11						
INSP	T.S.	T.S.						

5-694.727 WEEKLY CONCRETE REPORT (Form 2448)

This form is a summary of data relating to concrete production including mix design, test results, quantities, etc. and is submitted weekly to the Mn/DOT Concrete Engineering Unit. An interactive computerized version is available on the website which has point and click capabilities, drop down boxes, and automatic calculations.

Item numbers listed below correspond to the numbers on Figure A 5-694.727. See Figure B 5-694.727 for a completed example of a *Weekly Concrete Report* (Form 2448).

Instructions for Completing the Weekly Concrete Report

Item 1: Low S.P.
Use the lowest S.P. or S.A.P. Number for project. Do not create separate reports for each S.P. on a project.

Item 2: Bridge #
If concrete was placed on any part of a bridge structure, list the Bridge Number.

Item 3: Engineer
List the name of the Project Engineer or Project Supervisor.

Item 4: Inspector
List the name of the Chief Inspector responsible for the concrete listed in the weekly report.

Item 5: Contractor
For Ready-Mix list the Concrete Contractor. For paving jobs list the Paving Contractor.

Item 6: Batch Plant
For Ready-Mix Concrete, list the name and the city of the plant. If there is more than one plant with the same name, list the plant number (i.e. Togo Ready-Mix No. 3). If the concrete comes from 2 different plants - 2 Weekly Concrete Reports are required.

Item 7: Report #
Number the reports for each project sequentially starting with Number 1.

Item 8: Week Ending
Enter last date (M/D/YY) (Saturday) of current construction week.

Item 9: Size/Type
List the type of cement (I, II, or III).
List the fly ash class (C or F).
List the grade of slag (100 or 120).
Other is for microsilica, etc.
List the size fractions of aggregate (Sand, 3/4-, 3/4+, CA-50, etc.).
For Admixtures list the type (A, B, A(MR), etc.)

Item 10: Pit # or Manufacturer
The cement, fly ash, pit numbers, and other admixture information are found on the Certificate of Compliance. The pit number is also found on the Mix Design issued by Mn/DOT Concrete Engineering Unit or Paving Contractor's Approved Mix Design.

Item 11: Specific Gravity
This number is found on the Mix Design issued by the Mn/DOT Concrete Engineering Unit or Paving Contractor's Approved Mix Design. Use specific gravity of 2.58 for fly ash used at Ready-Mix Plants. Use the individual fly ash specific gravity for paving projects.

Item 12: Absorption Factor
This number is found on Mix Design issued by Mn/DOT Concrete Engineering Unit or Paving Contractor's Approved Mix Design.

Item 13: Mix Designation and Design Weights
List the mix designation and oven dry design weights for each mix. These weights are found on Mix Design issued by Mn/DOT Concrete Engineering Unit or Paving Contractor's Approved Mix Design. List the admixture dosage. This number can be found on the Certificate of Compliance or the Paving Batch Ticket.

Item 14: Design Water
This weight is found on Mix Design issued by Mn/DOT Concrete Engineering Unit or Paving Contractor's Approved Mix Design.

Item 15: Mix
List the mix designation for the load tested.

Item 16: Date
List the date (M/D/YY) the concrete was placed.

Item 17: Location
List stations for paving jobs. List component name for other work, i.e. W. Abutment, Pier Col #1, SE Wingwall, etc.

Item 18: Time
Indicate the time that the concrete was batched. To display time correctly, type in the actual time, then space, then A or P (8:42 P).

General Notes on Items 19-24

Record ALL concrete tests on this page. Record extra tests taken in addition to those required by the “Schedule of Materials Control.” DO NOT list any test averages, instead, list each test INDIVIDUALLY. Attach additional sheets if necessary.

Item 19: % Air
Record the air content to the nearest 0.1%. Compare results with specification 2461.4A4b. Air contents should range between 5% and 8% with a target of 6.5%.

Item 20: Slump
Record the slump to the nearest 5 mm (1/4 in.). Compare the results with Specification 2461.4A4a.

Item 21: Total Actual Water
Indicate the total water in kilograms per cubic meter (pounds per cubic yard) of concrete. This is the sum of the total water printed on the batch ticket and any additional water added at the plant and/or job site divided by the batch size.

Item 22: Cylinder/Beam No.
Indicate the field number of the test specimen. For cylinders, list the field ID number submitted on the *Cylinder ID Card* (Form 2409).

Item 23: Air Temperature
Indicate the ambient air temperature at the time the concrete tests were taken.

Item 24: Concrete Temperature
Indicate the concrete temperature at the time the concrete tests were taken.

Item 25: Water Ratio
This number is determined by dividing the total actual water (Item 21) by the design water (Item 14). This number should not be more than 1.04.

$$\text{Water Ratio} = \frac{\text{Total Actual Water}}{\text{Design Water}}$$

Item 26: Water/Cementitious Ratio
This number is determined by dividing the total actual water (Item 21) by the total design cementitious. Total cementitious includes cement, fly ash, slag, etc.

$$\text{Water/Cement Ratio} = \frac{\text{Total Actual Water}}{\text{Total Design Cementitious}}$$

Item 27: Remarks
List additional information or comments, i.e. change in air added at plant or jobsite, why some test results are out of spec, or where an air test was taken, etc.

Item 28: Additional Remarks
This space is for additional remarks that may have come up during the week that may affect the quality of the concrete.

Item 29: Mix Number
Enter the mix designations used on the project during this week.

Item 30: Date
List the date for each day of the week.

Item 31: Daily Totals
Enter daily totals in cubic meters (cubic yards) for each mix design used.

Item 32: Daily Totals (m^3 or yd^3)
List the daily totals in cubic meters (cubic yards) for all mixes.

Item 33: Weekly Totals (m^3 or yd^3)
List the total quantities for each mix.

Item 34: Grand Total
List the sum total of cubic meters (cubic yards) of concrete placed during the week.

Item 35: Inspector
Handwritten signature of person who filled out Weekly Concrete Report.

Item 36: Phone Number
Phone number of person who filled out Weekly Concrete Report.

Item 37: Engineer/Supervisor
The Project Engineer or Project Supervisor signs the completed report after they have reviewed the document for accuracy.

Mn/DOT WEEKLY CONCRETE REPORT (ENGLISH) - Form 2448-04 (6/20/2002)

Low S.P.	1
Bridge #	2
Engineer	3
Inspector	4
Contractor	5
Batch Plant	6
Report #	7
Week Ending	8

Material	Size/ Type	Pit # or Manufacturer	Specific Gravity	Absorp. Factor	Mix #1	Mix #2	Mix #3	Mix #4	Mix #5	Mix #6
					13					
Cement	9	10	3.15		13					
Fly Ash	9	10	11		13					
Slag	9	10	11		13					
Other	9	10	11		13					
F Agg 1	9	10	11	12	13					
F Agg 2	9	10	11	12	13					
C Agg 1	9	10	11	12	13					
C Agg 2	9	10	11	12	13					
C Agg 3	9	10	11	12	13					
C Agg 4	9	10	11	12	13					
Admix 1	AEA	10			13					
Admix 2	9	10			13					
Admix 3	9	10			13					
				Design Water	14					

Mix	Date	Location	Time	% Air	Slump (in)	Total Act. Water (lb/c.y.)	Cylinder/ Beam #	Air Temp °F	Concrete Temp °F	Water Ratio	W/C Ratio	Remarks
15	16	17	18	19	20	21	22	23	24	25	26	27

Additional Remarks:	Mix Number	30	30	30	30	30	30	30	Week Totals yd^3
28	29	31	31	31	31	31	31	31	33
	29	31	31	31	31	31	31	31	33
	29	31	31	31	31	31	31	31	33
	29	31	31	31	31	31	31	31	33
	29	31	31	31	31	31	31	31	33
	29	31	31	31	31	31	31	31	33
	Daily Totals yd^3	32	32	32	32	32	32	32	34

Inspector: 35 Phone Number: 36 Engineer/Supervisor: 37

Mn/DOT WEEKLY CONCRETE REPORT (ENGLISH) - Form 2448-04 (6/20/2002)

Low S.P.	1020-30
Bridge #	89002, 89003, 89006
Engineer	Clay Pitts
Inspector	Tom Sands
Contractor	Pebble Brothers
Batch Plant	Quickmix - Mill City
Report #	1
Week Ending	4/5/2003

Material	Size/ Type	Pit # or Manufacturer	Specific Gravity	Absorp. Factor	Mix #1 1A43	Mix #2 3A22	Mix #3 3A32	Mix #4 3Y43	Mix #5	Mix #6
Cement	I	Holcim@Mason City, IA	3.15		507	455	481	549		
Fly Ash	C	NSP@Eagan, MN	2.58		89	80	85	97		
Slag										
Other										
F Agg 1	Sand	123456	2.64	0.008	1372	1256	1229	1193		
F Agg 2										
C Agg 1	3/4-	123456	2.70	0.014	1296	1345	1316	1276		
C Agg 2	3/8-	134567	2.65	0.016	556	576	564	547		
C Agg 3										
C Agg 4										
Admix 1	AEA	Euclid - AEA 92				17 oz./c.y.	14 oz./c.y.	14 oz./c.y.		
Admix 2										
Admix 3										
				Design Water	276	245	262	271		

Mix	Date	Location	Time	% Air	Slump (in)	Total Act. Water (lb/c.y.)	Cylinder/ Beam #	Air Temp °F	Concrete Temp °F	Water Ratio	W/C Ratio	Remarks
3Y43	4/1/2003	End Diaphragm, South	8:55 AM	6.2%	3.5	260	3	54	70	0.96	0.40	Bridge 89006
3Y43	4/1/2003	End Diaphragm, South	10:15 AM			258				0.95	0.40	Bridge 89006
3Y43	4/1/2003	End Diaphragm, South	11:15 AM	5.2%	3.75	252				0.93	0.39	Bridge 89006
3Y43	4/1/2003	End Diaphragm, South	1:25 AM	6.1%		254		59	72	0.94	0.39	Bridge 89006 AEA = 19 oz./c.y.
3Y43	4/2/2003	Wing Wall	8:15 AM	7.0%	3.5	250				0.92	0.39	Bridge 89002
3Y43	4/2/2003	Wing Wall	10:00 AM		3.75	245				0.90	0.38	Bridge 89002
3A22	4/3/2003	Curb and Gutter	10:20 AM	6.2%		212				0.87	0.40	
3A22	4/3/2003	Curb and Gutter	10:45 AM	5.8%	1.25	222				0.91	0.41	
3A22	4/3/2003	Curb and Gutter	11:15 AM		1	220				0.90	0.41	
3A32	4/3/2003	Curb and Gutter	12:30 AM	6.0%		242		68	70	0.92	0.43	
3A32	4/3/2003	Curb and Gutter	1:55 AM	5.8%	2	240		70	70	0.92	0.42	

Additional Remarks:

Mix Number	3/30/2003	3/31/2003	4/1/2003	4/2/2003	4/3/2003	4/4/2003	4/5/2003	Week Totals yd³
1A43								
3A22					180.00			180.00
3A32					16.00			16.00
3Y43			185.00	72.00				257.00
Daily Totals yd³			185.00	72.00	196.00			453.00

Inspector: Tom Sands Phone Number: 651-123-4567 Engineer/Supervisor: Clay Pitts

5-694.730 CONCRETE PAVING REPORTS AND WORKSHEETS

All of the reports and worksheets in sections 5-694.730 through 5-694.745 are used on concrete paving projects. These sections include descriptions and examples of each form. **To obtain a blank form, download a copy of the form from the Mn/DOT Concrete Engineering website at www.mrr.dot.state.mn.us/pavement/concrete/forms.asp.**

5-694.731 CONTRACTOR MIX DESIGN REQUEST FORM

A minimum of 15 days prior to the start of paving operations, the Contractor must submit a *Request for Concrete Mix Approval* and *Job Mix Formula (JMF)* to the Mn/DOT Concrete Engineering Unit for review and approval. The mix is designed by the Contractor based on a volume of 1 cubic meter (cubic yard) according to industry standard practice. The concrete should be designed as Grade A with a water cementitious ratio not greater than 0.40. The JMF contains proportions of materials and individual gradations of each material plus a composite gradation of all materials. The Contractor must also submit working range limits that are shown in the Contract. See Figures A and B 5-694.731 for examples of a Contractor Mix Design and JMF submittal.

5-694.732 PAVING CONTACT REPORT (Form 2164)

Prior to the beginning of a project, an Agency Representative shall perform a thorough on-site inspection of the concrete plant in order to complete a Concrete Paving Plant Contact Report. This Contact Report contains the information necessary to assure that the plant is able to produce concrete meeting specifications, and has a signature block for the Contractor Representative verifying that the plant will remain in that condition. See Figure A 5-697.732 (1-4).

5-694.733 CONCRETE BATCHING REPORT (Form 2152)

This form is for calculating and proportioning mixes by either Mn/DOT or Contractor Technicians. The moisture results are used by the Contractor to make adjustments to the mix design. The free moisture calculated by this test is used on the Microwave Oven Worksheet to determine the water/cementitious (w/c) ratio of the concrete. See Figure A 5-694.733.

REQUEST FOR CONCRETE MIX APPROVAL

Requested by C. Calloway Phone 612-345-6789

Firm Name TUV Paving

Agency Engineer/Inspector Tom Sanders S.P. 8901-23

Proposed Aggregate Sources

	CA #1	CA #2	CA #3	CA #4	Sand
Pit Number	#188888	#188888	#177777		#199999
Pit Name	Rock Island	Rock Island	Pebble Pit		Salinger
Nearest Town	St. Cloud	St. Cloud	St. Cloud		Freeport
Size	1 1/2"	3/4"	3/8"		
Sp.G. & Abs. (Provided by MN/DOT)	2.77 .003	2.74 .004	2.65 .012		2.62 .011

Proposed Cementitious Sources

	Cement	Fly Ash	Other
Manufacturer/Distributor	Graymatter	Asher	
Mill/Power Plant	St. Paul, MN	Carter, MN	
Type/Class	I	C	
Specific Gravity	3.15	2.60	

Proposed Mix Designs

MN/DOT Mix Number	3A21	3A41	3A21HE
Water (lb./C.Y.)	208	212	216
Cement (lb./C.Y.)	450	450	530
Fly Ash (lb./C.Y.)	130	140	70
Other Cementitious (lb./C.Y.)			
W/CM Ratio	0.36	0.36	0.36
Sand (Oven Dry, lb./C.Y.)	1090	1085	1095
CA #1 (Oven Dry, lb./C.Y.)	770	680	775
CA #2 (Oven Dry, lb./C.Y.)	910	985	870
CA #3 (Oven Dry, lb./C.Y.)	390	390	390
CA #4 (Oven Dry, lb./C.Y.)			
% Air Content	6.5%	6.5%	6.5%
Admix#1(oz/100#CMT;oz/yd^3) Ajax	4.0 oz/yd^3*	3.5 oz/yd^3*	5.0 oz/yd^3*
Admix#2(oz/100#CMT;oz/yd^3) WRXX	35.0 oz/yd^3	36.0 oz/yd^3	30.0 oz/yd^3
Admix#3(oz/100#CMT;oz/yd^3)			

*Must be adjusted to maintain air content

The above mixes are approved for use, contingent upon satisfactory site performance and continuous acceptability of all materials sources, by:

Max Designer 4/1/2003

Concrete Engineering Specialist DATE

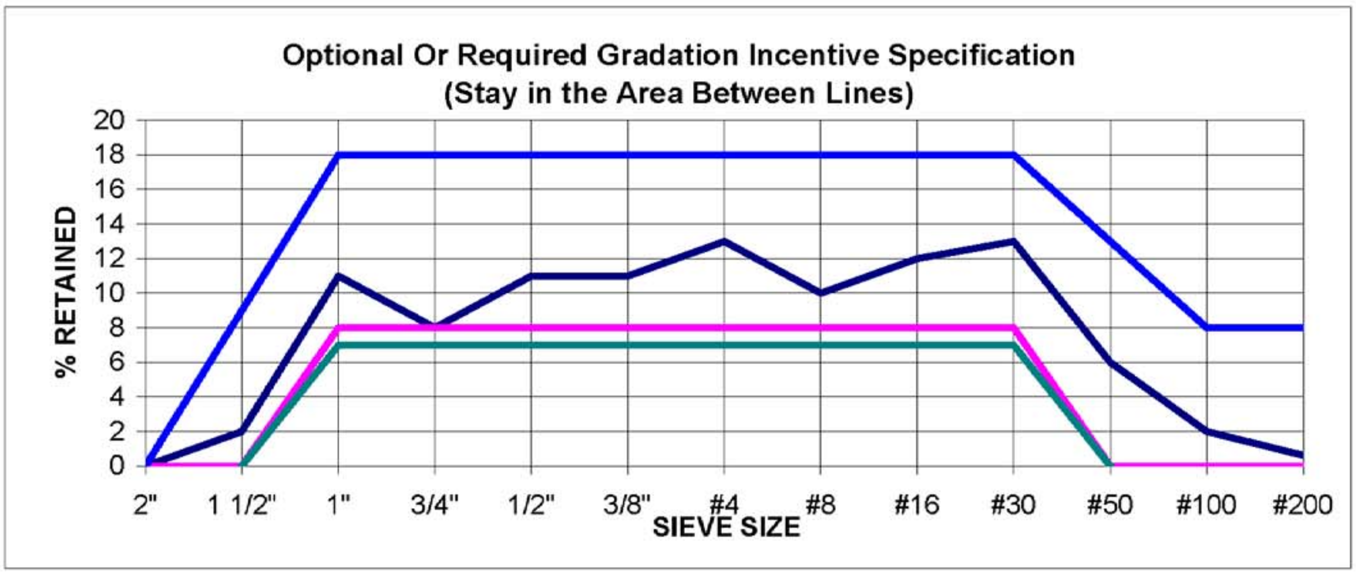
Comments:

8901-23 JMF submittal.xls
Job Mix Formula

AGGREGATE SIZE PROPORTION, %	CA #1 1 1/2" 14.00%	CA #2 3/4" 32.00%	CA #3 3/8" 12.00%	CA #4	FA #1 Sand 42.00%	FA #2	TOTAL % PASSING 100.00%	WORKING RANGE LIMITS	JMF WORKING RANGE		TOTAL % RETAINED
2"	100.0	100.0	100.0		100.0		100	± 5	95	100	0
1 1/2"	84.0	100.0	100.0		100.0		98	± 5	93	100	2
1"	7.5	100.0	100.0		100.0		87	± 5	82	92	11
3/4"	1.5	79.0	100.0		100.0		79	± 5	74	84	8
1/2"	1.1	46.0	92.0		100.0		68	± 5	63	73	11
3/8"	0.0	22.5	67.0		100.0		57	± 5	52	62	11
#4	0.0	2.1	7.5		100.0		44	± 5	39	49	13
#8	0.0	0.0	0.0		81.0		34	± 4	30	38	10
#16	0.0	0.0	0.0		52.0		22	± 4	18	26	12
#30	0.0	0.0	0.0		21.5		9	± 4	5	13	13
#50	0.0	0.0	0.0		7.0		3	± 3	0	6	6
#100	0.0	0.0	0.0		2.9		1	± 2	0	3	2
#200	0.0	0.0	0.0		0.9		0.4	1.6% max	0.0	2.0	1

Workability Factor
(% passing #8)
34

Coarseness Factor
(% retained above 3/8" / % retained above #8)
65



TP-2164-01 (3/2002) dual

Minnesota Department of Transportation

Contact Report – Paving 2003

Owner's Name: TUV Paving Date: 5/1/2003

Set Up Location: St. Cloud Phone: 612-987-6543

Plant Superintendent: Bill Batcher Fax: 612-987-3456

Prior to the production of Agency concrete **for a paving project**, an Agency Representative shall perform a thorough on-site inspection of the portable concrete plant to assure that the plant can produce concrete meeting Mn/DOT Specifications.

In addition, the Concrete Producer must also provide the following copies of documentation:

- [√] **Lab Equipment Calibrations** Producer must check and calibrate the sieves prior to starting production. The date of calibration should be clearly marked on the equipment using the procedures described in the Mn/DOT Lab Manual 2001, 2002, 2008, and 2009.
- [√] **Scale and/or Meter Calibrations** An approved scale company or the Minnesota Department of Public Service must check and calibrate the scales. They are checked each time a portable plant is set-up. Calibrations are made using the procedures described in the Mn/DOT Concrete Manual 5-694.431 and 5-694.433.
- [√] **Batch Ticket** A computerized ticket that includes all Mn/DOT Specifications and supporting information.
- [√] **Technicians**

Mn/DOT Certified Plant 1 Technician Whitey Walker Cert # 996633

Mn/DOT Certified Plant 1 Technician ____________ Cert # ______

Mn/DOT Certified Plant 2 Technician Sandy Beaches Cert # 991188

Mn/DOT Certified Plant 2 Technician Cell phone # 612-987-1111

Agency Representative: Leo Bean

- [√] Approved for concrete paving production on S.P. 8901-23
- [ ] Re-inspected and approved on ____________ by ____________
- [ ] Not approved for the following reason/s: ____________

The Concrete Producer agrees to maintain all plant and laboratory equipment within allowable tolerances as set forth in the Mn/DOT Specifications, to have all required tests run by a Plant Level I Technician certified by Mn/DOT, and to have the Plant Level II Technician certified by Mn/DOT on site at all times or available at the plant site in a reasonable time frame when called.

After completing the Concrete Plant Contact Report, any procedural changes that cause non-compliance will result in cessation of further production of Agency concrete.

Verified by: Bill Batcher

Plant Representative

Plant and Lab

Type of Mixer:

Type of Plant: Ready Mix _____ Paving __X__

Make: __Rex__ Model: __S__

Condition: __Serviceable__

Single Drum _____ Dual Drum __X__

Max. mixer batch size __8__ yd^3

Batching Equipment: Make: __Seltec__ Model: __1A__

All Dump Trucks are equipped with vibrators (y/n): __Y__ (Spec 2301.3D)

Batch Ticket:

Computerized Batch Printout (y/n)**: __Y__ English/Metric Conversion: __Y__

NOTE: The (**) items are required

____ **a**. Name of Plant
____ **b**. Contractor
__X__ **c**. Date
__X__ **d**. Agency Project #
__X__ **e**. Mixing Time
__X__ **f**. Batch Time
____ **g**. Truck #
__X__ **h**. Yd^3/load
__X__ **i**. Yd^3/Cum
__X__ **j**. Mix Design
____ **k**. Cement Brand & Mill
____ **l**. Fly Ash Power Plant
____ **m**. Admix Product Name
____ **n**. Pit Number
__X__ **o**. Admix Qty
____ **p**. Design Wts
____ **q**. Design Water
__X__ **s**. W/C Ratio
__X__ **r**. **Target and Actual Batched Wts of all components; and Trim and Total Water Wts

Scale and Meter Information:

Material	Type	Make	Capacity	Graduation	Date of Scale and Meter Calibration
Cement	Digital	Seltec	10,000 lb.	5 lb.	4/30/2003
Fly Ash	Digital	Seltec	10,000 lb.	5 lb.	4/30/2003
Slag					
Aggregate	Digital	Seltec	40,000 lb.	20 lb.	4/30/2003
Water Scale					
Water Meter	Digital	Badger	300	1 gallon	4/30/2003

Plant Lab – Office (2301.3A2):

Dimensions

__X__ Total Floor Area (224 ft^2)
__X__ Total Lab Area (144 ft^2)
__X__ Total Office Area (80 ft^2)
__X__ Areas Separated by a Wall

Plant Office

__X__ 2 Desks
__X__ Sufficient Seating
__X__ 2 file cabinets
__X__ Working Telephone

Plant Lab Furnishings

__X__ Workbench (30 in. x 144 in.)
__X__ Shelf Space (8 ft. x 8 in.)

__X__ Working Fax Machine (with cellular capability or dedicated line)
__X__ Working Copy Machine (or Fax machine with copier)

Materials

Cementitious Materials:

Material	Supplier w/Mill	# of Silos	Capacity (tons)	Delivered To Hopper By (gravity, auger)
Cement	Graymatter @ St. Paul, MN	1	240	Auger
Fly Ash	Asher @ Carter, MN	1	75	Auger
Slag				
Other				

Automatic Cement Recording __y__

Admixtures:

Type	Supplier	Name of Product	Sampled At (dispensing tubes recommended)
A.E.A.	Adcon	Ajax	Dispensing Tube
Water Reducer	Adcon	WRXX	Dispensing Tube
Other			

Does AEA bulk storage tank hold at least 300 gallons (2301.3F1) __y__

Aggregates:

Material	Aggregate Class (A, B, C, R)	Supplier	Pit Location	Pit Number	Delivered By	In Plant storage (tons)
Sand		Salinger	Freeport	199999	Truck	20
3/4"+ (19mm+)	C	Rock Island	St. Cloud	188888	Truck	15
3/4"- (19mm-)	C	Rock Island	St. Cloud	188888	Truck	20
1/2"- or 3/8"- (12.5mm or 9.5mm)	C	Pebble Pit	St. Cloud	177777	Truck	5

Plant is fed by: Field hoppers __X__ How many __4__

Number of working bins __4__

Are stockpiles separated (y/n) __Y__

How many belts feed plant working bins __4__

Is turn head used (y/n) __N__

Aggregate sampled at: Belt __X__ Stockpile ____

Water:

Source:
- __X__ City Water
- ____ Well Water
- ____ Other - What?____________

Proportioned by:
- __X__ Meter
- ____ Scale

Can water be heated with a boiler (y/n) __N__

Temperature gauge location: __On Water Tank__

Equipment

Equipment:

Mechanical Shakers, Screens and Sieves

Box Screens: **Must have all screens listed below** **Calibrated on 2/25/2003**

X 2" (50mm)
X 1 1/2" (37.5mm)
X 1 1/4" (31.5mm)*
X 1" (25mm)
X 3/4" (19.0mm)
___ 5/8" (16mm)*
X 1/2" (12.5mm)
X 3/8" (9.5mm)
X #4 (4.75mm)
X Bottom Pan
X Mechanical Shaker

*Sieves Not Required

NOTE: Additional fill-in sieves may need to be added to prevent overloading.

Brass Sieves: **Must have all sieves listed below** **Calibrated** on **2/25/2003**

X 3/8" (9.5mm)
X #4 (4.75mm)
X #8 (2.36mm)
X #16 (1.18mm)
X #30 (600µm)
X #50 (300µm)
X #100 (150µm)
X 2 - #200 (75µm)
X Bottom Pan
X Mechanical Shaker

NOTE: Two #200 (75µm) sieves are needed, one is for shaking the gradation and the second is for washing the sample during the final steps of the gradation process.

Scales, Microwave Oven Equipment and Miscellaneous

Scales:

___ Dairy Scale Calibrated on ___________ **MINIMUM 55 lb CAPACITY**
___ Platform Scale Calibrated on ___________ **MINIMUM 55 lb CAPACITY**
X Electronic Scale Calibrated on 2/25/2003 **MINIMUM 55 lb CAPACITY**

___ Triple Beam Balance including the needed Hanging Weights (1 - 500g and 2 - 1000g) Calibrated on_______________ **MINIMUM 2600g CAPACITY**

X Electronic Scale Calibrated on 2/25/2003 **MINIMUM 2600g CAPACITY**

Microwave Oven and Ancillary Equipment:

X Microwave Oven with turntable or wave deflection fan (900 Watt)
X Heat resistant glass pan (~ 9" x 9" x 2")
X Plain weave fiberglass cloth (10 oz./yd^2 and 14 mils thick)
X Metal scraper and grinding pestle

Miscellaneous:

X 2" (50mm) Sample Splitter with 3 Pans
X 3 Burners (minimum): Electric or Gas

TP 2152-02 (3/2001)

Minnesota Department of Transportation

Concrete Batching Report

Batch Plant TUV Paving Batch Plant Date 5/8/2003

Material		Sand	1 1/2	3/4	3/8									Average Free Water (Not Weighted)
A. Wt. Sample + Pan	Wet	722	2328	2336	1294									
B. Wt. Sample + Pan	Dry	692	2306	2298	1247									
C. Moisture Loss	A–B	30	22	38	47									
D. Tare Wt, Pan	-	145	300	300	145									
E. Dry Wt. Sample	B–D	547	2006	1998	1102									
F. Total Moisture Factor	C/E	.055	.011	.019	.043									
G. Absorb. Factor	-	.011	.003	.004	.012									
H. Free Moisture Factor	F-G	.044	.008	.015	.031									
I. Time Scales Set					8:50 a.m.									
		Mix No. 3A21		**Cement Wt.** 450			**Fly Ash Wt.** 130			**Design Water** 208				
J. Design Wt.	-	1090	770	910	390									
K. Total Moisture	FxJ	60	8	17	17									
L. Scale Setting	J+K	1150	778	927	407									
M. Free Moisture	HxJ	48	6	14	12									
Total Free Moisture				80										
		Mix No.			**Cement Wt.**			**Fly Ash Wt.**			**Design Water**			
J. Design Wt.	-													
K. Total Moisture	FxJ													
L. Scale Setting	J+K													
M. Free Moisture	HxJ													
Total Free Moisture														
		Mix No.			**Cement Wt.**			**Fly Ash Wt.**			**Design Water**			
J. Design Wt.	-													
K. Total Moisture	FxJ													
L. Scale Setting	J+K													
M. Free Moisture	HxJ													
Total Free Moisture														
		Mix No.			**Cement Wt.**			**Fly Ash Wt.**			**Design Water**			
J. Design Wt.	-													
K. Total Moisture	FxJ													
L. Scale Setting	J+K													
M. Free Moisture	HxJ													
Total Free Moisture														

5-694.734 CONCRETE W/C RATIO CALCULATION WORKSHEET

This worksheet is used to determine the water/cementitious ratio of the concrete. This information is needed for calculating the Contractor's incentives and disincentives for w/c ratio. A computerized version of this worksheet is available to download on the Mn/DOT Concrete Engineering Unit website at www.mrr.dot.state.mn.us/pavement/concrete/paving.asp.

Record all results on the Concrete W/C Ratio Calculation Worksheet. See Figure A 5-694.734 for a completed example. The abbreviations in bold caps listed after some of the instructions, correspond to the Concrete W/C Ratio Calculation Worksheet and are used in formulas on that worksheet.

A. Equipment Required for Microwave Oven Test (Supplied By Contractor)

- 900-watt microwave with a turntable or wave deflection fan and of sufficient size for glass pan
- Heat resistant glass pan approximately 9" x 9" x 2"
- Plain weave fiberglass cloth, 10 oz./yd and 14 mils thick
- Weighing scales for the microwave oven (5000 g min.) and the unit weight tests (100 lb. min.)
- Metal scraper and porcelain grinding pestle

B. Sampling Aggregates and Fresh Concrete Procedure

1. Take aggregate samples from belts for moisture content tests. Record results on the *Concrete Batching Report* (Form 2152). See Figure A 5-694.733.
2. Take sample of concrete from the batch representing the aggregates that were sampled for moistures. This is usually between four and ten loads from when the aggregate samples were taken for moisture testing. Ask the batchperson to help determine the correct interval. If a ready-mix truck that has the ability to add additional water is transporting the concrete, the concrete sample is taken at the point of placement in the field and protected from moisture loss until the test can begin, otherwise the fresh concrete is sampled at the plant.
3. Take samples large enough to run a unit weight test - 20 kg for a 0.007 m^3 (45 lb. for a 0.25 ft^3 bucket) and 1500 grams for a microwave oven test.

C. Unit Weight Test Procedure

1. Determine the volume of the unit weight bucket. It is typically written on the bucket. (**VOL)**
2. Weigh the unit weight bucket empty. (**BWT)**
3. On a level surface, fill container in 3 equal layers, slightly overfilling the last layer. Rod each layer 25 times with a 16 mm (5/8 in.) hemispherical end of rod, uniformly distributing strokes for a 14 L (0.5 ft^3) or smaller container. Rod each layer 50 times for a 28 L (1 ft^3) container.
4. Rod bottom layer throughout its depth without forcibly striking bottom of container.
5. Rod the middle and top layer throughout their depths and penetrate 25 mm (1 in.) into the underlying layer.
6. Tap the sides of the container smartly 10 to 15 times with the mallet after rodding each layer.
7. Strike off concrete level with top of container using a flat plate (or flat bar) and clean off rim.
8. Weigh the unit weight bucket with the concrete. (**CBWT)**
9. Calculate the unit weight. **(UW)**

D. Microwave Oven Test Procedure

1. The water content test must begin within 45 minutes after the water has contacted the cementitious material.
2. Weigh heat resistant glass pan and fiberglass cloth to the nearest 0.1 gram. (**WS)**
3. Weigh the pan, cloth and fresh concrete to the nearest 0.1 gram. (**WF)**
4. Microwave the sample at several time intervals until the sample has lost less than 1.0 gram within a two-minute interval. (5 min, 5 min, 2 min, 2 min, etc.) Break up the sample with grinding pestle between microwaving. (**WD)**
5. Calculate the **Water Content Percentage**. (**WC)**

$$WC\% = \frac{100 \times (WF - WD)}{(WF - WS)}$$

6. Calculate the **Total Water Content in Concrete**. (**WT)**

$$WT(kg/m^3) = WC \times UW$$

$$WT(lb/yd^3) = 27 \times WC \times UW$$

E. W/C Ratio Calculations

1. Calculate the **Total Absorbed Moisture** for all of the aggregates. The absorbed moisture content should remain the same throughout the project unless the mix design changes.

$$Absorbed\ Moisture\ (kg/m^3)\ or\ (lb/yd^3) = Oven\ Dry\ Batch\ Weight \times Absorption\ Factor$$

2. Calculate the **Total Cementitious** in the concrete mix design.
3. Calculate the **Total Free Moisture** in the aggregates. The free moisture is calculated by the Agency using the moistures taken at the time just before the concrete was sampled.
4. Calculate the **Total Batch Water**. The batch water and temper water is usually reported on the computer screen and printed in Liters (gallons) for the entire batch. The total batch water for calculating w/c is based on the average water compared from 10 batch tickets/Certificate of Compliances surrounding the randomly selected batch ticket/Certificate of Compliance sample (4 previous tickets, ticket representing sample taken, and 5 following tickets.)
5. Calculate the **Actual Batch Water** used.

$$Actual\ Batch\ Water\ (kg/m^3) = \left(\frac{Total\ Batch\ Water}{Batch\ Size}\right)$$

$$Actual\ Batch\ Water\ (lb/yd^3) = \left(\frac{Total\ Batch\ Water \times 8.33\ lb/1\ gallon}{Batch\ Size}\right)$$

6. Calculate the **Total Mix Water** used.

$$Total\ Mix\ Water\ (kg/m^3)\ or\ (lb/yd^3) = Actual\ Batch\ Water + Total\ Free\ Moisture$$

7. Calculate the **W/C Ratio** of the concrete. Round to the nearest 0.01.

$$w/c\ ratio = \frac{Total\ Mix\ Water}{Total\ Design\ Cementitious}$$

8. Calculate the **Total Water in Concrete** used. **Compare to Total Water in Concrete (WT)**.

$$Total\ Water\ (kg/m^3)\ or\ (lb/yd^3) = Total\ Mix\ Water + Absorbed\ Moisture$$

9. Calculate **Maximum Batch Water Available**. Compare this to the batching computer.

$$Max.\ Batch\ Water(L) = \{[(Cement + Fly\ Ash + Slag) \times 0.40] - Total\ Free\ Moisture\} \times Batch\ Size$$

$$Max.\ Batch\ Water(gal) = \frac{\{[(Cement + Fly\ Ash + Slag) \times 0.40] - Total\ Free\ Moisture\} \times Batch\ Size}{8.33\ lb/1\ gallon}$$

F. Percent Passing the 4.75 mm (No.4) Sieve

Weight of Sample Passing 4.75 mm (No.4) Sieve from Microwave Oven Sample

1. Let microwave oven sample cool.
2. Sieve dried sample through a 4.75 mm (No.4) sieve into a bottom pan.
3. Calculate the percent passing the 4.75 mm (No.4) sieve.

Percent Passing 4.75 mm (No.4) Sieve from Total Mix (Contractor Mix Design)

Calculate the percent passing the 4.75 mm (No.4) sieve of all of the dry materials using the Contractor's mix design (aggregates, cement, fly ash, etc.).

$$\%Passing\ 4.75\ mm\ (No.4) = \left[\frac{\left(\begin{array}{c} (\%\ passing\ 4.75\ mm\ (No.4)\ from\ JMF \times (wt.\ of\ all\ CA\ and\ FA)) \\ + (wt.\ of\ all\ cementitous) \end{array} \right)}{Total\ wt.\ of\ all\ CA\ and\ FA\ and\ all\ cementitious} \right] \times 100$$

Correction Factor

1. Calculate the Correction Factor to compare the two results to verify that the sample of concrete was representative.

$$CF = \frac{1 - (\%passing\ 4.75\ mm\ (No.4)\ of\ microwave\ oven)}{1 - (\%passing\ 4.75\ mm\ (No.4)\ of\ mix\ design)}$$

2. Determine the **Adjusted Total Water in Concrete** Microwave Oven Sample by multiplying the **Correction Factor**, **CF** by **Total Water in Concrete**, **WT.**

3. Compare the **Adjusted Total Water in Concrete** Microwave Oven **(L)** to the **Total Water in Concrete** calculation from the batch ticket **(F)**.

5-694.735 AGGREGATE MOISTURE CONTENT CHART

Quality Control charts are a visual and statistical method of tracking aggregate moistures in order to achieve better quality control of the concrete. This chart is used as an aid for Contractor and Agency Plant Personnel. See Figure A 5-694.735.

5-694.736 W/C RATIO QUALITY CONTROL CHART

This chart is used to track the w/c ratio of the concrete through the entire project. See Figure A 5-694.736.

5-694.737 CONCRETE AGGREGATE WORKSHEET JMF (Form 21764)

This worksheet is used for calculating gradations on Paving Projects using Combined Total Gradations (JMF). There is a non-computerized and computerized version of this worksheet. See Figure A 5-694.737.

5-694.738 COMPOSITE GRADATION (WELL-GRADED AGGREGATE) CHART

Quality Control charts are a visual and statistical method of tracking gradations in order to achieve better quality control of concrete aggregates. The results of the Contractor's gradations are recorded on the well-graded aggregate chart. The percent retained for each required individual sieve from the composite gradation are graphed on this chart. Review the Special Provisions for your project to determine if well-graded aggregate is required or is an optional incentive. See Figure A 5-694.738.

5-694.739 INCENTIVE WORKSHEETS

The incentive/disincentive provisions only apply to materials provided for or produced by the Contractor's primary concrete paving plant. The primary paving plant is either a batch plant or a ready mix plant. They do not apply to materials provided for or produced by a secondary concrete plant providing concrete for minor work such as fill-ins or other work not provided by the Contractor's primary concrete plant.

These worksheets are used to determine the water/cementitious ratio and well-graded aggregate incentives and disincentives for a paving project. Refer to the Special Provisions and 5-694.532 for an explanation of lots and sublots for w/cm ratio. See Figure A 5-694.739.

The Agency's statistical analysis of samples for well-graded aggregate control incentive is based on a lot representing one days paving. The lot represents the cumulative average of the sublot values on each sieve. Compliance is based on Contractor's aggregate gradation test results as verified by Agency testing. See the Special Provisions and Figure B 5-694.739 for an example.

CONCRETE W/C RATIO CALCULATION WORKSHEET (ENGLISH)

BATCH SIZE (yd^3) 7.5

S.P.	8901-23
DATE	5/8/2003
TIME	8:50 AM
TICKET #'S	27-36
LOT #	3
TEST #	10
TESTER	L. Bean
ENGINEER	T. Sanders

MIX DESIGN 3A21

	OVEN DRY WEIGHT	X ABS. FACTOR	= ABS. MOISTURE
COARSE AGG. (1 1/2)	770	0.003	2.31
COARSE AGG. (3/4)	910	0.004	3.64
COARSE AGG. (3/8)	390	0.012	4.68
COARSE AGG.			
SAND	1090	0.011	11.99
CEMENT	450		
FLY ASH	130		
SLAG			
WATER	208		

22.62 **TOTAL ABSORBED MOISTURE** (A)

TOTAL CEMENTITIOUS
CEMENT + FLY ASH + SLAG = 580 LB. (B)

WATER CALCULATION

(1 1/2) FREE MOISTURE	FROM CONCRETE BATCHING REPORT	6
(3/4) FREE MOISTURE	FROM CONCRETE BATCHING REPORT	14
(3/8) FREE MOISTURE	FROM CONCRETE BATCHING REPORT	12
FREE MOISTURE	FROM CONCRETE BATCHING REPORT	
SAND FREE MOISTURE	FROM CONCRETE BATCHING REPORT	48

TOTAL FREE MOISTURE IN AGGREGATE PER YARD 80 (C)

ACTUAL BATCH WATER USED PER YARD TOTAL BATCH WATER (GAL) x 8.33 / BATCH SIZE 133.6 (D)

TOTAL MIX WATER USED, BATCH + FREE; (C + D) 213.6 (E)

W/C RATIO, TOTAL MIX WATER / (CEMENT + FLY ASH + SLAG); (E / B) 0.37

TOTAL WATER IN CONCRETE, (TOTAL MIX + ABS); (A + E) 236.2 (F)

UNIT WEIGHT TEST

VOLUME OF UNIT WEIGHT BUCKET, **VOL**	0.25 ft^3
WT OF UNIT WEIGHT BUCKET, **BWT**	7.95 lb.
WT OF UNIT WEIGHT BUCKET AND CONCRETE, **CBWT**	43.5 lb.
WT OF CONCRETE, (CBWT - BWT), **CWT**	35.55 lb.
UNIT WEIGHT OF CONCRETE, CWT / VOL, **UW**	142.2 lb/ft^3

MICROWAVE OVEN TEST

WT. OF PAN AND CLOTH, **WS**	1081.6
WT. OF PAN, CLOTH AND FRESH CONCRETE, **WF**	2632.2
WT. OF PAN, CLOTH AND DRY CONCRETE, **WD**	2539.3
WATER CONTENT %, 100x(WF-WD)/(WF-WS), **WC**	6.0%
TOTAL WATER IN CONCRETE, 27xWCxUW, **WT**	230.4 lb/yd^3 (G)

COMPARE (G) TO (F) ABOVE

TOTAL BATCH WATER

TICKET #	BATCH WATER	TEMPER WATER
27	116	2
28	118	0
29	118	3
30	119	2
31	118	3
32	118	2
33	118	3
34	118	3
35	118	2
36	118	4
AVE.	117.9	2.4

TOTAL BATCH WATER 120.3

MAXIMUM BATCH WATER AVAILABLE

((B)*0.40]-C))*BATCH SIZE/8.33

136.9 gal

% PASSING #4 SIEVE

WT. OF SAMPLE PASSING #4 SIEVE, **W4**	706.3	
% PASSING #4, W4 / (WD - WS)	48.5 %	(H)
% PASSING #4 FROM JMF	44.0 %	(I)
% PASSING #4 FROM TOTAL MIX	52.7 %	(J)

$$\left[\frac{[(\text{Wt. of CA + FA}) \times I) + B)]}{(\text{Wt. of CA + FA}) + B}\right] \times 100$$

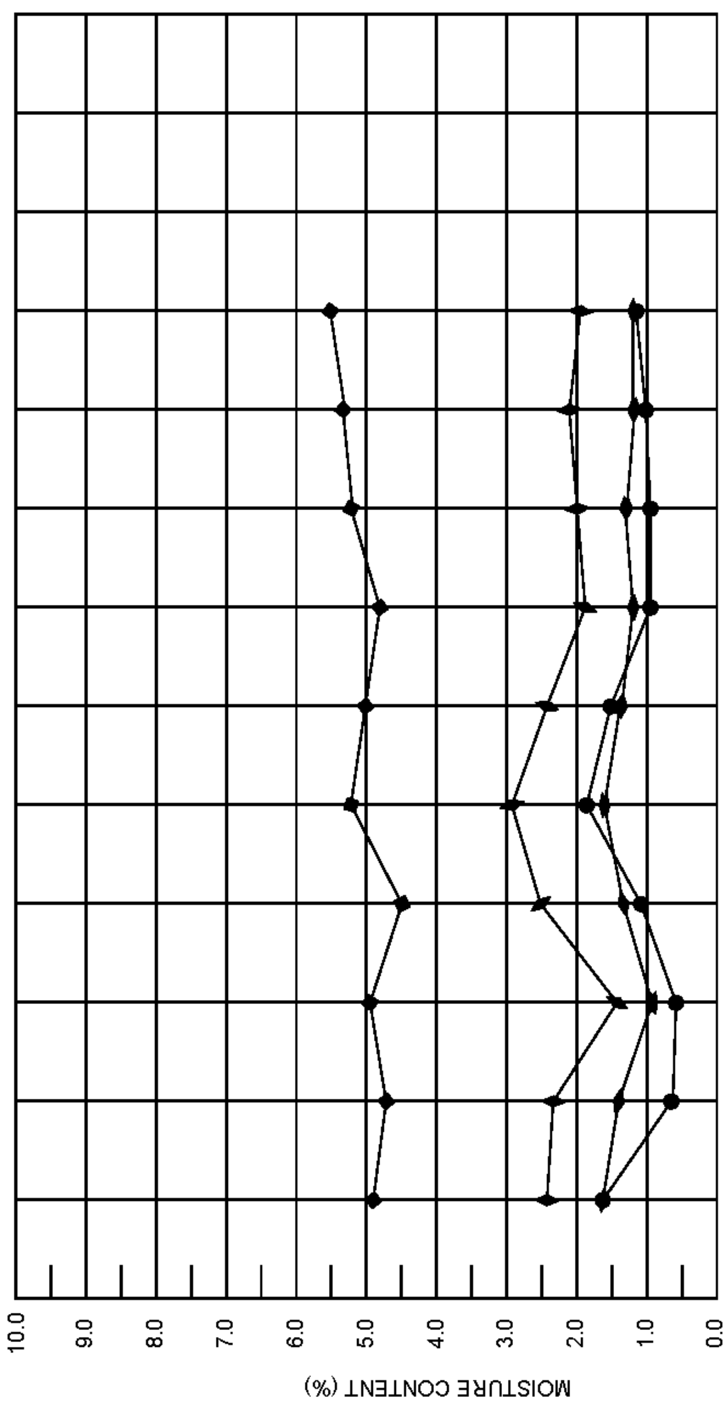
CORRECTION FACTOR

CF, 1 - H / 1 - J 1.09 (K)

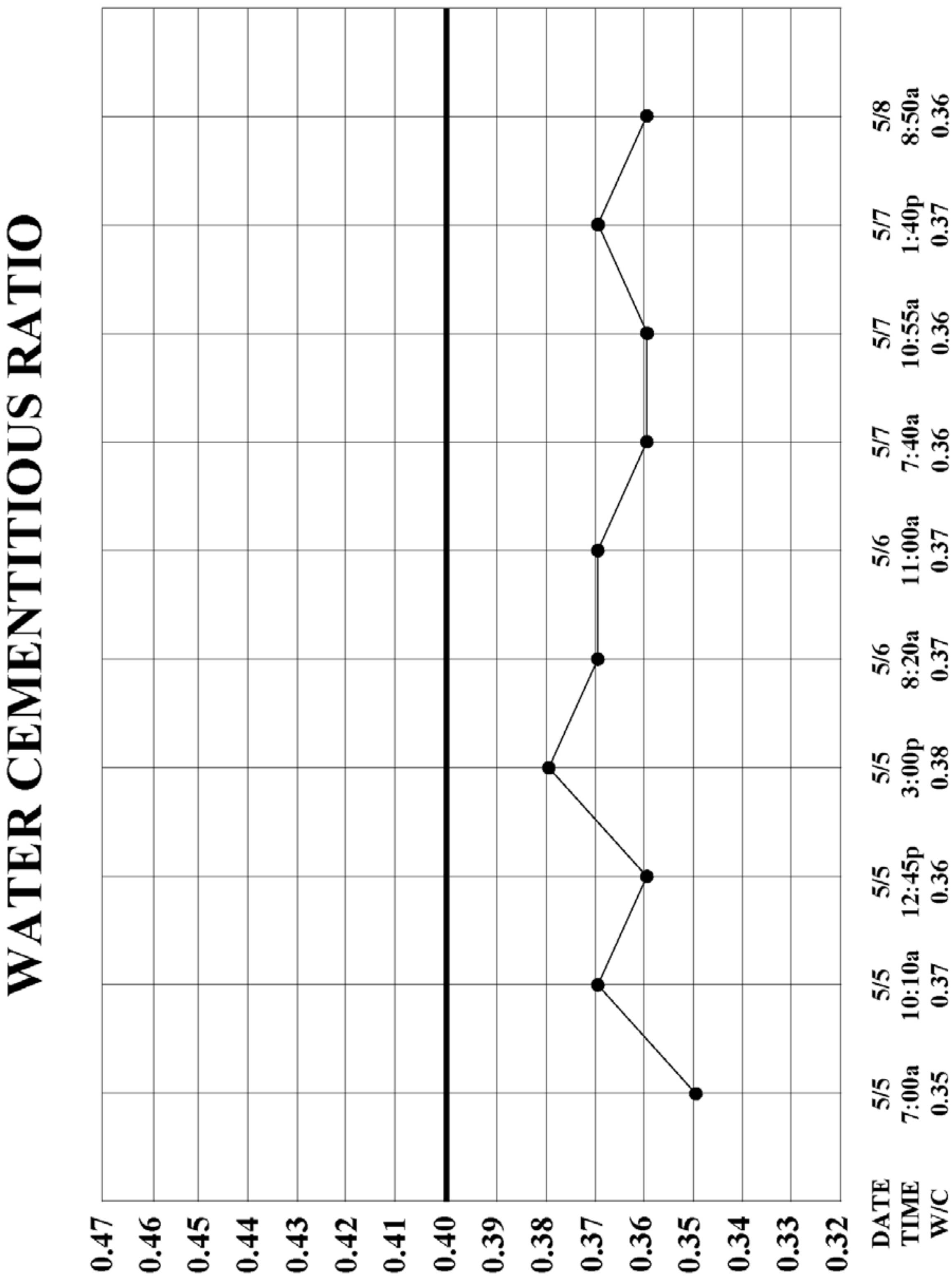
ADJUSTED TOTAL WATER IN CONCRETE, G x K 251.1 (L)

COMPARE (L) TO (F) ABOVE

AGGREGATE MOISTURE CONTENT



DATE	5/5	5/5	5/5	5/5	5/6	5/6	5/7	5/7	5/7	5/8			
TIME	7:00a	10:10a	12:45p	3:00p	8:20a	11:00a	7:40a	10:55a	1:40p	8:50a			
FINE AGGREGATE	4.8	4.7	4.9	4.5	5.2	5.0	4.8	5.2	5.3	5.5			
MOISTURE METER													
● CA- 1 1/2	1.6	0.7	0.6	1.1	1.8	1.5	0.9	0.9	1.0	1.1			
◆ CA- 3/4-	2.4	2.3	1.4	2.5	2.9	2.4	1.8	2.0	2.1	1.9			
◆ CA- 3/8-	1.6	1.4	0.9	1.3	1.6	1.4	1.2	1.3	1.2	1.2			


WATER CEMENTITIOUS RATIO
0.47
0.46
0.45
0.44
0.43
0.42
0.41
0.40
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0.32
DATE
TIME
W/C
5/5 7:00a 0.35
5/5 10:10a 0.37
5/5 12:45p 0.36
5/5 3:00p 0.38
5/6 8:20a 0.37
5/6 11:00a 0.37
5/7 7:40a 0.36
5/7 10:55a 0.36
5/7 1:40p 0.37
5/8 8:50a 0.36

Mn/DOT Concrete Aggregate Worksheet (JMF) Mn/DOT Form 21764-04 (3/2003)

S.P.	8901-23	Plant:	TUV Paving	Date:	5/8/2003	Aggregate Sources:	FA #1 199999	FA #2	
Engineer:	T. Sanders	Tester:	L. Bean	Time:	9:15 AM	CA #1 188888	CA #2 188888	CA #3 177777	CA #4

Sieve Analysis of Coarse Aggregate

	Test No.	10			Test No.	10			Test No.	10			Test No.	10		
	Sample Wt.	6868.10			Sample Wt.	4716.90			Sample Wt.	4495.60			Sample Wt.			
Aggregate	CA #1	1 1/2"			CA #2	3/4"			CA #3	3/8"			CA #4			
Fraction	Mix Prop.	14%			Mix Prop.	32%			Mix Prop.	12%			Mix Prop.			
Sieve Sizes	Weights		%	Grad.	Weights		%	Grad.	Weights		%	Grad.	Weights		%	Grad.
Pass - Ret.	Ind.	Cum.	Pass	Req.	Ind.	Cum.	Pass	Req.	Ind.	Cum.	Pass	Req.	Ind.	Cum.	Pass	Req.
2" - 1 1/2"	1360.50	6868.10	100.0%		0.00	4716.90	100.0%		0.00	4495.60	100%					
1 1/2" - 1 1/4"	2804.20	5507.60	80.2%		0.00	4716.90	100.0%		0.00	4495.60	100%					
1 1/4" - 1"	2240.10	2703.40	39.4%		117.80	4716.90	100.0%		0.00	4495.60	100%					
1" - 3/4"	342.60	463.30	6.7%		891.50	4599.10	97.5%		13.60	4495.60	100%					
3/4" - 5/8"	39.20	120.70	1.8%		1643.20	3707.60	78.6%		429.00	4482.00	100%					
5/8" - 1/2"																
1/2" - 3/8"	6.10	81.50	1.2%		851.00	2064.40	43.8%		1215.50	4053.00	90%					
3/8" - #4	2.80	75.40	1.1%		1112.70	1213.40	25.7%		2417.20	2837.50	63%					
#4 - Btm	72.60	72.60	1.1%		100.70	100.70	2.1%		420.30	420.30	9%					
Check Total	6868.10	± 100 g of Sample Wt			4716.90	± 100 g of Sample Wt			4495.60	± 100 grams of Sample Wt				± 100 grams of Sample Wt		

Sieve Analysis of Fine Aggregate

	Test No.	10		Test No.	10	
Aggregate	Sample Wt.	498.5		Sample Wt.		
Fraction	Mix Prop.	42%		Mix Prop.		
Sieve Sizes	Weights		%	Weights		%
Pass - Ret.	Ind.	Cum.	Pass	Ind.	Cum.	Pass
3/8" - #4	0.0	497.8	100.0%			
#4 - #6	76.4	497.8	100.0%			
*#6 - #8						
#8 - #16	146.7	421.4	84.7%			
#16 - #30	145.2	274.7	55.2%			
#30 - #50	86.3	129.5	26.0%			
#50 - #100	30.0	43.2	8.7%			
#100 - #200	5.5	13.2	2.7%			
*#200 - Btm	1.2	7.7	1.5%			
Loss by Washing	6.5	6.5	1.3%			
Check Total	497.8	± 2 g of Sample Wt			± 2 g of Sample Wt	

Percent Passing #200 Sieve Test

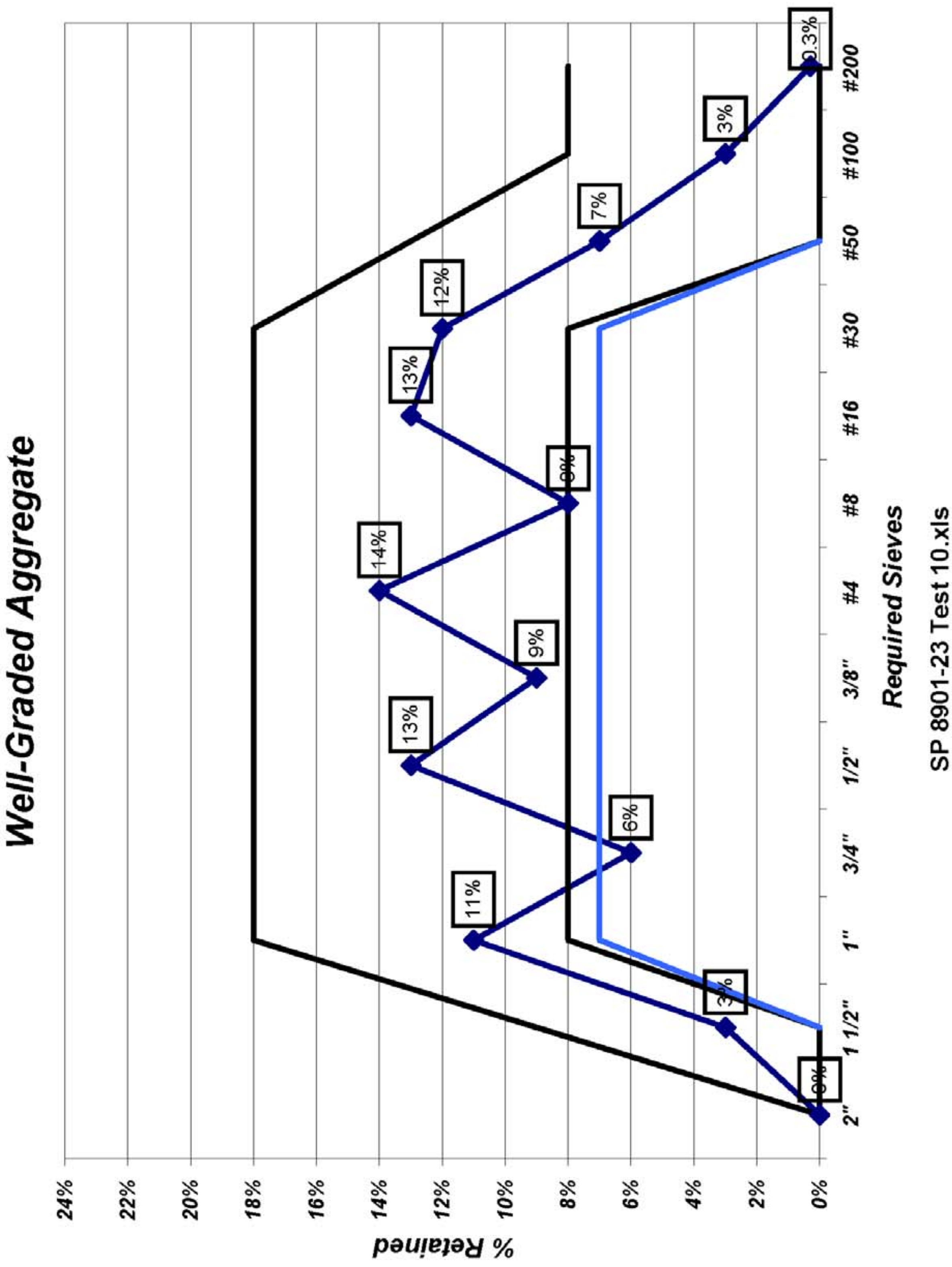
	CA #1	CA #2	CA #3	CA #4	FA #1	FA #2
(A) Dry weight of original sample					498.4	
(B) Dry weight of washed sample					491.9	
(C) Loss by washing (A-B)					6.5	
(D) % Passing #200 (C/A)*100					1.3	

Additional Remarks or Comments

Composite Gradation for Job Mix Formula

Aggregate	CA #1	CA #2	CA #3	CA #4	FA #1	FA #2	Total	Comp.	Working	JMF		Total
Fraction	1 1/2"	3/4"	3/8"					Grad. Req.	Range	Working		
Prop. %	14%	32%	12%		42%		% Passing	JMF		Range		% Retained
2"	14.0%	32.0%	12.0%		42.0%		100%	100	± 5	95	100	0%
1 1/2"	11.2%	32.0%	12.0%		42.0%		97%	98	± 5	93	100	3%
1"	0.9%	31.2%	12.0%		42.0%		86%	87	± 5	82	92	11%
3/4"	0.3%	25.2%	12.0%		42.0%		79%	79	± 5	74	84	7%
1/2"	0.2%	14.0%	10.8%		42.0%		67%	68	± 5	63	73	12%
3/8"	0.2%	8.2%	7.6%		42.0%		58%	57	± 5	52	62	9%
#4	0.2%	0.7%	1.1%		42.0%		44%	44	± 5	39	49	14%
#8					35.6%		36%	34	± 4	30	38	8%
#16					23.2%		23%	22	± 4	18	26	13%
#30					10.9%		11%	9	± 4	5	13	12%
#50					3.7%		4%	3	± 3	0	6	7%
#100					1.1%		1%	1	± 2	0	3	3%
#200					0.6%		0.6%	0.6	± 1.6% max	0.0	2.2	0.4%

Workability Factor (WF) **(% Passing #8)** **36**
Coarseness Factor (CF) **(% retained above 3/8"/** **% retained above #8)** **66**


Well-Graded Aggregate
% Retained
24%
22%
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
0%
3%
11%
6%
13%
9%
14%
13%
12%
7%
3%
0.3%
2"
1 1/2"
1"
3/4"
1/2"
3/8"
#4
#8
#16
#30
#50
#100
#200
Required Sieves
SP 8901-23 Test 10.xls

W/C RATIO INCENTIVE CALCULATION (ENGLISH)

LOT #	TEST #	DATE TESTED	W/C RATIO	YD^3 REPRESENTED BY TEST	YD^3 BATCHED FOR LOT	AVE W/C FOR LOT	PAY FACTOR	MEASURED YD^3 FOR LOT	INCENT/ DISINCENT
1	1	5/5/2003	0.35	1000					
1	2	5/5/2003	0.37	1000					
1	3	5/5/2003	0.36	1000					
1	4	5/5/2003	0.38	982.5					
					3982.5	0.36	$3.00	3980	$11,940.00
2	5	5/6/2003	0.37	1000					
2	6	5/6/2003	0.37	697.5					
2	7	5/7/2003	0.37	1000					
2	8	5/7/2003	0.36	1000					
2	9	5/7/2003	0.35	550					
					4247.5	0.36	$3.00	4241	$12,723.00
3	10	5/8/2003	0.37	1000					
3	11	5/8/2003	0.35	1000					
3	12	5/8/2003	0.37	958					
					2958	0.36	$3.00	2955	$8,865.00

GRADATION INCENTIVES

DATE TESTED	LOT #	TEST #	2"	1½"	1"	¾"	½"	3/8"	#4	#8	#16	#30	#50	#100	#200	8-18 INCENTIVE	7-18 INCENTIVE	FAILURE	PAY FACTOR	MEAS. C.Y. FOR POUR	MEAS. C.Y. FOR LOT	INCENTIVE
5/5	1	1	0	3	11	7	14	9	13	8	14	11	8	4	0.5							
5/5	1	2	0	4	13	8	13	8	12	8	13	12	7	2	0.4							
5/5	1	3	0	5	12	9	12	9	14	7	11	13	8	3	0.3							
5/5	1	4	0	4	10	9	12	8	15	8	13	12	6	3	0.3							
Ave.	**1**		**0**	**4**	**12**	**8**	**13**	**8**	**14**	**8**	**13**	**12**	**7**	**3**	**0.4**	**X**			**2.00**	**3980**	**3982.5**	**$7960.00**
5/6	2	5	0	4	12	7	11	9	15	7	12	11	7	3	0.4							
5/6	2	6	0	5	10	8	12	8	14	8	13	11	6	2	0.5							
5/7	2	7	0	5	14	7	12	7	14	8	12	13	5	5	0.3							
5/7	2	8	0	6	13	7	13	9	13	9	14	12	7	3	0.2							
5/7	2	9	0	6	12	8	12	10	14	8	14	12	7	3	0.4							
Ave.	**2**		**0**	**5**	**12**	**7**	**12**	**9**	**14**	**8**	**13**	**12**	**6**	**3**	**0.4**		**X**		**.50**	**4241**	**4247.5**	**$2120.50**
5/8	3	10	0	3	11	6	12	9	14	8	13	12	7	3	0.4							

5-694.740 CEMENT RECORD (Form 2157)

This form is used for concrete paving projects only. Do not use this form when the concrete is obtained from a ready-mix plant. Use this form for recording all cementitious materials including cement, fly ash, and slag received and used on the paving project. This form is a useful tool for calculating the required cementitious cut-offs per Mn/DOT Specification 2301.3F2. See Figure A 5-694.740.

5-694.741 CONCRETE TEST BEAM DATA (Form 2162)

The Agency should submit this form to the Mn/DOT Concrete Engineering Unit each week showing all beam breaks during that week of concrete paving production. See Figure A 5-694.741.

5-694.742 FIELD CORE REPORT (Form 24327)

This form is used by Field Personnel to summarize the location of cores taken in concrete pavement and is submitted to the Mn/DOT Office of Materials Laboratory. See 5-694.691 and Figure A 5-694.742.

5-694.743 TEST REPORT ON CONCRETE CORES (Form 24324)

This form is used by Mn/DOT Office of Materials Laboratory Personnel to report core thickness measurements and compressive strengths. See Figure A 5-694.743.

TP-2157-04 (3/2000)

Minnesota Department of Transportation

Cement Record

S.P. 8901-23 Plant: TUV Batch Plant – St. Cloud Engineer: T. Sanders Page: 1

Load No.	Invoice Number	Date Unloaded	Manufacturer	Source/Mill	Lbs./Shipment	Lbs. Shipped to Date
1	370002	5-2-03	Graymatter	St. Paul, MN	51,750	
2	370006	"	"	"	50,890	
3	370008	"	"	"	52,200	
4	370011	"	"	"	53,000	
5	370013	"	"	"	51,010	
6	370014	"	"	"	52,700	
7	370018	"	"	"	51,800	
8	370021	"	"	"	54,550	
9	370022	"	"	"	52,100	
10	370026	"	"	"	52,750	522,750
11	370027	"	"	"	51,800	
12	370028	"	"	"	52,100	
13	370031	"	"	"	52,650	679,300
14	370034	5-3-03	"	"	53,080	
15	370037	"	"	"	52,140	
16	370038	"	"	"	52,000	
17	370040	"	"	"	53,010	
18	370042	"	"	"	51,800	
19	370045	"	"	"	52,450	
20	370047	"	"	"	51,350	
21	370048	"	"	"	50,800	
22	370049	5-5-03	"	"	51,240	1,147,170
23	370051	"	"	"	52,100	
24	370055	"	"	"	51,750	
25	370059	"	"	"	52,100	1,303,120
26	370060	5-6-03	"	"	52,010	
27	370063	"	"	"	53,120	
28	370069	"	"	"	51,980	1,460,230

TP-2157-04 (3/2000)

Minnesota Department of Transportation

Cement Record

S.P. 8901-23 Plant: TUV Batch Plant – St. Cloud Engineer: T. Sanders Page: 2

Load No.	Invoice Number	Date Unloaded	Manufacturer	Source/Mill	Lbs./Shipment	Lbs. Shipped to Date
					From previous page	1,460,230
29	370071	5-6-03	Graymatter	St. Paul, MN	51,500	
30	370072	"	"	"	51,970	
31	370076	"	"	"	52,060	
32	370078	"	"	"	53,010	
33	370082	"	"	"	49,980	
34	370084	"	"	"	50,860	
35	370085	"	"	"	51,020	
36	370089	"	"	"	52,100	
37	370091	"	"	"	52,540	
38	370098	"	"	"	49,880	
39	370101	"	"	"	48,620	2,023,770

MINNESOTA DEPARTMENT OF TRANSPORTATION

PLANT LOCATION TUV Batch Plant – St. Cloud

CEMENT RECORD

Date	S.P.	Insp.	Mix Design	Lbs/yd³	Total yd³ (1)	Sub-Total lbs. (2)	Waste lbs. (3)	Total lbs. Used Today (4)	Lbs. Accountable To Date (5)	Lbs. received to Date (6)	Lbs. Diff. + or – (7)	% Diff. + or – (8)
												Ind.
5-5-03	8901-23	LB	3A21	450	1155	519,750	+500	520,250	520,250	522,750	+2500	+0.48%
							Scale					
←						Cement	Cut Off	#1				→
5-5-03	8901-23	LB	3A21	450	2827.5	1,272,375	-500	1,271,875	1,792,125			
							Scale					Overall
5-6-03	8901-23	LB	3A21	450	505	227,250	+1950	229,200	2,021,325	2,023,770	+2445	+0.12%
							Scale		520,250	522,750		Ind.
									1,501,075	1,501,020	-55	-0.004%
←						Cement	Cut Off	#2				→
5-6-03	8901-23	LB	3A21	450	3742.5	1,684,125	-1950	1,682,175	3,703,500			
							Scale					

(1) Used that date; (2) lb/yd³ x total yd³; (3) Spilled, wasted or concrete not used; (4) Includes waste; (5) Actual cement used including waste; (6) Same as kg shipped to date; (7) Difference between accountable and received, 6 – 5; (8) Percent overrun or underrun (7 ÷ 5) x 100; If received (6) is more than accountable (5) – an overrun exists (+ positive number), if accountable (5) is more than received (6) – an underrun exists (- negative number) and must be addressed as stipulated in Specification 2301.3F2

TP 2162-04 (2/2003)

Minnesota Department of Transportation

Concrete Test Beam Data

Low State Proj. No. 8901-23 Date 5/5/2003

Project Engineer T. Sanders Contractor TUV Paving

Brand of Cement: Graymatter Mill of Cement: St. Paul, MN Type: I

Source/Type of Fly Ash: Asher@ Carter, MN Source of Other (Slag, etc):

Source of Fine Agg.: #199999 - Salinger Source of Coarse Agg.: #188888 - Rock Island

Source of Coarse Agg.: #177777 - Pebble Pit

BEAM NO.	STATION	DATE MADE	MIX NO.	TEST DATE	AVE. WIDTH "B"	AVE. DEPTH "D"	TOTAL TEST LOAD (PSI)	AREA CORR. FACTOR (%)	MOD. OF RUPT. (PSI)	AGE
1a	32+50	5/5/03	3A21	5/8/03	6.05	6.00	431	-0.01	427	3 day
1b	"	5/5/03	3A21	5/12/03	6.05	6.05	545	-0.06	512	7 day
1c	"	5/5/03	3A21	6/2/03	6.00	6.10	610	-0.03	592	28 day
2a	57+00	5/5/03	3A21	5/8/03	5.95	6.05	460	-0.01	455	3 day
2b	"	5/5/03	3A21	5/12/03	6.05	6.12	590	-0.04	566	7 day
2c	"	5/5/03	3A21	6/2/03	6.00	6.12	735	-0.04	706	28 day
3a	81+50	5/6/03	3A21	5/9/03	6.00	6.03	440	-0.01	436	3 day
3b	"	5/6/03	3A21	5/13/03	6.05	6.18	575	-0.07	535	7 day
3c	"	5/6/03	3A21	6/3/03	6.00	6.05	670	-0.02	657	28 day
4a	106+50	5/7/03	3A21	5/14/03	6.05	6.20	605	-0.05	575	7 day
4b	"	5/7/03	3A21	6/4/03	6.00	6.10	740	-0.06	696	28 day
5a	131+50	5/7/03	3A21	5/10/03	6.02	6.02	580	-0.01	574	3 day
5b	"	5/7/03	3A21	5/14/03	6.00	6.20	635	-0.03	616	7 day
5c	"	5/7/03	3A21	6/4/03	6.00	6.10	715	-0.03	694	28 day
6a	155+00	5/8/03	3A21	5/12/03	6.03	6.10	490	-0.04	470	4 day
6b	"	5/8/03	3A21	5/15/03	6.00	6.15	605	-0.07	563	7 day
6c	"	5/8/03	3A21	6/5/03	6.05	6.05	735	-0.04	706	28 day
7a	180+50	5/8/03	3A21	5/12/03	6.00	6.15	455	-0.05	432	4 day
7b	"	5/8/03	3A21	5/15/03	6.05	6.12	540	-0.05	513	7day
7c	"	5/8/03	3A21	6/5/03	6.00	6.15	690	-0.03	669	28 day
8a	205+50	5/12/03	3A21	5/19/03	6.05	6.18	575	-0.07	535	7 day
8b	"	5/12/03	3A21	6/9/03	6.00	6.20	635	-0.03	616	28 day
9a	230+50	5/12/03	3A21	5/19/03	6.10	6.15	565	-0.02	554	7 day
9b	"	5/12/03	3A21	6/9/03	6.00	6.05	665	-0.02	652	28 day
10a	255+00	5/13/03	3A21	5/16/03	6.00	6.20	495	-0.06	465	3 day
10b	"	5/13/03	3A21	5/20/03	6.00	6.15	605	-0.05	575	7 day
10c	"	5/13/03	3A21	6/10/03	6.00	6.10	740	-0.03	718	28 day

MIX NO.	AGE	AVERAGE STRENGTH
3A21	3	471 psi – 5 beams
3A21	7	554 psi – 10 beams
3A21	28	670 psi – 10 beams

SPECIAL NOTES:

cc: Project Engineer
Concrete Engineer
District Engineer

INSPECTOR L. Bean

24327-03 (1/2002)

Minnesota Department of Transportation

Field Core Report

Date 5/30/2003

Project Number 8901-23
Project Location TH 11 to CSAH 88
Mix Designation 3A21

T.H. 999
Type of Construction Conc. Pvmt.
Req'd Thickness 8"

Proj. Engineer T. Sanders
Paving Contractor TUV Paving
Anticipated Strength 3900 psi

Field Core Number	Location			Corrected Location			Lane	Field Height	Date Poured	Date Cored	Steel Locat. (if any)	Remarks
	Station	Offset LT	Offset RT	Station	Offset LT	Offset RT						
21	32+40	10					EBL	8 1/4"	5/5/03	5/30/03		
22	37+60		11					8 1/4"	5/5/03	5/30/03		
23	40+50	2						7 3/4"	5/5/03	5/30/03		
24	42+70		4					8"	5/5/03	5/30/03		
25	47+50	3						8 1/4"	5/6/03	5/30/03		
26	57+40		2					8 1/4"	5/6/03	5/30/03		
27	55+80	12						8 1/2"	5/6/03	5/30/03		
28	64+70		5					8 1/2"	5/6/03	5/30/03		
29	65+00	2						8 1/4"	5/6/03	5/30/03		
30	77+30		5					8"	5/7/03	6/2/03		

STATE OF MINNESOTA DEPARMENT OF TTRANSPORTATION
Office of Materials
Test Report on Concrete Pavement Cores

Project No. 8901-23 T.H. 999 Location TH 11 to CSAH 88 Date 5/30/2003
Proj. Engr. T. Sanders Contractor TUV Paving Date Sawed ____ Soak Start ____ Break Date ____

Core #	Station	Station Change If Any	Postition	Roadway	Lab. W.M. Depth	Field W.M. Depth	Field Ht. (In.)	Avg. Lab. Ht. (In.)
2003-001	32+40		10 L	E.B.L.			8.25	8.30
002	37+60		11 R	"			8.25	8.25
003	40+50		2 L	"			7.75	7.80
004	42+70		4 R	"			8.00	7.95
005	47+50		3 L	"			8.25	8.20
006	57+40		2 R	"			8.25	8.25
007	55+80		12 L	"			8.50	8.55
008	64+70		5 R	"			8.50	8.50
009	65+00		2 L	"			8.25	8.30
010	77+30		5 R	"			8.00	8.05

Core #	Date Poured	Date Broken	Age in Days	Cap Ht. (In.)	Diameter (In.)	Area (Sq. In.)	Breaking Load (Lbs.)	Actual (P.S.I.)	H / D	Corr. Factor	Corr. for H / D (P.S.I.)	Age Corr. Factor	Corr. to 60 Days (P.S.I.)
2003-001	05/05/03	07/03/03	59	7.98	4.01	12.6293	74,980	5,937	1.99	0.9992	5,932	1.002	5,944
002	"	"	"	7.95	4.00	12.5664	77,350	6,155	1.99	0.9992	6,150	1.002	6,163
003	"	"	"	7.76	4.00	12.5664	76,420	6,081	1.94	0.9952	6,052	1.002	6,064
004	"	"	"	7.85	3.99	12.5036	69,810	5,583	1.97	0.9976	5,570	1.002	5,581
005	05/06/03	07/07/03	62	7.92	4.01	12.6293	77,560	6,141	1.98	0.9984	6,131	0.996	6,107
006	"	"	"	7.90	4.01	12.6293	68,430	5,418	1.97	0.9976	5,405	0.996	5,384
007	"	"	"	7.95	4.00	12.5664	69,120	5,500	1.99	0.9992	5,496	0.996	5,474
008	"	"	"	7.95	4.00	12.5664	78,710	6,264	1.99	0.9992	6,259	0.996	6,233
009	"	"	"	7.88	4.01	12.6293	68,920	5,457	1.97	0.9976	5,444	0.996	5,422
010	05/07/03	"	61	7.83	4.01	12.6293	65,440	5,182	1.95	0.9960	5,161	0.998	5,151

Anticipated Strength (P.S.I.) 3,900
Req'd. Thickness (In.) 8.00
Req'd. Steel Location ____
Average Cylinder PSI. on this page: **5,752**
Average Cylinder PSI. from all pages: **5,752**

Copies to: Concrete Engr.
Proj. File
T. Sanders
TUV Paving

Report approved by Mack Truck
Material Inspection & Testing Engineer

10 - 1088

5-694.744 WEEKLY CONCRETE REPORT (Form 2448)

This form is a summary of data relating to concrete production including mix design, test results, quantities, etc. and is submitted weekly to the Mn/DOT Concrete Engineering Unit. An interactive computerized version is available on the website which has point and click capabilities, drop down boxes, and automatic calculations.

Item numbers listed below correspond to the numbers on Figure A 5-694.744. See Figure B 5-694.744 for a completed example of a *Weekly Concrete Report* for paving.

Instructions for Completing the Weekly Concrete Report

Item 1: Low S.P.
Use the lowest S.P. or S.A.P. Number for project. Do not create separate reports for each S.P. on a project.

Item 2: Bridge #
If concrete was placed on any part of a bridge structure, list the Bridge Number.

Item 3: Engineer
List the name of the Project Engineer or Project Supervisor.

Item 4: Inspector
List the name of the Chief Inspector responsible for the concrete listed in the weekly report.

Item 5: Contractor
For Ready-Mix list the Concrete Contractor. For paving jobs list the Paving Contractor.

Item 6: Batch Plant
For Ready-Mix Concrete, list the name and the city of the plant. If there is more than one plant with the same name, list the plant number (i.e. Togo Ready-Mix No. 3). If the concrete comes from 2 different plants - 2 *Weekly Concrete Reports* are required.

Item 7: Report #
Number the reports for each project sequentially starting with Number 1.

Item 8: Week Ending
Enter last date (M/D/YY) (Saturday) of current construction week.

Item 9: Size/Type
List the type of cement (I, II, or III).
List the fly ash class (C or F).
List the grade of slag (100 or 120).
Other is for microsilica, etc.
List the size fractions of aggregate (sand, 3/4-, 3/4+, CA-50, etc.).
For Admixtures list the type (A, B, A(MR), etc.)

Item 10: Pit # or Manufacturer
The cement, fly ash, pit numbers, and other admixture information are found on the Certificate of Compliance. The pit number is also found on the Mix Design issued by Mn/DOT Concrete Engineering Unit or Paving Contractor's Approved Mix Design.

Item 11: Specific Gravity
This number is found on the Mix Design issued by the Mn/DOT Concrete Engineering Unit or Paving Contractor's Approved Mix Design. Use specific gravity of 2.58 for fly ash used at Ready-Mix Plants. Use the individual fly ash specific gravity for paving projects.

Item 12: Absorption Factor
This number is found on Mix Design issued by Mn/DOT Concrete Engineering Unit or Paving Contractor's Approved Mix Design.

Item 13: Mix Designation and Design Weights
List the mix designation and oven dry design weights for each mix. These weights are found on Mix Design issued by Mn/DOT Concrete Engineering Unit or Paving Contractor's Approved Mix Design. List the admixture dosage. This number can be found on the Certificate of Compliance or the Paving Batch Ticket.

Item 14: Design Water
This weight is found on Mix Design issued by Mn/DOT Concrete Engineering Unit or Paving Contractor's Approved Mix Design.

Item 15: Mix
List the mix designation for the load tested.

Item 16: Date
List the date (M/D/YY) the concrete was placed.

Item 17: Location
List stations for paving jobs. List component name for other work, i.e. W. Abutment, Pier Col #1, SE Wingwall, etc.

Item 18: Time
Indicate the time that the concrete was batched. To display time correctly, type in the actual time, then space, then A or P (8:42 P).

General Notes on Items 19-24

Record ALL concrete tests on this page. Record extra tests taken in addition to those required by the "Schedule of Materials Control." DO NOT list any test averages, instead, list each test INDIVIDUALLY. Attach additional sheets if necessary.

Item 19: % Air
Record the air content to the nearest 0.1%. Compare results with specification 2461.4A4b. Air contents should range between 5% and 8% with a target of 6.5%.

Item 20: Slump
Record the slump to the nearest 5 mm (1/4 in.). Compare the results with Specification 2461.4A4a.

Item 21: Total Actual Water
Indicate the total water in kilograms per cubic meter (pounds per cubic yard) of concrete. This is the sum of the total water printed on the batch ticket and any additional water added at the plant and/or job site divided by the batch size.

Item 22: Cylinder/Beam No.
Indicate the field number of the test specimen. For cylinders, list the field ID number submitted on the *Cylinder ID Card* (Form 2409).

Item 23: Air Temperature
Indicate the ambient air temperature at the time the concrete tests were taken.

Item 24: Concrete Temperature
Indicate the concrete temperature at the time the concrete tests were taken.

Item 25: Water Ratio
This number is determined by dividing the total actual water (Item 21) by the design water (Item 14). This number should not be more than 1.04.

$$\text{Water Ratio} = \frac{\text{Total Actual Water}}{\text{Design Water}}$$

Item 26: Water/Cementitious Ratio
This number is determined by dividing the total actual water (Item 21) by the total design cementitious. Total cementitious includes cement, fly ash, slag, etc.

$$\text{Water/Cement Ratio} = \frac{\text{Total Actual Water}}{\text{Total Design Cementitious}}$$

Item 27: Remarks
List additional information or comments, i.e. change in air added at plant or jobsite, why some test results are out of spec, or where an air test was taken, etc.

Item 28: Additional Remarks
This space is for additional remarks that may have come up during the week that may affect the quality of the concrete.

Item 29: Mix Number
Enter the mix designations used on the project during this week.

Item 30: Date
List the date for each day of the week.

Item 31: Daily Totals
Enter daily totals in cubic meters (cubic yards) for each mix design used.

Item 32: Daily Totals (m^3 or yd^3)
List the daily totals in cubic meters (cubic yards) for all mixes.

Item 33: Weekly Totals (m^3 or yd^3)
List the total quantities for each mix.

Item 34: Grand Total
List the sum total of cubic meters (cubic yards) of concrete placed during the week.

Item 35: Inspector
Handwritten signature of person who filled out the *Weekly Concrete Report*.

Item 36: Phone Number
Phone number of person who filled out the *Weekly Concrete Report*.

Item 37: Engineer/Supervisor
The Project Engineer or Project Supervisor signs the completed report after they have reviewed the document for accuracy.

Mn/DOT WEEKLY CONCRETE REPORT (ENGLISH) - Form 2448-04 (6/20/2002)

		Material	Size/ Type	Pit # or Manufacturer	Specific Gravity	Absorp. Factor	Mix #1	Mix #2	Mix #3	Mix #4	Mix #5	Mix #6
Low S.P.	1						13					
Bridge #	2	Cement	9	10	3.15		13					
		Fly Ash	9	10	11		13					
Engineer	3	Slag	9	10	11		13					
		Other	9	10	11		13					
Inspector	4	F Agg 1	9	10	11	12	13					
		F Agg 2	9	10	11	12	13					
Contractor	5	C Agg 1	9	10	11	12	13					
		C Agg 2	9	10	11	12	13					
Batch Plant	6	C Agg 3	9	10	11	12	13					
		C Agg 4	9	10	11	12	13					
Report #	7	Admix 1	AEA	10			13					
		Admix 2	9	10			13					
Week Ending	8	Admix 3	9	10			13					
						Design Water	14					

Mix	Date	Location	Time	% Air	Slump (in)	Total Act. Water (lb/c.y.)	Cylinder/ Beam #	Air Temp °F	Concrete Temp °F	Water Ratio	W/C Ratio	Remarks
15	16	17	18	19	20	21	22	23	24	25	26	27

Additional Remarks:	Mix Number	30	30	30	30	30	30	30	Week Totals yd^3
28	29	31	31	31	31	31	31	31	33
	29	31	31	31	31	31	31	31	33
	29	31	31	31	31	31	31	31	33
	29	31	31	31	31	31	31	31	33
	29	31	31	31	31	31	31	31	33
	29	31	31	31	31	31	31	31	33
	Daily Totals yd^3	32	32	32	32	32	32	32	34

Inspector: 35 Phone Number: 36 Engineer/Supervisor: 37

Mn/DOT WEEKLY CONCRETE REPORT (ENGLISH) - Form 2448-04 (6/20/2002)

Low S.P.	8901-23
Bridge #	
Engineer	T. Sanders
Inspector	S. Stone
Contractor	TUV Paving
Batch Plant	TUV Batch Plant - St. Cloud
Report #	1
Week Ending	5/10/2003

Material	Size/ Type	Pit # or Manufacturer	Specific Gravity	Absorp. Factor	Mix #1 3A21	Mix #2 3A41	Mix #3 3A21HE	Mix #4	Mix #5	Mix #6
Cement	I	Graymatter@St. Paul, MN	3.15		450	450	530			
Fly Ash	C	Asher@Carter, MN	2.60		130	140	70			
Slag										
Other										
F Agg 1	Sand	#199999 - Salinger, Freeport	2.62	0.011	1090	1085	1095			
F Agg 2										
C Agg 1	1 1/2"	#188888 - Rock Island, St. Cloud	2.77	0.003	770	680	775			
C Agg 2	3/4"-	#188888 - Rock Island, St. Cloud	2.74	0.004	910	985	870			
C Agg 3	3/8"-	#177777 - Pebble Pit, St. Cloud	2.65	0.012	390	390	390			
C Agg 4										
Admix 1	AEA	Ajax AEA								
Admix 2	A	WRXX								
Admix 3										
				Design Water	208	212	216			

Mix	Date	Location	Time	% Air	Slump (in)	Total Act. Water (lb/c.y.)	Cylinder/ Beam #	Air Temp °F	Concrete Temp °F	Water Ratio	W/C Ratio	Remarks
3A21	5/5/2003	25+50	7:15 AM	7.5%				68	74			
3A21	5/5/2003	29+00	8:30 AM	6.8%	1 1/4							
3A21	5/5/2003	32+50	9:45 AM	6.6%			1A, 1B, 1C	72	76			
3A21	5/5/2003		10:15 AM			201				0.97	0.35	Microwave Oven/Batch Ticket w/c ratio
3A21	5/5/2003	36+00	10:30 AM	6.8%								
3A21	5/5/2003	39+50	11:25 AM	6.2%								
3A21	5/5/2003	43+00	12:15 PM	7.0%				75	78			
3A21	5/5/2003		1:00 PM			212				1.02	0.37	Microwave Oven/Batch Ticket w/c ratio
3A21	5/5/2003	46+50	1:15 PM	6.9%								
3A21	5/5/2003	50+00	2:00 PM	6.7%								Front of Paver
3A21	5/5/2003	50+00	2:10 PM	5.9%								Behind Paver
3A21	5/5/2003		2:30 PM			208				1.00	0.36	Microwave Oven/Batch Ticket w/c ratio
3A21	5/5/2003	53+50	3:15 PM	6.8%								
3A21	5/5/2003	57+00	4:15 PM	7.2%			2A, 2B, 2C	70	74			
3A21	5/5/2003	60+50	5:00 PM	6.7%								
3A21	5/5/2003		5:20 PM			218				1.05	0.38	Microwave Oven/Batch Ticket w/c ratio
3A21	5/5/2003	64+00	5:45 PM	6.9%								
3A21	5/5/2003	67+50	6:00 PM	7.5%								
3A21	5/6/2003	71+50	7:10 AM	7.2%								
3A21	5/6/2003	75+00	8:25 AM	7.1%	1							

Additional Remarks:

Mix Number	5/4/2003	5/5/2003	5/6/2003	5/7/2003	5/8/2003	5/9/2003	5/10/2003	Week Totals yd^3
3A21		3980.00	1691.00	2550.00	2955.00			11176.00
3A41								
3A21HE								
Daily Totals yd^3		3980.00	1691.00	2550.00	2955.00			11176.00

Inspector: *S. Stone* Phone Number: 612-345-8888 Engineer/Supervisor: *T. Sanders*

5-694.750 IDENTIFICATION CARDS

Colored-coded cards are used for sample identification. They are designed to provide space for all pertinent information. Fill in all the information requested on the card.

5-694.751 ID CARD - SAMPLE (Form 2410)

Use this ID card for submitting various samples to the Laboratory. This pink card is used for submitting aggregate samples, curing compounds, concrete treating oil, and various other concrete products. Do not use this card for submitting cement, fly ash, slag, or concrete cylinders.

Numbers correspond to the ID sample card. See Figure A 5-694.751.

Check with the District Lab for further instructions.

<u>Item 1: Date Sampled</u>
Date the sample was taken.

<u>Item 2: Field I.D.</u>
Any identification assigned to the sample by field personnel or the individual submitting the sample.

<u>Item 3: Spec No./Type and Spec Yr.</u>
Specification number and year that applies to the test results.

<u>Item 4: Mix Design Report #</u>
Not required for Certified Ready-Mix or Concrete Paving.

<u>Item 5: Type of Project</u>
Check appropriate type of project.

<u>Item 6: Proj. No.</u>
Identify the project number(s).

<u>Item 7: Br No.</u>
Identify the appropriate bridge number(s) if applicable.

<u>Item 8: Submitted by</u>
Individual submitting the sample.

<u>Item 9: Tel. No.</u>
Submitter’s telephone number.

<u>Item 10: Proj. Eng.</u>
Project Engineer assigned to the project(s). (This may be a county or city engineer)

Item 11: Fax No.
Fax number of submitter.

Item 12: County/City
Responsible Agency, if not Mn/DOT

Item 13: District No.
Mn/DOT District where the project is located.

Item 14: T.H. No.
Trunk Highway on which the project is located.

Item 15: Type of Material and Use
Structure(s) and/or use(s).

Item 16: Mix Proportions
The proportion of a composite that this sample represents.

Item 17: Pit. No./Name
Mn/DOT pit number of aggregate material.

Item 18: Legal Description
Not required for ready-mix or paving

Item 19: Manufacturer/Contractor
Not used for aggregate samples.

Item 20: Lot No.
Not used for aggregate samples.

Item 21: Location
Ready-mix or paving plant name and location.

Item 22: Sample Taken from
Location the sample was taken (stockpile, belt, hopper).

Item 23: Tests Required
List the test(s) required. Be specific. Do not use routine, normal, etc..

Item 24: Remarks
Any notes or additional information the submitter would like to convey to the lab.

Item 25: Date Received
Date Received is for lab use.

Mn/DOT TP-02410-02
LAB I.D. NUMBER

Minnesota Department of Transportation
Sample Identification Card

Date Sampled **5-8-2003 [1]** Field I.D. **10C [2]**
Spec No./Type **3126 [3]** Spec Yr. **2000 [3]**
Mix Design Report # **[4]**

☑ S.P. Proj. No.: **8901-23 [6]** Br No.: **[7]**
☐ S.A **(5)** Submitted by: **L. Bean [8]** Tel. No.: **320-345-9876 [9]**
☐ Co/City Proj. Eng.: **T. Sanders [10]** Fax No.: **320-345-9999 [11]**
☐ Maint County/City: **[12]** District No.: **District 3B [13]** T.H. No.: **10 [14]**

Type of Material and Use: **Sand- Concrete Paving Aggregate [15]**
Mix Proportions: **14% - 1 1/2" 32% - 3/4" 12% - 3/8" 42% - Sand [16]**
Pit. No./Name: **199999 – Salinger [17]** Legal Description: **[18]**
Manufacturer/Contractor: **TUV Paving [19]** Lot No.: **[20]**
Location: **TUV Batch Plant – St. Cloud [21]**
Sample Taken from: **Belt [22]**
Tests Required: **Gradation [23]** Date Received:
Remarks: **Well-Graded Aggregate Incentive [24]**
PLEASE FILL OUT COMPLETELY(OVER)

	PERCENT PASSING[1] Field Result No. 10	Job Mix/Spec. Required[2] Class Comp.	JMF Mix Des.
50 mm(2")		100	100
37.5 mm(1 1/2")		97	100
31.5 mm(1 1/4")			
25.0 mm(1")		86	85
19.0 mm (3/4")		79	75
16.0 mm(5/8")			
12.5 mm (1/2")		67	65
9.5 mm(3/8")	100	58	55
4.7 mm(#4)	100	44	43
3.35 mm (#6)			
2.36 mm(#8)	84.7	36	34
2.00 mm(#10)			
1.18 mm(#16)	55.2	23	21
850 um (#20)			
600um (#30)	26.0	11	9
425 um (#40)			
300 um (#50)	8.7	4	4
180 um (#80)			
150 um (#100)	2.7	1	1
75 um (#200)	1.5	1.0	1.2
W.M. / F.M.			
200 / 1" Ratio (75 um/25 mm)			

Remarks:
Loss by washing 1.3% - % Passing #200

[1] Report field result in percent passing, not weight retained.
[2] See specification book, job mix formula, or mix design report.

Figure A 5-694.751

5-694.752 ID CARD - CEMENT SAMPLES (Form 24300)

A yellow cement sample I.D. card is used for submitting either cement or slag samples and must accompany each sample.

Mn/DOT TP-24300-02 (4-98)
LAB I.D. Number

Minnesota Department of Transportation
Cement Sample Identification Card

Date Sampled: 4-1-2003

Date Received: 4-2-2003

Field ID: 2

√ S.P. Proj. No.: 1020-30 Br. No. 89002
S.A.P. Submitted By: Tom Sands
Co./City Proj. Eng.: Clay Pitts
Maint.

Brand: HOLCIM Mill/Plant: MASON CITY, IA Type: I

Rail or Truck No. IXTL 32890 Shippers Invoice No.: 987987

Ready-Mix Plant: QUICKMIX –MILL CITY

Remarks:

1. Fill card out COMPLETELY in INK
2. Place card in ID card envelope (Form Mn/DOT TP-02407-02)
3. Attach envelope to cement sample. NOT inside.

Front

CEMENT TEST RESULTS			
3 Day Compressive Strength	Req'd		
7 Day Compressive Strength	Req'd		
Gillmore Initial Time of Set	Req'd Not Less Than		
Gillmore Final Time of Set	Req'd Not More Than		
Soundness	Req'd	Air Content	Req'd
Blaine	Req'd		
COPIES TO	CHARGE OUT	REMARKS Date Laboratory Chief	

Back

5-694.753 ID CARD - FLY ASH SAMPLES (Form 24308)

A yellow fly ash sample I.D. card must accompany each sample.

Mn/DOT 24308 (5-98) Minnesota Department of Transportation **Fly Ash Sample ID Card**	
Date Sampled **4-1-2003**	Date Received **4-2-2003**
S.P. No. **1020-30**	
Submitted By **Tom Sands**	Proj. Engr. **Clay Pitts**
Distributor/Supplier **Lafarge**	
Power Plant **NSP-Eagan**	Class **C**
Rail or Truck **ASH 456 999**	Shippers Invoice **067891**
Ready-Mix Plant **QuickMix –Mill City**	Field I.D. **2**
1. Fill card out **COMPLETELY** in **INK** 2. Place this card in ID envelope (Form 2407). 3. Attach envelope to sample, **NOT** inside.	

Front

Fly Ash Test Results	REQUIREMENTS
Specific Gravity	± 0.12
% Retained on 45 µm (#325)	30.0% Max. Ret.
Soundness	0.80 Max.
Strength Activity 7 day	75% Min. Of Control
Strength Activity 7 day	75% Min. Of Control
Loss of Ignition	3% Max

Copies To	Charge Out	REMARKS ________________
		________________ ________________ Date ________________ Laboratory Chief

Back

5-694.754 ID CARD - CONCRETE TEST CYLINDER (Form 2409)

A green cylinder identification card must accompany every cylinder submitted to the Laboratory. The card must contain all data requested. Place the card inside an envelope provided for this purpose and then insert into the sample bag with the cylinder.

Mn/DOT TP-02409-01 (4-98)
LAB I.D. Number

Minnesota Department of Transportation
Concrete Cylinder Identification Card

Date Made: 4-1-2003
Field ID: 3
Mix No. (3Y43, etc.): 3Y43

√ S.P. Proj. No.: 1020-30 Br. No.: 89002
S.A.P. Submitted By: Tom Sands Tel. No.: (612) 345-6789
Co./City Proj. Eng.: Clay Pitts Res. Eng.: Bob Loams
Maint. County/City: Dist. No.: Metro West
Part of Structure: End Diaphragm
Source of Ready-mix: QuickMix – Mill City Job Mix
Remarks: 28-day break

DO NOT WRITE BELOW THIS LINE

Date Received:

Break Date	Load	P.S.I./ MPa	Mold	Results Phoned

Front

INSTRUCTIONS

1. See Concrete Manual 5-694.511.
2. Fill in front of card completely.
3. If early break is desired, request under "Remarks".
4. Place this card in ID card envelope (Form Mn/DOT TP-02407-02).
5. Improperly finished or improperly molded cylinders will not be broken by the laboratory.

Back

5-694.760 BRIDGE REPORTS

5-694.761 CONCRETE MOBILE CALIBRATION WORKSHEET

The Concrete Mobile calibration worksheets are used to calibrate a standard Concrete Mobile. Instructions for calibrating the Concrete Mobile are found in 5-694.454 and blank forms are available on the Mn/DOT Concrete Engineering Unit website at www.mrr.dot.state.mn.us/pavement/concrete/forms.asp.

A Concrete Mobile calibration worksheet example is shown in Figure A 5-694.761 (1-4). Results of the calibration example are plotted in Figure D 5-694.454. Assumed constants are 70 revolutions and 30 seconds per 45 kg (100 lb.) of cement. A trap rock is assumed for the coarse aggregate to establish a specific gravity (2.97).

The data calculated in the calibration example was selected to show a "spread" of points that will still result in a reasonably straight line. Normally, the data is closer in agreement.

5-694.762 WEEKLY REPORT OF "LOW SLUMP CONCRETE" (Form 21412)

DO NOT report low slump concrete for bridge deck overlays on the *Weekly Concrete Report*. The *Weekly Report of "Low Slump Concrete"* (Form 21412) was developed for this operation. The Field Inspector completes the report for the Project files. The testing rates for gradations, air, slump, and cylinder requirements are on the back of the form. The back of the form contains instructions for slump tests, necessary waste calculations, and mix design data. See 5-694.450 and Figure A 5-694.762 (1-2).

Concrete Mobile CALIBRATION WORK SHEET
(Obtain from The Concrete Engineering Unit)

Low SP **0103-86010**

Concrete Mobile Serial Number: **1** Owned By: **Real Good Concrete Company**

Calibrated By: **Commander D.A. Caswell** Date Calibrated: **June 1, 2003**

Concrete Mobile Constants: 45 kg (100 lb.) cement per ~~70~~ 72.4 revolutions at ~~30~~ 31 seconds.

Aggregate Sources: Conc. S & G Fine Aggregate and Conc. Trap Rock Coarse Aggregate.

Step 1 - Cement Check (Pre-load the Belt, etc. for the first run)
Number of revolutions required 210 Run 1
Quantity of Cement and Weight of Container.................... 152.9 kg (337.0 lb.)
Weight of Container.. 18.6 kg (41.0 lb.)
Quantity of Cement... 134.3 kg (296.0 lb.) 6 (A)

A. If quantity of cement is between 45 and 46 kg (100 - 102 lb.), proceed to Step 2.
If not make two more runs. Run 2 Run 3

	Run 2		Run 3	
Quantity of Cement and Weight of Container....	153.8 kg	(339.0 lb.)	152.4 kg	(336.0 lb.)
Weight of Container..	18.6 kg	(41.0 lb.)	18.6 kg	(41.0 lb.)
Quantity of Cement...	135.2 kg	(298.0 lb.)	133.8 kg	(295.0 lb.)

Add cement quantities for the three runs and divide by 3 = 44.8 kg (98.77 lb.) 6 (B)

B. If average quantity of cement is between 45 and 46 kg (100 - 102 lb.), proceed to Step 2.
If not, correct as follows:

$$\text{New Meter Count} = \frac{\text{Previous meter Count x 46 kg (102 lb.)}}{\text{Average Cement Weight (B)}}$$

$$\frac{\text{New Meter Count}}{\text{45 kg (100 lb.) Cement}} = \frac{3x70 \text{ x } 46 \text{ kg}}{134.4 \text{ kg}} \text{ or } \frac{3x70 \text{ x } 102 \text{ lb.}}{296.3 \text{ lb.}} = 72.4 \text{ Revolutions}$$

$$\text{New Time Constant} = \frac{\text{New Meter Count x Previous Time Constant}}{\text{Previous Meter Count}}$$

$$= \frac{72.4 \text{ x } 30.0}{70} = 31.0$$

Empty Cement Bin.

Step 2 - Sand and Stone Dial Checks

A. Standard Concrete Mobile - use 76.2 mm x 76.2 mm x 203.2 mm (3” x 3” x 8”) hard wood block (provided by Contractor).
Sand and Stone Dial Pointers should read between 6.2 and 6.6.

B. Magnum Concrete Mobile - use 42.86 mm (1-11/16”) hard wood block (provided by Contractor).
Sand Dial Pointer should read between 7.8 and 8.0.
Stone Dial Pointer should read between 7.4 and 7.6.

Step 3 - Aggregate Calibration
Number of revolutions required 72.4 (Meter Count per 45 kg (100 lb.) Cement)

A. Fill Sand Bin (Cement Bin and Stone Bin must be empty)

Sand Dial Pointer set at 2.0 (6.0 Magnum) (Pre-load the Belt).

Run 1

Quantity of Sand and Weight of Container........................ 66.7 kg (147.0 lb.)
Weight of Container... 18.6 kg (41.0 lb.)
Quantity of Sand.. 48.1 kg (106.0 lb.)

Sand Dial Pointer set at 3.0 (7.5 Magnum) (Pre-load the Belt).

Run 2

Quantity of Sand and Weight of Container........................ 87.5 kg (193.0 lb.)
Weight of Container... 18.6 kg (41.0 lb.)
Quantity of Sand.. 68.9 kg 2 (152.0 lb.)

Sand Dial Pointer set at 4.0 (9.0 Magnum) (Pre-load the Belt).

Run 3

Quantity of Sand and Weight of Container........................ 130.0 kg (227.0 lb.)
Weight of Container... 18.6 kg (41.0 lb.)
Quantity of Sand.. 84.4 kg (186.0 lb.)

Plot Sand Dial Settings vs. Quantity of Sand. (See Figure D 5-694.454, Concrete Manual.)

B. Fill Stone Bin (Cement Bin and Sand Bin Empty)

Stone Dial Pointer set at 3.0 (7.0 Magnum) (Pre-load the Belt).

Run 1

Quantity of Stone and Weight of Container...................... 72.6 kg (160.0 lb.)

Weight of Container... 18.6 kg (41.0 lb.)

Quantity of Stone... 54.0 kg (119.0 lb.)

Stone Dial Pointer set at 4.0 (9.0 Magnum) (Pre-load the Belt).

Run 2

Quantity of Stone and Weight of Container........... .... 96.6 kg (213.0 lb.)

Weight of Container... 18.6 kg (41.0 lb.)

Quantity of Stone... 78.0 kg (172.0 lb.)

Stone Dial Pointer set at 5.0 (11.0 Magnum) (Pre-load the Belt).

Run 3

Quantity of Stone and Weight of Container...................... 113.9 kg (251.0 lb.)

Weight of Container... 18.6 kg (41.0 lb.)

Quantity of Stone... 95.3 kg (210.0 lb.)

Plot Stone Dial Setting vs. Quantity of Stone. (See Figure D 5-694.454, Concrete Manual.)

Step 4 - Admixture Calculations

HiFlo System - Water Reducer (8 parts solution).

A. Time Constant (Seconds/45 kg (100 lb.) Cement) 31.0

B. Milliliters (Ounces) of Water Reducer/45 kg (100 lb.) Cement - 90 ml (3.0 oz)
(Based on Manufacturer's Recommendations)

C. Determine Cement Discharged/Minute (45 kg units (100 lb.))
60) A = 1.94

D. Milliliters (Ounces) of Water Reducer Required/Minute
B x C = 170 ml (5.82 oz)

E. Milliliter (Ounces) of Solution Required/Minute
D x 8 = 1350 ml (46.6 oz)

F. Number of Liters (Quarts) of Solution Required/Minute
E) 1000 ml or (32 oz) = 1.35 Liters (1.5 Quarts)
Liter (Quart)

HiFlo Setting (from HiFlo Chart) 1.6

NOTE: The HiFlo setting will remain constant as long as the Time Constant remains and the Water Reducer Dose is not changed.

Form 2448, Weekly Concrete Report, requires the amount of Air Entraining agent per m^3 (yd^3). This is obtained as follows:

B x 496 kg (836 lb.) Cement = 990 ml (25.1 oz) Water Reducer/m^3 (yd^3).
45 kg (100 lb.)

LoFlo System - Air Entraining Agent (11 parts solution)

The LoFlo setting is obtained by trial and error based on air content of the mix as determined by the air meter. Use a trial setting of 0.8 and adjust to obtain 6.5% air (3U17A Concrete Mix).

Form 2448 requires the amount of Air Entraining agent per m^3 (yd^3). This is obtained as follows:

G. Milliliters (Ounces) of Solution/Minute (from LoFlo Chart) 650 ml (22 oz) to obtain 6.5% air content.

H. Milliliters (Ounces) of Air Entraining Agent/Minute
G) 11 = 60 ml (2 oz)

I. Milliliters (Ounces) of Air Entraining Agent/45 kg (100 lb.) Cement
H) C = 31 ml (1 oz)

Air Entraining Agent m^3 (yd^3) = I x 496 kg (836 lb.) Cement = 342 ml (8.4 oz)
45 kg(100 lb.)

TP 21412-04 (7/2003)

Minnesota Department of Transportation

Weekly Report of "Low Slump Concrete"

Low S.P. Number: 0132-50199
Contractor: TIMEWILTELL INC.
Admixture (AEA): Adcon Air Entrainer 100
Admixture (Water Reducer): Water Reducer: RDH20
Aggregate Source CA: Rock Island #188888

Engineer: D. Greenlight
Inspector: J. Reliable
Average oz/cwt
Average oz/cwt 2.0
FA: Salinger #199999

Report Number: 1
Mixer Type & Serial: Genuine Batchers #75mn76876IF
Week Ending: 7/12/30
Paddle Type Mixer-Volume Per Batch: 3 yd^3
Concrete-Mobile-Revolution to Produce 1 yd^3 590

	Date	7/11/03	7/11/03				
DATA APPLICABLE TO BOTH MIXERS:							
Air Test Results	Air (Percent)	6.5	6.5				
	Location	Br 50199 0.002	Br 50199 0.024				
	Air (Percent)	5.7					
	Location	Br 50199 0.012					
Test Specimen	Cyliner ID	6-33					
	Location	Br 50199 0.002					
	Cylinder ID	7-33	8-33				
	Location	Br 50199 0.012	Br 50199 0.024				
	Cylinder ID						
	Location						
Gradation	CA ID	1	2				
	Location	Stockpile	Stockpile				
	FA ID	3	4				
	Location	Stockpile	Stockpile				
Slump Tests	Slump	3/4"					
	Location						
	Slump						
	Location						
	Slump						
	Location						
CONCRETE-MOBILE							
Cement Meter Register and Batching	Start		0				
	End		39001				
	yd^3 Batched		41.5				
	Waste		3.0				
	yd^3 Used		38.5				
	yd^3 Placed		346.5				
PADDLE TYPE MIXER							
Batch Date	Number Batches						
	Total Volume Batched						
	Waste						
	yd^3 Used						
	yd^3 Placed						
Cement Record (Indicate Kilograms or Bags)	Quality at Start						
	Delivered today						
	Total						
	Waste						
	Used for Slurry						
	Used for Mix						
	Quality Remaining						
Water	Average Water/yd^3						

Aggregate Grading*

Date	7/11/03	7/11/03		
Spec.	3137	3126		
5/8" or 3/8"	100%			
1/2" or No. 4	97%	100%		
3/8" or No. 8	69%	97%		
No. 4 or No. 16	12%	78%		
No. 30		50%		
No. 50		15%		
No. 100		2.8%		

- Enter preliminary gradations on Report 1 only.

Remarks (Problems in placing, curing, etc.)

Remarkable difference between Previous and new Time constant.

Report by: J. Reliable

Checked by: R. Eagle-Eye

Signed: D. Greenlight
Engineer

WEEKLY REPORT OF "LOW SLUMP CONCRETE"

This is to be used for "Low Slump Concrete" produced by continuous mixers or paddle type mixers at the job site. The sections of the form that apply to the particular type of mixer designated. Continuous mixers (concrete-mobiles) control the batching by volumetric proportioning and each mixer requires calibration for the specific aggregates to be used for the project. Paddle type mixers control the batching by weighing the ingredients prior to mixing.

1. Low Slump Concrete Mix Design 3U17A

Strength	- 5600 psi concrete at 28 days			
Water	- 270 pounds	106002	Ortonville Stone	(Sp.G 2.64) – 1369 pounds
Air	- 6.5 percent	117001	Sioux Quartzite	(Sp.G 2.65) – 1374 pounds
Cement (C/V = 0.70)	- 836 pounds (Sp.G 3.15)	152003	New Ulm Quartzite	(Sp.G 2.63) – 1364 pounds
FA	- 1374 pounds, Concrete Sand (Specification 3126)	173006	St. Cloud Granite	(Sp.G 2.72) – 1411 pounds
CA *	- CA, Class A (Specification 3137):	187002	Granite Falls Granite	(Sp.G 2.67) – 1385 pounds
Slump	- 3/4 in. ± 1/4 in.	194009	Dresser Trap Rock	(Sp.G 2.97) – 1540 pounds
Water Reducer	- Must be a Mn/DOT Approved Water Reducer - Use Manufacturer's Recommendations for Dosage Rate			

* If a coarse aggregate other than listed is to be used, the concrete mix shall be obtained from the Concrete Engineering Section.

2. Aggregate Tests

a) A minimum of one gradation of stockpiled aggregates shall be run prior to commencing operations and each time aggregate is delivered to the site.

b) Submit one laboratory sample for gradation for both fine and coarse aggregate monthly during operations.

3. Moisture Control of Aggregates

The amount of moisture (water) in the mix is controlled by the slump. (The mix produced by the concrete mobile must be allowed to hydrate 4 - 5 minutes in order to measure the true slump.) A minimum of one slump test shall be made at the start of each day. Other slump tests will be taken when the consistency of the mix changes due to varying moisture in the aggregates at the job site or whenever the aggregate stockpile is replenished (a minimum of two/day is recommended, see Materials Control Schedule). Aggregates shall be well drained and protected from the elements to maintain moisture uniformity.

4. Other Tests

See Materials Control Schedule.

5. Cement Record (Paddle Type Mixer Only)

The cement record shall be maintained in the spaces provided. A positive cement cut-off is required at the end of each week's operations or at the completion of the overlay project. Indicate whether the cement is measured by pounds or bags.

6. Yield and Batching

a) Continuous mixers. Calibration of the equipment will include the determination of the number of cement meter revolutions required to produce 1.0 yd^3 of mix for yield (see Concrete Manual) and batching records. This value is then used to determine the quantity of concrete produced during the day's pour.

b) Paddle type mixers. Batch sizes will be determined by the capacity of the mixer. The quantity batched will be determined by the volume per batch and the number of batches produced during the day's pour.

The inspector is required to estimate the amount of concrete wasted and to calculate the volume placed during the day. The yd^2 of overlay produced during the day shall also be recorded.

SPECIAL TYPES OF CONCRETE
5-694.800

5-694.810 GENERAL

In the general use of the word concrete, the idea implied is the conventional placement of the material within formed areas where the material will remain. There are, however, many variations of this procedure and a few are listed below.

5-694.811 SHOTCRETE

This term is given to a special method of mortar placement. It is usually used to repair surface areas where concrete has deteriorated, but is also used to build up thin layers of concrete to protect steel from corrosion. The mortar is ejected from a nozzle under pressures of 175 to 345 kPa (25 to 50 psi). Dry sand and cement are premixed in relatively large quantities. The sand-cement mixture and the water are introduced into the nozzle through separate hoses and are blended in the nozzle to produce a fairly dry mortar. Both the dry mix and the wet mix are acceptable to Mn/DOT. The provisions for uniformly graded aggregate as in ACI 506R-90 or in Mn/DOT's Special Provisions for the specific project should be met. Pozzolan substitution is not allowed except with the permission of the Mn/DOT Concrete Engineer. ACI 506R-90 provides detailed guidelines for shotcreting.

Prior to application of shotcrete, the Contractor shall clean the surface to remove loose concrete, dust and metallic rust or scalings. See Figure A 5-694.811. Contractor shall apply shotcrete perpendicular to the surface as shown in Figure B 5-694.811. Placement should start in the corners and work toward the center. Place it in thin layers with about one to two hour time lapse between layers. See Figure C 5-694.811 for a completed section of shotcreted median barrier.

Figure A 5-694.811

Figure B 5-694.811

Figure C 5-694.811

5-694.812 LIGHTWEIGHT CONCRETE

Lightweight concrete is a material that is produced by using lightweight aggregate.

Lightweight aggregate may consist of processed shale, clay, clinker, or other material. The production includes a burning process where the material expands and as a result has less density (weight per unit volume). Due to this expansion, some lightweight aggregate may be very absorptive. Such aggregate may require pre-wetting prior to concrete batching.

Lightweight concrete has a range in unit weight from about 1280 to 1920 kg/m^3 (80 to 120 lb/ft^3) depending on the lightweight material used. Some lightweight aggregate will produce concrete of 1760 kg/m^3 (110 lb/ft^3) and have compressive strengths comparable to conventional concrete.

Because of the high water absorption of lightweight aggregate, the air content of the mixture is measured using ASTM C 173 "Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method." This method is necessary since the standard pressure method will give false readings.

5-694.813 TILT-UP CONSTRUCTION

In tilt-up construction, either conventional or lightweight concrete can be used. Concrete slabs or panels are cast on smooth surfaces on the ground or on the previously placed concrete floor. After the concrete has cured and attained sufficient strength, the concrete panels are raised into place.

Advantages of this method of construction are that concrete walls are fabricated without erecting side forms and elimination of the more difficult vertical placement method.

5-694.814 UNDERWATER CONSTRUCTION

The decision to perform an underwater concrete placement is made when the alternatives namely the use of cofferdams, caissons or pumping-dry are neither practical nor cost-beneficial and the hydrodynamic conditions will neither erode nor affect the concrete when placed underwater.

When concrete is placed under water, use extreme care to prevent the loss of cement from the concrete. Since some cement is lost in the best operation, the cement content of the concrete is higher than for the standard method of placement. Keep the water as still as possible. Move equipment slowly in the water so that cement erosion from the surface of the concrete will not occur. Check that the water temperature is at least $10^{\circ}C$ ($50^{\circ}F$) where practical, but not less than $2^{\circ}C$ ($35^{\circ}F$). When the water temperature is low, maintain the concrete temperature at 20 to $25^{\circ}C$ (70 to $80^{\circ}F$).

The best method for placing concrete under water is with a tremie. A tremie is a large tube or pipe, 250 mm (10 in.) or more in diameter, which has a funnel shaped hopper at the top for charging the tube with concrete, and a shut-off valve at the other end. The tremie is filled with concrete with the valve closed when the unit is out of the water. The unit is then lowered into the water until the valve end rests on the bottom. The valve is opened and the concrete permitted to slowly flow from the tremie. Keep the tremie filled with the concrete to the water level so that additional concrete is added as concrete is discharged. If water gets into the tube, remove the unit and recharge with concrete. Maintain a continuous operation until the full height of the planned section is in place.

5-694.815 PRE-STRESSED CONCRETE

Pre-stressed concrete is placed and finished similar to conventional concrete placement. The cement content is about 60 to 89 kg/m^3 (100 to 150 lb/yd^3) higher than most concrete.

Pre-stressed concrete is so named because it is intentionally placed under stress before any dead or live loads are applied to it. Steel strands that extend through a form are placed under high tensile stress. After the strands are securely anchored and the concrete is placed, finished and reaches required strength, the tensioning force is removed and the stress in the strands is transferred to the concrete as pre-compression.

There are two methods of tensioning concrete: pre-tensioning and post-tensioning. In the pre-tensioning process, strands are stressed prior to concrete placement. In the post-tensioning process, flexible tubes are cast in the concrete after which steel tendons are later pulled through the tubes, stressed and anchored into place. A grout is used to encase the tendons and bond them to the tube.

Below are several pictures that illustrate some of the pre-stressing concrete process.

Figures A and B 5-694.815 show placement of reinforcement and strands.

The arrangement of rebars and pre-stressing strands in a girder are shown in Figures C and D 5-694.815.

Concrete is placed and carefully vibrated in a pre-stressed girder in Figures E and F 5-694.815.

Figure G 5-694.815 shows torching of the strands in the finished girder.

Figure H 5-694.815 shows handling of the pre-stressed girders prior to transportation.

The pre-stressed concrete girder is ready for transportation in Figure I 5-694.815.

Figure A 5-694.815

Figure B 5-694.815

Figure C 5-694.815

Figure D 5-694.815

Figure E 5-694.815

Figure F 5-694.815

Figure G 5-694.815

Figure H 5-694.815

Figure I 5-694.815

5-694.816 CELLULAR CONCRETE

Cellular Concrete is defined as lightweight portland cement concrete containing a high percentage of gas cells (distinguishable from air voids in terms of cell sizes and lognormal distribution) created mechanically by means of the addition of foaming agents. A density range of 320 to 1900 kg/m^3 (20 to 120 lb/ft^3) characterizes cellular concrete products that include CLSM (Controlled Low Strength Material). This low density is due to the uniformly distributed non-contiguous air cells that also account for high workability and desirable thermal conductivity.

Usage of the material includes, filling of pipe annuli, load reduction in bridge approach, geofill, submerged load reduction and control of active pressures on retaining walls. The Mn/DOT Concrete Engineering Unit shall evaluate each proposed usage in any Agency project.

Materials Required:

- Foaming agent or gas forming admixture conforming to ASTM C 869
- Portland cement ASTM C 150
- Mn/DOT approved admixtures/pozzolans or as specifically approved for the project by the Mn/DOT Concrete Engineer
- Potable water free of deleterious material

When used as annular fill for pipe-liners, Contractors shall secure the pipeliner to the invert of the existing culvert with fasteners, blocks, or other means to prevent the pipe liner from floating during grouting operations. Another possible means of accomplishing this is by constructing multiple grout lifts.

Contractor Mix Design

A minimum of 15 days prior to the commencement of grout placement, the Contractor shall submit a mix design to the Mn/DOT Concrete Engineer for review and approval. To produce a cubic yard of grout, and a flow diameter of 200 to 250 mm (8 to 10 in.), the Contractor shall design the grout material as follows:

- A minimum of 45 kg (100 lb.) of portland cement
- Sufficient quantities of Class C fly ash
- Fine aggregate
- Foaming agent and water

The foaming agent shall comply with ASTM C 869 when tested in accordance with ASTM C 796. For the use of other admixtures, specific approval by the mix designer and the Mn/DOT Concrete Engineer are required. Only Mn/DOT certified cementitious sources are allowed. Final approval of the mix design is based on satisfactory field placement.

The mix design shall include the following test information:

- 7 and 28 day compressive strength
- Initial and final set times – ASTM C 403
- Flow diameter

The Contractor Shall:

- Design a grouting procedure that will fill all voids between the existing culvert and the liner pipe so that the liner pipe will not collapse.
- Provide a pressure gauge that will measure the grouting pressure and a means to accurately measure the volume of grout injected.
- Submit a grouting plan to the Engineer for approval.
- Fill with grout all voids between the existing culvert and pipe liner, including all breaks or holes in the existing culvert.
- After grouting the liner, which is connected to the in-place culvert, encapsulate the remaining length of liner with a 150 mm (6 in.) minimum thickness of 3Y43 concrete and seal the extreme ends of the annular space with an approved seal.
- Finish the inlet end with a 45 degree mitered fillet-transition between the in-place culvert and the inside of the liner.
- If grout holes are utilized, use cylindrical wooden plugs or other approved plugs to effectively plug holes until the grout has set and then remove and fill them with cement.
- Test the plastic material according to ASTM C 495 at a rate of 1 specimen per 15 m^3 (20 yd^3) after testing the first cubic meter (cubic yard). The minimum sampling rate is 2 samples per unit. A unit is defined as one annular length through which pumping is done from one injection point.
- Test the hardened cellular concrete according to ASTM C 513-86 or as required by the Engineer.

5-694.817 SELF-CONSOLIDATING CONCRETE

This includes such concretes other than cellular concrete that are placed without any mechanical consolidation or are, highly superplasticized for enhanced flowability to facilitate non-conventional placement methods. The use of self-consolidating concrete is restricted to the discretion of the Mn/DOT Concrete Engineer who will provide the guidelines on situation-specific cases.

CONCRETE PAVEMENT REHABILITATION
5-694.900

5-694.901 GENERAL

Concrete Pavement Rehabilitation is an extremely valuable tool of the Minnesota Department of Transportation in an effort to maintain our concrete pavements. The repair standards were developed in the early 1980's and revised yearly since. Great strides in technology were made in the first years, while more recently the changes have been minor as current techniques are now working well.

Note: It is recommended that the Engineer perform an investigation into the soundness of pavement before specific repairs are decided upon. This investigation should include chain dragging and hammering the concrete surface to locate delaminated areas of pavement, coring, and possibly milling some joints to determine the severity of deterioration, and coring near and away from joints to test for freeze-thaw durability. See Figures A through C 5-694.901 for methods and tools used in identifying concrete pavement deterioration.

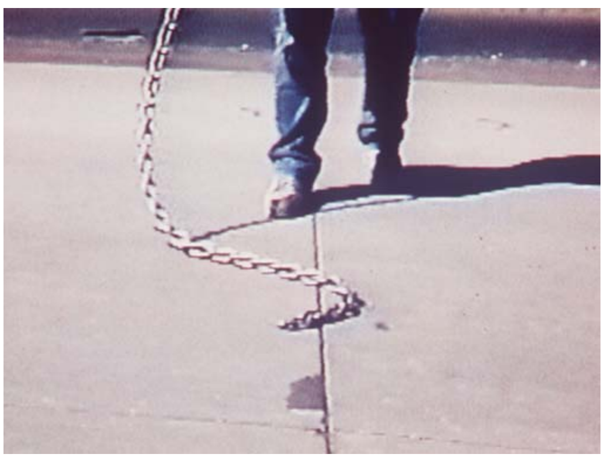


Figure A 5-694.901

Figure B 5-694.901

Figure C 5-694.901

The rehabilitation standards are available on the Mn/DOT Concrete Engineering Unit website at www.mrr.dot.state.mn.us/pavement/concrete/rehab.asp. The Special Provisions are located on the Office of Technical Support website. Audio-visual training aids are available by contacting the Mn/DOT Concrete Engineering Unit at 651-779-5576.

REPAIR TYPES

Mn/DOT breaks down concrete repairs into four basic types. The major areas of concrete pavement rehabilitation are partial depth patching, full-depth patching, slab replacement, joint/crack sealing. Other specialized repairs include Continually Reinforced Concrete Pavement (CRCP), retrofitting load transfer with dowel bars and texture planing concrete surfaces to restore ride (diamond grinding). Edge drains and shoulder replacement are other rehabilitation techniques that are sometimes added, although they are not discussed here.

5-694.910 TYPE A REPAIRS – JOINT AND CRACK SEALING

The letter "A" designates joint and crack sealing repairs. The term joint sealing is generic for sealing joints and cracks. These repairs include sawing and cleaning the concrete joint or crack face to provide a proper surface and shape factor to ensure adhesion of the sealer. Joints wider than 25 mm (1in.) may increase tire slapping. See Figures A and B 5-694.912 for examples of candidates for Type A repairs.

More information about joint sealing is available in Section 5-694.665 of this Manual.

5-694.911 JOINT AND CRACK SEALING PROCEDURES

The procedures are the same whether the joint or crack is in place or re-established. The joint is sawed to the shape specified in the plan. This operation includes water flushing. Before sealing, the joint/crack is cleaned by sand blasting and air blasting. The proper size, closed cell backer rod is then placed and the joint sealed with either silicone or hot pour sealant.

5-694.912 IMPORTANT POINTS OF JOINT AND CRACK SEALING

A perfectly clean and dry joint face is necessary for good adhesion. This is imperative for a successful joint sealing project. A proper joint shape is necessary for the seal to work properly. The shape is shown in the plans. The following is a list of Type A Repairs.

Type A-1H
Saw and reseal transverse contraction joints with hot pour sealant. See Figure C 5-694.912 for an example of a Type A-1H repair.

Type A-1S
Saw and reseal transverse contraction joints with silicone sealant.

Type A-2

Clean and seal/reseal transverse joints with hot pour or crumb rubber sealant. This is not recommended for high volume roads.

Type A-3H

Saw and seal cracks, or those portions of cracks, between 3 mm (1/8 in.) and 13 mm (1/2 in.) wide with hot pour sealant. Cracks less then 3 mm (1/8 in.) wide are generally not repaired.

Type A-3S

Saw and seal cracks, or those portions of cracks, between 3 mm (1/8 in.) and 13 mm (1/2 in.) wide with silicone sealant. Cracks less then 3 mm (1/8 in.) wide are generally not repaired.

Type A-4H

Saw and seal cracks, or those portions of cracks, between 13 mm (1/2 in.) and 25 mm (1 in.) wide with hot pour sealant. For cracks wider than 25 mm (1 in.), use Repair Type B-1.

Type A-4S

Saw and seal cracks, or those portions of cracks, between 13 mm (1/2 in.) and 2 mm (1 in.) wide with silicone sealant. For cracks wider than 25 mm (1 in.), use Repair Type B-1. See Figure D 5-694.912 for an example of a Type A-4S repair.

Type A-5H

Saw and seal/reseal non-spalled portions of untied longitudinal joints with hot pour sealant. It is not intended for tied centerline type joints.

Type A-5S

Saw and seal/reseal non-spalled portions of untied longitudinal joints with silicone sealant. It is not intended for tied centerline type joints.

Type A-6

Saw and seal/reseal non-spalled portions of tied longitudinal joints with hot pour sealant.

Type A-7H

Clean and seal cracks of 13 mm (1/2 in.) or less with hot pour sealant.

Type A-7S

Clean and seal cracks of 13 mm (1/2 in.) or less with silicone sealant.

Figure A 5-694.912

Figure B 5-694.912

Figure C 5-694.912

Figure D 5-694.912

5-694.920 TYPE B REPAIRS – PARTIAL DEPTH REPAIRS

Type B repairs generally consist of partial depth milling or chipping to remove deteriorated or delaminated concrete and preparation and placement of the repair. Type B-2D and B-2E repairs include removal to the bottom of the pavement if necessary.

5-694.921 PARTIAL DEPTH PROCEDURES

The removal area is defined by chain dragging and hammering the surface to find the complete limits of delamination. The area is then marked out clearly for the Contractor. The unsound concrete is generally milled (though chipping is allowed) a minimum of 50 mm (2 in.) and a maximum of the top of the dowel bars or 1/2 of the slab thickness. Clean the area by sand blasting and air blasting. The patch is then ready for concrete placement. See Figures A and B 5-694.922.

Between the initial milling and concrete placement, the Inspector must recheck the slab to insure that all unsound concrete is removed. Occasionally the removal operations cause some damage requiring additional removals of spalled areas.

The concrete mix design used is 3U18. Generally, there are three ways the concrete is mixed and all of these methods can achieve good concrete.

1. Continuous mixing concrete mobile - make sure that all concrete is out of the chute when production stops. Otherwise, when production starts again, the old concrete is re-tempered and the concrete will shrink excessively when it sets up.
2. Paddle mixer and bagged 3U18 concrete mix - the bagged mix must meet the requirements of Specification 3105.
3. Paddle mixer and virgin materials - normally the mix design is prorated to one or two bags of cement.

The patch area, that has been checked and cleaned, has bonding grout applied directly before concrete placement. The concrete is finished to grade, slope and texture. Grout is used to seal the edges, and then curing compound is applied.

5-694.922 IMPORTANT POINTS OF PARTIAL DEPTH REPAIRS

Partial depth repair is the most workmanship dependent operation that Mn/DOT does with respect to concrete.

Below are some of the very important points to follow for a successful repair.

- Sever misaligned dowel bars or those that have lost cross section. Coat dowel bars left in place with an approved form release agent. If the end of a dowel bar is exposed, attach a compressible material to allow movement.
- Maintain compression relief. No concrete shall extend below the dowels. Either sand or foam must extend below the bars to fill any void. In addition, either the green sawing or compression relief material must go to the depth of the dowels. Edge around all inserts.

- Re-establish all cracks and joints in the exact location as in the original pavement.
- Apply curing compound immediately after concrete placement otherwise shrinkage and de-bonding will occur. The following are a list of Type B Repairs.

<u>Type B-1</u>
Use for repairing spalled cracks greater than 2 m (6 ft).

<u>Type B-2A</u>
Use for shallow depth of 50 to 100 mm (2 to 4 in.) spot surface repairs that are less than 3 m^2 (30 ft^2). The repair may be along a joint or crack, or at any location within a panel. This repair is also used when Repair Types B-1, B-2C, B-2D or B-3 exceed the 250 mm (10 in.) minimum dimension because of deteriorated or delaminated concrete. Extra width to accommodate the Contractor's equipment shall be at the Contractor's expense. See Figures C, D, E, and F 5-694.922 for examples of partially and completed Type B-2A repairs.

<u>Type B-2B</u>
This repair is similar to Repair Type B-2A except that the minimum area is 3 m^2 (30 ft^2).

<u>Type B-2C</u>
Use for spalled concrete repair along a longitudinal edge of a panel. It has a minimum dimension of 2 m (6 ft.) along the edge and a maximum depth of T/2. If deterioration extends deeper than T/2, use a Type B-2D repair in addition to a Type B-2C repair.

<u>Type B-2D</u>
Use where deterioration along a longitudinal edge exceeds T/2 in depth. Generally, this deterioration will extend to the bottom of the pavement.

<u>Type B-2E</u>
For the ends of joints or cracks where the full-depth deterioration extends up to 450 mm (18 in.) from the end. Generally used in conjunction with a B-2A repair. See Figure F 5-694.922 for an example of a Type B-2E repair.

<u>Type B-3</u>
Use for spall repair along transverse joints. This repair may also be utilized to repair longitudinal joints, usually centerline joints that were formed with inserts. See Figures D 5-694.922 and F 5-694.922 for examples of partial and completed Type B-3 repairs.

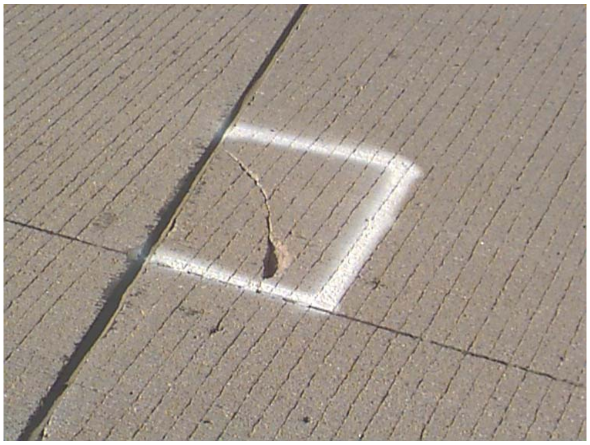


Figure A 5-694.922

Figure B 5-694.922

Figure C 5-694.922

Figure D 5-694.922

Figure E 5-694.922

Figure F 5-694.922

5-694.930 TYPE C REPAIRS - FULL-DEPTH REPAIR

The letter C designates full-depth repairs. Type C repairs consist of full thickness removal of the concrete for a distance of 1 m (3.5 ft.). A Type CX repair is used in conjunction with Type C repair if the removal extends beyond the required 1 m (3.5 ft.) but less than 4 m (13 ft.) total when measured with the centerline. See Figure A 5-694.932 for a candidate for a Type C3-D and CX Repair.

5-694.931 FULL-DEPTH PROCEDURES

The removal area is defined with the 1 m (3.5 ft.) minimum in mind. The deteriorated area is removed by saw cutting either end and then lifting the slab out. It is recommended to remove the slab using pick holes and pins to reduce the possibility of spalling off the edge of the remaining concrete. Re-compact the base material to grade if disturbed. Tie bars or dowel bars are put on each end of the repair by drilling holes and securing the bars with an approved epoxy or non-shrink grout. Sometimes dowel baskets or additional steel is required for the repair. See Figure B 5-694.932 for a partially completed C-3D repair.

While dowel bars are grouted or epoxied into place, check them for tolerance. The tolerance is 3 mm (1/8 in.) with respect to both the pavement profile and centerline. Verify all drilled bars are secure before concrete is placed. Secure dowel baskets if they are used and tolerance the base.

The concrete mix designs used for Type C repairs are 3A32HE, 3U22, 3U27, or 3U28. The use of accelerators is acceptable if early opening times are required. The mix is produced at a ready-mix plant. The Contractor must meet surface tolerance according to Specification 2301, concrete paving. The concrete is struck off, floated, textured, and cured.

5-694.932 IMPORTANT POINTS OF FULL-DEPTH REPAIRS

The alignment of the dowel bars is extremely important to the success of full-depth repairs. Check to assure the epoxy or non-shrinking grout is fully set up and the dowels are checked for straightness before concrete is placed.

The other most important point is that a white linseed oil or resin based curing compound is placed immediately and properly after concrete is placed. The following is a list of Type C Repairs.

<u>Type C-1</u>
For "spot" full-depth repairs. The detail sheet lists a 2 m (6 ft.) maximum dimension along a joint. The minimum and maximum dimensions of these repairs should be 1 m x 1 m (3.5 ft. x 3.5 ft.) and 1 m x 2 m (3.5 ft. x 6 ft.) respectively. If the maximum dimension exceeds 2 m (6 ft.), it is recommended to use a C-3A, C-3AS, or C-3D. See Figure C 5-694.932 for an example of a Type C-1 repair.

<u>Type C-2</u>
Is intended to repair concrete pavement over utility trenches.

Type C-3A
Use for full-depth repair of transverse contraction joints. The holes for the dowel bars must be drilled straight such that the dowels are aligned to within 3 mm (1/8 in.) tolerance of both the pavement profile and centerline. A Type C-3D repair is recommended for most repairs of this type since it is doweled at both ends, helping to ensure that at least one of the ends allows for contraction and expansion.

Type C-3AS
Use for full-depth repair of transverse contraction joints. It differs from the Type C-3A repair in that a dowel basket is used for alignment of the dowels. A Type C-3D repair is recommended for most repairs of this type since it is doweled at both ends, helping to ensure that at least one of the ends allows for contraction and expansion.

Type C-3B
This repair is similar to Type C-3A except that it is an expansion joint, not contraction.

Type C-3BS
This repair is similar to Type C-3AS except that it is an expansion joint, not contraction.

Type C-3D
This is the preferred full-depth contraction joint repair. It is doweled at both ends to help assure the repair will allow contraction and expansion. See Figure D and E 5-694.932 for examples of Type C-3D repairs.

Type C-4A
Use for full-depth repair of "non-tied" longitudinal joints between adjacent lanes.

Type C-4B
Use for full-depth repair of "tied" longitudinal joints between adjacent lanes.

Type C-4C
Use for full-depth repair of the longitudinal edge of a lane. If the repair required is greater than 600 mm (2 ft.) a Type C-3D repair is recommended.

Figure A 5-694.932

Figure B 5-694.932

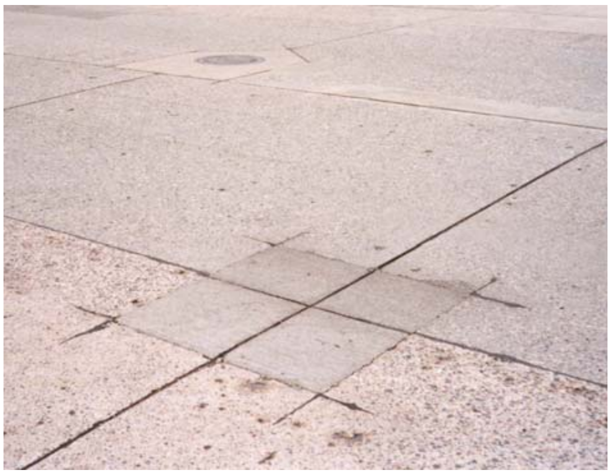


Figure C 5-694.932

Figure D 5-694.932

Figure E 5-694.932

5-694.940 TYPE D REPAIRS - SLAB REPLACEMENT

Any full-depth repair that is longer than 4 m (13 ft.) is a Type D repair. The procedures for this type of repair are the same as Type C repair. Possible concrete mixes used are 3A32, 3A32HE, 3U22, 3U27, 3U28, and 3A41. See Figure A 5-694.940 for a candidate Type D-2 repair.

A Type D repair is generally used for removal and replacement of one or more concrete pavement panels. It is also used if the length of full-depth repair within a panel exceeds 4 m (13 ft.) along centerline. The first 1 m (3.5 ft.) of a Type D repair is paid for as a Type C Repair. The remainder, 3 m (9.5 ft.) or more, is paid as a Type D repair.

Note: For repairs that require early opening times, a 3A32HE utilizing a Type E admixture has historically worked the best. A summary of mixes and their opening times is included in the Mn/DOT Repair Standards.

5-694.941 IMPORTANT POINTS OF SLAB REPLACEMENT

Often times a Type D repair exists in only one lane of a multi-lane slab. In many cases these pavements have 8.2 m (27 ft.) joint spacing. It is recommended that a joint be established near the middle of the repair to prevent a random mid-panel crack. If the 8.2 m (27 ft.) panel has a mid-panel crack, establish the joint to match where the mid-panel crack exists. The following is a list of Type D and other miscellaneous repairs.

<u>Type D-1</u>
For full-depth replacement of panels in adjacent lanes. It is also used for full-depth, partial panel repair, if the length exceeds 4 m (13 ft.) along centerline. See Figure A 5-694.941 for a Type D-1 repair.

<u>Type D-2</u>
For full-depth replacement of panels in single lanes. It is also used for full-depth, partial panel repair, if the length exceeds 4 m (13 ft.) along centerline. See Figure B 5-694.941 for a Type D-2 repair.

Figure A 5-694.940

Figure A 5-694.941

Figure B 5-694.941

5-694.945 OTHER TYPES OF SPECIALIZED REPAIRS

Type CRCP repair is rarely used. There is a small amount of continuous reinforced concrete pavement in Minnesota; therefore, Repair Standards include repair techniques for CRCP pavement.

CRCP-1
Generally, this repair is intended to repair concrete pavement over utility trenches.

CRCP-2
Used for full-depth repairs on continuously reinforced concrete pavement (CRCP) that utilizes a wide flange beam for an expansion device.

Relief Cut
The relief cut is not a repair. It is used at the discretion of the Engineer to prevent a pavement blowup during full-depth repair operations. The relief cut consists of making a temporary 100 mm (4 in.) wide full-depth cut prior to making a full-depth repair in an adjacent tied concrete lane. The relief cut portion of the joint is then repaired after completion of the adjacent full-depth repair.

5-694.950 CONCRETE TEXTURE-PLANING

To provide a smooth ride for the user, the Engineer may require the Contractor to texture-plane a concrete pavement after concrete pavement repairs or as a separate action to improve the ride. Texture-planing is commonly referred to as diamond grinding.

This work consists of planing and texturing the surface of the existing concrete pavement in the longitudinal direction as directed by the Engineer. The intent of this Specification is to improve skid resistance, correct surface defects and promote drainage. Remove existing joint seals prior to or in conjunction with the texture planing operation; however, tolerances for joint sealing are measured from the resulting planed surface.

Make all concrete repairs to the existing concrete pavement prior to beginning the concrete texture-planing operation. Texture-plane all repairs, except Type D repairs in excess of 9 m (30 ft.). Those Type D repairs in excess of 9 m (30 ft.) shall have a 5 m (15 ft.) minimum texture-planed run out at each end to eliminate bumps.

The entire surface area of the identified pavement is planed to a uniform texture. The surface shall have a finished texture with grooves between 2.5 mm (0.097 in.) and 3.3 mm (0.130 in.), and 2.03 mm (0.080 in.) and 2.92 mm (0.115 in.) apart. The Contractor shall adjust the width of kerf (space between the grooves) to maximize skid resistance with the grooves not less than 0.787 mm (0.031 in.) or more than 2.92 mm (0.115 in.) in depth. The Contractor shall provide texturing for at least 98% of any selected 0.6 m x 30 m (2 ft. x 100 ft.) longitudinal area of pavement.

Check the Mn/DOT Office of Technical Support Website for Texture-Planing Special Provisions with and without incentives for ride quality. A certified California Profilograph or Lightweight Inertial Profiler is required to check the smoothness. When using Incentive/Disincentive Specifications, the Engineer may choose to exempt large dips and bumps, to avoid excessive planing, and feather in and out of these areas.

See Figure A 5-694.950 for an example of planing equipment. See Figure B 5-694.950 for an example of a concrete pavement before and after texture-planing.

Figure A 5-694.950

Figure B 5-694.950

5-694.960 DOWEL BAR RETROFIT

The dowel bar retrofit repair is used for establishing load transfer at cracks or joints. This repair is considered when the concrete is structurally sound and the main deficiency of the pavement is load transfer. If this repair is considered and the pavement is faulted, texture-planing the pavement is also recommended. Contact the Mn/DOT Concrete Engineering Unit for further details and current specifications.

The Contractor installs slots in the pavement, places dowels in the slots, then places patching material in the slots and around the dowel bars. Figure A 5-694.960 illustrates sawing the slots for the repair. Figure B 5-694.960 illustrates a dowel bar retrofit repair prepared for placing patching material. Note how caulk prevents the intrusion of paste into the joints. Figure C 5-694.960 illustrates a repair where the patching material was just placed. Texture-planing as shown in Figure D 5-694.960 finishes off the retrofit dowel repair. See Special Provisions for details regarding this procedure.

Figure A 5-694.960

Figure B 5-694.960

Figure C 5-694.960

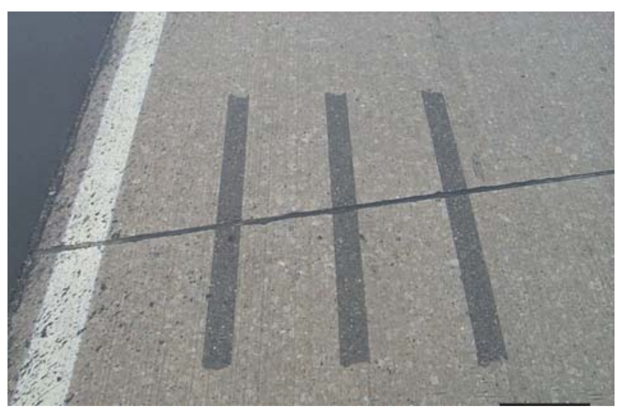


Figure D 5-694.960