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 4ºC (39ºF) 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.

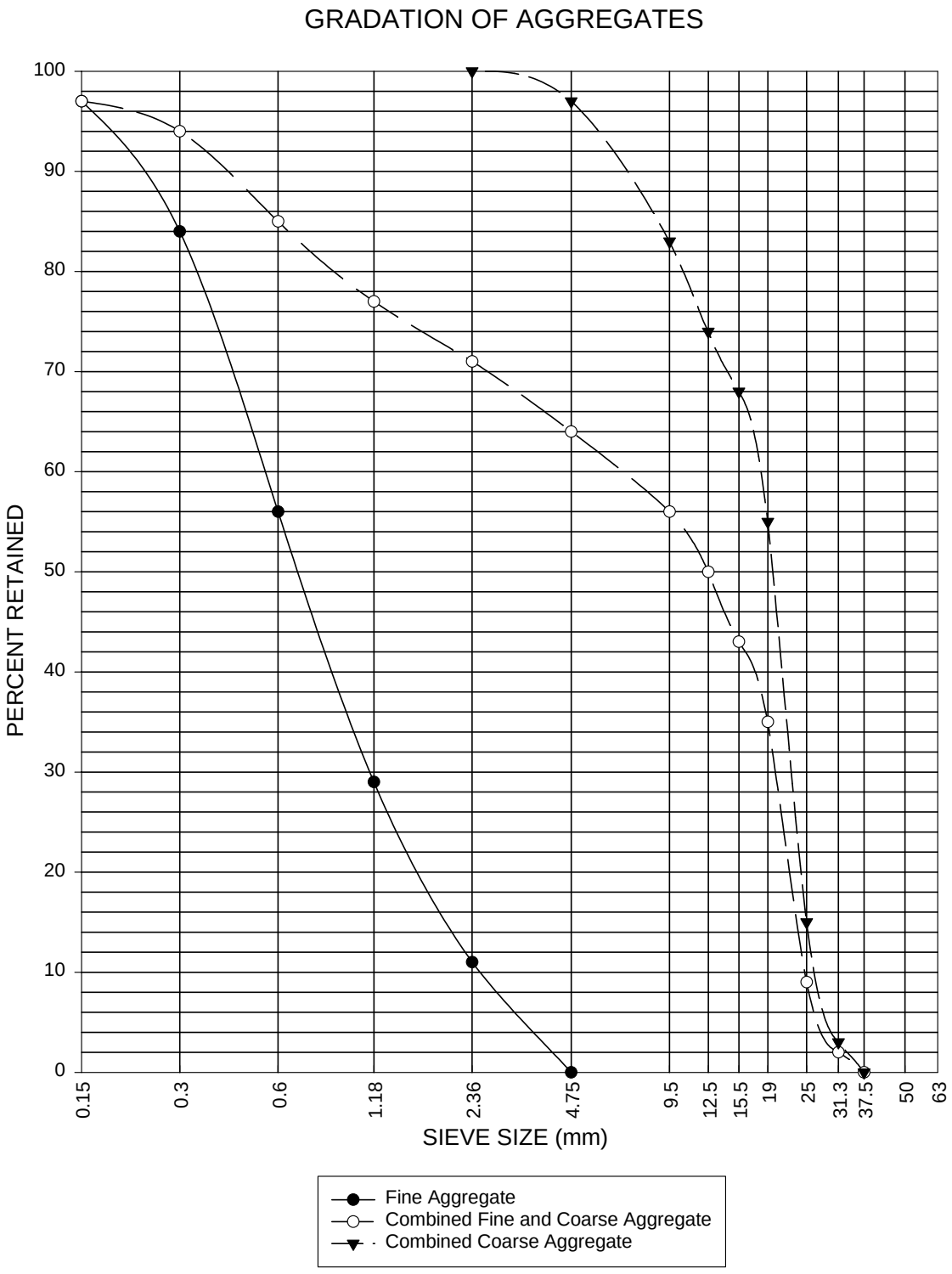

Figure A 5-694.312

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	Tremie	1	X	125-150 (5-6)	1.10	2	15-50 Incl.	1X62	
Hand Railings	Vib + Manual	3	Y	75-100 (3-4)		6	50-70 Incl.	3Y46	3Y46A may be required
Slipform Railings	Vibratory	3	Y	12-25 (1/2-1)		6	50-70 Incl.	3Y16	3Y16A may be required
Curbs & S.W. Etc.	Vib + Manual	3	Y	75-100 (3-4)		6	50-70 Incl.	3Y46	3Y46A may be required
General Reinf. Structural	Vib + Manual	1	A	75-100 (3-4)	1.10	3	35, 45, 50	1A43	
General Reinf. Structural	Vib + Manual	3	Y	75-100 (3-4)	1.00	3	35, 45, 50	3Y43	
Bridge Slabs	Vibratory	3	Y	50-75 (2-3)	1.00	3	35, 45, 50	3Y33	3Y33A may be required
End Diaphragms	Vib + Manual	3	Y	75-100 (3-4)	1.00	3	35, 45, 50	3Y43	
Interior Diaphragms	Vib + Manual	3	Y	75-100 (3-4)	1.00	3	35, 45, 50	3Y43	
Low Slump Bridge Deck Overlays	Vibratory	3	U	12-25 (1/2-1)		7	70	3U17A	
Precast Piles	Vib + Manual	3	W	25-75 (1-3)		6	50-70 Incl.	3W36	
Cast-in-Place Piles	Manual*	1	C	125-150 (5-6)	1.00	2	15-50 Incl.	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	Vib + Manual	1	W	50-75 (2-3)		6	50-70 Incl.	1W36	
Prestressed Conc. Girders	Vib + Manual	3	W	50-75 (2-3)		6	50-70 Incl.	3W36	
Precast Conc. Channels	Vib + Manual	3	W	25-50 (1-2)		6	50-70 Incl.	3W26	
Bridge Approach Panels	Vib + Manual	3	X	75-100 (3-4)	1.00	2	15-50 Incl.	3X42	
Precast Box Culvert	Vib + Manual	3	W	75-100 (3-4)		6	50-70 Incl.	3W46	
Precast Conc. End Section	Vib + Manual	3	W	75-100 (3-4)		6	50-70 Incl.	3W46	
Spec. 2411 MONOLITHIC CULVERTS									
Sidewalls and Wing Walls	Vib + Manual	3	Y	75-100 (3-4)	1.00	3	35, 45, 50	3Y43	
Top and Bottom Slabs	Vib + Manual	3	Y	50-75 (2-3)	1.00	3	35, 45, 50	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	Manual + Vib	3	Y	75-100 (3-4)	1.00	3	35, 45, 50	3Y43	
Gravity Type Walls	Manual + Vib	3	B	50-75 (2-3)	1.00	2	15-50 Incl.	3B32	
Concrete Sub-Foundation	Manual + Vib	1	A	75-100 (3-4)	1.00	3	35, 45, 50	1A43	
Spec. 2506 MANHOLES AND CATCH BASINS									
Structures of Design A, C, E, F, or G, Drop Inlet, and Surface Block	Manual	3	B	75-100 (3-4)	1.00	2	15-50 Incl.	3B42	
All Other	Manual	3	Y	75-100 (3-4)	1.00	3	35, 45, 50	3Y43	
EROSION CONTROL STRUCTURES									
Culvert Headwalls	Manual	3	A	75-100 (3-4)	1.00	2	15-50 Incl.	3A42	
Reinforced Type Dams	Manual	3	Y	75-100 (3-4)	1.00	3	35, 45, 50	3Y43	
Gravity Type Dams	Manual	3	B	50-75 (2-3)	1.00	2	15-50 Incl.	3B32	
Flumes, Aprons, Spillways, Etc.	Manual	3	A	50-75 (2-3)	1.00	4	35-60 Incl.	3A34	
Spec. 2521 SIDEWALKS									
Plain	Manual	3	A	50-75 (2-3)	1.00	2	15-50 Incl.	3A32	
Exposed Aggregate	Manual	3	A	50-75 (2-3)	1.00	6	50-70 Incl.	3A36	
Spec. 2531 CURB AND GUTTER									
Slipform Curb & Gutter	Vibratory	3	A	25-50 (1-2)	1.00	2	15-50 Incl.	3A22	
Hand Curb & Gutter	Vibratory	3	A	50-75 (2-3)	1.00	2	15-50 Incl.	3A32	
Spec. 2533 MEDIAN BARRIERS									
Cast-in-Place Barriers	Manual + Vib	3	Y	50-75 (2-3)	1.00	2	15-50 Incl.	3Y32	
Slipform Barriers	Manual + Vib	3	Y	12-25 (1/2-1)	1.00	2	15-50 Incl.	3Y12	
Precast Barriers	Manual + Vib	3	Y	50-75 (2-3)	1.00	2	15-50 Incl.	3Y32	
PRESTRESSED CONCRETE NOISE BARRIERS									
Wall Panels	Manual + Vib	3	W	50-75 (2-3)		6	50-70 Incl.	3W36	
Concrete Posts	Manual + Vib	3	W	50-75 (2-3)		6	50-70 Incl.	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**
For 2 1/2" Slump	**W = 571.70 - 55.00 M**	**Aggregate add 16.0**
For 3 1/2" Slump	**W = 595.30 - 57.30 M**	**pounds of water per cubic yard.**

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

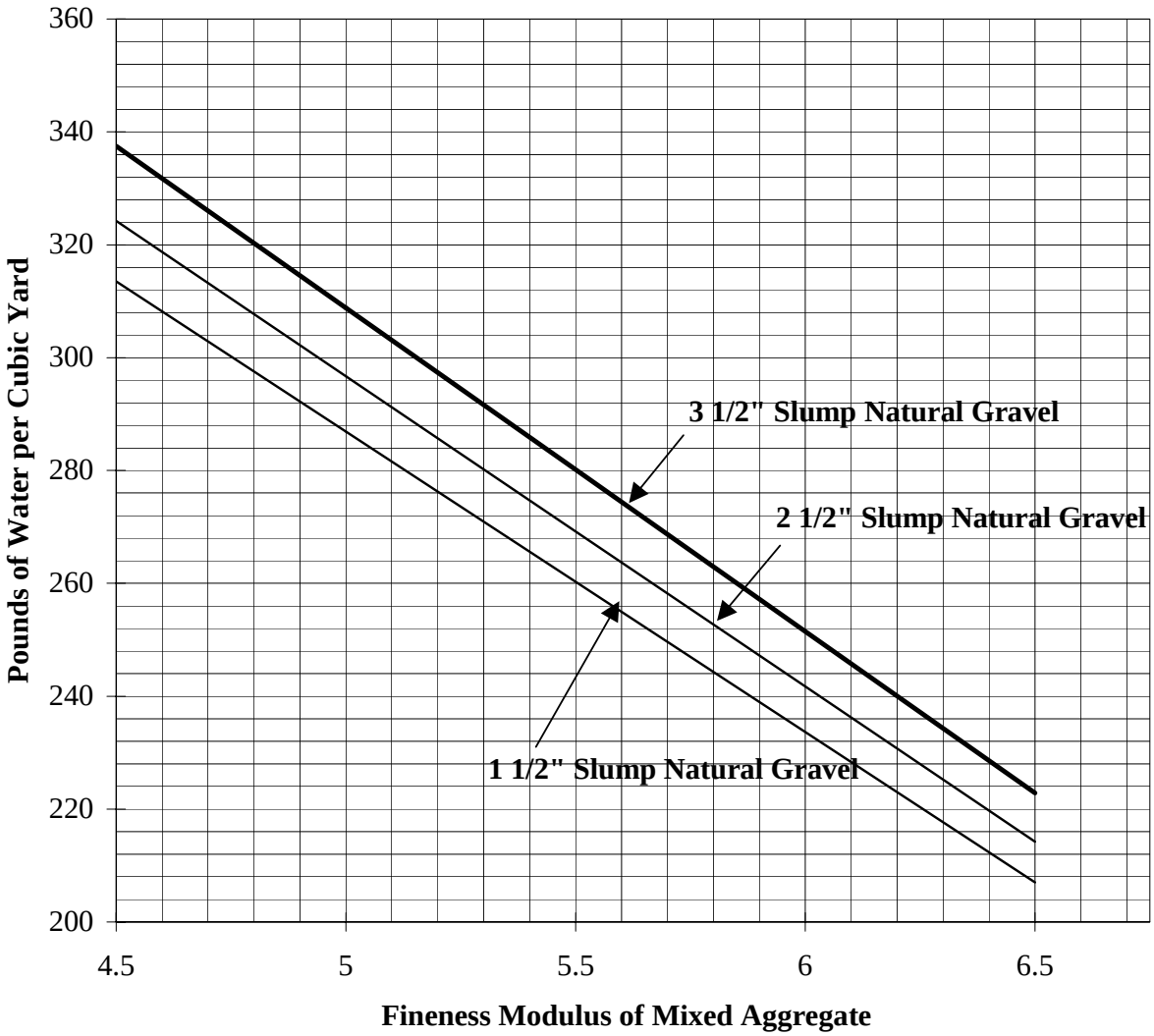

Figure B 5-694.312

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

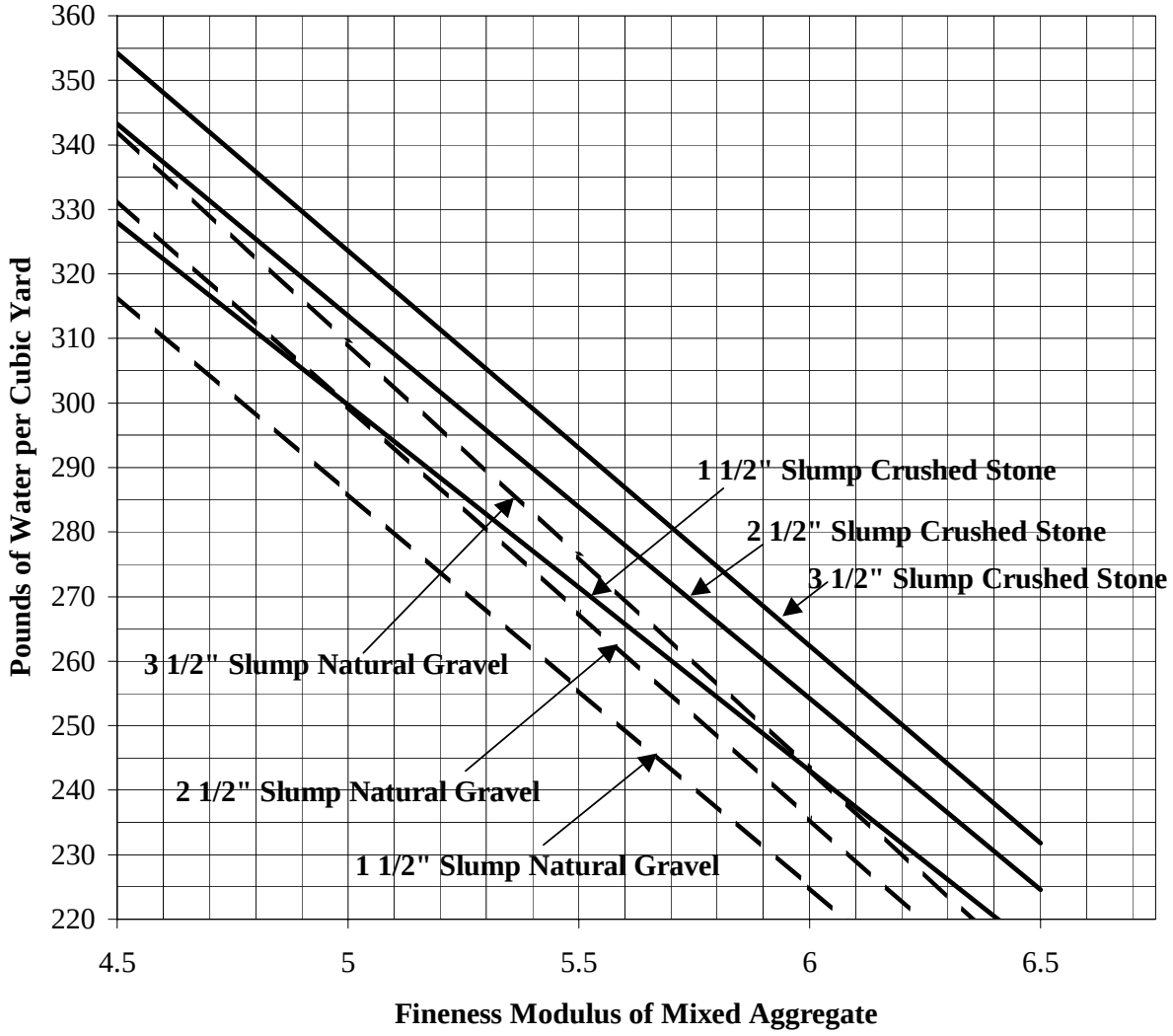

Figure C 5-694.312

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