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.

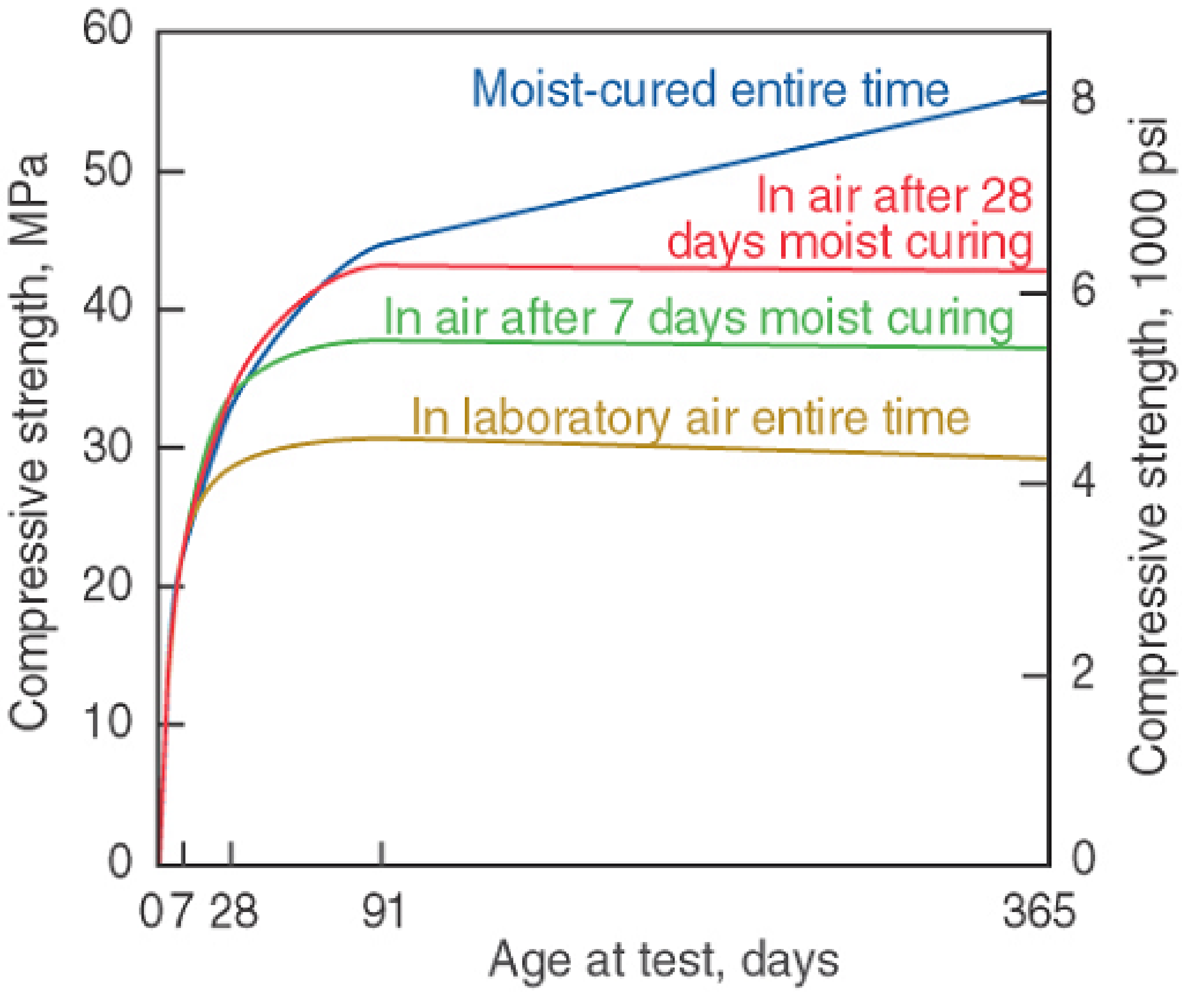

Figure A 5-694.213[1]

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.

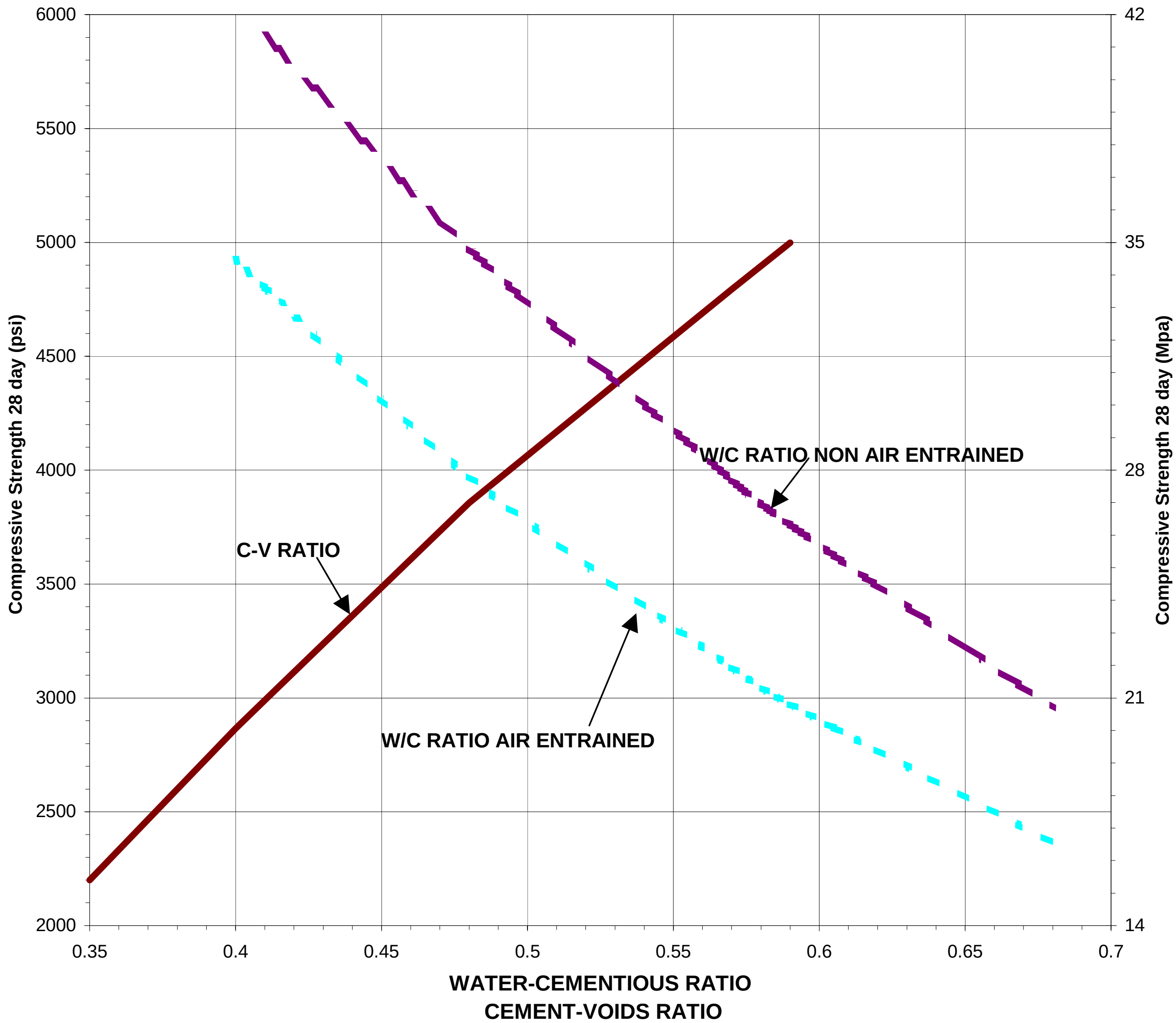

Figure B 5-694.213

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. Take care when placing concrete to consolidate the concrete without driving out the entrained air.

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.