CONCRETE MIX DESIGN TECHNICIAN STUDY GUIDE

Materials & Tests Unit

NCDOT

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Basics of Mix Design

Introduction

Concrete is a material made of cement/cementitious materials, water, and aggregates. It has been used for many years in Earth's history as a building material for structures such as bridges, houses, dams, highways, sidewalks, and skyscrapers. Concrete has several properties such as strength and durability and can be cast into any shape, form and texture, and be colored for aesthetics. Unfortunately, there are some challenges still faced today in delivering uniform and high quality concrete products, and therefore, concrete technologies continue to be developed to modify and improve both properties of fresh and hardened concrete.

Concrete mix design is the process of selecting suitable ingredients of concrete and determine the relative proportions to produce concrete with certain performance and durability requirements. Different concrete mix designs with different materials, even with the same proportions, can have significantly different properties of strength and durability. The properties of concrete can also be affected through production, placement, finishing, and curing practices. It is therefore important that concrete mixes are designed, produced, placed, cured, and tested by competent individuals.

The learning objectives for this course include:

- Understand the ACI Absolute Volume Method of concrete mix design
- Know how to design concrete mixes using NCDOT Specifications/Special Provisions
- Be able to adjust mixes using 5% ACI Variations
- Understand concrete mix design submittal and approval process for NCDOT
- Know how to correctly complete NCDOT mix design forms
- Understand the NCDOT mix design numbering system

Upon course completion and successfully passing the examination, the technician will be certified to design and submit concrete mixes for review and approval by the Department.

Abbreviations

- Specific Gravity = SG
- Weight = Wt. or lbs
- Cubic Yards = cy or yd^3
- Cubic Feet = cf or ft^3
- Pounds per Cubic Feet = pcf
- One hundred pounds of cement, or "hundred weight" = cwt
- Water-Cement Ratio = W/C

Constants

- 1 gallon of water = 8.33 lbs
- SG of water = 1.00
- 1 cubic yard (cy) = 27 cubic feet (cf)
- Unit weight of water = 62.4 pcf
- 1 bag of cement = 94 lbs

Significant Places For Rounding

- Pounds – round to whole number
- Gallons – round to tenth
- Unit Weight – round to hundredth
- Water-Cement Ratio – round to thousandths

Conversion Factors

- 1 cubic foot = 7.5 gallons
- 1 gallon of water = 8.33 pounds
- 1 bag of cement = 1.00 cubic foot ,(loose volume)
- bag of cement = 0.48 cubic feet, (absolute volume)
- 1 cubic foot of water = 62.4 lbs.
- 4 bags of cement = 1 barrel
- 1 cubic yard = 27 cubic feet

RATIO

Ratio is defined as the relation between two quantities expressed as the quotient of one divided by the other. The water to cement ratio, W/C, is the weight of mix water in the concrete divided by the weight of cement in the concrete. The water to cementitious ratio, W/Cm, is the weight of mix water in the concrete divided by the weight of the cementitious material, where the cementitious material is a combination of cement and pozzolans. The ratio is expressed as a decimal (example 0.446).

Ratio Rule 1:	Ratio = Term 1 / Term 2
	Term 1 is 300 lbs water and Term 2 is 600 lbs cement
	W/C = 300/600 = 0.500

Note that the W/C ratio is less than one for concrete. Usually the ratio for concrete should reflect about twice the amount of cement than water.

Ratio Rule 2:	Term 1 = Term 2 x Ratio
	Term 2 is 600 lbs cement and W/C is 0.500
	Term 1 = amount of water
	600 x 0.500 = 300 lbs of water

Ratio Rule 3:	Term 2 = Term 1 / Ratio
	Term 1 is 300 lbs of cement and W/C is 0.500
	Term 2 = amount of cement
	300 / 0.500 = 600 lbs of cement

Example 1
Determine the w/c ratio of a mix, given Cement = 500 lbs, and Water = 285 lbs

Answer: w/c = 285 / 500 = 0.570

Example 2
Determine the water / cementitious materials ratio (w/cm) for the following:

Cement = 360 Lbs
Fly Ash = 100 Lbs
GGBF Slag = 200 Lbs
Water = 300 lbs

Answer: w/cm = 300 / (360 + 100 + 200) = 0.455

Example 3
Determine the mixing water weight given:

w/c ratio requirement = 0.400
cement factor = 620 Lbs

Answer: 620 x 0.400 = 248 Lbs of water

Example 4
Determine w/c given a mix design with 32 gallons of water and 517 Lbs of cement per yd.

Answer: Water weight = 32 gal x 8.33 = 267 Lbs
w/c = 267 / 517 = 0.516

Dry Rodded Unit Weight

Dry rodded unit weight is sometimes called bulk or loose unit weight. Dry rodded unit weight is the ratio between the weight of the sample and the volume it occupies. ASTM C29 is used to determine the dry rodded unit weight. For aggregates approved for use by NCDOT, the aggregate dry rodded unit weight is determined by the NCDOT Materials and Tests Physical Testing lab on samples submitted by M&T Materials Inspectors or their representatives. In the procedure for determining the dry rodded unit weight, only the coarse aggregate is used.

Dry Rodded Unit Weight Example

Weight of container plus stone = 71.8 Lbs
Weight of container = 19.6 Lbs
71.8 – 19.6 = 52.2 Lbs = Wt of stone

Volume of container = 0.498 cf

Dry Rodded Unit Weight = 52.2 / 0.498 = 104.82 pcf

Dry rodded unit weight has a percentage of solids and voids. The percent solids can be calculated by dividing the dry rodded unit weight by the specific gravity of the aggregate multiplied by 62.4 (the weight of one cubic foot of water). The result is multiplied by 100 to convert to percentage.

Formula for % Solids and Voids

$$\left(\frac{\text{Dry Rodded Unit Weight}}{\text{(Specific Gravity)} \times 62.4} \right) \times 100$$

% Voids = 100 -% Solids

Example

Dry Rodded Unit Wt = 104.82 pcf
S.G. of Aggregate = 2.78

$$\% \text{ Solids} = \left[\frac{104.82}{2.78 \times 62.4} \right] \times 100 = 60\%$$

% Voids = 100 – 60 = 40%

Portland Cement Hydration and Microstructure

Hydration is the formation of a compound by the combining of water with some other substance. In concrete, hydration is the chemical reaction between hydraulic cement and water. The primary product of the reaction between cement and water is:

- Calcium Silicate Hydrate (C-S-H gel)

Calcium	**C**	Concrete
Silicate	**S**	Strength
Hydrate	**H**	Happens

A secondary product of the reaction between cement and water is Calcium Hydroxide.

- Calcium hydroxide is not a binder. It is a water soluble compound that takes up space and serves no useful purpose. Calcium hydroxide can contribute to problems such as sulfate attack.

Water of Convenience

The water to cement ratio necessary for hydration is approximately 0.220 to 0.250. Usually the mix design water cement ratio is twice the w/c ratio required for hydration. The extra water, the water of convenience is needed to provide workability.

Hydraulic Cements

Hydraulic cement is a material that sets and hardens when it comes in contact with water through a chemical reaction called hydration, and is capable of doing so under water. The hydration of cement and water form a stone-like mass called paste. When the paste is intermixed with aggregates, (sand, gravel, crushed stone or other granular material), it acts as an adhesive and binds the aggregates together to form concrete. The hydration begins immediately upon the water and cement coming in contact with each other and starts a fibrous growth. The fibrous growth continues until it links up with growth from other cement particles.

Hydraulic cements include portland cement and blended cements. Other types of hydraulic cements include masonry cements, expansive cements, and rapid-setting calcium sulfoaluminate cements.

Portland Cement (ASTM C150 /AASHTO M85)

Portland cement is the most common hydraulic cement used in concrete on NCDOT projects. It is composed primarily of calcium silicates, with a smaller proportion of calcium aluminates. By definition, the composition of portland cement falls within a relatively narrow band.

Portland cement is made primarily from four elements; calcium, silica, alumina, and iron. Raw materials containing these elements are carefully proportioned and finely interground to produce what is known as “raw meal”. The raw meal is then introduced into a rotary kiln and heated to a temperature on the order of 1400°C (2500°F). During the heating process a chemical transformation occurs among the elements to produce the primary potential compounds responsible for the setting and hardening of portland cement; principally Calcium silicates (C_3S), Calcium aluminates (C_3A), and Tetracalcium aluminoferrite (C_4AF). In addition to the primary potential compounds there will be minor amount of sodium and potassium collectively referred to as “alkalis”. The alkalis are expressed as sodium oxide-equivalent (Na_2Oeq) and represent less than 1% of the composition of the portland cement.

The product of this heat treatment is the formation of a clinker, normally in the form of hard spherical nodules approximately 25 mm or less (1 in.) in diameter. The clinker is then finely ground along with small amounts of gypsum (i.e. 5%) to control setting to produce the finished portland cement. Also limestone, and/or processing additions may be interground in the finished product. The average Blaine fineness of modern cements ranges from about 300 m^2/kg to 400 m^2/kg for Type I and II cements to as high as 700 m^2/kg for high-early (Type III) cement. (The inventor of the first portland cement thought its color was similar to that of rock found near Portland, England; thus, the name.)

Different types of portland cement are manufactured to meet physical and chemical requirements for specific purposes and to meet the requirements of ASTM C150/AASHTO M85. When ordering cements, be sure to inform the manufacturer which specification applies.

ASTM C150/AASHTO M85 describes types of portland cement using Roman numeral designations (Table 1). You might see these type designations with the subscript “A,” which indicates the cement contains air-entraining admixtures. However, air-entraining cements are not commonly available. Table 4 lists hydraulic cement types for various applications.

NCDOT allows the use of Type I, II, and III portland cements. The alkalinity of any cement, expressed as sodium-oxide equivalent, shall not excel 1.0%. For mix design that contain non-reactive aggregates and cement with an alkali content less than 0.6%, straight cement or a combination of cement and fly ash, cement and ground granulated blast furnace slag, or cement and microsilica may be used. For mixes that contain cement with an alkali content between 0.6% and 1.0% and that contain a reactive aggregate documented by the Department, use a pozzolan in the amount shown in Table 1024-1.

Table 1. Portland Cement Classifications (ASTM C150/AASHTO M85)

Type	Description
I	Normal
II	Moderate sulfate resistance
III	High early strength
IV	Low heat of hydration
V	High sulfate resistance

NCDOT Table 1024-1
Pozzolans for Use in Portland Cement Concrete

Pozzolan	Rate
Class F Fly Ash	20% - 30% by weight of required cement content with 1.0 lb Class F fly ash per lb of cement replaced
Ground Granulated Blast Furnace Slab	35%-50% by weight of required cement content with 1.0 lb slag per lb of cement replaced
Microsilica	4%-8% by weight of required cement content With 1.0 lb microsilica per lb of cement replaced

Blended Cements (ASTM C595/AASHTO M240)

Blended cements are manufactured by either intergrinding portland cement clinker or blending portland cement with fly ash or other pozzolans, slag cement (ground granulated blast-furnace slag), or limestone.

Blended cements are used in all aspects of concrete construction in the same way as portland cements. Blended cements can be used as the only cementitious material in concrete or they can be used in combination with other supplementary cementitious materials (SCMs) added at the concrete plant.

Blended cements are defined by ASTM C595/AASHTO M240, which are prescriptive-based specifications (Table 3). NCDOT specifies between 17% and 23% pozzolan content for Type IP and between 35% and 50% slag cement content for Type IS and the product must be interground. For Type IT cement, the Engineer will evaluate the blend of constituents for acceptance in Department work. These requirements for blended cements are modifications of the standard C595/M240 specification limits.

Table 3. Blended Cement Classifications (ASTM C595/AASHTO M240)*

Type	Description
IS	Portland blast-furnace slag cement
IP	Portland-pozzolan cement
IL	Portland-limestone cement
IT	Ternary blended cement

*Blended cement designations include the nominal amount of slag, pozzolan, and/or limestone in the cement. See C595 or M240 for details.

Table 4. Applications for Hydraulic Cements Used in Concrete Construction

Cement specification	General purpose	High early strength	Moderate heat of hydration	Low heat of hydration	Moderate sulfate resistance	High sulfate resistance	Resistance to alkali-silica reaction (ASR) [c]
ASTM C150 AASHTO M85 portland cements	I	III	II(MH)	IV	II, II(MH)	V	Low-alkali option
ASTM C595 AASHTO M240 blended hydraulic cements [d]	IP IS(<70) IL IT	—	IP(MH) IS(<70)(MH) IL(MH) IT(MH)	IP(LH) IL(LH) IT(LH)	IP(MS) IS(<70)(MS) IT(MS)	IP(HS) IS(<70)(HS) IT(HS)	Low reactivity option
ASTM C1157 hydraulic cements	GU	HE	MH	LH	MS	HS	Option R

[a]Adapted from Kosmatka and Wilson (2011).
[b]Check the local availability of specific cements as all cements are not available everywhere.
[c]*The option for low reactivity with ASR-susceptible aggregates can be applied to any cement type in the columns to the left.*
[d]*This table includes only the broad type designations for blended cements. Type IT cement designations include additional nomenclature that identify its composition. Type IP, IS(<70), and IL cements also include the nominal amount of pozzolan, slag, or limestone(respectively) in parentheses after the designation. See ASTM C595 or AASHTO M240 for more detail.*

Understanding a Cement Mill Test Report

The main purpose of a cement mill test report is to certify that the cement meets the requirements set forth in ASTM C150 and AASHTO M85 standards. It also provides information about the chemical and physical properties of cement, generally produced during a specific time period.

If we break down the mill test information in three main parts it would have:

- Plant and Production Information
- Chemical Data
- Physical Data

Plant and production information will identify the plant and location, production dates, and silos. Chemical data may show you the C3S, C3A, total alkalis, again varies. AASHTO M85 stipulates a minimum list of required compounds. Physical data often includes strength, set time, air content, etc. It is important to get familiar with the cement mill test report for cement used on NCDOT that you furnish.

Source: Sections copied from IMCP Manual

Alkali-Silica Reactions

What is ASR?

ASR is a reaction between the alkali hydroxides in concrete and reactive forms of silica in the aggregate. The reaction forms a gel that swells when moisture is present. The two step process can be visualized as:

1. Alkali + Silica → Gel reaction Product
2. Gel reaction Product + Moisture → Expansion

Why is ASR Bad?

ASR can cause serious expansion and cracking in concrete. This can result in major structural problems, which can lead to costly removal and replacement. The reaction can occur years after the concrete was placed. Structures most at risk are bridges, hydraulic structures, exposed frames, pavements, and foundations.

Factors Affecting ASR

For the reaction to occur the following three conditions must be present:

1. Sufficiently high alkali content of the cement
2. Reactive forms of silica in aggregate
3. Sufficient Moisture

If one of these three conditions is missing the reaction cannot occur.

How does NC DOT Mitigate the Problem?

The best way to avoid ASR is to take appropriate precautions before the concrete is placed. Section 1024-1 of the NC DOT Standard Specifications for Roads and Structures addresses these precautions.

I. The alkalinity of any cement, expressed as sodium-oxide equivalent, shall not exceed 1.0%.
II. For mix designs that contain non-reactive aggregates and cement with an alkali content less than 0.6%, straight cement or a combination of cement and fly ash, cement and ground granulated blast furnace slag or cement and microsilica may be used. The pozzolan quantity shall not exceed the amount shown in Table 1024-1 of the Standard Specifications.
III. For mixes that contain cement with an alkali content between 0.6% and 1.0%, use a pozzolan in the amount shown in Table 1024-1.
IV. For mixes that contain a reactive aggregate documented by the Department, use a pozzolan in the amount shown in Table 1024-1.

The following aggregate sources have exhibited alkali-silica reactivity in the field and/or laboratory. Concrete mix designs with these aggregates require a pozzolan if the alkalinity of the cement exceeds 0.6 %, as required by Section 1024-1 of the NCDOT Standard Specifications for Roads and Structures.

The specification states that “cement with a higher alkali content not to exceed 1 % is allowed if used with Class F fly ash, ground granulated blast furnace slag, microsilica or other Department-approved pozzolans” in a required amount. See the specification for details.

Stone from the following quarries has exhibited ASR in the field and laboratory:

Owner	**Location**	**Quarry Number**
Hanson	Princeton	CA 64
Martin Marietta	Pomona	CA 51
	Thomasville	CA 102
Vulcan	Gold Hill	CA 85

Stone from the following quarries has exhibited ASR in the laboratory:

Martin Marietta	Asheboro	CA 30
	Bakers	CA 32
Vulcan	Havre de Grace (Maryland)	CA 345

Chemical Admixtures

Admixtures have long been recognized as important components of concrete used to improve its performance. Materials used as admixtures included milk and lard by the Romans; eggs during the middle ages in Europe; polished glutinous rice paste, and boiled bananas by the Chinese; The American Concrete Institute defines Chemical admixtures as. “A material other than water, aggregates, hydraulic cement, and fiber reinforcement, used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing.”

Today, admixtures are used not just for traditional purposes, but to help concrete remain a sustainable building product. Admixture technologies allow for the use of non-traditional ingredients such as cement kiln dust, non-spec aggregates, non-reactive fly ash, non-spec silica fume, lime stone powders, and other non-typical powders to replace Portland cement in a concrete mix while maintaining all desired plastic and hardened properties.

Table 1. ASTM C 494 Admixture Classifications

Type	Description
A	Water-Reducing
B	Retarding
C	Accelerating
D	Water-Reducing & Retarding
E	Water-Reducing & Accelerating
F	Water-Reducing, High-Range
G	Water-Reducing, High-Range & Retarding
S	Specific Performance

Water-Reducing Admixtures

“Admixtures that either increase slump of freshly-mixed mortar or concrete without increasing water content or maintain slump with a reduced amount of water, the effect being due to factors other than air entrainment”.

Normal Water-Reducing Admixtures

Concrete containing a water-reducing admixture needs less water to reach a required slump than untreated concrete. The treated concrete can have a lower water-cement ratio. This usually indicates that a higher strength concrete can be produced without increasing the amount of cement. Type A Water Reducing Admixtures reduces the required water content for a concrete mixture by about 5-7%. To be classified as a Type A admixture, the product must not cause excessive retardation. When these products exceed the allowable retardation in set time, they become a Type D admixture.

Mid-Range Water-Reducing Admixtures

Mid-Range Water Reducing Admixtures reduce the required water content for a concrete mixture by about 7-15%. Mid-range water-reducing admixtures reduce the effort required to pump, place, and finish concrete. These products are generally used for slumps ranging from 5 to 8 inches. They allow for the production of concretes in these slump ranges without over retardation that would occur using traditional water reducing admixtures. Although the term mid-range water reducer is commonly used in the concrete industry, ASTM and ASHTO do not have a classification for these products. Due to this fact, they are generally classified as a Type A admixture, but can reach the water reduction requirements of a high-range water reducer.

High Range Water-Reducing Admixtures

High-Range Water Reducers, also known as Super plasticizers or (HRWR) meets:

ASTM Type A Water Reducer

ASTM Type F High-Range Water-Reducer

Super plasticizers reduce water content by 15 to 40 percent and used in concrete with low- to very low water-cement ratio in order to make high-slump flowing concrete. Without these technologies, today’s ultra-high preforming concretes would not be possible.

Retarding and Hydration Control Admixtures

Retarding Admixtures - delay the hydration of cement in concrete making concrete easier to place and finish in hot weather. In the past, these products have been used to help reduce slump loss during transit. The over use of retarders to prevent slump loss can lead to an unwanted retardation of the set time. Temperature of concrete is an indicator of cement hydration and set characteristics. General optimum conditions for concrete set, curing, and strength gain are 70 degrees F and 70% humidity. Normally accepted range =

68 F to 86 F. Retarding admixtures are set control (hydration control) admixtures and qualifies as a Type B, Retarder or as a Type D Water Reducer and Retarding Admixture.

Hydration Control Admixtures- These products are used to control the rate of hydration, and thus, the temperature of concrete. They have an advantage of over retarders because they have a quicker and more defined release of the retardation effect. They are commonly used in long-haul applications, drilled shafts, and stabilizing returned concrete.

Accelerating Admixtures

Accelerating admixtures increase the rate of early strength development; reduce the time required for proper curing, protection, and speeds up the start of finishing operations. Accelerating admixtures are classified into two different categories, chloride bearing and non-chloride bearing. It is very important to select the proper accelerator for the given project. Chloride bearing admixtures are not designed to be used in concrete that will have steel reinforcement. They will cause the steel to corrode, and the structure will be compromised. Accelerator also allow for fast track repairs to concrete pavement. With the use of non-chloride accelerators, concrete can reach a flexural strength of 400 p.s.i in 4 hours. With this performance, pavements can be repaired overnight, with lanes being opened in the morning for traffic.

Table 2.Setting Time of Concrete at Various Temperatures

Temperature	Setting Time
70 F	6 Hours
60 F	8 Hours
50 F	11 Hours
40 F	14 Hours
30 F	19 Hours
20 F	Set does not occur- concrete will freeze

Air-Entraining Admixtures

Among the first greatest advances in concrete technology was air entraining admixture. It was developed in the mid 1930’s. A study of certain concrete pavements revealed that the more durable pavements were slightly less dense, and that the cement used had been obtained from mills using beef tallow as a grinding aid in the manufacturing of cement. The beef tallow acted as an air-entraining agent, which improved the durability of the pavements.

Air-Entraining causes the development of a system of microscopic air bubbles in concrete, mortar, or cement paste during mixing, usually to increase its workability and resistance to freezing and thawing. These microscopic air bubbles allow for room for water to expand into when it freezes. This is important due to the fact that water expands 9 percent when it freezes. Without this space, the ice that is created internally would cause tensile stresses that cause premature concrete failure. Concrete is generally specified with 5-8 percent air to help overcome these mechanisms.

Specialty Admixtures

Water Repellency Admixtures block or impede the flow of water through the natural capillaries in hardened concrete and are used in structures below the water table or in water retaining structures. These products generally work by creating a crystalline structure in capillaries to keep out water, as well as, any compounds that might be dissolved in the water. These compounds could react with the concrete structure to cause a shorting of its life cycle.

Anti-washout / Underwater and Viscosity Modifying Admixtures

Anti-washout/ Underwater Admixtures are added to concrete that is placed under water or may be subject to washout during placing and before it hardens. These admixtures stabilize the mix, increasing cohesion and reducing the washout. By reducing the amount of mortar that is washout, they help to ensure that the concrete's designed hardened properties are maintained. Anti-washout admixtures also help to reduce the amount of mortar that is lost in the water supply thereby reducing the amount of environmental impact. Viscosity modifying admixture are also used in concrete mixes in which a non-spec aggregates are utilized. Sand that does not meet gradation requirements can cause excessive bleeding; VMAs help to reduce, or stop these unwanted bleeding chartists. Viscosity modifying admixtures are also commonly used in SCC mix designs to help maintain stability in the mix.

Corrosion Inhibiting Admixtures

Work for many years after the concrete has set, increasing the corrosion resistance of reinforcing steel to reduce the risk of rusting steel causing the concrete to crack and scale. When corrosion occurs to the steel contained in concrete; it causes tensile stresses which are the reason that cracking and scaling is seen. Although there are other technologies available, the most common products used in the concrete industry utilize a 30 percent calcium nitrite solution.

Workability Retaining Admixtures

This technology allows concrete to maintain workability and consistency throughout the transporting, placing, consolidating, and finishing operations without effecting the set time. By maintaining the slump, the air content does not vary to the degree that is usually seen when slump lose happens. Also, by maintaining the slump, the addition of water at the job site is greatly reduced.

Shrinkage Reducing Admixtures

Shrinkage reducing admixtures are used to lower the amount of drying shrinkage concrete experiences as hydration occurs over time. These products reduce the amount of drying shrinkage cracking and micro cracking thereby improving aesthetics, water tightness, and durability. They are used to reduce the amount of drying shrinkage in precast concrete which reduces the amount of pre-stress loss in the precast member. They also help to reduce the amount of curling in a concrete slab.

Rheology Modifying Admixtures

This technology is used in concrete mixes that are produced and placed with low slumps such as barrier rails and curbs. They intensify the concrete’s response to the energy that is applied from various types of extrusion machines. This allows for faster extrusion, and fewer touch ups on the concrete surface. RMAs also help to maintain the edge slump thereby insuring the shape of the extruded product is maintained after it leaves the extrusion machine.

Latex Modifying Admixtures

Latex admixtures are used to modify and improve concrete properties in mix designs. The polymer properties helps reduce the voids in concrete, improves adhesion of new concrete to existing concrete, improves both flexural and compressive strengths. Latex admixtures are typically utilized in concrete mixes used in bridge deck overlays.

Rules Of Thumb

Concrete strength

- 6” x 12” cylinder = 100% strength measure of test
- 4” x 8” cylinder = 103 – 105% strength measure of test
- 3” x 6” cylinder = 106% strength
- Flexural Strength = 1/6 of compressive strength
- Tensile Strength = 1/10 of compressive strength
- Shear Strength = 25% of compressive strength

Temperature

- 10°F temperature change in cement produces a 1°F change in concrete
- 3.8°F temperature change in water produces 1°F change in concrete
- 1.6°F temperature change in aggregate produces a 1°F change in concrete

Water

Adding 1 gallon of water to 1 cubic yard of concrete or adding 10 gallons to a 10 cubic yard load affect the following:

- Slump – 1 gallon of water will increase the slump of 1 yard of concrete by approximately 1”
- Strength – 1 gallon of water will decrease the compressive strength by as much as 200 to 250 psi
- Water / Cement Ratio
- Shrinkage Potential – 1 gallon of water will increase the shrinkage potential by approximately 10%
- Seepage Potential
- Freeze-Thaw Durability – 1 gallon of water will decrease freeze-thaw resistance by 20%

Section II
Sieve Analysis of Coarse and Fine Aggregate

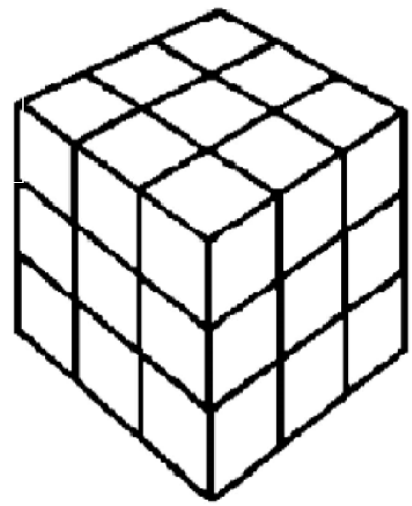
Sieve Analysis is the process by which aggregate is graded by being divided into various sizes by standard sieves. The standard sieves for coarse aggregate are 6”, 3”, 1 ½”, ¾” 3/8” and No. 4. The standard sieves for grading fine aggregate are No. 4, No. 8, No.16, No. 30, No. 50, and No. 100. Gradation limits for percentages of material passing each sieve are usually specified and are calculated to produce the minimum void content. Since the cement paste requirement for concrete is proportional to the void content of the combined aggregate, it is economically desirable to keep the void content to a minimum. Variation in grading may seriously affect the uniformity of concrete from one batch to another, because the changes in grading result in the variation of surface area which in turn results in changes in water demand. In general, variations in the grading of coarse aggregate do not affect the water demand as much as the variation in the grading of fine aggregates. The void content of fine aggregate of the same gradation varies with particle shape.

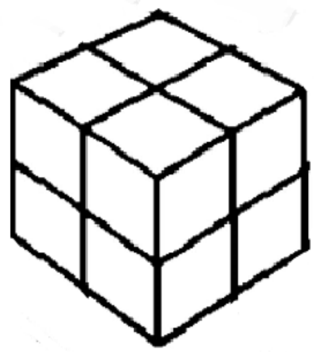
The Standard Sieves

	Sieve No.	Size of Opening	
	6”	6.0”	
	3”	3.0”	Coarse Aggregate
	1 1/2”	1.5”	Range
	¾”	0.75”	
	3/8”	0.375”	
	#4	0.187”	
Fine Aggregate	#8	0.093”	
Range	#16	0.047”	
	#30	0.0234”	
	#50	0.0117”	
	#100	0.0059”	

Effect of Particle Size on Aggregate Surface Area

Number of Cubes = 27
Number of Sides = 6
Size of Side = 1/3”
Surface = 1/3*1/3*6*27 = 18 sq. in.





Number of Cubes = 8
Number of Sides = 6
Size of Side = 1/2”
Surface = 1/2*1/2*6*8 = 12 sq. in.

Number of Cubes = 1
Number of Sides = 6
Size of Side = 1”
Surface = 1*1*6*1 = 6 sq. in.

Sieve Analysis Procedure

1. Take a Representative Sample

For any test to be valid it should be run on a sample that is representative of the total material to be used, or, as it is in concrete, the total stockpile. For aggregate gradations, the method of obtaining a representative sample requires that the sample be made up of small quantities of aggregate collected from all different sides and elevations of the stockpile. The correct procedure for sampling coarse and fine aggregate is designated by AASHTO T2, Standard Methods of Sampling and Testing. Sections 13 and 14 of AASHTO govern the correct procedures when sampling from railroad cars, barges, boats, trucks, bins, belts, and stockpiles. The number and size of samples are covered by Section 15 of AASHTO.

2. Reduce to Proper Size for Testing

The sample must be reduced to the proper size for testing by either the quartering method, or by the use of a sample splitter. Both methods reduce the sample to approximately half size each time it is used. This method is obtained in accordance with AASHTO T248, Method for Reducing Field Samples of Aggregate to Testing Size.

Samples of coarse aggregate in sieve analysis shall weigh, after drying, not less than an amount indicated in the following table.

AASHTO T27 7.4

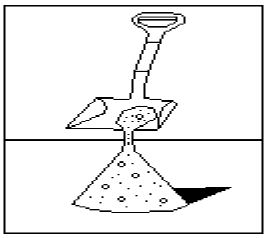
Nominal Maximum Size Of Particles mm	inches	Minimum Mass of Sample Kg. (Lb)
9.5	3/8”	1 kg (2)
12.5	½”	2kg (4)
19.0	3/’4”	5 kg (11)
25.0	1”	10 kg (22)
37.5	1 ½”	15 kg (33)

Note: 1 Kg. = 1000 grams

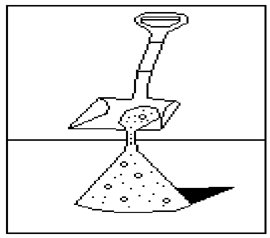
Maximum Size of an Aggregate – The smallest sieve opening through which the entire amount of the aggregate is required to pass.
Nominal Maximum Size, (of Aggregate) – The smallest sieve opening through which the entire amount of the aggregate is permitted to pass.

AASHTO T27 7.3 Fine Aggregate- The size of the test sample of aggregate, after drying, shall be 300 grams minimum.

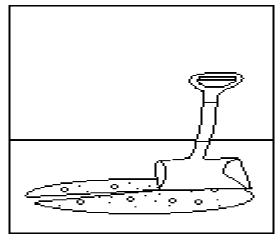
Astm C 702 Quartering Methods



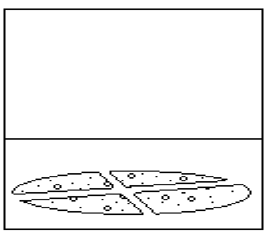
Cone Sample on Hard, Clean Level Surface



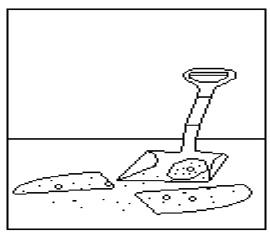
Mix by Forming New Cone



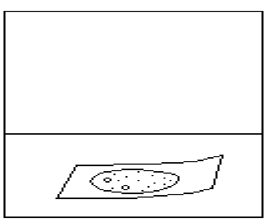
Quarter after Flattening Cone



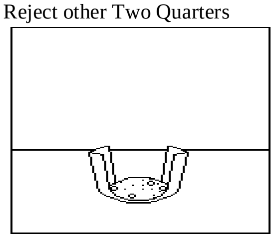
Sample into Quarters



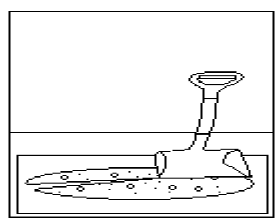
Retain Opposite Quarters
Reject other Two Quarters



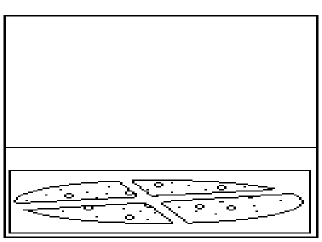
Mix by Rolling on Blanket



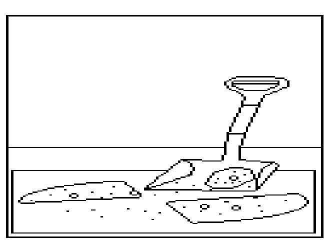
Form Cone after Mixing



Quarter after Flattening Cone

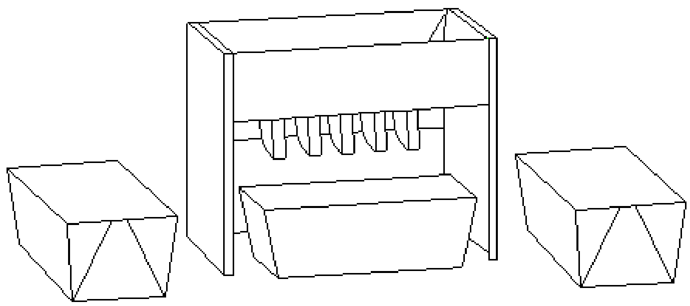


Sample into Quarters



Retain Opposite Quarters
Reject other Two Quarters

Sample Splitters



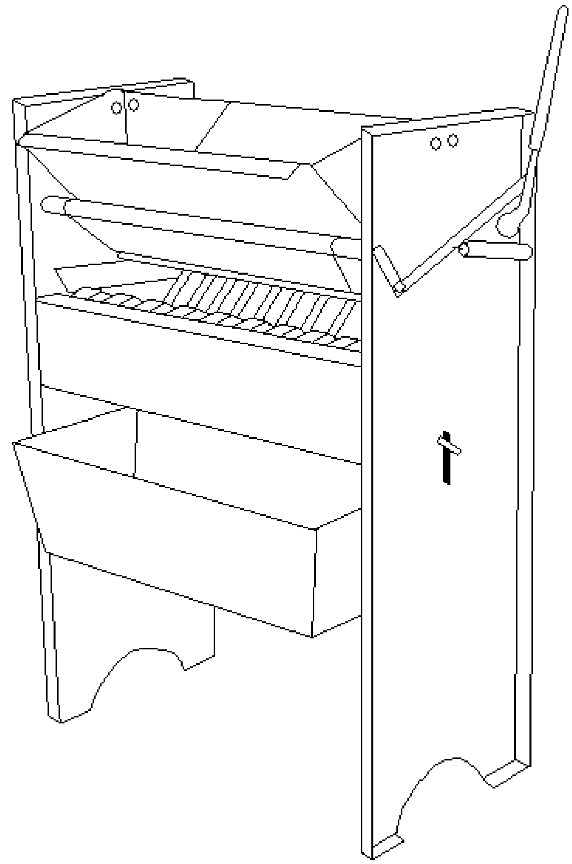


Table 1005-1
North Carolina Department of Transportation
Standard Specifications
Coarse Aggregate Gradation

Sieve	Percent by Weight Passing Each Sieve							
Std Size	1 ½”	1”	¾”	½”	3/8”	No. 4	No. 8	No. 200
#57	100	95-100	-	25-60	-	0-10	0-5	0-0.6*
#57M	100	95-100		25-45		0-10	0-5	0-0.6*
#67	-	100	90-100	-	20-55	0-10	0-5	0-0.6*
#78M	-	-	100	98-100	75-100	20-45	0-15	0-0.6*

When these sizes of aggregate are used for portland cement concrete the requirement pertaining to material passing through the No.200 Sieve shall be as follows:

*1 When tested during production, the amount passing the No. 200 sieve shall not be greater than 0.6% by weight.

*2 When tested at the job site, prior to use, the amount of material passing through the No. 200 sieve shall not be greater than 1.5% by weight and shall consist essentially of rock dust produced through the normal handling of the aggregate.

*3 If a stockpile at the job site is found to contain in excess of 1.5% passing the No. 200 sieve prior to use, the engineer may approve its use provided the total percentage by weight passing the No. 200 sieve, regarding the combined coarse and fine aggregate in the mix, does not exceed 3.5% and provided no increase in water-cement ratio is required by the use of this coarse aggregate.

Table 1005-2
Aggregate Gradation of Fine Aggregate

	Percentage of Total by Weight Passing								
STD Size	½”	3/8”	#4	#8	#16	#30	#50	#100	#200
2S	-	100	95-100	80-100	45-95	25-75	5-30	0-10	0-3
2MS	-	100	95-100	80-100	45-95	25-75	5-35	0-20	0-8*

- For Manufactured Fine Aggregate Sand used in Portland Cement Concrete:

When tested during production, the amount of material passing the No.200 sieve shall not be greater than 8%. When tested at the job site prior to use, the amount of material passing the No.200 sieve shall not be greater than 10%, shall not consist of the dust of fracture, and shall be essentially free from clay or shale. The minimum percent shown for material passing the No. 50 and No. 100 sieves may be reduced to 5 and 0 respectively, if the aggregate is to be used in air entrained concrete containing more than 400 pounds of cementitous material per cubic yard or in non air entrained concrete containing more than 500 pounds of cementitous material per cubic yard or as subdrain fine aggregate.

Selecting Proper Sieve Sizes

All standard sizes of fine and coarse aggregate shall meet the gradation and any other requirements of Table 1005-1 and 2 of the North Carolina Department of Transportation Standard Specifications for Roads and Structures. A number followed by a suffix “S” or “MS” identifies standard sizes of fine and coarse aggregate used in portland cement concrete. Where “S” is natural sand and “MS” is manufactured sand.

Coarse aggregates used in portland cement concrete are identified by number and sometimes followed by the suffix, “M”. This stands for modified aggregate. For example you may see both 57 and 57M, 67, and 78M. Fine and coarse aggregate must be tested for gradation in accordance with AASHTO T27.

The No. 200 Sieve Washing Procedure

NOTE: In a fine and coarse aggregate sieve analysis, the representative sample is washed over a No.200 sieve. The portion retained in the No.200 sieve is dried and weighed. The loss is then recorded in accordance with AASHTO T11.

1. The test sample shall be dried to a constant mass at a temperature of 110° ± 5°C, (230.9°F), and weighed to the nearest 0.2%. This weight shall be recorded.

2. The test sample, after being dried and weighed, shall be placed in a container and covered with water to assure a thorough separation of material finer then the No. 200 sieve from the coarser particles. The contents of the container shall be agitated vigorously and the wash water then poured immediately over the nested sieves. These sieves must be arranged with the coarser ones on top. The use of a large spoon to stir and agitate the aggregate has been found satisfactory. This operation shall be repeated until the wash water is clear.

3. All material retained on the nested sieves shall be returned to the washed sample. The washed aggregate shall then be dried to a constant mass at a temperature of 110° ± 5°C, (230.9°F), and weighed to the nearest 0.2%.

AASHTO T11 6.2 The mass of the sample, after drying, shall conform with the following:

Nominal Maximum Size	Minimum Mass, grams
4.75 mm (No.4) or smaller	300
9.5 mm (3/8 in.)	1000
19 mm (3/4 in.)	2500
37.5 mm (1 ½ in.)	5000

Calculations for Determining the Percent Passing the No.200 Sieve Using the Wash Method:

$$\text{Percent Passing the No.200 Sieve} = \frac{\text{Total Dry Weight of Sample} - \text{Dry Weight after Washing}}{\text{Total Dry Weight of Sample}} \times 100$$

Example:

Total Dry Weight of Sample = 514.0 grams
Dry Weight after Washing = 504.9 grams

$$\text{Percent Passing the No.200 Sieve} = \frac{514.0 \text{ grams} - 504.9 \text{ grams}}{514.0 \text{ grams}} \times 100 = 1.8\%$$

$$\begin{array}{r} 514.0 \text{ grams} \\ -\ 504.9 \text{ grams} \\ \hline 9.1 \text{ grams} \end{array}$$

$$\frac{9.1 \text{ g}}{514.0 \text{ g}} \times 100 = 0.0177 \times 100 = 1.8\% \text{ Passing}$$

Sieve Size	% Passing	NCDOT Specs. (% Passing)
200	1.8	0-3

NOTE: This sample meets NCDOT specifications for 2S sand passing a No.200 sieve.

Sieve Analysis Example

After we have completed the washing procedure in accordance with AASHTO T11, we can run a sieve analysis using a mechanical vibrator. In the washing process, we have determined the following information on our 2S sand:

Dry Weight of Sample Before Washing = 514.0 grams
Dry Weight of Sample After Washing = 504.9 grams.

1. Selection of the Proper Sieve Sizes

After checking Table 1005-2 of the NC DOT Standard Specifications for Roads and Structures you can then select the proper sieves. The nest of sieves is placed on a pan with the smallest opening sieve on the bottom and the largest on top. NOTE: All sieves selected from Table 1005-2 are placed in the nest of sieves except the No. 200 sieve.

2. Vibration

After recording the original weight of the sample and the weight of the sample after washing, place the sample in the top sieve. A lid is placed on the top sieve and the entire nest is then placed in the mechanical vibrator. The sample is vibrated until all the particles have been separated. The fraction of material retained on each sieve is weighed and the percent retained or passing through each sieve is calculated. The results are compared with the gradation range of the specifications to determine if the aggregate meets gradation requirements.

Sieve Analysis Example - 2S Sand

Total weight of sample oven dry, (before washing) = 514.0 grams
Oven dry weight, (after washing No. 200 sieve) = 504.9 grams

(514.0 -504.9) / 514.0 X 100 = 1.8%

Sieve Size	Grams Retained	Cumulative Gr.Retained	Cumulative % Retained	Percent Passing	NCDOT (% Passing)
3/8”	0	0	0	100	100
#4	15.4	15.4	3	97	95-100
#8	36.0	51.4	10	90	80-100
#16	102.8	154.2	30	70	45-95
#30	103.4	257.6	50	50	25-75
#50	159.3	416.9	81	19	5-30
#100	71.4	488.3	95	5	0-10
Pan	16.6	504.9	-	-	-
				Percent Passing	NCDOT Specs. (% Passing)
#200	9.1 washing method			1.8	0-3

In doing a sieve analysis the first step is to calculate the cumulative weight retained. This is accomplished by addition of the grams retained. The cumulative weight retained on the #4 sieve is the sum of the weight retained on the #4 sieve and the 3/8" sieve. In the above problem: 0 grams + 15.4 grams = 15.4 cumulative grams retained. Likewise, the cumulative weight retained on the #8 sieve is the sum of the grams retained on the 3/8", #4 and #8 sieves, (0 + 15.4 grams + 36.0 grams = 51.4 grams). The cumulative weight retained on the #16 sieve is the sum of the #3/8", 34, #8 and #16 sieves.
(0 + 15.4 grams + 36.0 grams + 102.8 grams = 154.2 grams).

Continue this pattern of addition until the total cumulative grams retained on each sieve has been solved. The next step is to determine the cumulative percent retained on each sieve. This is done by dividing the cumulative weight retained on each sieve, by the total weight of the sample. The result is then multiplied by 100 to convert the decimal into a percent.

EXAMPLE:

$$\text{Cumulative \% retained on the \#4 sieve} = \frac{\text{Cumulative Weight Retained}}{\text{Total Weight of the Sample}} \times 100$$

$$\frac{15.4 \text{ grams}}{514.0 \text{ grams}} = 0.030 \times 100 = 3 \text{ \% Retained on the No. 4 sieve}$$

We then subtract the cumulative percent retained on each standard sieve from 100 to obtain the percent passing.

Sieve Size			Cumulative % Retained		Percent Passing	NCDOT (% passing)
#3/8	100	-	0	=	100	100
#4	100	-	3	=	97	95-100

The percent passing is compared to the NC DOT Specifications to determine if the sample passes.

Section III
Study Problems Sieve Analysis of Coarse and Fine Aggregate

Sieve Analysis – No. 1

Check the following sieve analysis of a sample of natural sand for use in concrete and determine if it meets NC DOT requirements for Type 2S Sand. Circle the sieve not passing, if any.

Total weight of oven dry sample, (before washing) = 520.3 grams

Oven dry weight, (after washing No.200 sieve) = 514.9 grams

Sieve Size	Grams Retained	Cumulative Gr.Retained	Cumulative % Retained	Percent Passing	NC DOT (% passing)
3/8”	0				100
#4	0				95-100
#8	26.2				80-100
#16	113.6				45-95
#30	133.0				25-75
#50	162.1				5-30
#100	73.2				0-10
Pan	6.8				

		Percent Passing	NC DOT Specs. (% passing)
#200	(washing method)		0-3

Does this sample meet NCDOT specifications? ________________________

Sieve Analysis – No. 2

Check the following sieve analysis of a sample of natural sand for use in concrete and determine if it meets NC DOT requirements for Type 2S Sand. Circle the sieve not passing, if any.

Total weight of oven dry sample, (before washing) = 529.2 grams

Oven dry weight, (after washing No.200 sieve) = 518.1 grams

Sieve Size	Grams Retained	Cumulative Gr.Retained	Cumulative % Retained	Percent Passing	NC DOT (% passing)
3/8”	0				100
#4	11.4				
#8	20.2				
#16	105.8				
#30	85.9				
#50	180.6				
#100	88.1				
Pan	26.1				

		Percent Passing	NC DOT Specs. (% passing)
#200	(washing method)		

Does this 2S sand meet NCDOT specifications? ______________________________

Sieve Analysis – No. 3

Check the following sieve analysis of a sample of manufactured sand for use in concrete and determine if it meets NC DOT requirements for Type 2MS Sand. This sample was taken at the job site. Circle the sieve not passing, if any.

Total weight of oven dry sample, (before washing) = 547.9 grams

Oven dry weight, (after washing No.200 sieve) = 502.5 grams

Sieve Size	Grams Retained	Cumulative Gr.Retained	Cumulative % Retained	Percent Passing	NC DOT (% passing)
3/8"	0				
#4	6.7				
#8	62.1				
#16	114.6				
#30	161.9				
#50	97.2				
#100	51.4				
Pan	8.6				

		Percent Passing	NCDOT Specs. (% passing)
#200	(washing method)		

Does this 2MS sand meet NCDOT specifications? ______________________________

Sieve Analysis – No. 4

Check the following sieve analysis of a sample of coarse aggregate for use in concrete and determine if it meets NC DOT requirements for No. 67 stone. This sample was taken at the job site. Circle the sieve not passing, if any.

Total weight of oven dry sample = 37.6 pounds

Using the washing method, it was determined the percent passing the No.200 sieve is 0.9 %.

Sieve Size	lbs. Retained	Cumulative lbs.Retained	Cumulative % Retained	Percent Passing	NC DOT (% passing)
1”	0				
¾”	3.8				
3/8”	23.6				
#4	7.8				
#8	1.8				
Pan	0.6				

			Percent Passing	NCDOT Specs. (% passing)
#200	(washing method)	0.9		

Does this No.67 stone meet NCDOT specifications? ____________________

Sieve Analysis – No. 5

Check the following sieve analysis of a sample of coarse aggregate for use in concrete and determine if it meets NC DOT requirements for No. 57 stone. This sample was taken during production. Circle the sieve not passing, if any.

Total weight of oven dry sample = 35.2 lbs.

Using the washing method, it was determined that the percent passing the No.200 sieve is 1.2 %.

Sieve Size	lbs. Retained	Cumulative lbs.Retained	Cumulative % Retained	Percent Passing	NC DOT (% passing)
1 ½”	0				
1”	1.4				
½”	24.9				
#4	6.2				
#8	2.0				
Pan	0.7				

			Percent Passing	NCDOT Specs. (% passing)
#200	(washing method)	1.2		

Does this No.57 stone meet NCDOT specifications? ____________________

Section IV
Fineness Modulus

Fineness Modulus, (FM), is defined mathematically, as the sum of the cumulative percentages retained on the standard sieve divided by 100. The standards sieves are 6", 3", 1 ½", ¾", 3/8", No. 4, No.8, No.16, No.30, No.50, and, No.100. The FM is an index to the fineness or coarseness of an aggregate. The FM of fine aggregates should not be less than 2.3 or more then 3.1 – nor should it vary by more than 0.20 from batch to batch.

<u>Fineness Modulus Ranges</u>

COARSE SAND	2.80 – 3.10
MEDIUM SAND	2.50 – 2.80
FINE SAND	2.30 - 2.50

The fineness modulus of a fine aggregate is calculated from the sieve analysis. It is used for the purpose of estimating the quantity of coarse aggregate to be used in the mix design. (NOTE: When running the gradation, the No.200 sieve is used as a required specification, however; it is not used in calculating the FM.)

The American Concrete Institute, (ACI), has developed Table 5.3.6. This table for various size coarse aggregates gives the volume of dry-rodded coarse aggregate, per unit volume of concrete for different fineness moduli of sand. If the size of coarse aggregate and fineness modulus is known, the volume of dry-rodded coarse aggregate can be obtained from this table. The proportion of coarse and fine aggregate in a concrete mix depends upon the fineness modulus of the fine aggregate and the size of the coarse aggregate.

The volume relationship in the ACI Table actually relates to the total surface area of the aggregate, or the water demand of the aggregate. For example, if the FM is constant, the volume of coarse aggregate increases with the size of the aggregate, or with the decrease in surface area of the coarse aggregate. Likewise, as the fineness modulus of the fine aggregate decreases for any one size of coarse aggregate the volume of the coarse aggregate increases. As the particle size of the fine aggregate decreases, the surface area increases. Ergo, more coarse aggregate and less fine aggregate is used in the mix proportions. So it can be stated, that the volume of coarse aggregate, as determined by the ACI Table, increases or decreases to maintain a constant total surface area, or a constant water demand, with the variable being the fineness or coarseness, (the FM), of the sand.

<u>Recommended Practice for Selecting Proportions for Concrete – ACI 211</u>

Proportions shall be computed on the basis of the absolute volume. The 10 % adjustment allowed in Table A1.5.3.6 will not be permitted. The actual quantities used, as determined by the methods described herein, shall not deviate more than plus or minus 5 % from such quantities.

Note: NCDOT Specifications require an additional mix design be submitted if the quantity of components varies by more than the allowable batching tolerance.

ACI Table A1.5.3.6

Volume of Coarse Aggregate Per Unit of Volume of Concrete

Nominal Maximum Size of Aggregate	Volume of Dry-Rodded Coarse Aggregate* per unit Volume of Concrete for Different Fineness Moduli of Sand							
	Fineness Modulus of Sand							
inches	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00
3/8”	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.44
½”	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.53
¾”	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60
1”	0.72	0.71	0.70	0.69	0.68	0.67	0.66	0.65
1 ½”	0.76	0.75	0.74	0.73	0.72	0.71	0.70	0.69
2”	0.79	0.78	0.77	0.76	0.75	0.74	0.73	0.72
3”	0.83	0.82	0.81	0.80	0.79	0.78	0.77	0.76

***** Volumes are based on aggregates in dry-rodded condition as described in ASTM C 29 for Unit Weight on Aggregate.

These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction.

Fineness Modulus - Example

Complete the following sieve analysis of a sample of natural sand for use in concrete and determined the fineness modulus of this material.

Total Weight of Oven Dry Sample, (before washing)	=	514.8 grams
Oven Dry Weight, (after washing No.200 sieve)	=	504.0 grams

Sieve Size	Grams Retained	Cumulative Gr.Retained	Cumulative % Retained
3/8”	0	0	0
#4	15.1	15.1	3
#8	35.3	50.4	10
#16	69.5	119.9	23
#30	169.2	289.1	56
#50	145.1	434.2	84
#100	56.7	490.9	95
Pan	13.1	504.0	

Calculations:

						Cumulative % Retained
1.)	Sieve # 3/8”	=	$\frac{0}{514.8}$	= 0.0 x 100	=	0
2.)	Sieve # 4	=	$\frac{15.1}{514.8}$	= 0.029 x 100	=	3
3.)	Sieve # 8	=	$\frac{50.4}{514.8}$	= 0.098 x 100	=	10
4.)	Sieve # 16	=	$\frac{119.9}{514.8}$	= 0.233 x 100	=	23
5.)	Sieve # 30	=	$\frac{289.1}{514.8}$	= 0.562 x 100	=	56
6.)	Sieve # 50	=	$\frac{434.2}{514.8}$	= 0.843 x 100	=	84
7.)	Sieve # 100	=	$\frac{490.9}{514.8}$	= 0.954 x 100	=	95
8.)	Pan	=	504.0			

The fineness modulus, (FM), is defined mathematically as the sum of the cumulative percentages <u>retained</u> on the standard sieves, divided by 100.

$$FM = \frac{3 + 10 + 23 + 56 + 84 + 95}{100} = \frac{271}{100} = 2.71$$

FM is an index to the fineness and coarseness of the aggregate.

Section V
Study Problems Fineness Modulus

Fineness Modulus Problem - No. 1

Complete the following sieve analysis of a sample of natural sand for use in concrete and determine the fineness modulus of this material.

Total Weight of Oven Dry Sample, (before washing) = 573.0 grams

Oven Dry Weight, (after washing No.200 sieve) = 558.4 grams

Sieve Size	Grams Retained	Cumulative Gr.Retained	Cumulative % Retained	Percent %Passing	NCDOT Specs
3/8”	0				
#4	0				
#8	24.9				
#16	149.0				
#30	114.6				
#50	143.3				
#100	93.6				
Pan	33.0				
No.200	(washing method)				

Does this sample meet NCDOT Specifications?______________________

What is the Fineness Modulus of this material?______________________

Is this coarse, medium, or fine sand? ____________________________

Fineness Modulus Problem - No. 2

Complete the following sieve analysis of a sample of natural sand for use in concrete and determine the fineness modulus of this material.

Total Weight of Oven Dry Sample, (before washing)	=	520.5 grams
Oven Dry Weight, (after washing No.200 sieve)	=	500.3 grams

Sieve Size	Grams Retained	Cumulative Gr.Retained	Cumulative % Retained	Percent Passing	NCDOT Specs
3/8”	0				
#4	36.3				
#8	41.5				
#16	197.0				
#30	46.7				
#50	67.4				
#100	93.3				
Pan	18.1				
No. 200		(washing method)			

Does this sample meet NCDOT Specifications?________________________

What is the Fineness Modulus of this material?________________________

Is this coarse, medium, or fine sand? ______________________________

Sieve Analysis and Fineness Modulus - No. 3

Check the following sieve analysis of a sample of fine aggregate for use in concrete and determine if it meets NCDOT requirements for 2MS sand. This sample was taken at the Job Site. Circle the sieve not passing, if any.

Total Weight of Oven Dry Sample, (before washing) = 532.4 grams

Oven Dry Weight, (after washing No.200 sieve) = 509.7 grams

Sieve Size	Grams Retained	Cumulative Gr.Retained	Cumulative % Retained	Percent Passing	NCDOT Specs. (% passing)
3/8"	0				
#4	7.5				
#8	12.7				
#16	159.7				
#30	74.6				
#50	188.7				
#100	53.4				
Pan	13.1				

		Percent Passing	NCDOT Specs. (% passing)
No.200	(washing method)		

Does this sample meet NCDOT Specifications?________________________

What is the Fineness Modulus of this material?________________________

Is this coarse, medium, or fine sand?_______________________________

Sieve Analysis and Fineness Modulus - No. 4

Check the following sieve analysis of a sample of fine aggregate for use in concrete and determine if it meets NCDOT requirements for 2S sand. This sample was taken during production. Circle the sieve not passing, if any.

Total Weight of Oven Dry Sample, (before washing) = 524.3 grams

Oven Dry Weight, (after washing No.200 sieve) = 514.5 grams

Sieve Size	Grams Retained	Cumulative Gr.Retained	Cumulative % Retained	Percent Passing	NCDOT Specs. (% passing)
3/8”	0				
#4	36.9				
#8	20.8				
#16	127.4				
#30	180.1				
#50	81.6				
#100	51.6				
Pan	16.1				

		Percent Passing	NCDOT Specs. (% passing)
No.200	(washing method)		

Does this sample meet NCDOT Specifications?_______________________

What is the Fineness Modulus of this material?_______________________

Is this coarse, medium, or fine sand?______________________________

Section VI
Weight – Volume Relationships

In order to design concrete mixes in accordance with the ACI method, it is necessary to understand a few basic mathematical terms as they relate to volume. Please note the following definitions:

UNIT WEIGHT: The weight of one cubic foot of material. For concrete, the weight, in pounds, of one cubic foot of plastic concrete.
DRY –RODDED UNIT WEIGHT: The weight in pounds of one cubic foot of stone compacted in a container by rodding.
CEMENT YIELD: The volume of concrete, in cubic feet, produced from one bag of cement.
ABSOLUTE VOLUME: The volume of material in a voidless state.
SPECIFIC GRAVITY: The ratio of the weight of a given volume of material to the weight of an equal volume of water. One cubic foot of water weighs 62.4 pounds. One gallon of water weighs 8.33 pounds.

1 cu.ft. of water = 62.4 pounds
1 gallon of water = 8.33 pounds

$$\frac{62.4 \text{ lbs./cu.ft.}}{8.33 \text{ lbs./gal.}} = 7.5 \text{ gallons per cubic foot}$$

When we refer to specific gravity, the water is in a voidless state, as are all liquids by their very nature. When we determine the specific gravity of a solid material, such as cement and aggregate, they must be considered to be in a voidless state. Think of it as if they were melted into a liquid. If we know the weight and the specific gravity of a material, then we can calculate the absolute volume.

$$\text{Absolute Volume} = \frac{\text{Weight of Material}}{(\text{specific gravity} \times 62.4)}$$

$$\text{Absolute volume of water} = \frac{62.4}{1 \times 62.4} = 1 \text{ cu. ft.}$$

The specific gravity of a material is defined as being the ratio of the weight of a given volume of material to the weight of an equal volume of water. (It should be understood that both are at the same temperature).

A one inch cube of rock may weigh 41 grams. The weight of a one inch cube of water weighs 16.4 grams. Consequently, the specific gravity of the rock is 41 divided by 16.4, (41/16.4), or 2.50. This means that the rock is 2.50 times as heavy as an equal volume of water. The rock is 2.50 times heavier than the water.

Since aggregates do not generally occur in convenient shapes such as cubes, it can be difficult to determine the volume of the aggregate. The weight is easy enough to determine. There are two acceptable methods that can be used to determine the specific gravity.

<u>Method A</u>

Weigh the material in air. Then weight the material in water. Under water the material will be buoyed by a force equal to the weight of an equal volume of water. The specific gravity of the material will be equal to the weight of the material in air divided by the difference of the weight in air and the weight under water.

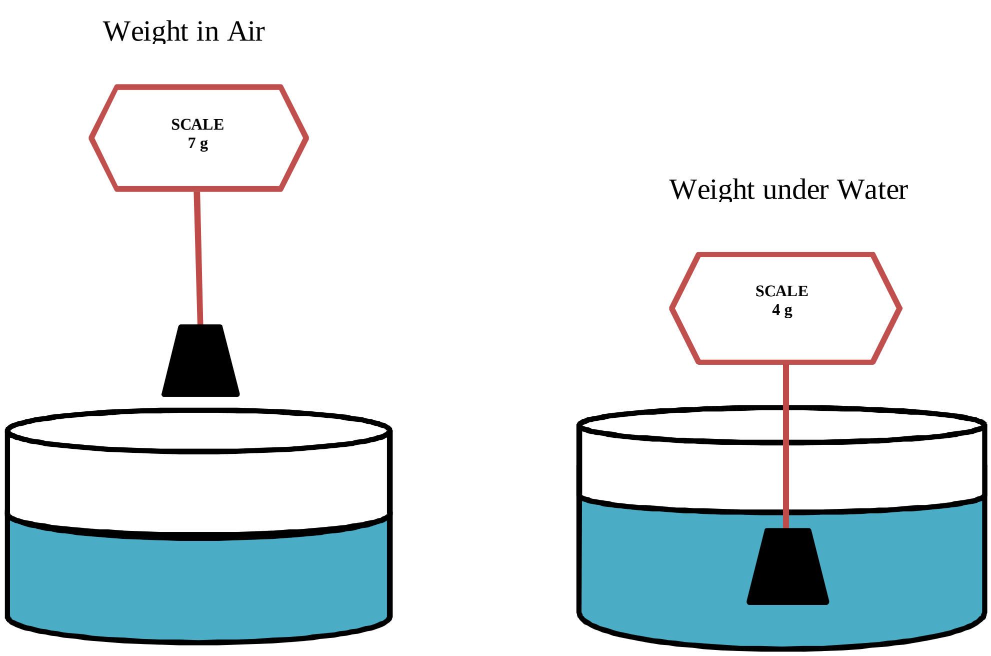


Figure 1: Specific Gravity

Method B

Weigh the material in air. Pour water into a calibrated flask and be sure to note the initial volume reading. Then gently lower the material into the flask and note the final volume reading on the flask. The volume of the material will displace an equal volume of water. Subtract the initial volume from the final volume to get the volume of the material. Since a milliliter of water weighs one gram, the weight of an equal volume of water, (in grams), will equal the difference in the water reading in milliliters.Divide this number into the weight of the material in air to get the specific gravity.

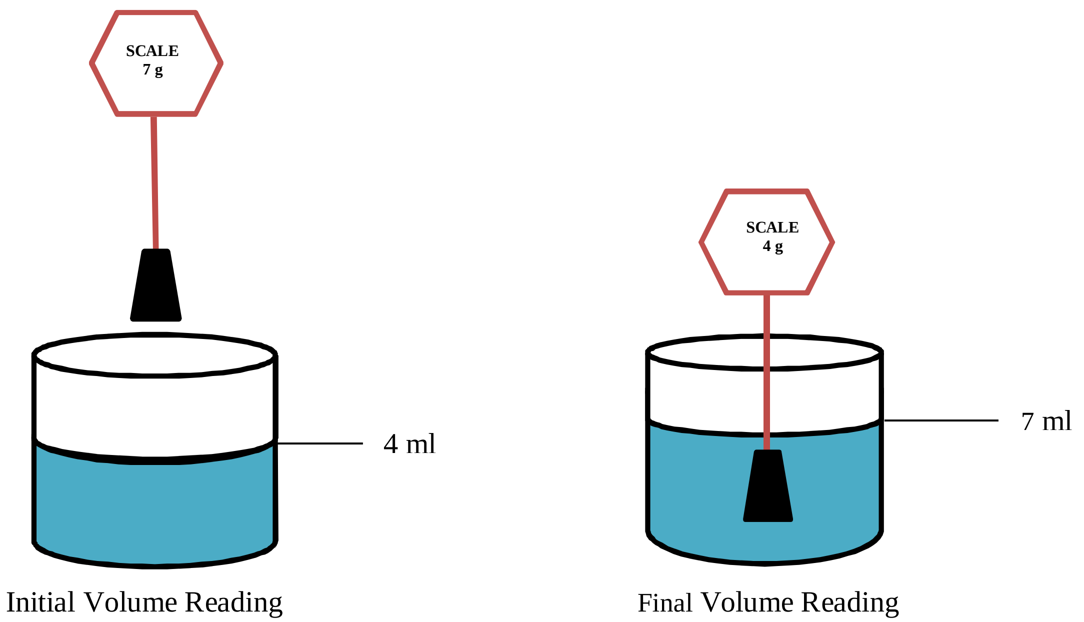


Figure 2: Specific Gravity

The specific gravity of any material multiplied by 62.4 is the unit weight of that material. It is the weight of one cubic foot of solid material if it were melted.

$$\text{Absolute Volume of an Aggregate} = \frac{\text{Weight of Aggregate}}{\text{Weight of One Cubic Foot of Aggregate Melted}}$$

Or

$$\text{Absolute Volume} = \frac{\text{Weight of Aggregate}}{\text{Specific Gravity of Aggregate} \times 62.4}$$

Problem: Find the absolute volume of 288 lbs. of water.

Pounds of Water

$$\text{Absolute Volume of Water} = \frac{288}{1 \times 62.4} = 4.62 \text{ cu.ft.}$$

When water is given in GALLONS rather than POUNDS, the absolute volume is calculated by dividing the gallons by 7.5. (7.5 are the gallons of water in 1 cubic foot).

Gallons of Water

$$\text{Absolute Volume of Water} = \frac{34.6}{7.5} = 4.61 \text{ cu.ft.}$$

Calculations for determining the absolute volume of each ingredient are shown in the following mix design:

Materials	Sp.Gr.	Weight In lbs.	Calculations		Absolute Vol. in cu.ft.
Cement	3.15	588	$\frac{588}{3.15 \times 62.4}$	=	2.99
# 57 Stone	2.65	1808	$\frac{1808}{1.65 \times 62.4}$	=	10.93
Sand	2.63	1129	$\frac{1129}{1.63 \times 62.4}$	=	6.88
Water	1	286 (34.3 gallons)	$\frac{286}{1 \times 62.4}$	=	4.58
Air (6 %)			.06 X 27	=	1.62
Total		3811 lbs.			27.00

In the above problem, it is necessary to determine the YIELD, the CEMENT FACTOR, (C/F), the WATER/CEMENT RATIO, (W/C), and the CALCULATED UNIT WEIGHT.

DEFINITIONS

C/F: The number of pounds of cement per cubic yard.

W/C: The pounds of water per pound of cement in a concrete mix.

UNIT WEIGHT: The pounds per cubic foot of concrete.

So, if we use the same numbers as in the previous problem:

C/F = 588 lbs. of cement per cubic yard

W/C Note: You must convert gallons of water to pounds of water

34.3 gallons X 8.33 = 285.72 lbs. of water

$$W/C = \frac{286 \text{ lbs. of water}}{588 \text{ lbs. of cement}} = 0.486 \text{ lbs. of water/lb. of cement}$$

$$\text{Calculated Unit Weight} = \frac{3811 \text{ lbs.}}{27.00 \text{ cu.ft.}} = 141.148 \text{ lbs./cu.ft.}$$

Unit Weight and Computing Percent Air by Unit Weight Method

There are a number of ways to check the air content of fresh concrete. One way is by running a field unit weight with a calibrated unit weight bucket. The formula for computing the unit weight is as follows:

$$\frac{(\text{Weight of Concrete} + \text{Weight of the Bucket}) - \text{Weight of Bucket}}{\text{Volume of the Bucket}} = \text{Unit weight of FreshConcrete}$$

Example:

Weight of Unit Weight Bucket:	23.2 lbs.
Volume of Bucket:	0.51 cu.ft.
Weight of Concrete and Bucket:	94.8 lbs.

$$\frac{94.8 - 23.2}{0.51} = 140.39 \text{ lbs. /cu.ft}$$

(Actual Unit Weight)

This unit weight is the actual, or measured, unit weight of the fresh concrete taken in the field. We will refer to this as the Field Unit Weight. This is the number that we will use when we compute the percent air in the mix. This is done by the following formula:

$$\frac{\text{Theoretical Unit weight} - \text{Actual Unit Weight}}{\text{Theoretical Unit Weight}} \times 100 = \text{Percent Air}$$

(Theoretical Unit Weight is the AIR-FREE unit weight)

Example: Using the preceding problem as an example, we can compute the theoretical unit weight.

Step 1

27.00 cu.ft. of concrete mix per 1 cubic yard
\- 1.62 cu.ft. of the concrete mix with 6 % air

25.38 cu.ft. of concrete mix without air

Step 2

$$\frac{\text{3811 lbs. of material in the concrete mix}}{\text{25.38 cu.ft. in the mix without air}} = \text{150.16 lbs./cu.ft.}$$

(Theoretical unit weight)
Air Free

Now that we have the theoretical unit weight, we can use this number to calculate the percent air.

T = Theoretical Unit Weight
A = Actual field Unit Weight

$$\frac{T - A}{T} \times 100 = \text{Percent Air}$$

$$\frac{150.16 - 140.39}{150.16} \times 100 = 6.5 \text{ Percent Air}$$

Checking the Yield of a Mix

The yield of a batch of concrete is the total volume occupied by the fresh concrete.

> **Batch Yield** in cubic feet, is determined by dividing the total weight in pounds of all the ingredients going into the batch, by the unit weight in pounds per cubic feet of the fresh concrete.

To convert cubic feet into cubic yards: divide the number of cu.ft. by 27.
There are 27 cu.ft. in a cu.yd.

In determining the total weight of all ingredients, use the actual scale readings for the cement and the aggregate in the moisture condition as it is batched. Add in the weight of any water combined with admixtures that was batched at the plant. Do not forget to add any water that was added through the truck mixer water system or that was in the drum prior to charging.

Example: Ingredients in a nominal 10 cu.yd. batch:

		lbs./batch
Wet Stone		18080
Wet Sand		12760
Cement		6006
Admixture		5 (can be included w/water)
Water through Plant		
230 gal. X 8.33 lbs./gal	=	1916
Water through Truck		
10 gal. X 8.33 lbs./gal.	=	83
(no water in drum before charging)		
		+
TOTAL WEIGHT		38850 lbs.

Air Content by Pressure Meter = 5.2%
Unit Weight of Fresh Concrete (Field Unit Weight) = 140.5 lbs./cu.ft.

$$\text{Yield in cu.ft.} = \frac{38850 \text{ lbs.}}{140.5 \text{ lbs./cu.ft.}} = 276.5 \text{ cu.ft.}$$

(Actually Batched)

$$\text{Yield in Cubic Yards} = \frac{276.5 \text{ cu.ft./batch}}{27.00 \text{ cu.ft/cu./yd.}} = 10.24 \text{ cu.yd./batch}$$

This batch is over yielded by 0.24 cu.yd. The goal is a 27 cu.ft/cu.yd. batch. Our actual, according to the calculations is 27.65 cu.ft./cu.yd.

$$\begin{array}{rl} & 27.65 \text{ cu.ft/cu.yd.} \\ - & 27.00 \text{ cu.ft/cu. yd.} \\ \hline & 0.65 \text{ cu.ft/cu.yd.} \quad \text{over yield} \end{array}$$

NOTE: Measured air content is not used in the calculations.
Measured air is accounted for in the actual unit weight.

Section VII
Problems Weight / Volume Relationships

Weight Volume Problem **#1**

Determine the absolute volume of each ingredient in the following one cubic yard mix design of a Class A concrete. Compute the cement factor, W/C ratio, calculated and theoretical unit weights, and percent air using the unit weight method.

Materials	Sp.Gravity	Weight,(lbs.)	Calculations	Abs.Volume,(ft³)
Cement	3.15	564	___________	_________
# 67 Stone	2.82	1966	___________	_________
Sand	2.62	1100	___________	_________
Water	1.0	288	___________	_________
Air 6 %		________	___________	_________
	Total:	________		_________

Cement Factor: _____________ lbs.

Water/Cement Ratio: _____________

Calculated Unit Weight: _____________ pcf

Actual Field Unit Weight: 147.95 pcf

Theoretical Unit Weight: _____________ pcf

% Air by Unit Weight Method: _____________ %

Weight Volume Problem **#2**

Determine the absolute volume of each ingredient in the following one cubic yard mix design of a Class AA concrete. Compute the cement factor, W/C ratio, calculated and theoretical unit weights, and percent air using the unit weight method.

Materials	Sp.Gravity	Weight,(lbs.)	Calculations	Abs.Volume,(ft^3)
Cement	3.15	714	___________	_________
# 67 Stone	2.88	1940	___________	_________
Sand	2.62	1015	___________	_________
Water	1.0	298	___________	_________
Air 6 %		________	___________	_________
	Total:	________		_________

Cement Factor: _____________ lbs.

Water/Cement Ratio: _____________

Calculated Unit Weight: _____________ pcf

Actual Field Unit Weight: 147.95 pcf

Theoretical Unit Weight: _____________ pcf

% Air by Unit Weight Method: _____________ %

Weight Volume Problem **#3**

Determine the absolute volume of each ingredient in the following one cubic yard Class B, Non-Vib, mix design. Compute the Yield, C.F, W/C Ratio, Calculated Unit Weight and the % Air using the Unit Weight Method.

Materials	Sp.Gravity	Weight,(lbs.)	Calculations	Abs.Volume,(ft^3)
Cement	3.15	545	___________	_________
# 67 Stone	2.85	1853	___________	_________
Sand	2.60	1197	___________	_________
Water	1.0	300	___________	________
Air 6 %		________	___________	_________
	Total:	________		_________

Cement Factor: _____________ lbs.

Water/Cement Ratio: _____________

Calculated Unit Weight: _____________ pcf

Actual Field Unit Weight: 144.35 pcf

Theoretical Unit Weight: _____________ pcf

% Air by Unit Weight Method: _____________ %

Weight Volume Problem **#4**

Determine the Yield, Cement Factor, (C.F.), W/C Ratio, and the Unit Weight of Design in the following one cubic yard mix. Also compute the % Air from the Actual Field Unit Weight.

Materials	Sp.Gravity	Weight,(lbs.)	Calculations	Abs.Volume,(ft^3)
Cement	3.15	588	________	________
# 67 Stone	3.04	1956	________	________
Sand	2.62	1228	________	________
Water	1	288	________	________
Air 6 %		________	________	________
	Total:	________		________

Cement Factor: ____________ lbs.

Water/Cement Ratio: ____________

Calculated Unit Weight: ____________ pcf

Actual Field Unit Weight: 149.20 pcf

Theoretical Unit Weight: ____________ pcf

% Air by Unit Weight Method: ____________ %

Weight Volume Problem **#5**

Determine the Yield, Cement Factor, (C.F.), W/C Ratio, and the Unit Weight of Design in the following one cubic yard mix. Also compute the % Air from the Actual Field Unit Weight.

Materials	Sp.Gravity	Weight,(lbs.)	Calculations	Abs.Volume,(ft^3)
Cement	3.15	677	__________	________
# 67 Stone	2.79	1895	__________	________
Sand	2.60	1081	__________	________
Water	1.00	275	__________	________
Air 6 %		_______	__________	________
	Total:	_______		________

Cement Factor: ____________ lbs.

Water/Cement Ratio: ____________

Calculated Unit Weight: ____________ pcf

Actual Field Unit Weight: 147.10 pcf

Theoretical Unit Weight: ____________ pcf

% Air by Unit Weight Method: ____________ %

Weight Volume Problem **#6**

Determine the Calculated Unit Weight, yield and Water Cement Ratio in the following one cubic yard Class A concrete mix design. Also compute the % Air from the Actual Field Unit Weight.

Materials	Sp.Gravity	Weight,(lbs.)	Calculations	Abs.Volume,(ft^3)
Cement	3.15	564	________	________
# 67 Stone	2.85	1853	________	________
Fine Aggregate	2.61	1187	________	________
Water	1	300	________	________
Air 6 %		________	________	________
	Total:	________		________

Cement Factor: ____________ lbs.

Water/Cement Ratio: ____________

Calculated Unit Weight: ____________ pcf

Actual Field Unit Weight: 141.50 pcf

Theoretical Unit Weight: ____________ pcf

% Air by Unit Weight Method: ____________ %

Weight Volume Problem **#7**

Determine the Yield, Cement Factor, (C.F.), W/C Ratio, and the Calculated Unit Weight of Design in the following one cubic yard mix. Also compute the % Air from the Actual Field Unit Weight.

Materials	Sp.Gravity	Weight,(lbs.)	Calculations	Abs.Volume,(ft³)
Cement	3.15	639	__________	________
# 67 Stone	2.71	1782	__________	________
Sand	2.63	1200	__________	________
Water	1	267	__________	________
Air 6 %		_______	__________	________
	Total:	_______		________

Cement Factor: ____________ lbs.

Water/Cement Ratio: ____________

Calculated Unit Weight: ____________ pcf

Actual Field Unit Weight: 144.62 pcf

Theoretical Unit Weight: ____________ pcf

% Air by Unit Weight Method: ____________ %

Weight Volume Problem **#8**

Determine the Yield, Cement Factor, (C.F.), W/C Ratio, and the Calculated Unit Weight of Design in the following one cubic yard mix. Also compute the % Air from the Actual Field Unit Weight.

Materials	Sp.Gravity	Weight,(lbs.)	Calculations	Abs.Volume,(ft^3)
Cement	3.15	564	__________	________
# 67 Stone	2.78	1948	__________	________
Sand	2.64	1100	__________	________
Water	1	287	__________	________
Air 6 %		_______	__________	________
	Total:	_______		________

Cement Factor: ____________ lbs.

Water/Cement Ratio: ____________

Calculated Unit Weight: ____________ pcf

Actual Field Unit Weight: 144.20 pcf

Theoretical Unit Weight: ____________ pcf

% Air by Unit Weight Method: ____________ %

Section VIII
ACI Concrete Mix Design

The Current Standard Specification reads as follows:

Composition and Design (Section 1000-4A):

Provide the class of concrete required by the contract. Submit proposed concrete mix designs for each class of concrete to be used in the work. Mix proportions shall be determined by a testing laboratory approved by the Department. Base mix designs on laboratory trial batches that meet Table 1000-1 and this section.

Submit mix designs in terms of saturated surface dry weights on Materials and Tests Form 312U at least 35 days before proposed use. Adjust batch proportions to compensate for surface moisture contained in the aggregates at the time of batching. Changes in the saturated surface dry mix proportions will not be permitted unless revised mix designs have been submitted to the Engineer and approved.

Accompany Materials and Tests Form 312U with a listing of laboratory test results of aggregate gradation, air content, slump and compressive strength from a certified laboratory. List the compressive strength of at least three 6 inch x 12 inch or 4 inch x 8 inch cylinders at the age of 7 and 28 days.

Perform laboratory tests in accordance with the following test procedures:

Aggregate Gradation	AASHTO T27
Air Content	AASHTO T152
Slump	AASHTO T119
Compressive Strength	AASHTO T22 and T23

The Engineer will review the mix design for compliance with the Specifications and notify the Contractor as to its acceptability. Do not use a mix until written notice has been received. Acceptance of the mix design does not relieve the Contractor of his responsibility to furnish a product that meets the contract. Upon written request from the Contractor, a mix design accepted and used satisfactorily on any Department project may be accepted for use on other projects.

ACI Concrete Mix Design

The NC DOT has adopted the ACI absolute volume method of design and requires that this method be used in the design of all concrete mixes.

$$\text{Absolute Volume} = \frac{\text{Weight}}{\text{Sp. Gravity} \times 62.4}$$

For the purpose of establishing concrete proportions and calculating yields, we will not concern ourselves with bulk yield or bulk volume of aggregate, cement, or other material. We must solely focus on the Absolute Volume of these materials. As previously stated, this is the volume of the material as a solid and without voids.

For example: A bag of cement in a bulk state occupies approximately one cubic foot of volume, however; the Absolute Volume of one bag of cement is only approximately 0.48 cubic feet. So, without any voids, the volume of the cement in the bag is only 0.48 cubic feet. This is what space the bag of cement will actually take up in the batch of concrete, 0.48 cubic feet of volume.

Example: We can calculate the absolute volume occupied by the cement in a cubic yard of concrete which contains 6.00 bags of cement.

Step 1. Find the weight of the cement.

6.00 bags of cement X 94 lbs. per bag = 564 lbs./cu.yd.

Step 2. Find the weight of a solid cubic foot of cement.
Cement has a specific gravity of 3.15. (This means that cement is 3.15 time heavier then water). Using the specific gravity we can find the weight of one solid cubic foot of cement.

3.15 X 62.4 lbs. of water/ cu.ft. = 196.56 lbs./cu.ft.

Step 3. Find the absolute volume of 6 bags of cement.

$$\frac{564 \text{ lbs.}}{196.56 \text{ lbs./cu.ft.}} = 2.87 \text{ cu.ft./cu.yd.}$$

This means that the absolute volume, or space in the mix 6 bags of cement will take up in the mix, is 2.87 cu.ft./cu.yd.

Before calculations can begin on a concrete mix design, there are certain items that must be made known or available to you. These items are as follows:

1. Class of concrete to be designed
2. Type of placement, vibrated or non-vibrated
3. For fine aggregates:
    a. Specific gravity, (found on fine aggregate data sheet)
    b. Fineness modulus, (found on the fine aggregate data sheet)
4. For coarse aggregates:
    a. Maximum size of the aggregate
    b. Specific gravity, (found on coarse aggregate data sheet)
    c. Dry- rodded unit weight, (found on coarse aggregate data sheet)
    d. Rounded or angular aggregate
5. N.C. specifications:
    a. Cement factor, (minimum cement content)
    b. W/C ratio, (maximum water to cement ratio)
    c. Air content, (mean air content)
    d. Nominal maximum aggregate size
6. You will need:
    a. ACI Table 5.3.6
       (volume of coarse aggregate per unit volume of concrete)
    b. M & T Form 312U
       (The concrete mix design approval request form)
    c. ACI Mix Design worksheet
    d. Know the source of all materials going into the mix.
       <u>The five basic ingredients of concrete</u> are:
       Cement
       Fine Aggregate
       Coarse Aggregate
       Water
       Air

Solve for the absolute volume of each of the five materials in the mix. The combined total should be one cubic yard, 27 cu.ft.

Quantities for three of the five materials are given by the specifications. These are:

1. Cement
2. Maximum W/C Ratio permitted – do not exceed!
3. Air quantity

Solve for the quantities of coarse aggregate and fine aggregate.

The following generic coarse aggregate properties table is for instructional use only.

Coarse Aggregate Datasheet				
NCDOT Stone	**Specific Gravity**	**Dry Rodded Unit Weight**	**% Absorption**	**Stone Size #**
Quarry 1	**2.82**	**103.1**	**0.2**	**57**
Quarry 2	**2.65**	**96.9**	**0.3**	**67**
Quarry 3	**2.79**	**96.6**	**0.1**	**57**
Quarry 4	**2.79**	**104**	**0.3**	**67**
Quarry 5	**2.75**	**99.5**	**0.2**	**57**
Quarry 6	**2.9**	**107**	**0.2**	**67**
Quarry 7	**2.78**	**97.8**	**0.2**	**57**
Quarry 8	**2.62**	**96.3**	**0.4**	**67**
Quarry 9	**2.82**	**99.2**	**0.1**	**67**
Quarry 10	**2.67**	**96**	**0.2**	**57**
Quarry 11	**2.65**	**97.2**	**0.2**	**67**
Quarry 12	**2.86**	**104**	**0.1**	**67**

The following generic fine aggregate properties table is for instructional use only.

Fine Aggregate Datasheet			
NCDOT Sand	**Specific Gravity**	**Fineness Modulus**	**% Absorption**
Mine 1	**2.64**	**2.37**	**0.3**
Pit 1	**2.65**	**2.42**	**0.3**
Pit 2	**2.63**	**2.75**	**0.5**
Pit 3	**2.64**	**2.81**	**0.5**
Pit 4	**2.61**	**2.94**	**0.6**
Pit 5	**2.62**	**2.71**	**0.6**
Quarry 1	**2.63**	**2.31**	**0.4**
Quarry 2	**2.82**	**2.6**	**0.4**
Quarry 3	**2.63**	**2.5**	**1.3**
Quarry 4	**2.63**	**2.65**	**1.2**
Quarry 5	**2.73**	**2.46**	**0.6**
Quarry 6	**2.67**	**3.1**	**0.3**

Example: Using the ACI worksheet provided, design a NCDOT Class A Vib-AE general mix. This mix is for one cubic yard.

Given Information:

Minimum Cement Content: 564 lbs./cu.yd. (from spec sheet)
Maximum Water/Cement Ratio: 0.532 (from spec sheet)

Aggregate structure: angular
Nom. Max size of aggregate: 3/4" (# 67 stone spec.)
Air content: 6 % ± 1.5% (from spec book)
Slump: 3.5" maximum (from spec book)
Fineness Modulus of the sand: 2.75 (from fine aggregate data sheet)
Specific gravity of fine aggregate: 2.63 (from fine aggregate data sheet)
Specific gravity of coarse aggregate: 2.86 (from coarse aggregate data sheet)
Dry-rodded unit weight of coarse aggregate: 104.0 lbs./cu.ft. (lab results)

Using the above information, solve for the absolute volume of each material.
Remember: The total for all materials must be 27.00 cu.ft.

Cement

Given: 564 lbs. of Cement

$$\frac{564}{3.15 \times 62.4} = \mathbf{2.87\ cu.ft./cu.yd.}$$

Water

As per spec, the maximum water allowed is .532 lbs. of water per lb. of cement with angular aggregate. If the cement content for 1 cubic yard is 564 lbs., the maximum design water will be as follows:

$$564 \times 0.532 = \frac{300\text{ lbs. of water}}{8.33\text{ (weight of 1 gal of water)}} = 36.0\text{ gals of water per cu.yd.}$$

If there are 7.5 gallons of water in 1 cubic foot, to find the absolute volume:

$$\frac{36.0\text{ gallons/cu.yd.}}{7.5\text{ gallons/ cu.ft.}} = \mathbf{4.80\ cu.ft./cu.yd.}$$

Air

The middle of the air spec. is 6 %. This is the number that is used for the absolute volume.

0.06 X 27.00 cu.ft. = **1.62 cu.ft./cu.yd.**

Because air technically does not weigh anything, it will not have a specific gravity, so what is solved for is the 6 % volume that is displaced by the air in a cubic yard of mix.

Coarse Aggregate

ACI Table 5.3.6

Volume of Coarse Aggregate Per Unit Volume of Concrete

Nominal Maximum Size of Aggregate	Volume of Dry-Rodded Coarse Aggregate* per unit Volume of Concrete for Different Fineness Moduli of Sand							
	Fineness Modulus of Sand							
inches	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00
3/8”	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.44
½”	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.53
¾”	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60
1”	0.72	0.71	0.70	0.69	0.68	0.67	0.66	0.65
1 ½”	0.76	0.75	0.74	0.73	0.72	0.71	0.70	0.69
2”	0.79	0.78	0.77	0.76	0.75	0.74	0.73	0.72
3”	0.83	0.82	0.81	0.80	0.79	0.78	0.77	0.76

***** Volumes are based on aggregates in dry-rodded condition as described in ASTM C 29 for Unit Weight on Aggregate.

From the ACI Table 5.3.6, the percent of total mix that should be coarse aggregate is found by taking the 3/4" nominal maximum size aggregate designated by the specification, and looking it up on the left side of the table. The Fineness Modulus, (FM), of the sand is found across the top of the table. As stated the FM of the sand in this problem was 2.75. Going across the top of the table, locate 2.80(2.75 rounded to closest number), then go down to 3/4" aggregate to find the 0.62. This tells us that 62% of the mix must be dry-rodded coarse aggregate.

This number must be converted into a volume.

0.62 X 27 cu.ft. = 16.74 cu.ft./cu.yd. (This is the dry-rodded volume)

The dry-rodded unit weight of the aggregate is 104.0 lbs./cu.ft. Using this information we can calculate the weight of the coarse aggregate going into the mix.

16.74 cu.ft./cu.yd. X 104.0 lbs./cu.ft. = 1741 lbs. of coarse aggregate
(this is the design weight of the # 67 stone)

As previously stated the specific gravity of the coarse aggregate is 2.86. With that knowledge we can now determine the absolute volume of the coarse aggregate.

$$\frac{1741 \text{ lbs.}}{2.86 \times 62.4} = \mathbf{9.76\ cu.ft./cu.yd.}$$

Fine Aggregate

To solve for the amount of fine aggregate, the problem is worked in reverse.

Step 1. Total the absolute volumes of the four other materials.

	Design	Absolute Volume cu.ft./cu.yd.
Cement	564 lbs.	**2.87**
Water	36.0 gals.	**4.80**
Air	6 %	**1.62**
Coarse Aggregate	1741 lbs.	**9.76**

Total		19.05 cu.ft./cu.yd.

The targeted total volume of the mix is 27.00 cu.ft. The total volume we have accounted for thus far is 19.05 cu.ft.

Step 2. The volume of the fine aggregate is the difference between the total required volume, (27.00 cu.ft.), and the actual volume you have with the first four ingredients.

27.00 cu.ft.
- 19.05 cu.ft.

7.95 cu.ft.

The 7.95 cu.ft. volume that is left, is the volume of the fine aggregate.

To determine the amount, or weight, of sand that is required for this mix:

volume of fine aggregate	X	specific gravity of fine aggregate	X	62.4 (unit weight of water)	=	pounds of fine aggregate

7.95 cu.ft. X 2.63 X 62.4 = 1305 lbs. of fine aggregate/cu.yd.

The Class A Concrete Mix design of this mix is as follows:

Cement	564 lbs.
Water	36.0 gals.
Air	6 %
Coarse Aggregate	1741 lbs.
Fine Aggregate	1305 lbs.

Example: DATE: 8-08-19

ACI WORKSHEET

CLASS: A - Vib. AE, #67 MIX DESIGN

FINE AGG: NCDOT Sand – Pit 2 COARSE AGG: NCDOT Stone – Quarry 12

FM: 2.75 MAXIMUM SIZE: 3/4 INCH

SP.GR. 2.63 X 62.4 = 164.11 LBS.CU.FT. UNIT WEIGHT: 104.0

(DRY RODDED)

SP.GR.: 2.86 X 62.4 = 178.46 LBS.CU.FT.

TABLE 5.3.6: 0.62

QUALITY OF COARSE AGGREGATE

0.62 X 27 = 16.74 X 104.0 = 1741 LBS.CU.YD.

TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH: none LBS. / 62.4 = 0 CU.FT./CU.YD.

CEMENT: 564 LBS. / 3.15 X 62.4 = 2.87 CU.FT./CU.YD.

WATER:

0.532 X 564 = 300.0 / 8.33 = 36.0 GALS / 7.5 = 4.8 CU.FT./CU.YD.

(MAX W/C) x LBS. OF CEMENT

AIR: 0.06 X 27 = 1.62 CU.FT./CU.YD.

COARSE AGG: 1741 LBS. / SP.GR. 2.86 X 62.4 = 9.76 CU.FT./CU.YD.

TOTAL: 19.05 CU.FT./CU.YD.

27.00 CU.FT./CU.YD.

\- 19.05 CU.FT./CU.YD. TOTAL

\------------------

FINE AGG: 7.95 CU.FT./CU.YD. X 2.63 X 62.4 = 1305 LBS./CU.YDS.

↑(SP.GR.)

SUGGESTED QUANTITIES:

FLY ASH	none	LBS.
CEMENT	564	LBS.
WATER	36.0	GALS.
AIR	6	%
COARSE AGG.	1741	LBS.
FINE AGG.	1305	LBS.

Mix Designs with Fly Ash

The current Standard Specifications for Roadway and Structures, section 1000-4(I) permits the use of fly ash in all classes of concrete. In all classes, fly ash may be substituted for portland cement up to 30% by weight of the required cement. Substitute at the rate of 1 pound of fly ash to each pound of cement replaced. Do not substitute for a portion of Type 1P or 1S cement or for portland cement in high early strength concrete. Fly ash shall not be used in sections 12” or less in thickness when insulation is to be used for cold weather protection.

Use Table 1000-1 to determine the maximum allowable water-cementitious material (cement + fly ash) ratio for the classes of concrete listed.

Example Problem: Design a Class A Fly Ash mix using the NCDOT Stone Quarry 5 for # 57 stone and NCDOT Sand Quarry 2 for fine aggregate. Substitute NCDOT Fly Ash for 20% of the cement. Use 1.5 gallons less then the maximum allowable water.

Specific Gravity of NCDOT Fly Ash	2.26
NCDOT Stone Quarry 5 # 57 Stone	Angular

Computation Suggestions:

Cement

Multiply 20 % times the 564 pounds of cement for Class A to get 112.8 lbs.
Subtract this from the original pounds, 564 lbs. to get 451 lbs.

564 lbs. - (564 X 0.20) = 451 lbs. of cement/cu.yd.

Fly Ash

Because the substitution ratio is 1:1, the pounds of fly ash needed is equal to the pounds of cement replaced:

112.8 lbs. X 1.0 = 112.8 lbs. of fly ash/cu.yd.

Water

Multiply the maximum water/cement ratio, (0.512 for Class A concrete as per the spec. book), times the total amount of cementitious material, (451.2 lbs. of cement + 112.8 lbs. of fly ash = 564 lbs.). This will give you 289 lbs. of water. Conve the pounds of water to gallons of water by dividing by 8.33 lbs./gal.. This gives you 34.7 gallons. Since the directions said that 1.5 gallons less than the maximum should be used, subtract the 1.5 gals. from the 36 gals. to get the total amount of water required for this particular mix.

(0.512 X 564 lbs.) / 8.33 - 1.5 gals. = 33.2 gals/cu.yd.

Example w/ Fly Ash: DATE: 9-18-18

ACI WORKSHEET

CLASS: A – Vib. AE Fly Ash MIX DESIGN

FINE AGG: NCDOT Sand Quarry 2   COARSE AGG: NCDOT Stone Quarry 5

FM: 2.60   NOMINAL MAX SIZE: 1” INCH

SP.GR. 2.82 X 62.4 = 175.97 LBS.CU.FT.   UNIT WEIGHT: 99.5 Lbs. (DRY RODDED)

SP.GR.: 2.75 X 62.4 = 171.60 LBS.CU.FT.

TABLE 5.3.6: 0.69

QUALITY OF COARSE AGGREGATE

0.69 X 27 = 18.63 X 99.5 = 1854 LBS.
TABLE 5.3.6.   DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH: $\frac{113 \text{ LBS.}}{2.26 \times 62.4}$ = 0.80 CU.FT./CU.YD.

CEMENT: $\frac{451 \text{ LBS.}}{3.15 \times 62.4}$ = 2.29 CU.FT./CU.YD.

WATER:
0.512 X 564 = $\frac{289}{8.33}$ - 1.5 = $\frac{33.2}{7.5}$ GALS = 4.42 CU.FT./CU.YD.

AIR: 0.06 X 27 = 1.62 CU.FT./CU.YD.

COARSE AGG: $\frac{1854 \text{ LBS.}}{\text{SP.GR. } 2.75 \times 62.4}$ = 10.80 CU.FT./CU.YD.

TOTAL: 19.93 CU.FT./CU.YD.

27.00 CU.FT./CU.YD.
- 19.93 CU.FT./CU.YD. TOTAL

FINE AGG: 7.07 CU.FT./CU.YD. X 2.82 X 62.4 = 1244 LBS./CU.YDS.
↑(SP.GR.)

SUGGESTED QUANTITIES:

FLY ASH	113	LBS.
CEMENT	451	LBS.
WATER	33.2	GALS.
AIR	6	%
COARSE AGG.	1854	LBS.
FINE AGG.	1244	LBS.

Concrete Mix Designs Modified with Latex

Guidelines for latex modified concrete are outlined in section 1000-7 of the current NCDOT Standard Specifications for Roads and Structures book. Tables 1000-3 and 1000-4 of this section show the latex and modified concrete properties respectively. When designing a latex modified mix, both the solids and water from the latex must be accounted for in the calculations for yield and water/cement ratio. The latex percent solids requirement in Table 1000-3 shows that at least 51% of the latex is water and based on the minimum dosage per cubic yard in Table 1000-4, about 13 gallons of water will contribute to the total water in the mix. The design yield is 27.00 ft^3 and this should include the latex. When submitting a latex modified mix design, the technical datasheet for the latex used must be submitted along with other required data.

Table 1000-3

PROPERTIES OF LATEX MODIFIER FOR CONCRETE	
Property	**Requirement**
Polymer Type	Styrene Butadiene: 68 ± 4% Styrene 32 ± 4% Butadiene
Average Polymer Particle Size	1500 to 2500 Angstroms
Emulsion Stabilizers	Anionic and non-ionic surfactants
Percent Solids	46.5% to 49.0%
Weight per gallon at 75°F	8.40 to 8.60 lb
pH	9.5 to 11.0
Shelf Life	2 Years
Color	White

Table 1000-4

PROPERTIES OF LATEX MODIFIED CONCRETE	
Property	**Requirement**
Cement Content, lb/cy	658 min.
Latex Emulsion Admixture, gal/cy	24.5 min.
Air Content of Plastic Mix, %	3.5 - 6.5
Slump, inches	3 - 6
% Fine Aggregate as percent of total aggregate by weight	50 - 55
7 day Compressive Strength, psi	3,000 min.
Water-Cement Ratio by weight	0.40 max.

<u>Latex Mix Design Example</u>**:** Design a Class "Latex Modified" vibrated, non-air entrained, concrete mix using natural sand from NCDOT Pit 1 and stone #78M with 2.73 specific gravity, 0.2 percent absorption, and 100 dry-rodded unit weight from NCDOT Quarry 13. Use 208 lbs (24.5 gallons) of NCDOT latex admixture with specific gravity of 1.02 and percent solids by weight of 48.7. Use the minimum type I/II cement from NCDOT Plant 1, 2 gallons less than maximum water, and 5% entrapped air.

Step 1: Determine the volume of cement
The minimum cement requirement for latex modified concrete is **658** lbs (Table 1000-4)

$$Absolute\,Volume = \frac{658}{3.15 * 62.4} = \mathbf{3.35}\,cu.ft.$$

Step 2: Determine volume of water
The maximum water-cement ratio is 0.40. Therefore,

$$Max\ Amount\ of\ water\ = \frac{658*0.40}{8.33} = 31.6 \text{ gals}$$

The water content in latex is 51.3 % of 208 lbs which is about 107 lbs or 12.8 gals. Therefore the new max water that can be added to the mix is 31.6 minus 12.8 which is 18.8 gals. However, the mix has requested for 2 gallons less than the maximum water. The amount of water is therefore **16.8** gals.

$$Absolute\,Volume = \frac{16.8}{7.5} = \mathbf{2.24}\,cu.ft.$$

Step 3: Determine volume of Latex

$$Absolute\,Volume = \frac{208}{1.02 * 62.4} = \mathbf{3.27}\,cu.ft.$$

Step 4: Determine volume of coarse aggregate
Factor from Table 5.3.6 is 0.50 and using the dry-rodded unit weight, the amount of stone is **1350** lbs.

$$Absolute\,Volume = \frac{1350}{2.73 * 62.4} = \mathbf{7.92}\,cu.ft.$$

Step 5: Determine volume of air

*Absolute Volume = 27*0.05 =* ***1.35*** *cu. ft*

Step 6: Determine volume of sand

The total absolute volume so far is 18.13 cu. ft. The volume of sand is therefore the difference from the target design volume of 27 cu. ft. which in this case is **8.87** cu. ft. The amount of sand is therefore **1467** lbs.

Note that when designing a mix with a **Corrosion Inhibitor**, similar consideration in the design process must be followed to account for extra water and solids from the admixture. See section 1000-4 part K of the Standard Specifications book for this admixture's specifications.

Form 312U

Producer's Mix ID	E	X	A	M	P	L	E		

08-17

North Carolina Department of Transportation, Division of Highways, Materials and Tests Unit
Statement of Concrete Mix Design and Source of Materials

Class of Concrete	Latex Modified	Concrete Producer Name	Latex Example	
Vibrated (Yes or No)	Yes	NCDOT Plant No.	Latex Example	
Air Entrained (Yes or No)	No	Date Requested	1/1/2018	
Reference Mix Design No.	n/a	7/28 Day Break Data (psi)	5000	7000

Mix Design Proportions Based on SSD Mass of Aggregates

Material	**Producer**	**Source**	**Qty. per Cu. Yd.**	
Cement	NCDOT	Plant 1	658	lbs.
Pozzolan				lbs.
Other Pozzolan				lbs.
Fine Agg.+ M	NCDOT	Pit 1	1467	lbs.
Coarse Agg.+ M	NCDOT	Quarry 13	1350	lbs.
Other Agg.+ M				lbs.
Total Water		City	16.8	gals.
Material	**Producer**	**Admixture Brand**	**Qty. per Cu. Yd.**	
Air Entraining Agent			As Recomm.	
Retarding Agent			As Recomm.	
Water Reducing Agent			As Recomm.	
Superplasticizer			As Recomm.	
Corrosion Inhibitor				gals.
Latex Modifier	NCDOT	Latex 1	24.5	gals.

Mix Properties and Specifications

Slump (inches)	6.0	Mortar Content (ft^3)	19.08
Max W/C Ratio	0.400	Air Content (%)	5
Max. Water (gals)	18.8	Design Volume (ft^3)	27

Aggregate and Cementitious Data

Material	**Type / Size**	**Coarse Agg. Shape**	**Specific Gravity**	**% Absorption**	**Unit Mass**	**Fineness Modulus**
Fine Aggregate	2S	N/A	2.65	0.3	N/A	2.42
Coarse Aggregate	#78M	Angular	2.73	0.2	100	N/A
Other Aggregate						N/A
Pozzolan		N/A		N/A	N/A	N/A
Other Pozzolan		N/A		N/A	N/A	N/A
Cement	I/II	N/A	3.15	N/A	N/A	N/A

Cast-in-place concrete shall conform to Section 1000, precast concrete to Section 1077, and prestressed concrete to Section 1078 of the applicable edition of the Standard Specifications for Roads and Structures plus all applicable Special Provisions.

Special Use Criteria: Is mix design governed by Special Provision/Plan Note? **YES or NO** NO

If **Yes** submit copy of Special Provision or Plan Note with this Form.

Signature and title of person who designed mix **Latex Example**

NCDOT Mix Design Certification No. Example **Or PE stamp or No.**

Comments: Latex modified mix design example

Section IX
NC DOT Concrete Mix Design Specifications

Table 1000-1
Requirements For Concrete

Class of Concrete	Minimum compressive Strength at 28 days, psi	Maximum Water-Cement Ratio				Consistency Max. Slump, Inches		Cement Content, Lbs/Yd^3			
		Air-Entrained Concrete		Non Air-Entrained Concrete		Vibrated	Non-Vibrated	Vibrated		Non-Vibrated	
		Rounded Aggregate	Angular Aggregate	Rounded Aggregate	Angular Aggregate			min.	max	min.	max
AA	4500	0.381	0.426	---	---	3.5	---	639	715	---	---
AA Slip Form	4500	0.381	0.426	---	---	1.5	---	639	715	---	---
A	3000	0.488	0.532	0.550	0.594	3.5	4	564	677	602	---
B	2500	0.488	0.567	0.559	0.630	2.5	4	508	---	545	---
B Slip Form	2500	0.488	0.567	---	---	1.5	---	508	---	545	---
Sand Lightweight	4500	---	0.420	---	---	4	---	715	---	---	---
Latex Modified	3000 (7day)	0.400	0.400	---	---	6	---	658	---	---	---
Flowable Fill excavatable	150 (max. @ 56 days)	as needed	as needed	as needed	as needed	---	flowable	---	---	40	100
Flowable Fill non-excavatable	125	as needed	as needed	as needed	as needed	---	flowable	---	---	100	as needed
Pavement	650 (flexural)	0.559	0.559	---	---	1.5 slip 3.0 hand	---	526	---	---	
Precast	See Table 1077-1	as needed	as needed	---	---	6	as needed	as needed	as needed	as needed	as needed
Prestress - 6000	6000 or less	0.450	0.450	---	---	8		564	as needed	---	---
Prestress +6000	greater than 6000	0.400	0.400	---	---	8		564	as needed	---	---

High Early Strength Concrete Mix Designs

Section 1000-5 High Early Strength Portland Cement Concrete

Use high early strength Portland cement concrete when required by contract. When not required, it may be used at the Contractor's option with approval of the Engineer. For all classes of concrete, high early strength concrete may be produced by using Type III Portland cement. To produce high early strength concrete with regular cement, use a higher class of concrete as follows:
For Class A and Class B, use Class AA with a cement content of at least 677 lbs/cy. Other classes that lend themselves to high early strength with regular cement will be reviewed by the Engineer on a case-by-case basis.

Section 723-4 Very High Early Strength Concrete for Concrete Pavement Repair

Submit mix designs for Very High Early Strength Concrete for Concrete Pavement Repair in terms of saturated surface dry weights on M & T Form 312U for acceptance at least 30 days before proposed use.

Use a mix sufficient to obtain at least a flexural strength of 400 psi at 4 hours or prior to opening to traffic. Entrain 5% ± 1.5% air in the freshly mixed concrete. Produce the mix with a maximum slump of 1.5 inches for placement by a fully mechanized paving train and a maximum slump of 3 inches for hand placement.
Use cement, fine aggregate, coarse aggregate, admixtures and, optionally, 1 pozzolan as shown on NCDOT's APL.

Submit 4 hour flexural strength results of at least 6 beams made and tested in accordance with AASHTO T126 and T97 with M & T Form 312U. In addition, submit 4 hour compressive strength results of at least six 4 inch by 8 inch or 6 inch by 12 inch cylinders and maturity test results of the mix. With permission of the Engineer, compressive strength testing and maturity testing may be used in lieu of or concurrent with flexural strength testing to determine the acceptability of the concrete in the field.

Design and produce the mix in accordance a concrete system that can produce 400 psi flexural strength in approximately 4 hours or a comparable equal system. The timing of the addition of hydration control admixtures is critical to the performance of this concrete; therefore, an admixture representative shall be present on the job when Very High Early Strength Concrete is batched.

Self-Consolidating Concrete Special Provision for Precast and Prestressed Concrete

11-28-05 (Revised 12-5-05)

Furnish and place Self-Consolidating Concrete (SCC) as noted on the plans or with the permission of the Engineer. Perform this work in accordance with this Special Provision and the applicable parts of the Standard Specifications.

Self-consolidating concrete is concrete designed to flow under its own weight, maintain homogeneity and completely fill the formwork, even in the presence of dense reinforcement. Do not form-vibrate SCC without permission of the Engineer. Internal vibration of self-consolidating concrete is prohibited.

Design the mix as follows:

A. Cement -- Use a minimum of 639 lbs. per cubic yard and a maximum of 850 lbs. per cubic yard.

B. Pozzolan – With permission of the Engineer, a pozzolan such as fly ash, ground granulated blast furnace slag, silica fume or limestone powder may substituted for a portion of the cement.

C. Coarse and fine aggregate – Use a fine aggregate content of 40 % to 60 % of the combined coarse and fine aggregate weight.

D. Water – For precast concrete, use a quantity of water that produces a water-cementitious material ratio no greater than 0.48. For prestressed concrete, see Table 1000-1 in the (2006) Standard Specifications.

E. Admixtures – Although not required, a viscosity modifier is recommended as a way to enhance the homogeneity and flow of the mix.

Submit the proposed mix design to the Engineer on M & T Form 312U. Attach supporting data from trial batches conducted by an approved testing laboratory. The Engineer will evaluate the data for compliance with the following test methods and specifications:

A. Shrinkage (required for prestressed concrete only) – Shrinkage, tested in accordance with ASTM C 157 as modified herein shall not exceed 0.04 % at 28 days. Use the mix proportions to be used in production. Use steel molds 3 inches x 3 inches x 11.25 inches in size. Do not rod, vibrate or otherwise consolidate the concrete. Finish the exposed surface of each specimen with a steel trowel. Report the length change of each specimen to the nearest 0.001 % of the effective gage length at 3, 7, 14 and 28 days and 8 weeks.

B. Slump flow – Slump flow, tested in accordance with ASTM C 1611, “Standard Test Method for Slump Flow of Self-Consolidating Concrete,” shall be within the range of 24 inches to 30 inches spread. Use Filling Procedure B.

C. J-Ring test – Follow the “Interim Guidelines for the Use of Self-Consolidating Concrete in Precast/Prestressed Concrete Institute Member Plants (TR-6-03)” published by PCI. The difference in spread between tests with and without the ring shall not exceed 2 inches.

D. L-Box test – Follow the guidelines referenced in Item C for design of the L-box and conducting the test. The ratio of H2 to H1 shall be within the range of 0.8 to 1.0.

E. Compressive strength – Report the compressive strength of concrete cylinders made in accordance with AASHTO T-23 as modified herein or T-126 as modified herein. Test cylinders in accordance with T-22 at 3, 7, 14 and 28 days. The strength shall meet the requirements shown on the plans or in the Standard Specifications. Fill the cylinder molds in one layer with no rodding or vibration of the sample. Do not cast specimens until the J-Ring test has been completed.

F. Modulus of elasticity (required for prestressed concrete only) – Report the modulus of elasticity of concrete specimens made and tested in accordance with ASTM C 469 at 3 and 28 days.

G. Air content – Test the air content of the plastic concrete in accordance with AASHTO T-152 or T-196.

Before beginning production, the producer shall demonstrate competence in using SCC by casting a mock item of like or similar design in the presence of the Engineer. With the permission of the Engineer, he may substitute in lieu of a mock item a production item being cast for another state or agency.

A representative of the admixture supplier shall be present during casting of the demonstration item and all production items. After production begins, the Engineer may waive this requirement.

Self-consolidating concrete shall remain plastic and within the specified range of slump flow during placement. Concrete delivery shall be timed such that consecutive lifts will combine completely without creating segregation, visible pour lines or cold joints. Do not allow more than 20 minutes between placement of consecutive lifts.

Concrete shall be placed from one point and be allowed to flow outward, or pumped from the bottom upward so as not to encapsulate air. Avoid opposing flow of concrete.

The distance of horizontal flow shall not exceed 30 feet and the vertical free fall distance shall not exceed 10 feet.

Perform the following field tests on the plastic concrete using the standards and modifications listed above and the sampling rates listed herein:

A. Slump flow – The slump flow shall range between 24 and 30 inches spread. For both precast and prestressed concrete, test the first batch and whenever cylinders are made. In addition, for precast, test each 30 cubic yards after the first batch; and for prestressed concrete, test each 10 cubic yards after the first batch. Whenever testing occurs, retest if the initial test fails. Reject the batch if the original and the retest fail.

B. J-Ring – The difference between tests with and without the ring shall not exceed 2 inches. For both precast and prestressed concrete, test the first batch and whenever cylinders are made. In addition, for precast concrete, test each 30 cubic yards after the first batch. Whenever testing occurs, retest if the initial test fails. Reject the batch if the original and the retest fail.

C. Air Content – For both precast and prestressed concrete, test the first batch and whenever cylinders are made. In addition, for prestressed concrete, test each 10 cubic yards after the first batch. Follow AASHTO T-152 or T-196. When testing occurs, retest if the initial test fails. Reject the load if the original and the retest fail.

D. Compressive strength – Report the compressive strength of concrete cylinders made in accordance with AASHTO T-23 as modified herein or T-126 as modified herein. Test cylinders in accordance with T-22. The strength shall meet the requirements shown on the plans or in the Standard Specifications. Fill the cylinder molds in one layer with no rodding or vibration of the sample. Do not cast specimens until the J-Ring test has been completed. For precast box culverts, make one set of cylinders for every 10 cubic yards cast. For all other precast items, make one set of cylinders per day.

E. Concrete temperature – Follow the Standard Specifications.

Changes to Mix Designs

Changes to an approved mix design are not permitted. If any change is made to the mix design, submit a new mix design. Form 312M is a Mass Change Request form that is used to make a change of producers or sources of materials in previously approved mix designs. This form applies to minor changes only: sources/brands of admixtures and sources of the same type of cement/pozzolan. If a major change needs to be made, Form 312U must be used and compressive strength test data must be submitted for review (Section 1000-1 of NCDOT Standard Specifications). Instructions on how to correctly fill out Form 312M are in appendix E. Form 312C is another Materials and Tests form used to request copies of already approved mix designs. Copies of both Form 312M and 312C are in appendix E.

Concrete Mix Design Numbering System

The NCDOT numbering system incorporates the Producers' Mix Design ID and adds a prefix and suffix to create the State Mix Design Number. The system is as follows:

1. The first 1, 2, or 3 numbers is the concrete plant number. For example, a ready mix plant has been approved by NCDOT and assigned the plant ID number 999. All mixes from that plant will begin with 999.
2. Next comes a three-place DOT code for (1) the class of concrete, (2) the vibration and air-entrainment status of the mix, and (3) the type of Pozzolan used, if any. For example, 2VF means Class AA, vibrated and air-entrained, with Class F fly ash. See Tables XI-1, Table XI-2 and Table XI-3 for codes.
3. The Producer's Mix Design ID number comes next. This number can be any combination of numbers and/or letters up to nine places. Each number must be unique within a given plant. This means when a producer changes a material source, quantity, or property he must assign a different number to the mix and resubmit it for approval and entry into the NCDOT database. Only admixture quantities are exempt from this requirement. It is understood that admixture quantities may vary in concrete production due to concrete temperature, environmental conditions, presence of other admixtures, etc.
4. Last is the suffix, which is always the letter "E" meaning English units of measurement (as opposed to metric units). No mixes are issued in metric, regardless of which units are used to design the job. Initial, it was planned to have a dual system with metric mixes ending in the letter "M", but metric conversion by hand proved too cumbersome and time-consuming for staff, and so a dispensation was given to issue all mixes in English.

Table XI-1: Table of Codes for Class of Concrete

Code	Class of Concrete
1	Class A
2	Class AA
3	Class AAA
B	Class B
C	Shotcrete
D	Drilled Shaft
E	Regular Precast
G	Grout
H	High Early Strength Patch Mix
L	Latex Modified Concrete
M	Class B Curb & Gutter Machine
N	Non-Excavatable Flowable Fill
P	Regular Prestress
R	Class AA Slip-form Barrier Rail
S	Class S
T	Pavement
X	Excavatable Flowable Fill
Y	Prestress Self-Consolidating
Z	Precast Self-Consolidating

Table XI-2: Table of Air Entrainment and Vibration Status

Code	Vibration and AEA Status
V	Vibrated and Air Entrained
N	Non-vibrated and Air Entrained
X	Vibrated and Non-air Entrained
Y	Non-vibrated and Non-air Entrained

Table XI-3: Table of Pozzolan

Code	Type of Pozzolan
O	No Pozzolan
F	Class F Fly Ash
C	Class C Fly Ash
G	Ground Granulated Blast Furnace Slag
U	Silica Fume

Example of Numbering System

Class of Concrete

Table XI-1

Air Entrainment and Vibration Status

Table XI-2

Pozzolan Type

Table XI-3

Always an "E" for English Units

$$\underbrace{\mathrm{9992}}_{\text{Plant ID}}\mathrm{2VF}\underbrace{\mathrm{15BP42}}_{\text{Producer's Mix Design ID}}\mathrm{E}$$

Section X
Study Problems ACI Mix Design

Design a Class “AA” vibrated, air entrained, concrete mix using sand from NCDOT Pit 3 and stone from NCDOT Quarry 9, size # 67, angular. Use minimum cement and 1 gallon less than maximum water.

MIX DESIGN PROBLEM #1 DATE:________

ACI WORKSHEET

CLASS:____________________MIX DESIGN

FINE AGG:____________________ COARSE AGG:______________________

FM:_______________ NOM. MAX. SIZE:_____________INCH

SP.GR._____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:_____________ LBS.CU.FT.
(DRY RODDED)
SP.GR.: _____X 62.4 =_______LBS.CU.FT.

TABLE 5.3.6:___________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = _________ X __________________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:_______________ LBS. = ________________________FT³
SP.GR._____ X 62.4

CEMENT:________________LBS. = ________________________FT³
3.15 X 62.4

WATER: ___________________GALS = ________________________FT³
7.5

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. = ______________________FT³
SP.GR.________ X 62.4

TOTAL: __________________________FT³

27.00 CU.FT./CU.YD.
\-
\------------------

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

<u>MIX DESIGN QUANTITIES</u>:

FLY ASH	_______________	**LBS.**
CEMENT	_______________	**LBS.**
WATER	_______________	**GALS.**
AIR	_______________	**%**
COARSE AGG.	_______________	**LBS.**
FINE AGG.	_______________	**LBS.**

Design a Class "A" vibrated, air entrained, concrete mix using sand from NCDOT Pit 2 and stone from NCDOT Quarry 8, size # 67, angular. Use the minimum cement and 2 gallons less than maximum water.

MIX DESIGN PROBLEM #2 DATE:________

ACI WORKSHEET

CLASS:____________________MIX DESIGN

FINE AGG:____________________ COARSE AGG:______________________

FM:_______________ NOM. MAX. SIZE:____________INCH

SP.GR.____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:____________ LBS.CU.FT.
(DRY RODDED)

SP.GR.: _____X 62.4 =_______LBS.CU.FT.

TABLE 5.3.6:___________

QUANTITY OF COARSE AGGREGATE

_________ X 27 CU.FT. = _________ X _________________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:______________ LBS. = ________________________FT³
SP.GR.____ X 62.4

CEMENT:________________LBS. = ________________________FT³
3.15 X 62.4

WATER: ___________________GALS = ___________________FT³
7.5

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. = _____________________FT³
SP.GR._______ X 62.4

TOTAL: _________________________FT³

27.00 CU.FT./CU.YD.
-

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

MIX DESIGN QUANTITIES:

FLY ASH _______________ **LBS.**
CEMENT _______________ **LBS.**
WATER _______________ **GALS.**
AIR _______________ **%**
COARSE AGG. _______________ **LBS.**
FINE AGG. ______________ **LBS.**

Design a Class “AA” vibrated, air entrained, concrete mix using sand from NCDOT Pit 4 and stone from NCDOT Quarry 2, size # 67, angular. Use 7.6 bags of cement per yard and the maximum water permitted.

MIX DESIGN PROBLEM #3 DATE:________

ACI WORKSHEET

CLASS:____________________MIX DESIGN

FINE AGG:____________________ COARSE AGG:______________________

FM:_______________ NOM. MAX. SIZE:____________INCH

SP.GR.____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:____________ LBS.CU.FT.
(DRY RODDED)
SP.GR.: _____X 62.4 =_______LBS.CU.FT.

TABLE 5.3.6:__________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = ________ X ________________ = __________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:______________ LBS. = ______________________FT³
SP.GR.____ X 62.4

CEMENT:________________LBS. = ______________________FT³
3.15 X 62.4

WATER: __________________GALS = ______________________FT³
7.5

AIR: ________________ X 27 = ____________________FT³

COARSE AGG: ________________LBS. = ____________________FT³
SP.GR.______ X 62.4

TOTAL: ______________________FT³

27.00 CU.FT./CU.YD.
-

FINE AGG:_________CU.FT./CU.YD. X __________ X 62.4 = ________LBS./CU.YDS.
↑(SP.GR.)

<u>MIX DESIGN QUANTITIES</u>:

FLY ASH ______________ LBS.
CEMENT ______________ LBS.
WATER ______________ GALS.
AIR ______________ %
COARSE AGG. ______________ LBS.
FINE AGG. ______________ LBS.

Design a Class "B" non-vibrated, air entrained, concrete mix using sand from NCDOT Quarry 5 and stone from NCDOT Quarry 1, size #57, angular. Use the minimum cement and two gallons of water per yard less than the maximum permitted.

MIX DESIGN PROBLEM #4 DATE:________

ACI WORKSHEET

CLASS:____________________MIX DESIGN

FINE AGG:____________________ COARSE AGG:______________________

FM:_______________ NOM. MAX. SIZE:____________INCH

SP.GR.____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:____________ LBS.CU.FT.
(DRY RODDED)

SP.GR.: _____X 62.4 =_______LBS.CU.FT.

TABLE 5.3.6:____________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = ________ X __________________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:______________ LBS. = ________________________FT³
SP.GR.____ X 62.4

CEMENT:________________LBS. = ________________________FT³
3.15 X 62.4

WATER: ___________________GALS = _____________________FT³
7.5

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. = _____________________FT³
SP.GR.______ X 62.4

TOTAL: _________________________FT³

27.00 CU.FT./CU.YD.
\-
\------------------

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

<u>MIX DESIGN QUANTITIES</u>:

FLY ASH _______________ **LBS.**
CEMENT ________________ **LBS.**
WATER ________________ **GALS.**
AIR ________________ **%**
COARSE AGG. ________________ **LBS.**
FINE AGG. _______________ **LBS.**

Design a Class "A" vibrated, air entrained, concrete mix using sand from NCDOT Pit 1 and stone from NCDOT Quarry 11, size #67, angular. Use the minimum cement content and 0.478 as a w/c ratio.

MIX DESIGN PROBLEM #5 DATE:________

ACI WORKSHEET

CLASS:____________________MIX DESIGN

FINE AGG:__________________ COARSE AGG:______________________

FM:_______________ NOM. MAX. SIZE:____________INCH

SP.GR.____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:____________ LBS.CU.FT.
(DRY RODDED)
SP.GR.: _____X 62.4 =_______LBS.CU.FT.

TABLE 5.3.6:___________

QUANTITY OF COARSE AGGREGATE

_________ X 27 CU.FT. = ________ X _________________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:______________ LBS. = _______________________FT³
SP.GR.____ X 62.4

CEMENT:________________LBS. = _______________________FT³
3.15 X 62.4

WATER: ___________________GALS = ______________________FT³
7.5

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. = _____________________FT³
SP.GR.______ X 62.4

TOTAL: _________________________FT³

27.00 CU.FT./CU.YD.
\-
\------------------

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

MIX DESIGN QUANTITIES:

FLY ASH _______________ **LBS.**
CEMENT ________________ **LBS.**
WATER ________________ **GALS.**
AIR ________________ **%**
COARSE AGG. ________________ **LBS.**
FINE AGG. _______________ **LBS.**

Design a class "B" vibrated, air entrained concrete mix using sand from the NCDOT Pit 5 and stone from NCDOT Quarry 12, size #67, angular. Use the minimum cement and one gallon of water per yard less than the maximum permitted.

MIX DESIGN PROBLEM #6 DATE:________

ACI WORKSHEET

CLASS:____________________MIX DESIGN

FINE AGG:____________________ COARSE AGG:______________________

FM:_______________ NOM. MAX. SIZE:____________INCH

SP.GR.____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:______________ LBS.CU.FT.
(DRY RODDED)

SP.GR.: ______X 62.4 =_________LBS.CU.FT.

TABLE 5.3.6:___________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = _________ X ___________________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:______________ LBS. / SP.GR.____ X 62.4 = ________________________FT³

CEMENT:_________________LBS. / 3.15 X 62.4 = ________________________FT³

WATER: ___________________GALS / 7.5 = ______________________FT³

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. / SP.GR.______ X 62.4 = _____________________FT³

TOTAL: __________________________FT³

27.00 CU.FT./CU.YD.
-

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

<u>**MIX DESIGN QUANTITIES**</u>:

FLY ASH	_______________	**LBS.**
CEMENT	_______________	**LBS.**
WATER	_______________	**GALS.**
AIR	_______________	**%**
COARSE AGG.	_______________	**LBS.**
FINE AGG.	_______________	**LBS.**

Design a Class "AA" vibrated, air entrained concrete mix using sand from NCDOT Quarry 1 and stone from NCDOT Quarry 9, size #67, angular. Use 7.6 sacks of cement per yard and two gallons of water per yard less then the maximum water permitted.

MIX DESIGN PROBLEM #7 DATE:________

ACI WORKSHEET

CLASS:____________________MIX DESIGN

FINE AGG:____________________ COARSE AGG:______________________

FM:_______________ NOM. MAX. SIZE:____________INCH

SP.GR.____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:____________ LBS.CU.FT.
(DRY RODDED)

SP.GR.: _____X 62.4 =_______LBS.CU.FT.

TABLE 5.3.6:__________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = ________ X _______________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:_______________ LBS. = ________________________FT³
SP.GR.____ X 62.4

CEMENT:__________________LBS. = ________________________FT³
3.15 X 62.4

WATER: ___________________GALS = ______________________FT³
7.5

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. = _____________________FT³
SP.GR.______ X 62.4

TOTAL: _________________________FT³

27.00 CU.FT./CU.YD.
-

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

<u>**MIX DESIGN QUANTITIES**</u>:

FLY ASH _______________ **LBS.**
CEMENT ________________ **LBS.**
WATER ________________ **GALS.**
AIR ________________ **%**
COARSE AGG. ________________ **LBS.**
FINE AGG. _______________ **LBS.**

Design a Class "B" non-vibrated, air entrained concrete mix using sand from NCDOT Pit 3 and stone from NCDOT Quarry 10, Size #57, angular. Use one bag additional cement per yard than the minimum and 0.523 as the w/c ratio.

MIX DESIGN PROBLEM #8 DATE:________

ACI WORKSHEET

CLASS:____________________MIX DESIGN

FINE AGG:____________________ COARSE AGG:______________________

FM:_______________ NOM. MAX. SIZE:____________INCH

SP.GR.____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:____________ LBS.CU.FT.
(DRY RODDED)

SP.GR.: _____X 62.4 =_______LBS.CU.FT.

TABLE 5.3.6:__________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = ________ X ________________ = __________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:____________ LBS. / SP.GR.____ X 62.4 = ________________________FT³

CEMENT:________________LBS. / 3.15 X 62.4 = ________________________FT³

WATER: __________________GALS / 7.5 = ______________________FT³

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. / SP.GR.______ X 62.4 = _____________________FT³

TOTAL: _________________________FT³

27.00 CU.FT./CU.YD.
\-
\------------------

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

MIX DESIGN QUANTITIES:

FLY ASH _______________ **LBS.**
CEMENT _______________ **LBS.**
WATER _______________ **GALS.**
AIR _______________ **%**
COARSE AGG. _______________ **LBS.**
FINE AGG. ______________ **LBS.**

Design a Class “AA” vibrated, air entrained, FLY ASH concrete mix using 20% NCDOT fly ash with a specific gravity of 2.26. Use sand from NCDOT Pit 4 and stone from NCDOT Quarry 11, size #67, angular. Use minimum cement and two gallons less of water than the maximum number of gallons per yard permitted.

MIX DESIGN PROBLEM #9 DATE:________

ACI WORKSHEET

CLASS:____________________MIX DESIGN

FINE AGG:__________________ COARSE AGG:______________________

FM:_______________ NOM. MAX. SIZE:__________INCH

SP.GR.____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:_____________ LBS.CU.FT.
(DRY RODDED)

SP.GR.: _____X 62.4 =_______LBS.CU.FT.

TABLE 5.3.6:___________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = _________ X __________________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:_______________ LBS. / SP.GR.____ X 62.4 = ________________________FT³

CEMENT:________________LBS. / 3.15 X 62.4 = ________________________FT³

WATER: ___________________GALS / 7.5 = ______________________FT³

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. / SP.GR.______ X 62.4 = _____________________FT³

TOTAL: ________________________FT³

27.00 CU.FT./CU.YD.
-

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

MIX DESIGN QUANTITIES:

FLY ASH _______________ **LBS.**
CEMENT _______________ **LBS.**
WATER _______________ **GALS.**
AIR _______________ **%**
COARSE AGG. _______________ **LBS.**
FINE AGG. ______________ **LBS.**

Extra Worksheet for Practice

ACI WORKSHEET

CLASS:____________________MIX DESIGN

FINE AGG:____________________ COARSE AGG:______________________

FM:_______________ NOM. MAX. SIZE:____________INCH

SP.GR.____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:____________ LBS.CU.FT.
(DRY RODDED)

SP.GR.: _____X 62.4 =________LBS.CU.FT.

TABLE 5.3.6:__________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = ________ X __________________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:______________ LBS. = ________________________FT³
SP.GR._____ X 62.4

CEMENT:________________LBS. = ________________________FT³
3.15 X 62.4

WATER: ____________________GALS = ____________________FT³
7.5

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. = ______________________FT³
SP.GR.________ X 62.4

TOTAL: _________________________FT³

27.00 CU.FT./CU.YD.
-

FINE AGG:_________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

MIX DESIGN QUANTITIES:

FLY ASH ________________ **LBS.**
CEMENT ________________ **LBS.**
WATER ________________ **GALS.**
AIR ________________ **%**
COARSE AGG. ________________ **LBS.**
FINE AGG. _______________ **LBS.**

Extra Worksheet for Practice

ACI WORKSHEET

CLASS:_____________________MIX DESIGN

FINE AGG:______________________ COARSE AGG:______________________

FM:________________ NOM. MAX. SIZE:____________INCH

SP.GR._____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:______________ LBS.CU.FT.
(DRY RODDED)

SP.GR.: _____X 62.4 =________LBS.CU.FT.

TABLE 5.3.6:_____________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = _________ X ____________________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:________________ LBS. = _________________________FT³
SP.GR._____ X 62.4

CEMENT:__________________LBS. = _________________________FT³
3.15 X 62.4

WATER: ____________________GALS = _________________________FT³
7.5

AIR: ________________ X 27 = ______________________FT³

COARSE AGG: _________________LBS. = ______________________FT³
SP.GR.________ X 62.4

TOTAL: ___________________________FT³

27.00 CU.FT./CU.YD.
-

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

MIX DESIGN QUANTITIES:

FLY ASH ________________ LBS.
CEMENT ________________ LBS.
WATER ________________ GALS.
AIR ________________ %
COARSE AGG. ________________ LBS.
FINE AGG. _______________ LBS.

Extra Worksheet for Practice

ACI WORKSHEET

CLASS:_____________________MIX DESIGN

FINE AGG:____________________ COARSE AGG:______________________

FM:________________ NOM. MAX. SIZE:____________INCH

SP.GR._____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:_____________ LBS.CU.FT.
(DRY RODDED)

SP.GR.: _____X 62.4 =_______LBS.CU.FT.

TABLE 5.3.6:___________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = __________ X __________________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:______________ LBS. = ________________________FT³
SP.GR._____ X 62.4

CEMENT:__________________LBS. = ________________________FT³
3.15 X 62.4

WATER: ___________________GALS = ________________________FT³
7.5

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. = _____________________FT³
SP.GR.________ X 62.4

TOTAL: ________________________FT³

27.00 CU.FT./CU.YD.
-

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

MIX DESIGN QUANTITIES:

FLY ASH ________________ LBS.
CEMENT ________________ LBS.
WATER ________________ GALS.
AIR ________________ %
COARSE AGG. ________________ LBS.
FINE AGG. _______________ LBS.

Extra Worksheet for Practice

ACI WORKSHEET

CLASS:______________________MIX DESIGN

FINE AGG:________________________ COARSE AGG:________________________

FM:________________ NOM. MAX. SIZE:____________INCH

SP.GR._____ X 62.4 = _____LBS.CU.FT. UNIT WEIGHT:______________ LBS.CU.FT.
(DRY RODDED)

SP.GR.: _____X 62.4 =_______LBS.CU.FT.

TABLE 5.3.6:___________

QUANTITY OF COARSE AGGREGATE

__________ X 27 CU.FT. = ________ X __________________ = ___________LBS.
TABLE 5.3.6. DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH:______________ LBS. = ________________________FT³
SP.GR._____ X 62.4

CEMENT:________________LBS. = ________________________FT³
3.15 X 62.4

WATER: ___________________GALS = ________________________FT³
7.5

AIR: ________________ X 27 = _____________________FT³

COARSE AGG: _________________LBS. = ______________________FT³
SP.GR.________ X 62.4

TOTAL: __________________________FT³

27.00 CU.FT./CU.YD.
-

FINE AGG:__________CU.FT./CU.YD. X ___________ X 62.4 = _________LBS./CU.YDS.
↑(SP.GR.)

MIX DESIGN QUANTITIES:

FLY ASH ________________ LBS.
CEMENT ________________ LBS.
WATER ________________ GALS.
AIR ________________ %
COARSE AGG. ________________ LBS.
FINE AGG. _______________ LBS.

Section XI
ACI Mix Design Variations

5% ACI Variations

Sometimes we will need to adjust the proportion of water, fine aggregate, and/or coarse aggregate in a mix. The following criteria are recommended for adjusting mix designs:

Problem:

1. **A workable slump can not be obtained with the design water less the maximum allowable water according to specifications**.

Solution:

Add water as necessary, up to the maximum allowed and subtract an equal volume of fine aggregate.

Problem:

2. **A workable slump can not be obtained using the maximum allowable water.**

Solution:

Reduce the surface area of aggregate by reducing the quantity of fine aggregate by 5% of its weight and replace it with an equal volume of coarse aggregate.

Problem:

3. **If a mix is too harsh**, (has too much coarse aggregate).

Solution:

Add fine aggregate in the amount of 5% of its weight and reduce the coarse aggregate by an equal volume. Always compute 5% with the sand first.

Remember...in the above adjustments, these are volumetric changes!

In order to maintain a yield of exactly 27.0 ft^3 when adding or subtracting a quantity of one of the components of a mix, it is necessary to make up the difference with an equal volume of another component. Only if the coarse aggregate and the fine aggregate have the same specific gravity will there be a pound for pound exchange.

To use the ACI 5% variation method of adjusting mixes, follow the steps below:

1. Determine the component to be reduced or added.

2. If the component is coarse or fine aggregate, compute the absolute volume of the component to be added or subtracted by dividing its weight by the product of its specific gravity times 62.4 lbs./ft^3. If the component to be changed is water, then compute the absolute volume by dividing the number of gallons by 7.5 gals/ft^3.

3. An equal volume of another component must be added or subtracted to offset the changed weight, (changed volume), of the other component. If the secondary component is coarse or fine aggregate, multiply the product of its specific gravity and 62.4 lbs./ft^3 by the absolute volume that was calculated in step 2. This will give you the weight of the part of the secondary aggregate component to be added or subtracted. If the secondary component is water, multiply 7.5 gals/ft^3 by the absolute volume that was calculated in step 2. This will give you the number of gallons to be added or subtracted.

4. Compute the new design quantities by adding or subtracting from the original design quantities.

Example # 1

ACI Variation Problem

This mix gives a 2 ½ inch slump. Increase the water by 1.5 gals./yd. and adjust the mix accordingly.

One Cubic Yard Class "B" non-vibrated mix

Cement	545	lbs.	NCDOT Pit 8 Fine Agg. Sp.Gr.:	2.67
Fine Aggregate	1307	lbs.	FM:	2.50
Coarse Aggregate	1466	lbs.	NCDOT Quarry 16 Coarse Agg. Sp.Gr.:	2.35
Water	32.1	gals.	Dry Rodded Unit Weight:	80.4
Air	6	%		

As per the problem, we must increase the water content by 1.5 gallons, therefore: we must reduce the fine aggregate by an equal volume.

➔ Increase the water by 1.5 gallons.

➔ Absolute Volume of the Fine Aggregate $= \dfrac{1.5 \text{ gals}}{7.5 \text{ gals. /ft}^3} = 0.20 \text{ ft}^3$

➔ Weight of Fine Agg. to be removed $= 0.20 \text{ ft}^3 \text{ X } 2.67 \text{ X } 62.4 = 33$ lbs. of Sand

(note: 62.4 lbs./ ft^3)

➔ Water: 32.1 gals. + 1.5 gals. = 33.6 gals. of water

Fine Aggregate: 1307 lbs. - 33 lbs. = 1274 lbs. of fine aggregate

The new Mix Design is:		
Cement	545	LBS.
Fine Agg.	1274	LBS.
Coarse Agg.	1466	LBS.
Water	33.6	GALS.
Air	6	%

Example # 2

ACI Variation Problem

Redesign the following mix:

One Cubic Yard		Class "A" vibrated mix		
Cement	564	lbs.	NCDOT Pit 9 Fine Agg. Sp.Gr.:	2.63
Fine Aggregate	1154	lbs.	FM:	2.60
Coarse Aggregate	1872	lbs.	NCDOT Quarry 17 #67 Coarse Agg. Sp.Gr.:	2.81
Water	36.0	gals.	Dry Rodded Unit Weight:	100.2
Air	6	%		

Because this mix in designed with the maximum allowable water, we cannot add water to increase the slump, therefore; we must decrease the surface area of the aggregates. This is done by reducing the fine aggregate by 5% and then replacing it with an equal volume of coarse aggregate.

➔ 0.05 X 1154 lbs. of fine aggregate = 58 lbs. of sand

➔ Absolute Volume of the fine agg. removed = $\dfrac{58 \text{ lbs.}}{2.63 \times 62.4 \text{ lbs./ft}^3} = 0.35 \text{ ft}^3$

➔ Weight of coarse agg. to be added = $0.35 \text{ ft}^3 \times 2.81 \times 62.4$ = 61 lbs. of stone

(note: 62.4 lbs./ ft^3)

➔ Fine Aggregate: 1154 lbs. - 58 lbs. = 1096 lbs. of sand

Coarse Aggregate: 1872 lbs. + 61 lbs. = 1933 lbs. of stone

The new Mix Design is:		
Cement	564	LBS.
Fine Agg.	1096	LBS.
Coarse Agg.	1933	LBS.
Water	36.0	GALS.
Air	6	%

Example #3

Adjusting Cement Content of Mixes

A procedure similar to the ACI variation can be used to change the cement content of a mix. This will enable you to go from a Class A mix design to a Class AA and back again by adjusting the amount of cement and fine aggregate. This eliminates repeating the mix design method for each class of concrete.

➔ Figure the difference in cement content in pounds.

➔ Calculate the absolute volume of this difference by dividing the weight difference by the unit weight. (e.q.: 3.15 X 62.4 lbs./ft³)

➔ Add or subtract an equal volume of fine aggregate by multiplying the volume computed above by the unit weight of the fine aggregate, (Sp.Gr. X 62.4 lbs./ft³).

One Cubic Yard			Class A Mix Design			
Cement	564	lbs.				
Fine Aggregate	1257	lbs.	NCDOT Pit 6	Sp.Gr.: 2.66	FM:	2.50
Coarse Aggregate	1853	lbs.	NCDOT Quarry 14	Stone #67	Sp.Gr.:	2.87
Water	34.0	gals.			Dry Rodded Unit Weight:	98.0
Air	6	%				

Change this to a Class AA concrete mix with 715 lbs. of cement.

➔ The difference in the cement content = 715 - 564 = 151 lbs.

➔ Absolute Volume of the cement added $= \dfrac{151}{3.15 \text{ X } 62.4 \text{ lbs./ft}^3} = 0.77 \text{ ft}^3$

➔ Weight of sand to be removed = 0.77 ft³ X 2.66 X 62.4 = 128 lbs. of sand

➔ Fine Aggregate: 1257 lbs. - 128 lbs. = 1129 lbs. of sand

The new Mix Design is:		
Cement	715	LBS.
Fine Agg.	1129	LBS.
Coarse Agg.	1853	LBS.
Water	34.0	GALS.
Air	6	%

Example #4

ACI Variation Problem

This mix is too harsh. Adjust the mix below by the 5% variation method.

Redesign the following:

<u>One Cubic Yard   Class AA Vibrated Mix Design</u>

Cement	715	lbs.		
Fine Aggregate	890	lbs.	NCDOT Pit 7	Sp.Gr.: <u>2.61</u> FM: <u>2.69</u>
Coarse Aggregate	1996	lbs.	NCDOT Quarry 15	Sp.Gr.: <u>2.79</u>
Water	36.5	gals.		Dry Rodded Unit Weight: <u>97.1</u>
Air	6	%		

Since the mix is too harsh; sand is added and the stone is then reduced by an equal volume.

➔ 0.05 X 890 lbs. of fine aggregate = 45 lbs. of sand

➔ Absolute Volume of the fine agg. added $= \dfrac{45}{2.61 \text{ X } 62.4 \text{ lbs./ft}^3} = 0.28 \text{ ft}^3$

➔ Weight of coarse agg. to be removed = 0.28 ft³ X 2.79 X 62.4 = 49 lbs. of stone

➔ Fine Aggregate: 890 lbs. + 45 lbs. = 935 lbs. of fine aggregate
Coarse Aggregate: 1996 lbs. – 49 lbs. = 1947 lbs. of coarse aggregate

The new Mix Design is:		
Cement	715	LBS.
Fine Agg.	935	LBS.
Coarse Agg.	1947	LBS.
Water	36.5	GALS.
Air	6	%

Study Problems ACI Mix Design Variations

Variation Problem

Problem # 1

Redesign the following mix:

One Cubic Yard			Class A Vib mix AE			
Cement	564	lbs.	NCDOT Quarry 5	Fine Agg.	Sp.Gr.:	2.73
Fine Aggregate	1276	lbs.			FM:	2.46
Coarse Aggregate	1826	lbs.	NCDOT Quarry 3	Coarse Agg.	Sp.Gr.:	2.79
Water	34.0	gals.		Dry Rodded Unit Weight:		96.6
Air	6	%				

This mix did not give the desired slump. Increase the water to the maximum permitted and adjust the mix accordingly.

The new Mix Design is:		
Cement		LBS.
Fine Agg.		LBS.
Coarse Agg.		LBS.
Water		GALS.
Air		%

ACI Variation Problem

Problem # 2

Redesign the following mix:

One Cubic Yard			Class A Vib mix AE			
Cement	564	lbs.	NCDOT Pit 10	Fine Agg.	Sp.Gr.:	2.63
Fine Aggregate	1210	lbs.			FM:	2.45
Coarse Aggregate	1916	lbs.	NCDOT Quarry 6	Coarse Agg.	Sp.Gr.:	2.97
Water	36.0	gals.		Dry Rodded Unit Weight:		101.4
Air	6	%				

This mix did not give the desired slump using the maximum water permitted. Adjust the mix using the 5% variation method.

The new Mix Design is:		
Cement		LBS.
Fine Agg.		LBS.
Coarse Agg.		LBS.
Water		GALS.
Air		%

ACI Variation Problem

Problem # 3

Redesign the following mix:

One Cubic Yard			Class B non-Vib mix			
Cement	545	lbs.	NCDOT Pit 10	Fine Agg.	Sp.Gr.:	2.63
Fine Aggregate	1329	lbs.			FM:	2.45
Coarse Aggregate	1688	lbs.	NCDOT Quarry 18	Coarse Agg.	Sp.Gr.:	2.75
Water	35.0	gals.		Dry Rodded Unit Weight:		89.3
Air	6	%				

Change this Class B mix so that it contains 7 bags per yard of cement. Adjust the other components as necessary.

The new Mix Design is:		
Cement		LBS.
Fine Agg.		LBS.
Coarse Agg.		LBS.
Water		GALS.
Air		%

ACI Variation Problem

Problem # 4

Redesign the following mix:

<u>One Cubic Yard</u>		<u>Class A vibrated mix</u>				
Cement	564	lbs.	NCDOT Quarry 5	Fine Agg.	Sp.Gr.:	2.63
Fine Aggregate	1105	lbs.			FM:	2.50
Coarse Aggregate	1790	lbs.	NCDOT Quarry 19	Coarse Agg.	Sp.Gr.:	2.60
Water	35.8	gals.		Dry Rodded Unit Weight:		94.7
Air	6	%				

Change this Class A mix to a AA mix with 7.6 bags of cement per yard. Adjust the other components as necessary.

The new Mix Design is:		
Cement		LBS.
Fine Agg.		LBS.
Coarse Agg.		LBS.
Water		GALS.
Air		%

ACI Variation Problem

Problem # 5

Redesign the following mix:

One Cubic Yard			Class AA vibrated mix			
Cement	714	lbs.	NCDOT Pit 11	Fine Agg.	Sp.Gr.:	2.63
Fine Aggregate	975	lbs.			FM:	2.30
Coarse Aggregate	2037	lbs.	NCDOT Quarry 20	Coarse Agg.	Sp.Gr.:	2.93
Water	35.0	gals.		Dry Rodded Unit Weight:		104.8
Air	6	%				

The above mix was found to be too harsh. Adjust the mix by using the 5% ACI variation method.

The new Mix Design is:		
Cement		LBS.
Fine Agg.		LBS.
Coarse Agg.		LBS.
Water		GALS.
Air		%

ACI Variation Problem

Problem # 6

Redesign the following mix:

<u>One Cubic Yard Class AA Vib mix AE</u>

Cement	639	lbs.	NCDOT Pit 5	Fine Agg.	Sp.Gr.:	2.62
Fine Aggregate	1148	lbs.			FM:	2.71
Coarse Aggregate	1779	lbs.	NCDOT Quarry 2	Coarse Agg.	Sp.Gr.:	2.65
Water	32.6	gals.		Dry Rodded Unit Weight:		96.9
Air	6	%				

The above Class AA mix did not give the contractor the desired slump using the maximum allowable water. Increase the water by 2 gallons per yard and increase the cement enough to maintain the same W/C ratio. Adjust the other components as necessary.

The new Mix Design is:		
Cement		LBS.
Fine Agg.		LBS.
Coarse Agg.		LBS.
Water		GALS.
Air		%

Section XII
Quality Concrete and Field Inspection/Control

Concrete placed on a NCDOT project must be properly sampled and tested. To ensure uniformity in testing, NCDOT Certified Concrete Field Testing technicians are expected to adhere to proper procedures outlined by:

- Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete ASTM C 1064
- Standard Practice for Sampling Freshly Mixed Concrete ASTM C 172
- Standard Test Method for Slump of Hydraulic Cement Concrete ASTM C 143
- Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete ASTM C 138
- Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method ASTM C 231
- Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method ASTM C 173
- Standard Practice for making and Curing Concrete Test Specimens in the Field ASTM C 31

The Chace Indicator is used by the NCDOT as a quick check to verify air content is within specification. Only calibrated Chace Indicators are allowed for use on NCDOT projects to ensure proper correction is made for a closer correlation with the standard air meter.

Standard Curing of Specimens

Standard curing is used for:

Acceptance Testing for Specified Strength

Checking adequacy of mixture proportions for strength

Quality Control

Initial curing temperature is 60 to 80°F for the first 20-24 hours. Final curing temperature is 73.5 ± 3.5°F. Final curing must begin within 72 hours according to NCDOT specifications. The difference of time frame for final curing in the NCDOT Specification and the ASTM standard is to allow NCDOT time to get the specimens to a regional testing lab where the final curing process will be initiated.

Temperature Effects on Setting

On a 70°F day, the first phase of the hydration process can occur within one or more hours. Each 10°F change in temperature will increase or decrease set time by 1/3rd of normal value. For example, a 3.5 hour set at 70°F will become 2 hours and 20 minutes at 80°F.

Plastic Shrinkage Cracks

Plastic shrinkage cracks appear when evaporation exceeds the rate at which bleed water rises to surface of the concrete. The cracking occurs on the surface of the fresh concrete during setting. When the rate of evaporation is around 0.2 pounds per square foot per hour, precautionary measures are necessary. Precautions include:

- Dampen subgrade and forms
- Dampen aggregates
- Erect windbreaks to reduce wind velocity over concrete surface
- Cool mixing water
- Protect concrete with wet coverings during any delay between placing and finishing
- Reduce time between placing and start of curing
- Protect concrete during the first few hours after placement and minimize evaporation
- Apply moisture to the surface using a fog sprayer nozzle

Field Inspection and Control of Portland Cement Concrete

In order to assure quality concrete, field control must begin long before the concrete arrives at the job site and continued long after it is placed. Concrete can be designed and produced to give the desired strength and durability under laboratory conditions but under field conditions it may fail. This is due to the fact that there are many conditions that may adversely affect concrete in the field. The required strength and durability should never be compromised, so it is imperative that field conditions be monitored and controlled to maintain the desired product specifications.

In order to control the field conditions we must first understand the factors which affect the quality of concrete in the field. The primary interfering factors are as follows:

1. Adequate support of foundations and forms.
2. Adequate field engineering to insure conformance with plans and design.
3. Transportation and handling of the concrete.
4. Placement and finishing of the concrete.
5. Weather conditions.
6. Methods of curing.

Adequate Support of Foundations and Forms

The famous quote, “A structure is no stronger than its weakest foundation,” may be an old adage, but in concrete construction it is a fact. Any concrete structure or concrete masonry unit must rest upon a foundation of uniform bearing which is firm enough to support the entire weight load.

It stands to reason, that a drop inlet or a paved ditch would not require as strong of a foundation as a footing for a bridge pier. This is why we may place a ditch on uniformly compacted fill but yet require a rock foundation for a pier footing.

Footings for large structures, such as bridge abutments and piers, are usually designed according to the foundation material on which they will be placed. If the material in the foundation is very poor for a great depth, then the footing may be designed to rest on a piling. If the foundation material is of a medium bearing quality, such as light clay, a spread footing may be used to distribute the load over a larger area. If the foundation material is of good, sound rock, of sufficient depth below the planned footing grade, a smaller footing may be used, in such that the rock will help support the load. Specifications require that “footings shall rest on firm material, solid rock, or a material of supporting capacity required by the design, whichever is called for on the plans.” To insure that the foundation is of the required supporting capacity, the contractor is require to explore the foundation to a depth of at least five feet below the bottom of the footing. This is done by use of rod soundings, drilling, or any other means that can assure the adequacy of the subfoundation. This must be done under the presence of the Resident Engineer; Assistant Resident Engineer, Project Engineer or other qualified personnel trained to identify adequate foundations for the NC DOT.

In other concrete work such as pavements, curb and gutter, paved ditches, drop inlets, et al., the foundation or subgrade should be prepared in accordance with the applicable specification and should always be of uniform density or bearing. For example, a box culvert footing should not rest partially on solid rock and partially on an earthen foundation. If the earth foundation settled it could cause the footing to crack. All wet and unsuitable material should be removed and replaced.

Before placing concrete on any foundation or subgrade, the subgrade should be moist to prevent rapid extraction of the moisture from the concrete. This is especially important in hot weather.

Adequate field engineering to insure conformance with plans and design

Concrete structures and concrete masonry units are designed to serve specific purposes to perform a given function. The size, shape, and strength of the concrete unit all have a purpose; either individually or separately. This is why it is important to adhere to the original lines, dimensions, and grades that are shown in the plans.

Many specific shapes are made with the use of concrete forms. The fresh concrete is poured or placed into the form and allowed to remain there until it has gained sufficient strength to support itself. Fresh concrete is a semi-liquid mass that which will exert great outward pressure on the form. Concrete that is being placed in a form may be dropped at a height of no more then five feet but this dropping can create additional pressure on the form. For this reason, concrete forms must be constructed with enough rigidity to prevent distortion, as the concrete is being placed and drying. All form braces and connections should be thoroughly checked to insure that they are tight enough to prevent the forms from giving or buckling. The material from which the forms are made, must produce the required specifications. This material may be plywood, metal, or another smooth faced composition material. The form should be constructed to provide minimum of joints and leakage, and should be framed and braced so as to be unyielding. This will help retain the proper dimensions and contours that are required by the plans.

Reinforcing steel is used in concrete to give added strength to the concrete structure. The reinforcing is so proportioned and positioned in the concrete as to maximize the load carrying abilities of both. The concrete and the rebar act as one to support the weight. Reinforcing steel is used for compressive and tensile strength. Compressive strength may be defined as the resistance to compression or “mashing together.” Tensile strength can be defined as the resistance to tension or the “pulling apart.” A good example is a concrete beam that has been loaded in the center. As the load is applied the beam, it will tend to bend in the center – this is because it is under compression – it is being mashed in the center. The ends on the beam will be in tension, as they tend to pull apart.

When concrete is designed using reinforcing steel, the placement of the steel is very important. It must be placed so that there will be a maximum resistance to tension and compression. For this reason, we must be certain that the reinforcing steel is placed according to the design and within the specified tolerance. The strength of the concrete depends upon the ability of the reinforcing steel and the concrete to act together as one. For this to happen, we must also have an extremely strong bond between the rebar and the concrete. The steel must be free from dirt, paint, oil and any other foreign substance. Rust or mill scale is not considered detrimental to the concrete unless the scale has pitted the steel to the extent that it will reduce its cross-sectional area. If you rub the steel hard between your fingers and the rust rubs off but does not flake off, you can be fairly certain that the area has not been reduced sufficiently enough to reduce the strength. If the rusting process has left a thick, dark colored scale that can be flaked off, the steel should be retested for strength. If it still complies with the specification, then it may be used provided that it is cleaned of all loose, flaky, scaling rust first.

Reinforcing steel should be supported by the use of chairs, or concrete blocks, for the type and size required by the applicable specifications. The use of red bricks, rocks, wood chips and such, is not permitted.

Transportation and handling of the concrete

Each step in the handling, transportation, and placing of concrete should be carefully monitored to maintain uniformity within the batch, (and from batch to batch). This is to insure that the completed structure has the same high quality throughout.

It is essential to avoid the separation of the coarse aggregate from the mortar, or of the water from the other ingredients. Segregation at the point of discharge from the mixer can be corrected by providing a downpipe at the end of the chute. This way the concrete will drop vertically into the center of the receiving bucket, hopper, or car. Similar provisions should be made at the end of all the other chutes and conveyors. All mixers should be fit with a vertical drop at the discharge gate. When the discharge of concrete takes place on a angle, the larger aggregate is thrown to the far side of the container, the mortar to the opposite side. This can result in such severe segregation that it can not be corrected despite further handling.

Concrete is handled and transported by many methods. These methods include chutes, push buggies; operated by runways, buckets; handled by cranes or cableways, small rail cars, trucks, pipelines through which it is pumped, and last but not least, the trusty wheelbarrow. The general idea is always to have your truck as close to the form as possible. Many times this can not happen and we need to use one of these alternate methods for transporting concrete. The method used in the handling and transporting of concrete and the equipment it comes in contact with should not affect the consistency and/or the quality at any time. It should be the placing conditions that affect the concrete the most, at this point. If the mix is stiff, then the materials used to handle and transport the concrete must be able to accommodate such a mix.

When chutes are used to transport concrete from trucks to the forms, they should be metal or metal lined. It is recommended that the bottom of the chute be rounded and of ample size to guard against over-flowing. The chute should be of such design that the concrete will travel fast enough to keep the chute clean but not so fast that the materials will segregate. A slope that is no flatter than 3:1 and no steeper than 2:1 is currently recommended. If the mix is stiffer, then a steeper incline is acceptable. The main criteria of these type of slopes and specifications are to maintain the integrity of the concrete as it discharges from the chute. A downpipe at the end of the chute will help the concrete drop vertically.

Pushcarts or buggies are sometimes used to transport concrete from the truck to the forms. Their normal capacity is about 6 to 11 cu.ft. with some having a pivoted body that will allow for a quick and rapid discharge. Smooth and fairly rigid runways should be provided for the carts as to minimize segregation. A bumpy path will cause more segregation then a flat one.

Buckets, which can be transported by cranes, derricks, or cableways, are used to move concrete from trucks to more inaccessible forms. Inaccessible forms would be those on a bridge deck, pier, column, or really high wall. Buckets come in a variety of shapes and sizes designed to carry from 1 to 8 cu.yds. Although some larger buckets have rectangular cross sections, most are cylindrical. The bottom of the bucket is actually a gate that can be opened to release the concrete. For massive work, the buckets have straight sides and gates that can open to the full area of the bottom. Under most circumstances, the buckets have a lower half of sloping sides and a smaller gate to allow better control of the release of material. Some of the buckets have gates that can release only a part of the concrete allowing for tighter control in small areas. They may be operated mechanically or manually. Mechanical operation can minimize the jerking of the bucket, which is especially important on a cable operation.

No matter what the method of concrete transportation and handling is used, it is very important to insure that segregation is kept to a minimum. The vehicle used to transport the concrete must always be kept clean. Chutes, buggies, buckets and any tools should be cleaned after each use and oiled with a light film to prevent rusting.

Placing and Finishing Concrete

Placing concrete in its final position is the operation that requires the most scrutiny by field personnel. Often the field inspector will spend a considerable amount of time checking the concrete at the point of discharge from the truck. He must run tests to insure that the mix meets requirements for slump, air, strength, etc., and watch that the concrete is being placed properly. If the concrete becomes segregated then much of its original design may be lost. This is why inspecting the placement procedures is so important.

The first thing that the inspector will check is to see that the subgrade has been properly moistened and that the forms have either been oiled of wet down. The wetting of the forms prevents the form material from absorbing water out of the concrete mix. If a form begins to dry out in the sun or wind, it should be re-wet as often as necessary. Forms should be kept clean, tight, and adequately braced. Any nails, sawdust, or other debris should be removed from within the forms. Be certain that the rebar you are using is clean, oil free, scale free and free of hardened concrete so that the concrete will better adhere to the steel.

When fresh concrete is placed on hardened concrete, it is a good idea to secure a good bond and a watertight joint between the two. The hardened concrete should be fairly level, reasonably rough, clean, moist, and have some aggregate particles exposed. Any laitance, or weak layers, of mortar should be removed from the top of the hardened concrete. (If there is a significant amount of such laitance, this is a good indication that segregation and bleeding have occurred. This can be prevented by using a stiffer mix in the upper part of the lift.) The hardened concrete should be scrubbed with a wire brush and thoroughly wet down just prior to pouring the fresh concrete.

When placing concrete in forms, the concrete should be placed as near to its final position as possible. It should not be placed in one location and then be allowed to run or to be dragged or worked in to position. Excessive working and handling of the concrete leads to increased segregation because the mortar tends to flow ahead
of the coarser material. Sloping plains can result between successive layers of concrete if too much dragging of the concrete has occurred. Generally speaking, the concrete should be placed in horizontal layers of uniform thickness. Each layer should be a maximum of 6 to 12 inches thick.

> Note: This segregation true with all concrete except the new "self compacting" concretes which allow the aggregate to "float" in the mortar and reduce segregation. These concretes are attained by the use of a special admixture and are currently being used on certain DOT projects. They are actually measured by their spread instead of their slump.

On some work, such as sloping walls, concrete is moved laterally within the forms over too long a distance. In these cases the concrete is dumped into the tallest section of the wall and forced out the end. Being pushed ahead of the concrete is any excess water and moisture that was inside the form, thus producing a poor quality concrete in this exposed location and along the top surface of the wall. This is who many concrete joints are extremely poor. Laitance is formed along the top of each layer, particularly at the outer end. For this reason, it is suggested that the top form boards of the sloping face be omitted, so that the concrete can be placed directly in wall section. If necessary, the boards forming the sloping surface may be placed as the concreting process continues.

Concrete should not be allowed to drop more than five feet, except in the cases of a thin wall sections, such as box culvert walls or drop inlet walls. Dropping concrete freely for any great distances will cause segregation as previously discussed.

When concrete can not be successfully moved near its final resting-place by the use of trucks, buggies, buckets, or chutes, the concrete can be placed by means of a tremie or drop chute. The tremie consists of short sections of round or rectangular pipe of approximately 4 to 6 inches in diameter coupled to a hopper at the top. Tremies should be spaced so that the concrete can be deposited in its final position. The concrete is dumped into the hopper with buggies or buckets in such a way that the pipe is kept full in order to prevent the concrete from separating as it slides through the chute. As the structure is filled, the pipe sections are removed; however, the end of the pipe should be kept as near to the concrete's final place as possible and never more then five feet off the concrete's surface.

In slab construction, placing of the concrete should be such that each batch will be dumped against the previously placed concrete, not away from it. The concrete should not be placed in separate piles and then worked together. If stone pockets occur, some of the excess large particles should be removed and distributed to the area where there is sufficient mortar to surround them. The order in placing concrete is also of prime importance. In walls, the first batches should be placed at either end of the section and progress inwards to the center. The procedure should be repeated for each layer. This method can also be followed in placing concrete in beams and girders. In large, open areas, the first batches should be placed around the perimeter. In all cases, the procedure should be such that water will not collect around the edges and corners of forms and along form faces.

During and immediately following the placement of concrete into forms, care must be taken to insure that the concrete is thoroughly consolidated. This is important to maintain the quality and proper density of the final mixture and structure and can easily be achieved by spading or vibrating. Specification requires that this consolidation be accomplished by mechanical vibrating internal to the concrete, unless the engineer gives authorization for other methods. Vibrators have proven to be practical and economical in regard to very large quantities of concrete, including dams and other structures of that magnitude. Vibrators also yield a better quality of concrete with regard to these large structures.

When portland cement concrete was first introduced to this country, it was placed in thin layers using a stiff mixture. Lockwalls and other massive concrete structures that were built in this manner show very little deterioration or faults in construction despite being in service for 70 or 80 years. With the advent of reinforced concrete, more fluid mixtures became necessary and thick heavy structure could now be made thinner and still have equal strength. Unfortunately, until this method was fully understood, as it is today, there was a period in concrete history where overly wet mixtures were too often used with rebar. These structures show signs of segregation, resulting in weaker, less durable concrete. As time went on, the importance of the quality of the ingredients and uniformity of the concrete are being better appreciated. A demand for economical methods of using stiffer mixes with lower water content became a goal. The easiest way to ascertain such a goal was to use a stiff mix and a high-frequency vibrator.

Laboratory and field testing has allowed engineers to research data and select the type of placement and method of consolidation best suited for a project. Modern, high-frequency vibrators make it possible to place mixtures that are impractical to place by hand under many circumstances. For example, concrete of a stiff consistency, with a 1 - 1 ½ slump, may be easily placed in forms with closely spaced reinforcing steel. If the only method of consolidation that was available were spading, then the slump would have to be at least 5 or 6 inches.

It is a well-established principle of good concrete production that, for given materials and conditions of curing, the quality of hardened concrete is determined by the amount of water used for its mixing. The less water used the better the quality of concrete, provided that it is compacted correctly. Smaller amounts of mixing water require either a richer or stiffer mix. It is vibration that allows us to use the stiffer mix. Concrete of better quality can be made with a given amount of cement because less mixing water can be used. For a given strength of concrete a stiffer mix can be more economical. Vibration permits improvements in the quality of the concrete at affordable costs.

The action of vibration is to set the particles in the fresh concrete into motion so that they reduce the amount of friction between them, thus giving the mixture the qualities of a thick mobile fluid that can easily settle into place. The vibratory action not only permits a stiffer mixture, but also a mixture that contains less fine material then usually required to give the cohesive qualities necessary to prevent segregation in hand-placed mixtures. This translates into the vibrator allowing for a smaller quantity of fine aggregate and a larger quantity of coarse aggregate to be used. This decreases the surface area that needs to be coated with paste which in turn means that less water is needed for a given consistency. So it can be said that quality and economy are improved by harsher as well as stiffer mixtures.

When using mechanical vibrators to consolidate concrete, the concrete should be placed as near to its final location and depth in the forms. Vibrators should not be used to move concrete around in the forms, as this can cause segregation. The process of vibrating the concrete should be done as the work progresses but never at the front edge to make the concrete flow farther. The vibrator should be inserted vertically into the fresh concrete slowly and removed just as slowly. You may notice ripples encircling the vibrator as the concrete is consolidated. These ripples, whether visible or not, will expend about 12” to 24” from the vibrator. After the vibrator is withdrawn, it should be inserted approximately 12” to 24” away from the last insertion point. Never leave the tip of the vibrator in the concrete too long, as this could cause a localized area of mortar only. For most concrete, the desired consolidation time is about 5 to 15 seconds of vibration. The time needed for successful vibration will vary with the temperature, the aggregate size and the consistency of the plastic concrete. It must be noted that even with only fifteen seconds of vibration, there is a considerable reduction in the air content of the concrete. Optimum vibration should be done to the minimum number of seconds required to produce the desired amount of consolidation.

At no time should the vibrator be placed against any forms or rebar. Doing so will cause a build up of grout along the form walls or around the rebar. Once concrete has attained its initial set do not use the vibrator. This will cause the bonds to break within the freshly hardened concrete. When there are areas that cannot be reached by the vibrator head, other means such as spading, maybe necessary to insure thorough consolidation.

The Curing of Concrete and the Weather

The properties of concrete, such as resistance to freezing and thawing, strength, water-tightness, wear resistance, and volume stability, improve with age as long as the conditions are favorable for continued hydration. The improvement is rapid at early ages and continues more slowly for an indefinite period. The two main conditions for such improvement are:

1. the presence of moisture
2. a favorable temperature.

Excessive evaporation of water from newly placed concrete can significantly retard the cement hydration process at an early age. Loss of water also causes concrete to shrink, thus creating tensile stresses on the surface of the drying concrete. If these stresses develop before the concrete has attained adequate strength, surface cracking may result.

Hydration proceeds at a much slower rate when the concrete temperature is low. This means that there is very little chemical action between the cement and the water when the temperature is near to below freezing. Concrete should be protected so that moisture is not lost during the early stages of the hardening period and that the concrete temperature is kept favorable for good hydration.

METHODS OF CURING:

Concrete can be kept moist and in some cases at a favorable temperature, by the following curing methods:

1. Methods that supply additional moisture to the surface of the concrete during the early hardening period. These methods are most beneficial in hot weather. Examples would be ponding, sprinkling, and wet covering.
2. Methods that prevent the loss of moisture from the concrete by sealing the surface. This may be done by means of waterproof paper, plastic sheets, liquid membrane sealing compounds, and forms that are left in place.

<u>Additional Moisture Methods</u>:

<u>Ponding</u>

On flat surface, such as pavements, sidewalks, and floors, concrete can be cured by ponding. Earth or sand dikes around the perimeter of the concrete surface retain a pond of water within the enclosed area. This is an efficient method for preventing loss of moisture from the concrete as well as for maintaining uniform temperature. Ponding generally requires considerable less labor and supervision but can be impractical on very large jobs. Ponding is extremely undesirable is the fresh concrete will be exposed to freezing.

Sprinkling

As soon as the concrete has sufficiently hardened to prevent surface damage, continuous sprinkling with water is an excellent method of curing. The sprinkling should be done at proper intervals to prevent the concrete from drying out between applications of water. A fine spray of water, applied continuously through a system of nozzles and sprinklers, provides a constant supply of moisture; thus giving the concrete the constant ability for continued hydration. The continuous sprinkling eliminates the possibility of "crazing" or cracking caused by the alternate cycles of wetting and drying. This method of curing can be costly, as it requires an adequate supply of water and careful supervision.

Wet Covering

Wet coverings, such as burlap, cotton mats, and other moisture retaining fabrics, are very commonly used for concrete curing. These fabrics should be placed as soon as the concrete has hardened sufficiently to prevent surface damage. Care should be taken so that the entire surface is covered. The coverings should also be kept continuously moist so the film of water always remains upon the concrete surface during the curing period. With new research, there are now fabrics, such as treated burlap, that have the ability to reflect light and be resistant to rot and fire.

Moisture Retaining Methods:

Waterproof Paper

Waterproof curing paper is an efficient way to cure horizontal surfaces and structural concrete of relatively simple shapes. One of the important advantages of this method is that no additional water is required. Curing paper assures suitable hydration of cement by preventing the loss of moisture from the concrete. It too, should be placed as soon as the hardened concrete is resistant to surface damage. The widest paper that is practical to use is usually the optimum selection, but caution should be taken to carefully follow the engineering specifications. Edges of adjacent sheet should be over lapped several inches and tightly sealed with sand, wooden planks, pressure sensitive tape, masking tape, or glue.

Curing paper provides some protection to the concrete against damage from subsequent construction activity as well as protection from direct sun. It should be light in color and nonstaining to the concrete. Paper with a white upper surface is preferable during hot weather.

Plastic Sheets
White polyethylene sheeting is often used to cure concrete. It is a lightweight, effective barrier and easily applied to both simple and complex shapes. White polyethylene sheeting is the only sheeting that is approved by the North Carolina Department of Highways.

Curing Compounds
Liquid membrane curing compounds retard or prevent the evaporation of moisture from the concrete. They are suitable for curing fresh concrete, as well as, curing concrete after form removal and after initial moist curing is completed.

The North Carolina Department of Transportaion recognizes two types of curing compound; clear and white pigmented. Clear compounds must contain a fugitive dye, which fades out after application. This is to insure complete coverage of the concrete surface. During hot, sunny days, white pigmented compounds are most effective, since they reflect the rays of the sun; thereby reducing the temperature of the concrete. White pigmented curing compound shall be use on bridge superstructures, culverts, and concrete pavements. Clear type curing compound should be used on substructures and retaining walls.

All curing compounds should be thoroughly mixed before application. Curing compounds are applied by hand operated or power-driven spray equipment immediately after the disappearance of the water sheen and the final finishing of the concrete. The power-driven method is preferred and the concrete surface should be moist when it is applied for maximum effectiveness. Normally, only one smooth, even cost is applied, but two coats may be necessary to ensure complete coverage. A second coat, when used, should be applied at right angles to the first. If the compound is applied in side to side sweeping motions on the first coat, then on the second coat, it must be applied up and down.

Curing compounds can prevent a bond from forming between hardened and fresh concrete, therefore it is not recommended if a bond is necessary. For example, a curing compound should not be applied to the base slab of a two-course floor since it may prevent the top layer from bonding to the lower. Similarly, some curing compounds affect the adhesion of resilient flooring materials to concrete floors. It is essential to understand fully, the correct usage and properties of a particular curing compound before use. Curing compound manufacturers should be consulted to best determine their product's abilities. Any curing compound that is to be used should be the specifications required.

Forms-in-Place Method
Formed concrete can be retained in the forms, for curing purposes, for a minimum of seven days after the concrete has been placed. If the contractor elects to leave forms in place for a part of the curing period and then use of one the other curing methods for the remainder of the

curing time, the concrete must be kept wet during the time that the curing methods are being changed.

Time, Temp, and Concrete Curing

The length of curing time that concrete should be protected against loss of moisture is dependent upon the type of cement, mix proportions, required strength, size and shape of the concrete mass, weather, and future exposure conditions.

As per the normal curing practices for concrete, the contractor shall advise the engineer in advance which method he proposes to use. Any of the fore-mentioned methods are acceptable, unless special provisions have been made. All material, equipment, and labor necessary to promptly apply the curing compound should be on site before any concrete is placed. All concrete shall be cured in accordance this procedure.

Curing temperature must be considered to be at atmospheric temperature. This temperature should be taken in the shade and away from artificial heat, except that it shall be the temperature surrounding the concrete where the concrete is protected, as per Article 420-7. A curing day will be considered as any consecutive 24-hour period beginning when the manipulation of each separate mass has been completed and during which the air temperature adjacent to the mass does not fall below 40°F. The curing period shall be a full 7 curing days after the concrete has been placed.

Wet steam curing periods are normally much shorter. Since all the desirable properties of concrete are improved by curing, the curing period should be as long as practical in all cases. During cold weather, additional heat is often required to maintain favorable curing temperature. Indirect heat can be supplied with a vented gas or oil-fired heaters, heating coils, or steam. In all cases, care should be taken to avoid loss of moisture from the concrete.

The rate of hydration is influenced by cement composition and fineness, because this can be such a large variable so is the curing period for cast-in-place concrete. It can be from three days to two weeks depending upon the temperature, cement type, mix proportions, etc. Longer curing periods are desirable for bridge decks and other slabs that are exposed to weather and chemical attack. The minimum curing period for adequate scale resistance from chemical de-icers, generally corresponds to the time required to develop the design strength of the concrete. A period of air drying which then enhances the resistance to scaling should then elapse before application of de-icing salts. This drying period should be at least one month. If the use of de-icers is required before the one month has expired, a surface treatment of linseed oil may be helpful in sealing the concrete surface against penetration by the water and de-icer mixtures. Boiled linseed oil may be used for faster drying. For required curing periods, please see the applicable section in the NC DOT Specification Book.

Prevention of Plastic Shrinkage Cracks

Cracking that can sometimes occur on the surface of fresh concrete as it is drying is called, "plastic shrinkage cracking." These cracks appear mostly on horizontal surfaces and may be practically eliminated if appropriate measures are taken to minimize the causes.

Plastic shrinkage cracking is usually associated with hot-weather concreting but it can occur at any time when the circumstances produce rapid evaporation of moisture from the concrete surface. Such cracks may appear when evaporation exceeds the rate at which bleed water rises to the surface of the concrete. The following conditions, either alone or combined, can increase evaporation of surface moisture and increase the possibility of plastic shrinkage cracking:

1. high concrete temperature
2. high air temperature
3. low humidity
4. high winds.

For example, when the concrete temperature is 70° F and the air temperature is 40° F, the air just above the surface of the concrete will have a rise in temperature, thereby reducing the relative humidity and causing shrinkage cracking.

There is no way to predict with any degree of certainty when plastic shrinkage cracking will occur. When the rate of evaporation is high, as in 0.2 lbs. per square foot per hour, precautionary measures are necessary. Cracking is possible anytime the rate of evaporation exceeds 0.1 lbs. per square foot per hour.

The simple precautions listed below can minimize the possibility of plastic shrinkage cracking. These items should be considered when planning a concrete construction job or when dealing with problems they occur after construction has started. Though not listed in order of importance, they are listed in the same order that they might appear in construction:

1. dampen the subgrade and forms
2. dampen the aggregates if they are dry and absorptive
3. erect windbreaks to reduce wind velocity over the concrete surface
4. lower the fresh concrete temperature during hot weather by using cool aggregates and cool mixing water
5. erect sunshades to reduce an increase in surface temperature
6. avoid over-heating the fresh concrete in cool weather
7. protect the concrete with temporary wet coverings during and appreciable delay between placing and finishing
8. reduce time between placing and start of curing by improving construction procedures

9. protect the concrete during the first few hours after placing and finishing to minimize evaporation – this is very important!
10. apply moisture to the surface using a fog sprayer nozzle until a suitable curing material such as curing compound, wet burlap or curing paper is applied

Hot Weather Concreting

The pouring and placing of concrete in hot weather requires good planning. High temperatures can accelerate the hardening of the concrete and more mixing water is usually needed to get the required consistency. If the water/cement ratio is not maintained by adding additional cement, the strength of the concrete will be reduced. Higher water contents also mean greater drying shrinkage possibilities. In very hot weather, fresh concrete may be plastic only for an hour or even less before it begins to harden. By exercising good control as outlined, concreting in hot weather can go quite smoothly.

When to take precautions:
The optimum temperature of fresh concrete is usually lower than can be obtained without artificial cooling in hot weather. A concrete temperature of about 50° to 60° F is desirable but at times this is impractical. For massive concrete structures, such as dams, the concrete temperature is often specified to be between 40° and 50° F. Many specifications require that concrete, as placed, should have a temperature of less than 80° to 85° F. The upper practical limit should be no more than 90° F. Satisfactory concrete has been placed at higher temperatures, but adjustments to the mixture for the temperature and careful adherence to hot weather placing and curing procedures are then mandatory. Even concrete that is in the acceptable temperature range can have problems when the weather is hot, dry, and with high winds. It is worse for large concrete slabs.

<u>Effects of High Concrete Temperatures</u>
The amount of mixing water required to make a cubic yard of concrete increases as the temperature of the fresh concrete increases. If the temperature of the fresh concrete is increased from 50° to 100° F, approximately 33 pounds of additional water are need per cubic yard of concrete in order to maintain the same 3" slump. Increasing water content without increasing the cement content results in a higher water/cement ratio which in turn will affect the strength and other properties of the concrete. The chart in Figure 10 shows the effect of high concrete temperatures on compressive strength. This chart shows that using identical concretes, with the same water/cement ratio, we will get concrete that is all about the same in it's early stages, but it is as it ages the difference become most apparent. The concrete gets weaker as it gets older instead of gaining strength; it looses it as the temperature of the fresh concrete increases. The temperatures of the concrete at the time of mixing, casting, and curing, were 73°, 90°, 105°, and 120°F. If the water content has been increased to maintain

the same slump, without changing the cement content, the reduction in strength would have been even greater then the results shown on the chart. In addition to reducing the strength and increasing the mixing water requirement, fresh concrete with a high temperature can have harmful effects. Setting is accelerated because high temperatures increase the rate of concrete hardening and shorten the length of time within which the concrete can be handled and finished. Concrete should remain plastic for a sufficiently long period of time so that each layer can be placed with out development of cold joints or discontinuities in the concrete. Cold joints occur when plastic concrete is placed against hardened concrete.

In hot weather, the tendency for cracks to form is increased both before and after hardening. Rapid evaporation of water from hot concrete may cause plastic shrinkage cracks before the surface has hardened. Cracks may also develop in hardened concrete because of increased shrinkage due to higher water requirement or volume changes due to cooling from initial high temperatures.

Due to the detrimental effects of high concrete temperatures, operation in hot weather should be directed toward keeping the concrete as cool as practical.

<u>Cooling Concrete Material</u>
The most practical method of maintaining low concrete temperatures is to control the temperature of the ingredients going into the mixture. One or more of the ingredients may be cooled before mixing. In hot weather, it is important to keep both water and aggregate as cool as possible.

Each material added to a concrete mixture is dependent upon the other material added to the mixture. The temperature, specific gravity and the quantities used are all variables. Concrete conforms to the following general formula:

$$\mathbf{T} = \frac{\mathbf{0.22\ (Ta\,Wa + Tc\,Wc) + Tf\,Wf + Tm\,Wm}}{\mathbf{0.22\ (Wa + Wc) + Wf + Wm}}$$

T = the temperature in degrees F of the fresh concrete.

Ta, Tc, Tf, and Tm = the temperature in degrees F of the aggregate, cement, free moisture, and added mixing water, respectively.

Wa,Wc,Wf, and Wm = the weight in pounds of the aggregate, cement, free moisture, and added mixing water, respectively.

Of the materials in concrete, the easiest and most cost effective to cool is water. It is extremely effective, pound for pound in cooling the concrete mixture. Mixing water from a cool source should be used during hot weather. Water that is store in tanks directly in the suns rays will not help in cooling the concrete. Tanks and pipelines carrying water should be buried, insulated, shaded, and/or painted white to maintain a cooler water temperature. Water may be cooled by refrigeration or by the addition of ice. Ice can also be used as part of the mixing water, provided that it is completely melted by the time the mixing is completed. When ice is used, the formula for the temperature of fresh concrete is modified as follows:

$$T = \frac{0.22 \quad (Ta\,Wa + Tc\,Wc) + Tf\,Wf + Tm\,Wm - 112Wi}{0.22 \quad (Wa + Wc) + Wf + Wm \quad Wi}$$

All symbols in the equation remain the same but now the weight in pounds of the ice, (Wi), must be taken into consideration.

Crushed or flaked ice is more effective then plain water in reducing the concrete temperature. As the cement and aggregates are cooled, the temperature of the cooling water/ice is raised. One pound of ice as it melts absorbs 144 BTU; however, 1 pound of water heated 1° F absorbs only 1 BTU. (1 lb. of ice heated from 32° to 73°F absorbs a total of 185 BTU. 1 lb. of water absorbs only 40 BTU when its temperature is raised from 33° to 73°F.) If 75 lbs. of ice per cubic yard were added to a concrete mix with a temperature of 90° - the temperature of the mix would drop to about 75°F. Always be sure never to exceed the total allowable mixing water.

Aggregates have a pronounced effect on the temperature of the fresh concrete because they make up 60-80% of the total weight of the concrete. There are several steps you can take to try to keep your aggregate cool.

1. Shade the aggregate stockpiles. These blocks the suns direct heating rays.
2. Sprinkle the stockpiles with water. This slows the evaporation process by adding moisture.
3. Injecting chilled water into the pile may cool large concrete projects, with large stockpiles. Sometimes chilled air is forced through the batch plant bins to cool the aggregate. Normally only coarse aggregate is chilled this way.

On massive dam projects, it is quite common to lower the mix temperature to 50° F or less, by cooling coarse aggregates and water and then adding ice to the mix.

Cement temperature has only a minor effect in the total temperature of the fresh mix because of cements low specific heat and the relatively small amount of it in the mix. Since cement

loses heat slowly during storage, it may be warm when delivered. This is leftover heat that was generated when the cement clinker was ground into fine particles.
In other words, the temperature of each ingredient that goes into the mix contributes to the temperature of the total mix. If you took the temperature of each material and then averaged it together you would have a close estimate of what the temperature of the mix would be. By adding ice to the mixture, you change the average temperature – you make it lower. By adding cooled aggregates – you do the same. The hotter the ingredients, the hotter the fresh concrete; the cooler the ingredients, the cooler the concrete. There are no specifications on the individual temperature of the materials but, as we know, there are specifications on the temperature of freshly mixed concrete.

Preparations before the pour

Before concrete is placed, certain precautions can be taken during hot weather to help lower that concrete temperature. Mixers, chutes, belts, hoppers, pump lines, and other concrete handling equipment should be shaded, painted white, or covered with wet burlap to reduce the effects of the sun's rays. Forms, reinforcing steel, and the subgrade should be sprinkled with cool water just before the concrete is placed. Wetting the area cools the surrounding air and increases relative humidity. This not only reduces the temperature rise of the concrete, but it also minimizes the evaporation of water from the concrete. For slabs on the ground, it is good practice to dampen the subgrade the evening before concreting. Prior to placement, there should be no standing water or puddles on the subgrade.

During extremely hot periods, it may be beneficial to place the concrete in the evening or at night. This is especially true in arid climates. On thick slabs and pavements, night pouring has resulted in less thermal shrinkage and cracking.

Transporting, Placing, and Finishing

The transportation and the placement of concrete should be done as quickly as practical during hot weather. Delays can contribute to loss of slump and increased concrete temperatures. It is important to have all the necessary equipment readily available and enough workers to handle and place the concrete immediately upon delivery. Prolonged mixing, even at agitating speed, should be avoided. When a delay does occur, it is better to agitate the concrete intermittently to avoid the excessive generation of heat from the mixing action.

Since concrete hardens more rapidly in hot weather, extra care should be taken to avoid cold joints. When placing walls, it may need to be done in shallow layers to assure consolidation with the previous lift. Temporary sunshades and windbreakers can help to minimize cold joints.

All finishing work requires both speed and accuracy, but on hot, dry, or windy days, extra care should be taken. Remember that if the concrete dries too rapidly on the surface, plastic shrinkage cracking and cold joints may occur. Fog sprays or temporary wet burlap coverings are effective preventives. The burlap should be kept wet and not permitted to dry out. If cracks do appear, they can often be worked together during finishing, though they can reoccur.

Curing and Protection

The curing and protection of fresh concrete are even more critical during hot weather. In cooler weather, concrete can be left in the forms, but in hot weather they should be loosened as soon as it can be done without damaging the concrete. Water should then be applied to the surfaces of the fresh concrete and allowed to run down inside the forms. This also prevents the forms from absorbing water from the concrete. On flat concrete surfaces and on hardened concrete, curing water should not be excessively cooler then the concrete as to avoid cracking due to a large temperature fluctuation.

During hot weather concreting, continuous moist curing is the preferred method, especially during the first few hours after finishing.

Cold Weather Concreting

Concrete can be successfully placed throughout the winter months if certain precautions are taken. Adequate protection must be provided when temperatures reach 35° F or lower during the placement and early curing stages of the concrete. Fresh, plastic concrete must be protected against freezing.

The temperature of the concrete should not be less than 50° F after placing in order to insure that freezing will not occur immediately. Plans should be made well in advance so that the correct equipment can be on hand for heating the concrete materials and/or maintaining favorable temperatures in a constructed enclosure.

Effects of Low Concrete Temperatures

Temperature affects the rate of hydration of cement by retarding the concrete ability to harden and to gain strength. When there is no or little moisture during curing, strength gain virtually stops. Concrete that is placed at low temperatures, but above freezing, may develop higher strengths than concrete placed at high temperatures, but curing must be continuous for a long period of time. It is not safe to expose the concrete to freezing temperature at early periods. If freezing occurs within the first 24 hours after a pour, it will significantly lower its strength. Concrete of low slump is desirable for cold weather flatwork. During cold weather, evaporation is slowed thereby minimizing bleed water, which will lessen delays in finishing.

Heating Concrete Materials

The temperature of the cement and aggregate varies with the weather and type of storage. Since aggregates usually contain moisture, frozen lumps and ice are often present when the temperature is below freezing. Frozen aggregates must be thawed to avoid pockets of excessively high water contents and to assure proper batching. At temperatures above freezing often only the fine aggregate needs to be heated to produce concrete of the required temperature. If aggregate temperatures are above freezing, the desired concrete temperature can usually be obtained by heating only the mixing water.

Circulating steam through pipes over which that aggregates are stockpiled is a recommended method for heating aggregates. Stockpiles should be covered with tarps to retains and distribute heat and to prevent the formation of ice. Care should be taken to prevent overheating the aggregate. The temperature of the aggregate should not exceed 150 ° F, which is considerably higher than is necessary for obtaining recommended concrete temperature.

Of the ingredients used is for making concrete, the mixing water is the easiest and most practical to heat. The weight of aggregate and cement in the average mix is much greater than the weight of the water; however, water can store up to five times the heat of solid materials of the same weight. BTU'S, (British Thermal Units), are the unit of energy that can raise the temperature of 1 pound of water, 1° F. For water, to raise the temperature of the concrete materials it takes 1 BTU of expelled energy. The other materials in the concrete mix average out with a specific heat of 0.22 BTU's, which means they are not as efficient at heating the mix as water is, because of the lower BTU's.

If the measured average temperature of the aggregate and cement is above 32° F, the proper mixing water temperature for the required concrete temperature can be calculated. The water should not be hotter then 150° F because of the possibility of causing a quick or flash set of the concrete. When either the aggregates or water are heated to above 100° F, they should be combined in the mixer first, before the cement is added to obtain a temperature not to exceed 80° F.

Curing Methods

Concrete on forms or covered with insulation seldom looses enough moisture at 40° to 55° F to impair curing. It can be necessary to use moist curing in winter to offset the dry air that is produced in an enclosed heated environment. It is important to supply the concrete with ample moisture when warm air is used. Live steam exhausted in to an enclosure is an excellent method of curing concrete because this supplies both heat and moisture. Steam is especially practical during extremely cold weather because the moisture provided successfully offsets the rapid drying that occurs when cold air is heated.

Early curing with liquid membrane curing compounds may be used on concrete surface within heated enclosures. The accepted practice is to moist cure the concrete first, then apply a curing compound, after protection is removed and air temperature is above freezing. The heat liberated during the hydration of the cement will offset considerably, the loss of heat during finishing and early curing operations.

Heat maybe retained in the concrete by use of commercial insulating blankets or bat insulation. The effectiveness of insulation maybe determined by placing a thermometer under the insulation in contact with the concrete. If the temperature falls below the minimum required, additional insulating material should be applied. Corners and edges of concrete are the most vulnerable to freezing and should be checked to determine the effectiveness of the protection. Recommendations on the amount of insulation necessary for protection of concrete at various temperatures may be obtained from manufacturers of these materials or by referring to ACI's, "Recommended Practice for Cold Weather Concreting." The North Carolina Department of Highways information can be found in the most recent "Standard Specification" book.

Wind, temperature, type and design of forms, and the extent that the construction is enclosed are all factors in determining how much protection is needed. Forms built for repeated use often can be economically insulated. Commercial blanket or bat insulation used for this purpose should have a tough water-proof covering to withstand abuse and exposure to both concrete and air when that temperature of below freezing. They can be made of wood, canvas, building board, plastic sheets, waterproof paper, or other suitable material. Wood framework covered with tarpaulin or plastic sheeting is commonly used. Enclosures should be sturdy and reasonably airtight, with ample space provided between the concrete and the enclosure to permit the free circulation of the warmed air.

Enclosures may be heated by live steam, steam in pipes, oil-fired blowers. Salamanders, and other heaters of various types. Control of the enclosure temperature is easiest with live steam. This method is also much safer then others due to the ever present danger of fire in the heated enclosure. It is imperative that all fire safety measures be enforced.

Oil-fired blowers located outside the enclosure, that blow hot air inside might provide adequate heat. Oil or coke –burning salamanders are easily handled and inexpensive to operate. They are convenient for small jobs, but do have several disadvantages. One of which is that they produce dry heat. Care must be taken to prevent drying of the concrete near the heat source. When placed on floor slabs, they should be elevated and the concrete near them protected with damp sand. Salamanders and other fuel burning heaters also produce gases that may cause surfaces to "dust." For this reason heaters that produce harmful gases should not be used while placing or curing concrete unless very well ventilated. Rapid cooling of the concrete at the end of the heating period should be avoided as it may cause cracking. This is especially true with regard to massive structures such as bridge piers, abutments, dams and the like. Cooling should be a gradual process. Simply shutting off the heating element and allowing the enclosure to cool to the outside temperature is sufficient. Removing the enclosure immediately after shutting off the heater would be a mistake.

Removal of Forms and Reshoring

It is good practice during cold weather concreting to leave forms in place as long as the job schedule permits. Even within heated enclosures, forms serve to distribute heat more evenly and help prevent drying and localized over-heating.

Without careful simultaneous reshoring, it is hazardous in freezing weather to remove shores even temporarily before suitable tests show conclusively that the specified strength has been attained. Ordinarily, for temporary removal of support from an entire panel during reshoring attainment of 55 % to 65 % of the design strength is sufficient.

Reshores should be left in place as long as necessary to safeguard each member and, thereby, the entire structure. The number of tiers reshored below the tier that is being placed and the length of time reshores remain in place are dependent on the development of sufficient strength to carry dead loads and any construction loads with adequate factors of safety.

Appendix A
Frequently Asked Questions

The following FAQ's pertain to the production of concrete which will be utilized on existing or potential NCDOT Projects.

- Question: Which aggregate sources have been determined by the Department to have a high potential of developing ASR?

  Answer: See Pages 12 and 13 or consult the following link: https://connect.ncdot.gov/resources/Materials/MaterialsResources/Alkali-Silica%20Reactive%20Bulletin.pdf

- Question: What if the aggregate source supplying aggregate at my plant is not on the NCDOT approved list?

  Answer: You cannot produce for NCDOT and must get an approved source to supply your plant with aggregate in compliance with NCDOT Specifications.

- Question: What paperwork is required on the materials?

  Answer: The plant is responsible for and must supply current copies of certifications for all cement, fly ash, slag, fine and coarse aggregates, all admixtures, and the water source. In addition, all sources must be on the "NCDOT Approved List".

- Question: How do I submit a mix design for the Mix Design database?

  Answer: The concrete producer submits a mix design on Form 312U and includes supporting documentation for the mix to the Materials and Tests Unit. Concrete mix designs are submitted to a service account at Concretedesigns@ncdot.gov . The mix is then verified by the Concrete Mix Design Engineer and if it meets the current Standard Specifications, it is approved and entered into the database. A copy of the mix as it was entered into the database is sent back to the concrete producer to verify everything is correct.

- Question: How does the DOT keep track of mix designs?

  Answer: By use of an electronic database (HiCAMS). The database contains a plant-by-plant list of mix designs that have been reviewed and accepted for each plant. When the mix design is entered in the database, the computer automatically assigns a prefix to the producer's mix design number. This prefix consists of the DOT-assigned plant number (one, two, or three places) and a three-place code to identify the class of concrete, the vibration/air-entrainment status, and the type of pozzolan used in the mix (if any). The computer also assigns a suffix to the producer’s mix number – the letter “E” – to designate that the mix proportions are in the English system of measurement. (All mixes are currently in English Units).

- Question: How do I know if a mix design is approved?

  Answer: After a mix design has been reviewed and approved, an approved copy of the mix design is emailed back to the concrete producer for verification and record. The mix design number also becomes available on the approved mix design website: https://engblp.services.ncdot.gov/EAS/CMD/Main.aspx .

- Question: How do I submit mix designs for a contract?

  Answer: Acceptance of a concrete mix design is now a one-step process and mix designs are no longer assigned to a specific contract. As long as the mix is approved at the plant, it can be used on any project provided it meets the projects requirements. Inspectors will verify that the mix delivered is consistent with mixes approved in the database and meets the intended purpose as defined in the contract.

- Question: Do I need to submit strength test results with each mix design?

  Answer: For structural and incidental concrete, DOT Standard Specifications require laboratory test results of 7- and 28-day compressive strength for each mix. For concrete paving, laboratory test results of 28-day flexural strength of each mix are also required. See Section 1000 of the current NCDOT Standard Specifications for Roads and Structures book for details. See below for exceptions.

- Question: May I submit compressive strength results from a three-point curve instead of from individual mix designs to cover all my structural and incidental mixes designed with the same materials?

  Answer: Yes, for Class AA, AA-barrier rail, A, B and B-curb & gutter machine mixes only.

- Question: If I want to change a source of material but retain its quantity in an approved mix design, do I need to submit strength results?

Answer: We permit source changes of cement, fly ash, ground granulated blast furnace slag, silica fume, water and admixtures without strength results. However, you must assign each altered mix design a new producer mix number and submit each new mix design for the database. Form 312M must be used to make these changes without strength results. If you change an aggregate source, you need to submit strength data and use Form 312U.

- Question: May I change quantities of materials in an approved mix without submitting strength data?

  Answer: No, except where changes in aggregate quantity are necessitated by significant specific gravity changes, in which case you should notify the Concrete Mix Design Engineer for instructions.

- Question: Who is required to be Mix Design certified?

  Answer: The designated person submitting the mix design must be Mix Design certified. Mixes for all Portland cement concrete shall be designed by a Certified Concrete Mix Design Technician or an engineer licensed by the State of North Carolina and competent in concrete mix designs.

- Question: I just discovered the wrong mix design was used to batch concrete for a NCDOT project. Whom do I notify about this mistake? Will I lose my certification?

  Answer: Once an error of this type is discovered, immediately notify project personnel. The M&T Section Materials Specialist should also be informed of the error. Depending on the circumstances, the error will not necessarily lead to loss of your certification. The batcher should still maintain all required documentation. The 903 form should reflect the mix design that was used. The worst possible thing to do in this case is to attempt to alter records to cover up the mistake.

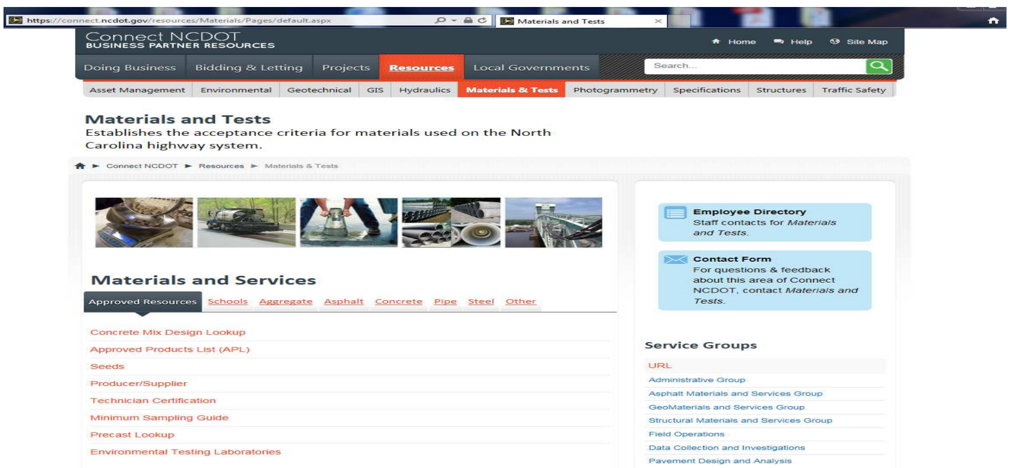
- Question: I am not getting my mix designs after they have been approved. What has happened to my copy?

  Answer: The concrete producer submits a mix design on Form 312U and includes supporting documentation for the mix to the Materials and Tests Unit at Concretedesigns@ncdot.gov . The mix is then verified and entered into the database and a copy of the mix as it was entered into the database is sent back to the concrete producer to verify everything is correct. A copy of the approved mix design may also be requested at the same email address above.

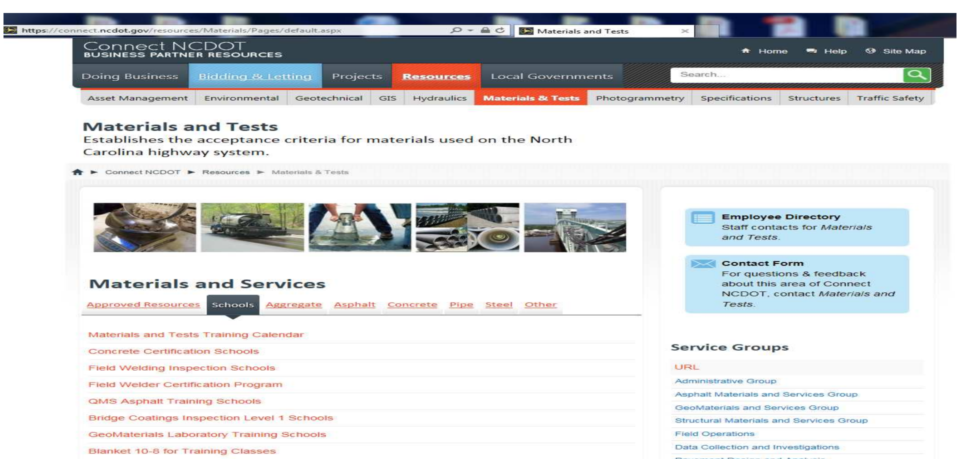
- Question: How Do I Access NCDOT Test Results from the M&T Website?

Answer**:** Access the M&T web site one week after the test date to view score. A letter with the test results and the Mix Design Certificate will be mailed out two weeks after the test date. Mix Design Certificate will be granted based on successful completion of the class to Technicians currently Batch and Concrete Field Technician certified. Directions to access the M&T web site are below.

- ➢ Type https://connect.ncdot.gov/resources/Materials/Pages/default.aspx in the web address bar



- ➢ Click on the Schools tab



- ➢ Click on the Concrete Certification Schools

Concrete Certification Schools

The classes offered are Concrete Field Technician, Concrete Batch Technician, Concrete Mix Design Technician, Concrete Pavement Technician, Concrete NCDOT Certification Only, and Concrete ACI Written Retest for the Materials and Test Unit.

Connect NCDOT ► Resources ► Materials & Tests ► Concrete Certification Schools

Concrete Certification School Documents

Name	School
Field Concrete Technician Three Day Agenda	Concrete Certification Schools
CONCRETE CERTIFICATION TRAINING DESCRIPTION updated 2-8-2018	Concrete Certification Schools
Concrete Certification Written Exam Grade Sheet	Concrete Certification Schools
Concrete Field Technician PowerPoint Presentation Study Guide	Concrete Online Material

Training Schedule

Class Dates	Status of class	Time	Location	Courses
January 1, 2018 - December 31, 2018 Administrative Entries	Open	NT	Miscellaneous	Miscellaneous Payment for Classes
February 7-8, 2018	Full	8:30 - 5:00	Marion, NC	Portland Cement Concrete Pavement (PCCP)
February 13-		8:30		Portland Cement

- ➢ Navigate down page to view certification grades

Grades

Name	School
Grades - Batch - Raleigh, NC - March 20-21, 2018	Concrete Certification Schools
Grades - CFT Castle Hayne March 12-14, 2018	Concrete Certification Schools
Grades - CFT Clemmons March 13-15	Concrete Certification Schools
Grades CFT Concord March 6-8, 2018	Concrete Certification Schools
Grades CRMCA February 27, 2018	Concrete Certification Schools
Grades - CFT Raleigh NCSU February12-14, 2018	Concrete Certification Schools
Grades - BATCH - Matthews, NC - February 14-15, 2018	Concrete Certification Schools
Grades - PCCP - Cary, NC - February 13-14, 2018	Concrete Certification Schools
Batch Class Grades CRMCA Charlotte	Concrete Certification

Class Dates	Status of class	Time	Location	Courses
Field Tech				
March 13-15, 2018 Clemmons Concrete Field Tech	Full	8:30am	Clemmons, NC	Concrete Field Technician
March 20-21, 2018 Raleigh Batch	Open	8:30 am - 5:00 pm	Raleigh, NC	Concrete Batch Technician
March 26-28, 2018 Raleigh, NC Concrete Field Technician	Full	8:30 am - 5:00 pm	Raleigh	Concrete Field Technician
April 3-5, 2018 Sylva Concrete Field Tech	Open	8:30am	Sylva	Concrete Field Technician
April 4-5, 2018 Cary PCCP Class	Open	8:30-5	Cary, NC	PCCP Class

- ➢ Locate the date, class, and site where test was taken

The grade will be listed by the first letter of last name and the last 4 digits of the Social Security number

Appendix B

Glossary of Terms and Definitions

Abrasion Resistance of an Aggregate – The ability of an aggregate to resist deterioration. It is a general index of an aggregate's quality.

Absolute Volume – The volume of a material, in cubic feet, in a voidless state.

Absorbed Moisture – The moisture within the pores and capillaries of an aggregate.

Accelerator – A chemical, such as calcium chloride, that is used to "speed up" the setting time of concrete.

Acid Water – Water which contains concentrations of hydrochloric, sulfuric or any other type of acid.

Aggregate – An inert filler material, such as crushed stone, gravel, and sand, which may be mixed with cement and water to make concrete.

Air-dry - A condition in which that aggregate particle is dry on the surface but contains moisture within its pores and capillaries.

Air-Entraining Agent – A material composed of vinsol resin which when added to concrete entrains microscopic air voids in the concrete.

Air-Entrained Concrete – Concrete that has had an air-entraining agent added to it, so that it has trapped microscopic air bubbles evenly distributed though-out it.

Alkaline Water – Water which contains concentrations of sodium hydroxide, potassium, or other hydroxide.

Bleeding of Concrete – A condition whereby an excess amount of mixing water accumulates on the surface of plastic concrete. This condition is caused by the settling and over-consolidation of the plastic concrete.

Cement – The bonding agent used in a concrete mix.

Cement Factor - The number of bags or pounds of cement in one cubic yard of concrete.

Coarse Aggregate – Aggregate that is larger than about ½" in diameter, usually referred to as stone or gravel.

Consistency – A condition of plastic concrete which relates to its cohesion, wetness or to its flow. The consistency is measured by the slump test.

Deleterious Substances in Aggregates – Undesirable substances that may be found in aggregates. These harmful substances include, but are not limited to, organic impurities, silty clay, coal lignite, and certain lightweight, and soft particles.

Dry–Rodded Unit Weight - The weight per unit volume of dry aggregate compacted in a container by rodding in three layers.

Durability – The ability of hardened concrete to resist the deterioration caused by weathering, (freezing, thawing, heating, cooling, wetting, drying, etc.), chemicals, and abrasions.

False Set – A significant loss of plasticity shortly after the concrete is mixed.

Fine Aggregate – A natural silica or manufactured aggregate smaller than about ¼" in diameter. Normally referred to as sand.

Fineness Modulus – An index to the coarseness and fineness of an aggregate.

Fineness of Cement – The particle size to which cement is ground. The fineness of cement affects the rate of hydration. As cement fineness increases, the rate of hydration increases and causes and acceleration in strength development.

Free Moisture – The moisture on the surface of an aggregate. The amount of free moisture is the difference between the total moisture and the absorbed moisture. (Total – Absorbed = Free).

Freeze-Thaw Resistance of an Aggregate – A condition related to an aggregate porosity, absorption, and pore structure.

Gradation of Aggregate – The relative amounts of aggregate particles of consecutively larger and smaller sizes.

Harsh Mix – An excessively coarse mix that is difficult to place and finish. This usually indicates that the mix does not contain enough fine aggregate to provide a dense, workable mixture. A harsh mix will segregate easily because it is not cohesive, (buttery).

Heat of Hydration – The heat generated when cement and water react.

Hydration – The chemical reaction between water and cement.

Nominal Maximum Size of an Aggregate – The smallest sieve opening through which all the aggregate is permitted to pass.

Maximum Size of an Aggregate – The smallest sieve opening through which the entire amount of the aggregate is required to pass.

Natural Cement – cement that has not been controlled in its making – it is generally found in its natural, unaltered state.

Oven-Dry – A condition of an aggregate, which contains no moisture: neither absorbed nor free.

pH – The measure of hydrogen ion concentration. The pH value of water is 7.0. Values above 7.0 are said to be alkaline. Values below 7.0 are said to be acids.

Portland Cement – A manufactured product obtained by heating clinker and then pulverizing with a properly proportioned combination of limestone, marl, shale, clay, silica sand, and iron ore.

Portland Cement Concrete – A concrete that consist of Portland cement, fine aggregate, coarse aggregate, water and any specified admixtures.

Saturated Surface Dry – A condition at which an aggregate will neither absorb nor contribute moisture in a concrete mix. (All internal pores and capillaries of the aggregate contain moisture but the surface is dry.)

Set Retarder - A material used for the purpose of delaying the setting time of concrete. Retarders provide a lubricating effect and function as a water reducing agent. A material composed of a combination of the following materials, (one from each column):

1	2	3
Calcium	Hydroxylated caboxlic acid	Carbohydrates
Sodium	Hydroxylated caboxlic acid salt	(Except sucrose)
Potassium		
Ammonium salt of lignosulfonic acid		

Setting Time – The time is takes for cement paste to begin hardening.

Sieve Analysis – A process in which an aggregate is separated into its various sizes by passing it through screens of various size openings for the purpose of determining the distribution of the quantities separated.

Soundness of a Hardened Cement Paste – The ability of hardened cement paste to retain its volume after setting.

Specific Gravity – The ratio of the weight of a given volume of material, to the weight of an equal volume of water, (both being at the same temperature). The specific gravity of water = 1.

Total Moisture – The sum of the moisture on the surface and the moisture absorbed into the pores and capillaries of an aggregate.

Unit Weight – The weight per unit volume. For concrete that weight is in pounds per cubic foot, (pcf).

Water – The ingredient in a concrete mix that causes the chemical reaction known as hydration. The water assists in providing the necessary workability of the concrete.

Water/Cement Ratio – The pounds of water per pounds of cement used in a concrete mix.

Water Reducing Agent – A material used for the purpose of reducing the quantity of mixing water in the concrete. This additive, which has a lubricating effect, will cause an increase in slump and workability when placed in a concrete mix of a given consistency.

Well-Graded Aggregate – An aggregate which contains a uniform percentage of material retained on each standard sieve. Gradation change is uniform from coarse to fine.

Workability – The property of freshly mixed concrete which relates to the ease or difficulty of placing and finishing the concrete. "Good workability," means that the concrete may be placed and finished with little difficulty. It also refers to the concrete as having a uniform gradation of aggregate. The slump test does not measure workability.

Yield – The volume of concrete, in cubic feet, produced from one bag of cement.

Appendix C
Study Questions

The following questions have been prepared to assist the student in their study of concrete technology. Many of the questions refer to Section 1000 of the North Carolina Standard Specification for Roads and Structures for answers. Some questions have the answers given.

These questions should help the student become more familiar with specifications and concrete technology in general. The questions on the following pages are but a sampling of what will be on the exam. It is highly advisable that the student spend ample time studying this complete manual; with particular attention to concrete specifications.

Materials Section:

1. On any concrete project, the specification book, plans, special provisions and supplemental specifications should be checked and compared. If a discrepancy is found, what is the order of precedence of these four documents?

2. What types of Portland cement are allowed in North Carolina Department of Highway concrete?

3. By what two means, may high early strength concrete be obtained?

4. What ingredient is used in the manufacture of Portland Cement to control the time of set?

5. In what ways will Portland cement vary from brand to brand?

   Answer – 1. Color
   2. Fineness of grains
   3. Chemical composition

6. What sources of water do not require testing before using it in concrete?

7. How should aggregate stockpiles be constructed?

8. At what moisture condition should the aggregate be at the time of its use in concrete?

9. What so the specification require when a stockpile of aggregate is too dry?

10. How long must aggregates be stockpiled for after being washed, before they can be used?

11. How are admixtures added to concrete?

12. Generally, whose recommendations must be followed in the use of admixtures?

13. What method does the North Carolina Department of Highways use for the notification of personnel, as to the approval of air entraining agents?

14. In what part(s) of a structure is the use of a set retarder required?

15. Are there any classes of concrete that are not required to be air entrained?

16. What is the difference between concrete and cement?

Answer - Concrete is a mixture of cement, water, and aggregate. Cement is the component of concrete which, when combined chemically with water, forms the bonding agents and gives concrete its strength and rigidity.

17. What is the special property of Type III Cement?

Answer – High early strength

18. If two Portland Cements have the same chemical composition, but one is ground to a finer particle size than the other, which one would generate heat faster, set quick, and give a higher early strength?

Answer – The finer ground cement

19. List some characteristics that an aggregate should possess to be considered a quality aggregate.

Answer – Well-graded, durable, hard, chemically inert, well-shaped, strong, clean, and abrasive resistance.

20. Why should care be exercised in handling aggregate?

Answer – To prevent a change in gradation by segregation or contamination.

21. How could an excessive coating of dust on the surface of aggregate be detrimental when used in concrete?

Answer – It may prevent bonding of the cement paste to the aggregate particles.

22. What are the limits of pH of concrete mixing water?

Answer – 4.5 to 8.5

Equipment and Mixing:

23. What two methods may be used to measure mixing water?

24. The water-measuring device must have an operating accuracy of what percent?

25. How are aggregate measured?

26. What accuracy is required when measuring aggregate?

27. What is required of the admixture dispensing devices, regarding accuracy and type?

28. Can cement and aggregate be measured on the same scale?

29. What two types of scales for weighing aggregate and cement may be used?

30. When beam type scales are used, what is required so that the operator can know that the required load on the weighing hopper is being approached?

31. Does all cement need to be weighed? If not, what is the exception?

32. What is the required weighing accuracy for cement?

33. How many bins are required for aggregate at the concrete plant?

34. Who approves the concrete ready mix trucks and plant equipment?

35. In checking the adequacy of a concrete mixer, what is the maximum consistency variation allowed in any one load?

36. Name the two special items required on truck mixers and tell what their functions are?

37. What are the minimum and maximum quantities of concrete that may be mixed in a concrete mixer?

38. What is ready mixed concrete?

39. What are two types of ready mixed concrete and how do they differ?

40. How should the delivery of concrete be regulated?

41. What is retempered concrete?

Answer – Retempered concrete has had water added and it is reworked or remixed after the cement has started hydrating. Concrete whose quality has been impaired as a result of the rearrangement of cement particles after it has begun the cementing action.

42. What are the mixing times for a stationary mixer?

43. Are the use of mechanical consistency measurement devices on the mixer approved for acceptance of concrete?

Answer – No.

44. When truck mixing is used, how many revolutions at mixing speed are required after all materials are in the mixer?

Answer – A minimum of 70

<u>Testing:</u>

45. Who is responsible for making the moisture determination in aggregates?

46. Who is responsible for the calculations, the batch adjustments, and the setting of dials, gauges, scales, and meters?

47. What are the steps the inspector should take when the air content or consistency is found to be outside the specification requirements?

48. If a load of concrete has been accepted by the Project Inspector and there is an obvious change in consistency, he should run another test. If this test is not within the specification requirements, what should be done with the remainder of that load?

49. When high early-strength Portland cement concrete is authorized, at what age must the minimum design strength be obtained?

50. If a load of concrete has been rejected due to excessive water content or consistency, is the addition of cement to bring the concrete within the specification tolerance allowed?

51. What is the free moisture of an aggregate?

Answer – The water on the surface of an aggregate particle that adds to the wetness of the concrete.

52. What is absorbed moisture?

Answer – The moisture contained in the pores and capillaries of the aggregate that does not contribute to the wetness of the concrete.

53. What is saturated surface dry, (SSD)?

Answer – This is the condition of an aggregate that has absorbed its limit of moisture but contains no free moisture. Aggregate in an SSD condition appears damp on the surface but is not glossy from the presence of water. – The exact condition can only be determined by testing.

54. What is meant by the total moisture content of an aggregate?

Answer – The free moisture plus the absorbed moisture.

55. How can the absorbed moisture content of an aggregate be determined?

Answer – By testing the moisture when the aggregate is in SSD condition. The North Carolina Department of Highway's Material and Testing Division normally furnishes the absorption value for any aggregate source.

56. How can the free moisture content of an aggregate be determined?

Answer – By completely drying a representative sample, determining the total moisture, and the subtracting the absorbed moisture.

57. What is the formula for calculating the free moisture content of an aggregate?

Answer –

$$\frac{\text{wt. of total moisture}}{\text{wt. of oven dry aggregate}} \times 100 - (\%\ \text{absorption}) = \textit{\% FREE MOISTURE}$$

58. What is the test used by the North Carolina Department of Highways to determine the resistance of an aggregate to abrasion?

Answer – The Los Angles Abrasion Test.

59. What are the four test methods that can be used to check the percent air in concrete?

Answer -
1. Pressure Meter Test
2. Chace Indicator Test
3. Unit Weight Test
4. Volumetric Meter Test, A.K.A. Roll-A-Meter (for light-weight concrete)

60. What can be done by the concrete producer if the air is too high?

Answer – Reduce the amount of air entraining agent in the next batch.

61. What equipment should be used for drying the aggregate when performing the moisture test?

Answer – A hot plate, oven, or any other device, which will insure complete drying of the aggregate.

Hot and Cold Weather Concrete – Curing and Protection:

62. What materials used in concrete may be heated and to what maximum temperature?

63. Name some of the restrictions that are placed by the concrete specification in regard to the heating of aggregates?

64. When using heated water, what precautions should be taken to prevent the possibility of a flash set?

    Answer – The temperature of the water is allowed to cool being combined with the aggregate in the mixer prior to the addition of the cement.

65. At what temperature must structural concrete be maintained during cold weather after being placed in the forms, and for how long?

66. What is the minimum allowable temperature of surfaces against which structural concrete may be placed?

67. When using a liquid membrane seal for curing, a white pigmented material must be used on most elements. What elements are excluded? On these elements, what type of curing compound is required?

68. How in concrete in retaining walls to be cured and protected?

69. How does the temperature of the fresh concrete affect the percent of entrained air?

    Answer – The higher the temperature, the more air-entraining agent needed to maintain the same percent of entrained air. The following things improve the quality of Portland cement concrete:

    a. Using good quality materials
    b. Proper proportioning
    c. Proper mixing
    d. Good construction practices – placing and finishing
    e. Adequate curing

70. Which of these is the least expensive in proportion to the effect it can have on the quality of concrete?

    Answer – Adequate curing.

71. What one ingredient of concrete controls the amount of shrinkage which drying concrete will experience?

    Answer – The more water that is used in the mix, the greater the drying shrinkage.

72. How can you prevent concrete from shrinkage?

Answer – Do not let it dry out.

73. Define curing.

Answer – Any process that will insure that water remains in the concrete to sufficiently hydrate the cement during hydration.

74. How much water is necessary to completely hydrate a sack of cement?

Answer – Approximately 3 ½ gallons.

75. What effect does proper curing have on the concrete?

Answer – As long as water is available, the cement will continue to hydrate for an infinite period of time. This will greatly improve the desirable characteristics of the concrete.

76. What effect does curing temperature have on the concrete's strength?

Answer – If the curing temperature is too high the ultimate strength attained will be reduced. However, concrete that is moist cured at a high temperature has a higher strength at an earlier age.

77. Which of the main components of concrete have the greatest affect, per pound, on the final concrete mixture temperature?

Answer – Water has five times the effect of sand, cement, or coarse aggregate per pound.

78. Why should concrete not be allowed to have its temperature fall below 32°F, before a minimum of time has elapsed or strength has been attained?

Answer – The chemical action of hydration will slow down or cease and /or the surface of the concrete could freeze and cause scaling.

79. How can concrete be properly heated?

Answer – By any method that maintains the temperature of the concrete within the specified limits, does not dry out the concrete, and does not cause harmful gases to come in contact with the concrete.

General Construction:

80. What are some of the requirements for the consolidation of structural concrete by mechanical vibration?

81. What are the two ways of controlling the removal of formwork and the construction of superimposed elements in structural concrete?

82. How should test cylinders, for control purposes, be cured?

83. Under what conditions might the contractor decide to use more cement then the minimum required?

84. What is the reason for using high-early strength concrete?

85. When may concrete be placed by pumping?

86. When pumping concrete, conduit systems may not be made of what material?

87. What class of concrete must be used if it is to be placed underwater?
By what method should is be deposited?

88. What are two advantages of obtaining high strength at an early age?

Answer – Early form removal, thereby speeding construction and the concrete may be loaded earlier, eq. opened to traffic earlier.

89. What three characteristics should "good quality" concrete have?

Answer – Durability
Water tightness
Strength

90. What relationship governs the more highly regarded characteristics of concrete, assuming that good materials and good construction practices were in practice?

Answer – The water/cement ratio.

91. What is the definition of the water/cement ratio, (W/C)?

Answer – It is the relative amounts of water and cement in a mix. It is usually expressed as the number of gallons of water per sack of cement.

92. How does the W/C ratio affect the characteristics of the concrete?

Answer –Generally, the lower the W/C, the stronger, more durable, and more watertight the concrete will be.

93. If we compare two identical mixes, with the exception that one mix is air entrained and the other is not. Which mix will be stronger and which mix will have the greater slump?

Answer – The mix with the entrained air would be weaker and it would also have the greater slump.

94. If we take the same mixes as in the problem above, but we reduce the water in the air entrained mix so that the slump is equal to that of the non-air entrained mix, which mix will yield a stronger and more durable concrete?

Answer – The air entrained mix with the reduced water.

95. In concrete that is air entrained, the bubbles improve the resistance of the concrete to freezing and thawing. Why?

Answer – The minute bubbles form capillaries and spaces that accommodate the change in volume of water to ice within the concrete.

96. List some of the advantages of air entrained concrete.

Answer -

a. Improves freeze/thaw resistance
b. Improves resistance to sulfate action
c. Improves resistance to salt action
d. Improves water tightness
e. Improves workability
f. Reduces segregation
g. Reduces bleeding
h. Reduces the required sand content
i. Reduces the W/C
j. Can be finished sooner

97. What are some of the disadvantages of air entrained concrete?

Answer –

a. May reduce strength
b. Requires strict control
c. should not be relied upon as a cure-all

98. If concrete is placed at 95° F, will its ultimate strength be greater or less then when placed?

Answer – It will be less.

99. What is the difference between workability and consistency?

Answer – Workability is the property of concrete, which is measured in terms of ease of placing, handling, and finishing. Consistency is a measure of the wetness or ability of the concrete to flow.

100. What are some of the factors that affect workability?

Answer –
a. Aggregate gradation
b. Aggregate shape and texture
c. W/c
d. The quality of the cement/water paste
e. Mixing
f. Admixtures

101. What are some of the factors that affect consistency?

Answer –
a. Total unit water
b. Aggregate gradation
c. Maximum size of aggregate
d. Air entrainment

102. Name four things that affect bleeding.

Answer –
a. Consistency
b. Fineness of cement
c. Percent of entrained air
d. Amount of material passing through the No.50 sieve.

103. A water tank holds 300 cubic feet of water. How many gallons would this be?
a. 2050 gallons
b. 2250 gallons
c. 2450 gallons
d. 2650 gallons

104. The ratio of the amount of water to the amount of cement in a concrete mix is t he __________?
a. Water Reducing Agent
b. Cement Factor
c. Water – Cement Ratio
d. Total Moisture

105. The volume of concrete, (in cubic feet, ft^3) produced from one bag of cement is _____________?

a. Specific Gravity
b. Yield
c. Absolute Volume
d. Unit Weight

106. One gallon of water equals:

a. 7.5 lbs.
b. 27 lbs.
c. 62.4 lbs.
d. 8.33 lbs.

107. The ratio of the weight of a given volume of material to the weight of an equal volume of water, (both being at the same temperature), is called ___________?

a. Unit Weight
b. Absolute Volume
c. Specific Gravity
d. Dry Rodded Unit Weight

108. The volume of a material, in cubic feet, in a voidless state is called ____________?

a. Absolute Volume
b. Unit Weight
c. Cement Factor
d. Yield

109. The number of pounds of cement in one cubic yard of concrete is:

a. Fineness of Cement
b. Natural Cement
c. Cement Factor
d. Hydration

110. The weight per unit volume of concrete is called ___________?

a. Consistency
b. Absolute Volume
c. Unit Weight
d. Yield

111. One cubic foot of water equals:

a. 7.5 lbs.
b. 8.33 lbs.
c. 14.9 lbs.
d. 62.4 lbs.

Appendix D
Mathematical Formulas

$$\textbf{Absolute Volume of a Solid} = \frac{\textbf{Lbs.}}{\text{Sp.Gr.} \times 62.4 \leftarrow \text{(unit weight of water)}}$$

$$\textbf{Lbs.} = \text{Solid Absolute Volume} \times \text{Sp. Gr.} \times 62.4$$

$$\textbf{Lbs. per Cu.Ft.} = \frac{\text{Total Lbs. of Batch}}{\text{Yield}}$$

Note: If the batch is one bag, then the yield of one bag must be used. If the batch is for one cubic yard, then the yield becomes 27.0 cubic feet.

$$\textbf{\% Air} = \frac{\text{Theoretical Weight} - \text{Actual Weight}}{\text{Theoretical Weight}} \times 100$$

$$\textbf{Unit Weight} = \frac{\text{Total Weight of Sample in Bucket} - \text{Weight of the Bucket}}{\text{Volume of the Bucket}} \times 100$$

$$\textbf{W/C Ratio} = \frac{\text{Pounds of Water}}{\text{Pounds of Cement in a Yard}}$$

Appendix E

Mix Design Forms

Form 312U

Form 312U

Producer's Mix ID									

08-17

North Carolina Department of Transportation, Division of Highways, Materials and Tests Unit
Statement of Concrete Mix Design and Source of Materials

Class of Concrete		Concrete Producer Name		
Vibrated (Yes or No)		NCDOT Plant No.		
Air Entrained (Yes or No)		Date Requested		
Reference Mix Design No.		7/28 Day Break Data (psi)		

Mix Design Proportions Based on SSD Mass of Aggregates

Material	Producer	Source	Qty. per Cu. Yd.	
Cement				lbs.
Pozzolan				lbs.
Other Pozzolan				lbs.
Fine Agg.+ M				lbs.
Coarse Agg.+ M				lbs.
Other Agg.+ M				lbs.
Total Water				gals.
Material	**Producer**	**Admixture Brand**	**Qty. per Cu. Yd.**	
Air Entraining Agent			As Recomm.	
Retarding Agent			As Recomm.	
Water Reducing Agent			As Recomm.	
Superplasticizer			As Recomm.	
Corrosion Inhibitor				gals.
Latex Modifier				gals.

Mix Properties and Specifications

Slump (inches)		Mortar Content (ft^3)	
Max W/C Ratio		Air Content (%)	
Max. Water (gals)		Design Volume (ft^3)	27

Aggregate and Cementitious Data

Material	Type / Size	Coarse Agg. Shape	Specific Gravity	% Absorption	Unit Mass	Fineness Modulus
Fine Aggregate		N/A			N/A	
Coarse Aggregate						N/A
Other Aggregate						N/A
Pozzolan		N/A		N/A	N/A	N/A
Other Pozzolan		N/A		N/A	N/A	N/A
Cement		N/A	3.15	N/A	N/A	N/A

Cast-in-place concrete shall conform to Section 1000, precast concrete to Section 1077, and prestressed concrete to Section 1078 of the applicable edition of the Standard Specifications for Roads and Structures plus all applicable Special Provisions.

Special Use Criteria: Is mix design governed by Special Provision/Plan Note? **YES or NO** ________
If **Yes** submit copy of Special Provision or Plan Note with this Form.

Signature and title of person who designed mix ______________________________

NCDOT Mix Design Certification No. ____________________ **Or PE stamp or No.** ____________________

Comments:

Instructions for Form 312U

The contractor/concrete producer submits the mix design to the North Carolina Department of Transportation, Structural Materials Laboratory, on the Materials and Test Form 312U at Concretedesigns@ncdot.gov . The form must be completely filled out and submitted with required data to avoid unnecessarily delays. Instructions on how to fill Form 312U correctly and completely are as follows:

1.) Fill in the Producer's Mix ID located at the top of the Form. **NOTE** that this ID cannot be more than nine (9) characters and it is generated by the Concrete Producer and not NCDOT.

Example: The producer's mix ID is 856ABC919

Form 312U

Producer's Mix ID	8	5	6	A	B	C	9	1	9

08-17

North Carolina Department of Transportation, Division of Highways, Materials and Tests Unit

Statement of Concrete Mix Design and Source of Materials

2.) In the second table on the form:

a. Select the Class of Concrete, Yes or No for Vibration Status and Air Entrainment Status. Enter the Concrete Producer Name, the NCDOT Plant No. including the prefix which indicate the type of plant e.g. RM25 for ready-mix plant 25 or PS25 for prestress plant 25, the date the form is completed, and the compressive strength at 7 days and 28 days. Submit the rest of the test data with Form 312U.

Example: A vibrated and air entrained class AA mix produced at NCDOT Plant No. RM777 by Awesome Concrete Inc. with a 7 day and 28 day strength results of 3000 psi and 7000 psi respectively is submitted on January 1st, 2018.

Class of Concrete	Class AA	Concrete Producer Name	Awesome Concrete Inc.	
Vibrated (Yes or No)	Yes	NCDOT Plant No.	RM 777	
Air Entrained (Yes or No)	Yes	Date Requested	1/1/2018	
Reference Mix Design No.	n/a	7/28 Day Break Data (psi)	3000	7000

b. If the mix design being submitted is identical to another NCDOT approved mix design at another Plant, write/type the identical mix design number in the

Reference Mix Design No. field. Note that if you are submitting a mix design identical to one already approved, you do not need to submit the break data. Example: If mix design is IDENTICAL to another approved mix design (8882VF856ABD919E) at RM888

Class of Concrete	Class AA	Concrete Producer Name	Awesome Concrete Inc.	
Vibrated (Yes or No)	Yes	NCDOT Plant No.	RM 777	
Air Entrained (Yes or No)	Yes	Date Requested	1/1/2018	
Reference Mix Design No.	8882VF856ABD919E	7/28 Day Break Data (psi)		

3.) In the third table on the form:
Enter the Producer, Source, and quantities of all the materials used in the mix design. Note that all quantities must be reported in **English Units** as indicated on the form. Dosages for admixtures will be as recommended by the manufacturers and you must indicate the **BRAND** of any admixture used in the mix. The source of mixing water shall be from wells or public water systems which are suitable for drinking and must meet the criteria listed in Table 1024-2 of our Standards Specifications.

Example: 560 lbs. of cement is produced by NCDOT and comes from Greensboro, NC Facility 3 and an AE-RGC brand of air entraining agent produced by Air Entraining Inc. are used for this mix. The mixing water, 28 gallons, comes from the city of Greensboro Public Water System.

Mix Design Proportions Based on SSD Mass of Aggregates				
Material	**Producer**	**Source**	**Qty. per Cu. Yd.**	
Cement	NCDOT	Facility 3, Greensboro, NC	560	lbs.
Pozzolan				lbs.
Other Pozzolan				lbs.
Fine Agg.+ M				lbs.
Coarse Agg.+ M				lbs.
Other Agg.+ M				lbs.
Total Water	City	City	28.0	gals.

Material	Producer	Admixture Brand	Qty. per Cu. Yd.	
Air Entraining Agent	Air Entraining Inc.	AE-RGC	As Recomm.	
Retarding Agent			As Recomm.	
Water Reducing Agent			As Recomm.	
Superplasticizer			As Recomm.	
Corrosion Inhibitor				gals.
Latex Modifier				gals.

4.) In the fourth table on the form:

a. Enter the Slump, Mortar Content, Air Content, and Maximum Water. Note that the Max W/C Ratio is calculated using the Max. Water weight and the total cementitious material weight:

$$\boldsymbol{Max\ Water/Cement\ \ Ratio} = \frac{\boldsymbol{Weight\ of\ Max\ Water}}{\boldsymbol{Weight\ of\ Cementitious\ Material}}$$

Example: For a given mix design, the Slump is 3.5 inch, Mortar Content is 16.7 cu. Ft., Max. Water is 33.5 gals, Air Content is 6%, Cement is 560 lbs., and Pozzolan is 100 lbs.
W/C ratio = (33.5*8.33)/(560+100) = 0.423 (note that this ratio is automatically calculated based on your input values)

Mix Properties and Specifications			
Slump (inches)	3.5	Mortar Content (ft^3)	16.7
Max W/C Ratio	0.423	Air Content (%)	6.0
Max. Water (gals)	33.5	Design Volume (ft^3)	27

5.) In the last table on the form:

a. Select or enter the Types or Sizes, the Specific Gravities, percent Absorptions, Unit Mass, and Fineness Modulus of the materials where applicable.

Example: Fine aggregate is type 2S with Specific Gravity of 2.65, % Absorption of 0.40 and Fineness Modulus of 2.56; Coarse aggregate is size 78M with Specific Gravity of 2.72, Absorption of 0.6, angular shape, and Dry-rodded Unit Weight (Unit

Mass) of 98.97; Pozzolan is Class F fly ash with Specific Gravity of 2.23 and Cement is type II.

Aggregate and Cementitious Data						
Material	**Type / Size**	**Coarse Agg. Shape**	**Specific Gravity**	**% Absorption**	**Unit Mass**	**Fineness Modulus**
Fine Aggregate	2S	N/A	2.65	0.4	N/A	2.56
Coarse Aggregate	#78M	Angular	2.72	0.6	98.97	N/A
Other Aggregate						N/A
Pozzolan	F Fly Ash	N/A	2.23	N/A	N/A	N/A
Other Pozzolan		N/A		N/A	N/A	N/A
Cement	Type II	N/A	3.15	N/A	N/A	N/A

6.) Indicate appropriately if the mix design is governed by **Special Provisions**; and if so, submit a copy of a **page or pages** showing the Special Provisions that apply to the mix.
7.) Lastly, enter your **name, title/position**, and your **certification number** or **PE number**. Sign the completed form. **Note** that form can be signed electronically. If signing traditionally, the signed form must be scanned with a **good scanner** to ensure the form is still **legible**.

Email the completed and signed form with your break data and special provisions pages (if applicable) to concretedesigns@ncdot.gov .

The approved 312U form will include the name of the technician and their Mix Design Certification number or name of the licensed engineer and their PE number. Mix designs submitted without the following will be rejected as incomplete:

- Producer’s mix ID number
- Class of concrete
- Vibration and air entrainment status
- Laboratory test results of 7 and 28 day compressive strength
- Maximum water, slump, material properties, e.g. types/sizes, specific gravities etc.
- Name and certification number of person who designed the mix

Mix designs submitted using outdated 312U forms will be returned for resubmission. Please also note that mix designs in terms of saturated surface dry weights must be submitted for review and approval at least 35 days before proposed use (Section 1000-4 of NCDOT Standard Specifications).

Aleterations of any type to the 312U Form or any other mix design forms are prohibited and any form submitted with changes other than selectable and fillable fields will also be rejected. Any mix comments must be entered in the comment section of the form.

Items to check:

1. Always use at least the minimum cement for that particular class of concrete.
2. Make certain that the W/C ratio and the maximum water have not been exceeded.
3. Be certain that the correct design air content is used.
4. Make sure that all materials used are state approved. Verify the specific gravity and the fineness modulus of the material.
5. Be sure to use the ACI method of design in the mix procedure.
6. Make sure the mix design produces 27.0 +/- 0.3 cu. ft.
7. Check that all the admixtures are on the approved list.

Form 312M

Form
312M
08-17

North Carolina Department of Transportation, Division of Highways, Materials and Tests Unit
Statement of Concrete Mix Design and Source of Materials

Concrete Producer Name	
NCDOT Plant No.	
Date Requested	

Old Producer's Mix ID	New Producer's Mix ID	Old Producer's Mix ID	New Producer's Mix ID	Old Producer's Mix ID	New Producer's Mix ID

Producers and Sources of Materials

Material	New Producer	New Source
Cement		
Pozzolan		
Material	**New Producer**	**New Admixture Brand**
Air Entraining Agent		
Retarding Agent		
Water Reducing Agent		
Superplasticizer		
Corrosion Inhibitor		

Cementitious Data

Material	New Type	New Specific Gravity
Pozzolan		
Cement		3.15

Cast-in-place concrete shall conform to Section 1000, precast concrete to Section 1077, and prestressed concrete to Section 1078 of the applicable edition of the Standard Specifications for Roads and Structures plus all applicable Special Provisions.

Name and Title of Person Requesting Changes to Mixes ______________________________

NCDOT Mix Design Certification No. ____________ **Or PE stamp or No.** ______________

Instructions for Form 312M

Form 312M must be filled completely and submitted to the Materials and Tests Unit Physical Lab at Concretedesigns@ncdot.gov to avoid unnecessarily delays. Instructions on how to fill Form 312M correctly and completely are as follows:

1.) In the first table on the form:

Write/type the Name of the Concrete Producer, Plant Location and NCDOT Plant No. e.g. RM25, PS25, CP25, VM10, or PC5, and the date the form is completed. **Example:** A source change for mixes produced at NCDOT Plant No. RM777 by Awesome Concrete Inc. is requested on January 1st, 2018.

Concrete Producer Name	Awesome Concrete Inc.
NCDOT Plant No.	RM 777
Date Requested	1/1/2018

2.) In the second table on the form:

a. Provide the Old Producer's Mix ID and the corresponding New Producer's Mix ID.
Example: Five mixes; 856ABC919, 856ABD919, 856ABE919, 856ABF919, and 856ABG919 will have the same source change at the given Plant and their new mix IDs will be 856ABC336, 856ABD336, 856ABE336, 856ABF336, and 856ABG336 respectively.

Old Producer's Mix ID	New Producer's Mix ID	Old Producer's Mix ID	New Producer's Mix ID	Old Producer's Mix ID	New Producer's Mix ID
856ABC919	856ABC336				
856ABD919	856ABD336				
856ABE919	856ABE336				
856ABF919	856ABF336				
856ABG919	856ABG336				

b. Note that the Producer's ID **CANNOT** be more than **nine (9) characters** and you can make a mass change for up to fifteen (15) mix designs per form. If you have more than fifteen mix designs to change, you must use another form.

3.) In the third table on the form:

Enter the name of New Producer and New Source of the materials in the mix design.
Example: Awesome Concrete Inc. would like to change the source of type I/II cement produced by NCDOT from Facility 3 Greensboro, NC to Facility 1 High Point, NC, and the admixture brand produced by Air Entraining Inc. from AE-RGC to AE-GSO.

Producers and Sources of Materials

Material	New Producer	New Source
Cement	NCDOT	Facility 1 High Point, NC
Pozzolan		
Material	**New Producer**	**New Admixture Brand**
Air Entraining Agent	Air Entraining Inc.	AE-GSO
Retarding Agent		
Water Reducing Agent		
Superplasticizer		
Corrosion Inhibitor		

NOTE that although the producer for cement and admixture did not change, their names must still be included in this form as shown in the above example.

4.) In the fourth/last table on the form:

Enter the type and/or specific gravity of the material being changed if applicable. **Note that the new type or class should equal the existing type or class respectively.**

Example: The producer would like to change the source of class F Fly Ash by NCDOT from Facility 1 in Greensboro to Facility 2 in High Point. The specific gravity for Facility 2 class F Fly As is 2.28.

Cementitious Data

Material	New Type	New Specific Gravity
Pozzolan	Fly Ash Class F	2.28
Cement	Type I/II	3.15

5.) Finally enter your name, your title/position, and your certification number or NC PE number.
Save and email your completed form to Materials and Tests Unit Physical Lab at concretedesigns@ncdot.gov . After changes have been made and new mix designs have been created, you will receive an email response with copies of new mix designs for your verification and record.

<u>Form 312C</u>

Form 312C
8 - 17

North Carolina Department of Transportation, Division of Highways, Materials and Tests Unit
Portland Cement Concrete Mix Design Copy Request Form

Concrete Producer: ______________________ Plant Location: ______________

Concrete Producer's E-mail Address: ______________________

DOT - Assigned Plant Number: __________ *(Use a separate form for each plant number)*

List concrete producer's mix ID numbers as filed with the Department's concrete mix design database.

Class A	______	Class AA	______
	______		______
	______		______
	______		______
	______		______
Class AA	______	Class B	______
Slip-Form	______		______
Barrier Rail	______		______
	______		______
	______		______
Class B -	______	Pavement	______
Curb & Gutter	______		______
Machine	______		______
	______		______
	______		______
Drilled Shaft	______	Flowable	______
	______	Fill	______
	______		______
	______		______
	______		______
Prestressed	______	Other	______
Concrete	______	*(include class)*	______
	______		______
	______		______
	______		______

Mixes Requested By: ______________ *Date Requested:* ______________

NCDOT Mix Design Certification No.: ______ Or PE stamp or No.: ______________

Instructions for Form 312C

Form 312C must be filled completely and submitted to the Materials and Tests Unit Physical Lab at Concretedesigns@ncdot.gov to avoid unnecessarily delays. Instructions on how to fill Form 312C correctly and completely are as follows:

1.) Enter the Concrete Producer's name, Email Address, NC DOT Assigned Plant Number with prefix (e.g RM1, PC1, PS1, CP1, or VM1), and Plant Location.
2.) List the Producer's Mix ID number under the appropriate class of concrete. DO NOT list the State Mix Design numbers.
3.) For classes of concrete not listed on the form, list the Producer's Mix ID numbers under Other and include the class of concrete in brackets.
4.) If you are requesting copies from more than one Plant, use a different 312C form for each Plant.
5.) Enter the name of the person requesting the mixes and the date requested.
6.) Enter the NCDOT mix Design Certification number or licensed NC PE number of the person requesting the mixes.
7.) Save the 312C form and submit it to the Concrete Designs Service Account at Concretedesigns@ncdot.gov .