CONCRETE MIX DESIGN TECHNICIAN
STUDY GUIDE

Materials & Tests Unit

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North Carolina Division of Highways
Materials and Tests Unit
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Frequently Asked Questions: REGARDING CONCRETE PRODUCTION

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 Page 9 or consult the following link: https://connect.ncdot.gov/resources/Materials/MaterialsResources/Alkali-Silica%20Reactive%20Aggregates.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:** Do I need to record the actual batch quantities and the individual batch weights?

  **Answer:** Yes, all quantities and weights must be computer generated or hand printed, but must be recorded for each batch produced (policy letter dated August 29, 2000).

- **Question:** What certification do I need to batch concrete for NCDOT?

  **Answer:** All batchers who produce concrete for NCDOT must keep a current Concrete Field Technician and Concrete Batching Technician Certification.

- **Question:** If my Concrete Batch Technician Certification is current, do I need to keep my Field Technician Certificate current?

  **Answer:** It is mandatory to keep both certifications current or you will have all certifications revoked.

- **Question:** Do I need to perform a moisture content on coarse aggregate?

  **Answer:** Yes, the certified batcher is required to perform moisture contents by the drying method on both fine and coarse aggregate a minimum of twice a day or whenever deemed necessary. These moisture calculations are to be recorded, documented and stored with the producer’s copy of the batch weight tickets.
• Question: What if the moisture the batcher computes is different from the moisture the computer indicates?

Answer: The batcher must have the capability to change/update the moisture contents for both fine and coarse aggregate prior to batching. This correction is to be performed at the batching facility and not at the central dispatch location.

• Question: What if the moistures are not changed in the computer?

Answer: The batcher and plant certifications will be investigated. Pending the investigation, disciplinary actions may be implemented towards the facility.

• Question: Does the batcher need to review the approved mix design?

Answer: Yes, the certified batcher is responsible for all production of concrete. All sources of materials should be correct on site and approved by NCDOT. If any producer/facility source on the mix design is different than on site, you must submit a new mix design or get the approved materials.

• 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: Should the plant and batcher have a hard copy of the approved mix design?

Answer: Yes, the certified Batch Technician is responsible for assuring that the materials and proportions shown on the approved mix design are incorporated into the concrete.

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

Answer: By use of two electronic databases. The Concrete Mix Design database is a plant-by-plant list of mix designs accepted for each plant. Data on each mix design includes mix number, class, proportions, mix properties, material sources, and material properties. Acceptance of a mix design in this database does not constitute its acceptance for any contract. Assignment of mix designs to contracts involves a separate submittal, review and acceptance procedure via the Concrete Mix Contract Assignment database. Mix designs must be in the Concrete Mix Design database to qualify for assignment to a contract. Upon written request from the Engineer for specific mix designs to be assigned to a contract, the Physical Testing Engineer reviews and assigns these mix designs in the Concrete Mix Contract
Assignment database. This database shows the list of mix designs assigned to each contract. Requests for mix design approval for contracts outside the scope of HiCams are handled similarly except that the Concrete Mix Contract Assignment database is not used, in which case approved hard copies are returned to the Engineer for distribution.

- **Question:** How do I submit a mix design for the Mix Design database?
  **Answer:** Complete Materials and Tests Form 312U (English units only) and mail it to Physical Testing Engineer, NCDOT, Materials & Tests Unit, 1801 Blue Ridge Rd., Raleigh, NC 27607.

- **Question:** How do I submit mix designs for a contract?
  **Answer:** It is the contractor’s responsibility to submit such requests to the DOT Engineer administering the contract. The contractor should request the concrete producer to complete M & T Form 312R, Mix Design Request Form, for each plant he plans to use to supply concrete and forward these forms to him for submittal to the Engineer.

- **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 (formerly 14-day) flexural strength of each mix are required. See Section 1000 of the 2006 Standard Specifications 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. If you change an aggregate source, you need to submit strength data.

- **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 Physical Testing Engineer for instructions.

- Question: My ACI Certification is good for another year, but my Field Technician certification expired this year. May I continue to test concrete and batch concrete for another year (provided my Batch Certification is good for another year)?

Answer: While the ACI certification may still be current, NCDOT requires a current Field Technician certification for testing sampling and producing concrete. The ACI is a component of the Field Technician certification. If the technician is currently batch certified, batching can continue as long as the certification is active.

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

Answer: The designated person submitting the mix design must be Mix Design certified.

- Question: My truck driver who is field tech certified informed me the concrete was not sampled properly during acceptance testing by project personnel. What should I do?

Answer: Once an error of this type is exposed, immediately notify the project personnel. In addition, inform the M&T Concrete Technician of the problem. Document the specific procedure you feel was run incorrectly. Keep a record including date, ticket number, project, and structure where the concrete is placed.

- Question: Do I physically have to be present in the batch room when concrete is batched for a NCDOT project? May I be on the premises, monitoring the batch process via two-way radio?

Answer: The batcher must be physically present during batching of concrete on a NCDOT project. The certified batcher should be the one actually batching the concrete, not supervising someone who is not certified.

- 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 concrete technician 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. I am required to have copy of the mix design when I batch concrete. What has happened to my copy?

  Answer: The contractor is actually the party that submits the mix design through the DOT Engineer responsible for the project to the Physical Testing Engineer. The Physical Testing Engineer returns the approved mix design to the DOT Engineer, who in turn returns the approved mix design to the contractor.

- **Question:** The mix I batched is stronger than the mix design approved. Why is this a problem?

  Answer: Strength is one measure of acceptance for DOT concrete. There are also durability issues. Approval of a mix design is based on several factors, including history of the performance of the mix submitted. Once approval is granted, deviating from the approved mix design creates an unknown product.
Alkali-Silica Reactive Aggregates

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 0.4 %, as required by Section 1024-1(A) 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:

<table>
<thead>
<tr>
<th>Owner</th>
<th>Location</th>
<th>Quarry Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanson</td>
<td>Princeton</td>
<td>CA 64</td>
</tr>
<tr>
<td>Martin Marietta</td>
<td>Pomona</td>
<td>CA 51</td>
</tr>
<tr>
<td></td>
<td>Thomasville</td>
<td>CA 102</td>
</tr>
<tr>
<td>Vulcan</td>
<td>Gold Hill</td>
<td>CA 85</td>
</tr>
</tbody>
</table>

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

| Martin Marietta| Asheboro       | CA 30         |
|                | Bakers         | CA 32         |
| Vulcan         | Havre de Grace | CA 345        |
|                | (Maryland)     |               |
ASSESSING NCDOT TEST RESULT FROM M&T WEB PAGE

The written tests will not be graded in the classroom. To learn the test result, assess the M&T web site one week after the test date to view score. A letter with the test results and the Batch Certificate will be mailed out two weeks after the test date. Batch Certificate will be granted based on successful completion of the class to Technicians currently Concrete Field Technician certified. Directions to access the M&T web site are below.

- Type [www.ncdot.org/~mtu](http://www.ncdot.org/~mtu) in the web address bar

- Click on Concrete Certification School
- Navigate down page to view certification grades
- 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
Section I

Basics of Mix Design
ABBREVIATIONS

- Specific Gravity = SG
- Weight = Wt. or lbs
- Cubic Yards = cy or yd³
- Cubic Feet = cf or ft³
- 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

CONVERSIONS

- 1 cubic foot = 7.5 gallons
- 1 gallon of water = 8.33 pounds
- 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: \[ \text{Ratio} = \frac{\text{Term 1}}{\text{Term 2}} \]
Term 1 is 300 lbs water and Term 2 is 600 lbs cement
\[ W/C = \frac{300}{600} = 0.500 \]

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: \[ \text{Term 1} = \text{Term 2} \times \text{Ratio} \]
Term 2 is 600 lbs cement and W/C is .500
Term 1 = amount of water
\[ 600 \times .500 = 300 \text{ lbs of water} \]

Ratio Rule 3: \[ \text{Term 2} = \frac{\text{Term 1}}{\text{Ratio}} \]
Term 1 is 300 lbs of cement and W/C is .500
Term 2 = amount of cement
\[ 300 / .500 = 600 \text{ lbs of cement} \]

Example 1

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

Answer: \[ w/c = \frac{285}{500} = .570 \]

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: \[ w/cm = \frac{300}{(360 + 100 + 200)} = .4545 \]
**Example 3**

Determine the mixing water weight given:

- w/c ratio requirement = .400
- cement factor = 620 Lbs

Answer: \[620 \times .400 = 248\] 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 \times 8.33 = 267 Lbs
\[\frac{\text{w/c}}{\text{cement}} = \frac{267}{517} = .516\]

**Water / Cementitious Problem**

- Cement used in Mix – 436 Lbs
- Fly Ash used in Mix – 131 Lbs
- Maximum Water – 36.0 gals
- Total Water – 33.5 gals
- Metered Water – 27.5 gals
- Free Water in aggregates – 50 Lbs

Determine the design water / cementitious ratio

Determine the maximum allowable water / cementitious ratio
AGGREGATE MOISTURE CONDITIONS

Moisture Conditions

State

- Ovendry
  - None
- Air dry
  - Less than potential absorption
- Saturated, surface dry
  - Equal to potential absorption
- Damp or wet
  - Greater than absorption

Total moisture

Total Moisture = Free (surface) Moisture + Absorbed Moisture

Methods used to determine moisture content

- Oven or Hot Plate
  - Results in total moisture, need to adjust for absorption
  - Performed on fine or coarse aggregate

- Chapman Flask
  - Determines free moisture volumetrically
  - Calculate or use chart, need to know specific gravity
  - Dependent on sand cleanliness

- Speedy Moisture Meter
  - Determines fine aggregate free moisture based on gas produced from reaction
  - Use manufacturer’s adjustment value

- Towel Dry
  - Performed on coarse aggregate to determine free moisture by weight
  (dependent on aggregate cleanliness and less accurate)
**Percent Absorption**

\[
\% \text{ Absorption} = \left( \frac{\text{Weight of Absorbed Water}}{\text{Dry Weight of Aggregate}} \right) \times 100
\]

\[
\% \text{ Absorption} = \left( \frac{\text{SSD Wt of Aggregate} - \text{Dry Wt of Aggregate}}{\text{Dry Weight of Aggregate}} \right) \times 100
\]

**Absorption Example**

SSD Wt of sample = 2046 grams  
Dry Wt of sample = 1989 grams

\[
\% \text{ Absorption} = \left( \frac{2046 - 1989}{1989} \right) \times 100
\]

\[= .029 \times 100 = 2.9\%
\]

Wt of Absorbed Water = 2046 – 1989 = 57 grams

**% Total Moisture**

\[
\% \text{ Total Moisture} = \left( \frac{\text{Total Wt of Water}}{\text{Dry Wt of Agg}} \right) \times 100
\]

\[
\% \text{ Total Moisture} = \left( \frac{\text{Wet Wt of Agg} - \text{Dry Wt of Agg}}{\text{Dry Wt of Agg}} \right) \times 100
\]

**Total Moisture Example**

Wet Wt of sample = 847 grams  
Dry Wt of sample = 792 grams

\[
\% \text{ Total Moisture} = \left( \frac{847 - 792}{792} \right) \times 100
\]

\[= .69 \times 100 = 6.9\%
\]

Total Wt of Water = 847 – 792 = 55 grams
Percent Free Moisture

\[
\% \text{ Free Moisture} = \% \text{ Total Moisture} - \% \text{ Absorption}
\]

\[
\text{Wt of Free Moisture} = \text{Wt of Total Water} - \text{Wt of Absorbed Water}
\]

Example

If a stone has an absorption of 1.6% and the total moisture content of a sample is determined to be 2.5%, what is the free moisture.

\[
\text{Percent Free Moisture} = 2.5\% - 1.6\% = 0.9\%
\]
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 = .498 cf

   Dry Rodded Unit Weight = 52.2 / .498 = 104.82 pcf

Bulk or loose 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

\[
\frac{\text{Dry Rodded Unit Weight}}{(\text{Specific Gravity}) \times 62.4} \times 100
\]

% Voids = 100 - % Solids

Example

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

% Solids = \left( \frac{104.82}{2.78 \times 62.4} \right) \times 100 = 60\%

% Voids = 100 - 60 = 40\%
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 1/2”, 3/4” 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

<table>
<thead>
<tr>
<th>Sieve No.</th>
<th>Size of Opening</th>
</tr>
</thead>
<tbody>
<tr>
<td>6”</td>
<td>6.0”</td>
</tr>
<tr>
<td>3”</td>
<td>3.0”</td>
</tr>
<tr>
<td>1 1/2”</td>
<td>1.5”</td>
</tr>
<tr>
<td>3/4”</td>
<td>0.75”</td>
</tr>
<tr>
<td>3/8”</td>
<td>0.375”</td>
</tr>
<tr>
<td>#4</td>
<td>0.187”</td>
</tr>
<tr>
<td>#8</td>
<td>0.093”</td>
</tr>
<tr>
<td>#16</td>
<td>0.047”</td>
</tr>
<tr>
<td>#30</td>
<td>0.0234”</td>
</tr>
<tr>
<td>#50</td>
<td>0.0117”</td>
</tr>
<tr>
<td>#100</td>
<td>0.0059”</td>
</tr>
</tbody>
</table>
Effect of Particle Size on Aggregate Surface Area

- Side = 1
  - Surface = 6
  - Volume = 1
  - Surface/Volume = 6

- Side = 2
  - Surface = $2^2 \times 6 = 24$
  - Volume = $2^3 = 8$
  - Surface/Volume = 3

- Side = 3
  - Surface = $3^2 \times 6 = 54$
  - Volume = $3^3 = 27$
  - Surface/Volume = 2
Stockpile – Aggregates
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

<table>
<thead>
<tr>
<th>Nominal Maximum Size Of Particles</th>
<th>Minimum Mass of Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>Kg.</td>
</tr>
<tr>
<td>9.5 3/8”</td>
<td>1 kg (2)</td>
</tr>
<tr>
<td>12.5 1/2”</td>
<td>2kg (4)</td>
</tr>
<tr>
<td>19.0 3/4”</td>
<td>5 kg (11)</td>
</tr>
<tr>
<td>25.0 1”</td>
<td>10 kg (22)</td>
</tr>
<tr>
<td>37.5 1 ½”</td>
<td>15 kg (33)</td>
</tr>
</tbody>
</table>

Note: 1 Kg. = 1000 grams

Nominal Maximum Size, (of Aggregate) – The smallest sieve opening through which the entire amount of the aggregate is required 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>
<thead>
<tr>
<th>Sieve</th>
<th>Percent by Weight Passing Each Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Std Size</td>
</tr>
<tr>
<td>#57</td>
<td></td>
</tr>
<tr>
<td>#57M</td>
<td></td>
</tr>
<tr>
<td>#67</td>
<td>-</td>
</tr>
<tr>
<td>#78M</td>
<td>-</td>
</tr>
</tbody>
</table>

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 2.0% 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

<table>
<thead>
<tr>
<th>STD Size</th>
<th>1/2”</th>
<th>3/8”</th>
<th>#4</th>
<th>#8</th>
<th>#16</th>
<th>#30</th>
<th>#50</th>
<th>#100</th>
<th>#200</th>
</tr>
</thead>
<tbody>
<tr>
<td>2S</td>
<td>-</td>
<td>100</td>
<td>95-100</td>
<td>80-100</td>
<td>45-95</td>
<td>25-75</td>
<td>5-30</td>
<td>0-10</td>
<td>0-3</td>
</tr>
<tr>
<td>2MS</td>
<td>-</td>
<td>100</td>
<td>95-100</td>
<td>80-100</td>
<td>45-95</td>
<td>25-75</td>
<td>5-35</td>
<td>0-20</td>
<td>0-8*</td>
</tr>
</tbody>
</table>

- 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 $110\degree\pm5\degree C$, (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 than 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 $110\degree\pm5\degree C$, (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:

<table>
<thead>
<tr>
<th>Nominal Maximum Size</th>
<th>Minimum Mass, grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75 mm (No.4) or smaller</td>
<td>300</td>
</tr>
<tr>
<td>9.5 mm (3/8 in.)</td>
<td>1000</td>
</tr>
<tr>
<td>19 mm (3/4 in.)</td>
<td>2500</td>
</tr>
<tr>
<td>37.5 mm (1 ½ in.)</td>
<td>5000</td>
</tr>
</tbody>
</table>

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

\[
\frac{514.0 \text{ grams} - 504.9 \text{ grams}}{514.0 \text{ grams}} \times 100 = 1.8\%
\]
9.1 gr
\[ \frac{\text{-----------}}{514.0 \text{ gr}} \times 100 = 0.0177 \times 100 = 1.8\% \text{ Passing} \]

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>% Passing</th>
<th>NCDOT Specs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>1.8</td>
<td>0-3</td>
</tr>
</tbody>
</table>

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

\[
\frac{(514.0 - 504.9)}{514.0} \times 100 = 1.8\%
\]

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grams Retained</th>
<th>Cumulative Gr.Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NCDOT (％ Passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>#4</td>
<td>15.4</td>
<td>15.4</td>
<td>3</td>
<td>97</td>
<td>95-100</td>
</tr>
<tr>
<td>#8</td>
<td>36.0</td>
<td>51.4</td>
<td>10</td>
<td>90</td>
<td>80-100</td>
</tr>
<tr>
<td>#16</td>
<td>102.8</td>
<td>154.2</td>
<td>30</td>
<td>70</td>
<td>45-95</td>
</tr>
<tr>
<td>#30</td>
<td>103.4</td>
<td>257.6</td>
<td>50</td>
<td>50</td>
<td>25-75</td>
</tr>
<tr>
<td>#50</td>
<td>159.3</td>
<td>416.9</td>
<td>81</td>
<td>19</td>
<td>5-30</td>
</tr>
<tr>
<td>#100</td>
<td>71.4</td>
<td>488.3</td>
<td>95</td>
<td>5</td>
<td>0-10</td>
</tr>
<tr>
<td>Pan</td>
<td>16.6</td>
<td>504.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sieve #200</th>
<th>Washing method</th>
<th>Percent Passing</th>
<th>NCDOT Specs. (% Passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>washing method</td>
<td>1.8</td>
<td>0-3</td>
</tr>
</tbody>
</table>
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”, #4, #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:

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

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

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

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NCDOT (% passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#3/8</td>
<td>100 - 0 = 100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>#4</td>
<td>100 - 3 = 97</td>
<td></td>
<td>95-100</td>
</tr>
</tbody>
</table>

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
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

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grams Retained</th>
<th>Cumulative Gr.Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NC DOT (% passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8”</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>95-100</td>
</tr>
<tr>
<td>#8</td>
<td>26.2</td>
<td>26.2</td>
<td>80</td>
<td>95-100</td>
<td></td>
</tr>
<tr>
<td>#16</td>
<td>113.6</td>
<td>140.6</td>
<td>45</td>
<td>45-90</td>
<td></td>
</tr>
<tr>
<td>#30</td>
<td>133.0</td>
<td>273.6</td>
<td>25</td>
<td>25-75</td>
<td></td>
</tr>
<tr>
<td>#50</td>
<td>162.1</td>
<td>435.7</td>
<td>5</td>
<td>5-30</td>
<td></td>
</tr>
<tr>
<td>#100</td>
<td>73.2</td>
<td>508.9</td>
<td>0</td>
<td>0-10</td>
<td></td>
</tr>
<tr>
<td>Pan</td>
<td>6.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Sieve Retained Grams</th>
<th>Cumulative Gr. Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NC DOT (% passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8”</td>
<td>0</td>
<td></td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>11.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td>20.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#16</td>
<td>105.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#30</td>
<td>85.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#50</td>
<td>180.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#100</td>
<td>88.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pan</td>
<td>26.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#200</td>
<td>(washing method)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percent Passing | NC DOT Specs. (% passing)

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

<table>
<thead>
<tr>
<th>Sieve Size 3/8”</th>
<th>Grams Retained</th>
<th>Cumulative Gr.Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NC DOT (% passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#4</td>
<td>6.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td>62.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#16</td>
<td>114.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#30</td>
<td>161.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#50</td>
<td>97.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#100</td>
<td>51.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pan</td>
<td>8.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percent Passing | NCDOT Specs. (% passing)

#200 (washing method)

Does this 2MS sand meet NCDOT specifications? _____________________
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 a ready mix concrete plant. **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 %.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>lbs. Retained</th>
<th>Cumulative lbs. Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NC DOT (% passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1”</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/4”</td>
<td>3.8</td>
<td>3.8</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>3/8”</td>
<td>23.6</td>
<td>23.6</td>
<td>6.6</td>
<td>6.6</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>7.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pan</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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 %.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>lbs. Retained</th>
<th>Cumulative lbs.Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NC DOT (% passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ½”</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1”</td>
<td>1.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>½”</td>
<td>24.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>6.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pan</td>
<td>.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percent Passing | NCDOT Specs. (% passing)
--- | ---
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 1/2”, 3/4”, 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 than 3.1 – nor should it vary by more than 0.20 from batch to batch.

**Fineness Modulus Ranges**

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>COARSE SAND</td>
<td>2.80 – 3.10</td>
</tr>
<tr>
<td>MEDIUM SAND</td>
<td>2.50 – 2.80</td>
</tr>
<tr>
<td>FINE SAND</td>
<td>2.30 - 2.50</td>
</tr>
</tbody>
</table>

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-rodced 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-rodced 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.

**Recommended Practice for Selecting Proportions for Concrete – ACI 211**

Proportions shall be computed on the basis of the absolute volume. The 10 % adjustment allowed in Table 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 5.3.6**

*Volume of Coarse Aggregate Per Unit of Volume of Concrete*

<table>
<thead>
<tr>
<th>Nominal Maximum size of aggregate</th>
<th>Volume of Dry-rodded coarse aggregate* per unit Volume of Concrete for Different Fineness Moduli of Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>Fineness Modulus of Sand</td>
</tr>
<tr>
<td>3/8”</td>
<td></td>
</tr>
<tr>
<td>1/2”</td>
<td></td>
</tr>
<tr>
<td>3/4”</td>
<td></td>
</tr>
<tr>
<td>1”</td>
<td></td>
</tr>
<tr>
<td>1 1/2”</td>
<td></td>
</tr>
<tr>
<td>2”</td>
<td></td>
</tr>
<tr>
<td>3”</td>
<td></td>
</tr>
</tbody>
</table>

* 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. For less workable concrete, such as those required for concrete pavement construction, the volumes may be increased about 10%. When concrete placement is to be by pump, then the volumes should be reduced by about 10%.
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

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

Calculations:

1.) Sieve # 3/8” = \frac{0}{514.8} = 0.0 \times 100 = 0

2.) Sieve # 4 = \frac{15.1}{514.8} = 0.029 \times 100 = 3

3.) Sieve # 8 = \frac{50.4}{514.8} = 0.098 \times 100 = 10

4.) Sieve # 16 = \frac{119.9}{514.8} = 0.233 \times 100 = 23
5.) Sieve # 30  =  \frac{289.1}{514.8} = 0.562 \times 100 = 56

6.) Sieve # 50  =  \frac{434.2}{514.8} = 0.843 \times 100 = 84

7.) Sieve # 100 =  \frac{490.9}{514.8} = 0.954 \times 100 = 95

8.) Pan  =  504.0

The fineness modulus, (FM), is defined mathematically as the sum of the cumulative percentages retained 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.
Sieve Analysis Worksheet

Sample Information:
Sample Type: ____________________________

Oven Dry Weight Before Washing:_____________________________ grams
Oven Dry Weight After Washing No.200 Sieve:______________________ grams

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grams Retained</th>
<th>Cumulative Gr.Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NCDOT Specs % passing</th>
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<tbody>
<tr>
<td>6”</td>
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<tr>
<td>Pan</td>
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</tbody>
</table>

200 Sieve__________________ (washing method)________________________ % Passing

Does this sample meet NCDOT Specifications, (Yes or No)?__________
What is the Fineness Modulus of this material?_____________________
What is the coarseness, (Fine, Medium, or Coarse)?_________________
Sieve Analysis Worksheet

Sample Information:

Sample Type: ____________________________

Oven Dry Weight Before Washing: ____________________________ grams
Oven Dry Weight After Washing No. 200 Sieve: ____________________________ grams

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grams Retained</th>
<th>Cumulative Gr. Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NCDOT Specs % passing</th>
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</tbody>
</table>

200 Sieve__________ (washing method)______________________________

% Passing

Does this sample meet NCDOT Specifications, (Yes or No)?_______________
What is the Fineness Modulus of this material?_________________________
What is the coarseness, (Fine, Medium, or Coarse)?_____________________


## Sieve Analysis Worksheet

**Sample Information:**

Sample Type: ____________________________

Oven Dry Weight Before Washing: ____________________________ grams

Oven Dry Weight After Washing No.200 Sieve: ____________________________ grams

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grams Retained</th>
<th>Cumulative Gr.Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
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</tr>
</thead>
<tbody>
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<td>Pan</td>
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</tr>
</tbody>
</table>

200 Sieve_________ (washing method)______________ % Passing

Does this sample meet NCDOT Specifications, (Yes or No)?________________

What is the Fineness Modulus of this material? ____________________________

What is the coarseness, (Fine, Medium, or Coarse)? ____________________________
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 determined 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

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grams Retained</th>
<th>Cumulative Gr.Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NCDOT Specs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8”</td>
<td>0</td>
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<tr>
<td>#4</td>
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<tr>
<td>#8</td>
<td>24.9</td>
<td></td>
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<td></td>
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<td>149.0</td>
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<td>114.6</td>
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<td>#50</td>
<td>143.3</td>
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<td>93.6</td>
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<tr>
<td>Pan</td>
<td>33.0</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

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? _________________________________
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) = 520.5 grams  
Oven Dry Weight, (after washing No.200 sieve) = 500.3 grams

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grams Retained</th>
<th>Cumulative Gr.Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NCDOT Specs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8”</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>#4</td>
<td>36.3</td>
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<tr>
<td>#8</td>
<td>41.5</td>
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<tr>
<td>#16</td>
<td>197.0</td>
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<tr>
<td>#30</td>
<td>46.7</td>
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<tr>
<td>#50</td>
<td>67.4</td>
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<td>93.3</td>
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<tr>
<td>Pan</td>
<td>18.1</td>
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</tr>
</tbody>
</table>

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 ready mix plant. 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

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grams Retained</th>
<th>Cumulative Gr.Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NCDOT Specs. (% passing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8”</td>
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<td>12.7</td>
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<td>188.7</td>
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<tr>
<td>Pan</td>
<td>13.1</td>
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</tbody>
</table>

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?_______________________________
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

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Grams Retained</th>
<th>Cumulative Gr. Retained</th>
<th>Cumulative % Retained</th>
<th>Percent Passing</th>
<th>NCDOT Specs. (% passing)</th>
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<tbody>
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<tr>
<td>Pan</td>
<td>16.1</td>
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</tbody>
</table>

Percent Passing
NCDOT Specs. (% passing)

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.

**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, (DENSITY)**: 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.

\[
\begin{align*}
1 \text{ cu.ft. of water} & = 62.4 \text{ pounds} \\
1 \text{ gallons of water} & = 8.33 \text{ pounds}
\end{align*}
\]

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

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.

Weight of sample in water

Figure 1
Since aggregates do not generally occur in convenient shapes such as cubes, it can be difficult to determine the specific gravity of the aggregate. The weight is easy enough to determine. There are two acceptable methods that can be used to determine the volume.

Method A

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.
Method B

Weigh the material in air. Pour water into a calibrated flask and be sure to note the original volume. Then pour the material into the flask also, noting the new reading on the flask. The volume of the material will displace an equal volume of water. You can then subtract the water volume from the water and material volume. Divide this number into the weight of the material in air to get the specific gravity. 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.
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.

\[
\text{Pounds of Water} = 288
\]

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

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).

\[
\text{Gallons of Water} = 34.6
\]

\[
\text{Absolute Volume of Water} = \frac{34.6}{7.5} = 4.61 \text{ cu.ft.}
\]
Calculations for determining the absolute volume of each ingredient are shown in the following mix design:

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td>588</td>
<td>588</td>
<td>3.15 X 62.4 = 2.99</td>
</tr>
<tr>
<td># 57 Stone</td>
<td>2.65</td>
<td>1808</td>
<td>1808</td>
<td>2.65 X 62.4 = 10.93</td>
</tr>
<tr>
<td>Sand</td>
<td>2.63</td>
<td>1129</td>
<td>1129</td>
<td>2.63 X 62.4 = 6.88</td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td>286 (34.3 gallons)</td>
<td>286</td>
<td>1 X 62.4 = 4.58</td>
</tr>
<tr>
<td>Air (6 %)</td>
<td>.06</td>
<td></td>
<td>.06 X 27</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>3811 lbs.</td>
<td></td>
<td>27.00</td>
</tr>
</tbody>
</table>

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 × 8.33 = 285.72 lbs. of water

\[
\frac{286 \text{ lbs. of water}}{588 \text{ lbs. of cement}} = 0.486 \text{ lbs. of water/lb. of cement}
\]

Calculated Unit Weight = \(\frac{3811 \text{ lbs.}}{27.00 \text{ cu.ft.}}\) = 141.148 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:

\[
\frac{(\text{Weight of Concrete} + \text{Weight of the Bucket}) - \text{Weight of Bucket}}{\text{Volume of the Bucket}} = \text{Unit weight of Fresh Concrete}
\]

Example:

- Weight of Unit Weight Bucket: 23.2 lbs.
- Volume of Bucket: .51 cu.ft.
- Weight of Concrete and Bucket: 94.8 lbs.

\[
\frac{94.8 - 23.2}{.51} = 140.39 \text{ lbs. /cu.ft (Actual Unit Weight)}
\]

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:
Theoretical Unit weight - Actual Unit Weight

\[ \frac{\text{Theoretical Unit Weight}}{\text{Actual Unit Weight}} \times 100 = \text{Percent Air} \]

(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

\[ 25.38 \text{ cu.ft. of concrete mix without air} \]

Step 2

3811 lbs. of material in the concrete mix

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

(Theoretical unit weight) Air Free

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

\[ T = \text{Theoretical Unit Weight} \]
\[ A = \text{Actual field Unit Weight} \]

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

\[ \frac{150.16 - 140.39}{150.16} \times 100 = 6.5 \text{ Percent Air} \]
Checking the Yield of a Mix

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

**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:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>lbs./batch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Stone</td>
<td>18080</td>
</tr>
<tr>
<td>Wet Sand</td>
<td>12760</td>
</tr>
<tr>
<td>Cement</td>
<td>6006</td>
</tr>
<tr>
<td>Admixture</td>
<td>5 (can be included w/water)</td>
</tr>
<tr>
<td>Water through Plant</td>
<td></td>
</tr>
<tr>
<td>230 gal. X 8.33 lbs./gal</td>
<td>1916</td>
</tr>
<tr>
<td>Water through Truck</td>
<td></td>
</tr>
<tr>
<td>10 gal. X 8.33 lbs./gal</td>
<td>83</td>
</tr>
<tr>
<td>(no water in drum before charging)</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL WEIGHT</strong></td>
<td>38850 lbs.</td>
</tr>
</tbody>
</table>

Air Content by Pressure Meter = 5.2%

Unit Weight of Fresh Concrete (Field Unit Weight) = 140.5 lbs./cu.ft.

Yield in cu.ft. = \( \frac{38850 \text{ lbs.}}{140.5 \text{ lbs./cu.ft.}} \) = 276.5 cu.ft. (Actually Batched)
Yield in Cubic Yards  \[= \frac{276.5 \text{ cu.ft./batch}}{27.00 \text{ cu.ft/cu/yd}} = 10.24 \text{ cu.yds}\]

This batch is over yielded by .65 cu.yds. The goal is a 27 cu.yds. batch. Our actual, according to the calculations is 27.65 cu.yds.

\[
\begin{align*}
27.65 \text{ cu.yds.} \\
- \quad 27.00 \text{ cu. yds.} \\
\hline
.65 \text{ cu.yds. \ over yield}
\end{align*}
\]

NOTE: Measured air content is not used in the calculations.
Measured air is accounted for in the unit weight.
## Weight – Volume Worksheet

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor: ____________ (lbs. Cement / Yd³)

Water/Cement Ratio: ____________

Unit Weight: ____________ (pcf)

Field Unit Weight: ____________ (pcf)

% Air by Unit Weight Method: ____________ (%)
# Weight – Volume Worksheet

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor: _____________(lbs. Cement / Yd³)

Water/Cement Ratio: ______________

Unit Weight: ______________(pcf)

Field Unit Weight: ______________(pcf)

% Air by Unit Weight Method: ______________( %)
### Weight – Volume Worksheet

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor: ______________(lbs. Cement / Yd³)

Water/Cement Ratio: ______________

Unit Weight: ______________(pcf)

Field Unit Weight: ______________(pcf)

% Air by Unit Weight Method: ______________( %)
Section VII

Study Questions and Problems

Weight / Volume Relationships
1. 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

2. The ratio of the amount of water to the amount of cement in a concrete mix is the __________?
   a. Water Reducing Agent
   b. Cement Factor
   c. Water – Cement Ratio
   d. Total Moisture

3. The volume of concrete, (in cubic feet, \( \text{ft}^3 \)) produced from one bag of cement is ______________?
   a. Specific Gravity
   b. Yield
   c. Absolute Volume
   d. Unit Weight

4. One gallon of water equals:
   a. 7.5 lbs.
   b. 27 lbs.
   c. 62.4 lbs.
   d. 8.33 lbs.

5. 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

6. 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

73
7. 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

8. The weight per unit volume of concrete is called ________________?
   a. Consistency
   b. Absolute Volume
   c. Unit Weight
   d. Yield

9. One cubic foot of water equals:
   a. 7.5 lbs.
   b. 8.33 lbs.
   c. 14.9 lbs.
   d. 62.4 lbs.
Determine the absolute volume of each ingredient in the following one cubic yard mix design of a Class A concrete.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td>564</td>
<td></td>
<td></td>
</tr>
<tr>
<td># 67 Stone</td>
<td>2.82</td>
<td>1966</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>2.62</td>
<td>1100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1.0</td>
<td>288</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor: ____________ Lbs

Water / Cement Ratio: ______________

Calculated Unit Weight: ______________ pcf

Field Unit Weight: 147.95 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.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td>714</td>
<td></td>
<td></td>
</tr>
<tr>
<td># 67 Stone</td>
<td>2.88</td>
<td>1940</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>2.62</td>
<td>1015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1.0</td>
<td>298</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor: _____________ Lbs

Water / Cement Ratio: _________________

Calculated Unit Weight: _________________ pcf

Field Unit Weight: 147.95 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.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td>545</td>
<td></td>
<td></td>
</tr>
<tr>
<td># 67 Stone</td>
<td>2.85</td>
<td>1853</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>2.60</td>
<td>1197</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1.0</td>
<td>300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designed air Content Air 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor: __________ Lbs

Water / Cement Ratio: _________________

Calculated Unit Weight: _________________ pcf

Field Unit Weight: 144.35 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 Field Unit Weight.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td>588</td>
<td></td>
<td></td>
</tr>
<tr>
<td># 67 Stone</td>
<td>3.04</td>
<td>1956</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>2.62</td>
<td>1228</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td>288</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designed Air Content 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor  ______________________ Lbs

Water / Cement Ratio  ______________________

Calculated Unit Weight  ______________________ pcf

Field Unit Weight  149.20 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 Field Unit Weight.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td>677</td>
<td></td>
<td></td>
</tr>
<tr>
<td># 67 Stone</td>
<td>2.79</td>
<td>1895</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>2.60</td>
<td>1081</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1.00</td>
<td>275</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designed Air Content 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor  
Water / Cement Ratio  
Calculated Unit Weight  
Field Unit Weight  147.10 pcf  
% Air by Unit Weight Method  

---------- Lbs  
------------------  
----------------- pcf
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 Field Unit Weight.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td>564</td>
<td></td>
<td></td>
</tr>
<tr>
<td># 67 Stone</td>
<td>2.85</td>
<td>1853</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>2.61</td>
<td>1187</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td>300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designed Air Content 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor
Water / Cement Ratio
Calculated Unit Weight
Field Unit Weight 141.50 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 Field Unit Weight.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td>639</td>
<td></td>
<td></td>
</tr>
<tr>
<td># 67 Stone</td>
<td>2.71</td>
<td>1782</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>2.63</td>
<td>1200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td>267</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designed Air Content 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor  

Water / Cement Ratio  

Calculated Unit Weight  

Field Unit Weight 144.62 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 Field Unit Weight.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sp.Gravity</th>
<th>Weight,(lbs.)</th>
<th>Calculations</th>
<th>Abs.Volume,(ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td>564</td>
<td></td>
<td></td>
</tr>
<tr>
<td># 67 Stone</td>
<td>2.78</td>
<td>1948</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>2.64</td>
<td>1100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td>287</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Air Content 6 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cement Factor: ______________________ Lbs

Water / Cement Ratio: ______________________

Calculated Unit Weight: ______________________ pcf

Field Unit Weight: 144.20 pcf

% Air by Unit Weight Method: ______________________
Section VIII

Cement, SCM’s, and Admixtures
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 (C₃S), Calcium aluminates (C₃A), and Tetracalcium aluminoferrite (C₄AF). 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 (Na₂Oeq) 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 m²/kg to 400 m²/kg for Type I and II cements to as high as 700 m²/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>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Normal</td>
</tr>
<tr>
<td>II</td>
<td>Moderate sulfate resistance</td>
</tr>
<tr>
<td>III</td>
<td>High early strength</td>
</tr>
<tr>
<td>IV</td>
<td>Low heat of hydration</td>
</tr>
<tr>
<td>V</td>
<td>High sulfate resistance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pozzolan</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class F Fly Ash</td>
<td>20% by weight of required cement content with 1.2 lb Class F fly ash per lb of cement replaced</td>
</tr>
<tr>
<td>Ground Granulated Blast Furnace Slab</td>
<td>35%-50% by weight of required cement content with 1.0 lb slag per lb of cement replaced</td>
</tr>
<tr>
<td>Microsilica</td>
<td>4%-8% by weight of required cement content With 1.0 lb microsilica per lb of cement replaced</td>
</tr>
</tbody>
</table>

**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>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS</td>
<td>Portland blast-furnace slag cement</td>
</tr>
<tr>
<td>IP</td>
<td>Portland-pozzolan cement</td>
</tr>
<tr>
<td>IL</td>
<td>Portland-limestone cement</td>
</tr>
<tr>
<td>IT</td>
<td>Ternary blended cement</td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th>Cement specification</th>
<th>General purpose</th>
<th>High early strength</th>
<th>Moderate heat of hydration</th>
<th>Low heat of hydration</th>
<th>Moderate sulfate resistance</th>
<th>High sulfate resistance</th>
<th>Resistance to alkali-silica reaction (ASR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM C150 AASHTO M85 portland cements</td>
<td>I</td>
<td>III</td>
<td>II(MH)</td>
<td>IV</td>
<td>II, II(MH)</td>
<td>V</td>
<td>Low-alkali option</td>
</tr>
<tr>
<td>ASTM C595 AASHTO M240 blended hydraulic cements</td>
<td>IS(&lt;70)</td>
<td>IL</td>
<td>IT</td>
<td>IP(MH)</td>
<td>IP(MH)</td>
<td>IP(MH)</td>
<td>IP(MH)</td>
</tr>
<tr>
<td>ASTMC1157 hydraulic cements</td>
<td>GU</td>
<td>HE</td>
<td>MH</td>
<td>LH</td>
<td>MS</td>
<td>HS</td>
<td>Option R</td>
</tr>
</tbody>
</table>

*Adapted from Kosmatka and Wilson (2011).

*Check the local availability of specific cements as all cements are not available everywhere.

*The option for low reactivity with ASR-susceptible aggregates can be applied to any cement type in the columns to the left.

*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
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

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Water-Reducing</td>
</tr>
<tr>
<td>B</td>
<td>Retarding</td>
</tr>
<tr>
<td>C</td>
<td>Accelerating</td>
</tr>
<tr>
<td>D</td>
<td>Water-Reducing &amp; Retarding</td>
</tr>
<tr>
<td>E</td>
<td>Water-Reducing &amp; Accelerating</td>
</tr>
<tr>
<td>F</td>
<td>Water-Reducing, High-Range</td>
</tr>
<tr>
<td>G</td>
<td>Water-Reducing, High-Range &amp; Retarding</td>
</tr>
<tr>
<td>S</td>
<td>Specific Performance</td>
</tr>
</tbody>
</table>

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. One of these technologies is demonstrated in the picture below.
Fig 1. High Flow Concrete Self Consolidating Concrete

Spread = 18 - 30+ in. Assured stability, non-segregating self-consolidating without vibration which demonstrates excellent engineering properties, structural integrity, and durability.

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>
<thead>
<tr>
<th>Temperature</th>
<th>Setting Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 F</td>
<td>6 Hours</td>
</tr>
<tr>
<td>60 F</td>
<td>8 Hours</td>
</tr>
<tr>
<td>50 F</td>
<td>11 Hours</td>
</tr>
<tr>
<td>40 F</td>
<td>14 Hours</td>
</tr>
<tr>
<td>30 F</td>
<td>19 Hours</td>
</tr>
<tr>
<td>20 F</td>
<td>Set does not occur - concrete will freeze</td>
</tr>
</tbody>
</table>

Table 2. Setting Time of Concrete at Various Temperatures

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.
Section IX

ACI CONCRETE MIX DESIGN
The 2006 Standard Specification reads as follows:

Composition and Design:

Provide concrete of the class called for by the plans or specifications. Submit proposed mix designs for each class of concrete to be used in the work. Have mix proportions determined by a testing laboratory which has been approved by the N.C. Division of Highways and base them on laboratory trial batches meeting the requirements of Table 1000-1 and other applicable sections of these specifications. Determine the quantities of fine and coarse aggregate necessary to provide concrete meeting the requirements of the specifications by the method described in ACI211, “Recommended Practice for Selecting Proportions for Normal weight Concrete”, using the absolute volume basis.

Submit mix designs in terms of saturated surface dry weights on M & T Form 312 at least 35 days prior to using the proposed mix. If the concrete is to be placed by pumping, note it on Form 312. 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 have been determined to be acceptable for use.

Accompany Form 312 with a listing of laboratory test results of aggregate gradation, air content, slump, and compressive strength. List the compressive strength of at least three 6” x 12” or 4” x 8” cylinders at the age of 7 and 28 days. Perform laboratory tests in accordance with the following test procedures:

<table>
<thead>
<tr>
<th>Test Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate Gradation</td>
</tr>
<tr>
<td>Air Content</td>
</tr>
<tr>
<td>Slump</td>
</tr>
<tr>
<td>Compressive Strength</td>
</tr>
</tbody>
</table>
When the combination of materials is such that the compressive strength and/or a workable slump can not be obtained at the minimum specified cement content with the maximum allowable water-cement ratio, increase the cement content at no cost to the Department by whatever amount is required to produce the required strength and/or slump without exceeding the allowable water-cement ratio.

The Engineer will review the mix design only to ascertain general compliance with specification requirements. After this review has been completed, the Engineer will notify the Contractor in writing that the mix design is either acceptable or unacceptable. Do not use the mix until written notice has been received. Acceptance of the mix design does not relieve the Contractor of his responsibility to furnish an end-product meeting specification requirements. Upon request from the Contractor, a mix design accepted and used satisfactorily on any Department of Transportation project may be accepted for use on other projects.
ACI Concrete Mix Design

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

Example:

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

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.

\[
6.00 \text{ bags of cement} \times 94 \text{ lbs. per bag} = 564 \text{ lbs. / cu.yd.}
\]
**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 times heavier than water). Using the specific gravity we can find the weight of one solid cubic foot of cement.

\[
3.15 \times 62.4 \text{ lbs. of water/ cu.ft.} = 196.56 \text{ lbs./cu.ft.}
\]

**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 312
      (The concrete mix design form)
   c. ACI Mix Design worksheet
   d. Know the source of all materials going into the mix.
      **The five basic ingredients of concrete** are:
      - Cement
      - Fine Aggregate
      - Coarse Aggregate
      - Water
      - Air – (no, you do not have to know the source for this)

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.
Example:

Using the ACI worksheet provided, design a NCDOT Class A 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:** .532 lbs. of water per lbs. of cement (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” 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-roddeed 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

\[
\frac{564}{3.15 \times 62.4} = 2.87 \text{ cu.ft./cu.yd.}
\]

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:

\[
300 \text{ lbs. of water} \times 0.532 = 36.0 \text{ gals of water per cu.yd.} \quad 8.33 \text{ (weight of 1 gal of water)}
\]

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

\[
\frac{36.0 \text{ gallons/cu.yd.}}{7.5 \text{ gallons/cu.ft.}} = 4.80 \text{ cu.ft./cu.yd.}
\]

Air

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

\[
0.06 \times 27.00 \text{ cu.ft.} = 1.62 \text{ cu.ft./cu.yd.}
\]

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 of Volume of Concrete

<table>
<thead>
<tr>
<th>Nominal Maximum size of aggregate</th>
<th>Volume of Dry-rodded coarse aggregate* per unit Volume of Concrete for Different Fineness Moduli of Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>Fineness Modulus of Sand</td>
</tr>
<tr>
<td></td>
<td>2.30</td>
</tr>
<tr>
<td>3/8”</td>
<td>0.51</td>
</tr>
<tr>
<td>1/2”</td>
<td>0.60</td>
</tr>
<tr>
<td>3/4”</td>
<td>0.67</td>
</tr>
<tr>
<td>1”</td>
<td>0.72</td>
</tr>
<tr>
<td>1 1/2”</td>
<td>0.76</td>
</tr>
<tr>
<td>2”</td>
<td>0.79</td>
</tr>
<tr>
<td>3”</td>
<td>0.83</td>
</tr>
</tbody>
</table>

* 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 2.75 (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.

\[
0.62 \times 27 \text{ cu.ft.} = 16.74 \text{ cu.ft./cu.yd.} \quad \text{(This is the dry-rodded volume)}
\]

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.

\[
16.74 \text{ cu.ft./cu.yd.} \times 104.0 \text{ lbs./cu.ft.} = 1741 \text{ lbs. of coarse aggregate}
\]

(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.

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

**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.
<table>
<thead>
<tr>
<th>Design</th>
<th>Absolute Volume cu.ft./cu.yd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>564 lbs.</td>
</tr>
<tr>
<td>Water</td>
<td>36.0 gals.</td>
</tr>
<tr>
<td>Air</td>
<td>6 %</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>1741 lbs.</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

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.

\[
\text{volume of fine aggregate} = 27.00 \text{ cu.ft.} - 19.05 \text{ cu.ft.} = 7.95 \text{ cu.ft.}
\]

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:

\[
\text{volume of fine aggregate} \times \text{specific gravity of fine aggregate} \times 62.4 = \text{pounds of fine aggregate}
\]

\[
8.95 \text{ cu.ft.} \times 2.63 \times 62.4 = 1305 \text{ lbs. of fine aggregate/cu.yd.}
\]

The Class A Concrete Mix design of this mix is as follows:
<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>564 lbs.</td>
</tr>
<tr>
<td>Water</td>
<td>33.0 gals.</td>
</tr>
<tr>
<td>Air</td>
<td>6 %</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>1741 lbs.</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>1305 lbs.</td>
</tr>
</tbody>
</table>

This is how these ingredients will be listed on the NC DOT 312U form.
Example:  

ACI WORKSHEET  

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

FINE AGG:  G.S. Materials – Emery Pit  

COARSE AGG:  Vulcan Mat’ls-North Quarry  

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.  

DRY RODDED UNIT WEIGHT  

ABSOLUTE VOLUME  

FLY ASH:  none____ LBS.  =  0____ CU.FT./CU.YD.  

62.4  

CEMENT:  564____ LBS.  =  2.87____ CU.FT./CU.YD.  

3.15  X  62.4  

WATER:  532____ X  564  =  300.0____  =  36.0  GALS  =  4.8____ CU.FT./CU.YD.  

(MAX W/C)  x  LBS. OF CEMENT  8.33  

7.5  

AIR:  .06____ X  27  =  1.62____ CU.FT./CU.YD.  

COARSE AGG:  1741____ LBS.  =  9.76____ CU.FT./CU.YD.  

SP.GR.  2.86____ X  62.4  

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 Using Fly Ash

The 2012 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 20% by weight of the required cement. Substitute at the rate of at least 1.2 pounds of fly ash per pound of cement. 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.

The maximum water/cement ratio based on total cementitious materials is as follows for each class of concrete in the proportions required by table 1000-3.

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Rounded Aggregate</th>
<th>Angular Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>.366</td>
<td>.410</td>
</tr>
<tr>
<td>A</td>
<td>.469</td>
<td>.512</td>
</tr>
<tr>
<td>B</td>
<td>.469</td>
<td>.545</td>
</tr>
<tr>
<td>Pavement</td>
<td>.538</td>
<td>.538</td>
</tr>
</tbody>
</table>

Example Problem: Design a Class A Fly Ash mix using the South McDowell Quarry for # 57 stone and North Buncombe Quarry for fine aggregate.
Substitute Carbo, VA Fly Ash for 20% of the cement. Use 1.5 gallons less then the maximum allowable water.

Specific Gravity of Carbo Fly Ash: 2.26
South McDowell Quarry # 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.

\[
564 \text{ lbs.} - (564 \times .20) = 451.2 \text{ lbs. of cement/cu.yd.}
\]

**Fly Ash**

To get the pounds of fly ash needed:
Multiply 112.8 times 1.2, which computes to 135lbs. of fly ash.
(The 1.2 represents the 20 % + the whole.)

\[
112.8 \text{ lbs.} \times 1.2 = 135.4 \text{ lbs. of fly ash/cu.yd.}
\]

**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 + 135.4 lbs. of fly ash = 586.6 lbs.). This will give you 300 lbs. of water. Convert the pounds of water to gallons of water by dividing by 8.33 lbs./gal.. This gives you 36 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.

\[
(0.512 \times 586.6 \text{ lbs.}) / 8.33 - 1.5 \text{ gals.} = 34.6 \text{ gals/cu.yd.}
\]
Example w/ Fly Ash:  

ACI WORKSHEET

CLASS:  A – Vib. AE Fly Ash  MIX DESIGN

FINE AGG:  North Buncombe Quarry  COARSE AGG:  South McDowell Quarry

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

\[
\begin{align*}
0.69 \times 27 &= 18.63 \\
0.69 \times 99.5 &= 1854 \\
\end{align*}
\]

ABSOLUTE VOLUME

FLY ASH:  135.4 LBS.  =  136 CU.FT./CU.YD.  2.26 X 62.4

CEMENT:  451 LBS.  =  2.29 CU.FT./CU.YD.  3.15 X 62.4

WATER:  0.512 X 586.6 = 390 = 34.6 GAL = 4.61 CU.FT./CU.YD.  8.33 X 7.5

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

COARSE AGG:  1854 LBS.  =  10.80 CU.FT./CU.YD.  2.75 X 62.4

TOTAL:  20.28 CU.FT./CU.YD.

27.00 CU.FT./CU.YD.  -  20.28 CU.FT./CU.YD.  TOTAL

FINA AGG:  6.72 CU.FT./CU.YD.  X  2.82 X 62.4 = 1183 LBS./CU.YDS.  ↑(SP.GR.)

SUGGESTED QUANTITIES:

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLY ASH</td>
<td>136 LBS.</td>
<td></td>
</tr>
<tr>
<td>CEMENT</td>
<td>451 LBS.</td>
<td></td>
</tr>
<tr>
<td>WATER</td>
<td>34.6 GALS.</td>
<td></td>
</tr>
<tr>
<td>AIR</td>
<td>6 %</td>
<td></td>
</tr>
<tr>
<td>COARSE AGG.</td>
<td>1854 LBS.</td>
<td></td>
</tr>
<tr>
<td>FINE AGG.</td>
<td>1183 LBS.</td>
<td></td>
</tr>
</tbody>
</table>
## FOR INSTRUCTIONAL USE ONLY

### Quality of Fine Aggregate from Approved Sources

<table>
<thead>
<tr>
<th>Source - Material Producer</th>
<th>ID #</th>
<th>Owner or Sales Agent</th>
<th>Div</th>
<th>Date</th>
<th>Sp.Gr.</th>
<th>Abs.</th>
<th>3 Day</th>
<th>7 Day</th>
<th>Date</th>
<th>% Loss</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Materials</td>
<td>432</td>
<td>Richardson Mine</td>
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<td>7-29-08</td>
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<td>0.3</td>
<td>109.9</td>
<td>110.0</td>
<td>2S 7-29-08</td>
<td>0.9</td>
<td>2.37</td>
</tr>
<tr>
<td>Carolina Sand</td>
<td>329</td>
<td>Johnsonville Pit</td>
<td>6</td>
<td>3/12/08</td>
<td>2.65</td>
<td>0.3</td>
<td>117.8</td>
<td>125.1</td>
<td>2S 2/21/07</td>
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<td>2.42</td>
</tr>
<tr>
<td>G.S. Materials</td>
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<td>Emery Pit</td>
<td>8</td>
<td>7/10/08</td>
<td>2.63</td>
<td>0.5</td>
<td>128.3</td>
<td>132.8</td>
<td>2S 7/10/08</td>
<td>1.2</td>
<td>2.75</td>
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<tr>
<td>Hanson Inc.</td>
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<td>Pageland Quarry</td>
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<td>116.8</td>
<td>112.1</td>
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<td>Hedrick Industries</td>
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<td>Lilesville Pit</td>
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<td>2.60</td>
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<tr>
<td>Martin Marietta</td>
<td>104</td>
<td>Belgrade Quarry</td>
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<td>2.65</td>
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<td>Pretty Good Sand Co</td>
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<td>Great Pit</td>
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<td>126.6</td>
<td>122.4</td>
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<td>2.94</td>
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<td>Candor Pit</td>
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<td>135.8</td>
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<td>3.10</td>
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North Carolina Division of Highways
Quality of Coarse Aggregate from Approved Sources

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<th>Dry Rodded Unit Weight</th>
<th>Source ID #</th>
<th>Materials Producer</th>
<th>Div</th>
<th>Date</th>
<th>L.A. Wear % Loss Grading</th>
<th>Bulk (SSD) Sp. Gr. “B” Grading</th>
<th>Abs. Size</th>
<th>Date</th>
<th>Soundness % Loss at 5 Cycles</th>
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</thead>
<tbody>
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<tr>
<td><strong>Ararat Rock Products</strong></td>
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<td>Crabtree Quarry</td>
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<td>South McDowell Quarry</td>
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<td>1/4/07</td>
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<td>12/20/06</td>
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<td><strong>Vulcan Materials</strong></td>
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<td>67</td>
<td>2/12/07</td>
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</tbody>
</table>
Recommended Practice for Selecting Proportions for Concrete, (ACI 211)

Proportions shall be computed on the Absolute Volume basis.

ACI Table 5.3.6
Volume of Coarse Aggregate per Unit of Volume of Concrete

<table>
<thead>
<tr>
<th>Maximum Size of Aggregate in inches</th>
<th>Volume of Dry-rododed Coarse Aggregate* per Unit Volume of Concrete for the Different Finess Moduli of Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.30</td>
</tr>
<tr>
<td>3/8”</td>
<td>0.51</td>
</tr>
<tr>
<td>1/2”</td>
<td>0.60</td>
</tr>
<tr>
<td>3/4”</td>
<td>0.67</td>
</tr>
<tr>
<td>1”</td>
<td>0.72</td>
</tr>
<tr>
<td>1 1/2”</td>
<td>0.76</td>
</tr>
<tr>
<td>2”</td>
<td>0.79</td>
</tr>
<tr>
<td>3”</td>
<td>0.83</td>
</tr>
</tbody>
</table>

* Volumes are based on aggregate in dry-rododed 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 for usual reinforced construction. For less workable concrete, such as that which is required for concrete pavement construction, volumes may be increased about 10 percent. When placement is to be by pump, the volumes should be reduced about 10 percent.
<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Minimum compressive Strength at 28 days, psi</th>
<th>Maximum Water-Cement Ratio</th>
<th>Consistency Max. Slump, Inches</th>
<th>Cement Content, Lbs/Yd³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air-Entrained Concrete</td>
<td>Non Air-Entrained Concrete</td>
<td>Vibrated</td>
<td>Non-Vibrated</td>
</tr>
<tr>
<td></td>
<td>Rounded Aggregate</td>
<td>Angular Aggregate</td>
<td>Rounded Aggregate</td>
<td>Angular Aggregate</td>
</tr>
<tr>
<td>AA</td>
<td>4500</td>
<td>0.381</td>
<td>0.426</td>
<td>---</td>
</tr>
<tr>
<td>AA Slip Form</td>
<td>4500</td>
<td>0.381</td>
<td>0.426</td>
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</tr>
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<td>0.488</td>
<td>0.532</td>
<td>0.550</td>
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<td>B</td>
<td>2500</td>
<td>0.488</td>
<td>0.567</td>
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<tr>
<td>B Slip Form</td>
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<td>0.488</td>
<td>0.567</td>
<td>---</td>
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<td>0.420</td>
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<tr>
<td>Latex Modified</td>
<td>3000 (7day)</td>
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<td>0.400</td>
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<tr>
<td>Flowable Fill</td>
<td>150 (max. @ 56 days)</td>
<td>as needed</td>
<td>as needed</td>
<td>as needed</td>
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<tr>
<td>Flowable Fill non-excavatable</td>
<td>125</td>
<td>as needed</td>
<td>as needed</td>
<td>as needed</td>
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<tr>
<td>Pavement</td>
<td>650 (flexural)</td>
<td>0.559</td>
<td>0.559</td>
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</tr>
<tr>
<td>Precast</td>
<td>See Table 1077-1</td>
<td>as needed</td>
<td>as needed</td>
<td>---</td>
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<tr>
<td>Prestress - 6000</td>
<td>6000 or less</td>
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<td>0.450</td>
<td>---</td>
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<tr>
<td>Prestress +6000</td>
<td>greater than 6000</td>
<td>0.400</td>
<td>0.400</td>
<td>---</td>
</tr>
</tbody>
</table>
Mix Designs Using Fly Ash

The *2012 Standard Specifications for Roadway and Structures*, section 1000-3 permits the use of fly ash in all classes of concrete. In all classes, fly ash may be substituted for portland cement up to 20% by weight of the required cement. Substitute at the rate of at least 1.2 pounds of fly ash per pound of cement. 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.

The maximum water/cement ratio based on total cementitious materials is as follows for each class of concrete in the proportions required by table 1000-3.

<table>
<thead>
<tr>
<th>Class of Concrete</th>
<th>Rounded Aggregate</th>
<th>Angular Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>.366</td>
<td>.410</td>
</tr>
<tr>
<td>A</td>
<td>.469</td>
<td>.512</td>
</tr>
<tr>
<td>B</td>
<td>.469</td>
<td>.545</td>
</tr>
<tr>
<td>Pavement</td>
<td>.538</td>
<td>.538</td>
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</tbody>
</table>
North Carolina Department of Transportation, Division of Highways, Materials and Tests Unit
Statement of Concrete Mix Design and Source of Materials

<table>
<thead>
<tr>
<th>Project</th>
<th>Concrete Producer</th>
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<tbody>
<tr>
<td>County</td>
<td>Plant Location &amp; DOT No.</td>
</tr>
<tr>
<td>Resident Engr.</td>
<td>Contractor</td>
</tr>
<tr>
<td>Class of Concrete</td>
<td>Date</td>
</tr>
<tr>
<td>Mix Design No.</td>
<td>Contractor’s Signature</td>
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</table>

Note Mix Design Units (US or Metric)

Mix Design Proportions Based on SSD Mass of Aggregates

<table>
<thead>
<tr>
<th>Material</th>
<th>Producer</th>
<th>Source</th>
<th>Qty. per Cu. Yd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td></td>
<td></td>
<td>lbs.</td>
</tr>
<tr>
<td>Pozzolan</td>
<td></td>
<td></td>
<td>lbs.</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td></td>
<td></td>
<td>lbs.</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td></td>
<td></td>
<td>lbs.</td>
</tr>
<tr>
<td>Total Water</td>
<td></td>
<td></td>
<td>gals.</td>
</tr>
<tr>
<td>Air. Entr. Agent</td>
<td></td>
<td></td>
<td>As recommended</td>
</tr>
<tr>
<td>Retarder</td>
<td></td>
<td></td>
<td>As recommended</td>
</tr>
<tr>
<td>Water Reducer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superplasticizer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosion Inhibitor</td>
<td></td>
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</table>

Mix Properties and Specifications

<table>
<thead>
<tr>
<th>Slump</th>
<th>_____ in.</th>
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<tbody>
<tr>
<td>Max. Water</td>
<td>_____ gals.</td>
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<table>
<thead>
<tr>
<th>Mortar Content</th>
<th>_____ cu. ft.</th>
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</thead>
<tbody>
<tr>
<td>Air Content</td>
<td>_____ %</td>
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Aggregate and Pozzolan Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity</th>
<th>% Absorption</th>
<th>Unit Mass</th>
<th>Fineness Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Aggregate</td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

Comment

Cast-in-place concrete shall conform to Section 1000, precast concrete to Section 1077, and prestressed concrete to Section 1078 of the 1995 Standard Specifications for Roads and Structures plus all applicable Special Provisions.

Accepted By ______________________ (Physical Testing Engineer)    Date _________________
Section X

Study Problems

ACI Mix Design
ACI WORKSHEET

MIX DESIGN CLASS: _________________________________

Fine Aggregate Location: __________ Coarse Aggregate Location: _______________
Fineness Modulus: __________ Nom max size aggregate: __________ inch
Sp.Gr. _____ X 62.4 = _______ LBS./ Ft³ Dry Roadded Unit Weight (pcf): ________
Sp.Gr.: _____ X 62.4 = ______ (pcf)

TABLE 5.3.6 FACTOR: ______________

QUALITY OF COARSE AGGREGATE

________ X 27 = __________ X _______ = ______________ (pcf)

dry roadded unit weight

ABSOLUTE VOLUME

FLY ASH: _______________ LBS. = _________________________ (ft³)
Sp.Gr. _____ X 62.4

CEMENT: _______________ LBS. = _________________________ (ft³)
Sp. Gr. _______ X 62.4

WATER: __________ GALS = _________________________ (ft³)
7.5

AIR: _______________ X 27 = _________________________ (ft³)

COARSE AGG: _______________ LBS. = _________________________ (ft³)
Sp.Gr.______ X 62.4

TOTAL: _________________________ (ft³)

FINE AGGREGATE: 27.00 - ________ = _______ X _______ X 62.4 = _______
(Total ft³) ↑(SP.GR.)

MIX QUANTITIES:
FLY ASH _______________ LBS.
CEMENT _______________ LBS.
WATER ______________ GALS.
AIR _______________ %
COARSE AGG. _______________ LBS.
FINE AGG. ______________ LBS.
ACI WORKSHEET

MIX DESIGN CLASS:__________________________

Fine Aggregate Location:__________ Coarse Aggregate Location:_____________

Fineness Modulus : ___________ Nom max size aggregate: ___________ inch

Sp.Gr. _____ X 62.4 = ______ LBS./ Ft³ Dry Rodded Unit Weight,(pcf): ______

Sp.Gr.: _____X 62.4 = ______ (pcf)

TABLE 5.3.6 FACTOR:_____________

QUALITY OF COARSE AGGREGATE

_______ X 27 = ___________ X _______ = ______________(pcf)

table 5.3.6. dry rodded unit weight

ABSOLUTE VOLUME

FLY ASH:_________________________ LBS. = _______________________________(ft³)

Sp.Gr._______ X 62.4

CEMENT:_________________________ LBS. = _______________________________(ft³)

Sp. Gr._______ X 62.4

WATER:_________________________ GALS = _______________________________(ft³)

7.5

AIR: _________________ X 27 = __________________________(ft³)

COARSE AGG:_________________________ LBS. = ______________________________(ft³)

Sp.Gr._______ X 62.4

TOTAL: ______________________________(ft³)

FINE AGGREGATE: 27.00 - ________ = _______ X _______ X 62.4 = ______

(Total ft³) ↑(SP.GR.)

MIX QUANTITIES:

FLY ASH ______________________ LBS.
CEMENT ______________________ LBS.
WATER _______________________ GALS.
AIR _____________________ %
COARSE AGG. ______________________ LBS.
FINE AGG. ______________________ LBS.
ACI WORKSHEET

MIX DESIGN CLASS: ________________________________

Fine Aggregate Location: ________ Coarse Aggregate Location: __________

Finess Modulus: ___________ Nom max size aggregate: ___________ inch

Sp.Gr. ______ X 62.4 = ______ LBS./ Ft³ Dry Rodded Unit Weight, (pcf): _______

Sp.Gr.: ______ X 62.4 = ______ (pcf)

TABLE 5.3.6 FACTOR: __________

QUALITY OF COARSE AGGREGATE

_______ X 27 = _______ X _______ = __________ (pcf)

table 5.3.6. dry rodded unit weight

ABSOLUTE VOLUME

FLY ASH: ______________ LBS. = __________________________ (ft³)

Sp.Gr. ______ X 62.4

CEMENT: ______________ LBS. = __________________________ (ft³)

Sp. Gr. ______ X 62.4

WATER: ______________ GALS = __________________________ (ft³)

7.5

AIR: ______________ X 27 = __________________________ (ft³)

COARSE AGG: ______________ LBS. = __________________________ (ft³)

Sp.Gr. ______ X 62.4

TOTAL: __________________________ (ft³)

FINE AGGREGATE: 27.00 - ______ = ______ X _______ X 62.4 = ______

(Total ft³) ↑(SP.GR.)

MIX QUANTITIES:

FLY ASH _______________ LBS.
CEMENT _______________ LBS.
WATER _______________ GALS.
AIR __________________ %
COARSE AGG. ______________ LBS.
FINE AGG. ______________ LBS.
ACI WORKSHEET

MIX DESIGN CLASS: ________________________________

Fine Aggregate Location: ____________ Coarse Aggregate Location: ____________

Fineness Modulus: ____________ Nom max size aggregate: ____________ inch

Sp.Gr. ______ X 62.4 = ______ LBS./ Ft³  Dry Rodded Unit Weight,(pcf): ______

Sp.Gr.: ______ X 62.4 = ______ (pcf)

TABLE 5.3.6 FACTOR: __________________

QUALITY OF COARSE AGGREGATE

______ X 27 = _______ X ________ = __________(pcf)

table 5.3.6.
dry rodded unit weight

ABSOLUTE VOLUME

FLY ASH: ______________ LBS. = __________________________(ft³)

Sp.Gr. ______ X 62.4

CEMENT: ______________ LBS. = __________________________(ft³)

Sp. Gr. ______ X 62.4

WATER: ______________ GALS = __________________________(ft³)

7.5

AIR: ______________ X 27 = __________________________(ft³)

COARSE AGG: ______________ LBS. = __________________________(ft³)

Sp.Gr. ______ X 62.4

TOTAL: __________________________(ft³)

FIRE AGGREGATE : 27.00 - ______ = ______ X ______ X 62.4 = ______

(Total ft³) ↑(SP.GR.)

MIX QUANTITIES:

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

MIX DESIGN CLASS: ____________________________

Fine Aggregate Location: __________ Coarse Aggregate Location: __________

Finess Modulus: __________ Nom max size aggregate: ______________ inch

Sp.Gr. _____ X 62.4 = ______ LBS./ Ft³ Dry Rodded Unit Weight, (pcf): ______

Sp.Gr.: ______ X 62.4 = ______ (pcf) TABLE 5.3.6 FACTOR: __________

QUALITY OF COARSE AGGREGATE

_________ X 27 = __________ X _______ = ____________ (pcf)

table 5.3.6.

dry rodded unit weight

ABSOLUTE VOLUME

FLY ASH: _______________ LBS. = ____________________ (ft³)

Sp.Gr. ______ X 62.4

CEMENT: _______________ LBS. = ____________________ (ft³)

Sp. Gr. ______ X 62.4

WATER: _______________ GALS = ____________________ (ft³)

7-5

AIR: _______________ X 27 = ________________ (ft³)

COARSE AGG: _______________ LBS. = ____________________ (ft³)

Sp.Gr. ______ X 62.4

TOTAL: ____________________ (ft³)

FINE AGGREGATE: 27.00 - ______ = _____ X _______ X 62.4 = ______

(Total ft³) \uparrow (SP.GR.)

MIX 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 the Lilesville Pit and stone from Matthews Quarry, size # 67, angular. Use minimum cement and 1 gallon less than maximum water.

**MIX DESIGN PROBLEM #1**

**ACI WORKSHEET**

<table>
<thead>
<tr>
<th>CLASS:</th>
<th>________________</th>
<th>MIX DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>FINE AGG:</td>
<td>________________</td>
<td>COARSE AGG:</td>
</tr>
<tr>
<td>FM:</td>
<td>________________</td>
<td>NOM. MAX. SIZE:</td>
</tr>
<tr>
<td>SP.GR.</td>
<td>________________</td>
<td>X</td>
</tr>
<tr>
<td>UNIT WEIGHT:</td>
<td>________________</td>
<td>(DRY RODDED)</td>
</tr>
<tr>
<td>SP.GR.:</td>
<td>________________</td>
<td>X</td>
</tr>
</tbody>
</table>

**QUALITY OF COARSE AGGREGATE**

| TABLE 5.3.6: | ________________ |
| ________________ | X | 27 | = | ________________ |

**ABSOLUTE VOLUME**

| FLY ASH: | ________________ | LBS. | = | ________________ FT³ |
| CEMENT: | ________________ | LBS. | 3.15 | X | 62.4 | = | ________________ FT³ |
| WATER: | ________________ GALS | = | ________________ FT³ |
| AIR: | ________________ | X | 27 | = | ________________ FT³ |
| COARSE AGG: | ________________ | LBS. | SP.GR. | ________________ | X | 62.4 | = | ________________ FT³ |
| TOTAL: | ________________ FT³ |

| FINE AGG: | ________________ | CU.FT./CU.YD. | X | ________________ | X | 62.4 | = | ________________ LBS./CU.YDS. |

**Mix Design Quantities:**

| 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 Emery Pit and stone from Kannapolis Quarry, size # 67, angular. Use the minimum cement and 2 gallons less than maximum water.

**MIX DESIGN PROBLEM #2**

---

**ACI WORKSHEET**

**CLASS:** ____________________  **MIX DESIGN**

**FINE AGG:** ____________________  **COARSE AGG:** ____________________

**FM:** ____________________  **NOM. MAX. SIZE:** ____________  **INCH**

**SP.GR.** ____________  **X** 62.4  =  ____________  **LBS.CU.FT.**  **UNIT WEIGHT:** ____________

(DRY RODDED)

**SP.GR.** ____________  **X** 62.4  =  ____________  **LBS.CU.FT.**

**QUALITY OF COARSE AGGREGATE**

__________  **X** 27  =  ____________  **X** 27  =  ____________  **LBS.CU.FT.**

**ABSOLUTE VOLUME**

**FLY ASH:** ____________  **LBS.**  =  ____________  **FT³**

**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 Great Pit and stone from Crabtree Quarry, size # 67, angular. Use 7.6 sacks of cement per yard and the maximum water permitted.

**MIX DESIGN PROBLEM #3**

**ACI WORKSHEET**

<table>
<thead>
<tr>
<th>CLASS:</th>
<th>MIX DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>FINE AGG:</td>
<td>COARSE AGG:</td>
</tr>
<tr>
<td>FM:</td>
<td>NOM. MAX. SIZE: INCH</td>
</tr>
<tr>
<td>SP.GR. X 62.4 = LBS.CU.FT.</td>
<td></td>
</tr>
</tbody>
</table>

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

**QUALITY OF COARSE AGGREGATE**

<table>
<thead>
<tr>
<th>TABLE 5.3.6:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X 27 =</td>
<td>X =</td>
</tr>
</tbody>
</table>

**ABSOLUTE VOLUME**

FLY ASH: LBS. = FT³

CEMENT: LBS. = FT³

WATER: GALS = FT³

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 = LBS./CU.YDS.

**Mix Design Quantities:**

| 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 the Boone Quarry and stone from Mt Airy Quarry, size #57, angular. Use the minimum cement and two gallons of water per yard less then 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: ________

(DRY RODDED)

SP.GR.: _____ X 62.4 = _______ LBS.CU.FT.

TABLE 5.3.6: __________

QUALITY OF COARSE AGGREGATE

______ X 27 = ________ X ________ = ________ LBS.CU.FT.

TABLE 5.3.6.

DRY RODDED UNIT WEIGHT

ABSOLUTE VOLUME

FLY ASH: _______ LBS. = ________________ FT³

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 “A” vibrated, air entrained, concrete mix using sand from the Johnsonville Pit and stone from Greystone Quarry, size #67, angular. Use the minimum cement content and .478 as a w/c ratio.

**MIX DESIGN PROBLEM #5**

**ACI WORKSHEET**

<table>
<thead>
<tr>
<th>CLASS:</th>
<th>MIX DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>FINE AGG:</td>
<td>COARSE AGG:</td>
</tr>
<tr>
<td>FM:</td>
<td>NOM MAX SIZE: INCH</td>
</tr>
<tr>
<td>SP.GR. X 62.4 = LBS.CU.FT.</td>
<td>UNIT WEIGHT: (DRY RODDED)</td>
</tr>
<tr>
<td>SP.GR.: X 62.4 = LBS.CU.FT.</td>
<td></td>
</tr>
</tbody>
</table>

**QUALITY OF COARSE AGGREGATE**

| TABLE 5.3.6: |
| X 27 = X = LBS.CU.FT. |

**ABSOLUTE VOLUME**

| FLY ASH: LBS. = FT³ |
| CEMENT: LBS. = FT³ |
| WATER: GALS = FT³ |
| AIR: X 27 = FT³ |
| COARSE AGG: LBS. = FT³ |
| 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. |

**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 Candor Pit and stone from North Quarry, size #67, angular. Use the minimum cement and one gallon of water per yard less then the maximum permitted.

**MIX DESIGN PROBLEM #6**

**ACI WORKSHEET**

**CLASS:** ____________________

**MIX DESIGN**

**FINE AGG:** ____________________

**COARSE AGG:** ____________________

**FM:** ____________________

**NOM MAX SIZE:** ______ INCH

**SP.GR.** ______ X 62.4 = ______ LBS.CU.FT.

**UNIT WEIGHT:** ______ (DRY RODDED)

**SP.GR.:** ______ X 62.4 = ______ LBS.CU.FT.

**TABLE 5.3.6:**

**QUALITY OF COARSE AGGREGATE**

______ X 27 = ______

**TABLE 5.3.6.**

**DRY RODDED UNIT**

**WEIGHT**

**ABSOLUTE VOLUME**

**FLY ASH:** ______ LBS. = ______ FT³

**CEMENT:** ______ LBS. = ______ FT³

$$3.15 \times 62.4$$

**WATER:** ______ GALS = ______ FT³

$$7.5$$

**AIR:** ______ X 27 = ______ FT³

**COARSE AGG:** ______ LBS. = ______ FT³

$$\text{SP.GR.} \times 62.4$$

**TOTAL:** ______ FT³

$$27.00 \text{ CU.FT.}/\text{CU.YD.}$$

__

**FINENESS MODULUS**

**FINE AGG:** ______ CU.FT./CU.YD. X ______ X 62.4 = ______ LBS./CU.YDS.

$$\uparrow \text{(SP.GR.)}$$

**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 Pageland Quarry and stone from the Matthews Quarry, 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**

**ACI WORKSHEET**

<table>
<thead>
<tr>
<th>CLASS:</th>
<th>MIX DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>FINE AGG:</td>
<td>COARSE AGG:</td>
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<tr>
<td>FM:</td>
<td>NOM MAX SIZE: INCH</td>
</tr>
<tr>
<td>SP.GR. X 62.4 = LBS.CU.FT.</td>
<td>UNIT WEIGHT: (DRY RODDED)</td>
</tr>
<tr>
<td>SP.GR.: X 62.4 = LBS.CU.FT.</td>
<td></td>
</tr>
<tr>
<td>TABLE 5.3.6:</td>
<td></td>
</tr>
<tr>
<td>QUALITY OF COARSE AGGREGATE</td>
<td></td>
</tr>
<tr>
<td>X 27 = X = LBS.CU.FT.</td>
<td>DRY RODDED UNIT WEIGHT</td>
</tr>
<tr>
<td>TABLE 5.3.6.</td>
<td></td>
</tr>
<tr>
<td>ABSOLUTE VOLUME</td>
<td></td>
</tr>
<tr>
<td>FLY ASH: LBS. = FT³</td>
<td></td>
</tr>
<tr>
<td>CEMENT: LBS. = FT³</td>
<td></td>
</tr>
<tr>
<td>3.15 X 62.4</td>
<td></td>
</tr>
<tr>
<td>WATER: gals = FT³</td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>AIR: LBS. = FT³</td>
<td></td>
</tr>
<tr>
<td>COARSE AGG: LBS. = FT³</td>
<td></td>
</tr>
<tr>
<td>SP.GR. X 62.4</td>
<td></td>
</tr>
<tr>
<td>TOTAL: FT³</td>
<td></td>
</tr>
<tr>
<td>27.00 CU.FT./CU.YD.</td>
<td></td>
</tr>
<tr>
<td>FINE AGG: CU.FT./CU.YD. X X 62.4 = LBS./CU.YDS.</td>
<td></td>
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</tbody>
</table>

**Mix Design Quantities:**

<table>
<thead>
<tr>
<th>FLY ASH</th>
<th>LBS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEMENT</td>
<td>LBS.</td>
</tr>
<tr>
<td>WATER</td>
<td>GALS.</td>
</tr>
<tr>
<td>AIR</td>
<td>%</td>
</tr>
<tr>
<td>COARSE AGG.</td>
<td>LBS.</td>
</tr>
<tr>
<td>FINE AGG.</td>
<td>LBS.</td>
</tr>
</tbody>
</table>
Design a Class “B” non-vibrated, air entrained concrete mix using sand from the Lilesville Pit and stone from the Elkin Quarry, Size #57, angular. Use one bag additional cement per yard than the minimum and .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:** _______

(SDRY RODDED)

**SP.GR.** X 62.4 = _______ LBS.CU.FT.

**QUALITY OF COARSE AGGREGATE**

_______ X 27 = __________ X __________ = _______ LBS.CU.FT.

**TABLE 5.3.6:** __________

**ABSOLUTE VOLUME**

**FLY ASH:** _______ LBS. = _______________ FT³

**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, FLY ASH concrete mix using 20% Carbo, VA fly ash with a specific gravity of 2.26. Use sand from Great Pit and stone from Greystone Quarry, size #67, angular. Use two gallons less of water than the maximum number of gallons per yard permitted.

MIX DESIGN PROBLEM #9

ACI WORKSHEET

class: ____________________
mix design

fine agg: ____________________
coarse agg: ____________________

fm: ________________
nom max size: ____________ inch

sp.gr. ___________ x 62.4 = __________ lbs./cu.ft.

 UNIT weight: __________ (dry rodded)

sp.gr.: __________ x 62.4 = __________ lbs./cu.ft.

quality of coarse aggregate

_________ x 27 = __________ x ______________ = __________ lbs./cu.ft.

TABLE 5.3.6:

absolute volume

fly ash: __________ lbs.

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.
Section XI

ACI Mix Design Variations

Form 312
5% ACI Variation

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:

<table>
<thead>
<tr>
<th>Problem:</th>
<th>Solution:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>A workable slump can not be obtained with the design water less the maximum allowable water according to specifications.</strong></td>
<td>Add water as necessary, up to the maximum allowed and subtract an equal volume of fine aggregate.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Problem:</th>
<th>Solution:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. <strong>A workable slump can not be obtained using the maximum allowable water.</strong></td>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Problem:</th>
<th>Solution:</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. <strong>If a mix is too harsh,</strong> (has too much coarse aggregate).</td>
<td>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.</td>
</tr>
</tbody>
</table>

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

In order to maintain a yield of exactly 27.0 ft³ 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 volumetric 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./ft³. If the component to be changed is water, then compute the absolute volume by dividing the number of gallons by 7.5 gals/ft³.

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./ft³ 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/ft³ 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

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>545</td>
<td>lbs.</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>1307</td>
<td>lbs.</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>1466</td>
<td>lbs.</td>
</tr>
<tr>
<td>Water</td>
<td>32.1 gals.</td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>6 %</td>
<td></td>
</tr>
</tbody>
</table>

As per the problem, we must increase the water content by 1.5 gallons, therefore:

→ Increase the water by 1.5 gallons.

→ Absolute Volume of the Fine Aggregate = \( \frac{1.5 \text{ gals}}{7.5 \text{ gals./ft}^3} = 0.20 \text{ ft}^3 \)

→ Weight of Fine Agg. to be removed = \( 0.20 \text{ ft}^3 \times 2.67 \times 62.4 = 33 \text{ lbs. of Sand} \)

   (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:

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>545</td>
<td>LBS.</td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>1274</td>
<td>LBS.</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>1466</td>
<td>LBS.</td>
</tr>
<tr>
<td>Water</td>
<td>33.6</td>
<td>GALS.</td>
</tr>
<tr>
<td>Air</td>
<td>6</td>
<td>%</td>
</tr>
</tbody>
</table>
Example # 2

ACI Variation Problem

Redesign the following mix:

One Cubic Yard Class “A” vibrated mix

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Aggregate</td>
<td>1154 lbs.</td>
<td></td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>1872 lbs.</td>
<td>Fieldale #67 Coarse Agg. Sp.Gr.: 2.81</td>
</tr>
<tr>
<td>Water</td>
<td>36.0 gals.</td>
<td>Dry Rodded Unit Weight: 100.2</td>
</tr>
<tr>
<td>Air</td>
<td>6 %</td>
<td></td>
</tr>
</tbody>
</table>

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 water.

⇒ .05 X 1154 lbs. of fine aggregate = 58 lbs. of sand

⇒ Absolute Volume of the fine agg. removed = \( \frac{58 \text{ lbs.}}{2.63 \times 62.4 \text{ lbs./ft}^3} \) = 0.35 ft\(^3\)

⇒ Weight of coarse agg. to be added = 0.35 ft\(^3\) X 2.81 X 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:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>564 LBS.</td>
<td></td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>1096 LBS.</td>
<td></td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>1933 LBS.</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>36.0 GALS.</td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>6 %</td>
<td></td>
</tr>
</tbody>
</table>
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 \( \times \) 62.4 lbs./ft\(^3\))

➔ 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. \( \times \) 62.4 lbs./ft\(^3\)).

One Cubic Yard Class A Mix Design

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight</th>
<th>Source</th>
<th>Sp.Gr.</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>564 lbs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>1257 lbs.</td>
<td>Elliott Pit</td>
<td>2.66</td>
<td>2.50</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>1853 lbs.</td>
<td>Burlington#67</td>
<td>2.87</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>34.0 gals.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>6%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 = \( \frac{151}{3.15 \times 62.4 \text{ lbs./ft}^3} \) = 0.77 ft\(^3\)

➔ Weight of sand to be removed = 0.77 ft\(^3\) \( \times \) 2.66 \( \times \) 62.4 = 128 lbs. of sand

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

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>715 lbs.</td>
<td>LBS.</td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>1129 lbs.</td>
<td>LBS.</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>1853 lbs.</td>
<td>LBS.</td>
</tr>
<tr>
<td>Water</td>
<td>34.0 gals.</td>
<td>GALS.</td>
</tr>
<tr>
<td>Air</td>
<td>6%</td>
<td></td>
</tr>
</tbody>
</table>
Example #4

ACI Variation Problem

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

Redesign the following:

One Cubic Yard  

Class AA Vibrated Mix Design

<table>
<thead>
<tr>
<th></th>
<th>715 lbs.</th>
<th>890 lbs.</th>
<th>Cloverfield</th>
<th>2.61</th>
<th>2.69</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td></td>
<td></td>
<td>Fine Aggregate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td></td>
<td></td>
<td>Coarse Aggregate</td>
<td>Statesville</td>
<td>2.79</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td></td>
<td></td>
<td>Water</td>
<td>36.5 gals.</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td>Air</td>
<td>6%</td>
<td></td>
</tr>
</tbody>
</table>

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

\[ 0.05 \times 890 \text{ lbs. of fine aggregate} = 45 \text{ lbs. of sand} \]

\[ \text{Absolute Volume of the fine agg. added} = \frac{45}{2.61 \times 62.4 \text{ lbs./ft}^3} = 0.28 \text{ ft}^3 \]

\[ \text{Weight of coarse agg. to be removed} = 0.28 \text{ ft}^3 \times 2.79 \times 62.4 = 49 \text{ lbs. of stone} \]

\[ \text{Fine Aggregate:} \quad 890 \text{ lbs.} + 45 \text{ lbs.} = 935 \text{ lbs. of fine aggregate} \]
\[ \text{Coarse Aggregate:} \quad 1996 \text{ lbs.} - 49 \text{ lbs.} = 1947 \text{ lbs. of coarse aggregate} \]

The new Mix Design is:

<table>
<thead>
<tr>
<th></th>
<th>715 LBS.</th>
<th>935 LBS.</th>
<th>1947 LBS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Agg.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>36.5 GAL.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>6%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
How to Fill Out Form 312

The contractor submits his own mix design to the North Carolina Department of Transportation, Physical Lab, on the Materials and Test Form 312U. Follow the design on the next page and note that the contractor must complete the items listed below. The Physical Testing Engineer or his representative will fill out the remaining items. Check the mix for yield and compliance with specifications.

Items to check:

1. Always use 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 cubic yards.
7. Check that all the admixtures are on the approved list.
## North Carolina Department of Transportation, Division of Highways, Materials and Tests
### Unit Statement of Concrete Mix Design and Source of Materials

<table>
<thead>
<tr>
<th>Project</th>
<th>C200009</th>
<th>Concrete Producer</th>
<th>McMullen Ready Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>County</td>
<td>Wake</td>
<td>Plant Location &amp; DOT No.</td>
<td>Farmingville, NC</td>
</tr>
<tr>
<td>Resident Engr.</td>
<td>H.Bunter</td>
<td>Contractor</td>
<td>I.B. Overtime Construction Co.</td>
</tr>
<tr>
<td>Class of Concrete</td>
<td>AA –Vib – AE</td>
<td>Date</td>
<td>6-1-2009</td>
</tr>
<tr>
<td>Mix Design No.</td>
<td>242VF157AE</td>
<td>Contractor’s Signature</td>
<td></td>
</tr>
<tr>
<td>Note Mix Design Units (US or Metric)</td>
<td>English</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Mix Design Proportions Based on SSD Mass of Aggregates

<table>
<thead>
<tr>
<th>Material</th>
<th>Producer</th>
<th>Source</th>
<th>Qty. per Cu. Yd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Giant Cement</td>
<td>Harleyville, S.C.</td>
<td>714 lbs.</td>
</tr>
<tr>
<td>Pozzolan</td>
<td></td>
<td></td>
<td>lps.</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>B.V.Hedrick</td>
<td>Lilesville Pit</td>
<td>1231 lbs.</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>Martin Marietta</td>
<td>Kannapolis Quarry</td>
<td>1717 lbs.</td>
</tr>
<tr>
<td>Total Water</td>
<td>City</td>
<td></td>
<td>34.5 gals.</td>
</tr>
<tr>
<td>Air. Entr. Agent</td>
<td>Master Builders</td>
<td>MB AE 90</td>
<td>As Recommended</td>
</tr>
<tr>
<td>Retarder</td>
<td>Master Builders</td>
<td>Pozzolith 100XR</td>
<td>As Recommended</td>
</tr>
<tr>
<td>Water Reducer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superplasticizer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosion Inhibitor</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Mix Properties and Specifications

- **Slump**: 3.5 in.
- **Max. Water**: 36.5 gals.
- **Mortar Content**: 17.14 cu. ft.
- **Air Content**: 6% 

### Aggregate and Pozzolan Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity</th>
<th>% Absorption</th>
<th>Unit Mass</th>
<th>Fineness Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Aggregate</td>
<td>2.64</td>
<td>0.5</td>
<td>NA</td>
<td>2.81</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>2.62</td>
<td>0.4</td>
<td>96.3</td>
<td>NA</td>
</tr>
</tbody>
</table>

### Comment

Cast-in-place concrete shall conform to Section 1000, precast concrete to Section 1077, and prestressed concrete to Section 1078 of the 1995 Standard Specifications for Roads and Structures plus all applicable Special Provisions.

__________________________ ____________________
Accepted By (Physical Testing Engineer) Date
EXAMPLE
FOR INSTRUCTIONAL USE ONLY

DATE: 6-1-09

ACI WORKSHEET

CLASS: ___ AA Vib AE ________ MIX DESIGN

FINE AGG: Lilesville Pit ________ COARSE AGG: Kannapolis Quarry

FM: 2.81 __________

NOM MAX SIZE: No. 67, 3/4” INCH

SP.GR. 2.64 X 62.4 = \frac{164.11 \text{ LBS.CU.FT.}}{} \quad \text{UNIT WEIGHT: 96.3}_\text{(DRY RODDED)}

SP.GR.: 2.62 X 62.4 = 163.49 LBS.CU.FT.

QUALITY OF COARSE AGGREGATE

\frac{0.62}{27} \times 27 = 16.74 \quad \frac{96.3}{1612} \times 27 = 1612 \text{ LBS.CU.FT.}

ABSOLUTE VOLUME

FLY ASH: \frac{714}{3.15 \times 62.4} \text{ LBS.} = \frac{3.63}{\text{FT}^3}

CEMENT: \frac{714}{3.15 \times 62.4} \text{ LBS.} = \frac{3.63}{\text{FT}^3}

WATER: \frac{34.5}{7.5} \text{ GALS} = \frac{4.60}{\text{FT}^3}

AIR: \frac{.06}{27} = \frac{1.62}{\text{FT}^3}

COARSE AGG: \frac{1612}{2.62 \times 62.4} \text{ LBS.} = \frac{9.86}{\text{FT}^3}

TOTAL: \frac{19.71}{\text{FT}^3}

27.00 \text{ CU.FT./CU.YD.}

- 19.71

FINE AGG: \frac{7.29}{\text{CU.FT./CU.YD.}} \times \frac{2.64}{27} \times 62.4 = \frac{1201}{\text{LBS./CU.YDS.}} \quad \hat{\text{(SP.GR.)}}

Mix Design Quantities:

FLY ASH: \frac{0}{\text{LBS.}}

CEMENT: \frac{714}{\text{LBS.}}

WATER: \frac{34.5}{\text{GALS.}}

AIR: \frac{6}{\%}

COARSE AGG: \frac{1612}{\text{LBS.}}

FINE AGG: \frac{1201}{\text{LBS.}}
Section XI

Study Problems

ACI Mix Design Variations and NCDOT Form 312
ACI Variation Problem

Problem # 1

Redesign the following mix:

One Cubic Yard Class A Vib mix AE

Cement 564 lbs. Boone Q Fine Agg. Sp.Gr.: 2.73
Fine Aggregate 1276 lbs. FM: 2.46
Coarse Aggregate 1826 lbs. Mission Dam Q Coarse Agg. Sp.Gr.: 2.79 Quarry
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:

<table>
<thead>
<tr>
<th></th>
<th>LBS.</th>
<th>GALS.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Agg.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ACI Variation Problem

Problem # 2

Redesign the following mix:

One Cubic Yard Class A Vib mix AE

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount</th>
<th>Source</th>
<th>Sp.Gr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>564 lbs.</td>
<td>White Pit</td>
<td>2.63</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>1210 lbs.</td>
<td>Fine Agg.</td>
<td>2.45</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>1916 lbs.</td>
<td>Bessemer City</td>
<td>2.97</td>
</tr>
<tr>
<td>Water</td>
<td>36.0 gals.</td>
<td>Quarry</td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>6%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Material</th>
<th>LBS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td></td>
</tr>
<tr>
<td>Fine Agg.</td>
<td></td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>GALS.</td>
</tr>
<tr>
<td>Air</td>
<td>%</td>
</tr>
</tbody>
</table>
ACI Variation Problem

Problem # 3

Redesign the following mix:

One Cubic Yard Class B non-Vib mix

<table>
<thead>
<tr>
<th>Component</th>
<th>LBS.</th>
<th>Description</th>
<th>Sp.Gr.:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>545</td>
<td>White Pit</td>
<td>2.63</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>1329</td>
<td>Sp.Gr.:</td>
<td>2.45</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>1688</td>
<td>Bakers Quarry</td>
<td>2.75</td>
</tr>
<tr>
<td>Water</td>
<td>35.0</td>
<td>Dry Rodded Unit Weight: 89.3</td>
<td></td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Component</th>
<th>LBS.</th>
<th>GALS.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Agg.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ACI Variation Problem

Problem # 4

Redesign the following mix:

One Cubic Yard Class A vibrated mix

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Amount</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>564 lbs.</td>
<td>Rose Pit</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>1105 lbs.</td>
<td></td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>1790 lbs.</td>
<td>Tom’s Creek Quarry</td>
</tr>
<tr>
<td>Water</td>
<td>35.8 gals.</td>
<td>Dry Rodded Unit Weight: 94.7</td>
</tr>
<tr>
<td>Air</td>
<td>6 %</td>
<td></td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>LBS.</td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>LBS.</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>LBS.</td>
</tr>
<tr>
<td>Water</td>
<td>GALS.</td>
</tr>
<tr>
<td>Air</td>
<td>%</td>
</tr>
</tbody>
</table>
ACI Variation Problem

Problem # 5

Redesign the following mix:

One Cubic Yard Class AA vibrated mix

Cement 714 lbs. Singleton Pit Fine Agg. Sp.Gr.: 2.63
Fine Aggregate 975 lbs. FM: 2.30
Coarse Aggregate 2037 lbs. Arrowood quarry 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:

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>LBS.</td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>LBS.</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>LBS.</td>
</tr>
<tr>
<td>Water</td>
<td>GALS.</td>
</tr>
<tr>
<td>Air</td>
<td>%</td>
</tr>
</tbody>
</table>
ACI Variation Problem

Problem # 6

Redesign the following mix:

**One Cubic Yard** Class AA Vib mix AE

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Description</th>
<th>Sp.Gr.</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>639 lbs.</td>
<td>Candor Pit Fine Agg.</td>
<td>2.62</td>
<td></td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>1148 lbs.</td>
<td>Crabtree Coarse Agg.</td>
<td>2.71</td>
<td></td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>1779 lbs.</td>
<td>Quarry</td>
<td>2.65</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>32.6 gals.</td>
<td>Dry Rodded Unit Weight:</td>
<td>96.9</td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>6%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Component</th>
<th>LBS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td></td>
</tr>
<tr>
<td>Fine Agg.</td>
<td></td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>GALS.</td>
</tr>
<tr>
<td>Air</td>
<td>%</td>
</tr>
</tbody>
</table>
Problem #7
For Instructional Use Only

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

<table>
<thead>
<tr>
<th>Project</th>
<th>Concrete Producer</th>
<th>County</th>
<th>Plant Location &amp; DOT No.</th>
<th>Resident Engr.</th>
<th>Contractor</th>
<th>Class of Concrete</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1234567</td>
<td>Blizzard Ready mix</td>
<td>Rowan</td>
<td>Rockwell, NC</td>
<td>A.L. Woodburn</td>
<td>Overtime Construction Co.</td>
<td>AA –Vib – AE</td>
<td>6-1-09</td>
</tr>
<tr>
<td>Mix Design No.</td>
<td>242VO167AE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note Mix Design Units (US or Metric)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mix Design Proportions Based on SSD Mass of Aggregates

<table>
<thead>
<tr>
<th>Material</th>
<th>Producer</th>
<th>Source</th>
<th>Qty. per Cu. Yd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Giant Cement</td>
<td>Harleyville, S.C.</td>
<td>639 lbs.</td>
</tr>
<tr>
<td>Pozzolan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>B.V. Hedrick</td>
<td>Lilesville Pit</td>
<td>1247 lbs.</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>Martin Marietta</td>
<td>Matthews Quarry</td>
<td>1795 lbs.</td>
</tr>
<tr>
<td>Total Water</td>
<td>City</td>
<td></td>
<td>32.7 gals.</td>
</tr>
<tr>
<td>Air. Entr. Agent</td>
<td>Master Builders</td>
<td>MB AE 90</td>
<td>As Recommended</td>
</tr>
<tr>
<td>Retarder</td>
<td>Master Builders</td>
<td>Pozzolith 100XR</td>
<td>As Recommended</td>
</tr>
<tr>
<td>Water Reducer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superplasticizer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosion Inhibitor</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mix Properties and Specifications

- **Slump**: 3.5 in.
- **Max. Water**: 32.7 gals.
- **Mortar Content**: 16.80 cu. ft.
- **Air Content**: 6%

Aggregate and Pozzolan Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity</th>
<th>% Absorption</th>
<th>Unit Mass</th>
<th>Fineness Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Aggregate</td>
<td>2.64</td>
<td>0.5</td>
<td>NA</td>
<td>2.81</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>2.82</td>
<td>0.1</td>
<td>99.2</td>
<td>NA</td>
</tr>
</tbody>
</table>

Comment
Cast-in-place concrete shall conform to Section 1000, precast concrete to Section 1077, and prestressed concrete to Section 1078 of the 1995 Standard Specifications for Roads and Structures plus all applicable Special Provisions.

______________________________________________________________________
______________________________________________________________________

Accepted By ______________________ (Physical Testing Engineer) Date _________
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: ___________
(DRY RODDED)

SP.GR.: _______ X 62.4 = _______ LBS.CU.FT.

TABLE 5.3.6: __________

QUALITY OF COARSE AGGREGATE

TABLE 5.3.6. DRY RODDED UNIT

WEIGHT

ABSOLUTE VOLUME

FLY ASH: _______ LBS. = _____________________ CU.FT./CU.YD.

CEMENT: _______ LBS. = _____________________ CU.FT./CU.YD.

3.15 X 62.4

WATER: _______ X _____ = _____ = _______ GALS = _____________________ CU.FT./CU.YD.

8.33 7.5

AIR: _______ X 27 = _____________________ CU.FT./CU.YD.

COARSE AGG: _______ LBS. = _____________________ CU.FT./CU.YD.

SP.GR. _______ X 62.4

TOTAL: _____________________

CU.FT./CU.YD.

27.00 CU.FT./CU.YD.

- _______ CU.FT./CU.YD. TOTAL

------------------------

FINE AGG: _______ CU.FT./CU.YD. X _______ X 62.4 = _______

LBS./CU.YDS. ↑(SP.GR.)

SUGGESTED QUANTITIES:

FLY ASH: _______ LBS.

CEMENT: _______ LBS.

WATER: _______ GALS.

AIR: _______ %

COARSE AGG: _______ LBS.

FINE AGG. _______ LBS.
Section XII

Quality Concrete and Field Inspection and Control
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)
  
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>S</td>
<td>H</td>
</tr>
</tbody>
</table>

  - Calcium
  - Silicate
  - Hydrate

  - Concrete
  - Strength
  - 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 .220 to .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.

Quality Control Testing
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.
Strength Rules of Thumb

- 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

Comparison Between 4”x8” & 6”x12” Cylindrical Specimens

<table>
<thead>
<tr>
<th>Material</th>
<th>4x8 Avg. Compressive Strength</th>
<th>6x12 Avg. Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wampum Blank</td>
<td>5930</td>
<td>5430</td>
</tr>
<tr>
<td>Wampum December</td>
<td>6240</td>
<td>5810</td>
</tr>
<tr>
<td>Wampum AA</td>
<td>6080</td>
<td>5560</td>
</tr>
<tr>
<td>Wampum &amp; 15% Ash</td>
<td>5460</td>
<td>5320</td>
</tr>
</tbody>
</table>
How much is a concrete cylinder worth?

- 500 yards of concrete = $30,000
- Place and Finish = $30,000
- Synthetic Fibers = $4,000
- Testing = $1,000
- 27, sq. ft. of Concrete Floor = $65,000

40 Cylinders Represent $65,000
1 Concrete Cylinder = $1,600

Why is concrete testing the least cost yet the most expensive if done improperly?
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.

Temperature Rules of Thumb

- 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

Adding 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%

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.

Adequate Support of Foundations and Forms

The famous quote, “A structure is no stronger then 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 of 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 then 3:1 and no steeper then 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 or 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 then 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.

Additional Moisture Methods:

Ponding

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 Highways 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 coat 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 420-9. 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 DOH 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.

The chart shown in Figure 9, page 130, is useful for determining when precautionary measures should be taken. 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 then 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 then 80° to 85° F. The upper practical limit should be no more then 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.
Evaporation Chart

Surface Evaporation From Concrete

To estimate evaporation rate:

1. Enter chart at appropriate air temperature and relative humidity above.

2. Move right to line corresponding to the concrete temperature.

3. Move down to line approximating the wind velocity.

4. Read evaporation rate on scale to left of this point.
Effects of High Concrete Temperatures

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.

**Cooling Concrete Material**

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:

\[
T = \frac{0.22 (Ta Wa + Tc Wc) + Tf Wf + Tm Wm}{0.22 (Wa + Wc) + Wf + Wm}
\]

- **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:

\[ T = \frac{0.22 (T_a W_a + T_c W_c) + T_f W_f + T_m W_m - 112W_i}{0.22 (W_a + W_c) + W_f + W_m W_i} \]

All symbols in the equation remain the same but now the weight in pounds of the ice, \( W_i \), 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 sun’s 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 cement’s 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 than 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 then 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 continues 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 retain 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 than 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 loses 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 into 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 may be retained in the concrete by use of commercial insulating blankets or bat insulation. The effectiveness of insulation may be 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.
Section XIII

Study Questions – Field Inspection and Control of Portland Cement Concrete
1. The limits of bridge deck concrete temperatures at the time of placing are:
   A. 50°F - 65°F
   B. 60°F - 80°F
   C. 50°F - 90°F
   D. 40°F - 85°F

2. Of all the ingredients that are used in a concrete mix, the one that is the easiest to heat and does more good pound for pound is:
   A. Fine Aggregate
   B. Coarse Aggregate
   C. Water
   D. Cement

3. All forms must be:
   A. Mortar tight
   B. Sufficiently rigid
   C. All of the above

4. The condition that is most conducive to causing plastic shrinkage cracks is:
   A. High winds and low humidity
   B. High humidity and low winds
   C. Low concrete temperature and low air temperature
   D. High air temperature and high humidity

5. During cold weather concreting:
   A. Permission from the NCDOT is required to pour if below 35°F
   B. Curing by flooding is not allowed
   C. Concrete may only be placed against surfaces that are above 32°F
   D. Cement may be heated to 150°F

6. In cold weather, the water may be heated to a temperature not to exceed:
   A. 100°F
   B. 150°F
   C. 200°F
   D. 250°F
7. Two conditions that improve the quality of concrete are:
   A. Hot weather and steam
   B. Cold weather and curing
   C. Presence of moisture and favorable temperatures
   D. Evaporation of water and high temperatures

8. The cracking that sometimes occurs on the surface of fresh concrete soon after it has been placed is called:
   A. Stress Cracking
   B. Plastic shrinkage cracking
   C. Horizontal cracking
   D. All of the above

9. When vibrating concrete, the desired consolidation should be attained at:
   A. 1 minute
   B. 5 to 15 seconds
   C. 10 to 25 seconds
   D. 30 to 45 seconds

10. Concrete may be allowed to drop freely:
    A. From any height
    B. Only inside thick wall sections
    C. No more than 5 feet
    D. In both thin and thick wall sections

11. During cold weather concreting, the only material that may not be heated before mixing is:
    A. Water
    B. Coarse Aggregate
    C. Fine Aggregate
    D. Cement

12. When ice is used as mixing water it is important that:
    A. All of it melts before mixing is completed
    B. All of it melts before batching is completed
    C. Some of it melts before the concrete is placed into forms
    D. None of the above
Appendix A

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, (pfc) 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.

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

**Nominal 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: either absorbed or 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):

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<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Calcium</td>
<td>Hydroxylated caboxlic acid</td>
</tr>
<tr>
<td></td>
<td>Sodium</td>
<td>Hydroxylated caboxlic acid salt</td>
</tr>
<tr>
<td></td>
<td>Potassium</td>
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</tr>
<tr>
<td></td>
<td>Ammonium salt of lignosulfonic acid</td>
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**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, or the gallons of water per bag of cement.

**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.
Conversion Factors

1 cubic foot = 7.5 gallons
1 cubic foot of water = 62.4 lbs.
1 gallon of water = 8.33 lbs.
1 cubic yard = 27 cubic feet
1 bag of cement = 94 lbs.

1 bag of cement = 1 cubic foot, (loose volume)
1 bag of cement = .48 cubic feet, (absolute volume)
4 bags of cement = 1 barrel
Appendix B

Questions and Answers
(102 things you need to know)

The following questions have been prepared to assist the student in their study of concrete technology. Many of the questions refer to a section of the North Carolina Standard Specification for Roads and Structures for answers. Most of the other questions have the answers given. Those answers that are not given may be found in this textbook.

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 and in 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 then 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

Testing:

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 –

\[
\frac{\text{wt. of total moisture}}{\text{wt. of oven dry aggregate}} \times 100 - (\% \text{ absorption}) = \% \text{ FREE MOISTURE}
\]

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 Angeles 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  
   (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 than 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 it 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.
Appendix C

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>AASHTO</td>
<td>American Association of State Highway Transportation Officials</td>
</tr>
<tr>
<td>ABS (%)</td>
<td>Percent of absorbed moisture</td>
</tr>
<tr>
<td>Abs. Vol.</td>
<td>Absolute volume</td>
</tr>
<tr>
<td>ACI</td>
<td>American Concrete Institute</td>
</tr>
<tr>
<td>AE</td>
<td>Air entrained</td>
</tr>
<tr>
<td>AEA</td>
<td>Air entraining admixture</td>
</tr>
<tr>
<td>Agg.</td>
<td>Aggregate</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
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<tr>
<td>Bbls</td>
<td>Barrels, (a measurement of cement)</td>
</tr>
<tr>
<td>CA</td>
<td>Coarse aggregate</td>
</tr>
<tr>
<td>Cem.</td>
<td>Cement</td>
</tr>
<tr>
<td>C.F.</td>
<td>Cement factor</td>
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<tr>
<td>Conc.</td>
<td>Concrete</td>
</tr>
<tr>
<td>CU.FT</td>
<td>Cubic feet</td>
</tr>
<tr>
<td>CU.YD.</td>
<td>Cubic yard</td>
</tr>
<tr>
<td>FA</td>
<td>Fine aggregate</td>
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<tr>
<td>F.M.</td>
<td>Fineness modulus</td>
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<tr>
<td>Gals.</td>
<td>Gallons</td>
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<tr>
<td>LA Abrasion</td>
<td>Los Angeles Abrasion</td>
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<tr>
<td>Lbs.</td>
<td>Pounds</td>
</tr>
<tr>
<td>Max.</td>
<td>Maximum</td>
</tr>
<tr>
<td>Min.</td>
<td>Minimum</td>
</tr>
<tr>
<td>Mod.</td>
<td>Modified</td>
</tr>
<tr>
<td>NCDOH</td>
<td>North Carolina Department of Highways</td>
</tr>
<tr>
<td>PCA</td>
<td>Portland Cement Association</td>
</tr>
</tbody>
</table>
Appendix D
Mathematical Formulas

Saturated Surface Dry – Absolute Dry

\[
\% \text{ Absorption} = \frac{\text{Absolute Dry} - \text{Weight of Wet}}{\text{Weight of Dry}} \times 100
\]

Note: If you dry the sample to the absolute dry condition, you must know the % absorption and subtract it from the total moisture. In such a case the formula would be as follows:

\[
\% \text{ Total Moisture} = \frac{\text{Weight of Wet} - \text{Weight of Dry}}{\text{Weight of Dry}} \times 100 \quad \% \text{ Absorption}
\]

Total Moisture = Free Moisture + Absorption

Dry Weight = SSD - (SSD \times Absorption)

Dry Weight = Wet Weight – (Wet Weight \times Total Moisture)

\[
\text{Bulk SSD Sp. Gr.} = \frac{\text{SSD}}{\text{SSD} - \text{Weight in Water}}
\]

Note: This is a ratio, not a percent, therefore do not multiply by 100.

\[
\text{Yield} = \frac{\text{Volume of Batch in Cubic Feet}}{\text{Bags of Cement in Batch}}
\]

27.00 CU.FT.

\[
\text{Cement Factor} = \frac{\text{Yield}}{27.00 \text{ CU.FT.}}
\]
Absolute Volume of a Solid = \[ \frac{\text{Lbs.}}{\text{Sp.Gr.} \times 62.4} \] (unit weight of water)

\[ \text{Lbs.} = \text{Solid Absolute Volume} \times \text{Sp. Gr.} \times 62.4 \]

Total Lbs. of Batch

\[ \text{Lbs. per Cu.Ft.} = \frac{\text{Total Lbs. of Batch}}{\text{Yield}} \]

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.

Theoretical Weight – Actual Weight

\[ \% \text{ Air} = \frac{\text{Theoretical Weight} - \text{Actual Weight}}{\text{Theoretical Weight}} \times 100 \]

Total Weight of Sample in Bucket – Weight of the Bucket

\[ \text{Unit Weight} = \frac{\text{Total Weight of Sample in Bucket} - \text{Weight of the Bucket}}{\text{Volume of the Bucket}} \times 100 \]

Pounds of Water

\[ \text{W/C Ratio} = \frac{\text{Pounds of Water}}{\text{Pounds of Cement in a Yard}} \]