Lab Manual for CE 3502
Materials for Civil and Construction Engineering

(Ver. Fall 2025)

Instructor: Younggguk Seo
Professor of Civil Engineering
E/ yseo2@kennesaw.edu
T/ 470-578-5496
H/ http://facultyweb.kennesaw.edu/yseo2/index.php

Table of Contents

Laboratory Safety Instructions (LSIs)

To ensure safe practices in our laboratories, the Department of Civil and Environmental Engineering (CEE) has adopted the following guidelines. These guidelines will be consistently enforced, and non-compliance will result in suspension from the laboratory. We believe that understanding inherent hazards and learning how to be safe should be an integral and important part of the education process. All students must understand and agree to the information in this document and *must sign the declaration before* undertaking any lab work.

DRESS

- Wear eye protection and use face masks when handling fine materials.
- Shoes must completely cover the foot. No sandals are allowed.
- Dress properly during all laboratory activities. Long hair, dangling jewelry, and loose or baggy clothing are hazards in the laboratory and must be secured.

BEHAVIOR

- Don't eat, drink, or smoke in the laboratory.
- Please don't yell, scream, or make any sudden loud noises that could startle others who are concentrating on their work.
- Do not attempt to identify chemicals by smell or taste.
- Consult with the instructor for proper disposal of specimens at all times.
- All accidents and unsafe behavior or conditions, no matter how minor, should be reported to your instructor immediately.
- Keep aisles clear and maintain unobstructed access to all exits, fire extinguishers, electrical panels, emergency showers, and eyewashes.
- Perform only those experiments authorized by the instructor. Never do anything in the laboratory that is not called for in the laboratory procedures or by your instructor.
- Carefully follow all instructions, both written and oral. Unauthorized experiments are prohibited.

EQUIPMENT

- Do not use any equipment unless you are trained and approved as a user by your instructor. Ask questions if you are unsure of how to operate something.
- If any laboratory equipment is malfunctioning, making strange noises, sparking, smoking, or smells "funny," get an instructor or staff member immediately.
- Do not handle electrical devices with wet hands or while standing on a wet floor. Be sure electrical cords are not lying on a wet floor.
- Turn electrical power switches to the OFF position before connecting or disconnecting the plug to or from the outlet.
- Exercise care when working with or near hydraulically- or pneumatically driven equipment. Sudden or unexpected motion can inflict serious injury.

I have read the "Laboratory Safety Instructions" and understand its contents. I agree to follow all of its rules at all times. I understand that violation of safety regulations may result in my expulsion from the laboratory and that continued infractions may result in my being withdrawn from the course.

____

Print Name　　　　　　　　Signature　　　　　　　　Date

Lab Report Presentation Guidelines

A technical report is a brief, but complete compilation of information generated during an investigation, experiment, or research project; thus, it must be accurate and impersonal (written in third person). The entire report (including tables, charts, and/or graphs) must be computer-generated unless stated otherwise. The report should be organized using the following sections and cannot exceed seven pages:

TITLE PAGE / COVER SHEET (all centered on page)

Course Name & Number (Section Number)
Title (should include name of test and material of specimen)
Date of Experiment:
Team Number, Members' Names, and Contributions
Submitted to: *Instructor's Name*
Date Report Submitted:

ABSTRACT

200-word maximum
Include key information in sections: background, objectives, methods, results, and conclusion
Write five keywords at the end of the Abstract
Do not reference any tables or figures

INTRODUCTION – up to half a page

Background (underlying information)
Material(s), shape & size of specimen(s)
Test objective(s)

PROCEDURE – up to one page

List and describe standard test procedures(s) followed and indicate any modifications to them.

RESULTS – up to three pages:

This section should contain a summary of the results obtained in the laboratory. You must report the required data and its analysis.

1. Data Sheets (Tables)

At top: Table Number - Title, Student's Name, Date of Experiment
Column title blocks should include name, symbol, and units

2. Photos/Images/Figures

At bottom: Figure Number – Title, Student's Name, Date of Experiment

3. Generated Graphs

At bottom: Figure Number – Title, Student's Name, Date of Experiment
[Title block includes name of graph, including the specimen's material]
Labels on axes [e.g., *Axial Stress, σ (ksi); Axial Strain, ε (in/in)]*
Use easy linear scales (e.g., 1, 2, 5, 10) and make them large enough to fill the page
Use *best-fit* straight lines and/or *best-fit* curves
If graphs are turned sideways (landscape), the staple will end up at the upper right corner

DISCUSSION – up to one page

Compare results with theoretical values if possible - Were the results reasonable?
Compare the materials (if more than one is used) - How did the specimen(s) behave?
Explain any errors observed in the experiment and the possible sources of error
Include any problems that were encountered that might have affected the results, and how to improve the results in future tests

CONCLUSIONS - up to half a page

Echo the objectives stated in the introduction and describe how they have been achieved through the experiment

Describe the main insights gained from the experiment and data analysis.

Do not reference tables or figures

Please note that conclusions are not a summary of results, but your accounts of what you learned from the results

Laboratory 1 - Aggregates

Mineral aggregate comprises the relatively inert filler material in Portland cement concrete and asphalt concrete mixes, as well as many other construction materials. It is extensively used as a filter medium in drainage, base material for road structures, and foundations, and as a protective or decorative coating. Aggregate usually occupies about 65-90 percent of the volume of concrete and can make up approximately 30 percent of the cost of pavement construction. Its selection and proportioning must be done in a manner that assures proper quality control.

The lab covers the following experiments (and their results) for both fine and coarse aggregates:

- Sieve analysis
- Unit weight
- Specific gravity
- Absorption
- %Voids

1.1 MATERIALS

Each team will be assigned two batches of aggregate (coarse and fine) to test. The aggregates are kept in an air-dry condition prior to testing.

1.2 EXPERIMENTAL PROCEDURES

1.2.1 Aggregate Sampling (ASTM C702, 2024; ASTM D75, 2019)

Field sampling from stockpiles requires blending small scoop samples from many different locations in the pile in each bin. Field samples of aggregate are obtained by methods detailed in the ASTM D75. The standard requires a field sample of approximately 50 lbs. per inch (or fraction thereof) of maximum aggregate size. For example, an aggregate with a maximum size of 1" would require a 50 lb field sample. An aggregate with a maximum size anywhere between 1" and 2" would require a 100 lb field sample.

These samples are usually too large for laboratory testing procedures, so they must be reduced in a manner that will maintain a representative sample. One of two methods is generally utilized for this purpose: Mechanical Splitting or Quartering.

The entire field sample should be placed into the hopper at a rate that will flow freely through the chutes into the collection pans below. As the aggregate is poured, its distribution should be from edge to edge of the splitter box so that approximately equal amounts flow through each chute.

Each splitting operation will reduce the sampling into two samples of roughly equal weight, and either of the two can be further split until a sub-sample of suitable size results.

1.2.1.1 Standards

- Sampling Aggregates - ASTM D75
- Reducing Field Samples of Aggregate to Testing Size - ASTM C702

1.2.1.2 Essential Equipment

- Scoops and shovels
- Sample splitter

Note: Due to the small lab facilities, a representative sample size will be used. (see Sec. 1.2.2.3 Test Procedure)

1.2.2 Sieve Analysis of Coarse and Fine Aggregates (ASTM C136, 2019)

Sieve analysis is used to determine the particle size distribution or gradation of an aggregate. Grain size distribution of a dry aggregate is determined by sifting the aggregate through a series of sieves (largest opening on top progressing to the smallest opening on the bottom). These sieves have square openings and are usually constructed of wire mesh. Usually, the sequence of sieves is chosen such that the next smaller sieve has approximately one-half the opening size of the sieve above it. When the results are presented graphically as a gradation curve, the sieve size is plotted as the opening size on the horizontal axis on a logarithmic scale.

The U.S. Standard Sieve Series and the clear opening of each sieve are given in Table 1.1. Aggregate larger than the #4 sieve is defined as coarse aggregate, or gravel, and aggregate smaller than that sieve is defined as fine aggregate, or sand. Some specifications would require the use of additional sieves between those sizes given in the table. The ½" and the 1", for example, are often used in coarse aggregate specifications.

Table 1.1 Standard U.S. Sieve Sizes

Sieve Number/Size	Inches	mm	µm
No. 200	0.00201	0.74	74
No.100	0.00585	0.150	150
No.50	0.0117	0.297	297
No.30	0.0232	0.589	589
No. 16	0.0469	1.19	1190
No. 8	0.0937	2.38	2380
No. 4	0.187	4.76	4760
3/8"	0.375	9.53	9530
3/4"	0.750	12.5	19,000
1/2"	1.50	19.0	38,000
1"	1.00	25.0	
1-1/2"11	1.50	37.5	

The coarseness of a fine aggregate is indicated by the value of its fineness modulus (or FM), while the coarseness of a coarse aggregate is indicated by its maximum aggregate size and fineness modulus.

The fineness modulus (FM) is a unitless number indicating the average size of the aggregate particles. The larger the value, the coarser the aggregate; if all the particles are held on the #4 sieve, the fineness modulus = 6 if all pass the #100, the fineness modulus = 0. The fineness modulus is computed by adding the cumulative percentage (%) retained on each of standard sieve sizes and dividing the sum by 100. The eleven sieves are the 6 in., 3 in., 1.5 in., 3/4 in., 3/8 in., #4, #8, #16, #30, #50, and #100.

The following example, using the data shown in Table 1.2 illustrates the calculation of the fineness modulus. Note that the #10 and the #200 sieves are not included in the calculation.

$$\text{Fineness Modulus (FM)} = \frac{9.7 + 22.6 + 41.9 + 53.2 + 67.7 + 80.6 + 96.8}{100} = 3.72$$

Table 1.2. Example sieve analysis used for calculation of Fineness Modulus (FM)

Sieve No.	Weight Retaine	Cumulative Weight Retained	Cumulative % Retained	Cumulative % Passing
4	30	30	9.7	90.3
8	40	70	22.6	77.4
10	30	100	(32.3)*	67.7
16	30	130	41.9	58.1
30	35	165	53.2	46.8
50	45	210	67.7	32.3
80	40	250	80.6	19.4
100	50	300	96.8	3.2
Pan	10	310	100	0

Numerically, fineness modulus is the sieve size, measured from the bottom of the stack, which represents the (weighted) average particle size of the aggregate. Thus, for sand with a fineness modulus of 3.00, sieve number 30 would be the sieve on which the average size particle is retained.

For coarse aggregates, there are two sets of maximum size definitions: Traditional and Superpave.

Traditional rule

- **The maximum aggregate size** for the aggregate is defined as the smallest sieve size through which 100% of the aggregate sample passes.
- **Nominal maximum aggregate size** is defined as the largest sieve that retains any of the aggregate particles, but generally less than 10%.

Superpave rule

- **The maximum aggregate size** for the aggregate is one sieve size larger than the nominal maximum aggregate size.
- **Nominal maximum aggregate size** is defined as one sieve size larger than the first sieve that retained more than 10% of the aggregate.

1.2.2.1 Standards

- Sieve Analysis of Fine and Coarse Aggregates - ASTM C136

1.2.2.2 Essential Equipment

- Brass sieves 8" round in various opening sizes and sieve shaker for 8" sieves

1.2.2.3 Test Procedure

1. Obtain the proper weight of air-dry aggregate for laboratory work. ASTM D75 lists the sample sizes shown in Table 1.3 for getting a representative material from the stock, and then the material is divided by a splitter to get the lab-size sample.

Table 1.3. ASTM Recommended Sample Sizes (ASTM D75)

Fine Aggregate	Sample Size
Sand	25 lbs (10 kg)
Coarse Aggregates (Maximum Size)	Sample Size
3/8" (9.5 mm)	25 lbs (10 kg)
1/2" (12.5 mm)	35 lbs (15 kg)
3/4" (19.0 mm)	55 lbs (25 kg)
1" (25.0 mm)	110 lbs (50 kg)
1.5" (37.5 mm)	165 lbs (75 kg)

Note: The amount needed for the sieving should be a maximum for accuracy, but not so much that blinding of any sieve occurs. Nominally, about 12 lbs (5000 g) of coarse aggregate and about 1.2 lbs (500 g) of fine aggregate are required using the circular sieves.

2. Assemble the sieves (see sizes used in Table 1.4) in order of largest opening on top to smallest opening on bottom. Be sure to place the pan on the bottom.
3. Secure the sieves in their rack and lock down. Place the weighed aggregates on the top of the sieve, hand shake the stack, and check to see that no sieve is near blinding. Place the special green lid from the shaker on the stack and insert it into the shaker. Fold down the hinged ring, fold forward the tamping hammer, and turn on the shaker (the switch is behind the motor). Shake for 5 min. minimum.
4. Weigh the materials that are retained on each of the sieves, including the weight retained on the pan, and record on the data sheet. If the sum of these weights is not within 1 percent of the original sample weight (the amount poured in the stack-remember to subtract any amount withheld to avoid blinding), the procedure should be repeated. Otherwise, use the sum of the weight retained to calculate the percentage retained on each sieve. Use a computer spreadsheet to calculate the cumulative percent retained on the sieves and percent passing each sieve. Include the spreadsheet in your report.
5. Plot the gradation curves for the coarse and fine aggregate on the same graph (use a semi-log scale to draw them on a computer-generated plot).
6. Compute the fineness modulus (set it up on the spreadsheet if needed).
7. Determine the maximum size for the coarse aggregate.
8. See the ASTM specifications to check details of the procedures and calculations.
9. Save the CA retained on 3/8 in. sieve and above for next week's lab. We need about 10 lbs (4000 g) of CA and about 2.5 lbs (1000 g) of FA, and soak them in a pan and a bowl, respectively.

Table 1.4 Data Sheet: Sieve Analysis of Fine and Coarse Aggregates

Coarse Aggregate

Material Type:_______________________

Test Date: _________________

Initial Sample Weight _________________ Final Sample Weight ______

% Loss/Gain _________________

Max. Aggregate Size __________

Nom. Max. Aggregate Size __________

Sieve Size	Empty Weight of Sieve (g)	Wt. of Sieve + Retained Aggregate (g)	Wt. of Aggregate Retained (g)	% Retained	Cumulative % Retained	% Passing
1.5"						
1"						
3/4"						
1/2"						
3/8"						
No. 4						
Pan						
		Total				

Fine Aggregate

Material Type:_______________________

Test Date: _________________

Initial Sample Weight _________________ Final Sample Weight ______

% Loss/Gain _________________

Fineness Modulus __________

Sieve Size	Empty Weight of Sieve (g)	Wt. of Sieve + Retained Aggregate (g)	Wt. of Aggregate Retained (g)	% Retained	Cumulative % Retained	% Passing
No. 4*						
No. 8*						
No.16*						
No. 30*						
No. 50*						
No. 100*						
Pan						
		Totals				

** Specified sieves for calculating the Fineness Modulus (FM) of fine aggregate*

1.2.3 Unit Weight of Aggregate (ASTM C29, 2023)

The unit weight of aggregate is commonly expressed in pounds per cubic foot or kilonewtons per cubic meter. The unit weight of an aggregate is significant in that it is used in computing the volume of voids in a loose amount of aggregate. The voids in aggregate depend on many factors, among them are size, shape, and surface texture of the aggregate, the size gradation, moisture content, and compaction energy applied to the aggregate volume.

Unit weight is determined by compacting the aggregate into a mold of known volume and determining the weight of the compacted aggregate. The known weight divided by the known volume is the unit weight.

1.2.3.1 Standards

- Unit Weight and Voids in Aggregate - ASTM C29

1.2.3.2 Essential Equipment

- Standard 5/8" diameter tamping rod
- Fine Aggregate - Scoop and standard 0.1 ft.^{3} container
- Coarse Aggregate - Shovel and standard 0.5 ft.^{3} container

1.2.3.3 Test Procedure (for Coarse Aggregate)

1. Using the shovel, fill the 0.5 cubic foot measure one-third full, level the surface, and tamp with 25 strokes, evenly distributed over the surface. Do not forcibly strike the 1.2.3.4
2. Fill the measure two-thirds full, level, and tamp 25 times over the surface. The tamping should penetrate only the last layer of aggregate during the tamping process.
3. Fill to overflowing, tamp as before, and strike off the surplus by rolling the tamping rod over the surface. Do not compress the aggregate during the strike-off process.
4. Determine the net weight of the aggregate in the measure and compute the unit weight (lb/ft^3). Repeat the procedure. Results should agree within one percent; if not, repeat the procedure a third time**.**

1.2.3.4 Testing Procedure (Fine Aggregate)

1. The procedure is essentially the same as for coarse aggregate, except use a scoop and the 0.1 cubic foot measure.

Table 1.5 Data Sheet: Unit Weight for Aggregates

Unit Weight of Coarse Aggregate

Material Type:_________________________ Test Date: _______

Step	Value	Calculation	Trial 1	Trial 2
A	Volume of container (ft^3)			
B	Weight of container (empty) (lb)			
C	Weight of container + Aggregate (lb)			
D	Weight of Aggregate (lb)	C - B		
E	Unit Weight (pcf)	D / A		
	Average Unit Weight, γ_b			

Unit Weight of Fine Aggregate

Material Type:_________________________ Test Date: _______

Step	Value	Calculation	Trial 1	Trial 2
A	Volume of container (ft^3)			
B	Weight of container (empty) (lb)			
C	Weight of container + Aggregate (lb)			
D	Weight of Aggregate (lb)	C - B		
E	Unit Weight (pcf)	D / A		
	Average Unit Weight, γ_b			

1.2.4 Specific Gravity and Absorption of Aggregates (ASTM C127, 2024; ASTM C128, 2022)
Specific gravity is the ratio of the weight of a given volume of material to the weight of an equal volume of water. However, there are several variations of this definition depending upon the aggregate material and its intended uses. In concrete work, specific gravity normally refers to the density of the individual particles (i.e., the density of solid particles), whereas the term unit weight refers to the density of a volume of aggregate particles (i.e., a cubic foot of crushed stone).

The most common definition of specific gravity in concrete aggregate is based upon the bulk volume of the individual aggregate particles in a saturated, surface-dry condition (i.e., the saturated, surface-dry, or "SSD," condition exists when all surface voids, cracks, crevices, etc., are filled with water, but the aggregate surface itself does not contain free water). The bulk (oven dry) specific gravity and the apparent specific gravity are used to a lesser degree. In any case, the solid unit weight of rock is computed as the specific gravity times the unit weight of water (62.3 lb/ft^3 or 9.81 kN/m^3 at room temperature).

Absorption is defined as the moisture content of an aggregate when it is in SSD. Coarse aggregates are considered to be SSD when they have been soaked in water for at least 24 hours and are wiped with a damp cloth and are free of any visible moisture films. The SSD condition of a fine aggregate is the moisture content at which a pile of standard size and shape (cone) will just flow when the mold is removed (see ASTM C128).

1.2.4.1 Standards

- Specific Gravity and Absorption
  - ⇒ Coarse Aggregate - ASTM C127
  - ⇒ Fine Aggregate - ASTM C128

1.2.4.2 Essential Equipment

- Fine Aggregate
  - ⇒ Pycnometer for specific gravity test of fine aggregate
  - ⇒ Conical SSD mold and tamping rod - ASTM C128
- Coarse Aggregate

1.2.4.3 Testing Procedure (for Coarse Aggregate)

1. Soak the coarse aggregate (retained on the No. 4 sieve and above) under water for 24 hours
2. Obtain about 10 lbs. (4000 g) of saturated coarse aggregate.
3. Towel dry the aggregate to the SSD condition. Work quickly and place individual SSD particles in a covered container until a sufficient quantity has been prepared. Note: the moisture will evaporate rather quickly in an open container.
4. Measure the SSD weight "B" of the coarse aggregate in air
5. Place the sample in the wire mesh basket, and determine its weight in water "C" (use worksheet). Be sure to zero the scale with the wire mesh basket submerged in the water without any aggregate.
6. Oven dry (110ºC±10º, ≈230ºF) the aggregate for about 24 hours, and then determine its dry weight "A".
7. From the above data, calculate three types of specific gravity and absorption as defined below:

- A = dry weight of coarse aggregate (measure next day)
- B = weight of coarse aggregate at SSD
- C = submerged weight of coarse aggregate
- $SG_{Apparent} = A / (A - C)$
- $SG_{Bulk,Dry} = A / (B - C)$
- $SG_{Bulk,SSD} = B / (B - C)$
- Absorption = ABS = (B - A) /A x100%
- %Voids = $[(SG \times \gamma_w - \gamma b) / (SG \times \gamma_w)] \times 100\%$

1.2.4.4 Testing Procedure (for Fine Aggregate)

1. Soak about 2-1/2 lbs (1000 g) of fine aggregate under water for 24 hours.
2. Bring a sample of the soaked fine aggregate to the SSD condition using ASTM C128.
3. Weigh the empty flask.
4. Fill pycnometer or flask with water to the 500 ml mark and record the weight of water and flask in grams, "B." The water temperature should be within 73 +/- 3 °F (23 +/- 1.5 °C).
5. Empty the water from the flask
6. Accurately weigh approximately 500 grams of SSD sand and place it in the flask.
7. Weigh the flask and SSD sand.
8. Add water until the flask is about ¾ full of water and sand.
9. Rinse down the walls of the flask, but do not fill above ¾ the volume.
10. Gently manually agitate the flask by rolling and gently shaking for approximately 10 minutes to remove entrapped air
11. Add water to the 500 ml mark. Weigh the total flask, sand and water, "C"
12. Wash the entire contents of the flask into a suitable pan and place it in the oven to dry (110ºC±10º, ≈230ºF). When dry, weigh the sand to obtain an accurate weight, "A"
13. From the above data, calculate the specific gravities and absorption as defined below:

- A = Weight of oven-dried sand used in flask
- B = Weight of flask filled with water
- C = Weight of flask, sand, & water at 500 ml
- S = Weight of SSD sand placed in the flask
- Absorption = ABS = (S - A) /A x100%
- $SG_{Apparent} = A / (B + A - C)$
- $SG_{Bulk,Dry} = A / (B + S - C)$
- $SG_{Bulk,SSD} = S / (B + S - C)$
- $\%Voids = [(SG \times \gamma_w - \gamma b) / (SG \times \gamma_w)] \times 100\%$

Table 1.6 Data Sheet: Specify Gravities and Absorptions of Aggregates

Specific Gravities and % Absorption of Coarse Aggregate

Material Type:_________________________ Test Date: ______

Step	Item	Calculation	Value
1, B	Weight of Coarse Aggregate SSD, B (lb)		
2, C	Submerged Weight of Coarse Aggregate, C (lb)		
3, A	Weight of Coarse Aggregate OD, A (lb)		
4	Apparent Specific Gravity	A / (A-C)	
5	Bulk, Dry Specific Gravity	A / (B-C)	
6	Bulk, SSD Specific Gravity	B / (B-C)	
7	Percent Absorption	(B-A) / A x 100	
8	Percent Voids		

Specific Gravities and % Absorption of Fine Aggregate

Material Type:_________________________ Test Date: ______

Step	Item	Calculation	Value
1	Weight of Empty Flask (g)		
2, B	Weight of Flask filled with Water (g)		
3	Weight of Flask + Fine Aggregate SSD (g)		
4, C	Weight of Flask + FA + Water added, C (g)		
5, A	Weight of Fine Aggregate OD, A (g)		
6, S	Weight of Fine Aggregate SSD, S (g)		
7	Apparent Specific Gravity	A / (B+A-C)	
8	Bulk Specific Gravity, Dry	A / (B+S-C)	
9	Bulk Specific Gravity, SSD	S / (B+S-C)	
10	Percent Absorption	(S-A) / A x 100	
11	Percent Voids		

1.3 ITEMS TO INCLUDE IN LABORATORY REPORT 1

Include the following items in the "Results" portion of your report:

- Sieve Analysis for both Coarse and Fine Aggregate (based on Table 1.4)
    1. A table of weights retained on each sieve, and the cumulative percentage of material passing and retained on each sieve
    2. Graph the gradation curves using a semi-log scale (label as Figures 1.1 and 1.2)
    3. Calculate and report the fineness modulus for fine aggregate
    4. Determine the maximum and nominal maximum aggregate sizes of the coarse aggregate

- Unit Weight for Fine and Coarse Aggregates (based on Table 1.5)
    1. Calculate and report the unit weights

- Specific Gravity and Absorption for Fine and Coarse Aggregates (based on Table 1.6)
    1. Apparent specific gravity
    2. Bulk specific gravity (Oven Dry)
    3. Bulk specific gravity (SSD)
    4. Calculate and report absorption
    5. Report the void content to the nearest 1%

- Reference

  The type of Coarse Aggregate (CA) is 57
  The type of Fine Aggregate (FA) is 810
  Typical Aggregate Properties (reference):
  FA & CA: All Specific Gravities 2.4-2.9 (PCA)
  FA & CA: Bulk Unit Weight 75-110 pcf (PCA)
  FA: Fineness Modulus (FM) 2.3-3.1 (from text)
  FA & CA Gradations: p. 185-186 (text)
  %Abs - FA: .2-2%; and CA: .2-4% (PCA)
  %Voids - FA: 40-50% CA: 30-45% (PCA)

Laboratory 2 – Determination of Compressive Strength of Cement Mortar Cube Specimens

Cement mortar strength is not directly related to concrete's strength. The most common strength testing is conducted in compression on a 50 mm (2-inch) cement mortar specimen. The test is conducted until failure. The compressive strength of a mortar cube is typically used as a quality control measure to determine if the cement meets ASTM specifications. This test is also done to determine if questionable water used for a concrete mix can be used in place of potable water.

The strength can be affected by a number of items, including water-cement ratio, cement-fine aggregate ratio, type and grading of fine aggregate, manner of mixing and molding specimens, curing conditions, size and shape of specimen, moisture content at time of test, loading conditions, and age. Since cement gains strength over time, the time at which a test is to be conducted must be specified. Typically, times are 1 day (for high early strength cement), 3 days, 7 days, 28 days, and 90 days (for low heat of hydration cement). The average compressive strength of the cubes must be no less than ASTM C150 (ASTM C150, 2024) compressive strength requirements for Portland cement mortars (see Table 2.1).

Table 2.1 ASTM C150 Portland Cement Mortar Compressive Strength Specifications in MPa (psi)

Curing Time	Portland Cement Type							
	I	IA	II	IIA	III	IIIA	IV	V
1 day±1/2 hr	-	-	-	-	12.4 (1800)	10.0 (1450)	-	-
3 days±1 hr	12.4 (1800)	10.0 (1450)	10.3 (1500)	8.3 (1200)	24.1 (3500)	19.3 (2800)	-	8.3 (1200)
7 days±3 hrs	19.3 (2800)	15.5 (2250)	17.2 (2500)	13.8 (2000)	-	--	6.9 (1000)	15.2 (2200)
28 days±12 hrs	-	-	-	-	-	-	17.2 (2500)	20.7 (3000)

If the compressive strength test is used to test questionable water, the strength of the cubes is tested after 7 days. The average compressive strength of the mortar cubes made with the questionable water should not be less than 90% of the average strength of cubes made with potable or distilled water (ASTM C109, 2024).

In this lab, two (2) batches of cement mortar will be made – one with potable water and the other with questionable water. Both batches will use the same W/C ratio and blend of sand, water, and cement. Each batch will be enough for 6 cubes (each team will mold 6 cubes – 3 with the potable water and 3 with questionable water). After seven (7) days of curing time, the samples will be tested in compression to determine strength.

For the lab reports, each student will analyze the collective results of all mortar cubes in their course section.

Important!!!

Please read the following cautionary note before handling Portland cement

Portland cement is a caustic material, and can cause skin irritation or irritation of the mucous membranes of the eyes and nose.

In the measuring and mixing processes:

- Minimize the amount of direct skin contact – With reasonable care, the amount of skin contact in these lab exercises normally does not cause problems.
- Wash the Portland cement off your skin promptly
- Minimize the amount of Portland cement dust by avoiding pouring or sifting the dry powder.

Once water is added to Portland cement, it will eventually set up, even when submerged in water. After setting, it cannot be removed from mixing bowls, utensils, sinks, drains, tools, concrete mixers, or the floor.

Do not use laboratory sinks for washing Portland cement from hands, tools, bowls, countertops or any other implement. Wash such items outside as directed by the instructor.
Wash all Portland cement (either wet or dry) from all equipment and tools before leaving the laboratory

Do not leave cement-coated tools or bowls to "soak". Submergence in water will not prevent the setting of the Portland cement, and will actually cause it to set more thoroughly.

Conduct all tests and prepare all test specimens of using fresh Portland cement in the room with the floor drain unless directed otherwise.

2.1 MATERIALS

- Graded Standard Sand (also known as ASTM Standard Sand) (ASTM C778, 2021)
- Tap water
- Questionable water
- Portland Type I Cement per ASTM C150 – Specification for Portland Cement

Mortar Composition:

- Each team will make one batch of cement mortar, enough to prepare six 2-inch cubes with the proportions listed below.
- The proportions of materials for the standard mortar shall be one part of cement to 2.75 parts of graded standard sand by weight. A water-cement ratio of 0.35 is used for all Portland cements and 0.30 for all air-entraining Portland cements. Please calculate the amount of water needed to have a water-cement ratio of 0.485 in Table 2.2

Table 2.2 Cement, Water and Sand Weights for Six Two-Inch Cement Mortar Cubes

W/C	0.485
Cement (grams)	500
Water (grams)	
Sand (grams)	1375

2.2 EXPERIMENTAL PROCEDURES

2.2.1 Mechanical Mixing of Cement Mortar and Molding Test Specimens

2.2.1.1 Standards

- Mechanical Mixing of Hydraulic Cement Pastes and Mortars - ASTM C305 (ASTM C305, 2020)
- Compressive Strength of Hydraulic Cement Mortars - ASTM C109

2.2.1.2 Essential Equipment

- Scale (2000 g)
- 2-inch cast aluminum mold frame, 3 removable polypropylene liners
- 5-qt. mixer, bowl, and spoon
- Polypropylene tamper and trowel
- Timer

2.2.1.3 Procedure Mixing Mortar

Place dry paddle and dry bowl in the mixing position of the mixer. Introduce the materials into the bowl in the following manner:

1. Place all the mixing water in the bowl.
2. Add the cement to the water; then start the mixer and mix at a slow speed (140 rpm) for 30 s.

3. Add sand slowly over a 30 s period, while continuing to mix at a slow speed.
4. Stop the mixer, change to medium speed (285 rpm), and mix for an additional 30 s.
5. Stop the mixer and let the mortar stand for 1.5 minutes. During the first 15 s, quickly scrape down into the batch any mortar that may have collected on the side of the bowl.
6. Finish mixing for 1 minute at medium speed (285 rpm).

2.2.1.4 Molding Test Specimens

Start molding within 2 minutes and 30 s after completion of the original mixing of the mortar.

1. Place a layer of mortar about 1 in. (25 mm) (approximately one half of the depth of the mold) in all of the lined cube compartments.

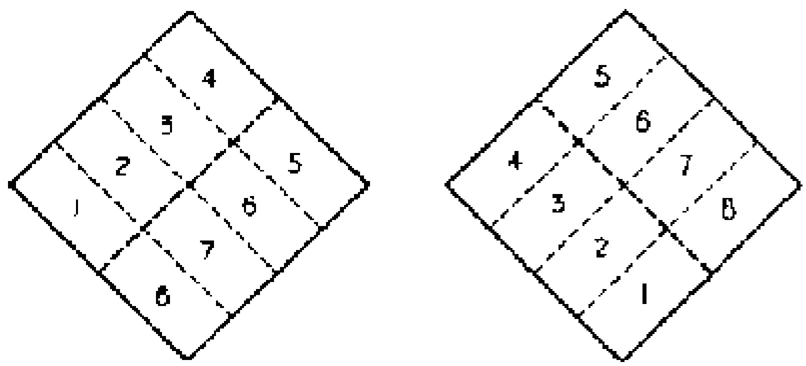

Figure 1. Order of Tamping in Molding of Test Specimens (top view).

2. Tamp the mortar in each cube compartment 32 times in about 10 s in four (4) rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen (see Figure 1).
3. Fill the compartments with the remaining mortar to overflowing and tamp as specified for the first layer. During tamping of the second layer, bring in the mortar forced out onto the tops of the molds after each round of tamping using a gloved finger and the tamper. On completion of the tamping, the tops of all cubes should extend slightly above the top of the mold.
4. Trowel mortar of each cube both laterally and longitudinally. Cut off the mortar to a plane surface with the top of the mold by drawing the straight edge of the trowel, held perpendicular to the mold, with a sawing motion over the length of the mold.
5. Cover molded specimens with plastic wrap or place in a curing machine (Ziploc bags) for 24 hours. Keep specimens in their aluminum molds for this initial curing period. After 24 hours, remove specimens from the molds and place back in the curing machine (Ziploc bags) for 6 additional days.

2.2.2 Determination of Cement Mortar Cube Compression Strength

2.2.2.1 Standards

- Compressive Strength of Hydraulic Cement Mortars - ASTM C109

2.2.2.2 Essential Equipment

- Ruler (inches)
- Utility knife
- Retainer caps
- Compression pads
- Compression testing machine

2.2.2.3 Procedure

Test all specimens according to the specified testing schedule.

1. Remove the specified test specimen from the curing tank. Make a slit in the bottom of each liner with the utility knife to pop out the cube. Wipe to a surface dry condition and remove any loose sand grains or incrustations from test surfaces.
2. Apply the load to the specimen faces that were in contact with the true plane surfaces of the mold. Check the straightness of these faces with a straight edge. Note that grinding is required if the surfaces have appreciable curvature. Select opposing surfaces that have the straightest profiles. Measure the area of the loaded surface (in^2) and record in Table 2.3.
3. Place the specimen with the compression pad below the center of the upper bearing block of the testing machine. Ascertain that this spherically seated block is free to tilt. Test at a loading rate such that the peak load will be reached in a period of 20 s to 80 s (usually 200 to 400 lbs/s, 900-1800 N/s). Make no adjustments in the controls of the testing machine while the specimen is yielding before failure. Continuously apply the load until the load no longer increases.
4. Test until the cube specimen is completely broken, and no additional load can be applied.
5. Record the total maximum load as indicated by the testing machine in Table 2.3.
6. Schematically show how the specimen failed (or take a photo) in Table 2.4
7. Calculate the compressive strength of each specimen to the nearest 10 psi.
8. Calculate the averages of cubes 1-6 and 7-12 and report each to the nearest 10 psi.

Table 2.3 Compressive Strength Test Results of Cement Mortar Cubes

POTABLE WATER			
Batch1/Team1	**Trial 1**	**Trial 2**	**Trial 3**
Area of Loaded Surface, A (in^2)			
Failure Load, P (lbs)			
Compressive Strength, S_m (nearest 10 psi)			
Batch1/Team2	**Trial 4**	**Trial 5**	**Trial 6**
Area of Loaded Surface, A (in^2)			
Failure Load, P (lbs)			
Compressive Strength, S_m (nearest 10 psi)			
Average Compressive Strength of Cubes 1 thru 6 (nearest 10 psi)			
90% of Average Compressive Strength (nearest 10 psi)			
QUESTIONABLE WATER			
Batch2/Team3	**Trial 7**	**Trial 8**	**Trial 9**
Area of Loaded Surface, A (in^2)			
Failure Load, P (lbs)			
Compressive Strength, S_m (nearest 10 psi)			
Batch2/Team4	**Trial 10**	**Trial 11**	**Trial 12**
Area of Loaded Surface, A (in^2)			
Failure Load, P (lbs)			
Compressive Strength, S_m (nearest 10 psi)			
Average Compressive Strength of Cubes 1 thru 6 (nearest 10 psi)			
90% of Average Compressive Strength (nearest 10 psi)			

Table 2.4 Description of Cement Mortar Cube Specimen Failures

POTABLE WATER			
Batch1/Team1	**Trial 1**	**Trial 2**	**Trial 3**
Fracture Photo/Detailed Description			
Batch1/Team2	**Trial 4**	**Trial 5**	**Trial 6**
Fracture Photo/Detailed Description			
QUESTIONABLE WATER			
Batch2/Team1	**Trial 7**	**Trial 8**	**Trial 9**
Fracture Photo/Detailed Description			
Batch2/Team2	**Trial 10**	**Trial 11**	**Trial 12**
Fracture Photo/Detailed Description			

2.3 ITEMS TO INCLUDE IN LABORATORY REPORT 2

- Include the final weight of ingredients used in each cement mortar batch (make similar to Table 2.2)
- Include all results from the compression strength tests (Tables 2.3 and 2.4)
- Make a bar chart of the 7-day compressive strength on the y-axis versus the potable water trial number (1 through 6) on the x-axis. Superimpose the required strength from ASTM C150. Figure 2 shows an example chart.

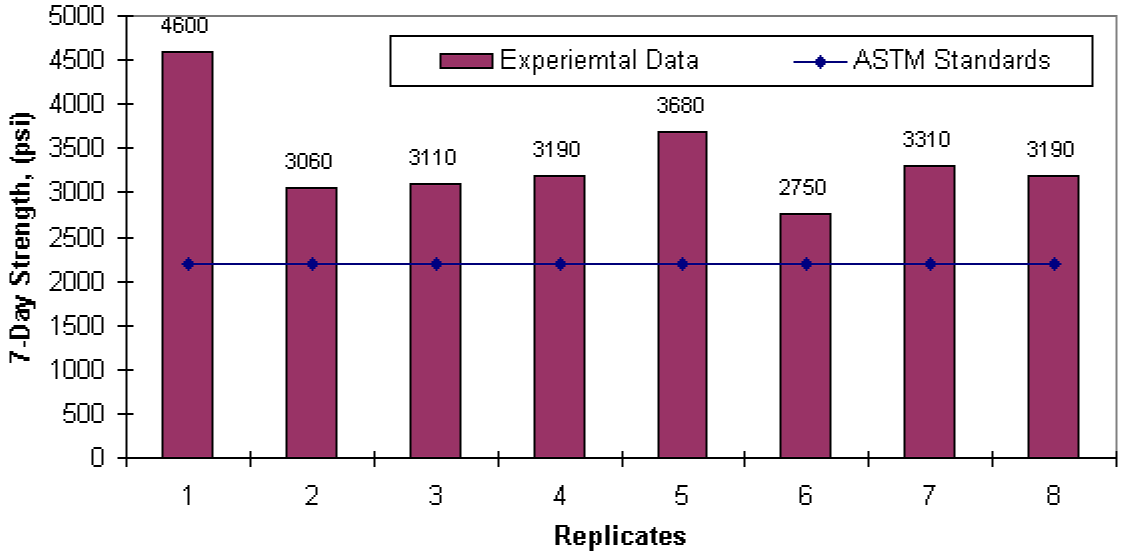

Figure 2. Example Plot for 7-day Compressive Strength of Mortar Cubes.

- Make a similar bar chart of the 7-day compressive stress (strength) on the y-axis versus the questionable water trial number (7 through 12) on the x-axis. Superimpose the required strength from ASTM C109 (90% of the Average Compressive Strength from trials 1 through 6)
- In the discussion, report the most common fracture shape. Explain the strength results and compare with requirements/expectations. Do the mortar cubes made with the potable water meet ASTM C150 strength requirements? Can this Portland cement be used for further lab tests and for making concrete? Do the mortar cubes made with the questionable water meet ASTM C109 requirements? Can this questionable water be used as concrete mixing water?

Remember: all tables and figures are to be numbered/titled and include your name and the date(s) of the experiment

Laboratory 3 - Fresh Concrete Properties: Concrete Mix Design by ACI Method and Trial for Slump, Workability, Unit Weight, Yield, and Air Content (Pressure Method)

In this lab, you will determine an initial concrete mix design based on the ACI mix design method. The mix design will be tested for slump, unit weight, yield, and air content. Based on the experimental data, you will make any necessary adjustments to your mix for the next lab to meet specifications for the slump.

3.1 MATERIALS

- Assigned coarse aggregate (gravel) and fine aggregate (sand)
- Portland cement (handle with proper safety precautions)
- Air-Meter Pressure Method test kit
- An ASTM C143 slump cone with a 5/8-inch diameter rod and clamp base

3.2 EXPERIMENTAL PROCEDURES

3.2.1 Concrete Mix Design (ACI PRC-211.1-91, 2009)

3.2.1.1 Standards
- ACI Standard 211.1-91 – "Standard practice for selecting proportions for normal, heavyweight, and mass concrete."

3.2.1.2 Essential Tool
- The mix design form was designed and provided by the instructor for each group

3.2.1.3 ACI Mix Design Procedure
Each group will be assigned a w/c ratio, and the desired slump of your mix will be 2 to 4 inches. You need to calculate or verify the volume of cement concrete mix required to fill a 0.25 ft^3 metal bucket and add a modest waste factor (50% to be safe). That volume of mix will be sufficient to measure the slump in the standard cone. The mix design calculations, slump, unit weight of concrete, yield, air content (using the pressure method), and other quality indicators are desired from this lab. Based on your maximum aggregate size and target slump (range), the expected air content of your mix can be noted in the Lab 3 Design Table.

Your next experiment will be to prepare a larger-scale mix from the same ingredients in a mechanical concrete mixer. Given a too high (low) slump in your trial mix, you should plan to add (decrease) water. In either case, the water/cement must remain constant, and the amount of fines (sands) will also change. The plans for mixing (i.e., change in aggregates and water weights based on the trial batch results) in the next experiment should be part of the discussion of the results section in this experiment.

Table 3.1 Target Percent Air Content (Mamlouk & Zaniewski, 2011).

	Nominal Maximum Aggregate Size							
	9.5 mm ($^3/_8$) in.	12.5 mm ($^1/_2$) in.	19 mm ($^3/_4$) in.	25 mm (1 in.)	37.5 mm ($1^1/_2$) in.	50 mm (2 in.)	75 mm (3 in.)	150 mm (6 in.)
Non-air-entrained concrete	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete**								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Design your mix with the following steps:

1. Set up a table of weight, density, and volume using the mix design form handout (labeled as Lab 3 Design Table for Fresh Conc Properties)
2. The required slump is given as 2 to 4 inches
3. Determine the nominal maximum size of aggregate – The nominal maximum aggregate size is defined as "… the size of the sieve that is one size smaller than the sieve through which 100% of the aggregate sample passes."
4. Estimate the amount of mixing water from Table 3.2, convert to per $ft^{3,}$ and place in (2).

Table 3.2 Mixing Water in kg/m^3 (lb/yd^3) for Different Slumps and Aggregate Sizes (Mamlouk & Zaniewski, 2011).

Slump, mm (in.)	9.5 ($^3/_8$)	12.5 ($^1/_2$)	19 ($^3/_4$)	25 (1)	37.5 ($1^1/_2$)	50 (2)***	75 (3)***	150 (6)***
	Non-air-entrained concrete							
25 to 50 (1 to 2)	207 (350)	199 (335)	190 (315)	179 (300)	166 (275)	154 (260)	130 (220)	113 (190)
75 to 100 (3 to 4)	228 (385)	216 (365)	205 (340)	193 (325)	181 (300)	169 (285)	145 (245)	124 (210)
150 to 175 (6 to 7)	243 (410)	228 (385)	216 (360)	202 (340)	190 (315)	178 (300)	160 (270)	—
	Air-entrained concrete							
25 to 50 (1 to 2)	181 (305)	175 (295)	168 (280)	160 (270)	150 (250)	142 (240)	122 (205)	107 (180)
75 to 100 (3 to 4)	202 (340)	193 (325)	184 (305)	175 (295)	165 (275)	157 (265)	133 (225)	119 (200)
150 to 175 (6 to 7)	216 (365)	205 (345)	197 (325)	184 (310)	174 (290)	166 (280)	154 (260)	—

Nominal Maximum Aggregate Size in mm (in.)**

5. Selection of water-cement ratio – the w/c ratio is given based on the lab group and will be between 0.40 and 0.70. Ask the instructor for your group's w/c ratio.
6. Calculate the cement content and place it in (3).
7. Cement [lb/ft^3] = Estimated mixing water content [lbs/ft^3] / (water/cement ratio)
8. Determine volume of coarse aggregate required from Table 3.3, convert to ft^3 basis and place in (9) – notice the coarse aggregate amount is a function

Table 3.3 Bulk Volume of Coarse Aggregate per Unit Volume of Concrete (Mamlouk & Zaniewski, 2011).

Nominal Maximum Size of Aggregate, mm (in.)	Bulk Volume of Dry-Rodded Coarse Aggregate Per Unit Volume of Concrete for Different Fineness Moduli of Fine Aggregate**			
	Fineness Modulus			
	2.40	2.60	2.80	3.00
9.5 (3/8)	0.50	0.48	0.46	0.44
12.5 (1/2)	0.59	0.57	0.55	0.53
19 (3/4)	0.66	0.64	0.62	0.60
25 (1)	0.71	0.69	0.67	0.65
37.5 ($1\frac{1}{2}$)	0.75	0.73	0.71	0.69
50 (2)	0.78	0.76	0.74	0.72
75 (3)	0.82	0.80	0.78	0.76
150 (6)	0.87	0.85	0.83	0.81

9. of the nominal maximum coarse aggregate size and the fine aggregate fineness modulus.
10. Determine the weight of the coarse aggregate and put in (10).
11. Estimate fine aggregate content with the absolute volume method.
12. First, calculate the volumes of water, air, cement and coarse aggregate and place in (11), (12), (13), and (14)
13. Fine aggregate volume is the unit volume of concrete minus the volume displaced by the other ingredients (water, air, cement, and coarse aggregate). Calculate fine aggregate volume and place in (15).
14. Calculate the fine aggregate weight and place it in (16).
15. Adjust the trial mix for aggregate moisture and place in (17), (18), (19).
16. Scale the estimated ingredients down to a convenient size (i.e., the bucket used in this case is $0.25ft^3$ plus about a 50% waste factor) – Calculate and place in (31), (32), (33), and (34).

3.2.2 Hand Mixing Concrete (ASTM C192, 2025)

3.2.2.1Essential Equipment

- Watertight, clean, damp, and metal pan
- Trowel

3.2.2.2 Procedure

1. Mix the cement and fine aggregate without the addition of water until they are thoroughly blended.
2. Add the coarse aggregate and mix the entire batch without the addition of water until they are thoroughly blended.
3. Add water and mix the mass until the concrete is homogeneous in appearance and has the desired consistency.

3.2.2 Trial for Slump (ASTM C143, 2015)

The slump test gives information regarding the workability of the concrete. A too-low slump indicates hard-to-work-with concrete.

3.2.2.1 Standards

- Slump of Cement Concrete (ASTM C143)

3.2.2.2 Essential Equipment

- An ASTM C143 slump cone with clamp base
- 5/8 in. diameter tamping rod
- A pan sufficiently large to contain the volume of a 0.25 ft3 bucket plus a waste factor

3.2.2.3 Procedure

1. Following the slump test procedure and perform your tests within 2-1/2 minutes:

   ⇒ Fill the cone in three equal volumes (2-5/8" from the bottom, 6-1/8" from the bottom, and the top), rodding each layer 25 times with a standard tamping rod. Level off the top by rolling the rod with a screening motion.
   ⇒ Remove the cone vertically at a constant rate in approximately 2 to 5 seconds
   ⇒ Measure the difference in the height of the slumped concrete from the original height of the cone (Put the cone next to the slumped concrete and use a level rod to compare the cone and slumped concrete height)

2. Report the slump to the nearest ¼ inch.
3. Based on the slump of the trial batch, the trial batch mix design should be adjusted for the larger mixture for casting cylinders in the next lab. Include a short discussion of what you expect (either increasing or decreasing the amount of water and therefore also adjusting the amounts of fine aggregate and cement in the mixture) based on the measured slump.

3.2.3 Unit Weight and Yield (ASTM C138, 2024)

For a given type of concrete, unit weight is an indicator of strength. Unit weight is also an indicator of air content, since as the unit weight decreases, air content generally increases. Yield is important for ordering and ensuring the correct amount of concrete has been delivered.

3.2.3.1 Standards

- Unit Weight and Yield of Freshly Mixed Concrete (ASTM C138)

3.2.3.2 Essential Equipment

- A 0.25 ft^3 metal bucket is provided with the Air-Meter Pressure Method test kit
- Tamping rod
- Mallet

3.2.3.3 Procedure

1. Obtain the 0.25 ft^3 bucket – weigh the empty bucket
2. Note the minimum capacity of the required measure, based on nominal maximum

aggregate size, as given in Table 3.4.

Table 3.4 Capacity of Measures (ASTM C138)

Nominal Maximum Size of Coarse Aggregate (in.)	**Capacity of Measure[A] (ft^3)**
1	0.2
1-1/2	0.4
2	0.5
3	1.0
4-1/2	2.5
5	3.5

The indicated size of measure shall be used to test concrete containing aggregates of a nominal maximum size equal to or smaller than that listed. The actual volume of the measure shall be at least 95% of the nominal volume listed.

3. Place the concrete mix into the bucket using the procedure of ASTM C138
4. Place the concrete in three equal layers
5. Rod each layer 25 times, penetrating the layer underneath 1 inch.
6. After rodding each layer, tap the side of the bucket 10 to 15 times with a mallet to remove any voids.
7. Strike any excess concrete off the top of the bucket with a straight edge to yield a flat surface.
8. Weigh the concrete-filled bucket after cleaning off any excess concrete on the sides.
9. Calculate the unit weight of concrete, **W,** using the data presented in Table 3.5.

Table 3.5 Measurements for Unit Weight of Concrete

Unit Weight of Concrete	Value
Weight of empty container	
Weight of container + concrete	
Weight of concrete	
Volume of container	
Unit weight of concrete, **W**	

10. Yield, **Y** – Calculate the yield using the following equation:

    $\mathbf{Y = (W_1/W)}$, where $\mathbf{W_1}$ = the weight of all the materials = sum of (31), (32), (33) & (34) in the mix design sheet provided by the instructor

11. Relative Yield, $\mathbf{R_y}$ – Calculate the yield using the following equation

    $\mathbf{R_y = (Y/Y_{designed})}$, where $\mathbf{Y_{designed}}$ = Volume batch designed to produce

12. A relative yield less than 1.0 indicates the batch is short of its design volume

13. Record **W**, **Y** and $\mathbf{R_y}$

3.2.4 Air Content (ASTM C231, 2024)

Air content affects the workability of freshly mixed concrete and the strength and durability of hardened concrete. The air content is needed for a properly proportioned concrete mix.

3.2.4.1 Standards

- Air Content of Freshly Mixed Concrete by Pressure Method (ASTM C231)

3.2.4.2 Equipment

- Press-Ur-Meter Kit with accessories included

3.2.4.3 Procedure

1. Follow the steps provided in the kit
2. Record the air content, A, in Table 3.6

Table 3.6 - Unit Weight, Slump, Yield, Relative Yield and Air Content

Fresh/Plastic Concrete Properties	Value
Water-to-Cement Ratio	
Unit weight of concrete, **W**	
Yield, **Y**	
Relative Yield, $\mathbf{R_y}$	
Measured air content (pressure method), **A**	
Measured Slump (to nearest 1/4 inch)	

3.3 ITEMS TO INCLUDE IN LABORATORY REPORT 3

- Provide the final ingredient proportions for $\mathbf{Y}_{\mathbf{designed}}$ and weights for your w/c ratio, W_l in the Results section - use your own table number.
- Place final calculated results in a table similar to Table 3.6 for unit weight, slump, yield, relative yield, and air content in the Results - use your own table number
- Comment on any problems encountered while running the slump test
- Based on the slump compared to the required slump, discuss any changes you plan to make to the mixture for mixing the larger concrete batch in the next lab.
- Include your mix design sheet (given by the instructor), unit weight table (W), Y and R_y calculations in the Appendix.

Laboratory 4 - Properties of Hardened Concrete

The purpose of this experiment is to prepare a concrete mix with the desired water/cement (w/c) ratio and slump, to make 6 cylindrical concrete specimens and one beam with that concrete, and test the cylinders for compressive strength versus time, splitting tensile strength, and Young's Modulus. This experiment is preceded by the trials of the previous experiment, which determined how close your mix was to your desired fresh concrete properties.

4.1 MATERIALS

- A mechanical concrete mixer, drum style, moistened inside
- Various containers for gravel, sand, cement, water, and withheld ingredients
- A deep pan to hold concrete after mixing
- Six (6) plastic cylinder molds (two for 6" diameter, four for 4" diameter) - write group number on each
- One 6x6x21-inch metal beam mold, pre-oiled with WD40 or lined with plastic
- Scales to weigh up to 220 lbs of materials
- Plastic mold splitting tool

4.2 EXPERIMENTAL PROCEDURES

4.2.1 Mixing and Casting of Cylinders and One Beam

4.2.1.1 Standards

- ACI Standard 211.1-91 – "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete"
- Making and Curing Concrete Test Specimens in the Laboratory (ASTM C192 or C31) (ASTM C31, 2025)

4.2.1.2 Essential Equipment

- Mix design with a final design volume equal to the volume of one 6"x6"x21" beam, two 6"x12", four 4"x8" cylinders, plus a 20% waste factor for concrete left on mixing drum and tools
- Mechanical mixer, moistened inside
- Large, moistened pan for holding mixed concrete

Important!!!

Please read the following cautionary note before running any experiment

Safety Notes:
Operate safely around moving equipment. Do not reach into moving parts. If one person is preparing to turn on the power and rotate the mixer drum, that person must always check with people on the other side of the mixer for safe positions before starting the mixer.
Handle concrete carefully, avoiding contact with skin as much as possible.

Cleanup:

- Place large excesses of concrete volume in additional cylinders and place cylinders in a low-traffic area of the mixing room.
- Wash out all remaining concrete and the tools in the designated outside area. Return tools to their proper storage locations.

4.2.1.3 Procedure

1. Each group will be assigned a w/c ratio, and the desired slump of your mix will be 2 to 4 inches.
2. Using your mix design from the previous lab, modify the mix to fill the 6 cylinders (plus a 20% waste factor) and to achieve your desired slump (if necessary)
3. If that mix had an incorrect slump, you will need to adjust your water, cement, and fine aggregate using the provided design table (normally designated as Table 4.1).
4. You will calculate the total volume of the 6 cylinders and beam (one 6"x6"x21" beam, two 6”x12” and four 4"x8” cylinders) and increase it by at least 20% to account for losses in the mixer and on tools and containers.
5. Check your planned weights with the instructor before you begin weighing your mix, and you will be assigned a mixer.
6. For mixing in the mechanical mixers, use the following steps:

    ⇒ Moisten the inside of the mixer (add only enough water to coat the inside of the mixer).
    ⇒ Add the coarse aggregate and about 1/3 of the water.
    ⇒ Turn on the mixer and allow it to turn a few revolutions (approximately 5 turns).
    ⇒ Turn off the mixer.
    ⇒ Add the fine aggregate, cement, and remaining mixing water.
    ⇒ Turn on the mixer and allow it to mix for 1 minute for the first cubic yard, plus an additional 15 seconds for each additional cubic yard of concrete.
    ⇒ Turn off the mixer.

7. Lightly moisten the large pan for holding the mixed concrete and discharge the mixer into the pan.
8. Cast the six cylinders and beam with proper rodding and tapping to remove air bubbles.
9. Place the concrete into each cylinder in **three** equal-height **layers**.
10. Rod each layer **25 times** using the 3/8" rod for the small cylinders and the 5/8" rod for the large ones.
11. Tap the sides of the mold lightly with a mallet **10 to 15 times** after each layer to remove entrapped air bubbles due to the rodding process.
12. Strike excess concrete off the top, cover them with the provided lids, transport them carefully, not squeezing the sides, and store them on a level surface.
13. Place the concrete into the beam mold in **two** equal-height layers. Rod each layer **25 times** using the 3/8" rod. Tap the sides of the mold lightly with a mallet **10 to 15 times** after each layer to remove entrapped air bubbles due to the rodding process.
14. If you are allowed to use a mechanical vibrator, place the concrete into the beam mold in one layer. Insert **4 inches** of the vibrator at **intervals of 6 inches or less** along the centerline of the beam, being careful not to touch the sides or the bottom of the mold.
15. Strike excess concrete off the top, cover the beam with plastic wrap (*write group number on plastic*), and store it on a level surface.
16. Report the summary of the mix design data in Table 4.1

Table 4.1 Mix Design Data

- Water/Cement Ratio Used: ________
- Required volume of one 6x6x21 inch beam, and four 4x8 inch and two 6x12 inch cylinders (plus 20% waste factor): ________

Ingredient	Volume (ft^3 for 1 ft^3	Weight (lbs per 1 ft^3)	Scaled Weight (lbs) for required volume with 20% waste factor
Coarse Aggregate			
Fine Aggregate			
Portland Cement			
Water			

4.2.2 Unmolding, Unit Weight Determination, and Inspection of Hardened Concrete Cylinders

4.2.2.1 Essential Equipment

- Mold splitting tools

4.2.2.2 Procedure

1. After seven days, unmold all the hardened concrete cylinders by splitting the plastic molds and mark your w/c ratio on each cylinder.
2. Examine and make notes regarding the quality of the cast cylinders, including any entrapped air bubbles or evidence of segregation.
3. Weigh for the calculation of cured unit weight. The cured unit weight will be used as an indicator of uniformity of the cylinder mixes.
4. Report the unit weights of all samples in Table 4.2

Table 4.2 - Cured Unit Weights

- Water/Cement Ratio used: _________

Item	4"x8"	4"x8"	4"x8"	4"x8"	6"x12"	6"x12"
Weight of Concrete Cylinder (lbs)						
Volume of Cylinder (in^3)						
Unit Weight of Hardened Cylinder (pcf)						

5. Retain one 4"x8" cylinder for compression testing and place the remaining cylinders in the curing chamber.

4.3 FLEXURE STRENGTH TEST

This test is important for the design and construction of road and airport pavements. One 6"x6"x21" beam will be tested at 7 days.

4.3.1 Standards

- Flexural Strength of Concrete Using Simple Beam with Third-Point Loading (ASTM C78, 2022)

4.3.2 Essential Equipment

- Compression machine
- Concrete beam compression head with third-point, load-applying rollers
- Rigid base with roller supports

4.3.3 Procedure

1. At 7 days, unmold the beam, turn the test specimen on its side, with respect to its position as molded. Take 3 measurements across each dimension (one at each edge and at the center) to determine the average width and average depth to the nearest 0.05 inch.
2. Center the beam on the bearing block. Center the loading system in relation to the applied force. Bring the load-applying blocks in contact with the surface of the specimen at the third points between the supports.
3. Apply the load rapidly up to approximately 50% of the breaking load. Thereafter, apply the load continuously at a rate that constantly increases the extreme fiber stress between 125 psi and 175 psi/min until rupture occurs.
4. Record the failure load and measure the distance from the crack to the nearest support.
5. Depending on whether the fracture initiates within the middle third or outside the middle third of the beam, use the appropriate part of Table 4.3 to calculate the flexural strength.
6. Calculate the theoretical flexure strength based on the 7-day compressive strength of the 4"x8" cylinders and report in Table 4.3

Table 4.3 - Flexural Strengths of 6"x 6" Beams at 7 Days for all groups

w/c ratio	Beam Size (after placing on its side)								Length between supports, L(in.)	Failure Load, P (lbs)
	Width, b (nearest. 05")				Depth, d (nearest .05")					
	Left Edge	Center	Right Edge	Avg. b	Left Edge	Center	Right Edge	Avg. d		
									18	
									18	
									18	
									18	

	If crack occurs in the middle third:	If crack occurs outside the middle third:					Theoretical Flexural Strength based on 7-day compressive strength of 4"x8" cylinder (psi) $R = (7.5 \text{ to } 10)\sqrt{f'_c}$ (nearest 5 psi)
	Experimental Flexural Strength, $R = PL/bd^2$ (nearest 5 psi)	a, distance from crack to nearest support	x, distance from third point to crack	5%x L	Is "a" acceptable? ("a" is acceptable if $x \leq .05xL$)	If "a" is acceptable, then Experimental Flexural Strength, $R = 3Pa/bd^2$ (nearest 5 psi)	
					Y or N		
					Y or N		
					Y or N		
					Y or N		

4.4 COMPRESSION TEST

The purpose of this test is to determine the compression strength of the four 4”x 8” cylinders over 28 days (or timespan assigned by the instructor). One 4-inch diameter cylinder is tested each successive week for 28 days.

4.4.1 Standards

- Compressive Strength of Cylindrical Concrete Specimens (ASTM C39, 2024)

4.4.2 Essential Equipment

- Compression machine
- Round, spherically seated steel compression head
- Steel upper and lower bearing blocks (caps)

4.4.3 Procedure

- Each week, one 4”x8” cylinder will be tested at each w/c ratio. The failure strength of the cylinder is recorded.
- Calculate the failure strength to the nearest 10 psi and report the failure strength as a function of w/c ratio and age (in days) in Table 4.4.
- Include a plot of strength versus time for each of the w/c ratios (include all w/c ratios on a single graph).

Table 4.4 - Failure Compressive Strength of 4"x 8" Cylinders at 7, 14, 21 and 28 Days for all groups (all in nearest 10 lb or psi)

w/c ratio				
7-Day Failure Load (lbs)				
14-Day Failure Load (lbs)				
21-Day Failure Load (lbs)				
28-Day Failure Load (lbs)				
7- Day Strength (to nearest 10 psi)				
14- Day Strength (nearest 10 psi)				
21- Day Strength (nearest 10 psi)				
28- Day Strength (nearest 10 psi)				

4.5 REBOUND HAMMER TEST

The purpose of this test is to assess the uniformity and strength of the concrete. One 6-inch diameter cylinder will be tested at 28 days before the compression test is performed.

4.5.1Standards

- Rebound Number of Hardened Concrete (ASTM C805, 2025)

4.5.2 Essential Equipment

- Rebound hammer

4.5.2 Procedure

1. At 28 days, one 6-inch cylinder at each w/c ratio will be tested.
2. Grind and clean the concrete surface by rubbing with the abrasive stone that accompanies the rebound device.
3. During the lab, each 6-inch cylinder should be tested with 9 impacts on both top and bottom sides. Each impact point (location) should be provided by the instructor.
4. Firmly hold the instrument in a position that allows the plunger to strike perpendicularly to the test surface.
5. Gradually increase the pressure on the plunger until the hammer impacts. Push the side button in to lock the impact plunger after every impact.
6. Record the rebound number to two significant digits.
7. Calculate the average rebound number. (Discard any readings that differ from the average by 7 units or more. If more than two readings differ by 7 units or more, discard all readings.)
8. Include this predicted compressive strength with the measured failure compressive strength

Table 4.5 - Rebound Hammer Value R and Predicted Compressive Strength of 6"x 12" Cylinder at 28 Days

- Water/Cement Ratio used: _________

Rebound Number, R (2 sig. figs.)	Top of Cylinder									
	Bottom of Cylinder									
Average Rebound Number										
Average Rebound Number with Discarded Readings										
Predicted Comp. Strength (nearest 50 psi) - from Conversion Curves										

4.6 SPLITTING TENSILE TEST

4.6.1Standards

- Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496, 2017)

4.6.2 Essential Equipment

- Compression machine
- Splitting tensile loading head
- Bearing strip

4.6.3 Procedure

At 28 days, a 6"x12" cylinder is tested in Splitting Tensile Strength, and the data is shared by all teams.

1. Determine the failure load in splitting tensile (denoted as T or f_{st}) using the following equation:

   $T = (2P)/(\pi L d)$, where P = maximum load; L = cylinder length; and d = diameter of cylinder

2. The splitting tensile strength can also be estimated from the 28-day compressive strength as $f_{st,est} = 6.5\sqrt{f'c}$ (psi)
3. You will use the compression strength of the other 6"x12" cylinder to estimate the splitting tensile strength and compare to the actual splitting tensile strength determined above.
4. Plot the splitting tensile strength and the estimated splitting tensile strength as a function of w/c ratio.
5. Report all strength results from 6-inch cylinders in Table 4.6

Table 4.6 - Compressive and Splitting Tensile Strengths of 6"x 12" Cylinders at 28 Days for all groups

28-Day Compression Strength	w/c			
28-Day Failure Load (lbs)				
28-Day Comp. Strength (nearest 10 psi)				
Predicted Comp. Strength (nearest 10 psi)*				
Splitting Tensile Strength	w/c			
Failure Load in Splitting Tensile (lbs)				
Splitting Tensile Strength (nearest 5 psi)				
Theoretical Tensile Strength (nearest 5 psi)				

* Use Rebound Hammer test results

4.8 ITEMS TO INCLUDE IN LABORATORY REPORT 4

Must include the following items in your report:

- Mix Design
    1. Include your mix design form (modified from the table your instructor offered) and all calculations you performed in the Appendix
    2. Include the final ingredient proportions and weights for your groups' w/c ratio in the Results (using your table similar to Table 4.1 in this manual)
    3. Report the cured unit weights of all cylinders for your w/c ratio in the Results (using your table similar to Table 4.2 in this manual). Check if all your cylinders are uniform in quality and cured unit weight

- Flexural Strength
    1. Report the experimental flexural strengths of all beams in the table similar to Table 4.3 in this manual.
    2. Discuss how your measured flexural strengths compare with the theoretical ones. Also, report if the flexural strength versus water-cement ratio relation was developed as expected

- Compression Strength
    1. Present the strength result as a function of water-to-cement ratio in figure(s), with failure compressive strength on the y-axis and curing time on the x-axis for 7, 14, 21, and 28 days.
    2. You may include your table similar to Table 4.4.
    3. Discuss the results and trends of the data in detail

- Rebound Hammer Test
    1. Report your group's readings in the table similar to Table 4.5, where the average rebound value can be presented with any adjustments you made.
    2. You have to find the related compressive strength from the conversion curves, either on the side of the hammer or a separate chart offered by the instructor. The predicted compressive strengths must be estimated for all tested water/cement ratios in your lab section.
    3. Compare and discuss the related compressive strength to the actual failure compressive strength.

- Splitting Tensile Strength
    1. Report the experimental splitting tensile strength and the theoretical splitting tensile strength in a table similar to Table 4.6.
    2. Plot the experimental splitting tensile strength and the theoretical splitting tensile strength as a function of water-cement ratio. Both curves will be on one graph.
    3. Compare and discuss the experimental and theoretical splitting tensile strengths.

Bibliography

[1]. Mamlouk, M. S., & Zaniewski, J. P. (2011). *Materials for Civil and Construction Engineers.* Prentice-Hall.

[2]. ACI PRC-211.1-91. (2009). *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*.

[3]. ASTM C29. (2023). *Test Method for Bulk Density (Unit Weight) and Voids in Aggregate*. ASTM International. https://doi.org/10.1520/c0029_c0029m-23

[4]. ASTM C31. (2025). *Practice for Making and Curing Concrete Test Specimens in the Field*. ASTM International. https://doi.org/10.1520/c0031_c0031m-25a

[5]. ASTM C39. (2024). *Test Method for Compressive Strength of Cylindrical Concrete Specimens*. ASTM International. https://doi.org/10.1520/c0039_c0039m-24

[6]. ASTM C78. (2022). *Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*. ASTM International. https://doi.org/10.1520/c0078_c0078m-22

[7]. ASTM C109. (2024). *Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 50mm [2 in.] Cube Specimens)*. ASTM International. https://doi.org/10.1520/c0109_c0109m-24

[8]. ASTM C127. (2024). *Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate*. ASTM International. https://doi.org/10.1520/c0127-24

[9]. ASTM C128. (2022). *Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*. ASTM International. https://doi.org/10.1520/c0128-22

[10]. ASTM C136. (2019). *Test Method for Sieve Analysis of Fine and Coarse Aggregates*. ASTM International. https://doi.org/10.1520/c0136_c0136m-19

[11]. ASTM C138. (2024). *Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*. ASTM International. https://doi.org/10.1520/c0138_c0138m-24a

[12]. ASTM C143. (2015). *Standard Test Method for Slump of Hydraulic-Cement Concrete*. ASTM International. https://doi.org/10.1520/c0143_c0143m

[13]. ASTM C150. (2024). *Specification for Portland Cement*. ASTM International. https://doi.org/10.1520/c0150_c0150m-24

[14]. ASTM C192. (2025). *Practice for Making and Curing Concrete Test Specimens in the Laboratory*. ASTM International. https://doi.org/10.1520/c0192_c0192m-25

[15]. ASTM C231. (2024). *Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*. ASTM International. https://doi.org/10.1520/c0231_c0231m-24

[16]. ASTM C305. (2020). *Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency*. ASTM International. https://doi.org/10.1520/c0305-20

[17]. ASTM C496. (2017). *Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*. ASTM International. https://doi.org/10.1520/c0496_c0496m-17

[18]. ASTM C702. (2024). *Practice for Reducing Samples of Aggregate to Testing Size*. ASTM International. https://doi.org/10.1520/c0702_c0702m-24

[19]. ASTM C778. (2021). *Specification for Standard Sand*. ASTM International. https://doi.org/10.1520/c0778-21

[20]. ASTM C805. (2025). *Test Method for Rebound Number of Hardened Concrete*. ASTM International. https://doi.org/10.1520/c0805_c0805m-25

[21]. ASTM D75. (2019). *Practice for Sampling Aggregates*. ASTM International. https://doi.org/10.1520/d0075_d0075m-19

Left Blank Intentionally