ARIZONA STATE UNIVERSITY

GENERAL STUDIES COURSE PROPOSAL COVER FORM

Course information:

*Copy and paste **current** course information from Class Search/Course Catalog.*

Academic Unit: School of Sustainable Engineering and the Built Environment
Department: Del E. Webb School of Construction

Subject: CON Number: 106 Title: Science of Materials for the Built Environment Units: 4

Is this a cross-listed course? No
If yes, please identify course(s)

Is this a shared course? No If so, list all academic units offering this course
Course description:

Requested designation: (Choose One)

*Note- a **separate** proposal is required for each designation requested*

Eligibility:

Permanent numbered courses must have completed the university's review and approval process.
For the rules governing approval of omnibus courses, contact the General Studies Program Office at (480) 965-0739.

Area(s) proposed course will serve:

A single course may be proposed for more than one core or awareness area. A course may satisfy a core area requirement and more than one awareness area requirements concurrently, but may not satisfy requirements in two core areas simultaneously, even if approved for those areas. With departmental consent, an approved General Studies course may be counted toward both the General Studies requirement and the major program of study.

Checklists for general studies designations:

Complete and attach the appropriate checklist

- Literacy and Critical Inquiry core courses (L)
- Mathematics core courses (MA)
- Computer/statistics/quantitative applications core courses (CS)
- Humanities, Fine Arts and Design core courses (HU)
- Social and Behavioral Sciences core courses (SB)
- Natural Sciences core courses (SQ/SG)
- Global Awareness courses (G)
- Historical Awareness courses (H)
- Cultural Diversity in the United States courses (C)

A complete proposal should include:

- ☒ Signed General Studies Program Course Proposal Cover Form
- ☒ Criteria Checklist for the area
- ☒ Course Syllabus
- ☒ Table of Contents from the textbook, and/or lists of course materials

Contact information:

Name: Dr. Allan Chasey Phone: 480-965-7437

Mail code: 0204 E-mail: allan.chasey@asu.edu

Department Chair/Director approval: *(Required)*

Chair/Director name (Typed): Dr. G. Edward Gibson Date: 9/10/13

Chair/Director (Signature): [signature]

Arizona State University Criteria Checklist for

NATURAL SCIENCES [SQ/SG]

Rationale and Objectives

In a relatively short time in the history of civilized societies, humankind moved from what was essentially an agrarian population into an industrial age, which in recent years has been profoundly shaped by such scientific and technological advances as genetic engineering, the computer, and space exploration. Our history of irrepressible ingenuity makes a compelling case for a future that will be even more profoundly influenced by science and technology. It is imperative that we react expeditiously and effectively to the problems and the promise that these advances create. We must ensure that technological change is directed to the benefit of society and that it will promote human dignity and values. Success in achieving this goal will depend upon the insight and knowledge of political and public opinion leaders and the scientific enlightenment of educated citizens. To a significant degree, the ability of these individuals to understand the nature of the issues and the alternative courses of action will determine by the quality of science presented at the nation's institutions of higher learning.

The recommendation of at least one laboratory course that includes a substantial introduction to the fundamental behavior of matter and energy in physical or biological systems derives from a number of considerations. First, all physical and biological systems derives phenomena have at their roots their fundamental principles governing the behavior of matter and energy. These principles have been show over a period of time to be a value in reliably predicting and rationalizing a broad range of phenomena. Unless the lines to theses roots are established, our understanding of broader range of sciences, and other field upon which these sciences impinge, will be impaired. Second, because these fundamental principles have been experimentally established beyond reasonable doubt, the essentials of scientific method can clearly and coherently revealed by the study of the behavior of matter and energy illustrates the usefulness of mathematics in precisely describing and rationalizing certain physical phenomena and the expressiveness of mathematical equation.

Proposer: Please complete the following sections and attach appropriate documentation.

ASU—[SQ] CRITERIA			
I. – FOR ALL *QUANTITATIVE* [SQ] NATURAL SCIENCE CORE AREA COURSES, THE FOLLOWING ARE CRITERIA AND MUST BE MET:			
YES	NO		Identify Documentation submitted
☒	☐	A. Course emphasizes the mastery of basic scientific principles and concepts.	Criteria Justification Detailed Syllabus Attachment A
☒	☐	B. Addresses knowledge of the scientific method.	Criteria Justification Detailed Syllabus & Attachment C
☒	☐	C. Includes coverage of the methods of scientific inquiry that characterized the particular discipline.	Criteria Justification Detailed Syllabus
☒	☐	D. Addresses potential for uncertainty in scientific inquiry.	Criteria Justification Detailed Syllabus
☒	☐	E. Illustrates the usefulness of mathematics in scientific description and reasoning.	Criteria Justification Detailed Syllabus & Attachment C
☒	☐	F. Includes **weekly** laboratory and/or filed sessions that provide hands-on exposure to scientific phenomena and methodology in the discipline, and enhance the learning of course material.	Criteria Justification Detailed Syllabus
☒	☐	G. Students submit written reports of laboratory experiments for constructive evaluation by the instructor.	Criteria Justification Detailed Syllabus & Attachment C
☒	☐	H. Course is general or introductory in nature, ordinarily at lower-division level; not a course with great depth of specificity.	Criteria Justification Detailed Syllabus Attachment E
II. – AT LEAST ONE OF THE FOLLOWING ADDITIONAL CRITERIA MUST BE MET WITHIN THE CONTEXT OF THE COURSES			
☒	☐	A. Stresses understanding of the nature of basic scientific issues.	Criteria Justification Detailed Syllabus Attachment A
☒	☐	B. Develops appreciation of the scope and reality of limitations in scientific capabilities.	Criteria Justification Detailed Syllabus
☐	☒	C. Discusses costs (time, human, financial) and risks of scientific inquiry.	N/A
NOTE: CRITERIA FOR [SG] COURSES BEGIN ON PAGE 4			

III. – [SQ] COURES MUST ALSO MEET THESE ADDITIONAL CRITERIA:			
YES	NO		Identify Documentation Submitted
☒	☐	A. Provides a substantial, quantitative introduction to fundamental principles governing behavior of matter and energy, in physical or biological systems.	Criteria Justification Detailed Syllabus Attachment B
		B. Includes a college-level treatment of some of the following topics **(check all the apply below):**	
☒	☐	a. Atomic and molecular structure	Criteria Justification Detailed Syllabus Attachments B & D
☐	☒	b. Electrical processes	N/A
☒	☐	c. Chemical processes	Criteria Justification Detailed Syllabus & Attachment B
☒	☐	d. Elementary thermodynamics	Criteria Justification Detailed Syllabus & Attachment B
☐	☒	e. Electromagnetics	N/A
☐	☒	f. Dynamics and mechanics	N/A

[SQ] REQUIREMENTS CANNOT BE MET BY COURSES:
• **Presenting a qualitative survey of discipline.**
• **Focusing on the impact of science on social, economic, or environmental issues.**
• **Focusing on a specific of limiting but in-depth theme suitable for upper-division majors**

Course Prefix	Number	Title	Designation
CON	106	Science of Materials for the Built Environment	SQ/SG

Explain in detail which student activities correspond to the specific designation criteria. Please use the following organizer to explain how the criteria are being met.

Criteria (from checksheet)	**How course meets spirit** (contextualize specific examples in next column)	Please provide detailed evidence of how course meets criteria (i.e., where in syllabus)
I.A. Course emphasizes the mastery of basic scientific principles and concepts.	*Materials in the Built Environment* is organized to give the student an understanding of how building materials and processes are utilized to design, manufacture, and operate sustainable structures. The science of soils as a support mechanism and how combining the appropriate amounts of rock and soil materials to produce building material such as concrete must be understood as well as properties that each ingredient brings to the strength and durability of the material during its life.	Chapters 1, 3, 4, 5, 6, 7, and 12 in the PCA Design and Control of Concrete Mixtures (D&C) manual and the associated lectures and laboratory exercises provide a basic understanding of the materials used in the construction industry to produce sustainable structures. See Syllabus lectures 2, 3, 4, and Lab 1.
I.B Addresses knowledge of scientific method.	Concrete, the second most widely used building material in the world after water, is used on every construction project, and is extremely complex in its design and use. Each lecture, lab activity, and/or field trip to a construction site or production facility emphasizes the scientific method to enable to student to draw conclusions and answer questions with certainty.	Concrete is designed and proportioned with specific parameters to meet the designer's needs. Thus, different combinations of materials both volumetrically and characteristically are batched to see if results meet the intended purpose and must be repeated. See Syllabus Page 4 for Lecture 5 and Lab 3 as well as D&C Chapter 12.
I.C. Includes coverage of the methods of scientific inquiry that characterized the particular discipline.	An understanding of the chemistry of concrete is essential for the student to determine the proper components to design a concrete mixture to meet specific environmental conditions.	Volumetric proportioning of concrete mixtures is discussed in Lecture 5 and Chapter 12 of the D&C manual along with Hot and Cold Weather Concreting uses in Chapters 16 and 17; Attachment C
I.D. Addresses potential for uncertainty in scientific inquiry.	Concrete mixtures do not always meet the anticipated performance due to the variables in materials and how the materials react with one another in practice and when produced in large quantities.	Chapter 9 in the D&C manual discusses properties and potential short and long-term problems that can occur. See Lectures 12 & 13.

Criteria (from checksheet)	**How course meets spirit** (contextualize specific examples in next column)	Please provide detailed evidence of how course meets criteria (i.e., where in syllabus)
I.E. Illustrates the usefullness of mathematics in scientific description and reasoning	Students must complete concrete proportioning exercises and study the strength gain (maturity) over time based on the material proportioning.	Concrete proportioning is a method for using volume/weight relationships to properly proportion a concrete mixture to meet specific needs. See Attachment C – Lectures 18 & 19. Lab 9.
I.F. Includes weekly laboratory and/or field sessions that provide hands-on exposure to scientific phenomena and methodology	Students learn how to test freshly mixed concrete for air content, consistency, and temperature based on the standards as set forth by the American Society of Testing and Materials (ASTM). Additionally, a lab for making concrete, testing aggregates for fineness modulus and specific gravity, and testing strength occur. Soil compaction is demonstrated and students calculate the maximum dry density and optimum water content to meet project specifications.	The students must perform fineness modulus and specific gravity tests on aggregates; mold, cure, and perform strength testing on concrete cylinders; utilize equipment to perform sampling, air, slump, temperature, and unit weight tests on freshly mixed concrete. Labs 5 and 8. The students will be able to obtain the American Concrete Institute (ACI) Grade I Concrete Field Testing Certification. Tests are shown in Attachment D.
I.G. Students submit written reports of laboratory experiments for constructive evaluation by the instructor.	All laboratory experiences require a write-up that includes methodologies and calculations used to support testing procedures performed. Field trips require a detailed two-page point paper discussing what the student learned from the trip.	See Syllabus in Attachment A for the Lab and Field Trip Schedule
I.H. Course is general or introductory in nature, ordinarily at lower-division level; not a course with great depth of specificity.	The course is designed to meet a broad range of topics and expose the student to the incredible diversity of the sustainable material we call concrete and its importance in the construction industry.	See Syllabus topics in Attachment A
II.A. Stresses understanding of the nature of basic scientific issues.	*Materials in the Built Environment* is organized to give the student an understanding of how building materials and processes are utilized to design, manufacture, and construct sustainable structures.	See I.A. and I.D.
II.B. Develops appreciation of the scope and reality of limitations in scientific capabilities.	By allowing the students to perform design of concrete mixtures and test materials in the laboratories, the students learn that limitations exist in meeting the parameters of the designs of concrete mixtures.	See laboratory schedule in Attachment A – Course Syllabus

Criteria (from checksheet)	**How course meets spirit** (contextualize specific examples in next column)	Please provide detailed evidence of how course meets criteria (i.e., where in syllabus)
III.A. Provides a substantial, quantitative introduction to fundamental principles governing behavior of matter and energy, in physical or biological systems.	The coursework deals with mathematical computations when dealing with soils bearing capacities and weight- volume relationships when proportioning materials in the production of concrete.	Soils compaction Lecture 3 and Chapter 12 Designing and Proportioning Concrete Mixtures. Labs 1 & 3.
III.B Includes a college-level treatment of some of the following topics		
a. Atomic and molecular structure	Materials must be examined on a molecular basis to see how they react to external energy and with the other materials when mixed together.	Chapter 1, 3, 4, 5, 6, and 10 in Design and Control Manual. See Attachment A – Lectures 6, 7, 8, and 9. Lab 4.
c. Chemical processes	Hydration of cement leading to concrete strength gain is a chemical process that creates a bonding of the aggregates that gives concrete a crystalline matrix structure.	See III.B.a.
d. Elementary thermodynamics	The hydration of cement particles is exothermic thus giving off tremendous heat which must be controlled to achieve a strong dense concrete material to prevent material degradation.	See III.B.a.

Attachment A
Course Syllabus

CON 106 Science of Materials for the Built Environment

Arizona State University | Del E. Webb School of Construction
Course Syllabus

COURSE INFORMATION: Meeting Time: T&Th: 8:30-10:10 am (includes Thursday Lab) Location: TBD

INSTRUCTOR: Edwin C. Weaver, PE 480-965-8366 edwin.weaver@asu.edu

OFFICE HOURS: M: 11:00-11:45 am; T&Th: 1:30-2:30 pm (else by pre-arranged appointment; please use course **BlackBoard** for all Correspondence)

INSTRUCTOR'S BIO: Mr. Weaver is a Senior Lecturer in the Del E. Webb School of Construction teaching and developing graduate and undergraduate courses in the Civil Engineering and Construction Management degree programs with current emphasis in Concrete, Construction Contracts, and Project Management. Before moving to Arizona, Mr. Weaver was on faculty in the Construction Engineering and Management program for seven years at NC State University. Before his tenure at NC State, he spent approximately 20 years working with a large Architectural/Engineering firm, several commercial contractors, as well as owning his own residential construction business. Airfield, roadway, and bridge construction are his specialties. Research areas of interest include Contracts and Specifications for Concrete Construction, Concrete Paving for Airfields and Roadways, and Safety during Concrete and Masonry Construction Operations. Mr. Weaver is a licensed Professional Engineer (PE) in Arizona and North Carolina; and an American Concrete Institute PE Examiner for Grade I Field, Strength, Aggregate, Flatwork Finisher Technician, and Level II Laboratory certification. Mr. Weaver is an authorized Occupational Safety and Health Administration (OSHA) educational trainer and serves on the National Council of Examiners for Engineering and Surveying (NCEES) Construction Committee.

PREREQUISITES: N/A

CATALOG DESCRIPTION: This course examines the effects of concrete-making materials (aggregates, cements, admixtures, etc.) on the properties of fresh and hardened concrete. Concrete mixture proportioning is discussed along with the calculations and statistical analysis of strength testing.

LEARNING OBJECTIVES: At end of this course, students must be able to:
- Demonstrate knowledge of building materials and their uses in constructing the built environment
- Distinguish between material properties related to design, manufacture, and application of concrete mixtures
- Analyze concrete strength requirements and calculate overdesign values economically
- Apply an understanding of concrete proportioning methods to meet specific building applications
- Formulate concrete mixtures for durability to meet long term sustainability goals
- Understand concrete testing procedures as set forth by the American Concrete Institute
- Summarize soil compaction methods to meet bearing capacity specifications to support building structures
- Critically examine construction problems and develop innovative solutions using tools such as mathematics, science, and engineering skills
- Clearly and effectively present qualitative and quantitative information using written, oral, and graphic presentation

SEMESTER CALENDAR: https://students.asu.edu/academic-calendar

TEXTS & REFERENCES (2): 1) Kosmatka, Stephen H. and Panarese, William C., *Design and Control of Concrete Mixtures*, 15th Edition 2012, Portland Cement Association; 2) *ACI Concrete Field Testing Technician Grade I Workbook*, CP-1 (12)

ELECTRONIC RESOURCES: Blackboard web address - https://myasucourses.asu.edu

ASSIGNMENTS & COURSE REQUIREMENTS: See Detailed Class Schedule on page 4.

WEIGHTING OF ASSIGNMENTS:

Test # 1	20 %
Test # 2	20 %
Quizzes	16 %
Homework/Lab & Class Participation (10/2)	16 %
ACI Certification (Written & Performance)	8 %
Final Exam (comprehensive)	20 %
	100 %

COURSE GRADING SCALE:

96.6-100	A+	80-83.2	B-
93.3-96.5	A	76.6-79.9	C+
90-93.2	A-	70.0-76.5	C
86.6-89.9	B+	60.0-69.9	D
83.3-86.5	B	0-59.9	👎

CLASSROOM EXPECTATIONS / STANDARDS:

- Students are expected to bring their text, a calculator, writing tablet or notebook, and appropriate writing materials to every class. No sharing of books, calculators, etc. will be allowed during quizzes or exams.
- Anyone requesting extra time for quizzes/exams must provide paperwork by **January 31st, 2013.**
- No FOOD is allowed in the classroom at any time during class per Departmental policy.
- **All cell phones, radios, ipods, computers, and other electronic devices must be turned off in classroom by 8:30 AM unless otherwise requested by Instructor. Discuss emergency use during class with Instructor prior to need.**
- **Each page of all submissions shall include your name, the assignment number, and the due date.** Failure to do so will result in point deductions.
- Spelling and grammar will be considered in the grading on all submissions.

ACADEMIC INTEGRITY & CODE OF CONDUCT: ASU maintains the highest standard for academic honesty and trusts that each student will perform ethically and professionally when preparing required work for this course. Each assignment must represent the student's collective **original** work, even for work designated as **group work**. Although ASU encourages collaboration between students, and faculty, in the sharing of ideas and experiences, **individual work** needs to represent the student's original thought and be distinguishably different from other students work. While discussions between students are encouraged, **CHEATING** will not be tolerated. Any student found cheating on an exam, a quiz, or assignment may be given a failing grade for the course and flagrant violations can result in additional consequences. You are cheating if you represent someone else's work as your own or if someone else represents your work as theirs. All graded work (exams, homework assignments, as well as any written exercises or quizzes) in this class must represent your own individual work only. Students may discuss the conceptual aspects of an assignment, but students must turn in their own, independently developed solutions. Grading will include comparing the structure and content of your solution with that of other students. By registration in this class, you are assumed to have read, understand and agreed to this policy, as well as to the procedures conveyed at the web sites below.

ABOR Student Code of Conduct and Student Disciplinary Procedures — http://students.asu.edu/srr/code

ASU Academic Integrity Policy: — http://provost.asu.edu/academicintegrity

ASSIGNMENT POLICY: The student is responsible for ALL reading assignments and class handouts whether or not the material has been covered in class or specifically listed on the course syllabus. Late assignments will not be accepted.

MAKE-UP POLICY: No make-up quizzes will be given. To be eligible to take a missed exam, the student must show either evidence of illness or extenuating circumstances that were no fault of their own.

ATTENDANCE & QUIZZES: Attendance will be taken during the semester – three (3) maximum allowable unexcused absences. Quizzes may be given at any time and sometimes given on the reading assignments. All quizzes are closed book and closed notes unless otherwise stipulated.

SCHEDULED EXAMS: Two (2) mid-semester exams plus a final are scheduled. These exams should be ~60-75 minutes in duration. Completing the homework assignments, quizzes, and other assigned readings will enable you to perform well in these scheduled exams. All quizzes are closed book and closed notes unless otherwise stipulated however, a one-sided crib sheet is allowed. The final exam will be comprehensive but emphasize material presented after exam #2.

ACI CONCRETE FIELD TESTING CERTIFICATION GRADE I: As part of this class near the end of the semester, you are required to successfully complete the ACI concrete field testing certification program that is broken into two parts. To obtain this credential, each student is required to physically demonstrate the proper procedure(s) for the seven (7) different ASTM methods for testing freshly mixed concrete. In addition, a written examination containing a total of 55 multiple choice questions on the seven (7) ASTM standards will be administered. The student must pass both the written and field examinations satisfactorily in order to receive the certification. In the event the student does not meet the criteria for certification during the current semester, he/she must obtain the certification at the next available session locally for a fee. Also, the final grade in this course will be reduced by a minimum one letter grade for non-certification.

The cost for the manual and initial certification testing is significantly sponsored by the Arizona Chapter of the American Concrete Institute (ACI). Testing sessions scheduled for the first week of April. If you are unsuccessful on your initial attempt at certification during the semester, the cost of re-examinations must be borne by the student at a subsequent session through the AZ-ACI.

LAB SESSIONS: All students must participate in the laboratory sessions on scheduled Thursdays – schedule of lab topics and dates to be announced. The assignment from the lab must be submitted at the beginning of the next class period the following Tuesday if not submitted at end of lab session.

Semester Laboratories: (schedule TBD)

- Soil Compaction Lab
- Fineness Modulus (FM) and Specific Gravity (G_s) of Aggregates
- Proportioning and molding of concrete strength testing cylinders
- Testing of concrete strength cylinders
- Air Content, Unit Weight (density), and Temperature testing of freshly mixed concrete
- Maturity and strength gain of hardened concrete
- Field Trip to Concrete Production Facility
- Field Trip to Precast Concrete Manufacturing Facility
- Field Trip to Construction Site to observe concrete placement

ACCOMMODATION: Reasonable accommodations are made on an individualized basis. It is the responsibility of persons with disabilities, however, to seek available assistance and make their needs known. The University has designated the Disability Resource Center as the campus coordinating office for the provision and delivery of services and reasonable accommodations that ensure the University's programs, services, and activities are accessible to students with disabilities. The Disability Resource Center is available to assist any student who has a qualified and documented disability. Please contact the Disability Resource Center at 480-965-1234 (Voice) 480-965-9000 (TTY) for additional information.

URL: http://www.asu.edu/studentaffairs/ed/drc/

DETAILED COURSE LECTURE SCHEDULE
CON 106 – SCIENCE OF MATERIALS FOR THE BUILT ENVIRONMENT

DATE	TOPIC	ASSIGNMENTS, ETC
Lecture 1	Introduction to Course	Read Chapter 1 – D&C
Lecture 2	Materials used for the Built Environment	
Lecture 3	Consolidation / w/cm ratio / Cements / Soils	Read Chapter 3
Lab 1	**Concrete 101 Lab / Soils Analysis**	
Lecture 4	Physical Properties of Cement / SCMs / Hydration	Read Chapter 4
Lab 2	**Concrete Batch Plant Site Visit**	Review Chap. 12
Lecture 5	Volumetric Concrete Proportioning / SSD	Read Chapter 5
Lab 3	**Volumetric Proportioning Lab**	
Lecture 6	Mixing Water for Concrete / Adjusting Moisture	Read Chapter 6
Lecture 7	Aggregates for Concrete / Characteristics / ASTM C33	
	EXAM #1	Read Chapter 7
Lecture 8	Recitation / Fineness Modulus / Bulk Density / ASR	
Lecture 9	Chemical Admixtures for Concrete – AEA / WRAs	Read Chapter 9
Lab 4	**Fineness Modulus / Specific Gravity of Aggregates Lab**	
Lecture 10	Properties of Concrete – Strength / Durability / Curing	Read Chapter 10
Lab 5	**Freshly Mixed Concrete Testing Lab**	
Lecture 11	Volume Changes in Concrete / Temperature	Read Chapter 11
Lecture 12	Curling and Warping / Elastic Deformation / Creep	Read Chapter 13
	SPRING BREAK	
Lecture 13	Deterioration Mechanisms	
Lab 6	**Field Trip to Construction Site**	
Lecture 14	Batching, Mixing, and Handling Concrete	
Lecture 15	Concrete Durability and Life Cycle	
	EXAM #2	Read Chapter 14
Lecture 16	Placing and Finishing Concrete	Read Chapter 15
Lecture 17	Curing Concrete – Curing Methods and Materials	
Lab 7	**Field Trip to Precast Concrete Manufacturing Facility**	Handout
Lecture 18	Hot / Cold Weather Concreting	Handout
Lab 8	**Cylinder Strength Testing Lab**	
Lecture 19	Sustainability and Concrete	Handout
Lab 9	**Concrete Maturity**	
Lecture 21	**Last Day of Classes – Recitation/Review for Final exam**	
FINAL EXAM		**Covers material from all lectures and readings**

- Schedule may change to reflect pace of the class, etc – please be flexible
- The CON 106 Labs will take place on Thursday mornings

Attachment B
PCA Design and Control Manual
Table of Contents

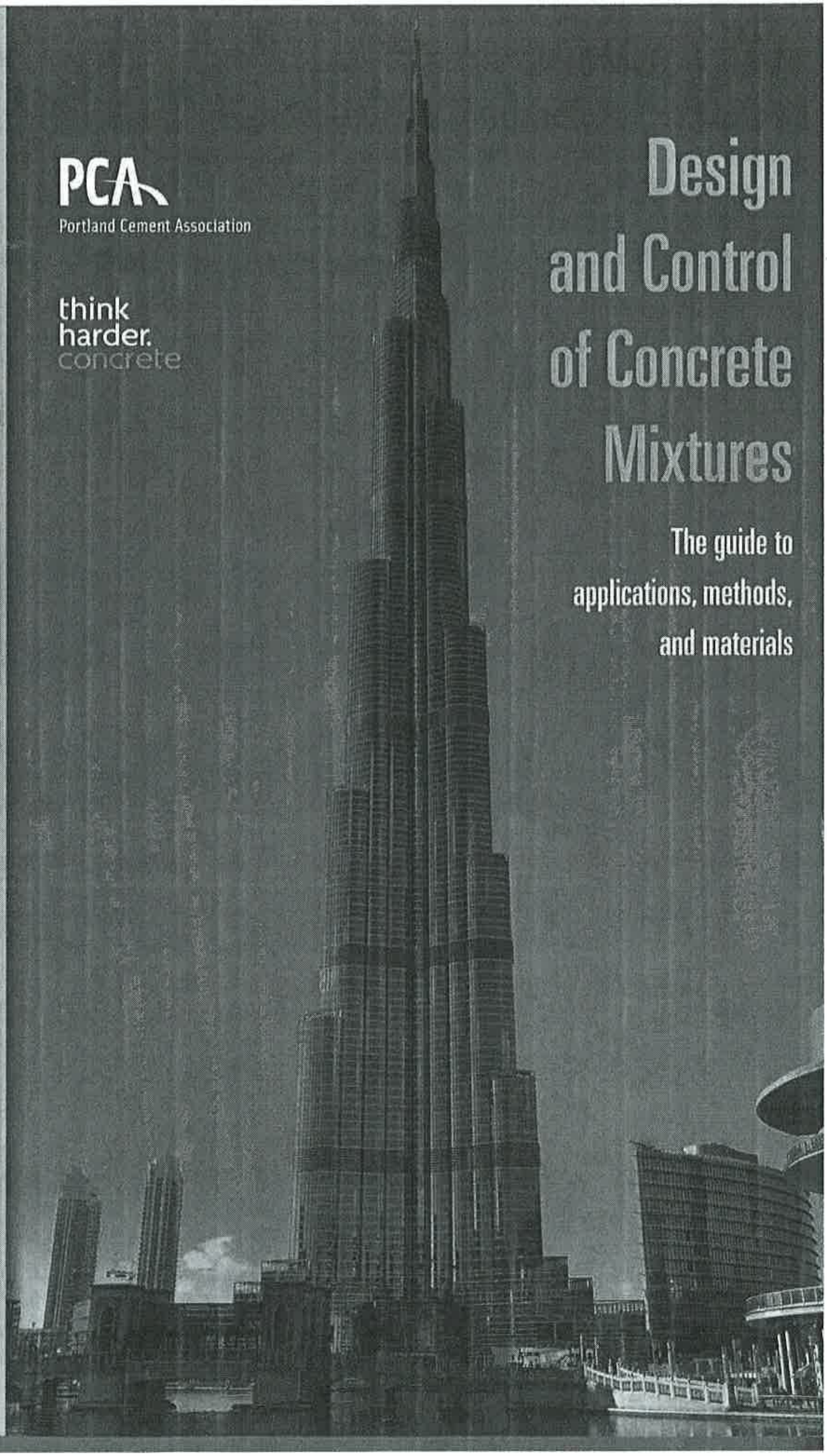
15th Edition

PCA
Portland Cement Association

think harder. concrete

Design and Control of Concrete Mixtures

The guide to applications, methods, and materials



ENGINEERING BULLETIN 001

Design and Control of Concrete Mixtures

The guide to applications, methods, and materials

FIFTEENTH EDITION

by Steven H. Kosmatka and Michelle L. Wilson

PCA

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www.cement.org

An organization of cement companies to improve and extend the uses of portland cement and concrete through market development, engineering, research, education, and public affairs work.

KEYWORDS: admixtures, aggregates, air-entrained concrete, batching, cement, cold weather, curing, durability, fibers, finishing, high-performance concrete, hot weather, mixing, mixing water, mixture proportioning, placing, portland cement concrete, properties, special concrete, standards, supplementary cementing materials, sustainability, tests, and volume changes.

ABSTRACT: This book presents the properties of concrete as needed in concrete construction, including strength and durability. All concrete ingredients (cementing materials, water, aggregates, admixtures, and fibers) are reviewed for their optimal use in designing and proportioning concrete mixtures. Applicable ASTM, AASHTO, and ACI standards are referred to extensively. The use of concrete from design to batching, mixing, transporting, placing, consolidating, finishing, and curing is addressed. Concrete sustainability, along with special concretes, including high-performance concretes, are also reviewed.

REFERENCE: Kosmatka, Steven H. and Wilson, Michelle L., *Design and Control of Concrete Mixtures*, EB001, 15th edition, Portland Cement Association, Skokie, Illinois, USA, 2011, 460 pages.

The authors of this engineering bulletin are:
Steven H. Kosmatka, Vice President, Research and Technical Services, PCA
Michelle L. Wilson, Director of Concrete Knowledge, PCA

Cover photos show the world's tallest building, the Burj Khalifa in Dubai, U.A.E. The tower is primarily a concrete structure, with concrete construction utilized for the first 155 stories, above which exists a structural steel spire.

Fifteenth Edition Print History
First Printing 2011

ISBN 0-89312-272-6

The Library of Congress has catalaoged the previous edition as follows:

Kosmatka, Steven H.
Design and control of concrete mixtures / by Steven H. Kosmatka, Beatrix Kerkhoff, and William C. Panarese.—14th ed.
p. cm.
ISBN 0-89312-217-3 (pbk. : alk. paper)
1. Concrete. 2. Concrete—Additives. 3. Portland cement. I. Kerkhoff, Beatrix. II. Panarese, William C. III. Title.
TA439 .K665 2002
666'.893--dc21

2001007603

Printed in the United States of America

EB001.15

WARNING: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS (THIRD-DEGREE), or SERIOUS EYE DAMAGE. Frequent exposure may be associated with irritant and/or allergic contact dermatitis. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately. Flush eyes with clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

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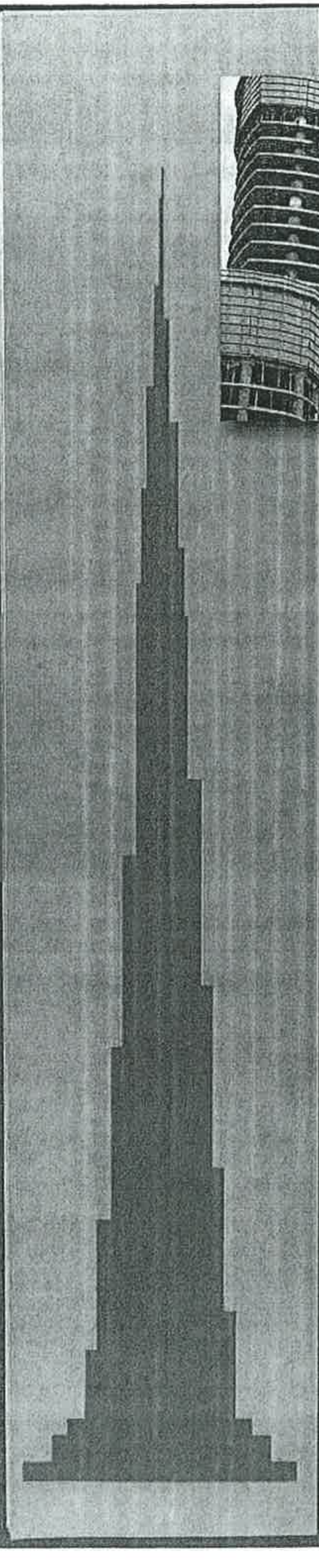

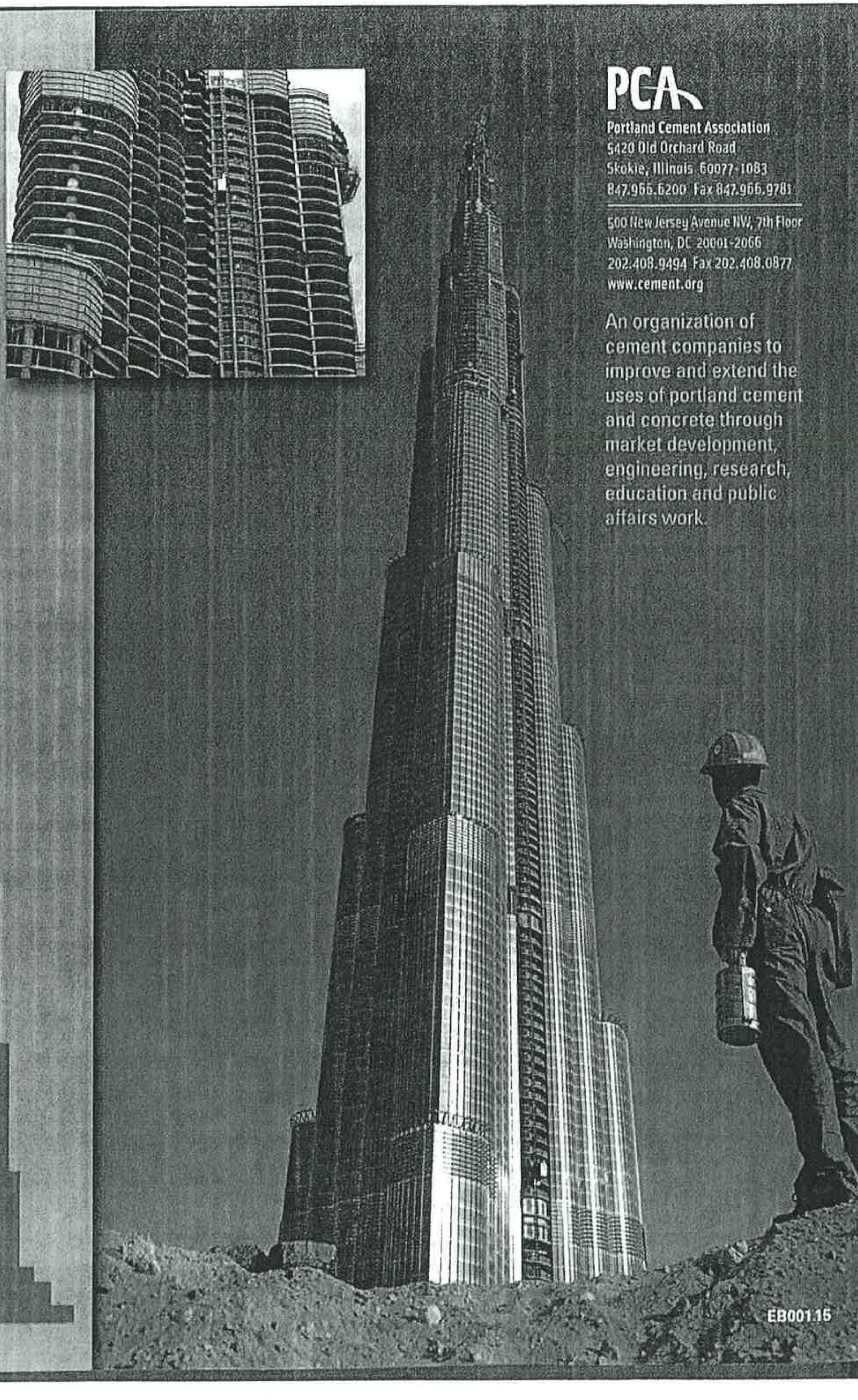

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An organization of cement companies to improve and extend the uses of portland cement and concrete through market development, engineering, research, education and public affairs work.

EB001.15

Attachment C
Class Exercises and Laboratories

CON 106 Mixture Proportioning Lab #1

SPR 2012

Given the following criteria: **a)** fill in the lines for *w/cm*, the metered water, and all shaded boxes in the table below. (Use tables attached) **b)** Calculate the theoretical unit weight of this mixture design. Note: Use a 20% fly ash replacement with a 1:1 substitution rate. Units are important !!

f'_{cr} = 4000 psi
Target Slump = 4"
NMSA = 3/4 " (#67 clean stone)
DRUW = 102 pcf

Fineness modulus (FM) = 2.70
No Exposure
w/cm including fly ash = _________
Water needed in gallons = __________

	Specific Gravity - G_s	Absolute Volume per Design (cf)	Batch Weights (lbs) SSD
Cement	3.15		
Fly Ash	2.06		
Sand, SSD	2.66		
Stone, SSD	2.62		
Metered Water	1.00		
Entrapped Air (1%)	-		-
Entrained Air			-
Batch Weight (lbs)	-	-	
Unit Weight, (lbs/cf)	-	-	

Show all calculations below in an organized manner. Please list any assumptions clearly. Round all batch weights in table to nearest one pound, record all volumes in table to three (3) decimal places. Record actual and theoretical batch unit weights to two (2) decimal places.

Theoretical Unit Weight = _______________ ____

Table 5-4. Determination of Fineness Modulus of Fine Aggregates

Sieve size	Percentage of individual fraction retained, by mass	Percentage passing, by mass	Cumulative percentage retained, by mass
9.5 mm (⅜ in.)	0	100	0
4.75 mm (No. 4)	2	98	2
2.36 mm (No. 8)	13	85	15
1.18 mm (No. 16)	20	65	35
600 µm (No. 30)	20	45	55
300 µm (No. 50)	24	21	79
150 µm (No. 100)	18	3	97
Pan	3	0	—
Total	100		283
			Fineness modulus = 283 ÷ 100 = 2.83

Table 9-11 (Inch-Pound Units). Required Average Compressive Strength When Data Are Not Available to Establish a Standard Deviation

Specified compressive strength, f'_c, psi	Required average compressive strength, f'_{cr}, psi
Less than 3000	f'_c + 1000
3000 to 5000	f'_c + 1200
Over 5000	1.10 f'_c + 700

Adapted from ACI 318.

Table 9-3 (Inch-Pound Units). Relationship Between Water to Cementitious Material Ratio and Compressive Strength of Concrete

Compressive strength at 28 days, psi	Water-cementitious materials ratio by mass	
	Non-air-entrained concrete	Air-entrained concrete
7000	0.33	—
6000	0.41	0.32
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

Strength is based on cylinders moist-cured 28 days in accordance with ASTM C 31 (AASHTO T 23). Relationship assumes nominal maximum size aggregate of about ¾ in. to 1 in.
Adapted from ACI 211.1 and ACI 211.3.

Table 9-4. Bulk Volume of Coarse Aggregate Per Unit Volume of Concrete

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*			
	2.40	2.60	2.80	3.00
9.5 (⅜)	0.50	0.48	0.46	0.44
12.5 (½)	0.59	0.57	0.55	0.53
19 (¾)	0.66	0.64	0.62	0.60
25 (1)	0.71	0.69	0.67	0.65
37.5 (1½)	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

*Bulk volumes are based on aggregates in a dry-rodded condition as described in ASTM C 29 (AASHTO T 19). Adapted from ACI 211.1.

Table 9-5 (Inch-Pound Units). Approximate Mixing Water and Target Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregate

Slump, in.	Water, pounds per cubic yard of concrete, for indicated sizes of aggregate*							
	⅜ in.	½ in.	¾ in.	1 in.	1½ in.	2 in.**	3 in.**	6 in.**
	Non-air-entrained concrete							
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	—
Recommended average total air content, percent, for level of exposure:†								
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	3.5	3.5	3.0
Severe exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

* These quantities of mixing water are for use in computing cement factors for trial batches. They are maximums for reasonably well-shaped angular coarse aggregates graded within limits of accepted specifications.

** The slump values for concrete containing aggregates larger than 1½ in. are based on slump tests made after removal of particles larger than 1½ in. by wet screening.

† The air content in job specifications should be specified to be delivered within −1 to +2 percentage points of the table target value for moderate and severe exposures.

Adapted from ACI 211.1. Hover (1995) presents this information in graphical form.

CON 106
LAB #1 Group #:_____ Last Name:____________________ First Name:______________________

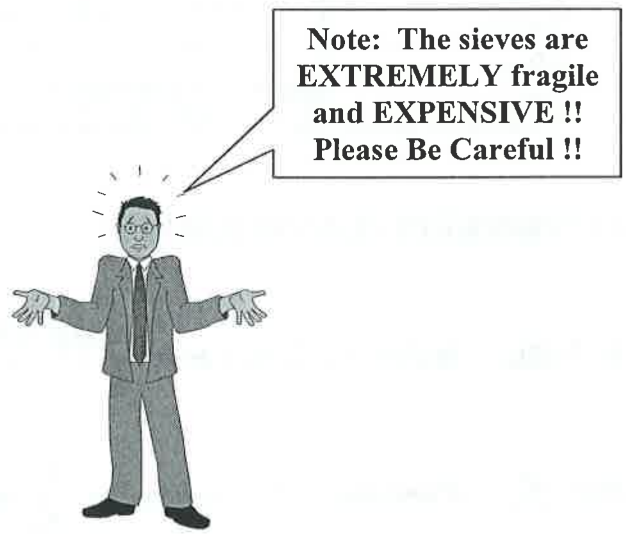
Fineness Modulus Lab

Purpose: **(pg. 84 – PCA Design and Control Manual)**

The Fineness Modulus (FM) is an index number which is roughly proportional to the average size of the particles in a given aggregate. In the concrete industry, FM is used primarily to find the *coarseness* of the fine aggregate in a concrete mixture, although the test can also be used for coarse aggregate. FM is determined in a similar way to an aggregate sieve analysis, although fewer sieves are used. In a standard aggregate sieve analysis, 13 sieves are used, however, when obtaining the FM of a fine aggregate for concrete mixture design proportioning; only seven (7) sieves are used. (The pan does not count as a sieve in the FM calculation.)

Supply List

- Scale (measures grams)
- 500g Sand Sample (minimum)
- Weighing Bowl
- Measuring cup
- Scoop
- Sieve Shaker
- Sieves
  - 3/8", #4, #8, #16, #30, #50, #100, Pan, Cover



Procedure

Sampling Procedure

1. Obtain representative sample of sand from green bins outside of Engineering Bldg (ISBN II)
2. Place weighing bowl on large scale and tare (zero) the scale.
3. Measure out 500g of sand sample and record initial mass in grams on next page.
4. Ensure sieves are stacked in the correct order from top to bottom (3/8", #4, #8, #16, #30, #50, #100, pan) and pour the measured sand sample into the 3/8" sieve.
5. Place cover on top of 3/8" sieve.
6. Place in aggregate shaker and ensure top plate is securely fastened on the sieve stack.
7. Set shaker timer for 5 min. and allow shaker to run uninterrupted.
8. When shaker has stopped, **CAREFULLY** remove sieve stack and place near scale.

Analysis Procedures

1. Place weighing bowl on scale and tare (zero) scale once again.
2. Carefully remove cover and set to side.
3. Start by removing the 3/8" sieve from the stack and carefully deposit all material into the bowl. (Ensure as much material as possible has been removed from the sieve. Ask your instructor on methods to remove excess material.)
4. Record data in table below.
5. Repeat steps 3 & 4 with remaining sieves and pan.
6. Complete table and then calculate Fineness Modulus to two (2) decimal places.

Fine Aggregate **Initial Mass:** ___________ **grams** **Final Mass:** ___________ **grams**

Sieve No.	Cumulative Mass Retained (grams)	Mass Retained (grams)	% of Sample Retained by Mass	Cumulative % Retained by Mass
3/8"				
#4				
#8				
#16				
#30				
#50				
#100				
Pan				
Total			100	

Use the following formulas to complete table:

Formula #1: $$\%\ Sample\ Retained = \frac{Mass\ Retained\ on\ Individual\ Sieve}{Total\ Mass} \times 100$$

Formula #2: $$Cumulative\ \%\ Retained = \sum \%\ Mass\ Retained\ on\ Individual\ Sieves$$

Formula #3: $$Fineness\ Modulus\ (FM) = \frac{Total\ Cumulative\ Mass\ Retained}{100}$$

Note: If your sample is not within 0.6% of the original sample mass, the procedure MUST be repeated.

Check mass tolerance by using the following equation:

$$Mass\ Deviation = \frac{Initial\ Mass - Final\ Mass}{Initial\ Mass} \times 100$$

☐ Check box if test is invalid

Fineness Modulus: ________________

Specific Gravity

Definition:

Specific Graving (Gs) is defined as the ratio of the mass of a given volume of material to the mass of an equal volume of water. Because the specific gravity of a material is a ratio, it has no units.

Absorption, or absorption capacity, represents the maximum amount of liquid an aggregate can absorb or retain.

Purpose:

Specific gravity is an important material characteristic that is utilized for the purpose of material testing and for the proportioning of the concrete ingredients that are used for creating a mix design. Absorption is another important material characteristic. Absorption is primarily used to ensure the adequate amount of water is included in a concrete mixture.

Equipment:

Conical mold and tamping rod, balance sensitive to 0.01 gm, 500 ml volumetric flask, metal pan, large flat pan, drying oven, vacuum pump

Process:

1. Collect approximately 2 pounds of air dry fine aggregate and put in a flat metal pan.
2. Sprinkle a few drops of water on the aggregate and mix thoroughly. Hold the conical mold firmly on the flat metal pan with the large diameter down. Place a portion of the sand loosely in the mold by filling it to overflow then heap additional sand above the top of the mold. Lightly tamp the sand into the mold with 25 light drops of the tamping rod. Starting each drop about ¼ inch above the top of the sand. Permit the rod to fall freely on each drop. Adjust the starting height to the new surface elevation after each drop and distribute the drops evenly over the surface. Clean loose sand around from around the base and remove the mold by lifting it vertically. When the sand slumps slightly it indicates that it has reached a surface dry condition. If the sand retains the mold shape, it indicates the sand is in a wet condition.
3. Record the exact weight of around 1 pound of SSD sand (D).
4. Fill the flask with water (73+/-3° F) to 500-ml or 16.9 fl oz. and record weight (B).
5. Empty water in flask and add the entire SSD sand sample to the flask. Fill flask with water to about ½ inch above the aggregate. Apply vacuum and rolling action to eliminate the air entrapped in the aggregate. This will take at least 5 minutes.
6. Fill the flask with water up to 500-ml mark. Record total weight of flask plus water plus aggregate (C).
7. Pour entire contents of flask into a pan and place in oven. Then measure the weight of the oven-dry aggregate the next day (A).

OBSERVATIONS AND RESULTS

OBSERVATIONS	
(D) SSD Weight of Sample in Air	
(B) Weight of Flask + Water	
(C) Weight of Flask + Water + Sample	
(A) Oven dry weight	

RESULTS	
Apparent Specific Gravity (DRY)	A / (B+A-C) = ________
Bulk Specific Gravity (DRY)	A / (B+D-C) = ________
Bulk Specific Gravity (SSD)	D / (B+D-C) = ________
Absorption	(D-A) / (A) x 100 = ____%

Aggregate Properties

The objectives of these laboratory experiments are to determine specific gravity (bulk and apparent), absorption capacity, and fineness modulus of a fine aggregate sample and to plot a gradation curve for the sample.

Part A - Specific Gravity and Absorption of Aggregate

Background

Specific gravity is generally defined as the ratio of the mass of a given volume of material to the mass of an equal volume of water. However, several variations of this definition exist depending upon the material considered and the purposes for which the value of specific gravity are to be used. When considering aggregate for portland cement concrete, the most common definition for specific gravity is based upon the bulk volume of the individual aggregate in a saturated, surface-dry (SSD) condition. The bulk (oven-dry) specific gravity and apparent specific gravity are used more commonly in asphalt mixtures. The solid unit weight of an aggregate of an aggregate is customarily defined as the specific gravity multiplied by the unit weight of water (62.4 pcf or 1 g/cm^3) and has units of pounds per cubic foot (pcf) or grams per cubic centimeter.

Absorption capacity, or absorption, represents the maximum amount of water an aggregate can absorb. It can be determined by finding the weight of an aggregate under both SSD conditions and oven-dry conditions. The difference in weights expressed as a percentage of the oven-dry sample weight is the absorption capacity. Coarse aggregates are considered to be saturated surface-dry when they have been wiped free of visible moisture films with a cloth after the aggregates have been soaked in water for a long period of time (over 24 hours). The saturated surface-dry condition of fine aggregate is usually taken as that at which a previously wet sample just becomes free-flowing.

Essential Equipment (for Fine Aggregate)

Conical mold and tamping rod
Balance sensitive to 0.01 gm
500 ml volumetric flask
Metal Pan
Large Flat Pan
Drying oven
Vacuum Pump

Testing Procedure (for Fine Aggregate)

1. Obtain approximately 1 kg air dry fine aggregate and put in a flat metal pan.

2. Bring the aggregate to SSD condition. To speed up the process of obtaining the SSD sand, a procedure slightly different from that used by the ASTM standard test C128 is used. Sprinkle a few drops of water on the air dry sand and thoroughly mix. Hold the conical mold firmly on the flat metal pan with the large diameter down. Place a portion of the sand loosely in the mold by filling it to overflow then heap additional sand above the top of the mold. Lightly tamp the sand into the mold with 25 light drops of the tamping rod. Start each drop about 0.2 in. above the top of the sand. Permit the rod to fall freely on each drop. Adjust the starting height to the new surface

elevation after each drop and distribute the drops evenly over the surface. Clean loose sand around from around the base and remove the mold by lifting it vertically. When the sand slumps slightly it indicates that it has reached a surface dry condition. If the sand retains the mold shape, it indicates the sand is in a wet condition.

3. Take approximately 400 g of the SSD aggregate. Record exact weight of SSD sample (D).

4. Fill the flask with water to 500-ml mark and record weight of water and flask in grams (B). The water temperature should be about 73 ± 3°F (23 ± 1.5°C).

5. Empty water in flask and add the entire SSD sand sample to the flask. Fill flask with water to about 1/2 in. above the aggregate. Apply vacuum and rolling action to eliminate the air entrapped in the aggregate. This will take at least 5 minutes.

6. Fill the flask with water up to 500-ml mark. Record total weight (grams) of flask plus water plus aggregate (C).

7. Calculate the Bulk Specific Gravity (SSD) based on the weights B, C, D, and compare the calculated value with the typical value to ensure that the data obtained is accurate.

8. Pour entire contents of flask into a pan and place in oven (party must record the number of their pan). Additional tap water may be used as necessary to wash all aggregate out of the flask. Return next day to measure the weight of the oven-dry aggregate (A).

9. From the above data, calculate specific gravity values and absorption as defined below:

Apparent Specific Gravity (DRY) = A / (B+A-C)

Bulk Specific Gravity (DRY) = A / (B+D-C)

Bulk Specific Gravity (SSD) = D / (B+D-C)

Absorption = (D-A) / (A) x 100%

SPECIFIC GRAVITY AND ABSORPTION OF AGGREGATE TEST RESULTS

Group's Pan #: __________

Fine Aggregate Test Data

SSD weight in air (D)	=
Weight of flask + water (B)	=
Weight of flask + water + sample (C)	=
Oven dry weight (A)	=

Summary of Test Results

	Fine Aggregate
Apparent Specific Gravity (dry)	
Bulk Specific Gravity (dry)	
Bulk Specific Gravity (SSD)	
Absorption %	

Part B - Sieve Analysis

Background

Sieve analysis is used to determine the particle size distribution or gradation of an aggregate. A suitable gradation of an aggregate in a portland cement concrete mixture is desirable in order to secure workability of the concrete mix and economy in the use of cement. For asphalt concrete, suitable gradation will not only affect the workability of the mixture and economy in the use of asphalt, but also will affect significantly the strength, stability, resistance to aging, and other important properties.

The sieve analysis of an aggregate is performed by "sifting" the aggregate through a series of sieves nested in order, with the sieve with the smallest openings on the bottom. These sieves have square openings and are usually constructed of wire mesh. In the testing of aggregates, a series of sieves are usually used where any sieve in the series has twice the clear opening of the next smaller size in the series. The US Standard Sieve Series and the clear opening of each sieve are given below:

Table 2.1 - US Standard Sieve Size

US Standard Sieve Size	Clean (in)	Opening (mm)
No. 200	0.0029	0.074
No. 100	0.0059	0.15
No. 50	0.0117	0.30
No. 30	0.0232	0.59
No. 16	0.0469	1.19
No. 8	0.0937	2.38
No. 4	0.187	4.75
3/8 in.	0.375	
1/2 in. (half size)	0.500	
3/4 in.	0.750	
1 in. (half size)	1.000	
1-1/2 in.	1.50	

Sometimes closer sizing than that given by the standard series is desired, in which case "half" sizes or "odd" sizes are employed; the 1/2 in. and 1 in. shown above are half sizes.

Coarse aggregate is usually defined as particles which are retained on a #4 sieve and fine aggregate as particles which pass the #4 sieve. Thus, all sieves need not be used physically in the nest but are still considered in the analysis. For example, sieves larger than 3/8 in. are not used for the sand and sieves smaller than the No.8 are seldom used for coarse aggregate.

The fineness modulus (FM) is an index number which is roughly proportional to the average size of the particles in a given aggregate. It is computed by adding the cumulative percentages coarser than each of the standard sieves (cumulative percent retain) and dividing by 100. (Note: Even though some material may be retained on the pan, it is not considered a sieve and does not enter into the computations for fineness modulus. In addition, if sieves other than those standard sieves listed above are used, they are not used directly in the computations and any material retained on such sieves should be considered as being retained on the <u>next smaller sieve</u> of the series used in the computations, e.g., any material retained on a 1 in. sieve would be added to the 3/4 in. sieve for purposes of fineness modulus computation. However, the amount and percentage of the 1 in. material would appear in the tabular listing in the sieve analysis). **When computing the FM of a fine aggregate, only the cumulative percent retained in 7 standard sieves (3/8 in., #4, #8, #16, #30, #50, and #100) are used.**

The following illustrates the calculation of the fineness modulus. An interpretation of the fineness modulus might be that it represents the (weighted) average sieve of the group upon which the material is retained, No. 100 being the first, No. 50 the second, etc. Thus, for sand with a FM of 2,92, sieve No. 30 (the third sieve) would be the average sieve size upon which the aggregate is retained.

Table 2.3 Sample Calculation in Determining Fineness Modulus

Sieve No.	Wt. Retained	Cumulative Wt. Retained	Cumulative % Retained
4	30	30	9.7
8	40	70	22.6
10	30	100	--*
16	30	130	42.0
30	35	165	53.3
50	45	210	67.8
80	40	250	--*
100	50	300	96.8
200	6	306	98.7 **
Pan	10	310	100

Fineness Modulus of Sand = Σ(Cumulative % retained)/100
= (9.7 + 22.6 + 42.0 + 53.3 + 67.8 + 96.8)/100 = 2.92

* Sieves not ordinarily used in sieve analysis are not included in fineness modulus calculations.
** #200 sieve should not be included in computing the FM

Essential Apparatus

Balance
One set of 8 in. diameter sieves with pan and cover
Mechanical shaker
Brush

Testing Procedure

1. Obtain proper weight of dry aggregate
   -Fine aggregate: 400 grams

2. Assemble sieves in following order:
   -Fine aggregate: 8" diameter size sieves, #4, #8, #16, #30, #50, #100, pan

3. Place the aggregates in the top of the sieve stack and cover with the lid. Properly secure the sieves in the mechanical shaker and turn on the shaker for five minutes.

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 0.1% times the number of sieves used (0.6%) of the original sample weight, the procedure should be repeated. Otherwise, **use the sum of the weight retained in the pan** to calculate the percentage retained on each sieve.

5. Compute the cumulative percent retained on, and the percent passing each sieve. Plot the gradation curves for the fine aggregates from the experiment on the gradation chart as shown below in the example plot below.

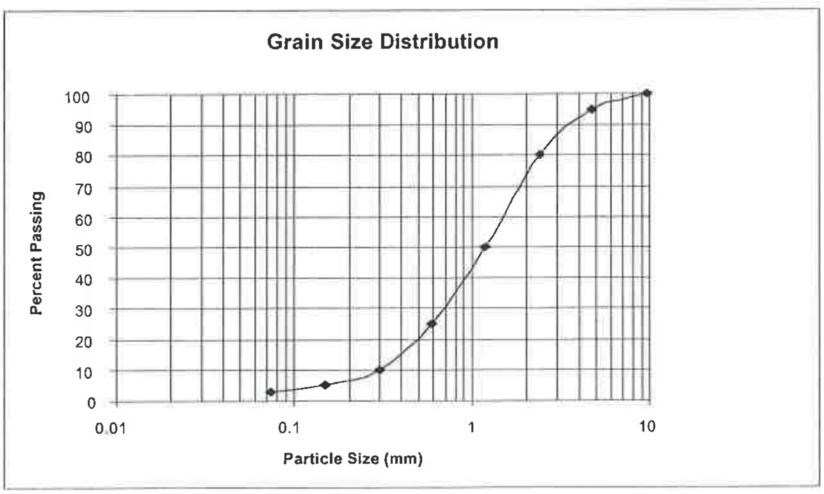


Figure 2. 1

6. Compute the Fineness Modulus for the fine aggregate.

SIEVE ANALYSIS TEST DATA SHEET

FINE AGGREGATE **Initial Weight: __________**

Sieve No.	Weight Retained	Cumulative Weight Retained	Cumulative % Retained	% passing

FINENESS MODULUS (FM) = ________________

Results

Present data for tests performed in Parts A and B. Calculate specific gravities (apparent, bulk SSD, and bulk OD) and absorption capacity at SSD. Present sieve analysis data, including a gradation plot. Calculate fineness modulus.

Discussion

Part A.

1. Discuss possible sources of error in test procedure or calculations which may have affected the test results.
2. Compare values of apparent specific gravity, bulk specific gravity (SSD), and bulk specific gravity (oven dry). Does the relationship, $G_b < G_{bSSD} < G_a$, hold true? Explain why or why not.
3. Explain why specific gravity (SSD) is more appropriate for aggregate used in portland cement concrete mixtures while specific gravity (oven dry) is more appropriate for aggregate used in asphalt concrete mixtures?
4. Classify the aggregate as light, normal, or heavy weight based on the classification of aggregate by specific gravity described in class.

Part B.

1. Discuss possible sources of error in test procedure or calculations which may have affected the test results.
2. Compare the FM of the lab sample to the FM for the aggregate sample in Table 10.4 of the textbook. Which aggregate is "more fine"?
3. Use the gradation plot generated from the lab data to classify the aggregate as gap graded, open/uniform graded, or dense/smooth/continuous graded, as defined in Chapter 10 of the textbook.
4. The gradations and the specific gravity of two aggregates (Aggregate A and Aggregate B) are given below. Graph the gradation and determine the specific gravity of the aggregate which combines 35% Aggregate A, 35% aggregate B and 30% of the sand used in the laboratory.

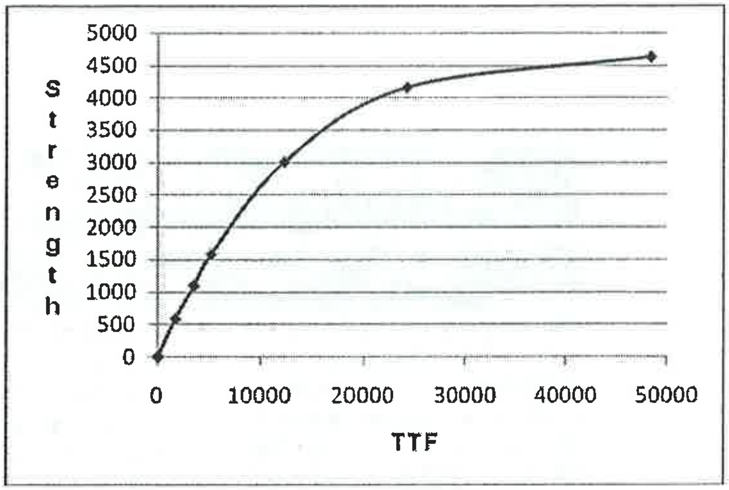
Sieve size	Percent Passing, %		
	Agg. A	Agg. B	Sand
1"	100		
¾	85		
½	45	100	
3/8	10	70	
#4	5	55	
#8	0	20	
#16		0	
Specific Gravity (Bulk ssd)	2.65	2.69	

CON 106 Concrete Fundamentals – Lab #4

Spring 2012 ______________ ______________
LAST NAME FIRST NAME

1) Given the following maturity data from correlation cylinders in the lab, a) how long in hours must we wait before stripping the forms if the temperature in the field runs an average of 24°F *higher* than that in the lab and we need 65% of design strength (f'_c = 5000 psi) before removing the formwork ? The units on the tracking information (TTF) are in °F · hours.

Ave f'_c	*Ave F°	Hours	TTF
585	68	24	1680
1100	73	48	3504
1585	72	72	5184
3010	73	168	12264
4160	72	336	24192
4630	72	672	48384



a) ______________

Note: *The average temperature in the lab over the 28-day period was 72.2 °F. Assume linearity between points on the curve.

Concrete in Practice

What, why & how?

NRMCA®

CIP 39 - Maturity Methods to Estimate Concrete Strength

WHAT is Concrete Maturity?

The maturity concept uses the principle that concrete strength (and other properties) is directly related to both age and its temperature history. Maturity methods provide a relatively simple approach for reliably estimating the in-place early-age compressive (and flexural) strength of concrete (14 days or less) during construction. The maturity concept assumes that samples of a concrete mixture of the same maturity will have similar strengths, regardless of the combination of time and temperature yielding the maturity. The measured *maturity index* of in-place concrete, a function of temperature history and age, is used to estimate its strength development based on a pre-determined calibration of the time-temperature-strength relationship developed from laboratory tests for that mixture.

WHY use Maturity Methods?

Maturity methods are used as a more reliable indicator of the in-place strength of concrete during construction in lieu of testing field-cured cylinders. The traditional approach of measuring the strength of field-cured cylinders, cured in the same conditions as the structure, are used to schedule construction activities such as removal of forms or reshoring, backfilling walls, schedule prestressing and post-tensioning operations, determining the time for opening the pavements or bridges to traffic, sawing joints, and to determine when protection measures can be terminated in cold weather.

Maturity methods use the fundamental concept that concrete properties develop with time as the cement hydrates and releases heat. The rate of strength development at early ages is related to the rate of hydration of cement. Heat generated from the hydration reaction will be recorded as a temperature rise in the concrete. The main advantage of the maturity method is that it uses the actual temperature profile of the concrete in the structure to estimate its in-place strength. The traditional approach of using field-cured cylinders does not replicate the same temperature profile of the in-place concrete and likely does not estimate its in-place strength as accurately. With maturity methods strength information is provided in real-time since maturity measurements are made on-site at any time. As a result, construction workflow is optimized, and construction activity timing can be based on more accurate in-place strength information.

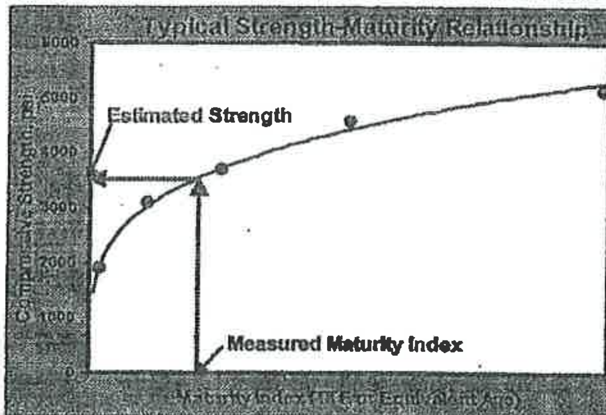


Figure 1. Strength-Maturity Relationship from lab tests used to estimate in-place strength from measured maturity index.

HOW are Maturity Methods Used?

The procedure for estimating concrete strength using maturity concepts is described in ASTM C 1074, *Standard Practice for Estimating Concrete Strength by the Maturity Method*. The temperature-time-strength relationship of a concrete mixture is developed in laboratory tests. This establishes one of two maturity functions (explained below) for that mixture. During construction a maturity index is determined from measured temperature and age. The maturity index is used to estimate the in-place strength from the pre-established maturity-strength relationship. This is illustrated in Figure 1.

The maturity concept is governed by the underlying assumption that concrete samples of a given mixture will have the same strength when they have the same maturity index. For example, concrete cured at a temperature of 50°F (10°C) for 7 days may have the same maturity index as concrete cured at 80°F (27°C) for 3 days and therefore would have similar strengths.

ASTM C 1074 provides two types of maturity functions:

The Nurse-Saul function assumes that the rate of strength development is a linear function of temperature. The maturity index is expressed as a *temperature-time factor* (TTF) from the product of temperature and time in °C-hours or °C-days. The method requires a value for a *datum temperature* below which it is assumed that no cement hydration occurs. ASTM C 1074 provides a procedure to determine this value for the specific concrete mixture or suggests assuming a value of 0°C. The accuracy of the Nurse-Saul prediction breaks down when there are wide ranges of curing temperatures, but its accuracy is considered adequate for most applications.

The Arrhenius function assumes that the rate of strength development follows an exponential relationship with temperature. The maturity index is expressed in terms of an *equivalent age* at a reference temperature. Actual age is typically normalized to an equivalent age at 20°C or 23°C. A value of the *activation energy* is needed for this maturity function. ASTM C 1074 provides a procedure to determine the activation energy or alternatively suggests that a value of 40,000 to 45,000 J/mol is a reasonable assumption for concrete with a Type I cement. Using the established maturity function, the actual age and measured temperature is converted to an equivalent age to predict the concrete strength.

The Arrhenius function is considered to be more scientifically accurate. However, the Nurse-Saul function is more commonly used by the various state highway agencies in the United States mainly due to its simplicity.

The maturity method involves the following steps:

- Determine a strength-maturity relationship for the concrete mixture to be used in the structure using materials and mixture proportions proposed for the project. Monitor the temperature history of the test specimens using temperature probes embedded in one or more of the cylinders. Measure the compressive strength of standard-cured test cylinders at various ages. These data are used to establish the maturity function (Nurse-Saul or Arrhenius).
- Measure the temperature history of the concrete in the structure by embedding sensors at locations in the structure that are critical in terms of exposure conditions and structural requirements.
- Calculate the maturity index from the recorded temperature and age.
- Estimate the in-place strength of the field concrete from the calculated maturity index and the predetermined strength-maturity relationship (Figure 1).

Some of the limitations of maturity methods that can lead to erroneous estimation of in-place strength are:

a. Concrete used in the structure is not representative of that used for the labortory calibration tests - due to changes in materials, batching accuracy, air content, etc.
b. High early age temperatures will result in incorrect prediction of long-term strength;
c. Concrete should be properly placed, consolidated and cured - conditions should permit continued cement hydration;
d. Use of datum temperature or activation energy values that are not representative of the concrete mixture.

Points (a) and (b) above are inherent limitations of maturity methods. ASTM C 1074 suggests that supplementary tests be conducted prior to performing safety-critical operations such as formwork removal or post-tensioning. While these additional tests are not always required, it is a good idea to periodically verify that the established maturity-strength relationship for the specific concrete is still valid. Suggested methods include:

(1) In-place non-destructive tests ASTM C 803 (penetration resistance), ASTM C 873 (cast-in-place cylinders), or ASTM C 900 (pullout strength).
(2) Test method C 918 that projects later age strength from early age tests.
(3) Using accelerated curing of test specimens to estimate later age strength according to ASTM C 684.
(4) Early-age tests of field-molded cylinders instrumented with maturity instruments.

Strength-maturity relationships, datum temperature and activation energy are concrete mixture specific. Therefore any significant modifications to the mixture design or material source should be accompanied by a re-calibration of these values.

Several maturity devices are commercially available that continuously measure concrete temperature, calculate maturity and display the maturity index digitally at any time. An unlimited number of locations can be monitored simultaneously. It is important to select a system that is rugged, provides uninterruptible and unalterable data, supports the maturity function being used for the project, and allows adjustment of the appropriate maturity constants.

It is important to realize that maturity is not intended to replace standard cured cylinder testing. Maturity used in conjunction with other non destructive testing can replace field cured cylinder testing and facilitate decision making for construction operations. It can be a good tool for quality control while reducing the amount of strength tests performed. Because of maturity testing, projects are proceeding more quickly, safely, and economically as a result of having the right information at the right place and at the right time.

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Chemical Properties of Cement

Measured

- SiO_2
- Al_2O_3
- Fe_2O_3
- CaO
- MgO
- SO_3
- LOI
- Residue
- Alkalies

(SiO_2 through SO_3: *Oxides*)

Calculated

- C_3S (Tricalcium silicate)
- C_2S (Dicalcium silicate)
- C_3A (Tricalcium aluminate)
- C_4AF (Tetracalcium aluminoferrite)

(*90% of Portland Cement*)

Chemical Properties of Cement – what those crazy compounds do !

C_3S ➲ Early strength

C_2S ➲ Late strength

C_3A ➲ Set time (early reaction chemistry)

C_4AF ➲ Color: more iron = darker

Attachment D American Concrete Institute (ACI) Field Testing Technician Workbook

ACI Certification

Concrete Field Testing Technician Grade I

Technician Workbook
Publication CP-1 (08)

American Concrete Institute®

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TECHNICIAN WORKBOOK

ACI Certification Program for

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