Specifications: Do you know what you are specifying?

Kevin MacDonald

Beton Consulting Engineers

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The Current System for Concrete Specification

- Specification is prepared which lays out all requirements
- A submittal is prepared to address those requirements
- Testing Laboratories are hired to check what is being supplied is what was submitted.

Specification and Concrete Requirements

- Section 3300 and Notes
- Strength
- W/C ratio
- Material Properties
- Minimum Quantities

Architectural Concrete

Discoloration

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Prescription Specification

- 4000 psi at 28 days
- 0.40 w/c ratio
- Minimum 550 lb type I cement
- Coarse Aggregate 60 percent of aggregate volume

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Prescription Specifications

- Do not take into account the unspecified performance requirements – and may in fact be in conflict with them.
- Codifies the concept of concrete as a combination of materials rather than a material in the plastic and solid states.

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Prescription Specifications

- Cater to the lowest common denominator – and prevent innovation
- Minimum cement contents specified to compensate for poor aggregates and to provide added safety
- Water Cement Ratios are specified occasionally to decrease shrinkage

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Prescription Specifications

- 28 day strengths specified may conflict with maximum water cement ratios
- Concrete Supplier held responsible for performance irrespective of specification methodology
- Specifier "approval" of mixture does not alleviate manufacturer of responsibility
- May not allow benefit of using pozzolans or other materials for long term performance

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ACI Document Taxonomy

- There are reports, guides, standards, specifications and codes
- Only the last two are in Mandatory Language

- Specifications are written to the contractor and contain a checklist
- Codes are written to the designer and contain a commentary

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Clear Intent of Specifications

- The specification has to be read in its entirety. If there are conflicts the need to be clarified (RFI) or the stricter condition applies.

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ACI 318 - Written to the Designer

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CONCRETE SOLUTIONS

Prescription vs. Performance

- ***US lagging behind Europe / Canada in code development***
- ***I.e. CSA A23.1 class C1 exposure***
- ***Economic advantage of "how" is removed***
- ***Innovation is stifled***
- ***Often meeting the prescription can result in undesirable, unintended consequences***

CEMSTONE CONCRETE SOLUTIONS BUILDING THE FUTURE TOGETHER

Prescriptive Issues

- The supplier is held responsible for the ingredients and the performance.

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1950's

- Cement Contents increase
- Water Cement Ratios stay constant
- Strength increases

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1960's

- Quality Control improves –
- Strength is achieved more frequently
- Cement content decreases
- Water Cement Ratio increases
- Durability problems

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Column on Gardiner Expressway 1992 MacDonald

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1970's

- Recognizing the issue many national codes change = exposure class
- Strength is tested more frequently
- Cement content decreases
- Water Cement Ratio increases
- Durability problems occur as high strength concrete is not always high durability concrete

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1980's

- Now turning around the problem -
- specify durability-
- set water cement ratio and water content
- Strength is tested less frequently
- Admixtures come in to general use
- Problem - no "fingerprint tests"
- Durability problems begin to improve - high durability concrete is also high strength concrete

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Windsor Star July 10 2010

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Windsor Star July 10 2010

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1990's

- Developments in durability
- Durability problems begin to improve – high durability concrete is also high strength concrete
- Use of alternate binder systems
- Very low water cement ratios are possible

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2000's

- Performance Criteria are becoming more detailed.

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Lets look at some Spec's

3.3 CAST-IN-PLACE CONCRETE
A. Mix Design
1. Mix design(s) shall be prepared by an independent testing agency in accordance with ACI 211 and ACI 318.
2. Concrete exposed to weather shall contain 5% to 7% entrained air.
3. Maximum 3" slump for slab-on-grade concrete with a water/cement ratio no greater than 0.55.
4. Submit mix designs to the Engineer at least 14 days prior to placing concrete.

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B. Material
1. Portland cement shall conform to ASTM C150, Type I.
2. High early strength cement shall conform to ASTM C150, Type III.
3. Use only one brand of cement through out project.
4. Regular weight aggregate shall conform to ASTM C33. Light weight aggregate shall conform ASTM C330.

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Some More Specifications

B. Material

1. Portland cement shall conform to ASTM C150, Type I.
2. High early strength cement shall conform to ASTM C150, Type III.
3. Use only one brand of cement through out project.
4. Regular weight aggregate shall conform to ASTM C33. Light weight aggregate shall conform ASTM C330.
5. Maximum aggregate sizes: 1-1/2" for footings, 1/2" for toppings, 3/4" for other concrete.
6. Admixtures approved by the Engineer shall meet the appropriate ASTM specifications.

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This document has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

ACI 211.1-91
(Reapproved 2009)

Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete

An ACI Standard

Reported by ACI Committee 211

CONTENTS

ACI 211 - Guide to proportioning

- Presents the absolute volume method of proportioning mixtures

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ACI 211 - Guide to Proportioning

Table 6.3.1 – Recommended slumps for various types of construction*

Types of construction	Slump, in. Maximum+	Slump, in. Minimum
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

*Slump may be increased when chemical admixtures are used, provided that the admixture-treated concrete has the same or lower water-cement or water-cementitious material ratio and does not exhibit segregation potential or excessive bleeding.
+May be increased 1 in. for methods of consolidation other than vibration.

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Workability

Slump

Design and Control

TABLE II
RECOMMENDED SLUMPS FOR CONCRETE

Type of Structure	Slump—Inches Minimum	Maximum
Massive sections, pavements and floors laid on ground	1	4
Heavy slabs, beams or walls	3	6
Thin walls and columns, ordinary slabs or beams	4	8

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How old is it?

DESIGN *and* CONTROL
of
CONCRETE MIXTURES

THIRD EDITION
January, 1929

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ACI 211 - Guide to proportioning

Table 6.3.4(a) — Relationship between water-cement or water-cementitious materials ratio and compressive strength of concrete

Compressive strength at 28 days, psi*	Water-cement ratio, by weight Non-air-entrained concrete	Air-entrained concrete
6000	0.41	—
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

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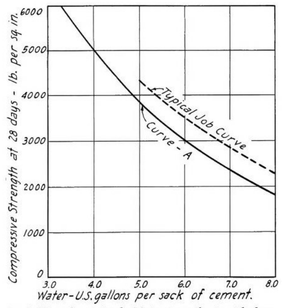
Design and Control of Concrete Mixtures



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Research Bulletin 1 Design of Concrete Mixtures

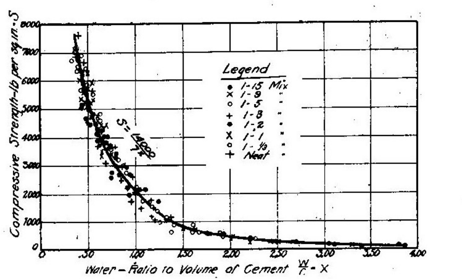

FIG. 1. RELATION BETWEEN STRENGTH OF CONCRETE AND WATER CONTENT
Twenty-eight-day compression tests of 6 by 12-inch cylinders. (Series 83.)

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Ideal Gradations

- 8-18
- Fuller's Curve(s) $y = \left(\frac{d}{D}\right)^{0.5}$
- 0.45 Power Gradation $y = \left(\frac{d}{D}\right)^{0.45}$
- Idea – aggregate is not inert – its all ert and particle size distribution is important

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Optimal Gradation

- Palotas Equation

$$y = \frac{100}{\log_{10}^{\frac{1+0.3m_o}{\log(D)-0.3m_o+1}}(100D)} \log_{10}^{\frac{1+0.3m_o}{\log(D)-0.3m_o+1}}(100D)$$

M_o = Optimum Fineness modulus

Applies for D 5 to 80 mm, Agg/Cement Ratio 4 to 10 by mass

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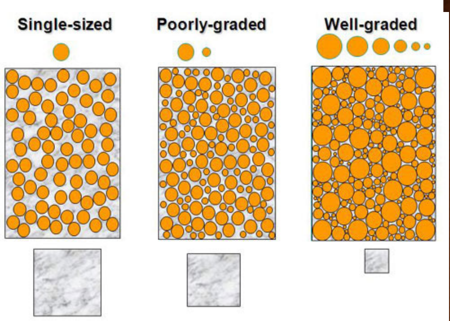
Gradation vs Paste Content



Shrinkage

- Affected by water content
- Predictable
- Often specified where not required

- Relationship to Curling
- Relationship to Water : Cement Ratio

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Strength Limits

- Slab with low w/c ratio – 0.40 results in strengths above 6000 psi
- 3500 psi was specified
- New Specification – 3250 to 3750 psi at 28 days

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Testing and Sampling

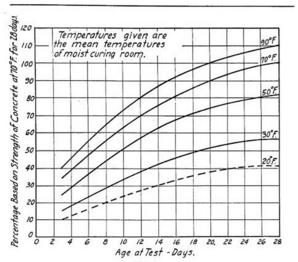

Fig. 4
Effect of temperature during curing period on the compressive strength of concrete. Data taken from Bulletin No. 81, Engineering Experiment Station, University of Illinois.

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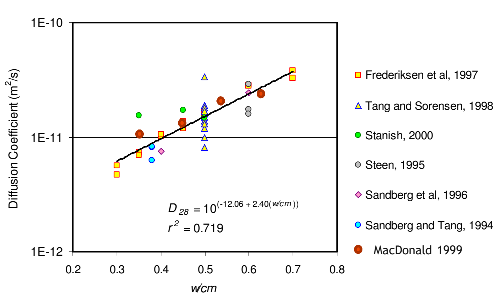

Figure 4.3 Relationship between D28 and w/cm for concrete at 20°C

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Unwritten Owner Requirements

- Shrinkage
- Curling
- Cracking
- Appearance
- Longevity

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Constructor Requirements

- Workability
- Finishability
- Setting Characteristics
- Strength Gain for Stripping and Stressing
- Cold and Hot Weather

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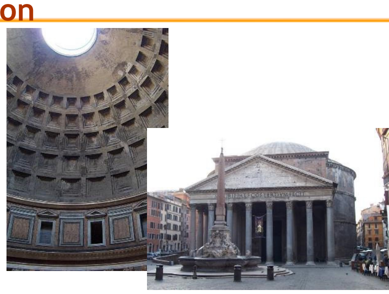
Pantheon



Evolution of Structural Engineering

- Elasticity
- Plasticity
- Finite Element

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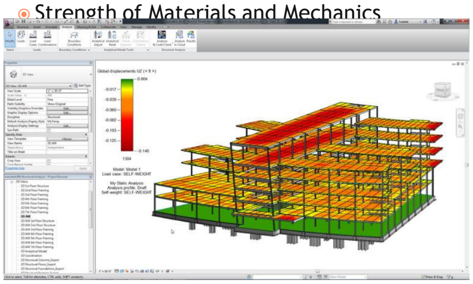
Current Approach to Design of Structures

- Strength of Materials and Mechanics



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Current Approach to Concrete Durability

- Minimum cement content
- Maximum water-cementitious material ratio—0.45
- Slump
- Aggregates are sound, clean, durable, and well graded (see low volume PCC paper)
- Adequate air void system for freeze-thaw climates
- Proper proportioning, mixing, placing, finishing, and curing

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Use of Exposure Classes

- ACI 318
- CSA A23.1
  - Defines a series of requirements based on the environmental exposure

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ACI 318

- **19.3.1** *Exposure categories and classes*
- **19.3.1.1** The licensed design professional shall assign exposure classes in accordance with the severity of the anticipated exposure of members for each exposure category in Table 19.3.1.1.

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Introduction

- New ACI 318 requirements for exposure class
- Code sets minimum requirements - cannot be less

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Scope of the ACI "Code"
(Design and Construction Standard)

- Life safety (strength)
- Serviceability
- Durability
- Materials and construction

Public safety issues?

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Prescription Specifications

- Do not take into account the unspecified performance requirements – and may in fact be in conflict with them.
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Table 5
Alternative methods for specifying concrete
(See Clauses 4.1.2.1, 4.1.2.3, 4.4.1.1, 5.2.4.3.2, and 8.1.5 and Annex J.)

Alternative	The owner shall specify	The contractor shall	The supplier shall
(1) Performance: When the owner requires the concrete supplier to assume responsibility for performance of the concrete as delivered and the contractor to assume responsibility for the concrete in place.	(a) required structural criteria, including strength at age; (b) required durability criteria, including class of exposure; (c) additional criteria for durability, volume stability, architectural requirements, sustainability, and any additional owner performance, pre-qualification or verification criteria; (d) quality management requirements (see Annex J); (e) whether the concrete supplier shall meet certification requirements of concrete industry certification programs; and (f) any other properties that might be required to meet the owner's performance criteria.	(a) work with the supplier to establish the concrete mix properties to meet performance criteria for plastic and hardened concrete, considering the contractor's criteria for construction and placement and the owner's performance criteria; (b) submit documentation demonstrating the owner's pre-qualification performance requirements have been met; and (c) prepare and implement a quality control plan to ensure that the owner's performance criteria will be met and submit documentation demonstrating the owner's performance requirements have been met.	(a) certify that the plant, equipment, and all materials to be used in the concrete comply with the requirements of this Standard; (b) certify that the mix design satisfies the requirements of this Standard; (c) certify that production and delivery of concrete will meet the requirements of this Standard; (d) certify that the concrete complies with the performance criteria specified; (e) prepare and implement a quality control plan to ensure that the owner's and contractor's performance requirements will be met, if required; (f) provide documentation verifying that the concrete supplier meets industry certification requirements, if specified; and (g) at the request of the owner, submit documentation to the satisfaction of the owner, demonstrating that the proposed mix design will achieve the required strength, durability, and performance requirements.
(2) Prescription: When the owner assumes responsibility for the concrete.	(a) mix proportions, including the quantities of any or all materials (i.e., admixtures, aggregates, cementing materials, and water) by mass per m^3 of concrete; (b) the range of air content; (c) the slump range; (d) use of a concrete quality plan, if required; and (e) other requirements.	(a) plan the construction methods based on the owner's mix proportions and parameters; (b) obtain approval from the owner for any deviation from the specified mix design or parameters; and (c) identify to the owner any anticipated problems or deficiencies with the mix parameters related to construction.	(a) provide verification that the plant, equipment, and all materials to be used in the concrete comply with the requirements of this Standard; (b) demonstrate that the concrete complies with the prescriptive criteria as supplied by the owner; and (c) identify to the contractor any anticipated problems or deficiencies with the mix parameters related to construction.

Notes:
(1) *The owner may accept recognized concrete facility certification programs from British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec or the Atlantic Concrete Association.*
(2) *Some of these specification performance requirements necessitate that performance be measured (pre-qualified) by test submissions that demonstrate conformance. If the requested performance characteristics cannot be demonstrated from a pre-existing concrete mix design, timing for developing the mix, testing, and reporting need to be accommodated in the job schedule and planning process.*
(3) *See Annex J for background information and guidance on the use of this Table.*

Specifying Performance Criteria

- The challenge : state performancerequirements that can be satisfied and that can be measured by accepted industry standards andmethods.
- Specifications are normally written by and for the owner, whose interest is usually, but not always, long-term. The required performance criteria should therefore be stated in terms that can be measured early in the life cycle of the concrete and can be used to verify at that time that the long-term performance criteria will be met.
- verification process becomes an essential and critical part of the success of the performance approach.
- Without a comprehensive and reliable verification process, the performance requirements cannot be verified at the appropriate time and the process is not workable.

Design Authority

- The designer is responsible for
- (a) establishing the performance criteria, usually in consultation with the owner;
- (b) preparing the technical specification that states the performance criteria in appropriate terms; and
- (c) under the direction of the owner, conducting quality assurance and reviewing quality assurancereports, or both, to ascertain on the owner's behalf that the performance criteria have been met.

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Contractor

- responsible for procuring concrete and related materials and incorporating them into the structure in a manner that meets the performance requirements.
- The contractor is also responsible for conducting appropriate and sufficient quality control to demonstrate and document that the performance requirements have been met.
- The quality control documents should be communicated to the design authority and owner in a manner, and according to a schedule, that will accommodate the quality assurance process.

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Concrete Supplier

- procuring materials and producing concrete that will, in its plastic and hardened states, meet the performance requirements.
- Implementing a quality control program to demonstrate and document that the product as delivered is of appropriate quality and will meet the performance requirements.
- coordination is required between supplier and contractor to ensure that the final product meets the performance criteria and that the quality control processes are compatible and demonstrate compliance.

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Example Specification

Element		Mix Strength (psi)	Design Life (Years)	ASTM C1556 28	ASTM C1556 180	RCP ASTM C1202 28	RCP ASTM C1202 180	- Decay Value m	ASTM C157 shrinkage %	Mass Concrete	ASTM C642 Exposure	ASTM C642 Absorption % max	ASTM C642 Porosity % max
				$x10^{-12}$ m^2/sec		Coulombs							
Superstructure - Pier Segments	P/C	8,000	170	3.5	1.1	948	204	0.6	0.05	No	SR	6	13

1 Shrinkage is allowed to be 20 percent higher for Post-Tensioned members. P/C
Following for Cable Stay Bridge Only CIP
2 Both Absorption and porosity are the boiling values.
3 Later age D cl was calculated assuming a decay value. Resistivity measurements of the concrete test cylinders should be performed to serve as a baseline for QC monitoring.
4 Absorption and Porosity are specified to control penetration of chloride under intermitent drying conditions.
5 RCP values are shown to instruct the mix designer. Where the D values are met the RCP value may be larger than specified.
6 ASTM C642 is used to limit the intrusion by convection of chloride.
7 Exposure is the condition of the element in service.

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- 2. The Contractor shall designate a 3” slump range. The slump shall be kept consistent during the entire placement. If a spread range is specified a Visual Stability Index (VSI) of 1 or less is required according to ASTM C1610.

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- The unit weight of the concrete shall be determined for every set of cylinders cast in accordance with the method outlined in ASTM C--- by the Contractor’s Designated Laboratory. The concrete shall not deviate by more than +/- 3 lb/ft3. If the deviation exceeds this quantity then the load shall be rejected, and each of the next 5 loads tested using the same criteria, until 5 consecutive results show compliance with the submitted mixture proportions.
-

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- After the curing period is complete a total often (10) cores shall be removed from the deck to a depth of 6 inches, taking care not to cut reinforcement or penetrate the full depth of the deck. Core Locations shall be obtained by segmenting the deck along the centerline into 10 equal lengths and randomly determining a station and offset.
- The core locations and methodology shall be submitted to the Engineer for review and approval prior to any coring taking place. Cores shall be subject to inspection using the modified point count method found in ASTM C457. Concrete shall not have a spacing factor greater than 0.010. Concrete failing to meet these requirements will be taken to represent the entire lot and a payment reduction as shown below shall be applied to the payment for that fraction of the concrete

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