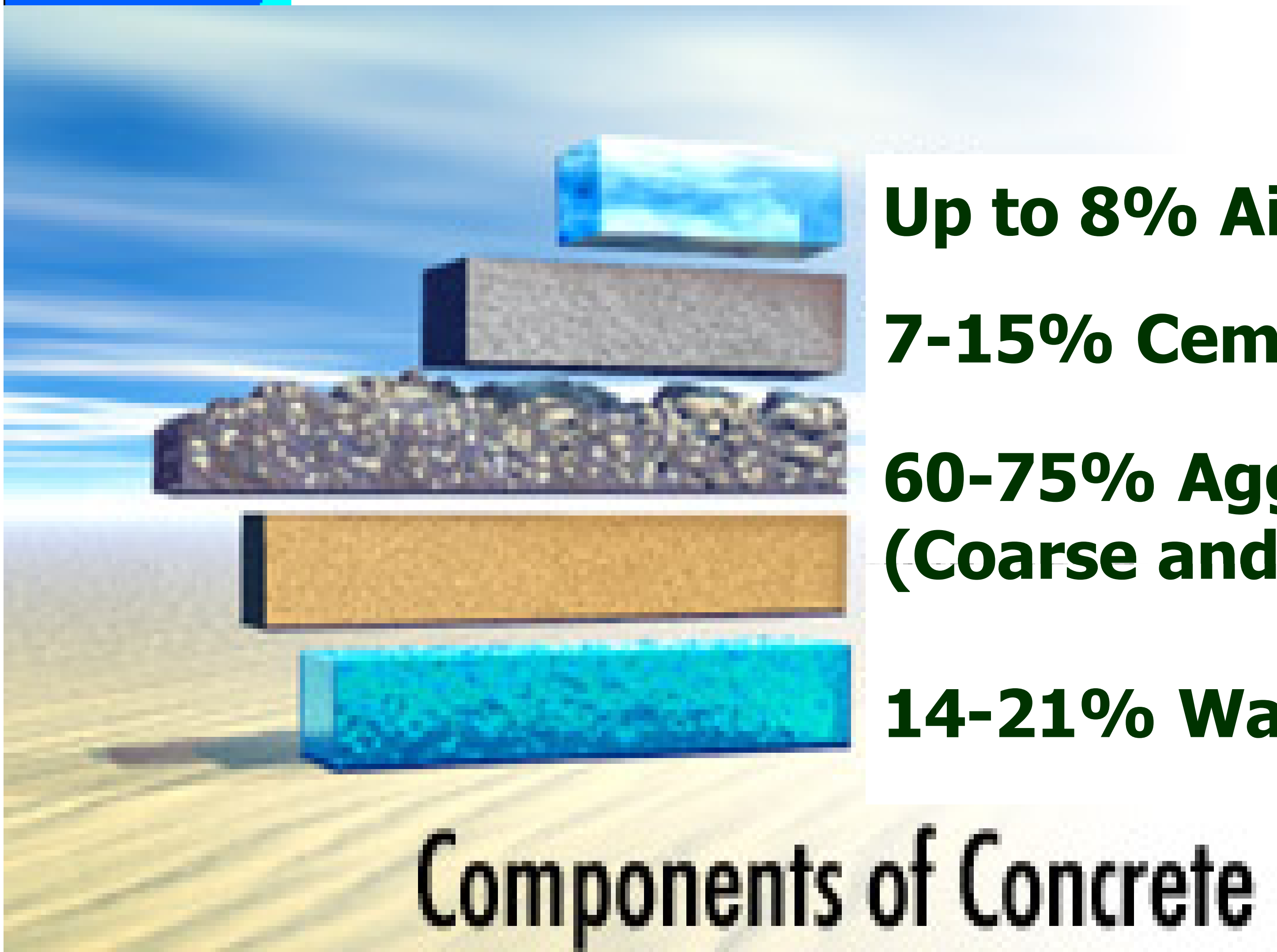
Designing Concrete Mixtures

Concrete Technology and Codes

Designing Concrete Mixtures

Objective:

To determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.


Up to 8% Air
7-15% Cement
60-75% Aggregates
(Coarse and Fine)
14-21% Water
Components of Concrete

Materials for Concrete

- Cement- *ASTM C150 (AASHTO M 85)*
- Blended Cement- *ASTM C595 (AASHTO M 240) or C 1157*
- Pozzolans (Fly Ash)- *ASTM C618 (AASHTO M 295)*
- GGBFS (Slag-Cement)- *ASTM C989 (AASHTO M 302)*
- Silica Fume- *ASTM C1240 (AASHTO M 307)*
- Water- *ASTM C1602 & C1603 (AASHTO M 157)*
- Aggregates- *ASTM C33 (AASHTO M 80-Coarse, M 6-Fine)*
- Air-Entraining Admixtures- *ASTM C260 (AASHTO M 154)*
- Chemical Admixtures- *ASTM C494 (AASHTO M 194)*

Designing Concrete Mixtures

Objective:

To determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.

Factors to be considered:

- **Workability**

Designing Concrete Mixtures

<u>Objective:</u>

To determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.

<u>Factors to be considered:</u>

- Workability
- **Placement Conditions**

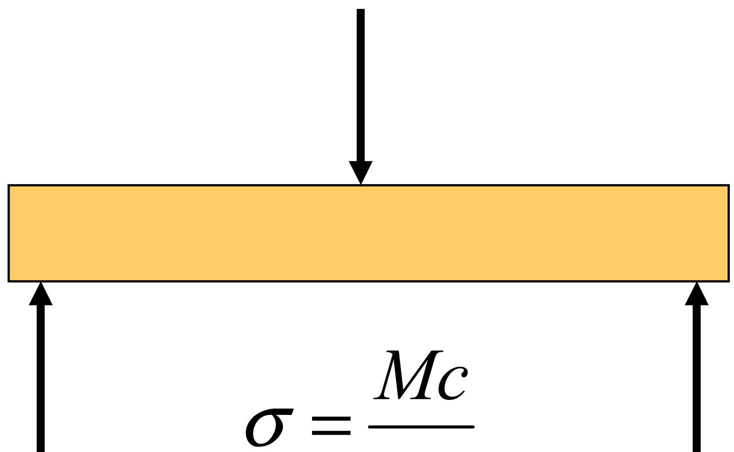
Designing Concrete Mixtures

<u>Objective:</u>

To determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.

Factors to be considered:

- Workability
- Placement Conditions
- **Strength**



$$\sigma = \frac{Mc}{I}$$

Designing Concrete Mixtures

Objective:

To determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.

Factors to be considered:

- Workability
- Placement Conditions
- Strength
- **Durability**

Designing Concrete Mixtures

Objective:

To determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.

Factors to be considered:

- Workability
- Placement Conditions
- Strength
- Durability
- **Appearance**

Designing Concrete Mixtures

Objective:

To determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.

Factors to be considered:

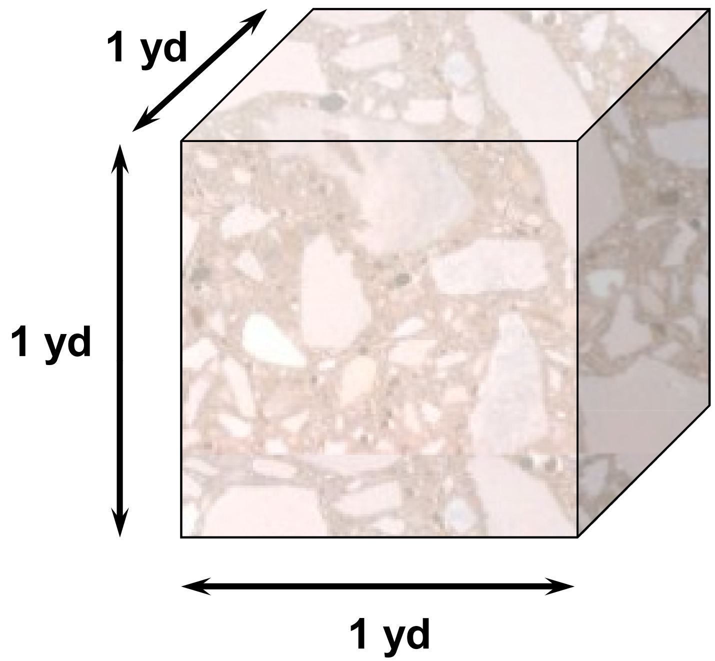
- Workability
- Placement Conditions
- Strength
- Durability
- Appearance
- **Economy**

Proportioning

Absolute Volume Method

ACI 211.1	Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete
ACI 211.2	Standard Practice for Selecting Proportions for Structural Lightweight Concrete
ACI 211.3	Standard Practice for Selecting Proportions for No-Slump Concrete
ACI 211.4R	Standard Practice for Selecting Proportions for High Strength Concrete with Portland Cement and Fly Ash
ACI 211.5	Guide for Submittal of Concrete Proportions

Absolute Volume

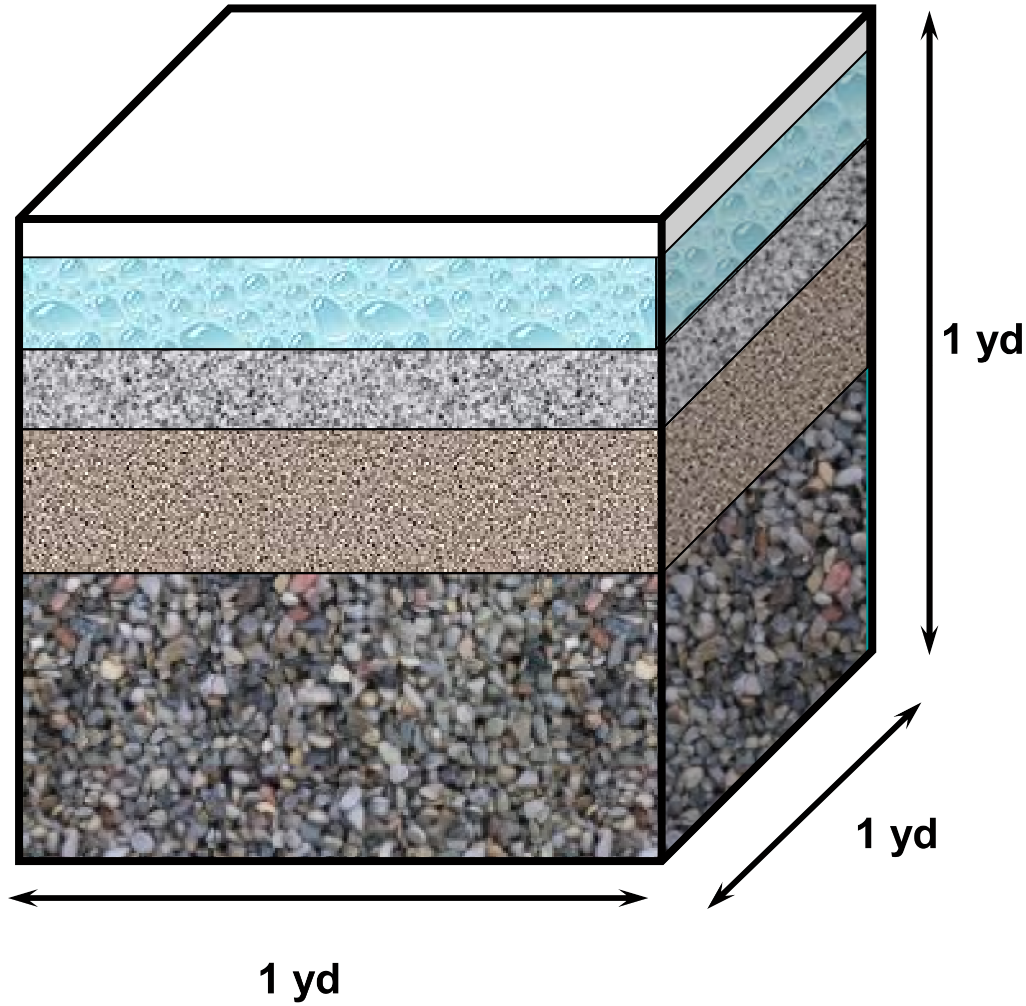


Concrete mixture proportions are usually expressed on the basis of the mass of ingredients per unit volume.

The unit of volume used is either a cubic meter or a cubic yard of concrete.

Absolute Volume

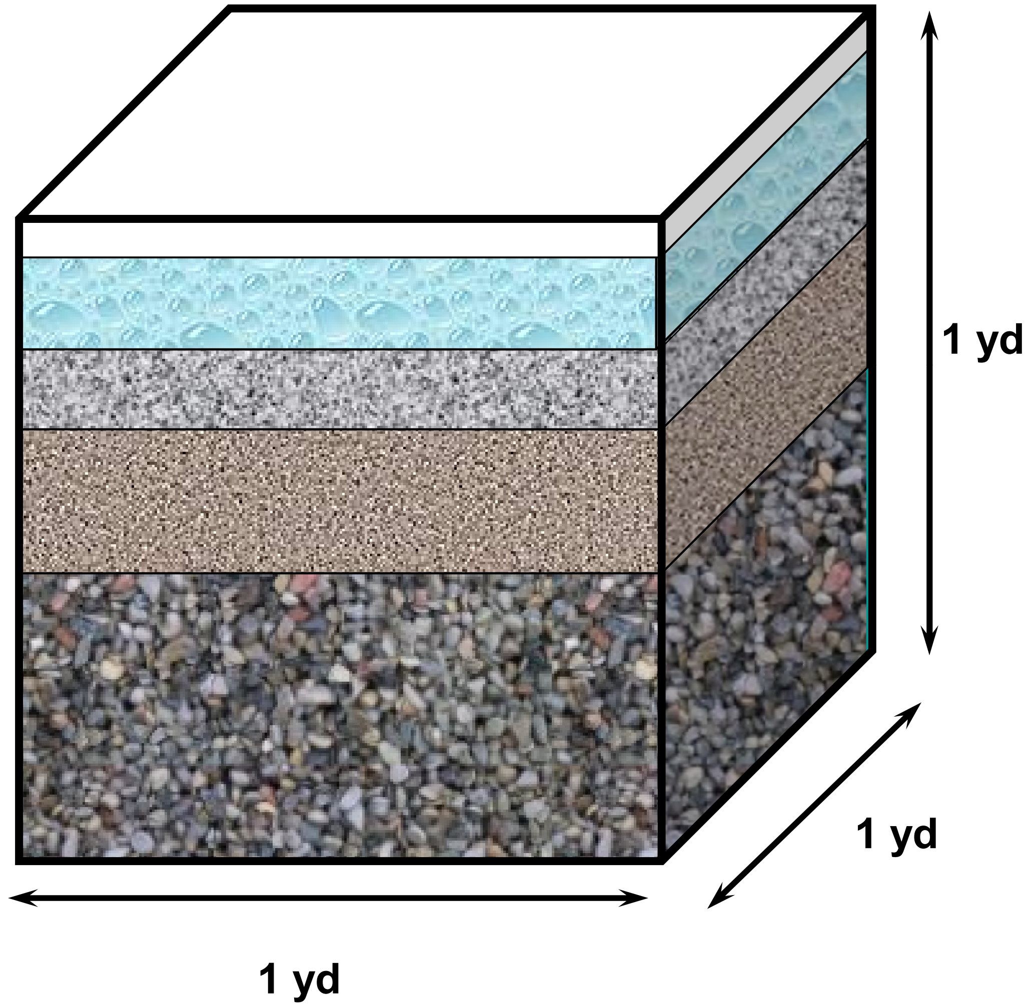
	Volume yd^3
Air	0.060
Water	0.150
Cement	0.111
Sand	0.245
Stone	0.434
Total	1.000



Absolute Volume

Calculate the Density of each material based upon specific gravity:

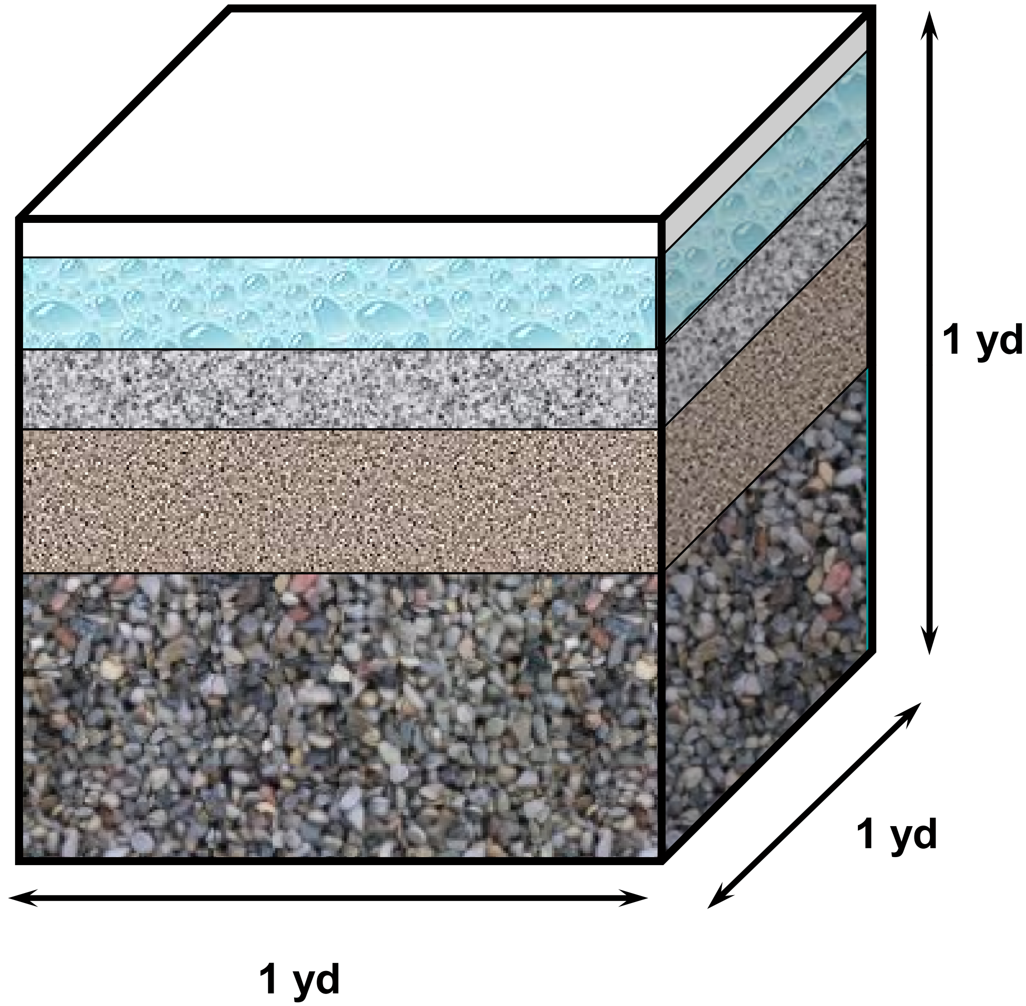
	S.G.		Density lb/yd^3
Air			
Water	1.0	x 62.4 x 27=	1685
Cement	3.15	x 62.4 x 27=	5307
Sand	2.64	x 62.4 x 27=	4448
Stone	2.64	x 62.4 x 27=	4448



Absolute Volume

Calculate the Mass of each material based upon volume and density:

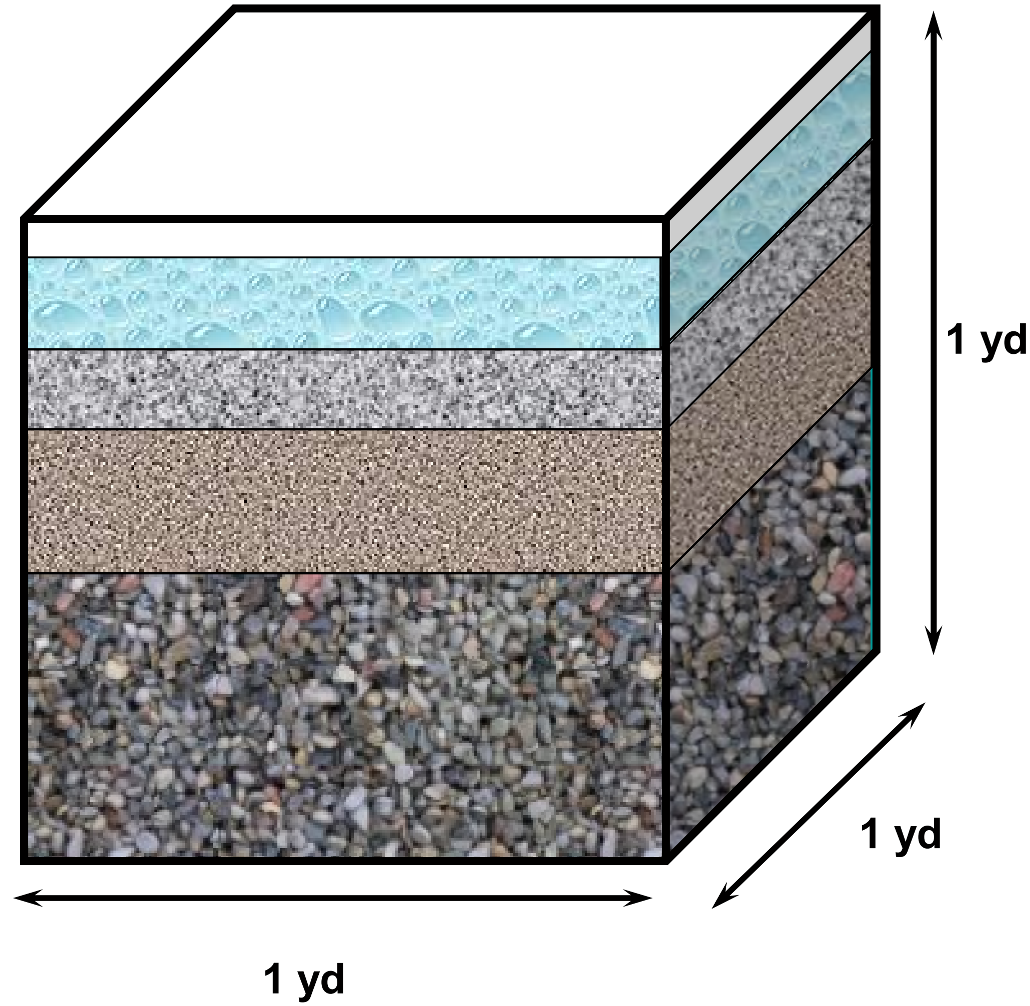
	Volume yd^3		Density lb/yd^3		Mass lb
Air	0.060				
Water	0.150	x	1685	=	253
Cement	0.111	x	5307	=	589
Sand	0.245	x	4448	=	1090
Stone	0.434	x	4448	=	1930
Total	1.000				3862



Absolute Volume

Mixture Proportions

Water	253	lb/yd^3
Cement	589	lb/yd^3
Sand	1090	lb/yd^3
Stone	1930	lb/yd^3
Air	6%	



Concrete Mix Design

Summary of Absolute Volume Method ACI 211.1

1. Strength Requirements
2. Determining W/CM
3. Coarse Aggregates
4. Air Content
5. Workability
6. Water Content
7. Cement Content
8. Cement Type
9. Admixture Effects
10. Sand Requirements
11. Moisture Corrections
12. Trial Mixes

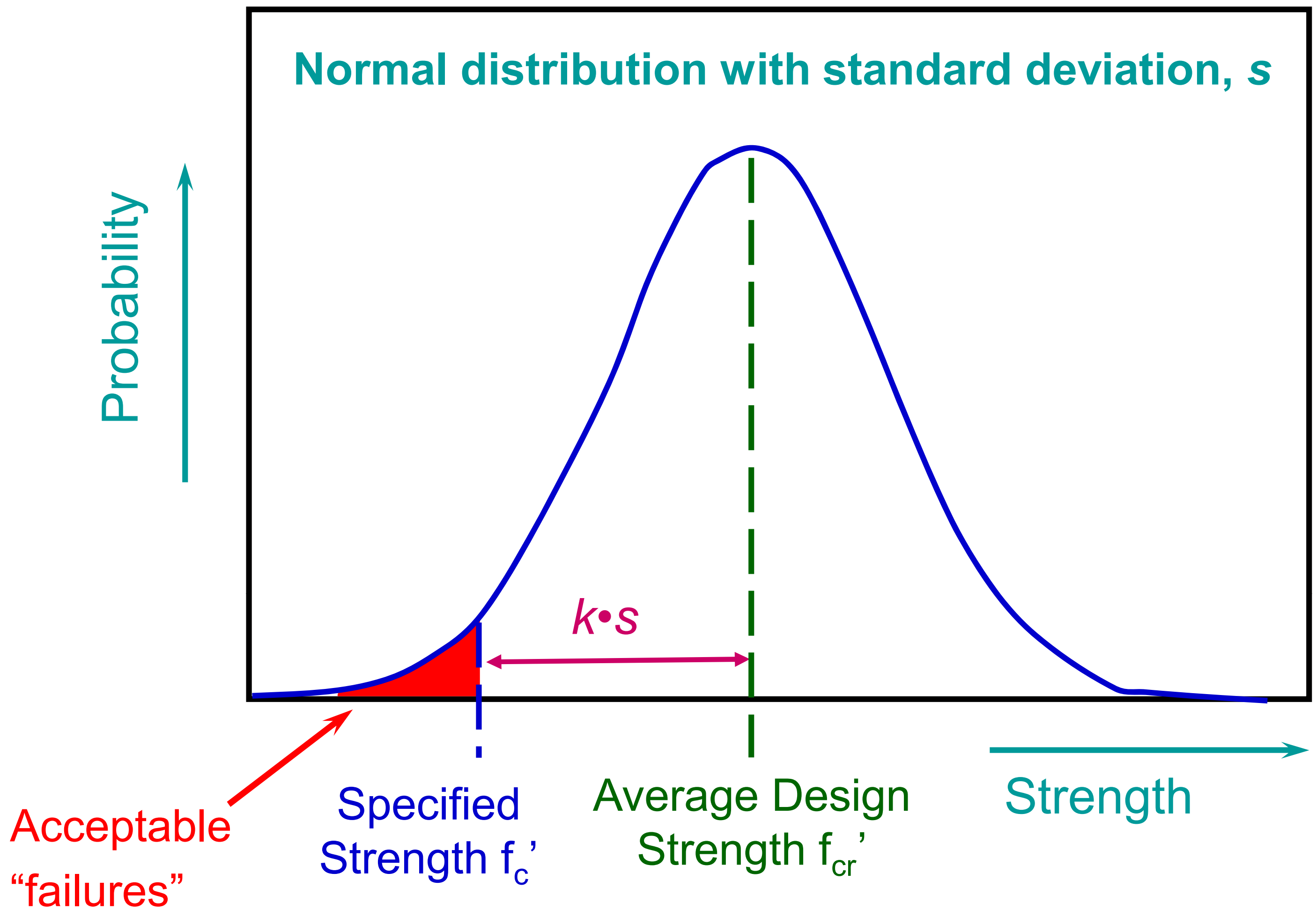
1. Strength Requirements

Specified strength, f_c' , is determined from:

- **Structural design considerations**
- **Durability considerations**

Note:

Although the durability of concrete is not directly related to strength – strength is used as an indirect means of assuring adequate durability



$$f_{cr}' > f_c'$$

Design strength > Specified strength

ACI 318 Building Code has requirements for the average strength f_{cr}' of a mix in relation to the specified (or required) strength f_c'

For f'c ≤ 35 MPa (5000 psi):

1. The probability that the average of three consecutive tests (a test being defined as an average of two cylinders) is smaller than the specified strength f_c' is 1%

   $$f_{cr}' = f_c' + 1.34S$$

2. The probability of an individual test result being more than 3.45 MPa below the specified strength f_c' is 1%

   $$f_{cr}' = f_c' + 2.33S - 3.45 \text{ MPa}$$

   or $$f_{cr}' = f_c' + 2.33S - 500 \text{ psi}$$

ACI 318 Building Code has requirements for the average strength f_{cr}' of a mix in relation to the specified (or required) strength f_c'

For f'c > 35 MPa (5000 psi):

1. The probability that the average of three consecutive tests (a test being defined as an average of two cylinders) is smaller than the specified strength f_c' is 1%

   $$f_{cr}' = f_c' + 1.34S$$

2. The probability of an individual test result being less than $0.90f_c'$ is 1%

   $$f_{cr}' = 0.90f_c' + 2.33S$$

The standard deviation should be based on at least 30 consecutive strength tests, representing concrete whose design strength is within 7 MPa (1000 psi) of that required for the work made with similar materials and under similar conditions to those expected.

If only 15 to 29 consecutive tests are available – multiply the standard deviation by the following modification factors:

Number of Tests	Modification Factor
Less than 15	Use Tables
15	1.16
20	1.08
25	1.03
30 or more	1.00

If less than 15 consecutive tests are available - the following table can be used to determine the required average strength f_{cr}'

Specified Strength f_c' (MPa)	Required Average Strength f_{cr}' (MPa)
Less than 21	$f_c' + 7.0$
21 to 35	$f_c' + 8.5$
Over 35	$1.10f_c' + 5.0$

Specified Strength f_c' (psi)	Required Average Strength f_{cr}' (psi)
Less than 3000	$f_c' + 1000$
3000 to 5000	$f_c' + 1200$
Over 5000	$1.10f_c' + 700$

Durability Requirements

Category	Severity	Class	Condition		Max w/cm	Min. f'_c (psi)	Cement ?	USE ?
F (Freezing and Thawing)	Not Applicable	FO	Concrete **not exposed** to freezing-and-thawing cycles		N/A	2,500	No Type Restriction	
	Moderate	F1	Concrete exposed to freezing-and-thawing cycles and **occasional** exposure to moisture		0.45	4,500		
	Severe	F2	Concrete exposed to freezing-and-thawing cycles and in **continuous** contact with moisture		0.45	4,500		
	Very Servere	F3	Concrete exposed to freezing-andthawing and in **continuous** contact with moisture and **exposed to deicing chemicals**		0.45	4,500		
S* (Sulfate) *PCA			**Water-soluble sulfate (SO_4) in soil (percent by weight)**	**Dissolved sulfate (SO_4) in water (ppm)**				
	Not Applicable	SO	$SO_4 < 0.10$	$SO_4 < 150$	N/A	2,500	No Type Restriction	
	Moderate	S1	$0.10 \le SO_4 < 0.20$	$150 \le SO_4 < 1500$ Seawater	0.50	4,000	II	
	Severe	S2	$0.20 \le SO_4 \le 2.00$	$1500 \le SO_4 \le 10,000$	0.45	4,500	V	
	Very Servere	S3	$SO_4 > 2.00$	$SO_4 > 10,000$	0.40*	5000*	V*	
C (Corrosion Protection)	Not Applicable	CO	Concrete **dry or protected** from moisture		N/A	2,500	No Type Restriction	
	Moderate	C1	Concrete **exposed to moisture** but **not to external sources of chlorides**		N/A	2,500		
	Severe	C2	Concrete **exposed to moisture and an external source of chlorides** from deicing chemicals, salt, brackish water, seawater, or spray from these sources		0.40	5,000		
Summary of Most Restrictive Requirements								

2. Water-Cement Ratio

The water-cement ratio (W/C) is determined from:

- Durability considerations
- Required strength f_{cr}'

  - w/c: $\dfrac{\text{Quantity of Water}}{\text{Quantity of Cement}}$

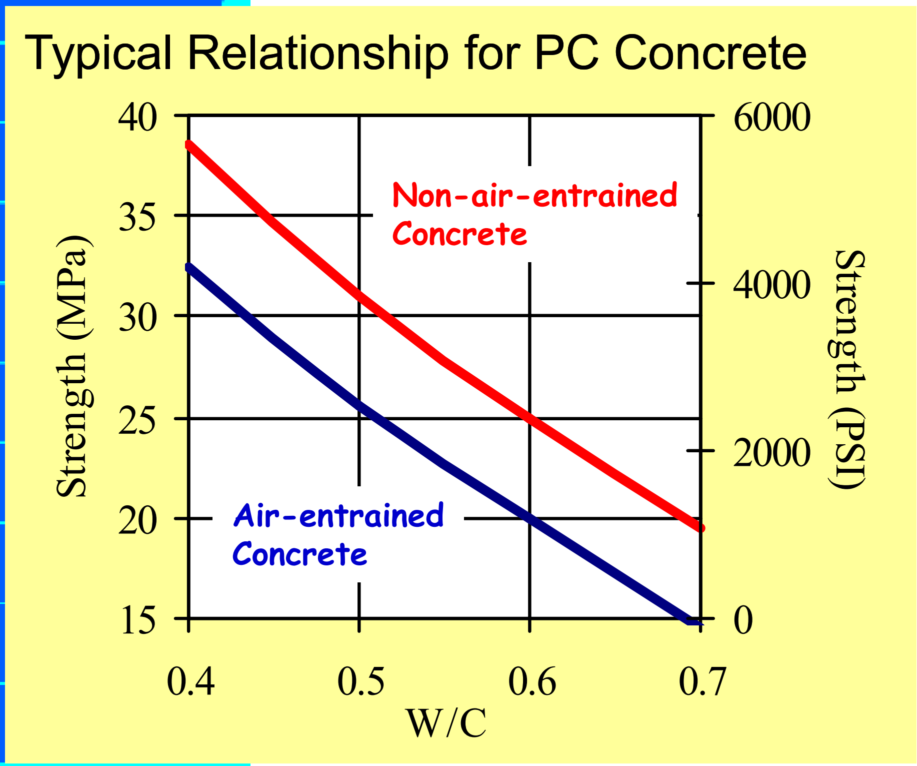
Water in excess of 0.25-0.28 w/c
is considered "water of convenience"

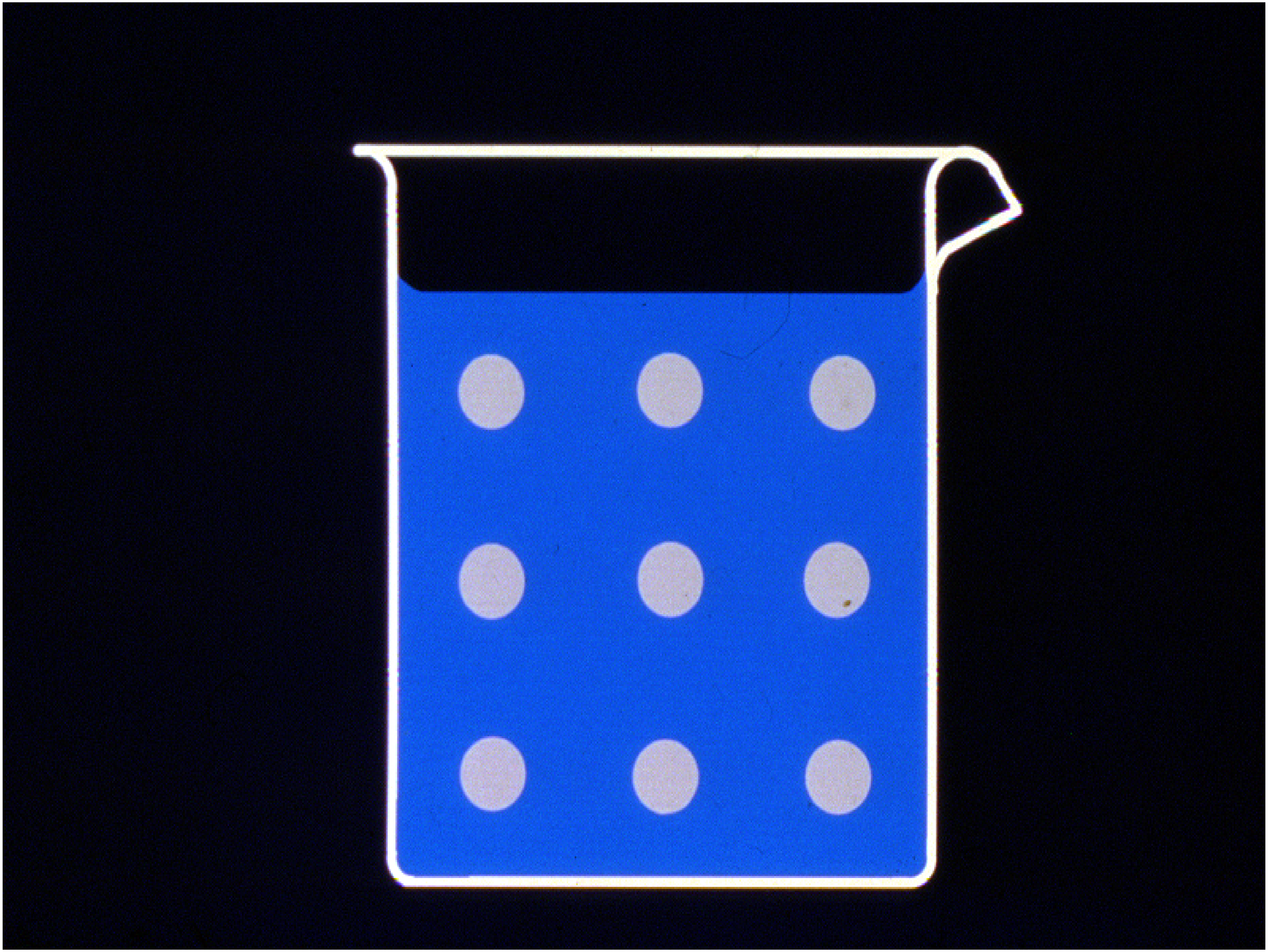
For optimum workability during
placement recommend a 0.42-0.45 w/c
or use of chemical admixtures.

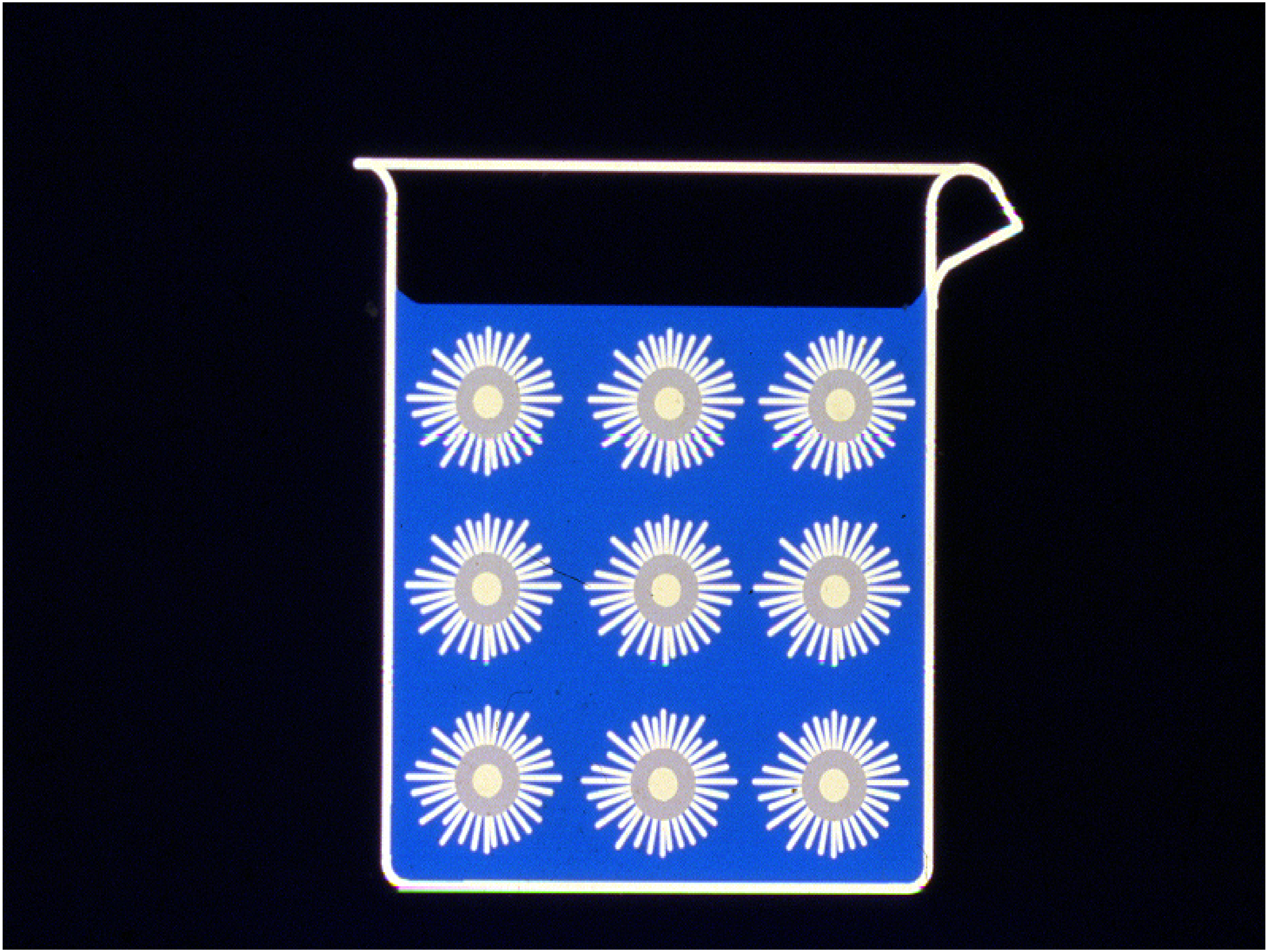
The Water-Cement Ratio Law

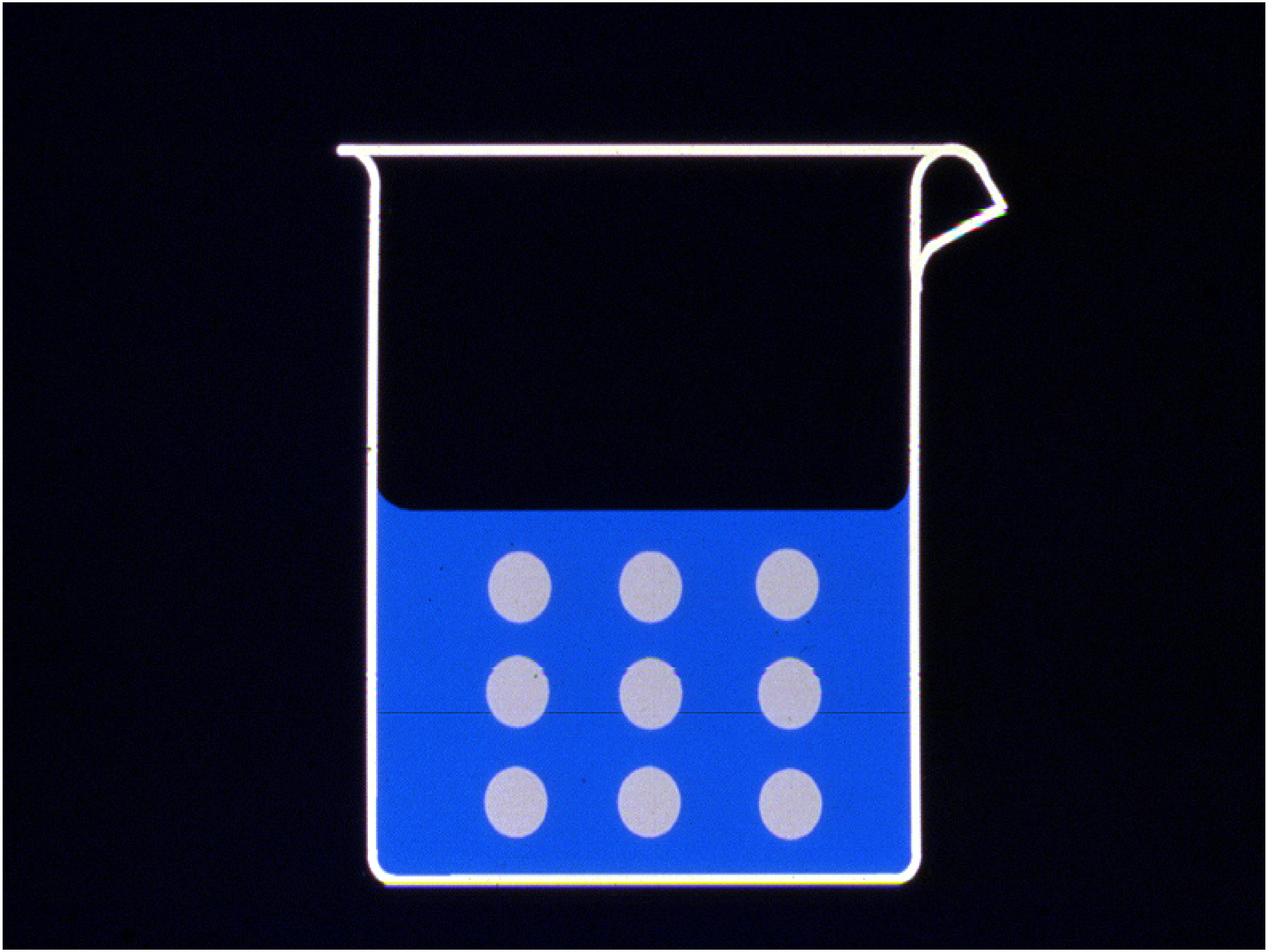
For given materials the strength of the concrete (so long as we have a plastic mix) depends solely on the relative quantity of water as compared with the cement, regardless of mix or size and grading of aggregate.

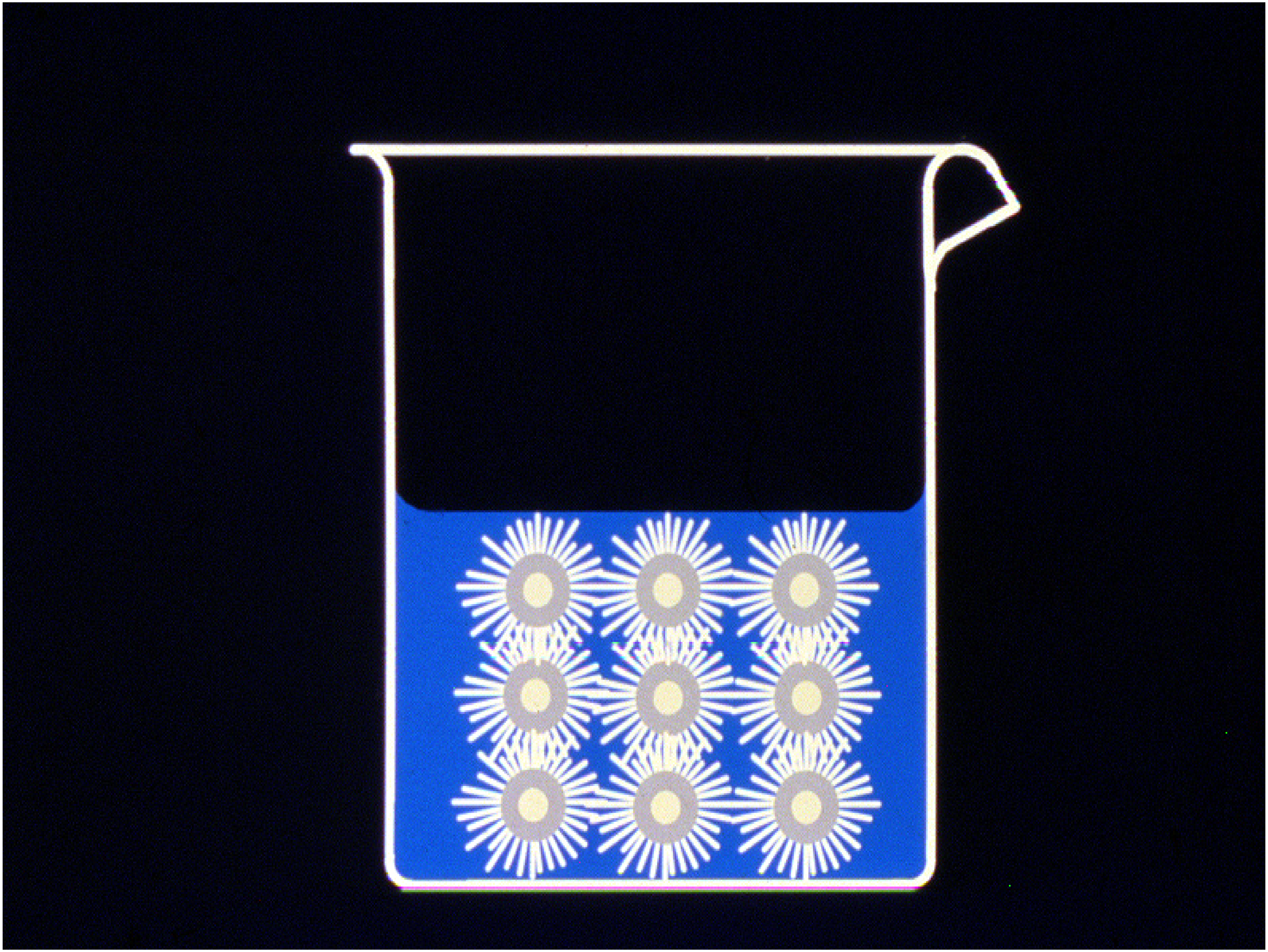
Duff A. Abrams
May, 1918







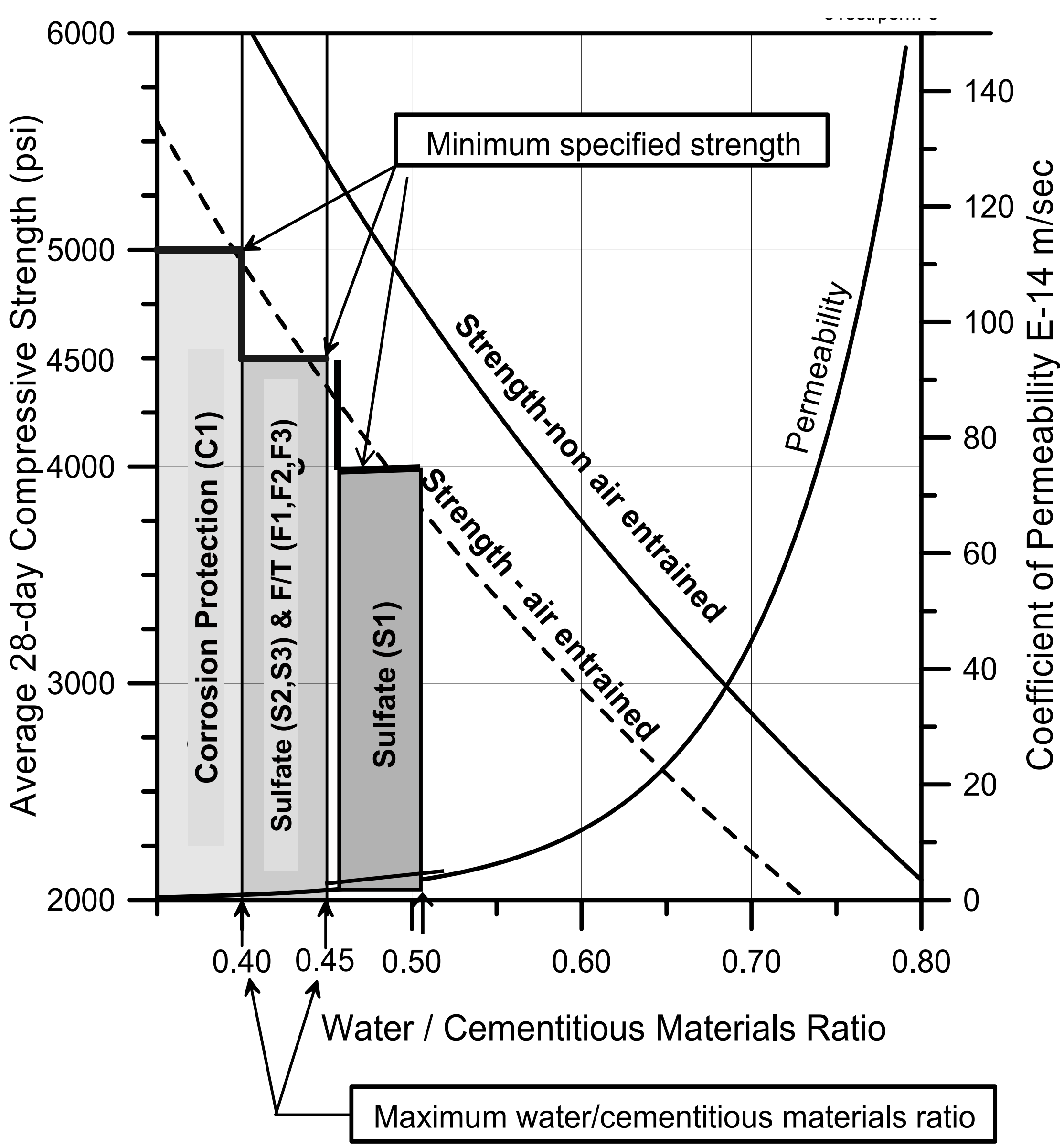




Durability Requirements

Category	Severity	Class	Condition		Max w/cm	Min. f'_c (psi)	Cement ?	USE ?
F (Freezing and Thawing)	Not Applicable	FO	Concrete **not exposed** to freezing-and-thawing cycles		N/A	2,500	No Type Restriction	
	Moderate	F1	Concrete exposed to freezing-and-thawing cycles and **occasional** exposure to moisture		0.45	4,500		
	Severe	F2	Concrete exposed to freezing-and-thawing cycles and in **continuous** contact with moisture		0.45	4,500		
	Very Servere	F3	Concrete exposed to freezing-andthawing and in **continuous** contact with moisture and **exposed to deicing chemicals**		0.45	4,500		
S* (Sulfate)			**Water-soluble sulfate (SO_4) in soil (percent by weight)**	**Dissolved sulfate (SO_4) in water (ppm)**				
	Not Applicable	SO	$SO_4 < 0.10$	$SO_4 < 150$	N/A	2,500	No Type Restriction	
	Moderate	S1	$0.10 \leq SO_4 < 0.20$	$150 \leq SO_4 < 1500$ Seawater	0.50	4,000	II	
	Severe	S2	$0.20 \leq SO_4 \leq 2.00$	$1500 \leq SO_4 \leq 10{,}000$	0.45	4,500	V	
*PCA	Very Servere	S3	$SO_4 > 2.00$	$SO_4 > 10{,}000$	0.40*	5000*	V*	
C (Corrosion Protection)	Not Applicable	CO	Concrete **dry or protected** from moisture		N/A	2,500	No Type Restriction	
	Moderate	C1	Concrete **exposed to moisture** but **not to external sources of chlorides**		N/A	2,500		
	Severe	C2	Concrete **exposed to moisture and an external source of chlorides** from deicing chemicals, salt, brackish water, seawater, or spray from these sources		0.40	5,000		
Summary of Most Restrictive Requirements								

Durability Considerations



(Image adapted from Hover 2003)

W/CM required for strength:

- Use data from field or trial mixtures using the same materials
- Where no data are available – may estimate using the table shown:

Required design strength f_{cr}' (psi)	W/CM	
	Non-Air Entrained	Air-Entrained
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

3. Coarse Aggregate Requirements

Influence of Aggregates

- **Physical Properties**

  Gradation

  Shape

  Size

  Surface texture

  Color

Specified by-
ASTM C33
(Fine- AASHTO M 6)
(Coarse- AASHTO M 80)

3. Coarse Aggregate Requirements

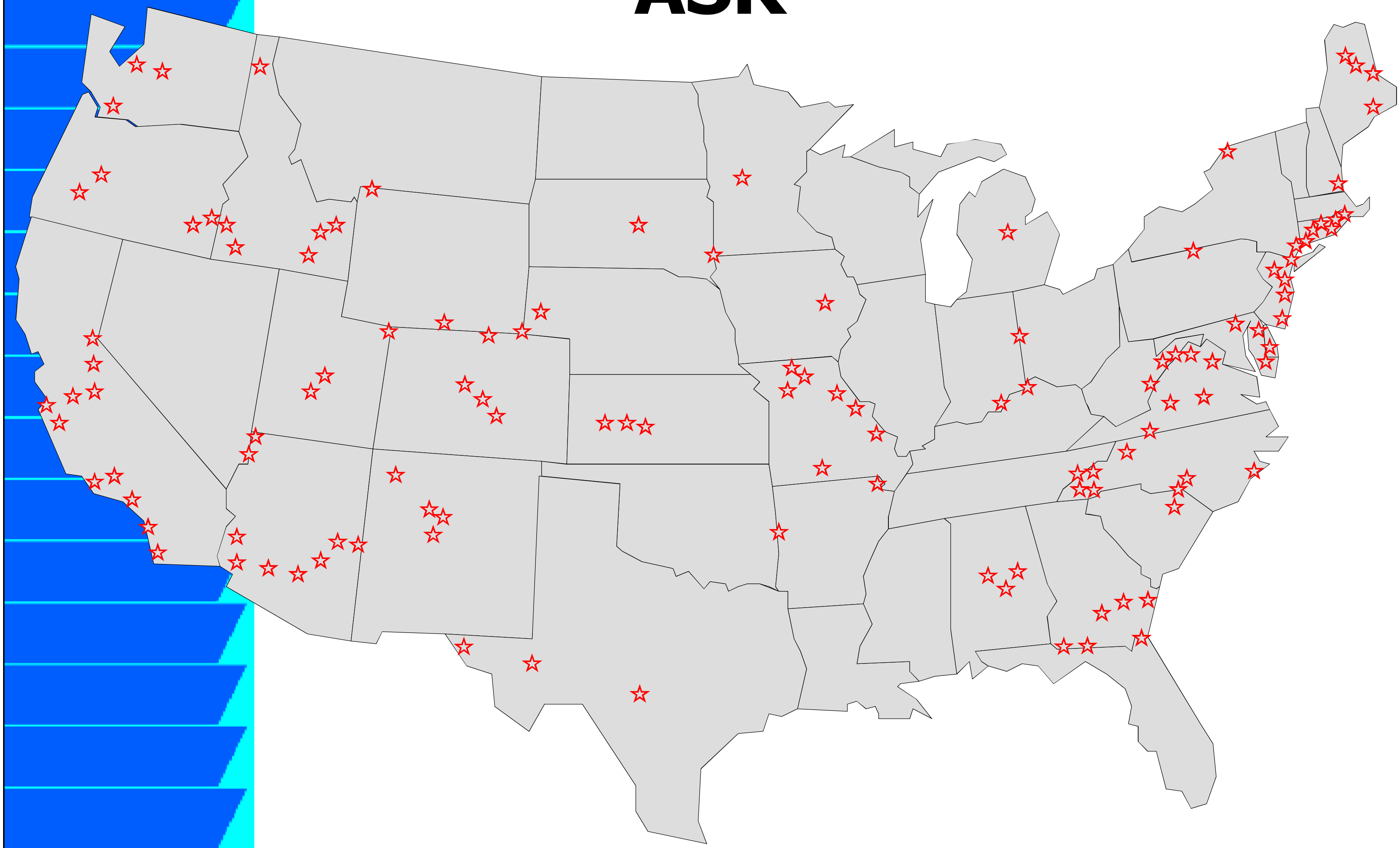
Influence of Aggregates

- **<u>DURABILITY</u>**
  Weathering
  Impurities

Harmful Materials

Substances	Effect on concrete	Test designation
Organic impurities	Affects setting and hardening, may cause deterioration	ASTM C40 ASTM C87
Materials finer than the 75-µm (No. 200) sieve	Affects bond, increases water requirement	ASTM C117
Coal, lignite, or other lightweight materials	Affects durability, may cause stains and popouts	ASTM C123
Soft particles	Affects durability	ASTM C235
Clay lumps and friable particles	Affects workability and durability, may cause popouts	ASTM C142
Chert of less than 2.40 relative density	Affects durability, may cause popouts	ASTM C123 ASTM C295
Alkali-reactive aggregates	Causes abnormal expansion, map cracking, and popouts	ASTM C227, C289, C295, C342, C586, C1260, C1293

ASR



FHWA Report, 2002

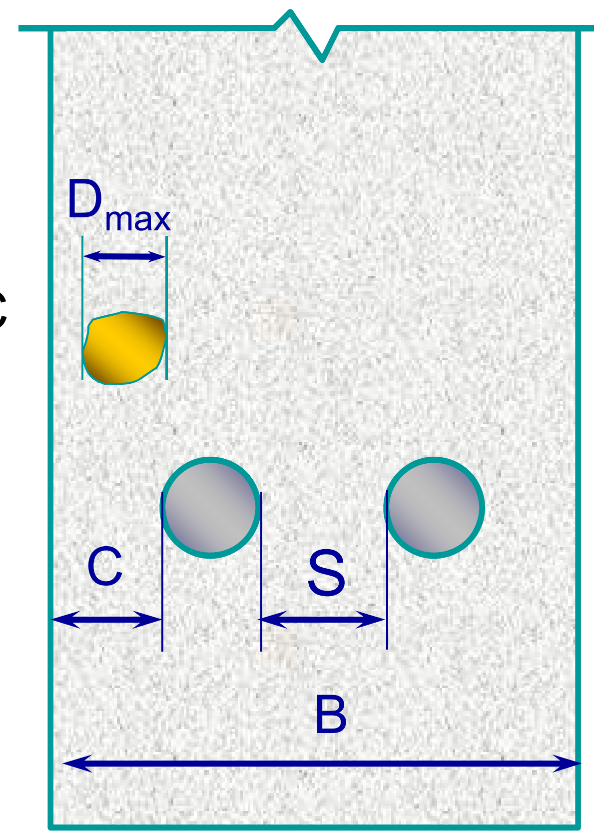
In general, coarse aggregate graded up to the largest size practical for the job conditions provides the most economical mix.

Maximum aggregate size, D_{max}, is governed by:

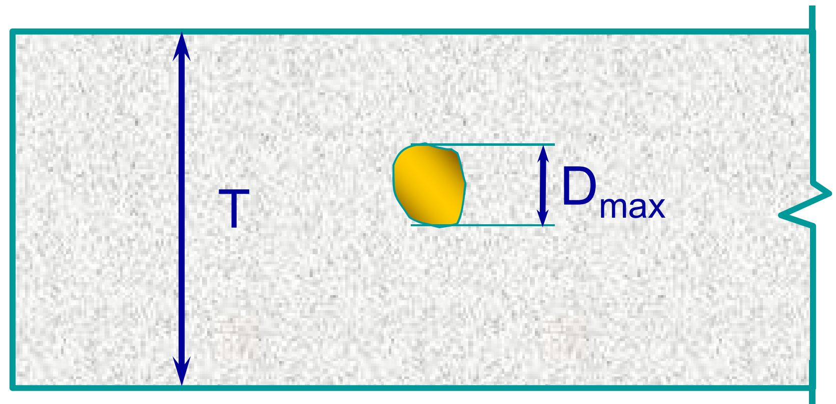
Cover between steel and forms, C: $D_{max} \leq ¾C$

Spacing between bars, S: $D_{max} \leq ¾S$

Distance between forms, B: $D_{max} \leq B/5$



In general, coarse aggregate graded up to the largest size practical for the job conditions provides the most economical mix.



Maximum aggregate size, D_{max}, is governed by:

Thickness of the slab, T: $D_{max} \leq T/3$

For pumped concrete:

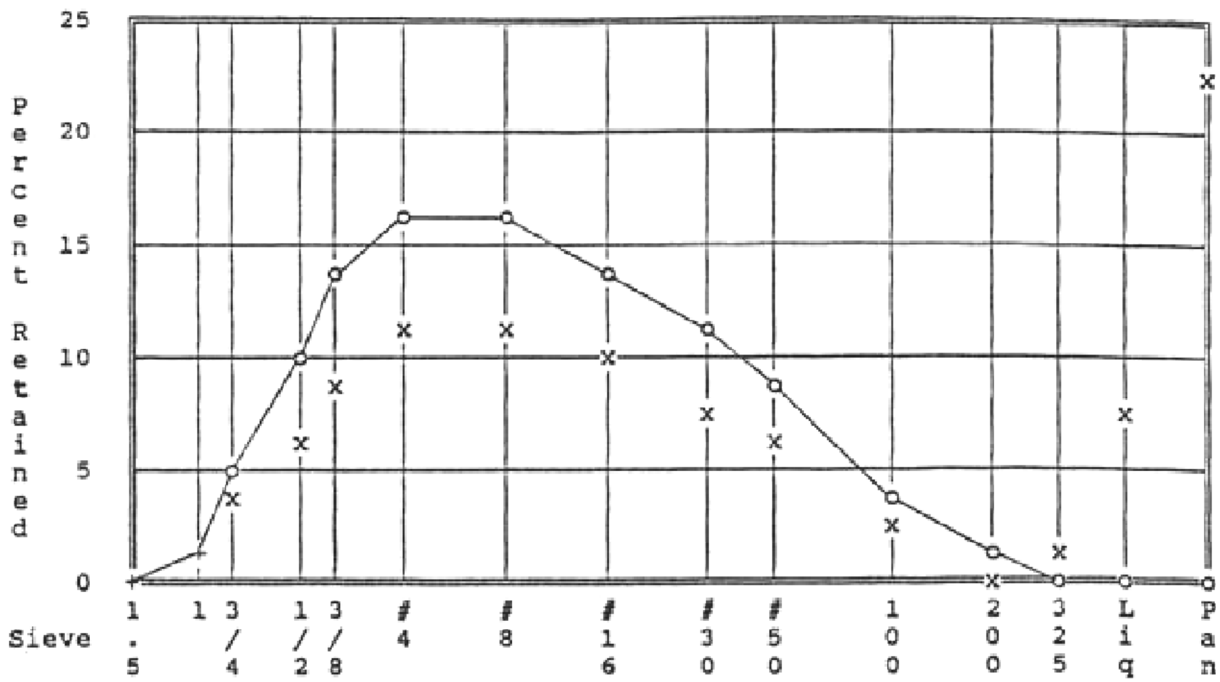
$D_{max} \leq$ 1/3 diameter of hose

or $\leq$ 40 mm (1½ in.)

whichever is smaller

Aggregate Optimization

- Combined fineness modulus
- 8 to 18% retained on each standard sieve
- Coarseness factor chart
- 0.45 power chart



Fineness Modulus of Sand

- The fineness modulus is calculated from the particle size distribution of the fine aggregate (sand).
- Values for sand suitable for concrete should range between 2.3 and 3.1
- Coarse sand has a higher fineness modulus than fine sand.
- The fineness modulus influences the bulk volume of coarse aggregate.

Calculating the fineness of modulus

Sieve size	% retained		
9.5 mm (3/8 in.)	0		
4.75 mm (No. 4)	2		
2.36 mm (No. 8)	13		
1.18 mm (No. 16)	20		
600 μm (No. 30)	20		
300 μm (No. 50)	24		
150 μm (No. 100)	18		
Pan	3		
Total	**100**		

Calculating the fineness of modulus

Sieve size	% retained	Cumulative % passing	
9.5 mm (3/8 in.)	0	100	
4.75 mm (No. 4)	2	98	
2.36 mm (No. 8)	13	85	
1.18 mm (No. 16)	20	65	
600 µm (No. 30)	20	45	
300 µm (No. 50)	24	21	
150 µm (No. 100)	18	3	
Pan	3	0	
Total	**100**		

Calculating the fineness of modulus

Sieve size	% retained	Cumulative % passing	Cumulative % retained
9.5 mm (3/8 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**

$$\textbf{Fineness modulus, FM} = \frac{283}{100} = 2.83$$

Bulk Volume of Coarse Aggregate

Max. Size 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 (3/8)	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 volume:

- Volume occupied by dry-rodded coarse aggregates
- Includes void space between the aggregate

Bulk volume = 0.67

Bulk volume occupied by the coarse aggregate is 0.67 yd^3

Bulk Volume of Coarse Aggregate

Max. Size 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
10 (3/8)	0.50	0.48	0.46	0.44
12.5 (½)	0.59	0.57	0.55	0.53
20 (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 Volume of Coarse Aggregate

The values in the tables are based on aggregates in a dry-rodded condition (ASTM C29).

They are suitable for producing concrete with a moderate workability suitable for general concrete construction

For less workable concrete (slipform paving) – the bulk volume may be increased by about 10%

For more workable concrete (pumped concrete) – the bulk volume may be reduced by up to 10%

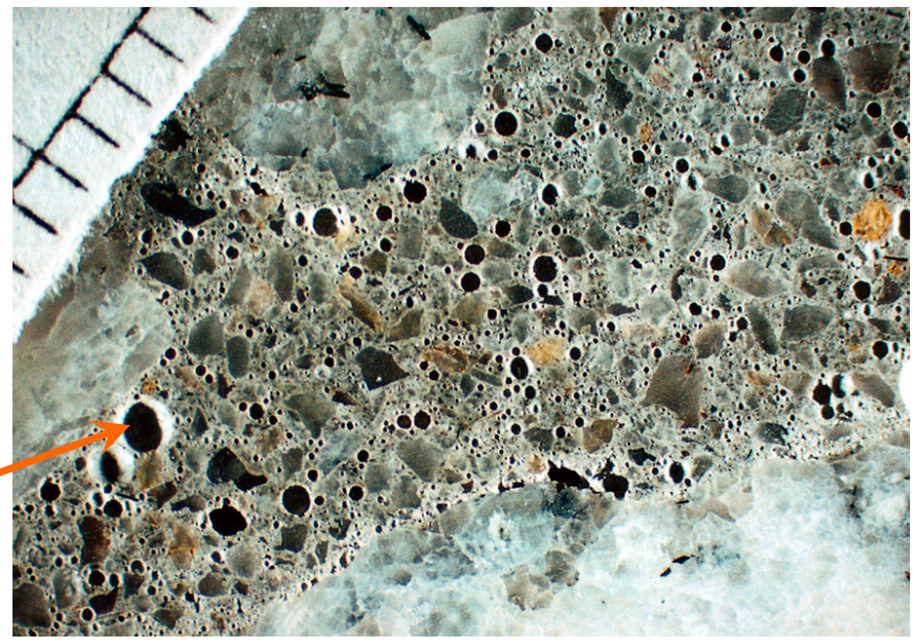
4. Air Content

Entrained air must be used in concrete that will be exposed to freezing and thawing and can be used to improve workability even when not required.

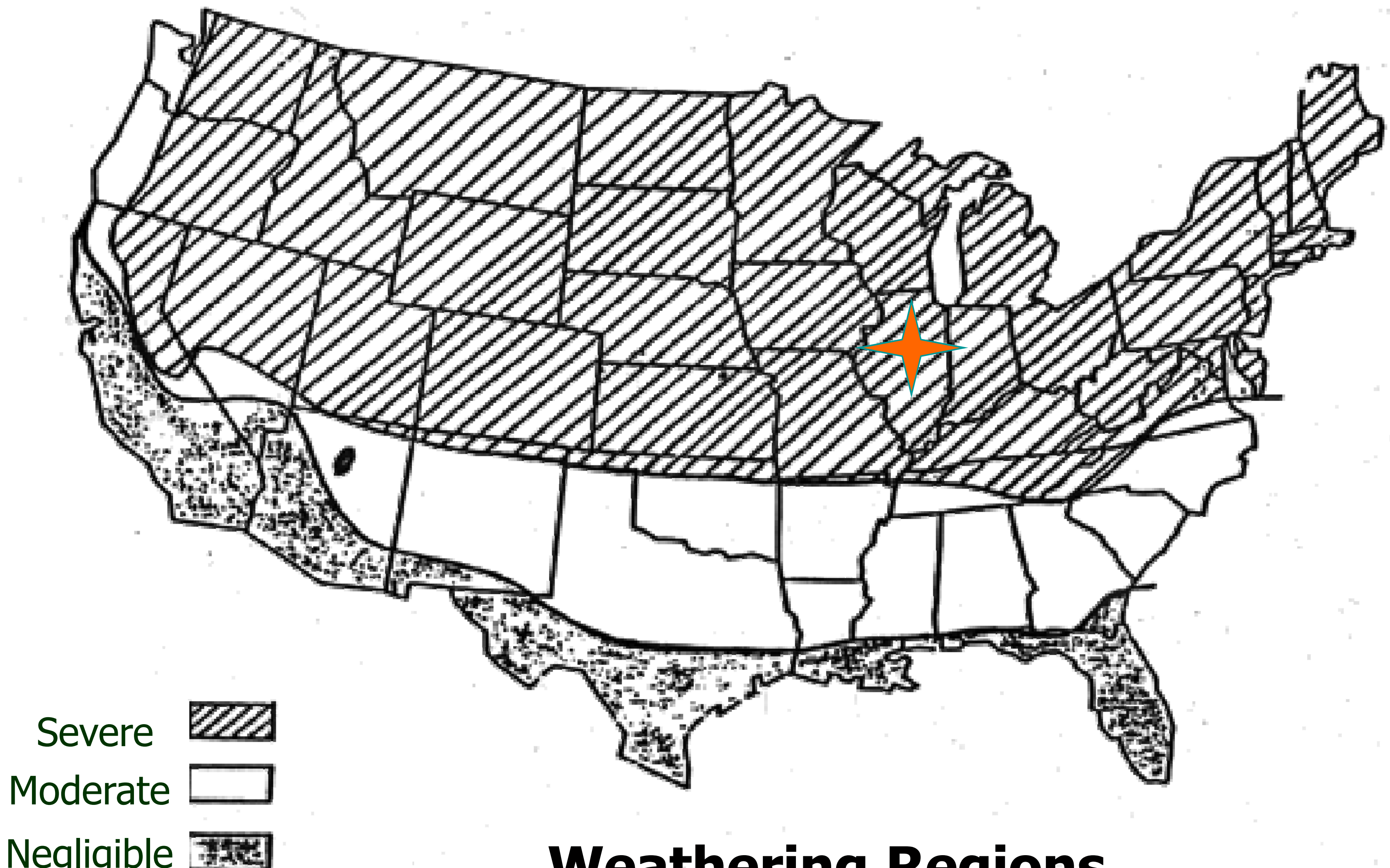
The amount of air required in concrete depends on:

- Max. aggregate size
- Level of exposure

Entrained Air



Air is entrained in the paste fraction of the concrete, and in properly proportioned mixes, the volume of the paste decreases as the max. aggregate size increases



Weathering Regions

4. Air Content

ACI 318-08 Durability Requirements:

Nominal maximum aggregate size, in.*	Air content, percent	
	Exposure Class F1	Exposure Classes F2 and F3
3/8	6	7.5
1/2	5.5	7
3/4	5	6
1	4.5	6
1-1/2	4.5	5.5
2†	4	5
3†	3.5	4.5

*See ASTM C33 for tolerance on oversize for various nominal maximum size designations.

†Air contents apply to total mixture. When testing concretes, however, aggregate particles larger than 1-1/2 in. are removed by sieving and air content is measured on the sieved fraction (tolerance on air content as delivered applies to this value). Air content of total mixture is computed from value measured on the sieved fraction passing the 1-1/2 in. sieve in accordance with ASTM C231.

4. Air Content

Typical (entrapped) air content percents % in non-air-entrained concrete

Nominal Maximum Aggregate Size							
10 mm 3/8 in.	12.5 mm 1/2 in.	20 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.
3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2

4. Air Content

Effect of air content on water demand

Rule of thumb: decrease water by 3 kg/m^3 (5 lb/yd^3) for each 1% air

5. Workability Requirements

Concrete must always be made with a **workability**, **consistency** and **plasticity** suitable for job placement conditions.

Slump is a measure of concrete consistency.

Slump should not be used to compare mixtures of totally different proportions.

5. Workability Requirements

When slump is not specified –

Caution using the workability table in ACI 211:

Concrete construction	Slump, mm (in.)	
	Maximum	Minimum
Reinforced foundation walls and footings	75 (3)	25 (1)
Plain footings, caissons, and substructure walls	75 (3)	25 (1)
Beams and reinforced walls	100 (4)	25 (1)
Building columns	100 (4)	25 (1)
Pavements and slabs	75 (3)	25 (1)
Mass concrete	75 (3)	25 (1)

6. Water Content

Water demand is influenced by:

- slump requirements
- aggregate size
- aggregate shape
- air content
- cementing materials content
- temperature
- admixtures
  (water-reducing & superplasticizing)

6. Water Content

Adjusting slump:

Slump increased by 10 mm by adding 2 kg/m^3 of water (increased by 1 in. by adding 10 lb/yd^3)

6. Water Content

Water requirements (lb/yd^3) for non-air-entrained concrete

Slump (in)	Nominal Maximum Aggregate Size						
	3/8 in.	1/2 in.	3/4 in.	1 in.	1-1/2 in.	2 in.	3 in.
1 to 2	350	335	315	300	275	260	220
3 to 4	385	365	340	325	300	285	245
6 to 7	410	385	360	340	315	300	270

Values shown are for angular aggregate (crushed stone). These estimates can be reduced by approximately 20 lb for sub-angular aggregate, 35 lb for gravel with some crushed particles, and 45 lb for rounded gravel.

6. Water Content

Water requirements (lb/yd^3) for air-entrained concrete

Slump (in)	Nominal Maximum Aggregate Size						
	3/8 in.	1/2 in.	3/4 in.	1 in.	1-1/2 in.	2 in.	3 in.
1 to 2	305	295	280	270	250	240	205
3 to 4	340	325	305	295	275	265	225
6 to 7	365	345	325	310	290	280	260

Values shown are for angular aggregate (crushed stone). These estimates can be reduced by approximately 20 lb for sub-angular aggregate, 35 lb for gravel with some crushed particles, and 45 lb for rounded gravel.

7. Cement Content

$$\textbf{Cement Material Content} = \frac{\text{Water Content}}{\text{W/CM}}$$

A minimum cement content may be specified for the purpose of:

- Durability
- Finishability
- Improved wear resistance
- Appearance

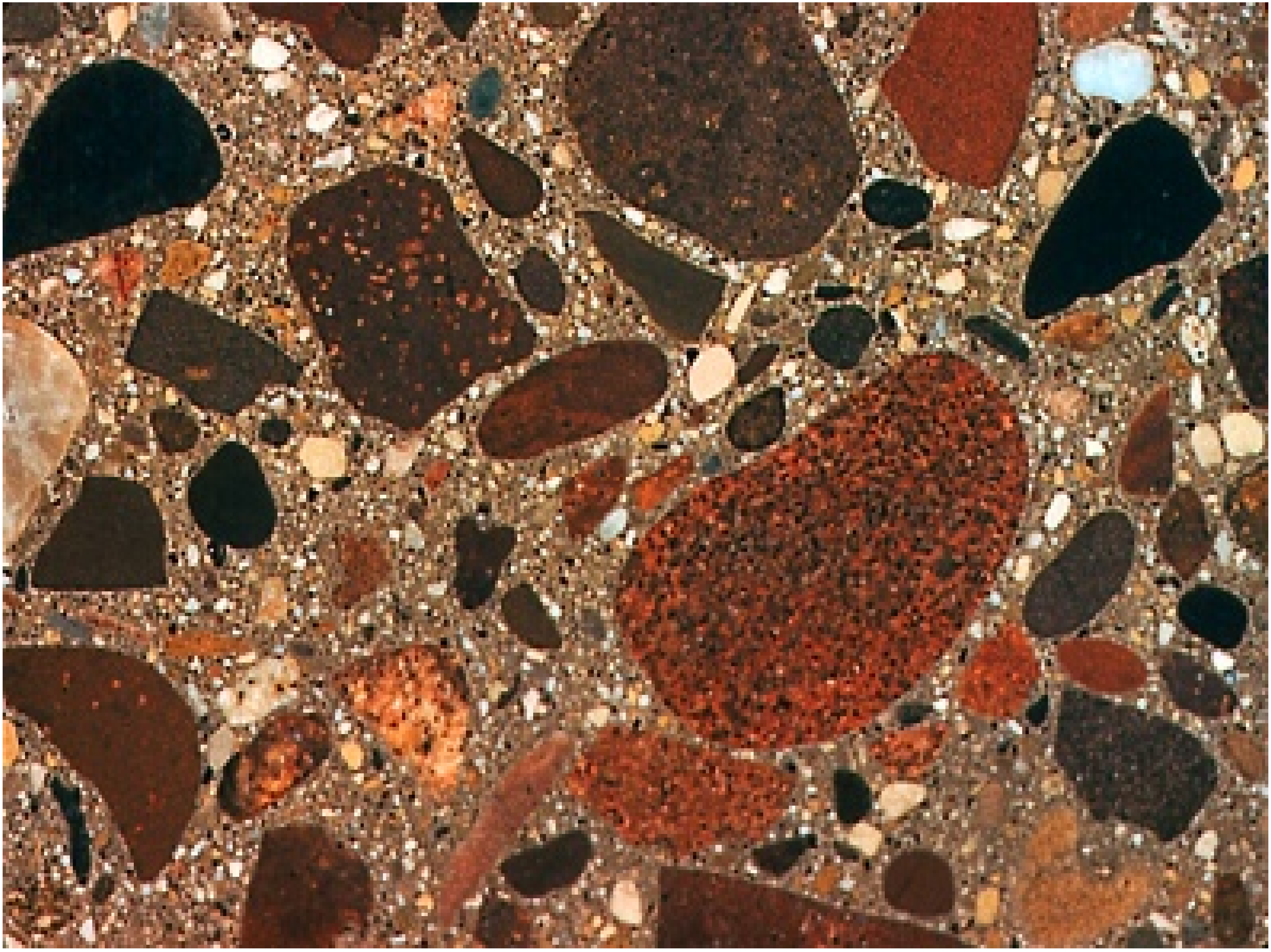
Cement Content

Cement Material Content = $\frac{\text{Water Content}}{\text{W/CM}}$

Excessively high cementitious material contents should be avoided for:

- economy
- avoid adverse effects
  - -workability
  - -shrinkage
  - -heat of hydration


Illinois
03-04
4C0068532
6 BAG MX
B
TRUCK
Land of Lincoln
BUMPER CAPACITY ONLY
VEHICLE CAPACITY
MAY DIFFER
SEE OWNER'S GUIDE



Cement Content

General recommendations:

- Cementitious material ≥ 335 kg/m^3 (564 lb/yd^3) for severe freeze-thaw, deicer, and sulfate exposures
- Cementitious material ≥ 390 kg/m^3 (650 lb/yd^3) for concrete to be placed under water (also W/CM ≤ 0.45)

flatwork follow recommendations in table:

Max. Aggregate, mm (in)	Min Cement, kg/m^3 (lb/yd^3)
37.5 (1½)	280 (470)
25 (1)	310 (520)
20 (¾)	320 (540)
12.5 (½)	350 (590)
10 (3/8)	360 (610)

8. Cement Type

- Type I
  - Normal
- Type II
  - Moderate Sulfate Resistance
- Type III
  - High Early Strength
- Type IV
  - Low Heat of Hydration
- Type V
  - High Sulfate Resistance

Specified by: ASTM C150,
AASHTO M 85

8. Cement Type

Requirements for Sulfate Exposure

Sulfate exposure*	Cement Type
S0- Negligible	No special type required
S1- Moderate	II, MS, IP(MS), IS(MS)
S2- Severe	V, HS
S3- Very Severe	V*, HS

*PCA Requirements

8. Cement Type

The use of pozzolans or slag or blended cements should be considered in conjunction with portland cement for the purposes of:

- Improving economy
- Improving workability
- Reducing heat of hydration
- Increasing long-term strength
- Improving durability
  - -Reduced permeability
  - -Resistance to chloride ingress & corrosion
  - -ASR resistance
  - -Sulfate resistance

Specified by ASTM C595 (AASHTO M 240) or ASTM C1157

Typical Amounts of SCM in Concrete by Mass of Cementing Materials

- Fly ash
  - Class C 15% to 40%
  - Class F 15% to 20%
- Slag 30% to 45%
- Silica fume 5% to 10%
- Calcined clay 15% to 35%
  - Metakaolin 10%
- Calcined shale 15% to 35%

8. Cement Type

The use of pozzolans or slag impacts the mix proportions in a number of ways, including:

- Changes in water demand
  - Fly ash reduces
  - Silica fume (and to a lesser effect metakaolin) increases
  - Slag has minimal effect
- Changes in volume of cementitious material component due to different specific gravities (Portland cement = 3.15):
  - Fly ash = 1.9 to 2.8
  - Silica fume = 2.25
  - Slag = 2.85 to 2.95
  - Metakaolin = 2.5
- Changes relationship between W/CM and strength

Limits on SCM Content

The ACI 318 Building Code also places limits on the maximum amount of supplementary cementing material (SCM) allowed in concrete exposed to deicing salts as follows:

- Slag ≤ 50%
- Fly ash ≤ 25%
- Silica fume ≤ 10%
- Total SCM in concrete with slag ≤ 50%
- Total SCM in concrete without slag ≤ 35%

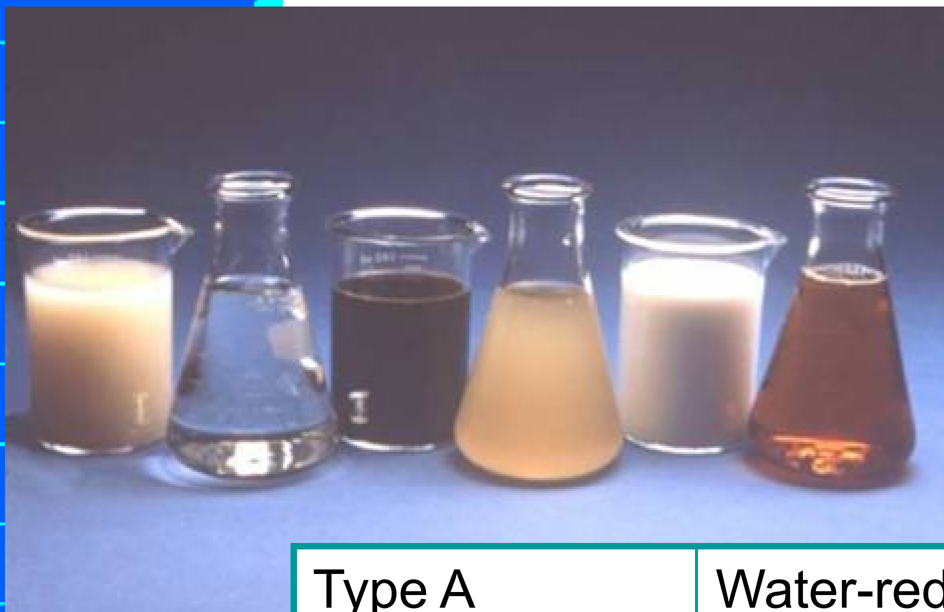
9. Admixture Effects

The use of admixtures may affect the water requirements and air content of concrete:

- Water reducers typically decrease water requirements by 5 to 10% and may increase air contents by up to 1%
- High-range water reducers decrease water contents between 12 to 30% and may increase air contents by up to 1%
- Calcium chloride-based admixtures reduce water requirements by about 3% and increase air by up to 0.5%
- Retarders may increase air contents

The use of fibers will also affect water demand

Chemical Admixtures



ASTM C494 (AASHTO M 194)

Classification

Water Reducing &

Set Control Admixtures

Type A	Water-reducer
Type B	Retarding
Type C	Accelerating
Type D	Water-reducing & retarding
Type E	Water-reducing & accelerating
Type F	Water-reducing, high range
Type G	Water-reducing, high-range & retarding

9. Admixture Effects

Chloride-containing admixtures should be used with caution in reinforced concrete because of the increased risk of corrosion of the embedded steel reinforcement.

ACI 318 Building Code limits the amount of chloride in reinforced and prestressed concrete.

	* Chloride (%)
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

* *Maximum water-soluble chloride ion expressed as a mass percentage of the cementitious material content*

10.Fine Aggregate Requirements

Mass proportions (kg/m^3 or lb/yd^3)

- Cement content
- Water content
- Coarse aggregate content

Air content (% volume)

} Already determined

Convert to volumetric proportions using the appropriate material density.

Calculate the volume of sand required to make up a unit volume (1 m^3 or 1 yd^3)

Convert volume of sand to mass quantity using appropriate density.

10.Fine Aggregate Requirements

	Mass per unit volume (lb/cy)	Density (lb/cy)	Volume (cy)
Cement	665		
Water	265		
Air			0.060
Coarse Aggregate	1833		
Fine Aggregate			
Total			

10.Fine Aggregate Requirements

	Mass per unit volume (lb/cy)	Density (lb/cy)	Volume (cy)
Cement	665	5307	
Water	265	1685	
Air			0.060
Coarse Aggregate	1833	4515	
Fine Aggregate		4448	
Total			

10.Fine Aggregate Requirements

	Mass per unit volume (lb/cy)	Density (lb/cy)	Volume (cy)
Cement	665	5307	0.125
Water	265	1685	
Air			0.060
Coarse Aggregate	1833	4515	
Fine Aggregate		4448	
Total			

Volume of cement = mass/density= 665/5307 = 0.125

10.Fine Aggregate Requirements

	Mass per unit volume (lb/cy)	Density (lb/cy)	Volume (cy)
Cement	665	5307	0.125
Water	265	1685	0.157
Air			0.060
Coarse Aggregate	1833	4515	0.406
Fine Aggregate		4448	
Total			1.000

10.Fine Aggregate Requirements

	Mass per unit volume (lb/cy)	Density (lb/cy)	Volume (cy)
Cement	665	5307	0.125
Water	265	1685	0.157
Air			0.060
Coarse Aggregate	1833	4515	0.406
Fine Aggregate		4448	0.252
Total			1.000

Volume sand =
$1.000 – (0.125 + 0.157 + 0.060 + 0.406) = 0.252\ yd^3$

10.Fine Aggregate Requirements

	Mass per unit volume (lb/cy)	Density (lb/cy)	Volume (cy)
Cement	665	5307	0.125
Water	265	1685	0.157
Air			0.060
Coarse Aggregate	1833	4515	0.406
Fine Aggregate	1121	4448	0.252
Total			1.000

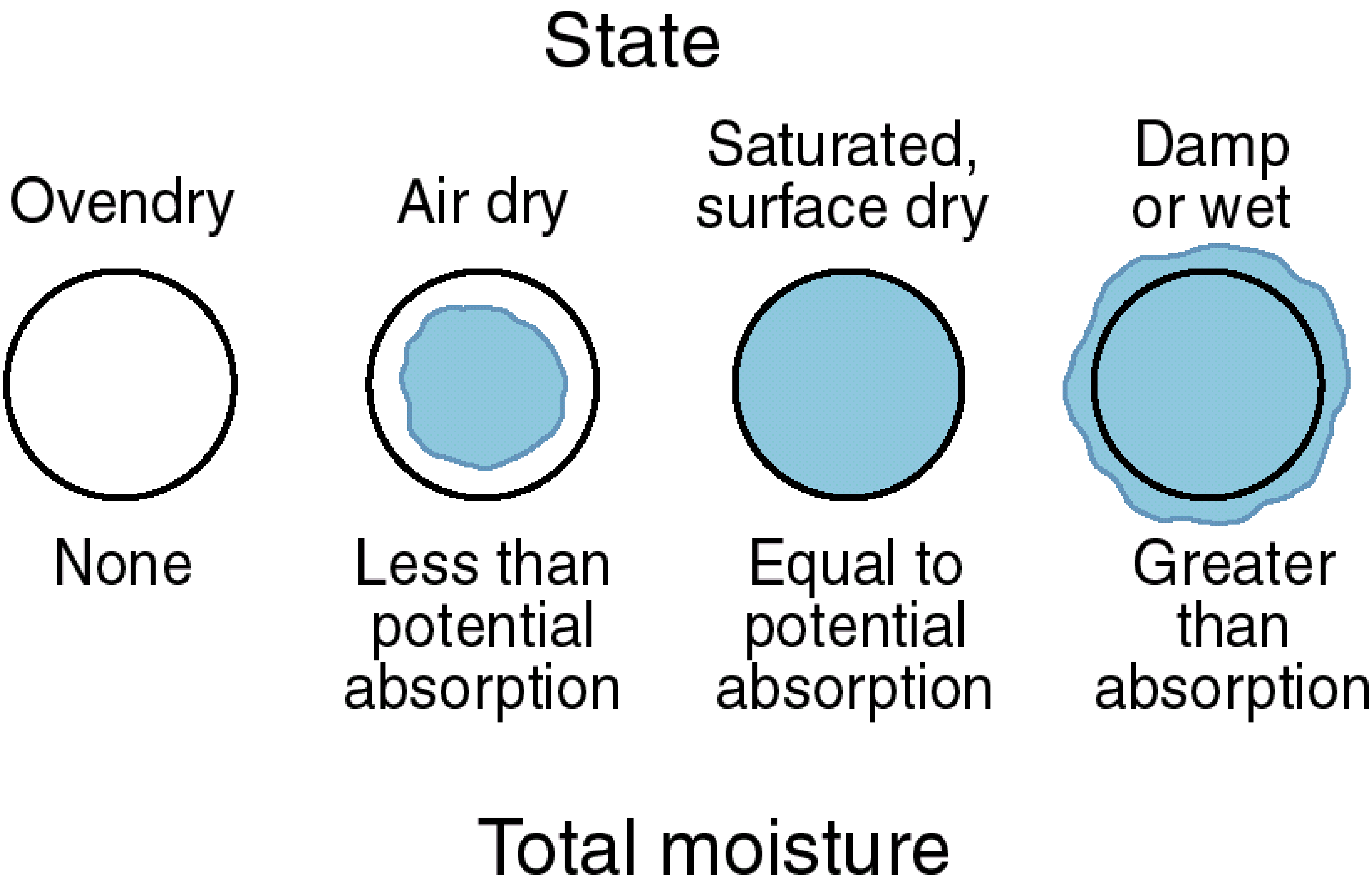
Mass of sand =
volume x density = 4448 x 0.252 = 1121 lb

10.Fine Aggregate Requirements

	Mass per unit volume (lb/cy)	Density (lb/cy)	Volume (cy)
Cement	665	5307	0.125
Water	265	1685	0.157
Air			0.060
Coarse Aggregate	1833	4515	0.406
Fine Aggregate	1121	4448	0.252
Total	3884		1.000

Concrete density =
665 + 265 + 1833 + 1121 = 3884 lb/yd^3

11. Moisture Corrections



11. Moisture Corrections

$$M_{batch} = M_{SSD} \times \frac{1+mc}{1+abs}$$

M_{batch}	=	Mass of aggregate to be batched
M_{SSD}	=	Mass required in mix design (in SSD)
mc	=	Moisture content of aggregate
abs	=	Aggregate absorption

11. Moisture Corrections

$$M_{batch} = M_{SSD} \times \frac{1+mc}{1+abs}$$

M_{batch}	=	Mass of aggregate to be batched
M_{SSD}	=	Mass required in mix design (in SSD)
mc	=	Moisture content of aggregate
abs	=	Aggregate absorption

Example:

A mix design requires 1050 lb/yd^3 of (SSD) sand. The sand has an absorption value of 1.5% and a current moisture content of 2.9%. The quantity required for batching is:

$$M_{batch} = 1050 \times \frac{1+0.029}{1+0.015} = 1064.5\ lb/yd^3$$

11. Moisture Corrections

$$W_{corr} = M_{SSD} \times \frac{(abs - mc)}{1 + abs}$$

W_{corr} = Correction to water content

11. Moisture Corrections

$$W_{corr} = M_{SSD} \times \frac{(abs - mc)}{1 + abs}$$

W_{corr} = Correction to water content

Example:

A mix design requires 650 kg/m^3 of (SSD) sand. The sand has an absorption value of 1.5% and a current moisture content of 2.9%. The quantity required for batching is:

$$M_{batch} = 1050 \times \frac{1 + 0.029}{1 + 0.015} = 1064.5\, lb/yd^3$$

$$W_{corr} = 1050 \times \frac{(0.015 - 0.029)}{1.015} = -14.5\, lb/yd^3$$

12. Trial Batches

Trial batches are performed to determine whether the slump, air content and strength are as required. If not, modifications to the mix design are made and further trials are performed until the properties of the concrete are satisfactory.

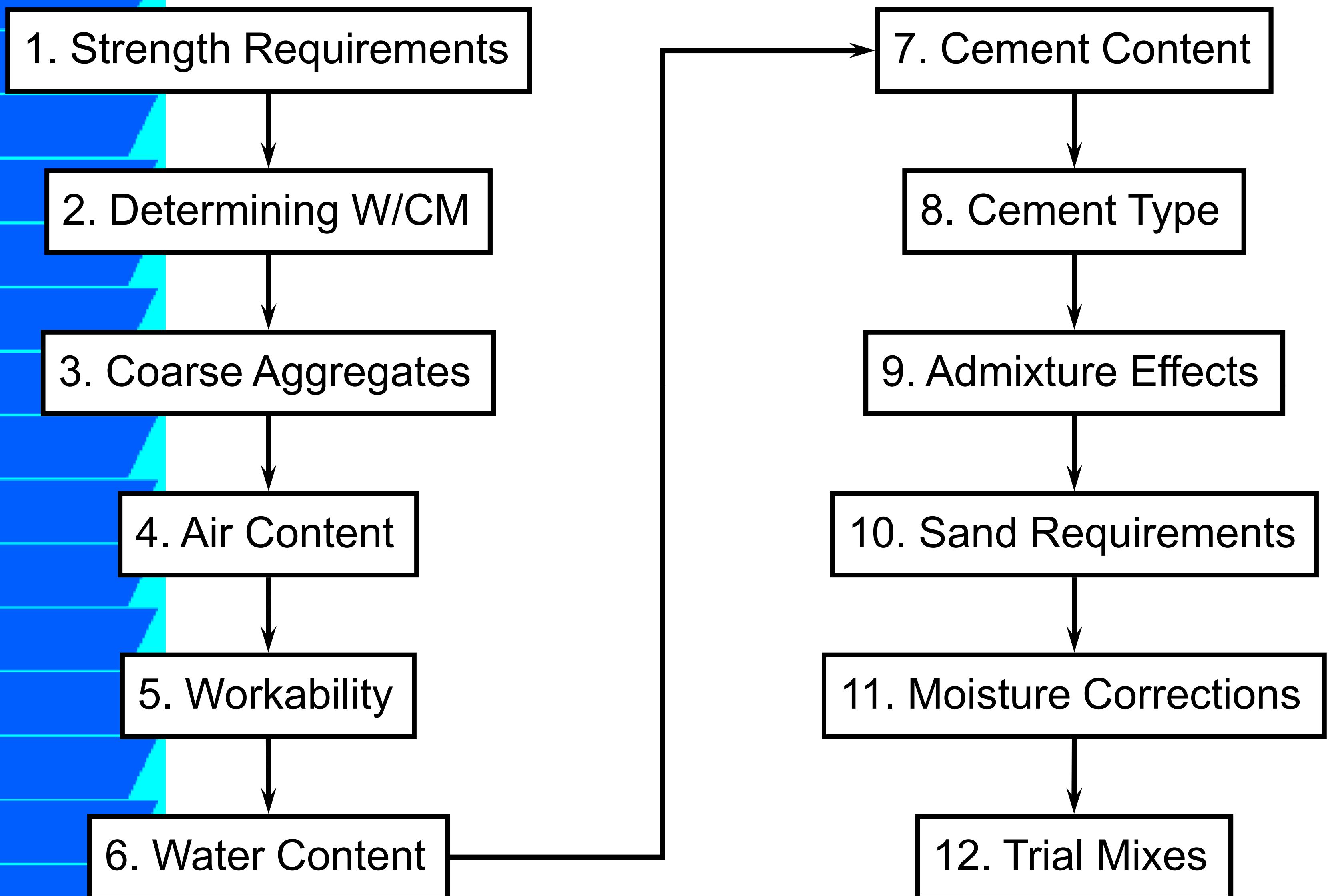
12. Trial Batches

Trial batches are performed to determine whether the slump, air content and strength are as required. If not, modifications to the mix design are made and further trials are performed until the properties of the concrete are satisfactory.

In addition to these tests, some qualitative assessment of the mix may be carried out to determine if it has the desired characteristics

Concrete Mix Design

Summary of Absolute Volume Method ACI 211.1



?