Advanced Mix Design

www.concrete-pipe.org

American **Concrete Pipe** Association

Definitions

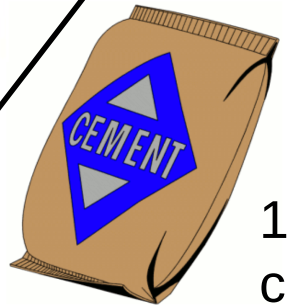
- Water / Cement(itious) Ratio (w/c)
- Specific Gravity (SG)
- Aggregate Moisture

Water / Cement(itious) Ratio

- It’s a calculation:
  - w/c ~ lbs. of water / lbs. of cement
  - w/c_m ~ lbs. of water / lbs. of cementitious

Often when w/c is discussed its really w/c_m that is intended as the reference

45 lbs of
water



100 lbs of
cement

= Water cement ratio

0.45 expressed as decimal

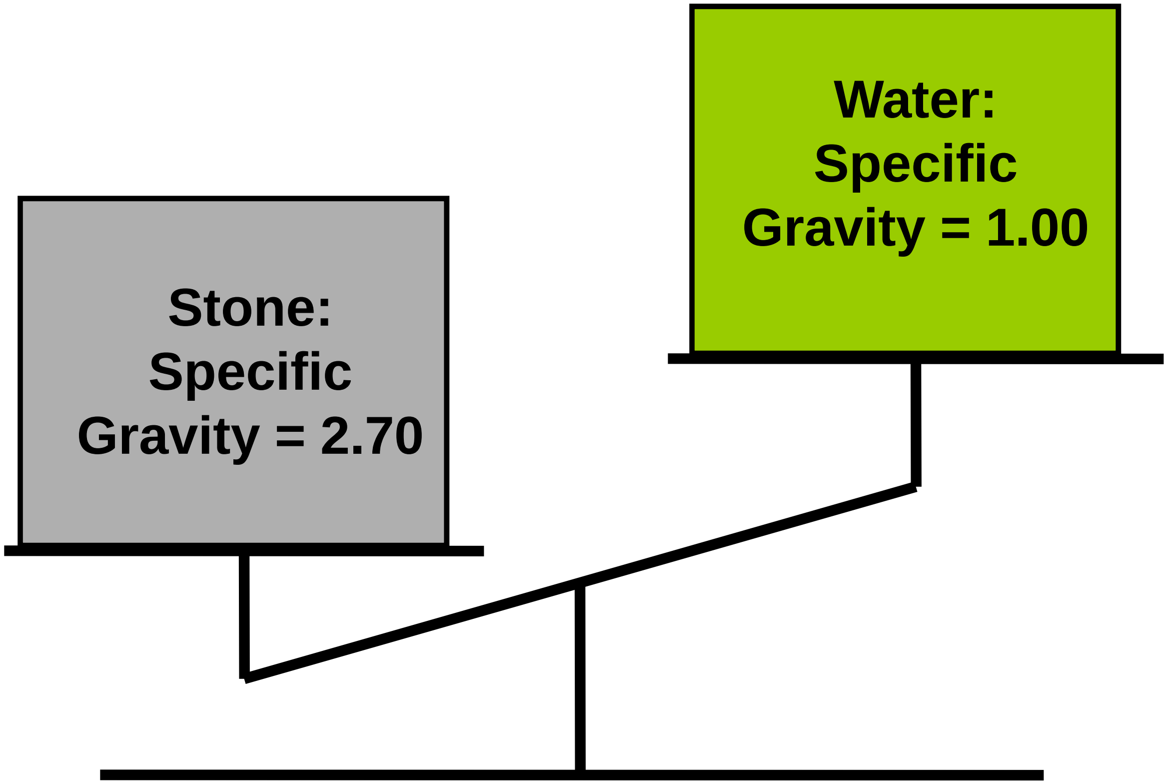
Water needs to be drinkable or meet ASTM 1602

Specific Gravity

What is Specific Gravity?

- Specific Gravity
  - The relative density of a material compared to water
  - The ratio of a material's weight to the weight of an equal volume of water
- Bulk specific gravity (SSD):
  - Used to determine the "solid volume" (absolute volume) of a material going into concrete
  - It is determined by submerging the material in water for 24 hours in order to fill any permeable voids

Specific Gravity



Stone: Specific Gravity = 2.70

Water: Specific Gravity = 1.00

Same Volume, but 2.70 Times More Mass

Cement – 3.15
Steel – 7.85

Aggregate Moisture

Bone Dry or Oven Dry

Air Dry

Saturated and Surface Dry

Moist

Absorbed moisture (absorption) — **Add Water**

SSD (ideal)

Free moisture (moisture content) — **Subtract Water**

Review of Raw Materials

- Portland Cement
- Fly Ash
- Slag Cement
- Water
- Aggregates

Portland Cement

Why is it called "Portland Cement"?

Named after Portland Stone found on the Isle of Portland, in Dorset, England

Portland Stone

Portland Cement

Cement Compounds

- Tricalcium Silicate – C_3S
  - Lots of Heat Production and Early Age Strength
  - Controls Initial and Final Setting
- Dicalcium Silicate – C_2S
  - Later Age Strength and Less Heat Production
- Tricalci
  - Lots o
  - Contr
  - Contr
- Tetraca
  - Some ittle Strength
  - Resp

Cement Compounds

- Tricalcium Silicate – C_3S
  - Lots of Heat Production and Early Age Strength
  - Controls Initial and Final Setting
- Dicalcium Silicate – C_2S
  - Later Age Strength and Less Heat Production
- Tricalcium Aluminate – C_3A
  - Lots of Heat Production
  - Contributes to very early Age Strength
  - Controls Sulfate Attack Resistance
- Tetracalcium Aluminoferrite – C_4AF
  - Some Heat Generation but Contributes Little Strength
  - Responsible for Grey Color

Type of portland cement	Potential Compound Composition,%				Blaine fineness m^2/kg
	C_3S	C_2S	C_3A	C_4AF	
I	54	18	10	8	369
II	55	19	6(max8)	11	377
III	55	17	9(max15)	8	548
IV	42	32	4	15	340
V	54	22	4(max5)	13	373
White	63	18	10	1	482

NO LONGER AVAILABLE

CHEMICAL REQUIREMENTS (ASTM C-114)	Spec. Limit (ASTM C-150)	TYPE I Low Alkali	TYPE II Low Alkali	TEST RESULTS
Silicon Dioxide (SiO2), %	Min	---	---	**20.6**
Aluminum Oxide (Al2O3), %	Max	---	6.0	**4.6**
Ferric Oxide (Fe2O3), %	Max	---	6.0	**3.5**
Calcium Oxide (CaO), %	---	---	---	**64.5**
Magnesium Oxide (MgO), %	Max	6.0	6.0	**1.3**
Sulfur Trioxide (SO3), % *	Max	3.0	3.0	**2.8**
Loss on Ignition (LOI), %	Max	3.0	3.0	**1.7**
Insoluble Residue (IR), %	Max	0.75	0.75	**0.20**
Free Lime, %	---	---	---	**1.8**
Alkalies (Na2O equivalent), %	Max	0.60	0.60	**0.53**
Na2O Equ. @ 95% Confidence Level	---	---	---	**0.53 +/-0.02**
CO2 in Cement, %	---	---	---	**0.0**
Limestone in Cement, %	Max	5.0	5.0	**0.0**
CaCO3 in Limestone, %	Min	70	70	**95**
Inorganic Processing Addition, % **	Max	5.0	5.0	**0.5**
PONTENTIAL PHASE COMPOSITION ***				
Tricalcium Silicate (C3S), %	Max	---	---	**60**
Tricalcium Aluminate (C3A), %	Max	---	8	**6**
Heat Index, C3S + (4.75 C3A)	Max	100	100	**90**
PHYSICAL REQUIREMENTS				
(ASTM C-204) Blaine Fineness, m2/kg	Min	280	280	**382**
(ASTM C-191) *Time of Setting (Vicat)*				
Initial Set, mins	Min	45	45	**110**
Final Set, mins	Max	375	375	**205**
(ASTM C-266) *Time of Setting (Gillmore)*				
Initial Set, mins	Min	60	60	**150**
Final Set, mins	Max	600	600	**230**
(ASTM C-185) Air Content, %	Max	12	12	**8**
(ASTM C-151) Autoclave Expansion, %	Max	0.80	0.80	**0.03**
(ASTM C-109) *Compressive Strength*				
1-Day, psi	---	---	---	**2590**
3-Day, psi	Min	1740	1450	**3950**
7-Day, psi	Min	2760	2470	**4880**
(Previous) 28-Day, psi	---	---	---	**5960**
(ASTM C-186) Heat of Hydration (7-Day), cal/g	*Test result is provided for information only*			**79**

STANDARD CHEMICAL REQUIREMENTS	SPECIFICATIONS ASTM	II	TEST RESULTS
Silicon Dioxide (SiO2) - Percent			20.3
Aluminum Oxide (Al2O3) - Percent	**Maximum >**	**6.0**	4.7
Ferric Oxide (Fe2O3) - Percent	**Maximum >**	**6.0**	3.6
Calcium Oxide (CaO) - Percent		*	64.4
Magnesium Oxide (MgO) - Percent	**Maximum >**	**6.0**	1.98
Sulfur Trioxide (SO3)- Percent	**Maximum >**	**3.0**	2.77
Loss on Ignition - Percent	**Maximum >**	**3.0**	2.35
Insoluble Residue - Percent	**Maximum >**	**0.75**	0.36
Carbon dioxide (CO2) - Percent			1.57
Limestone content --Percent	**Maximum >**	**5.0**	3.78
Corrected Limestone -Percent	**Maximum >**	**5.0**	3.01
CaCO3 in Limestone - Percent	**Minimum >**	**70.0**	94.0
Tricalcium Silicate (C3S) - Percent		*	55
Dicalcium Silicate (C2S) - Percent		*	17
Tricalcium Aluminate (C3A) - Percent	**Maximum >**	**8.0**	6.3
Tetracalcium Aluminoferrite (C4AF) - Percent		*	11
C4AF + 2 (C3A) or C4AF + C2F - Percent		*	24
Alkalies (Sodium Oxide Equivalent) - Percent *	**Maximum >**	**0.60**	0.57
STANDARD PHYSICAL REQUIREMENTS			
Specific Surface , Blaine ,m2/kg	**Minimum >**	**280**	345
- 325 Mesh - Percent		*	93.5
Compressive Strengths,psi (MPa)(C 109 cubes)			
psi (MPa)		**psi (Mpa)**	
1 DAY		*	1810 (12.5)
3 DAYS	**Minimum >**	**1500 (10.0)**	3415 (23.5)
7 DAYS	**Minimum >**	**2500 (17.0)**	4370 (30.1)
28 DAYS	**Minimum >**	*	)
Time of Setting (Vicat)			
Initial ,minutes	**Minimum >**	**45**	150
Final ,minutes	**Maximum >**	**375**	280
False Set - Percent *	**Minimum >**	**50**	89
Air Content of Mortar - Percent	**Maximum >**	**12**	7.2
Autoclave Expansion - Percent	**Maximum >**	**0.80**	0.03
Mortar Bar Expansion (ASTM C -1038) Only for T-V - Percent	**Maximum >**		

Cement comparison

	Cement 1	Cement 2
C3S	60	55
Blaine	382	345
Initial Vicat	110	150
Final Vicat	205	280

Cement Reaction

Primary cement reaction (fast):

C_3S (and C_2S) + **water** = **C-S-H gel**

Byproduct from hydration = **Calcium Hydroxide**

Pozzolanic reaction (slow):

Fly Ash + Calcium Hydroxide = **C-S-H gel**

Fly Ash

- Byproduct from the burning of coal used in power plants
- Class F
  - Produced from burning anthracite or bituminous coal
  - Older coal, eastern & west coast
  - Pozzolanic (no cementing properties, reacts to cement hydration byproducts only)
- Class C
  - Produced from burning subbituminous coal
  - Younger coal, western
  - Cementing and pozzolanic properties

Fly Ash

- Classes are usually grouped by
  - Sum of Silica, Alumina, and Iron oxides
    - > 50% - Class C Fly Ash
    - > 70% - Class F Fly Ash
  - Calcium Content (CaO)
    - < 20% typically Class F Fly Ash
    - > 20% typically Class C Fly Ash

Fly Ash

Advantages

- Improve workability
- Lower mix cost
- Reduce Heat
- Lower permeability
- Improve Durability
- Mitigates ASR and DEF (Class F only)

Disadvantages

- Low Early-Age Strength
- Increase set time
- Effect Air entrainment (Class F)

Slag Cement

•Byproduct from the iron manufacturing process

- **ASTM C 989** *Standard Specification for Slag Cement for Use in Concrete and Mortars* (classified by Strength Activity Index compared to a **reference** Portland Cement)
  - Grade 80 (SAI @ 28days = 75%)
  - Grade 100 (SAI @ 7days = 75% & 28days = 95%)
  - Grade 120 (SAI @ 7days = 95% & 28days = 115%)

Slag Cement is a hydraulic cement

Ground Granulated Blast-Furnace Slag

Ball Mill

Slag Cement

Slag - Features and Benefits

- Benefits for Hardened Concrete
  - Later age strength
  - Increased flexural strength
  - Lighter, brighter color (substitute for white cement)
  - Increased ability to reflect solar heat
  - Reduced permeability and increased durability
  - Increased resistance to alkali silica reaction
    - 25% to 70%
  - Increased sulfate resistance (low alumina slag)
    - 40% to 70%

Slag - Cautions

- As cement replacement rates increase, freeze/thaw durability can be reduced (on flat work)
- Sensitive to cold weather, below 40 deg F (set time and early strength)
- As levels of unoxidized sulfide sulfur increase, a temporary greening of the hardened concrete may occur

Water

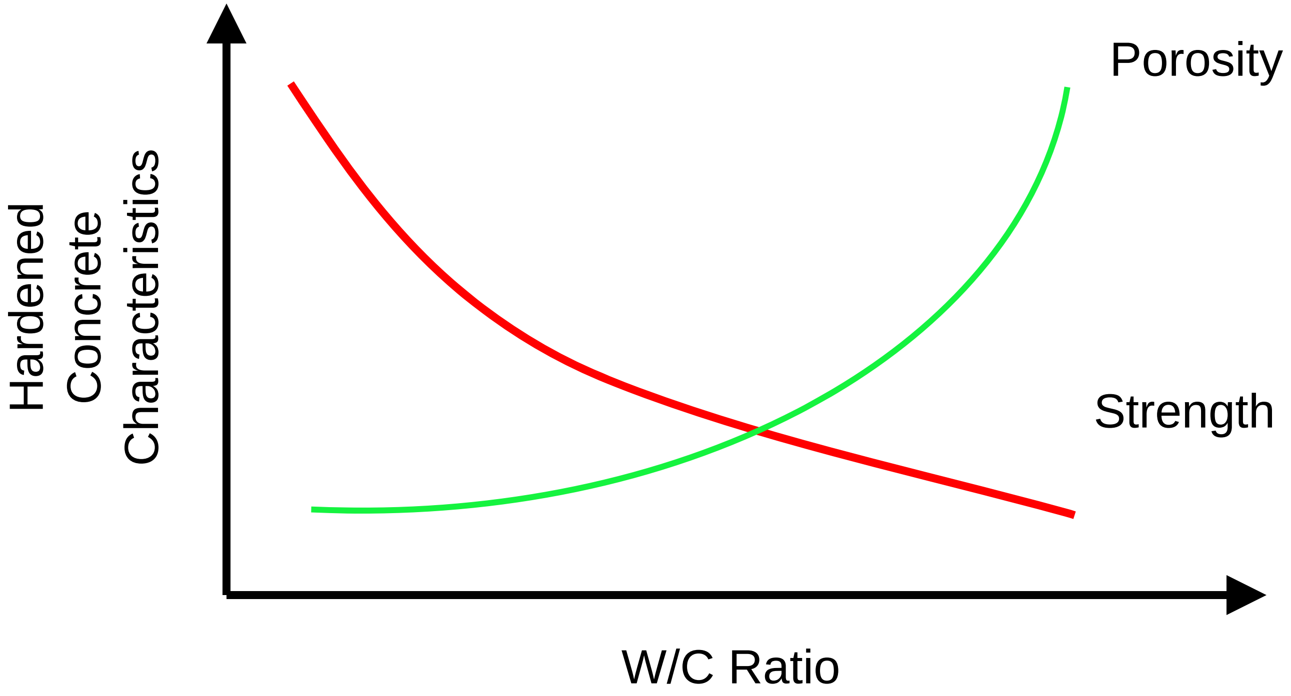
- Use potable water for concrete
- Non-potable water contains deleterious substances
  - Oils
  - Acids
  - Alkalis
  - Salts
- These items have negative effects on concrete strength

How Much Water?

- Hydration water
  - About 0.24 lb of water to hydrate 1 lb of cement
  - This water takes part in the hydration reactions
- Water of Convenience
  - Water for mixing, placing and finishing
  - This water dictates the pore structure of the cement paste

W/C Ratio

$$W/C = \frac{\text{Weight of Water}}{\text{Weight of Cementitious Material}}$$



W/C Ratio

- Water/Cement ratio impacts concrete strength and durability
- Low w/c ratio = strong & durable concrete
- Arbitrarily adding water to the mix will have a negative effect on strength and durability

Water

Adding 1 gal of water / yd^3 of concrete

- Increases slump 1”
- Decreases compressive strength by 5%
- Wastes the effect of 24 lbs/yd^3 of cement
- Increases shrinkage by 10%
- Increases permeability by up to 50%
- Decreases freeze-thaw durability by 20%
- Decreases resistance to deicing salts and lowers quality in many other ways

Aggregates

- Fine
  - Consists of natural sand, manufactured sand or crushed stone
  - <3/8”
  - Fine aggregate will pass the # 4 sieve
- Coarse
  - Natural or crushed stone
  - 3/8” to 1 ½” (or more)
  - Coarse aggregate is larger than the #4 sieve

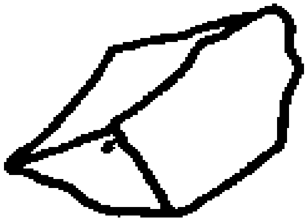
Particle Shape

- Impacts friction within mixture
- Impacts voids content
- Influences water demand
- Influences paste / aggregate bond
- Impacts strength

Particle Shape

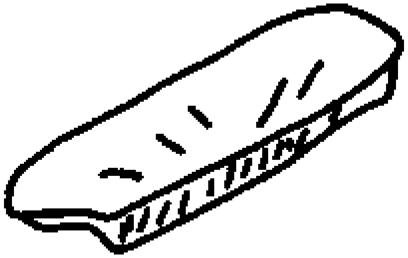
(a) Rounded

(d) Flaky



(c) Angular

(e) Elongate



(f) Elongate and Flaky

Particle Shape

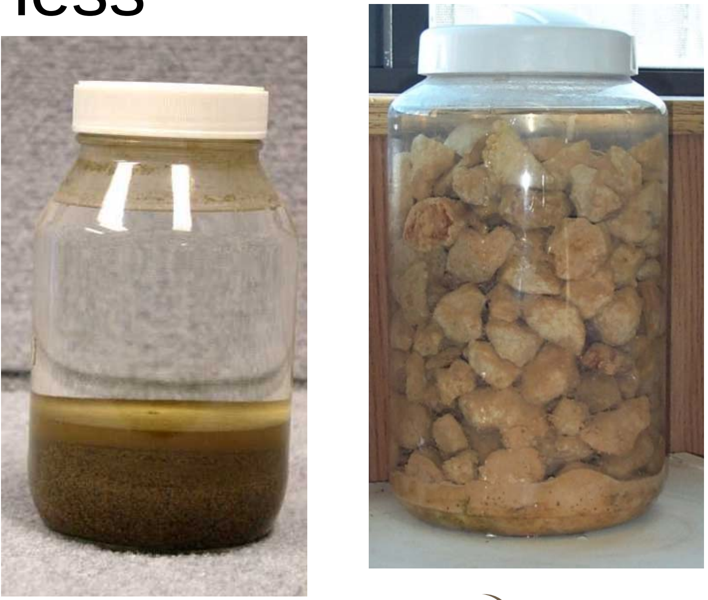
- Rounded particles
  - Decrease friction (improve workability)
  - Decrease water demand
  - Enhance finishing
- Angular/Crushed particles
  - Increase water demand, improve strength due to paste aggregate bond
  - Higher stability
  - Resistance to volumetric changes under loads

Particle Shape

- Flat and/or elongated particles can
  - Reduce workability
  - Interfere with consolidation
  - Reduce mass stability due to lower strength
  - Recommended limit 15% (3:1 ratio)

Cleanliness

- Clay or other very fine materials (-200 mesh)
  - Limit is 3% in fine aggregate and 1% in coarse aggregate
  - Can negatively affect strength & admixture effectiveness



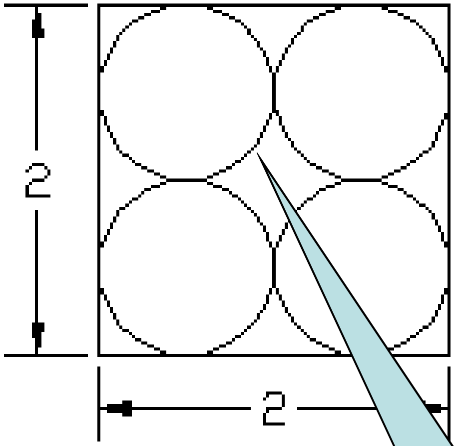
Cleanliness

- Organic matter such as loam, silt, bark, leaves, etc.
    - Can negatively affect strength & admixture effectiveness
- Soft friable particles
    - Limit is 3% in fine aggregate or 1% in coarse aggregate
    - Can cause pop-outs or staining in finished units

Voids

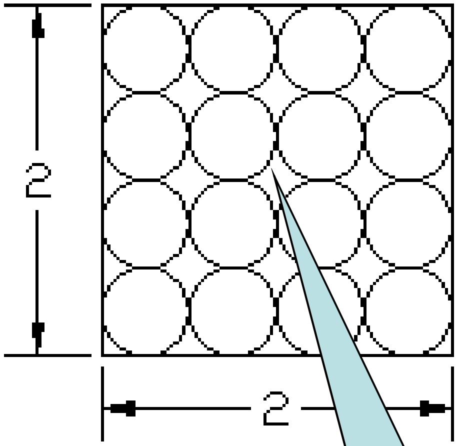
Which one has the greatest void content?

1- inch diameter
Spherical aggregate



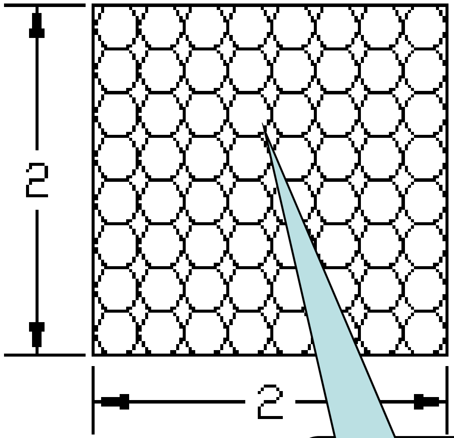
0.858

½ - inch diameter
Spherical aggregate



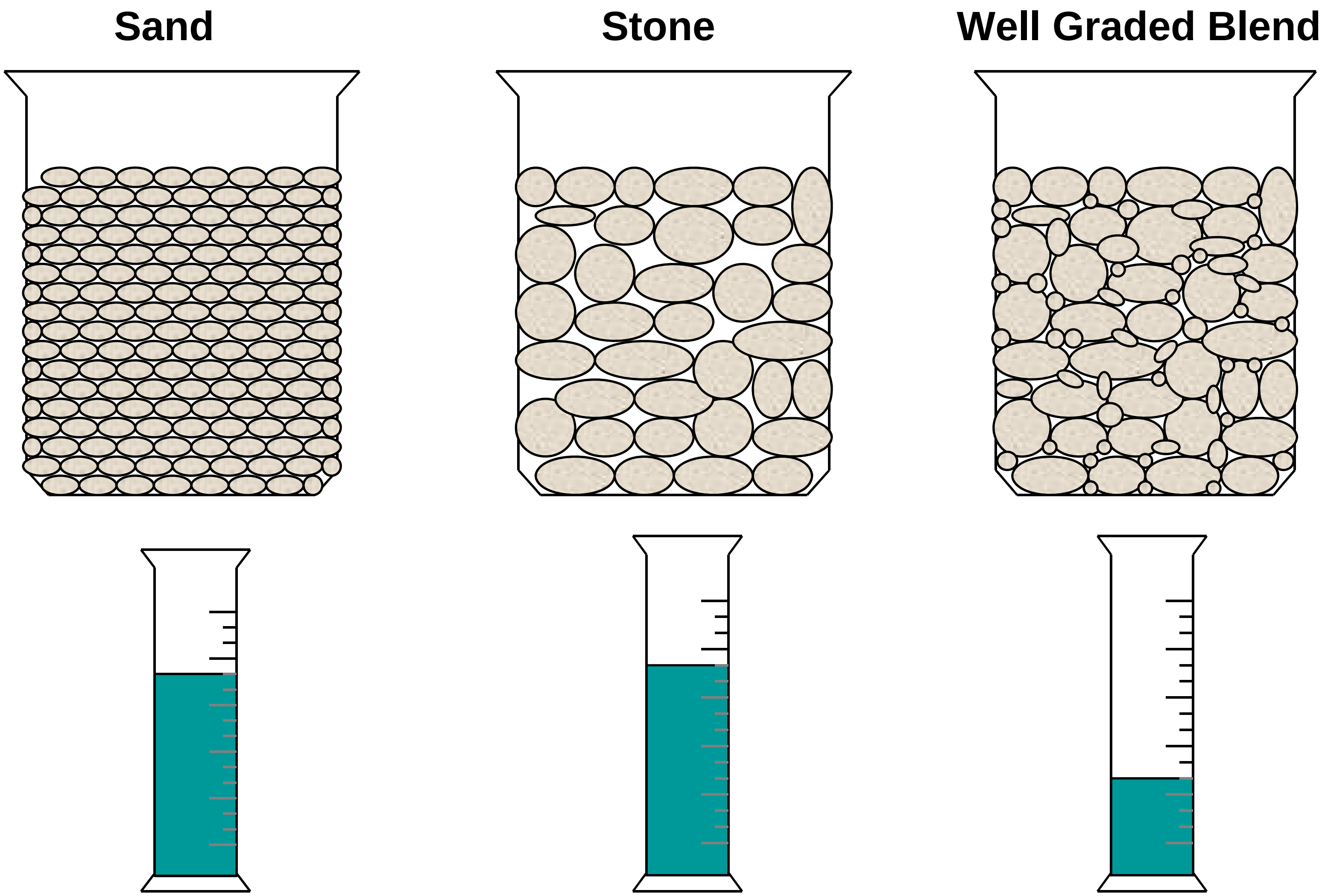
0.858

¼ - inch diameter
Spherical aggregate



0.858

Voids



Sand

Stone

Well Graded Blend

Voids

- Reduce core compressive and tensile strength
- Lower D-load results
- Increased Absorption
- Lower durability
- Higher permeability
- Increased paste requirements
- Increase cost

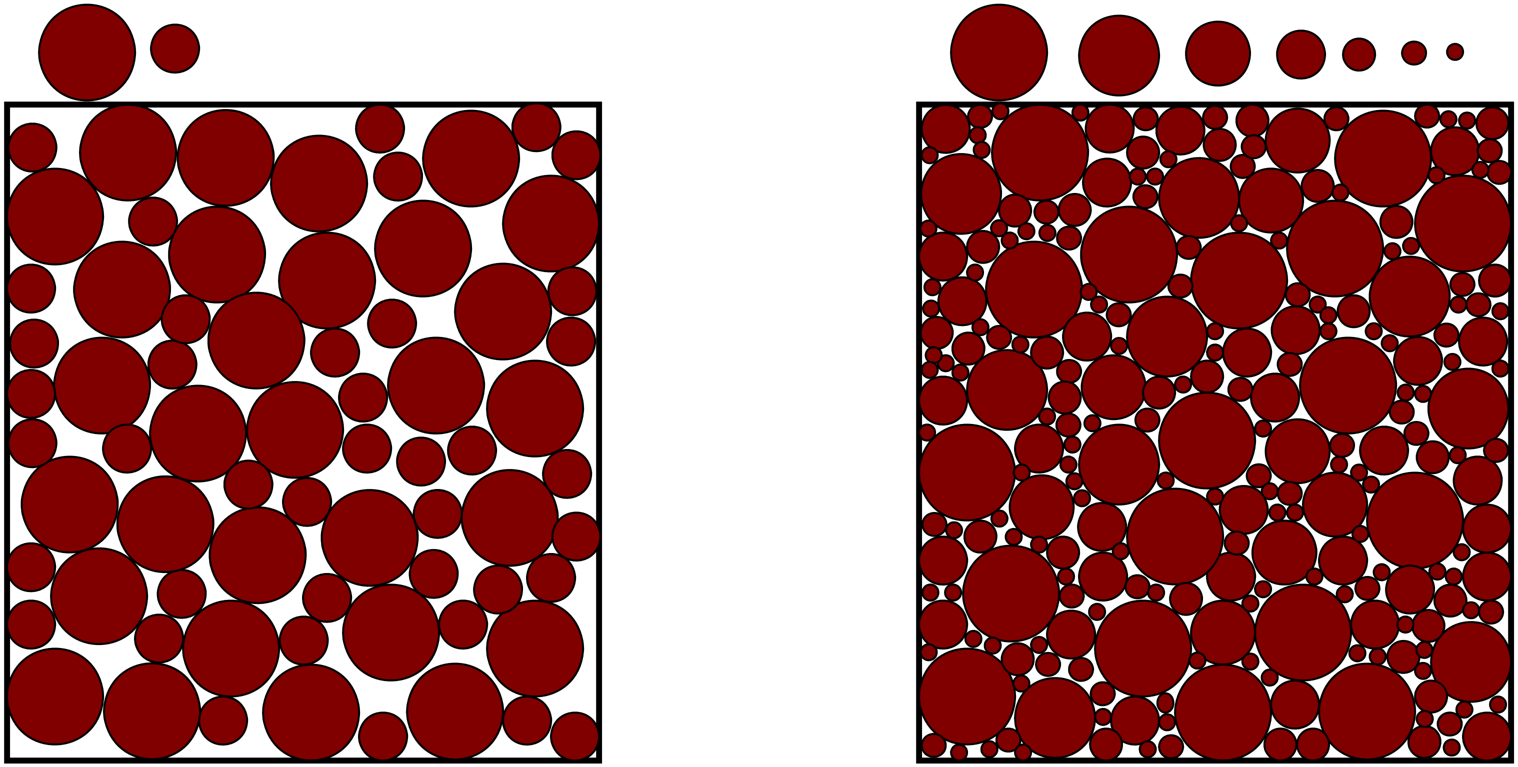
Gradation

- Particle size distribution influences the workability, roughness and texture of mixes
- Well-graded aggregate structure reduces paste requirement
- Poorly-graded aggregate structure will result in voids that will have a negative effect on the mix

Gradation

- Poor/Gap-Graded
  - More paste volume needed
  - Higher water demand
- Well Graded
  - Increase packing density
  - Reduce paste content
  - Improve workability and finishability
  - Reduce permeability

Gap Graded vs. Well Graded



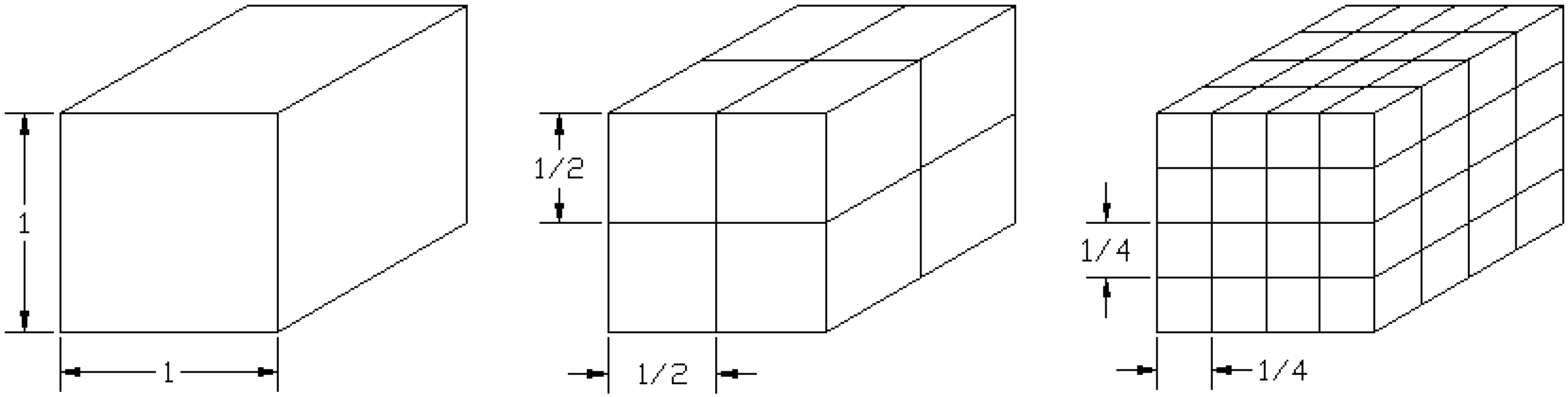
Fine Aggregate Gradation

- Fine Aggregate Gradation can affect
  - Water Demand, Bleeding, Workability, Finishability, and Durability
- Excessive amount of fines increases the water demand
- Insufficient amount of fines results in excessive bleeding and difficulty in finishing
- Excessive amount of material passing the No. 200 sieve can result in:
  - Reduced Strength, Poor Durability, Poor Abrasion Resistance, increased shrinkage

Fineness Modulus

- Indicates how fine or coarse the material is, lower FM = finer aggregate
- Finer material particles have larger surface area, more water/cement is required to coat the particles
- Typical range for sand 2.3 – 2.9
- FM lower than 2.5 can reduce strength

Gradation



1x1 Square

6 Sides

1 Cube

1x1x6x1=
6 Area

½ x ½ Square

6 Sides

8 Cube

½ x ½ x 6 x 8 =
12 Area

¼ x ¼ Square

6 Sides

64 Cube

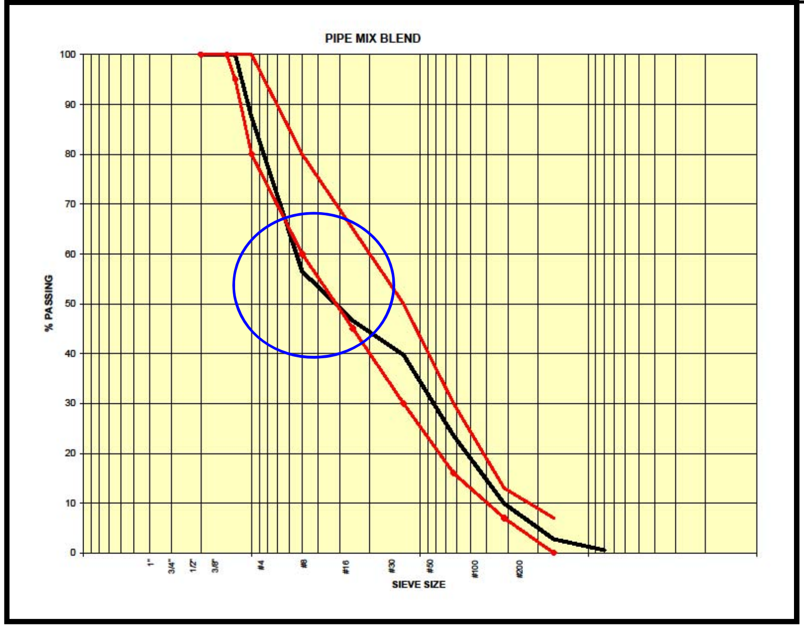
¼ x ¼ x 6 x 64
= 24 Area

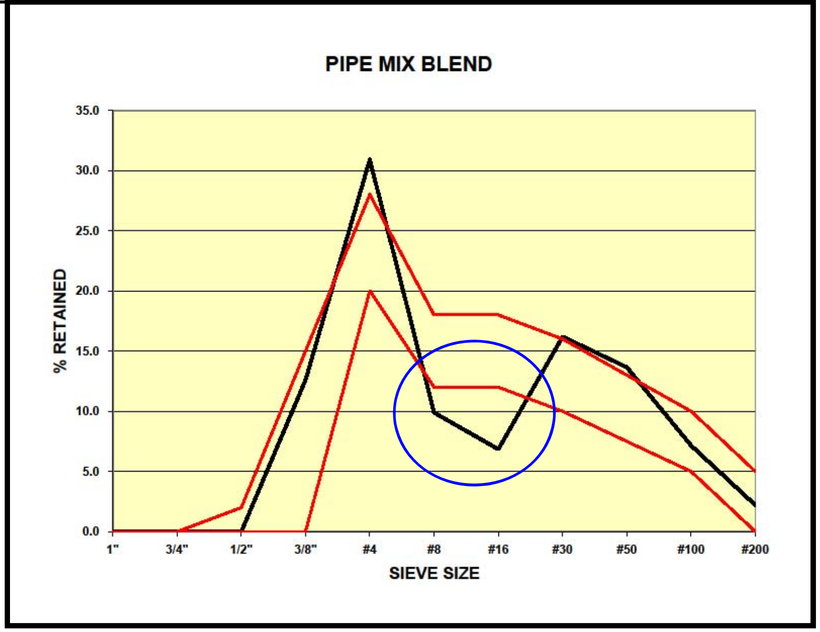
Sieve Analysis

SCREEN	% PASSING		
SIZE	3/8"	1/4"	Sand
1"	100.0	100.0	100.0
3/4"	100.0	100.0	100.0
1/2"	100.0	100.0	100.0
3/8"	72.0	100.0	100.0
#4	18.0	78.0	88.0
#8	7.0	40.0	79.0
#16	4.0	3.0	69.0
#30	1.0	1.0	42.0
#50	0.0	1.0	18.0
#100	0.0	1.0	5.0
#200	0.0	1.0	1.0

AGGREGATE BLENDING

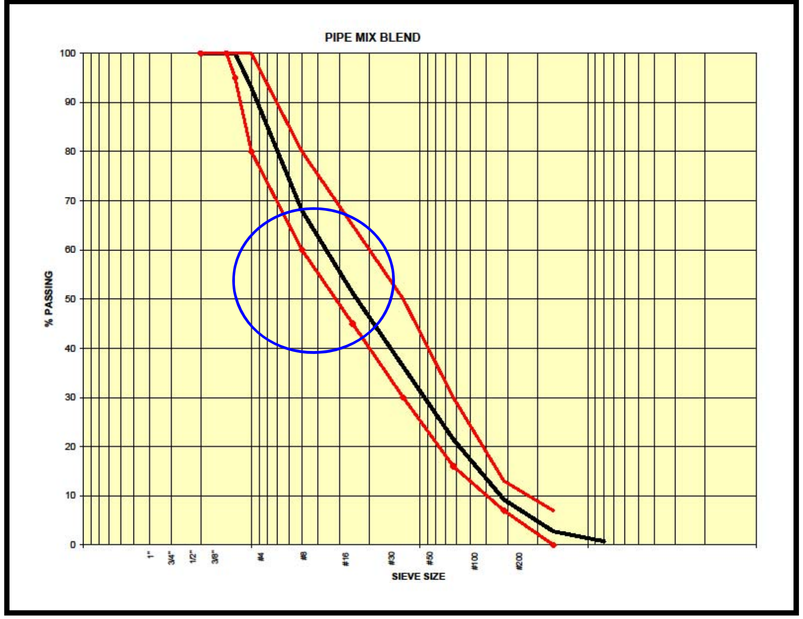
BLEND %	45.0	0.0	55.0	% PASSING	% RETAINED
SCREEN SIZE	3/8"	1/4"	Sand	COMBINED SAMPLE	COMBINED SAMPLE
1"	100.0	100.0	100.0	100.0	0.0
3/4"	100.0	100.0	100.0	100.0	0.0
1/2"	100.0	100.0	100.0	100.0	0.0
3/8"	72.0	100.0	100.0	87.4	12.6
#4	18.0	78.0	88.0	56.5	30.9
#8	7.0	40.0	79.0	46.6	9.9
#16	4.0	3.0	69.0	39.8	6.9
#30	1.0	1.0	42.0	23.6	16.2
#50	0.0	1.0	18.0	9.9	13.7
#100	0.0	1.0	5.0	2.8	7.2
#200	0.0	1.0	1.0	0.6	2.2

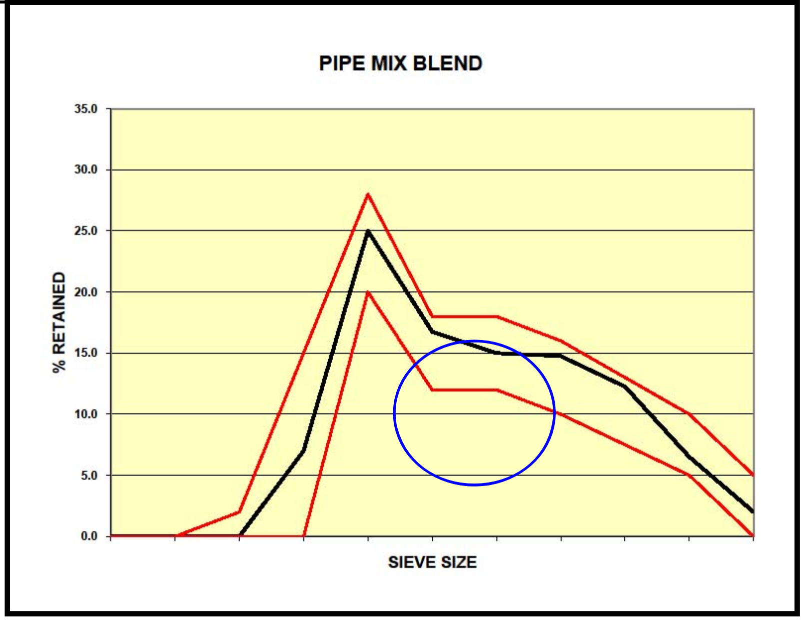




AGGREGATE BLENDING

BLEND %	25.0	25.0	50.0	% PASSING	% RETAINED
SCREEN SIZE	3/8"	1/4"	Sand	COMBINED SAMPLE	COMBINED SAMPLE
1"	100.0	100.0	100.0	100.0	0.0
3/4"	100.0	100.0	100.0	100.0	0.0
1/2"	100.0	100.0	100.0	100.0	0.0
3/8"	72.0	100.0	100.0	93.0	7.0
#4	18.0	78.0	88.0	68.0	25.0
#8	7.0	40.0	79.0	51.3	16.8
#16	4.0	3.0	69.0	36.3	15.0
#30	1.0	1.0	42.0	21.5	14.8
#50	0.0	1.0	18.0	9.3	12.3
#100	0.0	1.0	5.0	2.8	6.5
#200	0.0	1.0	1.0	0.8	2.0





Mix Design

- Mix design is the process of determining required and specifiable characteristics of a concrete mixture
- The characteristics can be based on fresh and/or hardened concrete properties, and inclusion, exclusion or limits of specific ingredients
- Mix design requirements are based on intended use, environment, etc.

Mix Proportioning

- Mix proportioning is the process of determining the quantities of concrete ingredients that meet the mix design criteria

Cement?

Fine Aggregate?

SCM's?

Coarse Aggregate?

Water?

Admix?

Mix Proportioning

- The primary considerations include:
  - Meeting or exceeding specifications
  - Availability of raw materials
  - Acceptable workability of the mix
  - Durability, strength & uniform appearance of the finished concrete
  - Economy

Mix Proportioning

- There are number of ways to proportion mixes:
    - Water-cement ratio method
    - Weight method
    - Absolute volume method (ACI 211.1)
    - Field experience (statistical data)
- We will focus on the

  Absolute Volume Method

Mix Proportioning

Absolute Volume Method

- Required strength
- w/c ratio
- Air content
- Slump
- Water content
- Cementitious
- Coarse aggregate
- Admixtures
- Fine aggregate

Required Strength

- Strength requirements are based on specifications and design assumptions
- Variability exists in both materials and testing procedures

Example:

5000 psi at 28 days

W/C Ratio

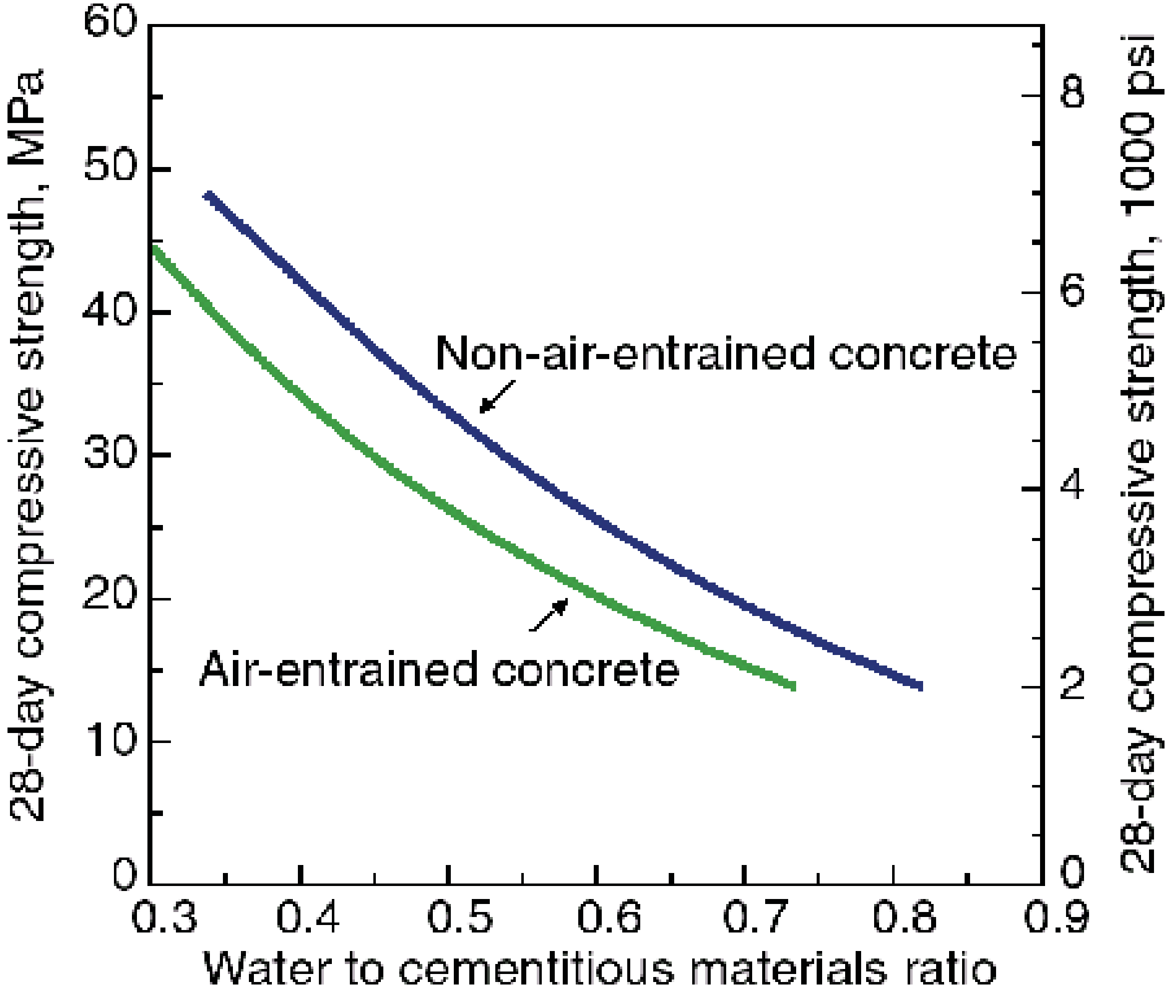
- w/c should be based on strength and durability requirements (specs)
- Check relationship between strength & w/c
- Durability requirements based on various exposure conditions
- Most severe case governs

Example:

5000 psi at 28 days

w/c = 0.40

Compressive strength vs. w/c ratio



Relationship between w/c ratio & strength

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

Requirements for exposure conditions

Exposure Condition	Max w/c ratio by mass	Min strength, f'c, psi
No freeze-thaw, deicers, aggressive substances	Select for strength, workability, and finishing needs	Select for structural requirements
Concrete with low permeability; exposed to water	0.50	4000
Concrete exposed to freezing and thawing in a moist condition or deicers	0.45	4500
For corrosion protection for reinforced concrete exposed to chlorides	0.40	5000

Requirements for exposure to sulfates

Sulfate exposure	Sulfate (SO_4) in soil, % by mass	Sulfate (SO_4) in water, ppm	Cement type	Max w/c ratio, by mass	Min strength, f’c, psi
Negligible	Less than 0.10	Less than 150	No special type required	-	-
Moderate	0.10 to 0.20	150 to 1500	Type II	0.50	4000
Severe	0.20 to 2.00	1500 to 10,000	Type V	0.45	4500
Very severe	Over 2.00	Over 10,000	Type V	0.40	5000

Air Content

- Air entrained concrete target from exposure conditions & nominal maximum aggregate size
- For the example use 3/8” nominal aggregate & non air entrained concrete (3.0% air)

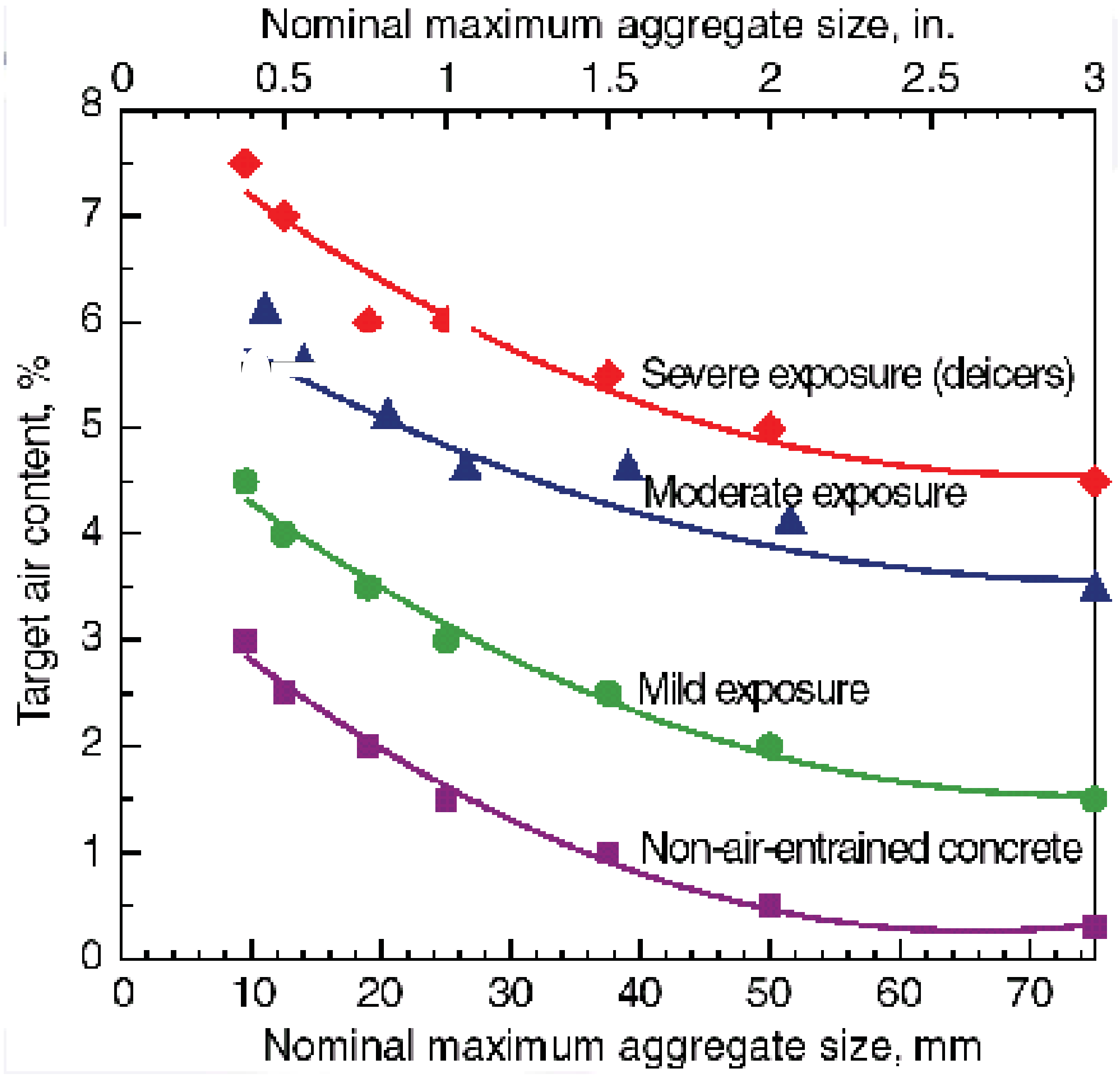
Example:

5000 psi at 28 days

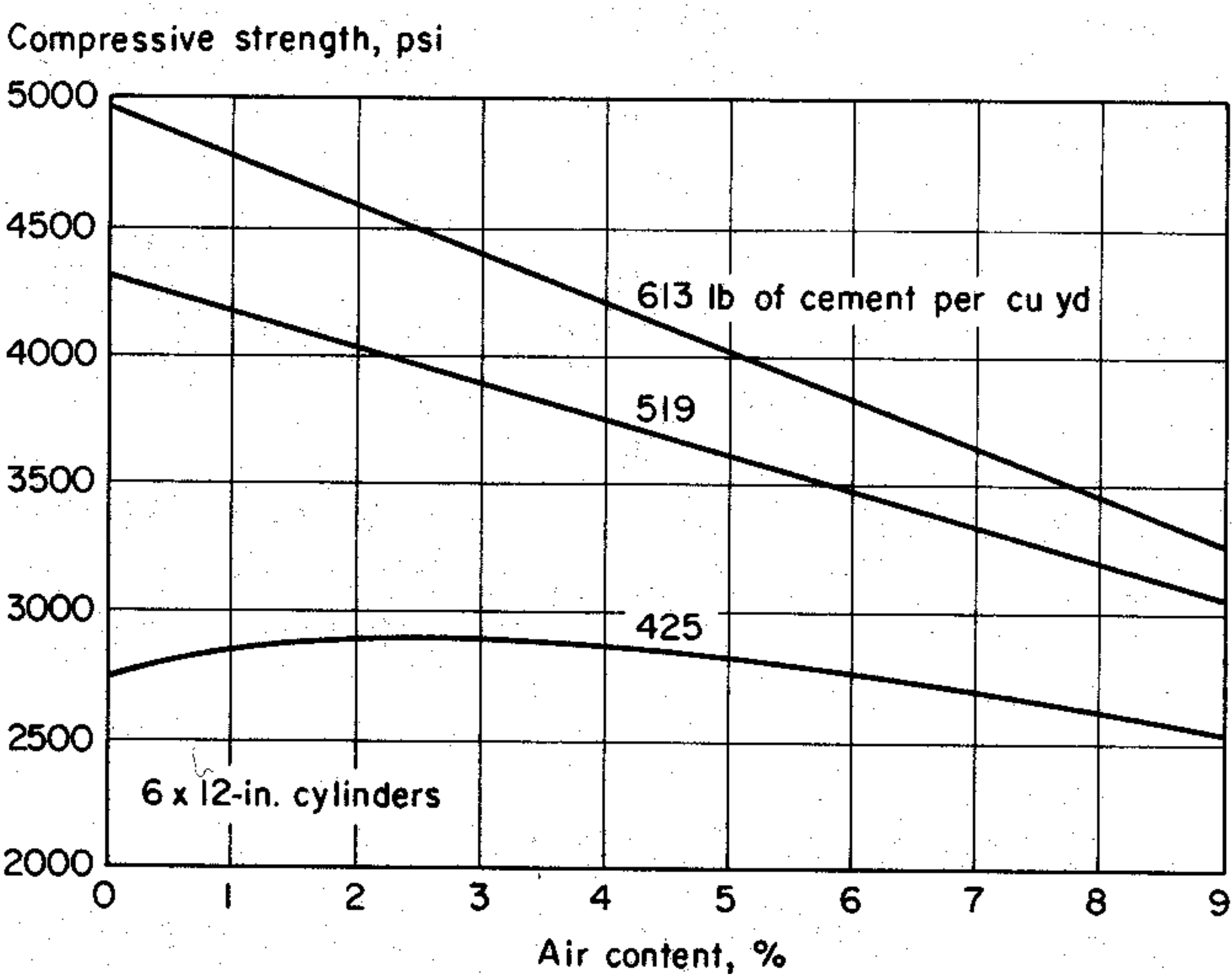
w/c = 0.40

3.0% air

Air content and aggregate size



Compressive Strength Vs % Air



Water content was reduced with increased air content to maintain a constant slump

Slump

- Target workability in terms of slump is based on method of placement

Example:

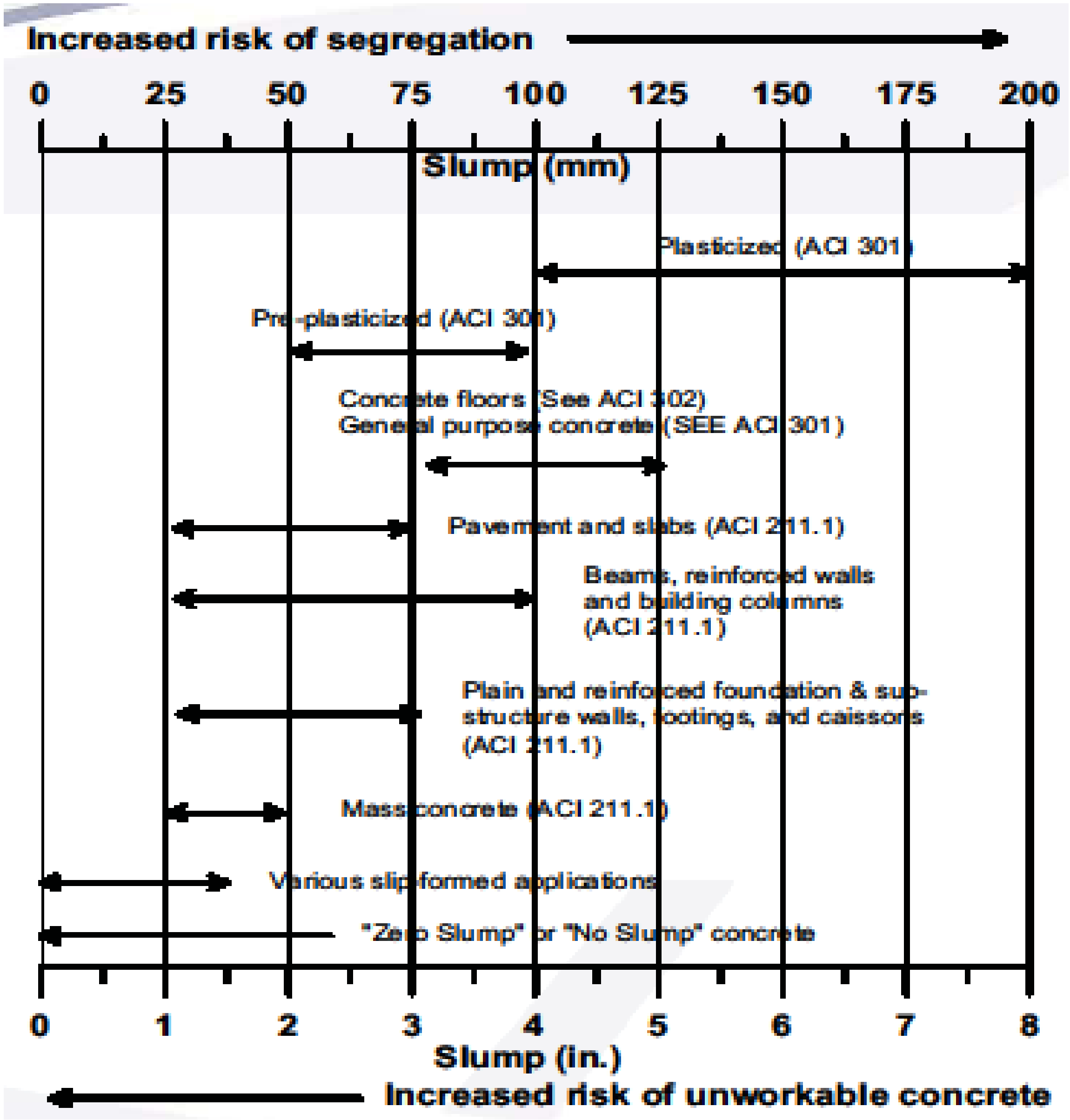
5000 psi at 28 days

w/c = 0.40

3.0% air

Zero slump

Workability requirements



Water content

- Water content is influenced by:
    - Agg size, shape, texture
    - Slump
    - w/c ratio
    - Air content
    - Cementitious type
    - Cem content
    - Admixtures
    - Environmental conditions
- Even with drycast concrete there is a minimum water requirement based on the above

Example:

5000 psi at 28 days

w/c = 0.40

3.0% air

Zero slump

200 lbs water/yd^3

Water requirements for various slumps

Slump, in.	Water, lbs/yd^3 of concrete for indicated size of aggregate			
	3/8 in.	1/2 in.	3/4 in.	1 in.
	Non air entrained concrete			
1 to 2	350	335	315	300
3 to 4	385	365	340	325
6 to 7	410	385	360	340

Above is based on crushed stone, water estimates can be reduced by 20 lbs for sub-angular stone, 35 lbs for some crushed particles and 45 lbs for rounded gravel.

Water can be reduced for various other factors including admixtures.

Correct slump should be verified by trial batches.

Cementitious content

- Cementitious materials content based on previously determined w/c ratio and water requirements
- Check specification limits for minimum content required
- Use 20% fly ash replacement by weight for the example

$$\frac{200 \text{ lbs}}{0.40} = 500 \text{ lbs}$$

500 lbs x 0.8 = 400 lbs

Example:

5000 psi at 28 days

w/c = 0.40

3.0% air

Zero slump

200 lbs water/yd^3

400 lbs cement/yd^3

100 lbs fly ash/yd^3

Cementitious content

What is the minimum cement content per yard specified by ASTM C76?

470 lbs/yd^3

Coarse Aggregate

- Aggregates are the least expensive and the most dimensionally stable ingredient
- Proper blending of aggregates will minimize the amount of paste required
- Aggregate proportions can be selected from blending worksheets or ACI 211.1 tables
- Use 45/55 agg blend for the example

Example:

5000 psi at 28 days

w/c = 0.40

3.0% air

Zero slump

200 lbs water/yd^3

400 lbs cement/yd^3

100 lbs fly ash/yd^3

Bulk volume of coarse aggregate (ACI 211.1)

Nominal max size of aggregate, (in.)	Fineness modulus of sand			
	2.40	2.60	2.80	3.00
3/8	0.50	0.48	0.46	0.44
1/2	0.59	0.57	0.55	0.53
3/4	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
1-1/2	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

*For calculations, use dry rodded bulk density

Example: density = 100 lb/ft^3, stone per yard = 100 x 27 x 0.48 = 1296 lbs
Stone SG = 2.68, Abs. vol. of stone per yard = 1296/(2.68x62.4)= 7.750 ft^3

Admixtures

- Admixtures should be dozed based on manufacturers recommendations and verified with trial batches & testing
- Use no admix for the example

Example:

5000 psi at 28 days

w/c = 0.40

3.0% air

Zero slump

200 lbs water/yd^3

400 lbs cement/yd^3

100 lbs fly ash/yd^3

45/55 Agg Blend

Fine Aggregate

- Fine aggregate volume is determined by subtracting the absolute volumes of the known ingredients from 27 cu ft (1 yd^3)

Example:

5000 psi at 28 days

w/c = 0.40

3.0% air

Zero slump

200 lbs water/yd^3

400 lbs cement/yd^3

100 lbs fly ash/yd^3

45/55 Agg Blend

Mix Proportion Calculations

Given:

400 lbs of Cement, SG = 3.15

100 lbs of Fly Ash, SG = 2.50

200 lbs of Water, SG = 1.00

3% Air

45/55 Stone/Sand Blend

Stone SG = 2.68, Abs = 1.0%

Sand SG = 2.62, Abs = 1.5%

Mix Proportion Calculations

- Calculate the absolute volume of each component

$$\text{Absolute Volume} = \frac{\text{Weight of Material (lbs)}}{\text{S.G. x 62.4}}$$

Density of water = 62.4 lb/ft^3

Mix Proportion Calculations

$$V_{cement} = \frac{400}{3.15 \times 62.4} = 2.035\ ft^3$$

$$V_{flyash} = \frac{100}{2.50 \times 62.4} = 0.641\ ft^3$$

$$V_{water} = \frac{200}{1.00 \times 62.4} = 3.205\ ft^3$$

$$V_{air} = 0.03 \times 27 = 0.810\ ft^3$$

$$V_{total} = 6.691\ ft^3$$

Mix Proportion Calculations

$V_{aggregates}$ = 27 – 6.691 = 20.309 ft^3

V_{stone} = 0.45 x 20.309 = 9.139 ft^3

W_{stone} = 9.139 x 2.68 x 62.4 = 1528 lbs

V_{sand} = 0.55 x 20.309 = 11.170 ft^3

W_{sand} = 11.170 x 2.62 x 62.4 = 1826 lbs

Mix Proportion Calculations

	Lbs/yd^3	S.G.	Volume
Cement	400	3.15	2.035
Fly ash	100	2.50	0.641
Water*	200	1.00	3.205
Stone*	1528	2.68	9.139
Sand*	1826	2.62	11.170
Air	3%	-	0.810
Total	4054		27.00

*Stone & sand moisture at SSD

Mix Proportioning

- These are the proportions for a trial batch
- Batch needs to be tested and adjusted
  - Make adjustments for moisture
  - Check workability, finishing, etc
  - Make appropriate adjustments and rebatch
  - If fresh properties are satisfactory, make samples for hardened properties

Mix Proportion Calculations

- Make the following adjustments to the trial batch
  - Adjust aggregate moisture, actual moisture of stone = 3%, sand = 4.5%
  - Eliminate fly ash and use 100% cement

Mix Proportion Calculations

Aggregate moisture adjustment

Stone abs = 1%
Sand abs = 1.5%

Free water in stone = 3% - 1% = 2%

Free water in sand = 4.5% - 1.5% = 3%

1528lb SSD
1826lb SSD

Weight of water in stone

0.02 x 1528 = 31 lbs

Weight of water in sand

0.03 x 1826 = 55 lbs

Batch water adjustment

31 + 55 = 86 lbs

	design	actual	
Cement	400	400	lbs
Fly ash	100	100	lbs
Water	200	114	lbs
Stone*	1528	1559	lbs
Sand*	1826	1881	lbs
Total	4054	4054	Lbs/yd^3

Mix Proportion Calculations

Eliminate fly ash from the mix

Keeping the volume constant, how many lbs of cement equals 100 lbs of fly ash?

$$V_{flyash} = \frac{100}{2.50 \times 62.4} = 0.641 \text{ ft}^3$$

$$W_{cement} = 0.641 \times 3.15 \times 62.4 = \underline{126 \text{ lbs}}$$

Mix Proportion Calculations

- Two ways to eliminate 100 lbs of fly ash from the mix
    - Make a quick adjustment based on equal volumes
        - (eg. 100 lbs FA = 126 lbs cement)
    - Adjust quantities by weight and re-calculate aggregate proportions

	design	**actual**	
Cement	400	500	lbs
Fly ash	100	0	lbs
Water	200	200	lbs
Stone*	1528	1538	lbs
Sand*	1826	1838	lbs
Total	4054	4076	Lbs/yd^3

Mix Proportioning

If aggregate proportions were not adjusted and 100 lbs of cement was exchanged for 100 lbs of fly ash, what would happen to the total volume?

	Weight	Volume
Cement	500	2.544
Fly ash	0	0
Water	200	3.205
Stone*	1528	9.137
Sand*	1826	11.169
Air	3%	0.810
Total	4054	26.865

Under yield

Mix Proportioning

- Under yield situation happens when not enough of one or more raw material is batched, or material is substituted by weight and not corrected for volume
- Since volume stays constant, more raw materials are needed to fill that volume (more cement!)

Mix Proportioning

- Over yield situation happens when one or more raw material is batched over the required weight
- Batch occupies a larger volume, therefore less of the other raw materials are used in the product (less cement!)
- Could lead to lower strengths, workability issues, less cementitious material than allowed by specs

Mix Proportioning

- Substituting/Replacing raw materials (eg. Fly Ash for Cement) by weight will throw the yield off
- Raw material substitution/replacement must be done based on volume, not weight!
- Aggregate moisture will affect add-water, batch needs to be adjusted to maintain proper w/c and stone/sand ratio

QUESTIONS?