Mix Design Adjustments
Quickly and Accurately Adapting to Changes

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1

References

- PCA - Design and Control of Concrete Mixtures
- ACI 211.1-91: Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (Reapproved 2009)

2

Review of Important Concepts and Terminology

- Volume
- Density
- Specific Gravity
- Aggregate Properties

3

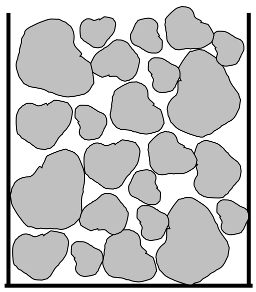
Volume

Volume will play the biggest role in making mix design adjustments

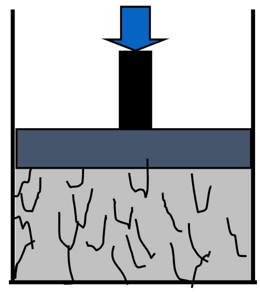
Absolute volume is the volume of the solid matter excluding solid spaces between particles.

4

Apparent vs absolute Volume



Apparent vol. =
Bucket vol. = $0.25 ft^3$



Absolute vol.
= $0.15 ft^3$

5

Density & Specific Gravity

$$\text{Density(Unit Weight)} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Relative Density aka Specific Gravity} = \frac{\text{Density of Material}}{\text{Density of Water}}$$

For density of water, we use $62.4\ \text{lbs/ft}^3$ or $1000\ \text{kg/m}^3$

6

Aggregate Properties

Density

When discussing aggregate density, the term used will depend on whether we are talking about impermeable or permeable pores within the aggregates.

Apparent density: solid portion + impermeable (air) pores.

Absolute density: just the solid portion of the aggregate.

7

Aggregate Properties

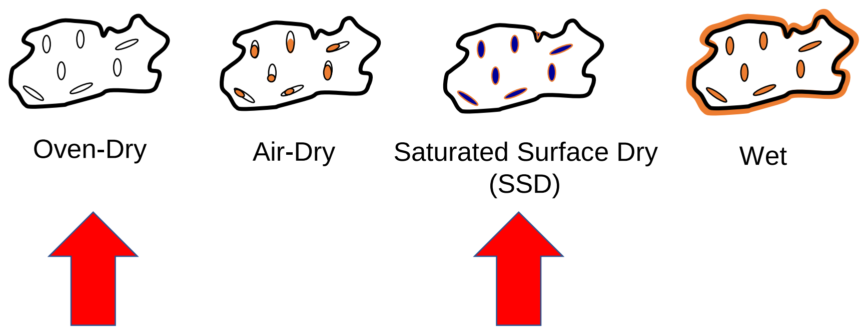
Moisture Related Density

When we include permeable pores in the density calculations, we then have to delineate if it's oven dry (OD) or saturated surface dry (SSD) conditions

8

Aggregate Properties

Aggregate properties are usually given as dry or saturated surface dry (OD or SSD)



9

Aggregate Properties

Bulk Density

Measure of the mass of a unit volume of bulk aggregate material (includes the volume of the individual particles and the volume of the voids between the particles)

10

Aggregate Properties

Dry Rodded Unit Weight (DRUW)

Compacting dry aggregate into a container of a known volume

Weighing the aggregate and dividing it by the volume of the container.

11

Aggregate Properties

Specific Gravity

Aggregate SG are usually given as dry or saturated surface dry
(OD or SSD)

SG of an aggregate can be BULK SG – Using absolute volume of a dry aggregate.

OR

SG of an aggregate can be BULK SSD SG – Using absolute volume of an SSD aggregate (includes water)

That has to be known up front!!!!

12

Aggregate Properties

Fineness Modulus

The fineness modulus (FM) is an empirical figure obtained by adding the cumulative percentage retained from a sample of aggregates. For fine agregates, you would add the cumulative percent retained from each of the following sieves: #100, #50, #30, #16, #8, #4, 3/8"

The result is divided by 100 to arrive at the fineness modulus. For conventional concrete the fineness modulus of the fine aggregate should range from 2.3 to 3.1

Higher FM → **Coarser material**

Lower FM → **Finer material**

13

Aggregate Properties

Fine Aggregates/Total Aggregate Ratio (Sand to Aggregate Ratio)

Most commonly done volumetrically.

$$\frac{\text{Volume of Sand}}{\text{Volume of Total Aggregate}}$$

Common starting point is 0.40
Higher for SCC and Dry Cast

14

Aggregate Properties

Total Moisture (TM)

Percentage of all moisture in and on aggregate to the aggregate in dry state

$$TM = \frac{\text{Weight Sample - Weight at Oven Dry}}{\text{Weight at Oven Dry}} \times 100$$

15

Aggregate Properties

Absorption Capacity (AC)

Maximum amount of water the aggregate can absorb. It is calculated from the difference in weight between the SSD and OD states, expressed as a percentage of the OD weight.

Given by aggregate supplier.

16

Aggregate Properties

Free Moisture Content (FMC)

Difference between total aggregate moisture (TM) and absorption capacity (AC)

FMC = TM – AC

It represents the amount of moisture above or below the SSD state

17

Reasons for Adjusting mix design

- Aggregate Moisture
- Initial Trial Batch Results
- Change in Cementitious Materials
- Addition/Removal of an Admixture
- Addition/Removal of Fiber Reinforcing
- Adjustments for SCC Mixes

18

Example mix design

Our Initial Mix	SSD Weights
Cement	665 lbs
Water	266 lbs
Coarse Agg (CA)	1835 lbs
Fine Agg (FA)	1157 lbs

19

Example Mix Design

Cement
Type I/II
SG 3.15

Coarse Agg
AC – 1.3%
SG_{SSD} – 2.60

Fine Agg
AC – 1.8%
SG_{SSD} – 2.66

Cement
Slump
1 – 3 inches

W/C ratio
Maximum of 0.42

Strength
Min 4500 psi

Air
4% (+/-0.5%)

20

Example Mix Design

Our Initial Mix

Materials	Weight (lbs)	Specific Gravity
Cement	665	3.15
SCM		
Coarse Agg	1835	2.60 (SSD)
Fine Agg	1157	2.66 (SSD)
Water	266	1.0
Air (%)	4.0%	
Total	3923	

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21

Example Mix Design

$$\frac{\text{Weight}}{\text{SG x 62.4 lbs/ft}^3}$$

Our Initial Mix

Materials	Weight (lbs)	Specific Gravity	Volume (ft^3)
Cement	665	3.15	3.38
SCM			
Coarse Agg	1835	2.60 (SSD)	11.31
Fine Agg	1157	2.66 (SSD)	6.97
Water	266	1.0	4.26
Air (%)	4.0%		1.08
Total	3923		27.00

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22

Aggregate Moisture Adjustment

Sample of aggregates are collected.

Coarse Agg

Sample weight:	9.69 lbs
Sample OD weight:	9.48 lbs

Fine Agg

Sample weight:	7.21 lbs
Sample OD weight:	6.99 lbs

23

Aggregate Moisture Adjustment

TM Calculation

Coarse Agg

$$TM_{CA} = \frac{9.69 \text{ lbs} - 9.48 \text{ lbs}}{9.48 \text{ lbs}} \times 100 = \mathbf{2.22\%}$$

Fine Agg

$$TM_{FA} = \frac{7.21 \text{ lbs} - 6.99 \text{ lbs}}{6.99 \text{ lbs}} \times 100 = \mathbf{3.15\%}$$

24

Aggregate Moisture Adjustment

FMC Calculation

Coarse Agg

FMC_{CA} = 2.22 - 1.3 = **0.92%**

Fine Agg

FMC_{FA} = 3.15 - 1.8 = **1.35%**

25

Aggregate Moisture Adjustment

Aggregate water content excess/deficit

CA
1835 lbs x 0.0092 = **16.88** lbs excess water

FA
1157 lbs x 0.0135 = **15.62** lbs excess water

Total: **32.50** lbs of excess water

26

Aggregate Moisture Adjustment

Water weight adjustment

266 lbs – 32.50 lbs = 233.50 lbs = 234 lbs

27

Aggregate Moisture Adjustment

Aggregate weight adjustment

CA

1835 lbs + 16.88 lbs = 1851.88 = **1852** lbs of CA

FA

1157 lbs + 15.62 lbs = 1172.6 = **1173** lbs of FA

This additional weight of agg will theoretically contain 0.36 lbs of water. Negligible

28

Mix Design Adjustment

	Initial MD	Adj MD
Cement	665 lbs	665 lbs
Water	266 lbs	233 lbs
Coarse Agg (CA)	1835 lbs	1852 lbs
Fine Agg (FA)	1157 lbs	1173 lbs
Total Weight	3923 lbs	3923 lbs

29

Mix Design Adjustment

Quick Note!
If adjustment was not made, we would have ended up with:

	Initial MD		Real MD
Cement	665 lbs		665 lbs
Water	266 lbs	+33lbs	299 lbs
Coarse Agg (CA)	1835 lbs	-17lbs	1818 lbs
Fine Agg (FA)	1157 lbs	+16lbs	1141 lbs
w/c ratios	0.40		0.45

30

Adjustment After First Trial Batches

Trial Batch Results

Slump: 5”
Air: 6%

Analysis:
Slump and air is high

Requirements
Slump
1 – 3 inches
W/C ratio
Maximum of 0.42
Air
4% (+/-0.5%)

Back off a bit on air entraining and adjust water content

31

Adjustment After First Trial Batches

Slump adjustment

Slump measures 5” . Desired slump was 1-3”

Every 10 lbs can increase/decrease slump by 1”

Reduce water by 20 lbs

32

Adjustment After First Trial Batches

Air adjustment

Air measures 6% . Desired air was 4%
Adjust air entraining admixture dosage.
Adjust water due to air content change

For every % decrease in air content, increase water content by 5lbs.

Increase water by 10 lbs

33

Adjustment After First Trial Batches

Net water adjustment

Reduce water by 20 lbs

Increase water by 10 lbs

Reduce water content by 10 lbs

34

Adjustment After First Trial Batches

Cement	665 lbs
Water	266 lbs – 10 lbs = 256 lbs
Coarse Agg (CA)	1835 lbs
Fine Agg (FA)	1157 lbs
Total Weight	3923 lbs

Maintain w/c ratio at 0.40 so decrease cementitious content by:

cement = water/ratio = 256/0.40 = 640 lbs

35

Adjustment After First Trial Batches

Cement	640 lbs
Water	256 lbs
Coarse Agg (CA)	1835 lbs
Fine Agg (FA)	1157 lbs
Total Weight	3888 lbs

36

Adjustment After First Trial Batches

Materials	Weight (lbs)	Specific Gravity
Cement	640	3.15
SCM		
Coarse Agg	1835	2.60 (SSD)
Fine Agg	1157	2.66 (SSD)
Water	256	1.0
Air (%)	4.0%	
Total	3888	

37

Adjustment After First Trial Batches

Materials	Weight (lbs)	Specific Gravity	Volume (ft^3)
Cement	640	3.15	3.26
SCM			
Coarse Agg	1835	2.60 (SSD)	11.31
Fine Agg	1157	2.66 (SSD)	6.97
Water	256	1.0	4.10
Air (%)	4.0%		1.08
Total	3888		26.72

Need to add 0.28 ft^3

38

Adjustment After First Trial Batches

FA / Total Agg Volumetric Ratio

$\frac{6.97}{18.28}$ = 0.38 = 38% which means CA is 62%

0.28 ft^3 difference

FA – Add 0.11 ft^3
CA – Add 0.18 ft^3

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39

Adjustment After First Trial Batches

Materials	Weight (lbs)	Specific Gravity	Volume (ft^3)
Cement	640	3.15	3.26
SCM			
Coarse Agg	1835	2.60 (SSD)	11.31
Fine Agg	1157	2.66 (SSD)	6.97
Water	256	1.0	4.10
Air (%)	4.0%		1.08
Total	3888		26.72

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40

Adjustment After First Trial Batches

Materials	Weight (lbs)	Specific Gravity	Volume (ft^3)
Cement	640	3.15	3.26
SCM			
Coarse Agg	1835	2.60 (SSD)	11.49
Fine Agg	1157	2.66 (SSD)	7.07
Water	256	1.0	4.10
Air (%)	4.0%		1.08
Total	3888		27.00

41

Adjustment After First Trial Batches

Materials	Weight (lbs)	Specific Gravity	Volume (ft^3)
Cement	640	3.15	3.26
SCM			
Coarse Agg	1864	2.60 (SSD)	11.49
Fine Agg	1174	2.66 (SSD)	7.07
Water	256	1.0	4.10
Air (%)	4.0%		1.08
Total	3934		27.00

42

Adjustment for Change in Cementitious Material

20% Fly Ash Required (by weight)

Cement	665 lbs
Water	266 lbs
Coarse Agg (CA)	1835 lbs
Fine Agg (FA)	1157 lbs

Current cement content - 665 lbs

20% of 665 is 133 lbs.

So we would have 133 lbs of fly ash and 532 lbs of Portland cement

43

Example Adding Fly Ash

Our Initial Mix

Cement	532 lbs
Fly Ash	133 lbs
Water	266 lbs
Coarse Agg (CA)	1835 lbs
Fine Agg (FA)	1157 lbs

Most likely has a different SG than our original cement

44

Example Adding Fly Ash

Cement

Type I/II

SG 3.15

Fly Ash

Class F

SG – 2.55

133 lbs of fly ash with an SG of 2.55 will have a volume of:

=133 lbs / (2.55 x 62.4)

= 0.84 ft^3

Typical SCM SG

- Fly ash = 1.9 to 2.8
- Silica fume = 2.25
- Slag = 2.85 to 2.95
- Metakaolin = 2.5

45

Example Adding Fly Ash

Mix Design

Materials	Weight (lbs)	Specific Gravity	Absolute Volume (ft^3)
Cement	532	3.15	2.71
SCM	133	2.55	0.84
Coarse Agg	1835	2.60	11.31
Fine Agg	1157	2.66	6.97
Water	266	1.0	4.26
Air (%)	4.0%		1.08
Total	3923		27.17

Need to subtract 0.17 ft^3

46

Example Adding Fly Ash

Option 1 – Modify just Fine Agg Content

Coarse agg –	11.31 ft^3
Cement	2.71 ft^3
Fly Ash	0.84 ft^3
Water	4.26 ft^3
Air	1.08 ft^3
Total:	**20.20 ft^3**

27 – 20.20 = 6.80 ft^3

47

Mix Design Adjustment

Option 1 – Modify Fine Agg Content

Weight of 6.80 ft^3 of FA

= 6.80 x 2.66 x 62.4 = 1128.69 = 1129 lbs

48

Cementitious Materials

Mix Design

Materials	Weight (lbs)	Specific Gravity	Absolute Volume (ft^3)
Cement	532	3.15	2.71
SCM	133	2.55	0.84
Coarse Agg	1835	2.60	11.31
Fine Agg	1129	2.66	6.97
Water	266	1.0	4.26
Air (%)	4.0%		1.08
Total	3895		27.17

49

Cementitious Materials

Mix Design

Materials	Weight (lbs)	Specific Gravity	Absolute Volume (ft^3)
Cement	532	3.15	2.71
SCM	133	2.55	0.84
Coarse Agg	1835	2.60	11.31
Fine Agg	1129	2.66	6.80
Water	266	1.0	4.26
Air (%)	4.0%		1.08
Total	3895		27.00

50

Cementitious Materials

Mix Design

Materials	Weight (lbs)	Specific Gravity	Absolute Volume (ft^3)
Cement	532	3.15	2.71
SCM	133	2.55	0.84
Coarse Agg	1835	2.60	11.31
Fine Agg	1129	2.66	6.80
Water	266	1.0	4.26
Air (%)	4.0%		1.08
Total	3895		27.00

This will change the sand/agg ratio from 0.39 to 0.38

51

Example – Adding Fly Ash

Option 2 – Maintain Sand/Agg Ratio(Vol) and modify both aggregate amounts

Current Sand/Agg ratio = 6.97/(6.97+11.31) = **0.38**

52

Example Adding Fly Ash

Option 2 – Maintain Sand/Agg Ratio(Vol) and modify both aggregate amounts

Cement	2.71 ft^3
Fly Ash	0.84 ft^3
Water	4.26 ft^3
Air	1.08 ft^3
Total:	**8.89 ft^3**

27 – 8.89 = 18.11 ft^3

53

Example Adding Fly Ash

Option 2 – Maintain Sand/Agg Ratio(Vol) and modify both aggregate amounts

18.11 ft^3 x 0.38 = 6.88 ft^3 for fine aggregates

18.11 ft^3 – 6.88 ft^3 = 11.23 ft^3 for coarse aggregates

54

Example Adding Fly Ash

Mix Design

Materials	Weight (lbs)	Specific Gravity	Absolute Volume (ft^3)
Cement	532	3.15	2.71
SCM	133	2.55	0.84
Coarse Agg	1835	2.60	11.23
Fine Agg	1129	2.66	6.88
Water	266	1.0	4.26
Air (%)	4.0%		1.08
Total	3895		27.00

55

Example Adding Fly Ash

Mix Design

Materials	Weight (lbs)	Specific Gravity	Absolute Volume (ft^3)
Cement	532	3.15	2.71
SCM	133	2.55	0.84
Coarse Agg	1822	2.60	11.23
Fine Agg	1142	2.66	6.88
Water	266	1.0	4.26
Air (%)	4.0%		1.08
Total	3895		27.00

56

Adjustment for Change in Aggregate Properties

Fine Agg FM has increased by 0.3

That means fine aggregate is… Coarser

This means our water demand should… Decrease

You decide to back off 5 lbs

57

Example Reducing Water

Our Initial Mix

Cement	532 lbs
Fly Ash	133 lbs
Water	266 lbs – 5 lbs = 261 lbs
Coarse Agg (CA)	1793 lbs
Fine Agg (FA)	1172 lbs

58

Example Reducing Water

Materials	Weight (lbs)	Specific Gravity	Absolute Volume (ft^3)
Cement	532	3.15	2.71
SCM	133	2.55	0.84
Coarse Agg	1793	2.60	11.05
Fine Agg	1172	2.66	7.06
Water	261	1.0	4.18
Air (%)	4.0%		1.08
Total	3895		26.92

59

Example Reducing Water

Materials	Weight (lbs)	Specific Gravity	Absolute Volume (ft^3)
Cement	532	3.15	2.71
SCM	133	2.55	0.84
Coarse Agg	1793	2.60	11.10
Fine Agg	1172	2.66	7.09
Water	261	1.0	4.18
Air (%)	4.0%		1.08
Total	3895		27.00

60

Example Reducing Water

Unit Weight went up slightly
w/c ratio went from 0.40 to 0.39

Previous Mix

Materials	Weight (lbs)	Specific Gravity	Absolute Volume (ft^3)
Cement	532	3.15	2.71
SCM	133	2.55	0.84
Coarse Agg	1793	2.60	11.05
Fine Agg	1172	2.66	7.06
Water	266	1.0	4.26
Air (%)	4.0%		1.08
Total	3895		27.00

New Mix

Materials	Weight (lbs)	Specific Gravity	Absolute Volume (ft^3)
Cement	532	3.15	2.71
SCM	133	2.55	0.84
Coarse Agg	1801	2.60	11.10
Fine Agg	1177	2.66	7.09
Water	261	1.0	4.18
Air (%)	4.0%		1.08
Total	3904		27.00

61

Effects of Admixtures on Mix

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%
- Retarders may increase air contents
- Air entraining admixtures may reduce water demand (-5 lbs/+1%)

62

Adjustments Due to Fiber Use

The use of fibers can also affect water demand.

May result in less slump.
<u>But</u> may not affect workability as much as anticipated.

Nylon fibers could increase water demand

Trial Batches

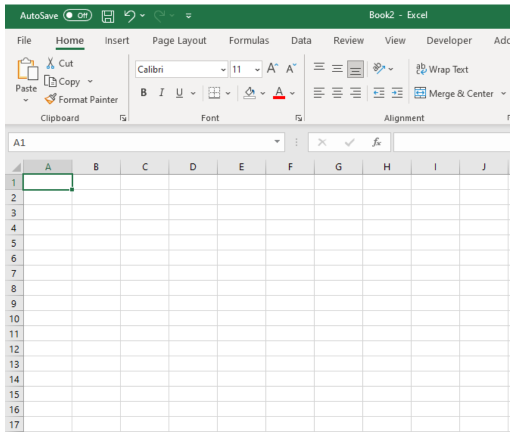
63

Adjustments for SCC Mixes

Property	Powder Content	Water Content	Maximum Coarse Aggregate Size	Sand-to-Aggregate Ratio	VMA Dosage	HRWRA Dosage
Fluidity						
Too Low		↑			↓	↑
Too High		↓			↑	↓
Viscosity						
Too Low	↑	↓			↑	
Too High		↑			↓	
Insufficient Passing Ability	↑	↓	↓	↑	↑	
Stability						
Excessive Segregation	↑				↑	
Aggregate Pile			↓	↑		
Mortar Halo	↑	↓			↑	↓

64

Using Excel



65

Questions?

66

Mix Design Adjustments
Quickly and Accurately Adapting to Changes

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67