Chapter 8: Proportioning Concrete Mixes

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.

Also, to determine the proportion of ingredients that would produce a workable concrete mix that is durable, and of required strength, and at a minimum cost

Factors to be considered include:

- **Workability.**
- **Cohesiveness, slump.**
- **Placement conditions.**
- **Strength.**
- **Durability.**
- **Appearance.**
- **Economy.**
- **Minimize the amount of cement, Minimize w/c ratio.**
- **Minimum amount of water, to reduce cement content.**
- **do not sacrifice the quality.**

- Economical consideration
  - Minimize water and cement, Stiffest possible mix
  - Largest practical max size of aggregate, Shape, Surface Texture
  - Optimize ratio of fine to coarse
  - Grading (Particle Size distribution, PSD) and its significance, Consistency, Strength, Finishability
- Size and shape of members
  - Max size of aggregate
- Physical properties
  - Strength
- Exposure condition
  - Air entraining or not, sulfate attack

- The most economical mix is the one with the largest possible max size aggregate
- Max size of aggregate
  - < 1/5 of narrowest dimensions of form
  - or ¾ of spacing between rebars
  - or unreinforced slabs < 1/3 thickness

Principles of Mix Design

- Workable mix.

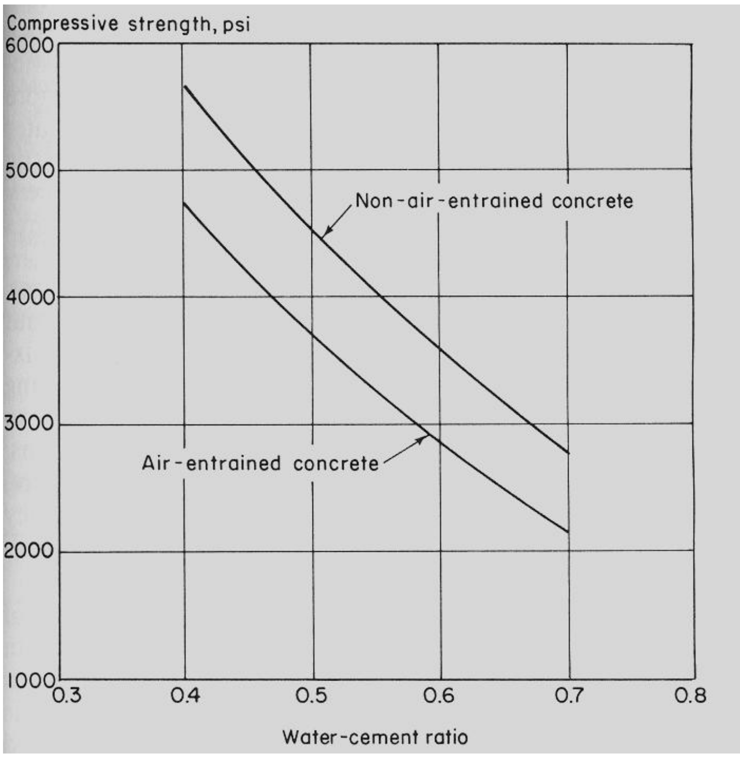
- Use as little cement as possible.

- Use as little water as possible.

- Gravel and sand to be proportioned to achieve a dense mix

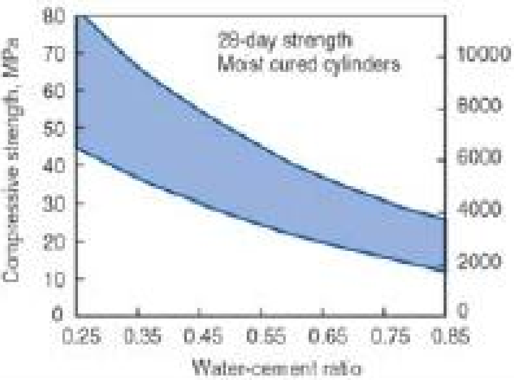
- Maximum size of aggregates should be as large as possible, to minimize surface area of aggregates

Affect of Water/cement Ratio (w/c ratio)



Water/Cement Ratio

- A minimum *w/c ratio* (water-to-cement ratio) of about 0.3 by weight is necessary to ensure that the water comes into contact with all cement particles (thus assuring complete hydration).
- Typical values are in the 0.4 to 0.6



Water/cement ratio (w/c ratio) theory states that for a given combination of materials and as long as workable consistency is obtained, the strength of concrete at a given age depends on the w/c ratio.

In 1918, Duff Abrams established a water/cement ratio law for the strength of concrete :

$$\sigma_c = \frac{A}{B^{1.5(w/c)}}$$

$\sigma_c =$ **compressive strength at some fixed age, A = empirical constant (96.5 MPa), B= constant that depends mostly on the cement properties (about 4) , and w/c (water/cement ratio by weight).**

Advantages of low water/cement ratio:

- **Increased strength.**
- **Lower permeability.**
- **Increased resistance to weathering.**
- **Better bond between concrete and reinforcement.**
- **Reduced drying shrinkage and cracking.**
- **Less volume change from wetting and drying.**

Methods of Mix Proportioning

- **Absolute volume method**

  Most commonly used method (ACI mix dsign)

- **Other methods**

- **ACI 211.1 Standard practice for selecting Normal, Heavyweight and Mass Concrete.**
- **ACI 211.2 Standard practice for selecting Structural lightweight concrete.**
- **ACI 211.3 Standard practice for selecting Proportions for no-slump concrete.**
- **ACI 211.4R Standard practice for selecting high strength concrete with Portland cement and fly ash.**

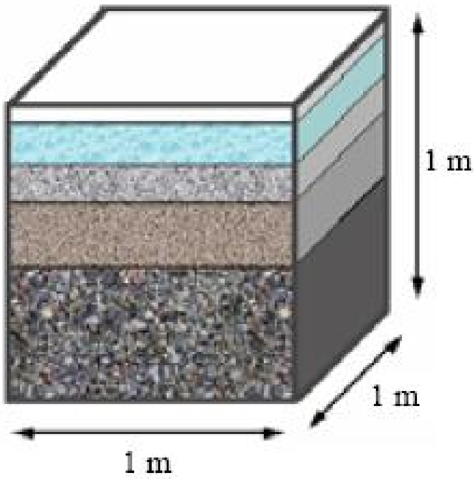
Designing Concrete Mixtures

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 yard or a cubic meter of concrete.

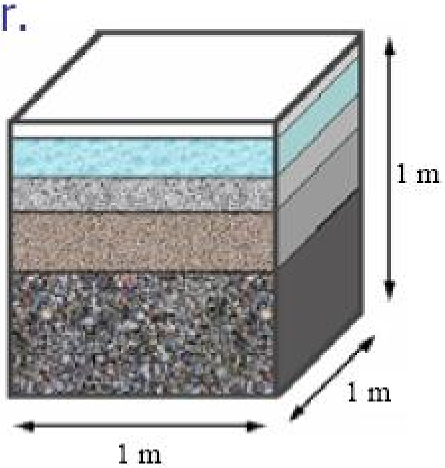
Material	Volume m^3	Density kg/m^3	Mass kg
Air	0.060		
Water	0.150	1000	150
Cement	0.111	3150	350
Sand	0.245	2650	650
Stone	0.434	2650	1150
Total	**1.000**		**2300**

Absolute Volume



- The mixture proportions of concrete are usually written in terms of mass per cubic meter.

Absolute Volume



Mixture proportions

Water	150 kg/m^3
Cement	350 kg/m^3
Sand	650 kg/m^3
Stone	1150 kg/m^3
Air	6%

ACI Mix Design

The most common method used which is established by ACI Recommended Practice 211.1

Any mix design procedure will provide a first approximation of the proportions and must be checked by trial batches.

Local characteristics of materials should be considered.

The following sequence of steps should be followed:

(1) determine the following:

- the job parameters
- aggregate properties
- maximum aggregate size
- slump
- w/c ratio
- admixtures,

(2) calculation of batch weight, and

(3) adjustments to batch weights based on trial mix.

The aim of the designer should always be to get concrete mixtures of optimum strength at minimum cement content and acceptable workability.

Once the w/c ratio is established and the workability or consistency needed for the

specific design is chosen, the rest should be simple manipulation with diagrams and tables based on large numbers of trial mixes.

ACI METHOD OF PROPORTIONING CONCRETE MIXES

The ACI Standard 211.1 is a "*Recommended Practice for Selecting Proportions for Concrete*". The procedure is as follows:

Step 1. Choice of slump

Step 2. Choice of maximum size of aggregate

Step 3. Estimation of mixing water and air content

Step 4. Selection of water/cement ratio

Step 5. Calculation of cement content

Step 6. Estimation of coarse aggregate content

Step 7. calculation of Fine Aggregate Content

Step 8. Adjustments for Aggregate Moisture

Step 9. Trial Batch Adjustments

Step 1. Choice of slump

If slump is not specified, a value appropriate for the work can be selected from the below Table which is reproduced from the text book below*, (note that the table numbers are given from the text book rather than the ACI standard).

Type of Construction	Slump	
	(mm)	(inches)
Reinforced foundation walls and footings	25 - 75	1 - 3
Plain footings, caissons and substructure walls	25 - 75	1 - 3
Beams and reinforced walls	25 - 100	1 - 4
Building columns	25 - 100	1 - 4
Pavements and slabs	25 - 75	1 - 3

Mass concrete	25 - 50	1 - 2

Step 2. Choice of maximum size of aggregate.

Large maximum sizes of aggregates produce less voids than smaller sizes. Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete, and of coarse it is the mortar which contains the most expensive ingredient, cement. Thus the ACI method is based on the principle that the **MAXIMUM SIZE OF AGGREGATE SHOULD BE THE LARGEST AVAILABLE SO LONG IT IS CONSISTENT WITH THE DIMENSIONS OF THE STRUCTURE.**

In practice the dimensions of the forms or the spacing of the rebars controls the maximum CA size.

ACI 211.1 states that the maximum CA size should not exceed:

- one-fifth of the narrowest dimension between sides of forms,
- one-third the depth of slabs,
- 3/4-ths of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pre-tensioning strands.

• **Special Note:** When high strength concrete is desired, best results may be obtained with reduced maximum sizes of aggregate since these produce higher strengths at a given w/c ratio.

Step 3. Estimation of mixing water and air content.

The ACI Method uses past experience to give a first estimate for the quantity of water per unit volume of concrete required to produce a given slump.

In general the quantity of water per unit volume of concrete required to produce a given slump is dependent on the

maximum CA size, the shape and grading of both CA and FA, as well as the amount of entrained air.

The approximate amount of water required for average aggregates is given in Table 10.2.

Table 10.2: Approximate Mixing Water and Air Content Requirements for Different Slumps and Maximum Aggregate Sizes.

	Mixing Water Quantity in kg/m^3 (lb/yd^3) for the listed Nominal Maximum Aggregate Size							
Slump	9.5 mm (0.375 in.)	12.5 mm (0.5 in.)	19 mm (0.75 in.)	25 mm (1 in.)	37.5 mm (1.5 in.)	50 mm (2 in.)	75 mm (3 in.)	100 mm (4 in.)
Non-Air-Entrained								
25 - 50 (1 - 2)	**207 (350)**	**199 (335)**	**190 (315)**	**179 (300)**	**166 (275)**	**154 (260)**	**130 (220)**	**113 (190)**
75 - 100 (3 - 4)	**228 (385)**	**216 (365)**	**205 (340)**	**193 (325)**	**181 (300)**	**169 (285)**	**145 (245)**	**124 (210)**
150 - 175 (6 - 7)	**243 (410)**	**228 (385)**	**216 (360)**	**202 (340)**	**190 (315)**	**178 (300)**	**160 (270)**	**-**
Typical entrapped air (percent)	**3**	**2.5**	**2**	**1.5**	**1**	**0.5**	**0.3**	**0.2**
Air-Entrained								
25 - 50 (1 - 2)	**181 (305)**	**175 (295)**	**168 (280)**	**160 (270)**	**148 (250)**	**142 (240)**	**122 (205)**	**107 (180)**
75 - 100 (3 - 4)	**202 (340)**	**193 (325)**	**184 (305)**	**175 (295)**	**165 (275)**	**157 (265)**	**133 (225)**	**119 (200)**
150 - 175 (6 - 7)	**216 (365)**	**205 (345)**	**197 (325)**	**184 (310)**	**174 (290)**	**166 (280)**	**154 (260)**	**-**
Recommended Air Content (percent)								
Mild Exposure	**4.5**	**4.0**	**3.5**	**3.0**	**2.5**	**2.0**	**1.5**	**1.0**
Moderate Exposure	**6.0**	**5.5**	**5.0**	**4.5**	**4.5**	**4.0**	**3.5**	**3.0**
Severe Exposure	**7.5**	**7.0**	**6.0**	**6.0**	**5.5**	**5.0**	**4.5**	**4.0**

Step 4. Selection of water/cement ratio.

The required water/cement ratio is determined by strength, durability and finishability. The appropriate value is chosen from prior testing of a given system of cement and aggregate or a value is chosen from Table 10.3 and/or Table 10.4.

Table 10.3: Water-Cement Ratio and Compressive Strength Relationship

28-Day Compressive Strength in MPa (psi)	Water-cement ratio by weight	
	Non-Air-Entrained	Air-Entrained
41.4 (6000)	**0.41**	**-**
34.5 (5000)	**0.48**	**0.40**
27.6 (4000)	**0.57**	**0.48**
20.7 (3000)	**0.68**	**0.59**
13.8 (2000)	**0.82**	**0.74**

TABLE 10-4 MAXIMUM PERMISSIBLE WATER/CEMENT RATIOS FOR CONCRETE IN SEVERE EXPOSURES

Type of Structure	Structure wet continuously or fequently exposed to freezing & thawing*	Structure exposed to seawater
Thin sections (railings, curbs, sills, ledges, ornamental work) & sections with less than 1-inch cover over steel	0.45	0.40
All other structures	0.50	0.45

* Concrete should also be air-entrained.

Step 5. Calculation of cement content.

The amount of cement is fixed by the determinations made in Steps 3 and 4 above.

$$\text{weight of cement} = \frac{\text{weight of water}}{w/c}$$

Step 6. Estimation of coarse aggregate content.

The most economical concrete will have as much as possible space occupied by CA since it will require no cement in the space filled by CA.

Table 10.5: Volume of Coarse Aggregate per Unit Volume for Different Fine aggregate Fineness Moduli

Nominal Maximum Aggregate Size	Fine Aggregate Fineness Modulus			
	2.40	2.60	2.80	3.00

9.5 mm (0.375 inches)	0.50	0.48	0.46	0.44
12.5 mm (0.5 inches)	0.59	0.57	0.55	0.53
19 mm (0.75 inches)	0.66	0.64	0.62	0.60
25 mm (1 inches)	0.71	0.69	0.67	0.65
37.5 mm (1.5 inches)	0.75	0.73	0.71	0.69
50 mm (2 inches)	0.78	0.76	0.74	0.72

Notes:

1. These values can be increased by up to about 10 percent for pavement applications.
2. Coarse aggregate volumes are based on oven-dry-rodded weights obtained in accordance with ASTM C 29.

The ACI method is based on large numbers of experiments which have shown that for properly graded materials, the finer the sand and the larger the size of the particles in the CA, the more volume of CA can be used to produce a concrete of satisfactory workability.

Step 7. Estimation of Fine Aggregate Content.

At the completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity can be determined by difference if the "absolute volume" displaced by the known ingredients-, (i.e., water, air, cement, and coarse aggregate), is subtracted from the unit volume of concrete to obtain the required volume of fine aggregate.

Then once the volumes are know the weights of each ingredient can be calculated from the specific gravities.

Step 8. Adjustments for Aggregate Moisture.

Aggregate weights. Aggregate volumes are calculated based on oven dry unit weights, but aggregate is typically batched based on actual weight. Therefore, any moisture in the aggregate will increase its weight and stockpiled aggregates almost always contain some moisture. Without correcting for this, the batched aggregate volumes will be incorrect.

Amount of mixing water. If the batched aggregate is anything but saturated surface dry it will absorb water (if oven dry or air dry) or give up water (if wet) to the cement paste. This causes a net change in the amount of water available in the mix and must be compensated for by adjusting the amount of mixing water added.

Step 9. Trial Batch Adjustments.

The ACI method is written on the basis that a trial batch of concrete will be prepared in the laboratory, and adjusted to give the desired slump, freedom from segregation, finishability, unit weight, air content and strength.