MIX DESIGN OF CONCRETE

BACKGROUND

- ACI = American Concrete Institute
- ACI 211.1-91 is part of ACI manual published by American Concrete Institute. The document reapproved in 2009.
- Standard Practice for selecting proportions for normal, heavyweight and mass concrete is described
- Guide for selecting proportions for high-strength concrete is described in ACI 211.4R-93.
- Mean target strength up to 6000 psi (41 MPa) is considered as normal strength concrete and mean target strength above 6000 psi is considered as high strength.
- Smaller size aggregates have been shown to provide higher strength potential.
- Exposure condition of concrete limits the w/c ratio to ensure durability of concrete in adverse environment.

Table 6.3.4 (b) maximum permissible water-cement or water-cementitious material ratios for concrete in severe exposures

Type of structure	structure wet continuously or frequently and exposed to freezing and thawing*	structures exposed to sea water or sulphates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 1" clear cover over steel	0.45	0.40**
All other structures	0.50	0.45**
*concrete should also be air entrained		
*** if sulphate resisting cement (Type II or Type V of ASTM C 150) is used, permissible water-cement ratio may be increased by 0.05*		

Slump value of concrete should be selected based on scope of compaction during casting, for example, to make **flowing concrete** slump should be in the range of **100-150 mm**, concrete for **cast in situ piles** should be in the range of **150-175 mm**. in addition, ACI recommended slump values are given below.

- **Table 6.3.1: recommended slumps for various types of construction**

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

- **Concrete mix proportion should be such that *compressive strength of most of the concretes would be more than design strength to get target mean strength of concrete mix*.**
- **Detail description of this is available in ACI 318-14.**
- **The simplest one is to use the following table to calculate mean target strength or required average compressive strength.**

Table 5.3.2.2- required average compressive strength when data are not available to establish a standard deviation

specified compressive strength, f'_c, psi	required average compressive strength, f'_{cr}, psi
Less than 3000	f'_c +1000
3000 to 5000	f'_c +1200
over 5000	1.10f'_c +700

specified compressive strength, f'_c, MPa	required average compressive strength, f'_{cr}, MPa
Less than 21	f'_c + 7.0
21 to 35	f'_c + 8.5
over 35	1.10f'_c + 5

MIX DESIGN EXAMPLE

- ACI method
- Ready mixed concrete will be cast by pumping
- Admixture (super plasticizer) will be used to make flowing concrete
- Concrete will remain under sea water (i.e. offshore structure)
- Design strength of concrete is 35 MPa
- All necessary data are given in the following tables

Table 1: properties of fine aggregate

Sl No.	Property	Test method	Value	Unit
1	Bulk Specific Gravity (OD Basis)	ASTM C127	2.54	-
2	Apparent Specific Gravity (OD Basis)	ASTM C127	2.60	-
3	Absorption Capacity	ASTM C127	1.34	%
4	Dry Rodded Unit Weight	ASTM C29	1590	kg/m3
5	Moisture content of FA in Laboratory	-	4.0	%
6	Fineness Modulus (FM)	ASTM C136	2.62	-

Table 2: Properties of coarse aggregate (stone)

Sl No.	Property	Test method	Value	Unit
1	Bulk Specific Gravity (OD Basis)	ASTM C127	2.66	-
2	Apparent Specific Gravity (OD Basis)	ASTM C127	2.68	-
3	Absorption Capacity	ASTM C127	0.69	%
4	Dry Rodded Unit Weight	ASTM C29	1550	kg/m3
5	Moisture content of CA in Laboratory	-	0.38	%
6	Maximum size	-	20	mm

Table 3: Properties of cement

Sl No.	Property	Test method	Value	Unit
4	Compacted unit weight	---	1510	kg/m^3
5	Loose unit weight	---	1220	kg/m^3
6	Specific gravity of Cement	---	3.15	-

Table 4: Properties of water reducing admixture

Sl No.	Property	Test method	Value	Unit
1	Brand name		Master Polyheed 8320	-
2	Recommended dose		400-1200 ml per 100 kg cement	-
3	Expected water reduction		> 20	%
4	Specific gravity		1.08	-

Table 5: ACI recommended w/c ratio for normal strength concrete

Mean target strength		w/c ratio
psi	MPa	
6000	41	0.41
5000	34	0.48
4000	28	0.57
3000	21	0.68
2000	14	0.82

Table 6: ACI recommended dry rodded bulk volume of coarse aggregate per unit volume of concrete

Max size of aggregate (mm)	FM of fine aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Table 7: First estimate of density of fresh concrete

Nominal max size of coarse aggregate	Density of fresh concrete (kg/m^3)
9.5	2280
12.5	2310
19	2345
25	2380
37.5	2410
50	2445
75	2490
150	2530

Table 8: ACI recommended mixing water content for 1 m3 fresh concrete

Maximum size of aggregate (mm) →	10	12.5	20	25	40	50	70	150
Slump value (mm) ↓	Amount of mixing water in kg per 1 m^3 concrete							
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
Entrapped air (%)	3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2

STEP BY STEP DESIGN

Step 1: Selection of slump value

To make flowing concrete, slump = 100 -150 mm

Step 2: Selection of maximum size of coarse aggregate

a) Nominal maximum size of coarse aggregate should be the largest possible which is economically available;

b) Maximum size of coarse aggregate should be less than:

- **One-fifth of the narrowest dimension of the structure;**
- **One-third of the depth of slab;**
- **Three-fourth of minimum clear spacing between bars;**
- **Clear cover.**

Here, we have no information about size of structure and maximum size of available aggregate is 20 mm.

So, maximum size of CA = 20 mm

Step 3: Estimation of mixing water content and air content

Usually for concrete structures exposed to severe weathering, air-entrained concrete is needed. As air-entraining admixture is expensive and not readily available in Bangladesh, non air-entrained concrete will be used.

Using Table 8, for slump = 100-150 mm and maximum size of CA = 20 mm,

Mixing water

$$= \frac{205 + 216}{2} = 210.5 \text{ kg per m3 fresh concrete}$$

Entrapped air content = 2% (Table 8)

Super plasticizer Master Polyheed 8630 will be used to increase workability. Polyheed can reduce mixing water content upto 20% depending on its dose.

If we use the dose of Polyheed 8630 = 1000 ml per 100 kg cement and assume that it would reduce water content by 15%,

So, mixing water = 210.5 × 0.85 = 179 kg per 1 m^3 fresh concrete

Step 4: Selection of w/c ratio

Considering durability of concrete which is exposed to sea water, maximum permissible w/c ratio is 0.45 (see Table 6.3.4 b of ACI 211.1-91)

$$\text{So, } \frac{w}{c} \leq 0.45$$

Considering strength of concrete

Design compressive strength		=	35.0 MPa
Safety Margin		=	8.5 MPa
Target Mean strength		=	43.5 MPa
For 41 MPa	w/c ratio	=	0.41
For 34 MPa	w/c ratio	=	0.48
For 7 MPa difference in strength, diff in w/c ratio		=	0.07

For (43.5-41.0=) 2.5 MPa diff in strength, diff in w/c ratio

$$= \left(\frac{0.07}{7}\right) \times 2.5 = 0.025$$

So, for 43.5 MPa, w/c ratio = 0.41- 0.025 = 0.385 = 0.38

i.e., $\frac{w}{c} \leq 0.38$ (***governs***)

or to avoid interpolation or extrapolation, we can use following formula to get w/c ratio

$$\frac{w}{c} = 1.1734\, e^{-0.0259\, f_c^{/}}$$

Step 5: Calculation of cement content and admixture

Cementitious material or binder $\frac{w}{w/c} = \frac{179}{0.38} = 471kg$

Dose of admixture depends on the requirement of workability and past experience of using the same admixture.

Here, let us use 700 ml Polyheed 8630 per 100kg cement

So, amount of admixture $= \frac{700}{100}(471) ml\ per\ 1\ m3\ concrete =$

$3297\ ml = \ 3297\ cm3 = \ 3297\ (1.08)\ gm = \ 3561\ gm = \ 3.651\ kg$

Admixture is generally water based solution. Amount of mixing water will be changed, Mixing water = 179 – 4 = 175 kg

Step 6: Estimation of coarse aggregate content

Using Table 6,

Dry rodded bulk volume of CA= 0.64 m^3 per 1 m^3 concrete

Dry mass of CA = 0.64 × 1550 kg = 992 kg per 1 m^3 concrete

SSD mass of CA $= 992\left(1+\frac{0.69}{100}\right) = 999kg$

Step 7: Calculation of fine aggregate content

Fine aggregate content can be calculated using mass method or volume method

Mass method

Using Table 7, approximate density of fresh concrete = 2345 kg/m3

So, SSD mass of FA = 2345 –W-C – CA (SSD) – Adm
= 2345 – 175 – 471-999 -4
= 696 kg

OD mass of FA $= \frac{696}{1+\frac{1.34}{100}} = 687kg$

Volume method

Total volume of concrete is 1 m3 which must be equal to sum of solid volumes of all ingredients

$$\frac{W}{1000}+\frac{Cement}{(3.15)1000}+\frac{FA_{(OD)}}{(BSG_{FA-OD})1000}+\frac{CA_{(OD)}}{(BSG_{CA-OD})1000}+\frac{Adm}{(SG)1000}+\frac{Air\ Content}{100}(1)=1$$

So,

$$\frac{175}{1000}+\frac{471}{(3.15)1000}+\frac{FA_{(OD)}}{(2.54)1000}+\frac{992}{(2.66)1000}+\frac{3.956}{(1.08)1000}+\frac{2}{100}(1)=1$$

FA (OD) =686 kg

FA (SSD) $= 686\left(1+\frac{Absorption\ capacity}{100}\right)= 686\left(1+\frac{1.34}{100}\right)= 695$kg

Volume method does not require assumption of density of fresh concrete, so it is more rational than mass method

So, FA (OD) = 686 Kg

FA (SSD) = 695 Kg

Basic mix design is complete here.

Mix proportion for 1 m3 fresh concrete

Water	**= 175 kg**
Cement	= 471 kg
FA (SSD)	= 695 kg
CA (SSD)	= 999 kg
Polyheed 8630	= 3.956 kg
Total	= 2344 kg

Step 8: Adjustment and First lab trail mix

Surface moisture or free moisture in FA =

$$686\left(\frac{Moisture\ content - Absorption\ capacity}{100}\right) = 686\left(\frac{4.0-1.34}{100}\right) = 18.2\ kg$$

Surface moisture or free moisture in CA $= 992\left(\frac{0.38-0.69}{100}\right) = -3.1\ kg$

Adjust mixing water = 175 – 18.2 – (-3.1) = 159.9 kg = 160 kg

Adjusted FA = 695 +18.2 = 713.2 Kg = 713 kg

Adjusted CA = 999 -3.1 = 995.9 Kg = 996 kg

Mix proportion for 1m3 fresh concrete

	SSD mass (kg)	Adjusted wet mass (kg)
Water	175	160
Cement	471	471
Fine aggregate	695	713
Coarse aggregate	999	996
Polyheed8630	3.956	3.956
Total	2344	2344

Using first lab trail mix, we have to measure density of fresh concrete and slump value. In the laboratory we have cylindrical mould of diameter 6″ and 4″. We shall use three cylindrical mould of diameter 6″ and height 12″. Volume of 3 cylinders

$$= 3\left(\frac{\pi}{4}(0.150)^2(0.300)\right) = 0.0159\ \mathrm{m}^3$$

Consider 25% loss during handling,

So, volume of fresh concrete needed for first lab trail mix = 1.25 × 0.0159 = 0.0199 m^3 = 0.02m^3

Mix proportion for 0.02 m3 fresh concrete

	Adjusted wet mass (kg)	**Adjusted wet mass (kg)**
water	160 × 0.02 =	3.20
cement	471 × 0.02 =	9.42
Fine aggregate	713 × 0.02 =	14.26
Coarse aggregate	996 × 0.02 =	19.92
Polyheed 8630	3.956 × 0.02 =	0.079

Table 10: First trail mix result

	Weight of cylinder	Weight of cylinder +concrete	Weight of concrete	Diameter (mm)	Height (mm)	Volume mould (m^3)	Density (kg/m^3)	Average density (kg/m^3)
Cylinder1	11.00	24.50	13.50	155	305	0.005755	2346	2390
Cylinder2	10.99	24.67	13.68	153	305	0.005608	2440	
Cylinder3	10.88	24.60	13.72	155	305	0.005755	2384	

Water added	0.3 kg more water added than calculated for first trail mix
Slump measured	100 mm
Measured density of fresh concrete	2390 kg/m^3

Mixing procedure

- At first coarse aggregate, fine aggregate and cement are weighted separately and put into mixer machine. Mixer machine is rotated for 1-2 minutes.
- Then water and admixture are weighed separately and mixed together before pouring into mixed machine.
- Admixture mixed water is now poured into mixed machine. Mixer machine is rotated for more than 5 minutes to make homogeneous mix of concrete.
- Freshly mixed concrete is taken out from mixer machine and slump test is performed.
- Then half of 9 moulds are filled up and compacted. Compaction can be performed using vibrator, rodding or vibratory table.
- Rest portion of moulds are filled up, compacted and levelled at top of mould. Next day, concrete cylinders are taken out from moulds and kept submerged into water or lime water for curing.
- Let us name this final trail mix as M35 – 01
- Perform strength tests at designated period of curing