Concrete Mix Design

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Concrete Mix Design

Mix design is defined as the process of selecting suitable ingredients of concrete and determine their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible.

- Variables in Proportioning :4 varaible factors to be considered:

1. Water – cement Ratio
2. Cement –aggregate ratio
3. Gradation of the aggregates
4. Consistency

- In design mix ,generally 2-3 factors are specified & others are adjusted.
- To use minimum amount of cement paste that can lubricate the mass and will bind the aggregates together and fill the space between them.
- Excess paste involves more cost, shrinkage, impermeability etc.
- Good gradation of aggregates to minimize voids.

Methods of Proportioning

1. Indian Standards Recommended method IS 10262-82
2. American Concrete Institute Method of Mix Design (ACI 211)
3. DOE method
4. Mix design for pumpable concrete
5. Indian Road Congress , IRC 44 method
6. Road note no.4 (Grading curve method)
7. Mix design based on flexural strength
8. Arbitrary proportion
9. Fineness modulus methods
10. Maximum density method
11. Surface area method

American Concrete Institute Method of Mix Design (ACI)

Data to be collected:

a) Fineness modulus of fine aggregates
b) Sp gravity of coarse & fine aggregates
c) Absorption characteristics of coarse & fine aggregates
d) Sp gravity of cement

STEPS IN ACI METHOD

1. From minimum strength specified, estimate average design strength using standard deviation method
2. Find w/c ratio from table 2. Find water cement ratio for durability from table 3. adopt lower value.
3. Decide maximum size of aggregate (generally 20 mm for RCC)
4. Decide workability in terms of slump for the type of job in hand. Table 4.
5. Total water in kg/m3 is read from table 5 entering the table with selected slump & selected maximum size of aggregate.
6. Cement content is computed by dividing total water content by w/c ratio.

7. From table 4 the bulk volume of dry rodded coarse aggregate / unit volume of concrete is selected, for particular maximum size of coarse aggregate & fineness modulus of fine aggregate.
8. The weight of CA /M3 of concrete is calculated by multiplying the bulk volume with bulk density.
9. The solid volume of coarse aggregate in one M3 of concrete is calculated by knowing the sp. Gravity of CA
10. Solid volume of cement, water & volume of air is calculated in one m3 of concrete
11. Solid volume of sand is calculated by substracting soild volume of cement, CA,water, & air from total volume of concrete.
12. Weight of fine aggregate is calculated by multiplying the solid volume of fine aggregate by sp gr of FA.

(1) Dry Bulk Volume of coarse aggregate/ unit volume of concrete as per ACI 211.1-91

Maximum size of aggregate	**Bulk volume of dry rodded CA /unit volume of concrete for fineness modulus of sand of**			
FM	2.4	2.6	2.8	3.OO
10	0.5	0.48	0.46	0.44
12.5,	0.59	0.57	0.55	0.53
20 (25,40,50,70)	0.66	0.64	0.62	0.60
150	.87	0.85	0.83	0.81

(2) Relation between water/cement ratio & average compressive strength of concrete, as per ACI211.1-91

Average compressive strength at 28 days	Effective water/cement ratio (by mass)	
MPa	Non air entrained concrete	Air entrained concrete
45	0.38	-
40	0.43	-
35 (30,25,20)	0.48	0.4
15	0.8	0.71

(3) Requirements of ACI-318-89 for w/c ratio & strength for special exposure conditions

Exposure condition	**Maximum w/c ratio, normal density aggregate concrete**	**Minimum design strength, low density aggregate concrete MPa**
Concrete intended to be watertight		
(a) Exposed to fresh water	0.5	25
(b) Exposed to sea water	0.45	30
Concrete exposed to freezing in a moist condition	0.45	30
For corrosion protection of reinforced concrete exposed to de icing salts, sea water	0.4	33

(4) Recommended value of slump for various types of construction as per ACI 211.1-91

Type of construction	Range of slump (mm)
Reinforces foundation walls & footings	20-80
Plain footings,substructure wall	20-80
Beams & reinforced walls	20-100
Building columns	20-100
Pavements & slabs	20-80
Mass concrete	20-80

(5) Approximate requirements for mixing water & air content for different workabilities & nominal maximum size of aggregates as per ACI211.1-91

Non air entrained concrete				
Workability or air content (Slump)	Water content, kg/m3 of concrete for indicted maximum aggregate size			
	10 mm (25, 40,50,70)	12.5 mm	20 mm	150 mm
30 -50 mm	205	200	185	125
80-100 mm	225	215	200	140
150-180 mm	240	230	210	-
Approx entrapped air (%)	3	2.5	2	0.2

(6) First estimate of density of fresh concrete as per ACI 211.1-91

Maximum size of aggregate (mm)	First estimate of density of fresh concrete	
	Non air entrained kg/m^3	Air entrained kg/m^3
10	2285	2190
12.5 (20,25,40,50)	2315	2235
20	2355	2280
150	2505	2435

(7) Required increase in strength (mean strength) for specified design strength when no tests records are available as per ACI 318-89

Specified design strength (MPa)	Required increase in strength (MPa)
Less than 21	7
21-35	8.5
35 or more	10

Example –ACI method

Design a concrete mix for construction of elevated water tank.

a) Specified design strength = 30 MPa
b) Standard deviation = 4 MPa
c) Sp gr. FA & CA = 2.65 & 2.7
d) Dry rodded bulk density of CA = 1600 kg/m3
e) FM of FA = 2.8
f) Slump = 50 mm
g) CA is absorptive up to = 1 %
h) Free surface moisture in sand = 2 %

Calculation

- Mean Strength fm = fmin+ks (k =1.64)
- fm = 30+1.64x4 = 36.56 say 36.5
- From table 2 w/c = 0.47
- From exposure condition w/c = .5
- Minimum of 0.47 & 0.5 = 0.47
- From table 5 for slump 50 mm, 20 mm maximum aggregate & non air entrained condition Mixing water is 185 kg/m3
- Required cement content = 185/0.47 = 394 kg/m3
- From table 1, for 20 mm CA, FA 2.8, the dry rodded bulk vol of CA = 0.62
- Weight of CA = 0.62x1600 = 992 kg/m3
- From table 6,the first estimate of density of fresh concrete for 20 mm CA & non air entrained concrete is 2355 kg/m3
-

- Weight of all ingredient :
- Weight of water = 185 kg/m3
- Weight of cement =394 kg/m3
- Weight of CA = 992 kg/m3
- Weight of sand = 2355 –(185+394+992) = 784 kg/m3

ingredients	Weight kg/m3	Absolute volume cm3
cement	394	$394/3.15 \times 10^3 = 125 \times 10^3$
Water	185	$185/1 \times 10^3 = 185 \times 10^3$
CA	992	$992/2.7 \times 10^3 = 367 \times 10^3$
air		$2/100 \times 10^3 = 20 \times 10^3$
	Total abs vol	697×10^3 cm3

- Therefore absolute vol of FA =(1000 -697) X 10^3 = 303 10^3 cm3
- Weight of FA = 303 x 2.65 = 803 kg/m3
- Estimated qty of ingredients;

a) Weight of water = 185 kg/m3

b) Weight of cement =394 kg/m3

c) Weight of CA = 992 kg/m3

d) Weight of sand = 803 kg/m3

- Proportion
- C : FA : CA ; WATER
- 394: 803 : 992 : 185
- 1 : 2.04 : 2.52 : 0.47
- For one bag of cement 50 kg Ratio in kg is = 50:102:126:23.5

Indian Standard Method of Concrete Mix-IS 10262-1982

STEPS

IS Method - Step 1

Target mean strength of concrete

$$f_{ck} = f_{ck1} + tS$$

Refer table 1 & 2 for t & S

- f_{ck} = strength at 28 days
- f_{ck1} = characteristics strength at 28 days
- t = 1.65 = statistical value; (depends on expected proportion of low results(risk factor)
- S = standard deviation

IS Method – Step 2

Selection of water cement ratio:

- From graph 1 ,w/c ration corresponding to target strength is determined.

IS Method – Step 3

- If 28 days strength of cement is known then w/c ratio can also be calculated from graph 2.

IS Method – Step 4

Estimation of entrapped air:

- Air content is estimated from table 3 for maximum size of CA

IS Method – Step 5

Selection of water content & Fine to Total aggregate ratio:

a) water content & % of sand in total aggregate is determined from table 4 & 5
b) w/c ratio in table 4 is 0.6 & in table 5 it is 0.35
c) For any departure from above values, corrections are made as per table 6 for w/c ratio & sand in total aggregate.

IS Method – Step 6

Calculation of cement content:

- Cement content = water content from step 5 divided by w/c ratio
- Cement content = Water content /w/c

IS Method – Step 7

Calculation of aggregate content:

1. $V = [W+C/S_c + F_a/PS_{fa}] \times 1/1000$

   $0.98 = [191.6 + 383/3.15 + F_a/ 0.315 \times 2.6]/1000$ F_a = 546 kg/m3

1. $C_a = (1-P)/P \times f_a \times S_{ca}/S_{fa} = (1-0.315)/0.315 \times 546 \times 2.6/2.6$ = 1188 kg/m3

V = absolute volume =gross vol – entrapped air

W = mass of water (kg)/m3 of concrete

C= mass of cement (kg)/m3 of concrete

S_c= sp gr of cement

P= ratio of FA to total aggregate by absolute volume

F_a, C_a Total masses of FA & CA kg/m3 of concrete

S_{ca} , S_{fa} Sp Gr of saturated, surface dry FA & CA

Example – IS method

Given:

a) Characteristic compressive strength : 20 Mpa
b) Maximum size aggregate : 20 mm (angular)
c) Degree of workability : 0.9 compacting factor
d) Degree of quality control : good
e) Type of exposure : mild

Test data for materials :

a) Sp gr of cement : 3.15
b) Comp strength of cement at 7 days : satisfies requirement of IS 269
c) Sp gr of CA : 2.6
d) Sp gr of FA : 2.6
e) Water absorption CA ; 0.5 %
f) Water absorption FA : 1.0 %
g) Free moisture CA : nil
h) Free moisture CA : 2 %

sieve analysis-CA

IS Sieve size	Analysis of CA fractions(% passing) I	II	Analysis of CA fractions(% passing) I 60%	II 40%	combined 100%	remark
20	100	100	60	40	10	Conforming to table 2 of IS 383
10	0	71.2	0	28.5	28.5	
4.75		9.4	3.7	3.7		
2.36	-	-	-	-		

sieve analysis -FA

IS Sieve size	Fine aggregate (% passing)	remark
4.75 mm	100	Conforming to grading zone III of table 4 IS 385-1970
2.36 mm	100	
1.18 mm	93	
600 µ	60	
300 µ	12	
150 µ	2	

Answer –IS Method
step 1

Target mean strength of concrete

$$f_{ck} = f_{ck1} + tS = 20 + 1.65 \times 4 = 26.6 \text{ MPa}$$

Refer table 1 & 2 for t & S

- f_{ck} = strength at 28 days
- f_{ck1} = characteristics strength at 28 days
- t = 1.65 = statistical value; (depends on expected proportion of low results(risk factor)
- S = standard deviation

Table 1-Values of tolerance factor(f)(risk factor)

Tolerance level No. of samples	1 in 10	1 in 15	1 in 20	1 in 40	1 in 100
10	1.37	1.65	1.81	2.23	2.76
20	1.32	1.58	1.72	2.09	2.53
30	1.31	1.54	1.7	2.04	2.46
Infinite	1.28	1.5	1.64	1.96	2.33

Table 2- assumed standard deviation as per IS 456-2000

Grade of concrete	Assumed standard deviation N/mm²
M 10	
M 15	3.5
M 20	
M 25	4
M 30	
M 35	
M40	5
M45	
M50	

Step 2

- Selection of w/c ratio
- From graph 1, w/c ratio for target mean strength 26.6 MPa is 0.50
- Refer table 4 of IS 456: maxmimum w/c ratio for “Mild exposure” is 0.55.
- Adopt lower value from above 2 options i.e 0.50

Graph 1-IS method

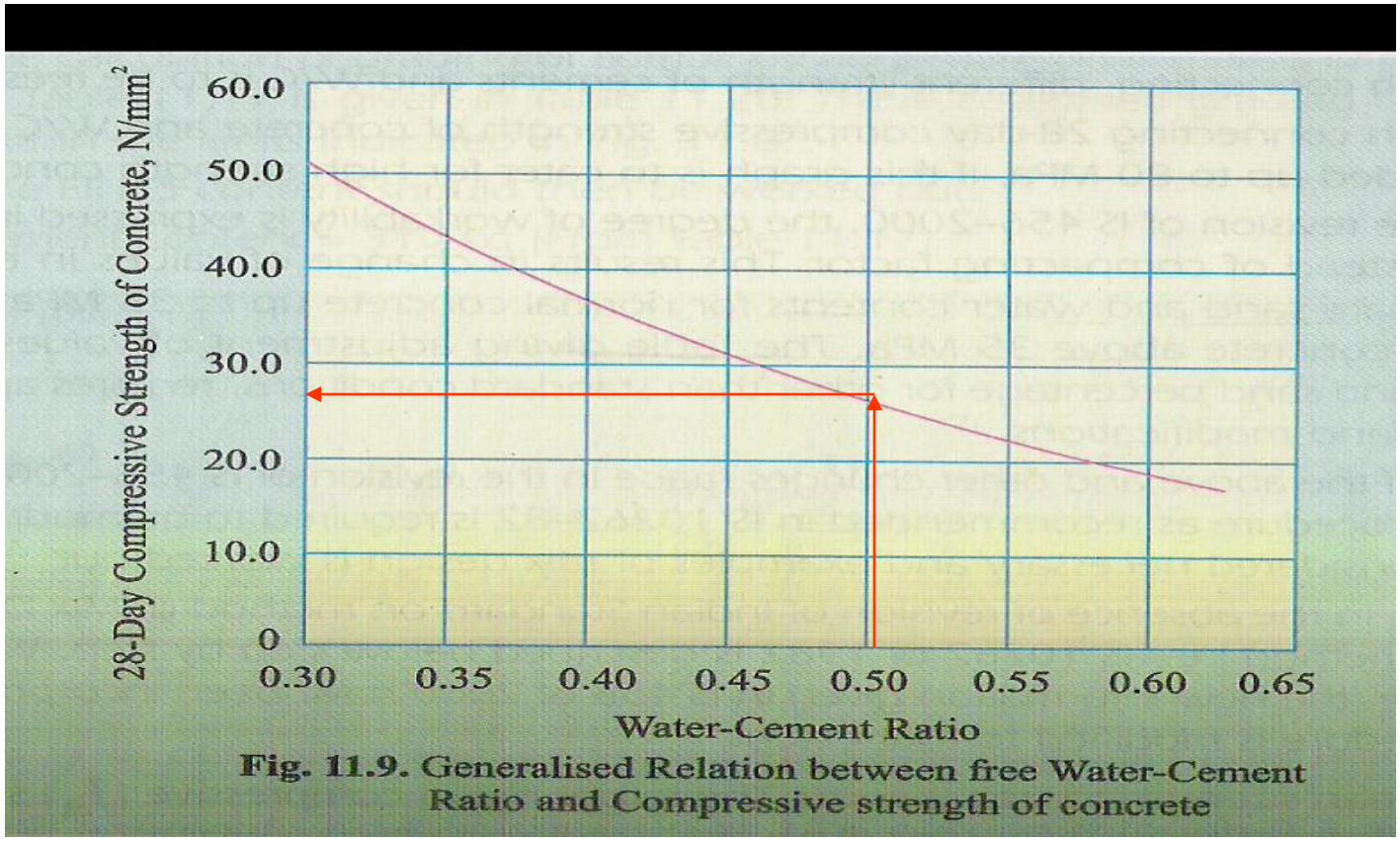


Fig. 11.9. Generalised Relation between free Water-Cement Ratio and Compressive strength of concrete

Table 3 – approximate entrapped air content

Maximum size of aggregate (mm)	Entrapped air, as % of volume of concrete
10	3
20	2
30	1

Table 4- approx sand,watercontent / m^3 of conc. ; w/c=0.6, workability 0.8 C.F.(slump 30 mm approx) (Applicable for grade up to M 35)

Max size aggregate(mm)	Water content/ m^3 of conc. (kg)	Sand as % of total aggregate by absolute volume
10	200	40
20	186	35
40	165	30

STEP 3

Selection of water & sand content:

- From table 4, for 20 mm maximum size aggregate, sand conforming to grading zone II, water content kg/ M3 of concrete = 186 kg & sand as % of total aggregate by absolute volume = 35 %.

Step 3

From Table 6 For change in value in water in w/c ratio, compaction factor, for sand belonging to zone III, following adjustment is required :

Change in condition (see table)	% adjustment required	
	water content	sand in total aggregate
For decrease in water –cement ratio by (0.60 – 0.50) i.e. 0.10	0	- 2.0
For increase in compacting factor (0.9-0.8) , i.e. 0.10	+3	0
For sand conforming to zone III of table 4 , IS 383	0	- 1.5
Total	+ 3	- 3.5

Therefore required sand content as % of total aggregate by absolute volume

= 35 – 3.5 = 31.5 %

Required water content = 186 + 5.58 = 191.6 kg/m3

Table 6- Adjustment of values in water content & sand % for other conditions

Change in conditions stipulated for tables	Adjustment required in Water content	% sand in total aggregate
Sand conforming to grading zone III or IV of table IS 383-1979	0	+1.5 % for zone I -1.5 % for zone III -3% for zone IV
Increase or decrease in value of compacting factor by 0.1	+/- 3%	O
Each 0.05 increase or decrease in water cement ratio	0	+/- 1 %
For rounded aggregate	-15 kg	-7 %

Table 5- approx sand,watercontent / m^3 of conc. ; w/c=0.35, workability 0.8 C.F.(slump 30 mm approx) (Applicable for grade above M 35)

Max size aggregate(mm)	Water content/ m^3 of conc. (kg)	Sand as % of total aggregate by absolute volume
10	200	28
20	180	25

Step 4

Determination of cement content :

w/c ratio = 0.5

Water = 191.6

Cement = 191.6/0.5 = 383 kg/m3

Step 5

Determination of CA & FA :

From table 3, for 20 mm CA, amount of entrapped air is 2 %. Taking this into account & applying equations 1 & 2 we get:

I. $V = [W+C/S_c + F_a/PS_{fa}] \times 1/1000$

II. $0.98 = [191.6 + 383/3.15 + F_a/ 0.315 \times 2.6]/1000$ $F_a = 546$ kg/m3

III. $C_a = (1-P)/P \times f_a \times S_{ca}/S_{fa} = (1-0.315)/0.315 \times 546 \times 2.6/2.6 = 1188$ kg/m3

V = absolute volume =gross vol – entrapped air = 100-2=98 %

W = mass of water (kg)/m3 of concrete = (191.6 from step 3)

C= mass of cement (kg)/m3 of concrete

S_c= sp gr of cement =3.15 (given in question)

P= ratio of FA to total aggregate by absolute volume = (31.5% from step 3.)

F_a, C_a Total masses of FA & CA kg/m3 of concrete =546 calculated above @ II

S_{ca} , S_{fa} Sp Gr of saturated, surface dry FA & CA = 2.6 (given in question)

RESULT

- Estimated qty of ingredients;

a) Weight of water = 191.6 kg/m3

b) Weight of cement =383 kg/m3

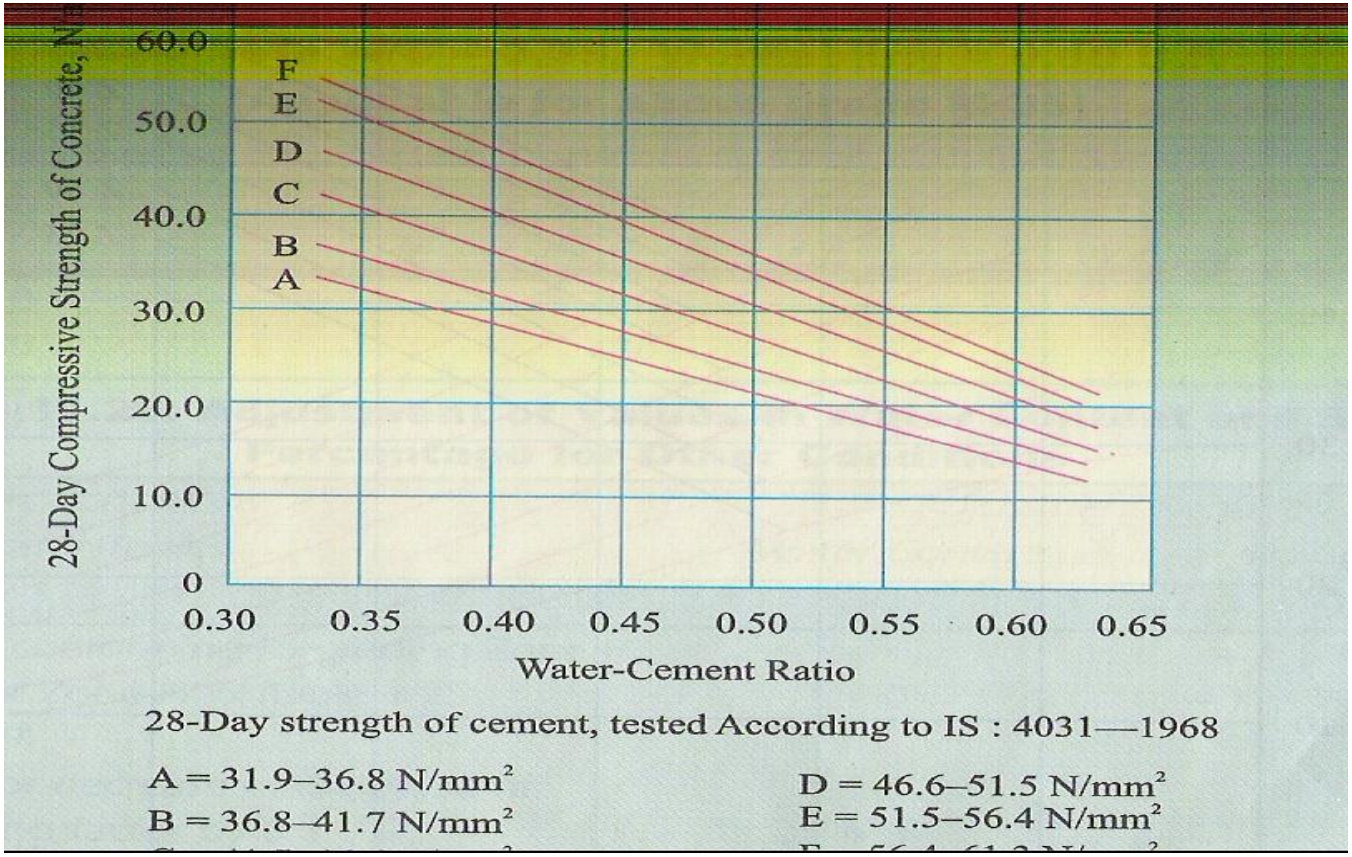
c) Weight of CA = 1188 kg/m3

d) Weight of sand = 546 kg/m3

- Proportion
- C : FA : CA ; WATER
- 383: 546 : 1188 : 191.6
- 1 : 1.425 : 3.1 : 0.5
- For one bag of cement 50 kg Ratio in kg is = 50:71:155:25

- Extra qty of water for absorption in CA = 0.5 % by mass = 0.77 liters
- Qty of water to be deducted for 2 % moisture in sand =1.42 liters
- Actual qty of water required = 25+.77-1.42 =24.35 liters
- Actual qty of sand = 71+1.42 =72.42
- CA : fraction I =93-0.46=92.54 kg
- Fraction II : 62-0.31=61.69 kg
- Actual qty :
- C : FA : CA ; WATER
- 50: 72.42 : 92.54 & 61.69 : 24.35

Graph 2 – I S method



Graph 3-IS method

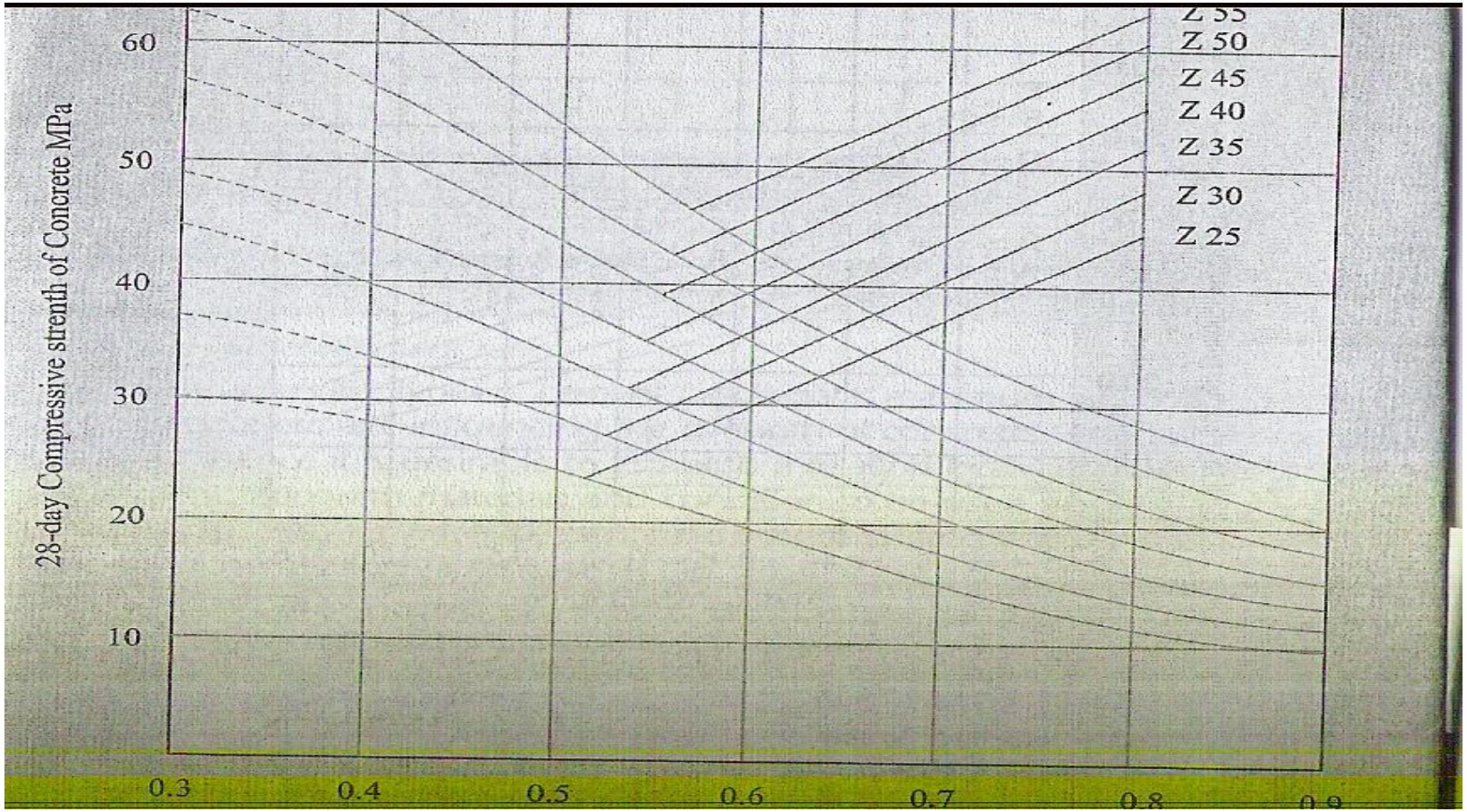


Table 4- IS METHOD

Table 9.18. Minimum Cement Content, Maximum W/C Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum size. IS 456 : 2000

Sl No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum cement contents kg/m^3	Maximum Free W/C ratio	Minimum Grade of concrete	Minimum Cement Content kg/m^3	Maximum Free W/C ratio	Minimum Grade of Concrete
1	Mild	220	0.60	–	300	0.55	M 20
2	Moderate	240	0.60	M 15	300	0.50	M 25
3	Severe	250	0.50	M 20	320	0.45	M 30
4	Very Severe	260	0.45	M 20	340	0.45	M 35
5	Extreme	280	0.40	M 25	360	0.40	M 40

Notes: (1) Cement content prescribed in this table is irrespective of the grade of cement and it is inclusive of all supplementary cementitious materials. The additions of all supplementary cementitious materials may

THANK YOU