CONCRETE MIX DESIGN:DEPARTMENT OF ENVIRONMENT APPROACH

A 2 - DAY MANDATORY NATIONAL WORKSHOP (WEBINAR) ORGANIZED

BY

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BY

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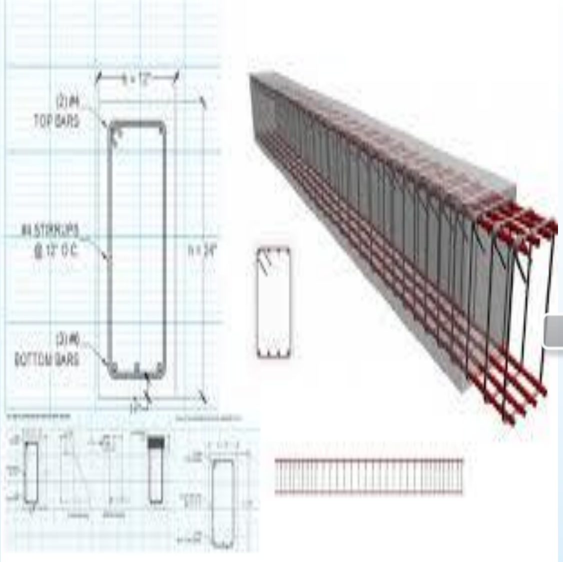
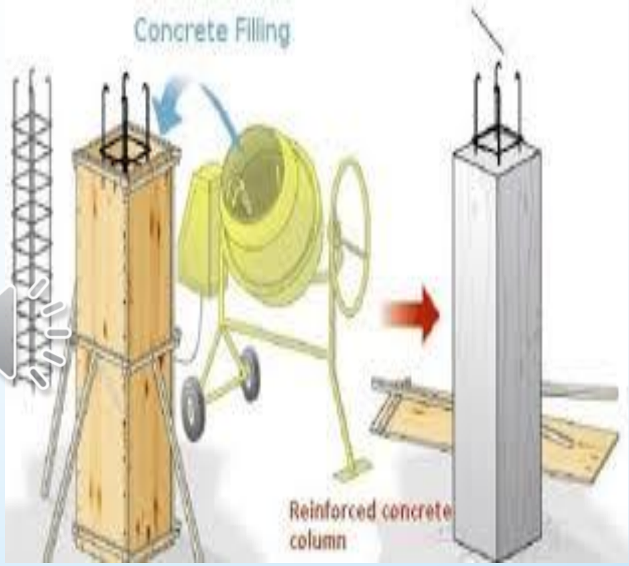
INTRODUCTION

- **Reinforced concrete structural elements such as slabs, beams, columns and foundations.**

SLAB



BEAM



COLUMN

FOUNDATION

- **While the reinforcement requires testing of the bar specimen in a tensile testing machine in the laboratory to ascertain that the specified strength is use in the production of the element, whereas the specified concrete strength should be designed by the Builder.**

INTRODUCTION CONTD.

- **The process of proportioning constituents of concrete to obtain concrete mixture satisfying the performance requirements at the lowest possible cost can be regarded as concrete mix design.**

- **It entails selecting the suitable ingredients among the available materials and determining the most economical combination that will produce concrete with certain minimum performance characteristics.**

- **The two most essential properties/requirements are the workability of fresh concrete and the strength of hardened concrete at a specified age, durability of concrete is generally assumed that under normal exposure conditions, will be satisfied if the concrete mixture develops the necessary strength.**

FACTORS FOR CONSIDERATION IN CONCRETE MIX DESIGN

- **1. cost: The most obvious consideration when choosing concrete-making materials is that they are technically acceptable and, at the same time, economically attractive.**

- **A key consideration governing many concrete mix design procedures is the recognition that cement costs much more than aggregates.**

- **All possible steps should be taken to reduce the cement content of a concrete mixture without compromising strength and durability.**

FACTORS FOR CONSIDERATION IN CONCRETE MIX DESIGN CONTD.

- 2. **workability: Workability of fresh concrete has a direct effect on the pump ability and constructability because it determines the ease with which a concrete mixture can be handled without harmful segregation (A) and bleeding (B).**

It embodies certain characteristics of fresh concrete, such as consistency and cohesiveness.

- **Consistency is a measure of the**
- **wetness of the concrete mixture, which is commonly evaluated in terms of slump (that is, the wetter the mixture, the higher the slump) (C& D).**

(A)

(B)

(C)

(D)

- **Most mix design procedures rely on slump as a crude index of workability.**

FACTORS FOR CONSIDERATION IN CONCRETE MIX DESIGN CONTD.

- **3. Strength and Durability: The strength of concrete specified by the designer is treated as the minimum required strength.**

- **A target mean strength, based on statistical consideration, higher than the minimum specified strength is used in mix design calculations to account for variation in concrete.**

- **When concrete is subject to normal conditions of exposure, the mix design procedures ignore durability because strength is considered to be an index of general durability.**

DEPARTMENT OF ENVIRONMENT CONCRETE MIX DESIGN APPROACH

- **The DOE method is based on the water-cement (w/c) ratio law of duff Abrams that states that the strength of concrete depends on the ratio of the water to the cement content**

- **It recognizes the problem of variability of concrete strength and other properties of concrete by assuming it to have certain minimum characteristics.**

- **The method adopts the generally accepted knowledge that variation in concrete strength follows the normal distribution curve.**

- **Concrete strength is specified as a characteristic strength, which is the strength below which specified percentage of the test results (called defectives) may be expected to fall.**

- **Structural use of concrete adopts the 5% defective level.**

BASIC STATISTICAL QUALITY CONTROL AND MATERIALS TESTING REQUIRED OF DOE CONCRETE MIX DESIGN

- **Variations occur on concrete strength from batch to batch and also within the batch. Variations could arise due to differences in the quality of the materials used, disparity in the mix proportions as a result of batching, protection or curing etc.**

- **The aim of quality control is to limit the variability as much as practicable. Statistical quality control method provides a scientific approach to the concrete designer to understand the realistic variability of the materials so as to lay down design specifications with proper tolerance to cater for unavoidable variations.**

- **The average design strength to be aimed at should be higher than the specified minimum strength stipulated by the designer, and this depends upon the quality control exercised at the time of making concrete.**

BASIC STATISTICAL QUALITY CONTROL AND MATERIALS TESTING REQUIRED OF DOE CONCRETE MIX DESIGN CONTD.

Common statistical tools used in the statistical quality control of concrete are:

1). Mean Strength, $\bar{X} = \Sigma X/N$

Where $\bar{X}$ = Mean Strength, ΣX = Sum of the Strength of Cubes

N = Number of Cubes

2). Variance: This is the measure of variability or difference between any single observed data from the mean strength.

3). standard deviation, $\sigma = [\, \Sigma(X - \bar{X})^2 \;/ N - 1]^{1/2}$

Where σ = Standard Deviation, N = Number of Observations, X = Particular value of observations, $\bar{X}$ = Arithmetic mean.

EXAMPLE OF CALCULATION OF STANDARD DEVIATION

Sample Number	Compressive Strength (X) (N/mm^2)	Average Strength $\bar{X} = \Sigma x / n$	Deviation $(X - \bar{X})$	Square of Deviation $(X - \bar{X})^2$
1	43		2.8	7.84
2	48		7.8	60.84
3	40		-0.2	0.04
4	38		-2.2	4.84
5	36		-4.2	16.64
6	39		-1.2	1.44
7	42		1.8	3.24
8	45		4.8	23.04
9	37		-3.2	10.24
10	35		-5.2	27.04
11	39	40.2	-1.2	1.44
12	41		0.8	0.64
13	49		8.8	77.44
14	46		5.8	33.64
15	36		-4.2	16.64
16	38		-2.2	4.84
17	32		-8.2	67.24
18	39		-1.2	1.44
19	41		0.8	0.64
20	40		-0.2	0.04
Total	804			359.20

Standard deviation, $\sigma = (359.20/N-1)^{1/2} = 359.2/19 = 4.34$ N/mm^2

Note: if the number of sample is < 20, σ should be taken as 8

EXAMPLES OF MATERIALS TESTINGS REQUIRED IN DOE MIX DESIGN

Table 4: Sieve Analysis of Sand

Mass of Sample = 500g			
Sieve size (mm)	Weight of material retained (g)	Percentage of material retained (%)	Percentage passing (%)
4.75	0.0	0.0	100.0
2.36	19.0	3.82	96.18
1.18	80.5	16.16	80.02
0.600	185.0	37.15	42.87
0.300	173.0	34.74	8.13
0.150	35.0	7.03	1.10
pan	5.5	1.10	0.00
Total	498.0	100	-

Table 5: Sieve Analysis of Coarse Aggregate (Granite)

Mass of Sample = 1500g			
Sieve size (mm)	Weight of material retained (g)	Percentage of material retained (%)	Percentage passing (%)
20	0.0	0.0	100.0
14	240.0	16.00	84.0
9.5	496.0	33.09	50.91
4.75	670.6	44.74	6.17
2.36	80	5.34	0.83
pan	12.4	0.83	0.0
Total	1499.0	100.0	-

Table 6: Specific gravity of sand (fine aggregate)

Sample number	Test 1(g)	Test 2(g)	Test 3 (g)
Weight of density bottle, w_1	40.9	35.6	35
Weight of density bottle + sample, w_2	85.5	66.8	79.8
Weight of density bottle + sample + water, w_3	168.9	155.55	163.4
Weight of water, $w_{4} = w_3 - w_2$	141.2	135.9	135.8
Weight of density bottle + water, w_5	83.4	88.75	83.6
Specific gravity, $Gs = w_2 - w_1/(w_5 - w_1 - w_{4})$	2.64	2.70	2.60
Mean G_s		2.65	

Table 7: Specific gravity of coarse aggregate (granite)

Sample number	Test 1(g)	Test 2(g)	Test 3 (g)
Weight of pycnometer, w_1	600	600	600
Weight of pycnometer + sample, w_2	1325	880	1330
Weight of pycnometer + sample + water, w_3	2025	1775	2028
Weight of water, $w_4 = w_3 - w_2$	725	895	722
Weight of pycnometer + water, w_5	1600	1600	1600
Specific gravity, $Gs = w_2 - w_1/(w_5 - w_1 - w_4)$	2.64	2.67	2.63
Mean G_s		2.65	

DESIGN PARAMETERS

parameters		Data
Characteristic strength of concrete specified		$30N/mm^2$
Cement type		Ordinary Portland (class 42.5)
Nominal maximum size of coarse aggregate		20mm (Table 5)
Type of aggregate	Coarse	Crushed
	Fine	Natural River Sand
Specific gravity of	Coarse aggregate	2.65 (Table 7)
	Fine aggregate	2.65 (Table 6)
Percentage of Fine aggregate passing 600µm sieve		43 (Table 4)
Workability desired (medium workability)		30 – 60mm slump
Standard deviation		4.2 (Table 2)

DEPARTMENT OF ENVIRONMENT CONCRETE MIX DESIGN PROCEDURE

- **STEP 1**: Determine the target mean strength (F_M) from the specified characteristic strength (F_{CU}) and standard deviation using the expression:

  $F_M = F_{CU} + K\sigma$

  where F_M = target mean strength, F_{CU} = specified characteristic strength,

  σ = standard deviation, K = Himsworth constant

- The value of k, which is derived from the statistics of the normal distribution, depends on the proportion of the defective result in a test. for instance, if 5% of result is allowed to fall below the minimum, the value of k is taken as 1.64. the various values of k are as provided in table 3.

Table 3: k factors used in statistical control

Percentage	16	10	5	2	1
K	1.00	1.28	1.64	2.05	2.33

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- **STEP 2:** Obtain the required information, including test results, on materials to be used.
- **STEP 3:** Determine the w/c ratio. the use of Table 8 and Figure 2 are employed based on an approximate compressive strength of concrete made with a free w/c ratio of 0.50. Compare the determined w/c ratio with maximum allowable value (Table 9) for adequate durability.

Table 8: approximate compressive strength of concrete made with a free - w/c ratio of 0.50.

Cement class	Type of Coarse aggregate	Compressive Strength at the age (cube) of days N/mm2			
		3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Uncrushed

crushed

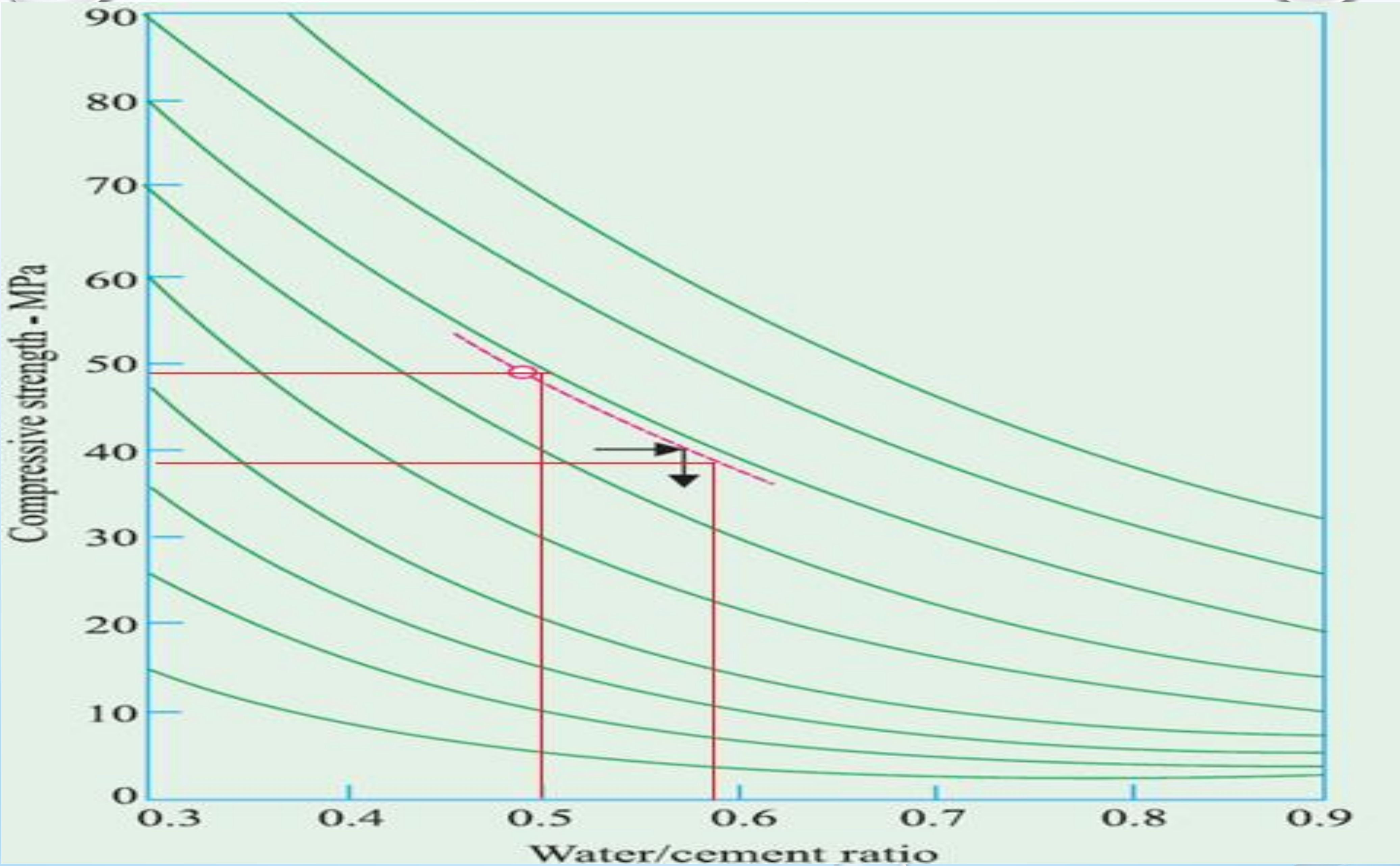

Figure 2: Relationship between compressive strength and free water/cement ratio.

Table 9: maximum water/cement ratio for reasonable durability

Condition of exposure	Maximum water-cement ratio	
	Plain concrete	Reinforced concrete
Internal, subject to heavy condensation	-	0.60
Alternate wetting and drying	0.60	0.60
Freezing and thawing	0.55	0.50
Seawater or salt spray	0.50	0.45
Water retaining structures	-	0.50

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- **STEP 4: D**ecide free water content for the required workability expressed in terms of slump, taking into consideration the size and type of aggregate from Table 10.

Table 10: Approximate free-water content (Kg/M^3) required to give various levels of workability.

Slump (mm)		1– 10	10 – 30	30 – 60	60 – 180
Vebe time (s)		>12	6 - 12	3 - 6	0 - 3
Maximum size of aggregate (mm)	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

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- **STEP 5:** Calculate the cement content from w/c ratio already obtained. Cement content (kg/m^3) = water content (kg/m^3)/w/c. Compare the amount of the cement content obtained with the minimum allowable content for durability given in Table 11.

Table 11: Maximum cement content for concretes with 20 mm maximum aggregate size under different condition of exposure.

Exposure conditions	Minimum cement content for concrete (Kg/m^3)		
	Plain	Reinforced	Pre-stressed
Non-corrosive	220	250	300
Buried or sheltered from rain	250	290	300
Exposed to alternate wetting and drying or seawater	310	360	360
Subject to de-icing salt (air-entrained concrete)	280	390	300

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- **STEP 6: F**ind out the total aggregate content. This requires an estimate of the wet density of the fully compacted concrete. The use of Figure 3 for approximate water content and specific gravity of aggregate can be used. if specific gravity is unknown, the value of 2.6 for uncrushed aggregate and 2.7 for crushed aggregate can be assumed. the aggregate content is obtained by subtracting the weight of cement and water content from weight of fresh concrete.

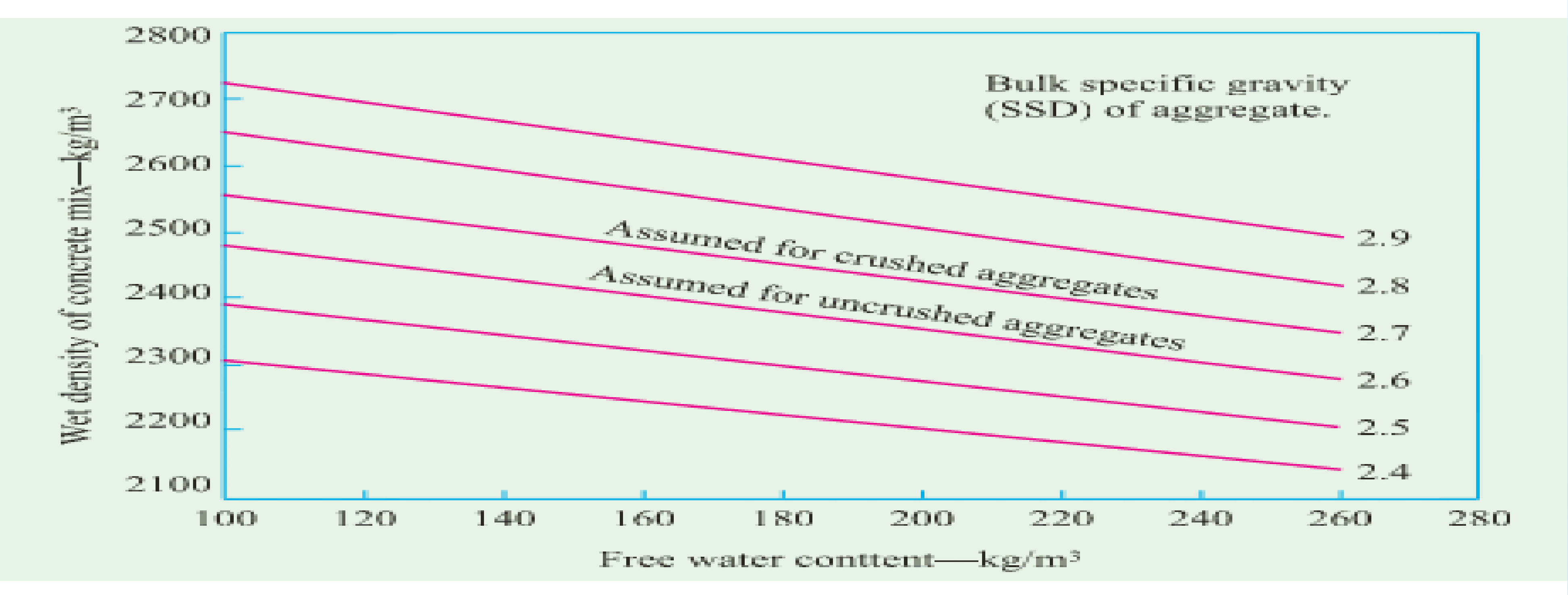

Fig. 3: Relationship between free-water cement ratio and wet density of fresh concrete

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- **STEP 7:** Compute the percentage of fine aggregate. This is computed from the total aggregate using Figures 4 – 6. the percentage of the fine aggregate passing through sieve 600µm size is used to determine the percentage proportion of the fine aggregate is the total quantity of aggregate. This proportion is then multiplied by the total quantity to obtain the quantity of fine aggregate. the weight of coarse aggregate is deduced by subtracting the weight of fine aggregate from the total aggregate.

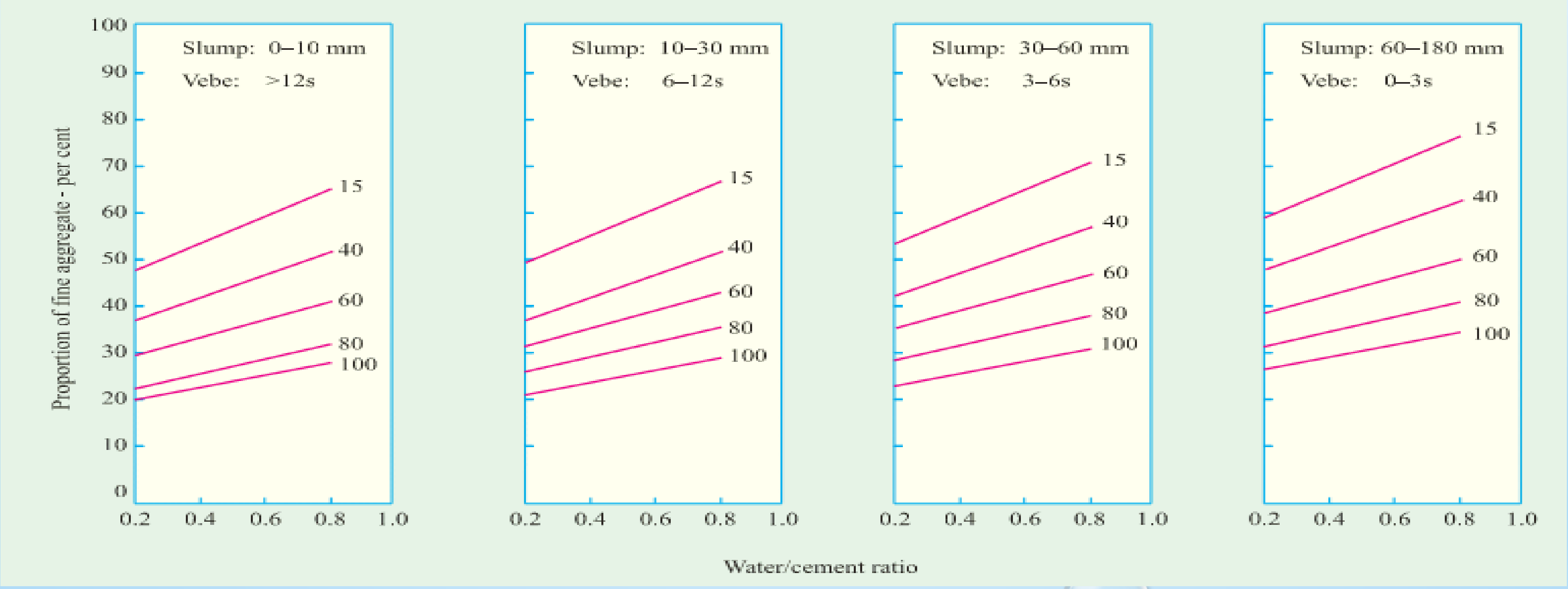

Figure 4: 10 mm coarse aggregate size

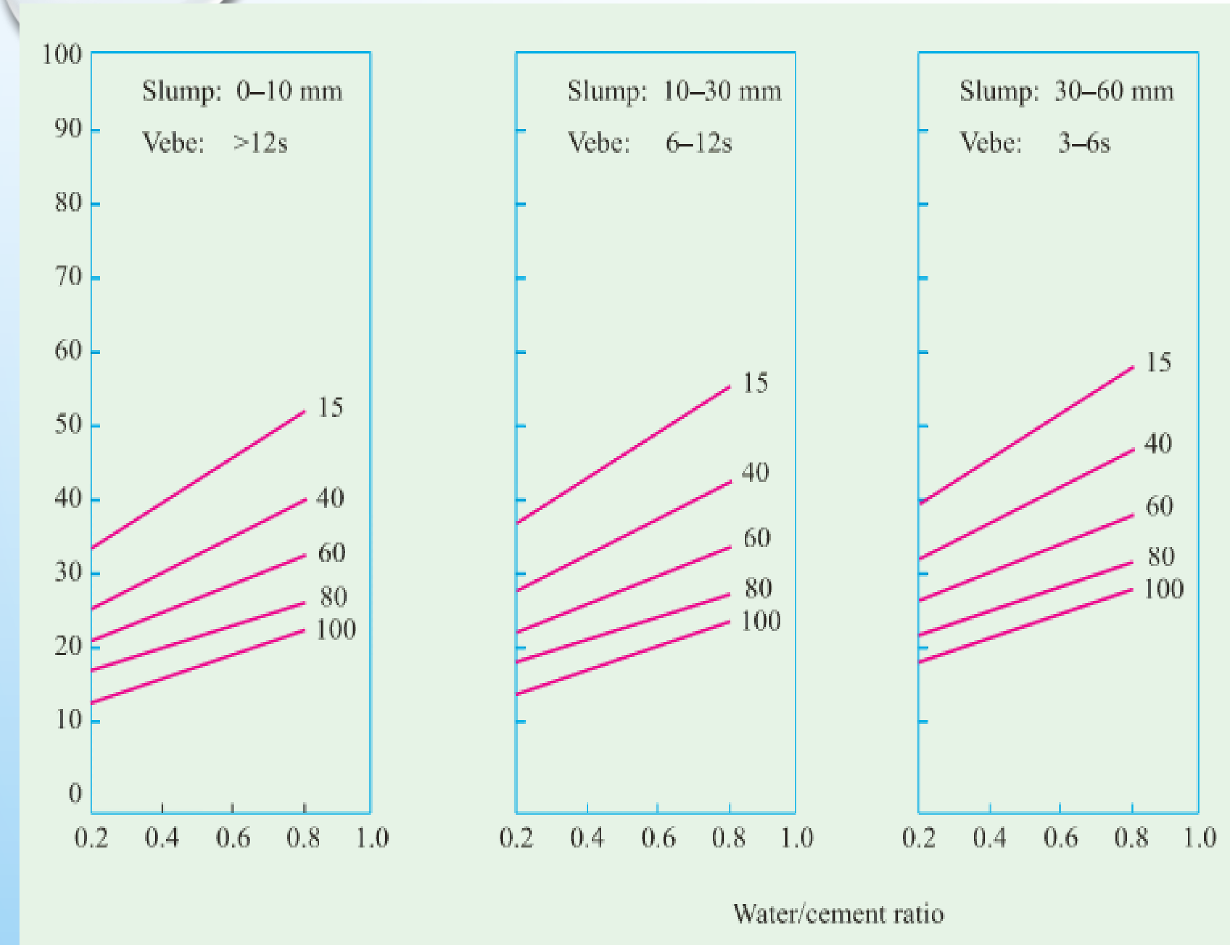

Figure 5: 20 mm coarse aggregate size

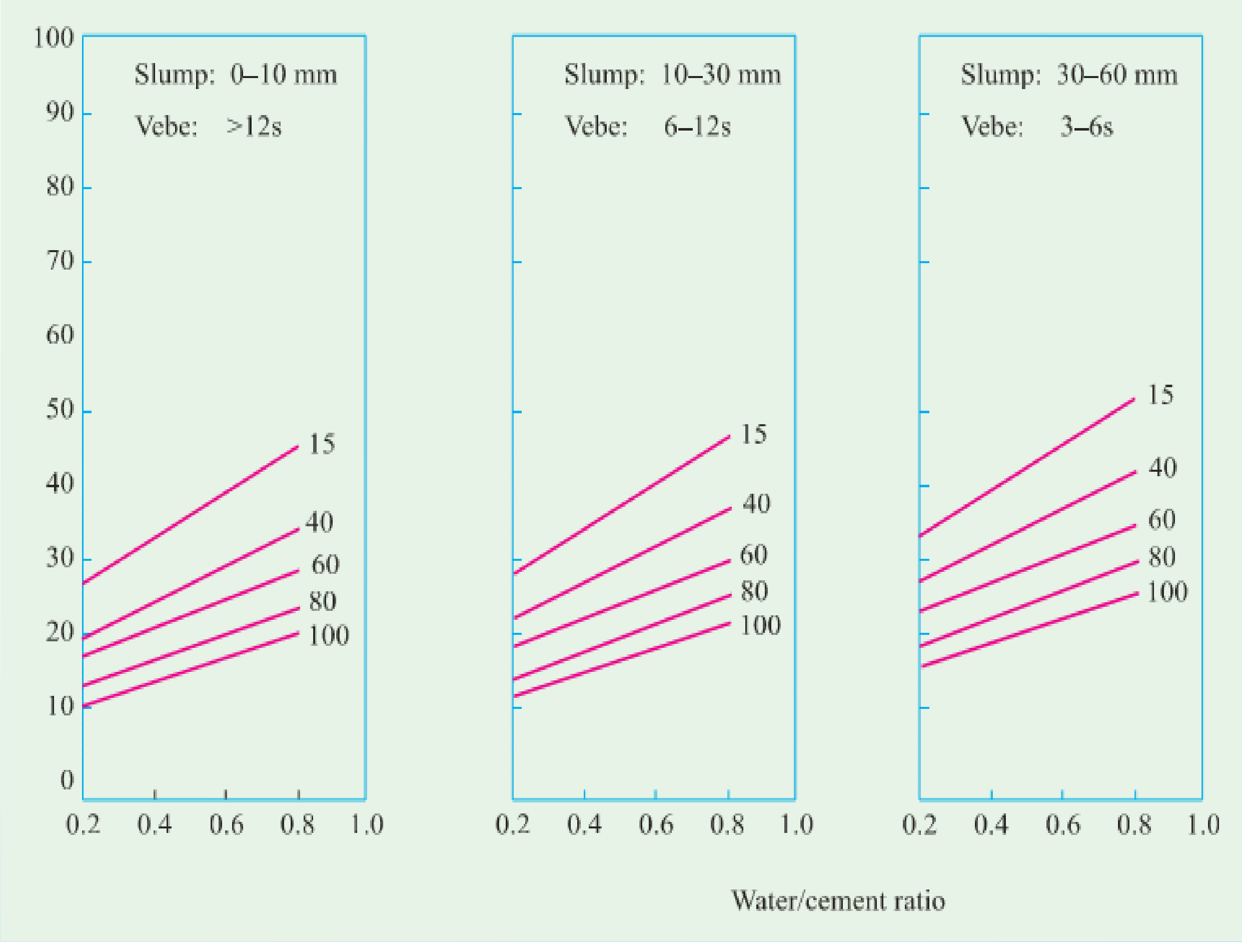

Figure 6: 40 mm coarse aggregate size

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- **Step 8:** Deduce the mix proportion by weight while taking cement proportion as 1.

- **Step 9:** Adjust the water content to take the moisture condition of the aggregates on site into consideration if necessary.

- **Step 10:** Present a summary of the result of the concrete mix designed on the concrete mix design form.

CONCRETE MIX DESIGN FORM

Stage	Item		Ref. or Cal.	Values
1	1.1	Characteristics strength	specified	.... N/mm^2 at 28 days Proportion defective 5%
	1.2	Standard deviation	table 2	----N/mm^2 or No. data ---N/mm^2
	1.3	Margin	Kδ	(K = 1.64) x = ... N/mm^2
	1.4	Target mean strength	F_m	..... +...... = ... N/mm^2
	1.5	Cement type	specified	....
	1.6	Aggregate type : coarse		....
		Aggregate type: fine		....
	1.7	Free-water/cement ratio	table 8, fig.2	....
	1.8	Max. Free-water/cement ratio	specified	.... use the lower value
2	2.1	Slump or V-B	specified	slump.......... Or V-B..............
	2.2	Max. Aggregate size	specified	.... mm
	2.3	Free-water content	table 10	.....................kg/m^3
3	3.1	Cement content		.... / .... _= ....kg/m^3
	3.2	Max. Cement content	specified	------- kg/m^3
	3.3	Minimum cement content	specified	------ kg/m^3 – use if greater than 3.1 and Calculate item 3.4
	3.4	Modified free water/cement ratio		--------------------------
4	4.1	Specific gravity of aggregate (SSD)		.... known /assumed
	4.2	Concrete density	fig. 3	.... Kg/m^3
	4.3	Total aggregate content		.... – .... –...... = ...kg/m^3
5	5.1	Grading of fine aggregate	percent passing 600μm	.... percent
	5.2	Proportion of fine aggregate	fig. 6	.... Percent
	5.3	Fine aggregate content		.... x........ = ...kg/m^3
	5.4	Coarse aggregate content		.... –.......... = ...kg/m^3

Quantities	Cement (Kg)	Water (Kg or L)	Fine aggregate (Kg)	coarse aggregate (Kg)
Per M^3 (to the nearest 5kg)	....	....	....	....
Per trial mix of 0.065	....	....	....	....

Thank You