WORK INSTRUCTIONS FOR ENGINEERS

Compiled by : CEL

Checked by : TYC

Approved by : LSS

OP-020. CONCRETE MIX DESIGN

20.0 PROCEDURE FOR CONCRETE MIX DESIGN

20.1. OVERALL PROCEDURE

This section will briefly list down the overall procedures for the design of concrete mix. These processes can be divided into 5 stages as follows:

1) Stage 1 – determine the free-water/cement ratio for the targeted mean strength.
2) Stage 2 – determine the free-water content for the targeted workability.
3) Stage 3 – combines the results of Stages 1 and 2 to give the cement content
4) Stage 4 – deals with the determination of the total aggregate content
5) Stage 5 – deals with the selection of the fine and coarse aggregate content

20.2. MARGIN FOR MIX DESIGN

As a result of the inherent variability of concrete in production, it is necessary to design a mix to have a mean strength greater than the specified characteristic strength by a statistical amount termed as the margin. Thus:

$$\mathbf{f_m = f_c + ks}$$

where f_m = the target mean strength

f_c = the specified characteristic strength

ks = the margin, which is the product of k x s

s = the standard deviation

k = a statistical constant

The constant k is derived from the statistic theory based on the normal distribution function and increases as the proportion if defectives is decreased, thus:

k for 10% defectives = 1.28

k for 5% defectives = 1.64

k for 2.5% defectives = 1.96

k for 1% defectives = 2.33

20.3. STAGE 1 – SELECTION OF TARGET WATER/CEMENT RATIO

Step 1. Determine the margin M for calculation C1 (please refer to Table 1Item 1.3):

$$\mathbf{M = k \times s} \quad \textbf{....... C1}$$

where

M = the margin

k = a value appropriate to the ‘percentage defectives’ permitted below the characteristic strength

(please refer to section 42.2 of this operating procedure)

s = standard deviation (Figure 1)

Step 2. Calculate the target mean strength f_m :

$$\mathbf{f_m = f_c + M} \textbf{ ....C2} \qquad \text{(please refer to Table 1-Item 1.4):}$$

where f_m = the target mean strength

f_c = the specified characteristic strength

M = the margin

Step 3. From Table 2, a value is obtained for the strength of a mix made with a free-water/cement ratio of 0.5 according to the specified age, the type of cement * and the aggregate to be used.

* OPC = Ordinary Portland Cement
SRPC = Sulphate-Resisting Portland Cement
RHPC = Rapid-Hardening Portland Cement

Step 4. The strength value from Step 3 is then plotted on the starting line on Figure 2 ***(which corresponds to w/c ratio of 0.5)*** and an envelope curve is drawn from this point and parallel to the printed envelope curves until it intercepts a horizontal line passing through the ordinate representing the target mean strength.

The corresponding value for the free-water/cement ratio can then be read from the abscissa. However, this should be compared with any maximum free-water/cement ratio that may be specified and the lower of these two values used.

20.4. STAGE 2 – SELECTION OF FREE-WATER CONTENT FOR WORKABILITY

From Table 3, determine the free-water content depending upon the type (crushed/uncrushed) and maximum size of the aggregate to give a concrete mix with specified slump or Vebe time.

20.5. STAGE 3 – DETERMINATION OF CEMENT CONTENT

Step 1. The cement content is determined from calculation C3

(please refer to Table 1-Item 3.1):

$$\text{Cement Content} = \frac{\text{Free-water Content}}{\text{Free-water / Cement ratio}}$$

Step 2. The resulting value should be checked against any maximum or minimum value that may be specified. If the calculated cement content from C3 is below a specified minimum, this specified minimum value must be adopted. A modified free-water/cement ratio shall be calculated, based on this specified minimum cement content and reiterate the calculation process from Stage 1 until all requirements are satisfied.

Step 3. If the design method indicates cement content that is higher than a specified maximum than it is probable that the specification cannot be met simultaneously on strength and workability requirements with the selected materials. Consideration should then be given to change the type of cement, the type and maximum size of aggregate or the level of workability of the concrete, or to the use of a water reducing admixture.

20.6. STAGE 4 – DETERMINATION OF TOTAL AGGREGATE CONTENT

Step 1. From Figure 3, estimate the density of the fully compacted concrete depending upon the free-water content and the relative density of the combined aggregate in the saturated surface-dry condition (SSD).

Step 2. If no information is available regarding the relative density of the aggregate, an approximation can be made by assuming a value of 2.6 for uncrushed aggregate and 2.7 for crushed aggregate.

Step 3. From the estimated density of the concrete, the total aggregate content is determined from calculation C4 (please refer to Table 1-Item 4.3):

Total aggregate content = D – C – W
(for saturated and surface-dry condition)

where D = the wet density of concrete (kg/m^3)

C = the cement content (kg/m^3)

W = the free-water content (kg/m^3)

20.7. STAGE 5 – SELECTION OF FINE AND COARSE AGGREGATE CONTENTS

Step 1. To determine the quantity of materials smaller than 5mm, (i.e. sand or fine aggregate content) from the total aggregate content.

Step 2. Figure 4 recommends values for the proportion of fine aggregate depending on the maximum size of aggregate, the workability level, the grading of the fine aggregate (defined by its percentage passing a 600μm sieve) and the free-water/cement ratio.

Step 3. Solving calculation C5 (please refer to table 1-item 5.3 & 5.4):

Fine Aggregate Content =	Total Aggregate Content (from Table 1-Item 4.3)	X	Proportion of Fines (from Step 2)
Coarse Aggregate Content =	Total Aggregate Content	–	Fine Aggregate Content

Table 1 :Concrete mix design form

Stage	*Item*		*Reference or calculation*	*Value*
1	1.1	Characteristic strength	Specified	______ N/mm^2 at ______ days; Proportion defective ______ per cent
	1.2	Standard deviation (σ)	Fig 3	______ N/mm^2 or no data ______ N/mm^2
	1.3	Margin (*k x σ*)	C1	(k = ______) ______ x ______ = ______ N/mm^2
	1.4	Target mean strength	C2	______ + ______ = ______ N/mm^2
	1.5	Cement type	Specified	OPC / SRP / RHPC
	1.6	Aggregate type : coarse		______
		Aggregate type : fine		______
	1.7	free-water / cement ratio	Table 2, Fig 4	______ } Use the lower value
	1.8	*Maximum free-water / cement ratio*	*Specified*	______ }
2	2.1	Slump or V-B	Specified	Slump ______ mm or V-B ______ s
	2.2	Maximum aggregate size	Specified	______ mm
	2.3	Free - water content	Table 3	______ kg/m^3
3	3.1	Cement content	C3	______ ÷ ______ = ______ kg/m^3
	3.2	*Maximum cement content*	*Specified*	______ kg/m^3
	3.3	*Minimum cement content*	*Specified*	______ kg/m^3 - Use if greater than Item 3.1 and calculate Item 3.4
	3.4	Modified free-water /cement ratio		______
4	4.1	Relative density of aggregate (SSD)		______ known/ assumed
	4.2	Concrete density	Fig 5	______ kg/m^3
	4.3	Total aggregate content	C4	______ - ______ - ______ = ______ kg/m^3
5	5.1	Grading of fine aggregate	BS 882	Zone ______
	5.2	Proportion of fine aggregate	Fig 6	______ per cent
	5.3	Fine aggregate content	C5	______ x ______ = ______ kg/m^3
	5.4	Coarse aggregate content	C5	______ - ______ = ______ kg/m^3

Quantities	Cement (kg)	Water (kg or l)	Fine aggregate (kg)	Coarse aggregate (kg)
per m^3 (to nearest 5 kg)	______	______	______	______
per trial mix of ______ m^3	______	______	______	______

Item in italics are optional limiting values that may be specified (see Section 7)
1 N/ mm2 = 1 MN/ m = 1 MPa (see footnote on page 8)
OPC = ordinary Portland cement; SPRC = sulphate-resisting Portland cement; RHPC = rapid-hardening Portland cement
Relative density = specific gravity (see footnote on page 15)
SSD = based on a saturated surface-dry basis

Table 2: Approximate Compressive Strength (N/mm^2) of Concrete Mixes Made with a Free-Water / Cement Ratio 0.5

Type of Cement	Type of Coarse Aggregate	Compressive Strengths (N/mm2)			
		Age (days)			
		3	7	28	91
Ordinary Portland (OPC) or Sulphate Resisting Portland (SRPC)	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
Rapid Hardening Portland (RHPC)	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

1 N/mm^2 = 1 MN/m^2 = 1 MPa

Table 3: Approximate Free-Water Contents (kg/m^3) Required To Give Various Levels of Workability

Slump (mm)		0-10	10-30	30-60	60-180
Vebe Time (s)		>12	6-12	3-6	0-3
Maximum Size 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

Note: When coarse and fine aggregate of different types are used, the free-water content is estimated by the expression

$$2/3\ W_f + 1/3\ W_c$$

where W_f = free-water content appropriate to type of fine aggregate

and W_c = free-water content appropriate to type of coarse aggregate

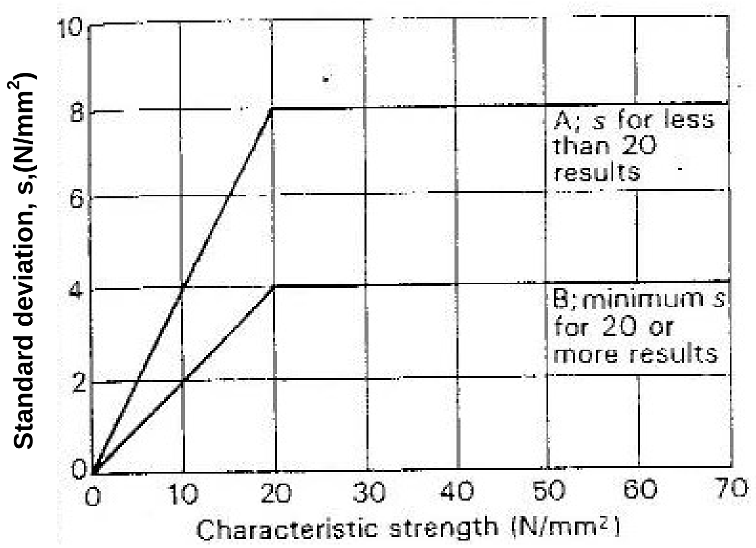

Figure 1: Relationship between standard deviation and characteristic strength

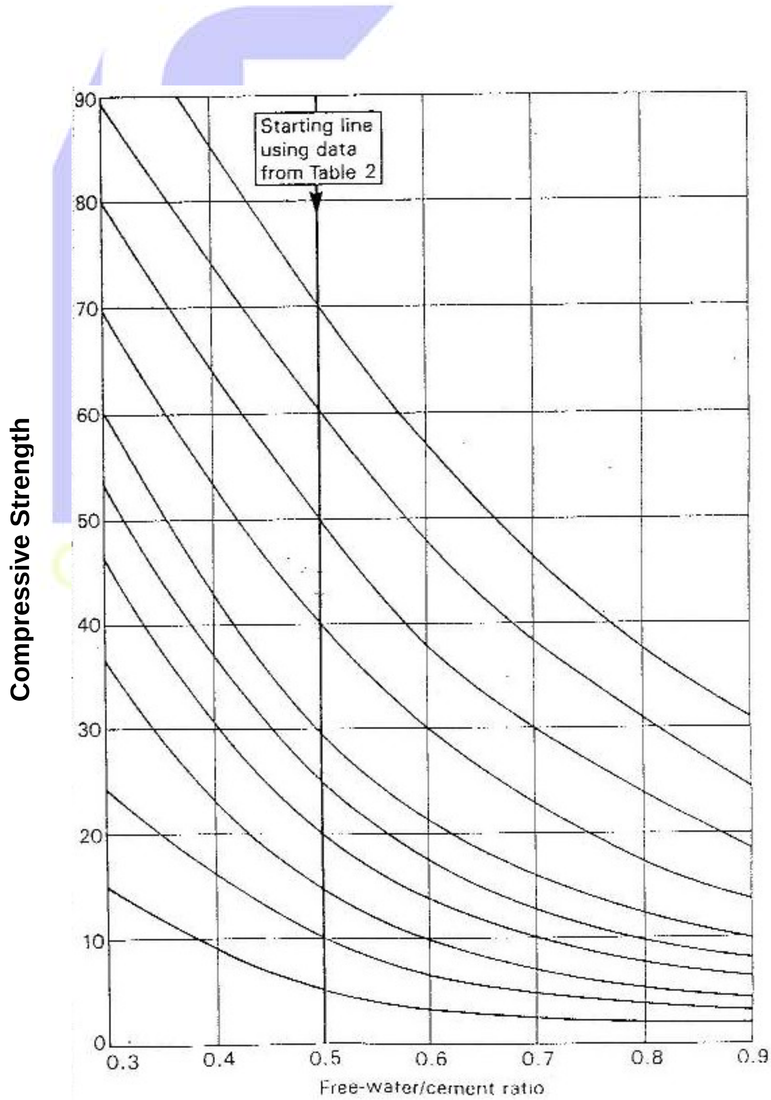

Figure 2: Relationship between compressive strength and free-water/cement ratio

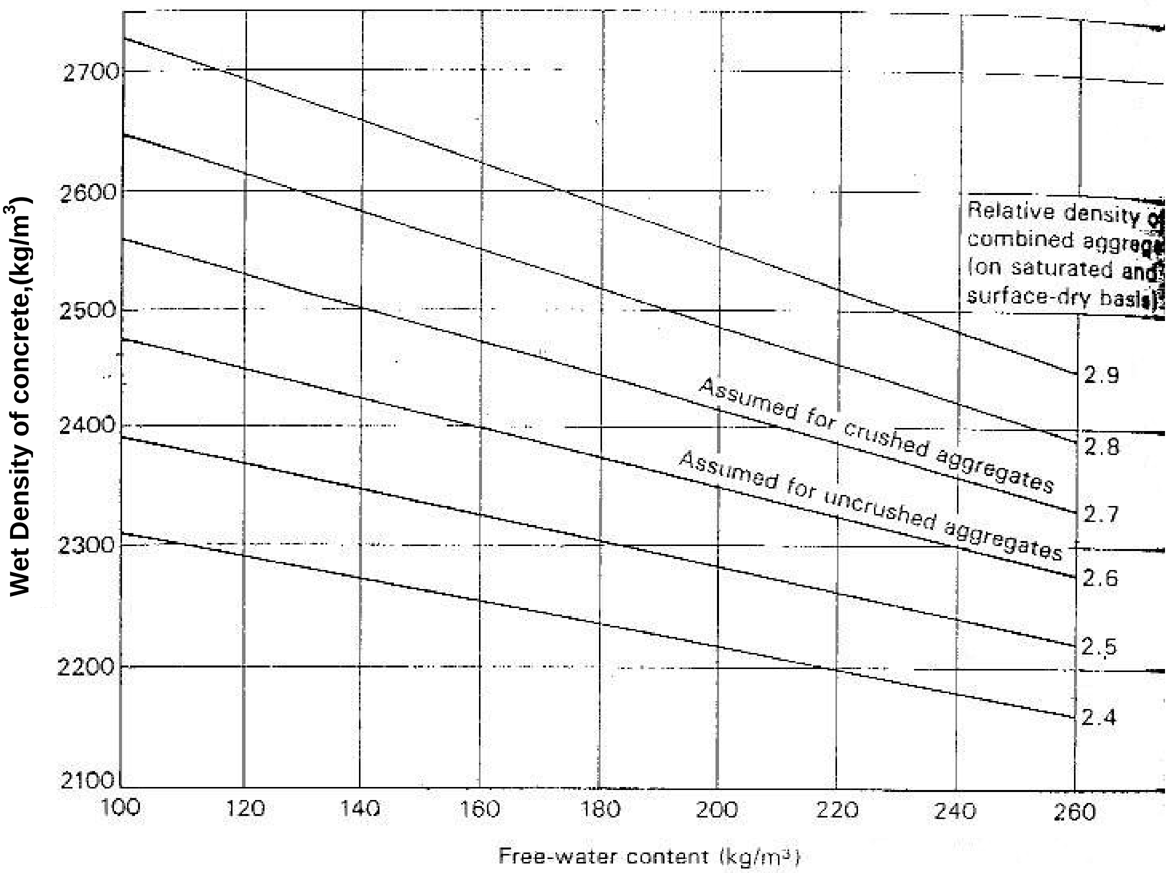

Figure 3: Estimated wet density of fully compacted concrete

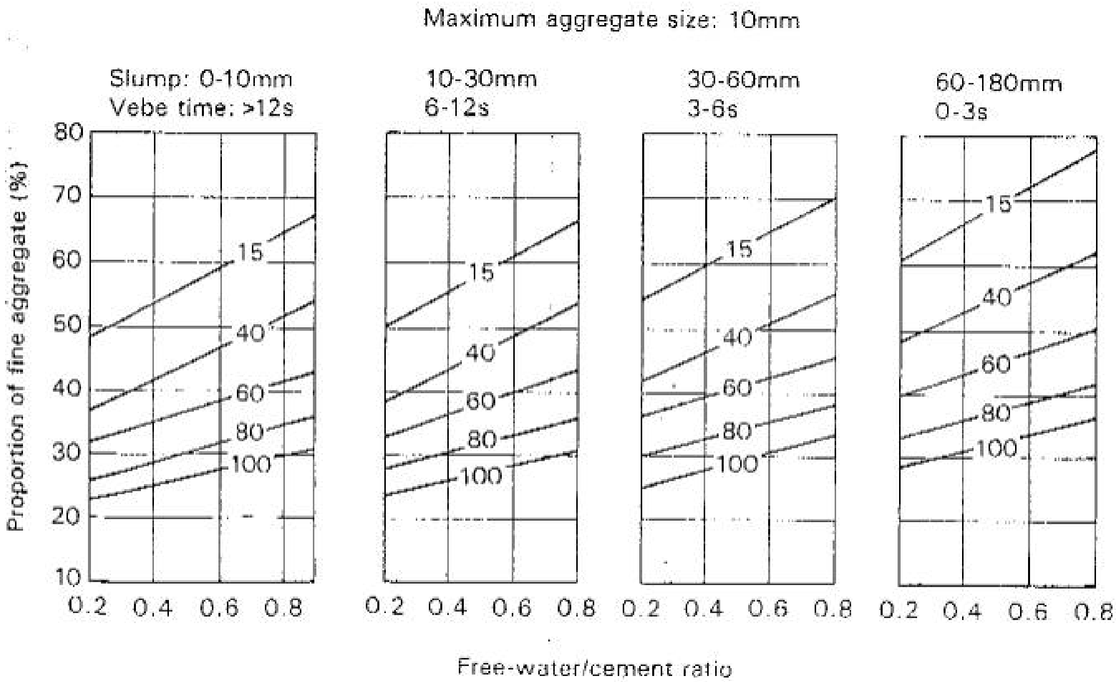

Figure 4a: Recommended proportions of fine aggregate according to percentage passing 600 μm sieve

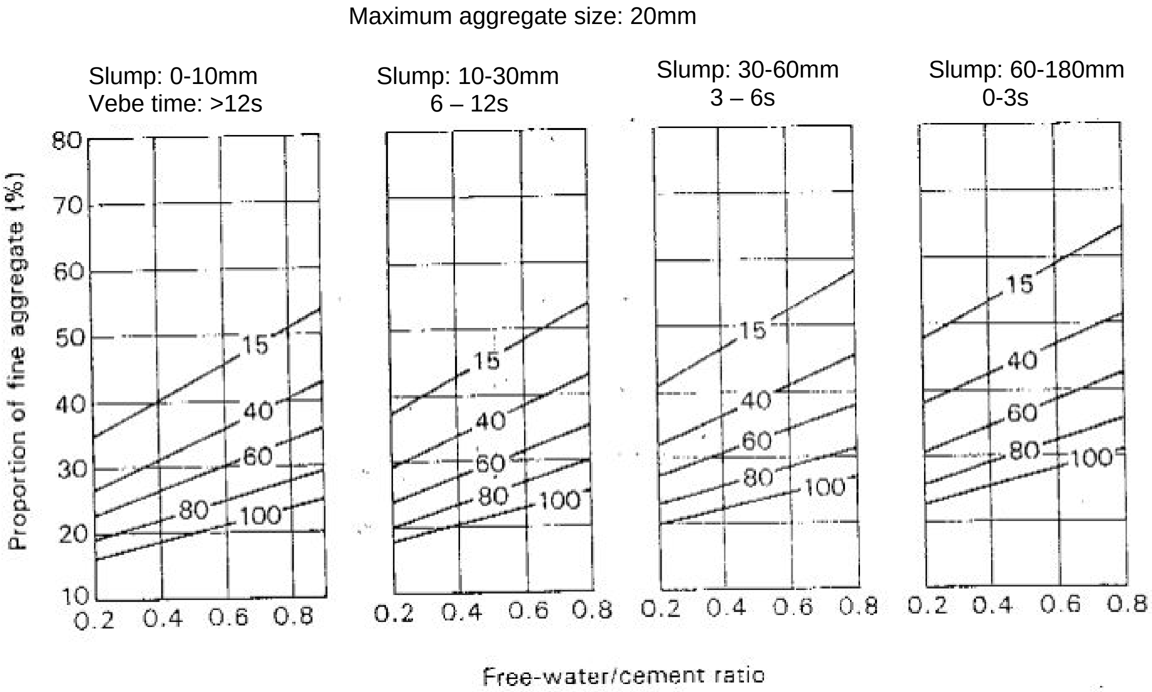

Figure 4b: Recommended proportions of fine aggregate according to percentage passing 600 μm sieve

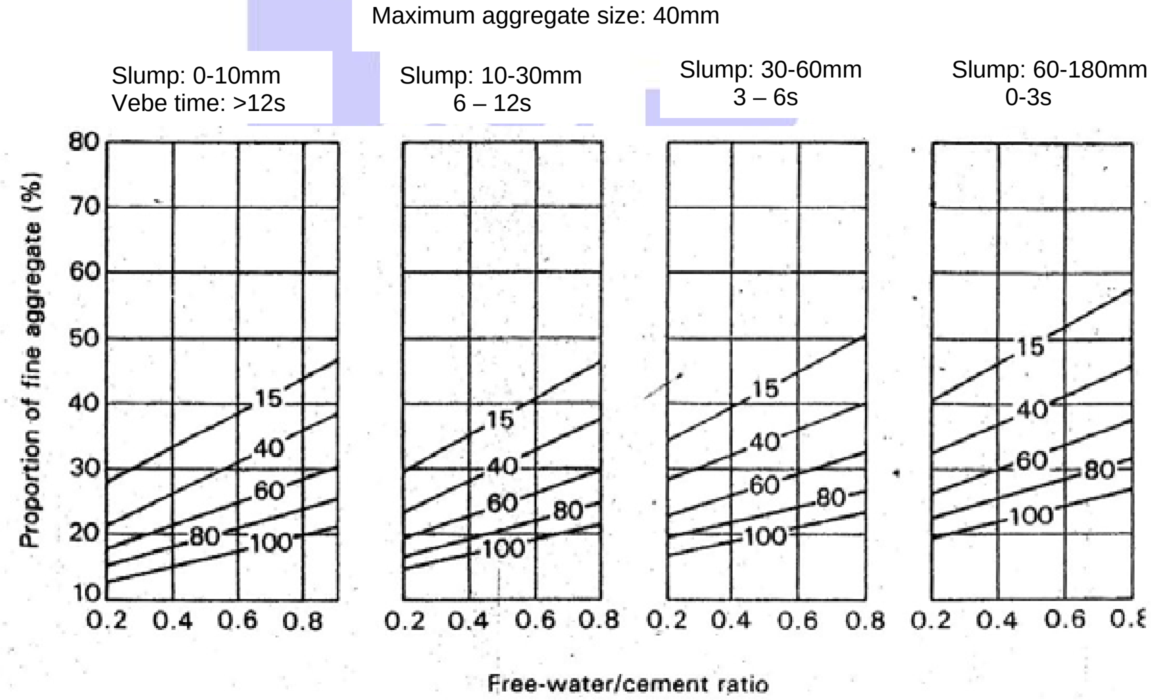

Figure 4c: Recommended proportions of fine aggregate according to percentage passing 600 μm sieve