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ADAPTING THE D.O.E. METHOD FOR THE DESIGN OF CONCRETE MIXES USING LOCAL MATERIALS

by

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1.0 Introduction

The main objective of concrete mix design is to select the most economical and practical combination of ingredients of concrete, which will yield fresh concrete of desirable workability, and hardened concrete possessing the characteristic compressive strength and durability. The mix proportion should also satisfy the additional requirement of the use of minimum possible cement content so that maximum economy is achieved, without affecting durability.

Significant advances have been made in the field of concrete mix design, when Duff Abrams enunciated the famous water-cement ratio law in 1918(1). Ever since, numerous researchers have illustrated the importance of various parameters such as water-cement ratio, aggregate-cement ratio, aggregate type and size, and grading of coarse and fine aggregates in selecting concrete mix proportion to achieve desired strength and workability.

With the advances made in the field of concrete technology, technically advanced countries have developed their own standards and specifications to design concrete mixes to suit their local materials. Due to the lack of research in developing countries, the majority of them have accepted the methods developed in other countries depending on their popularity. For an example, the 'Current British Method', popularly known as D.O.E. method, is widely used in practice in Sri Lanka. The D.O.E. method has superseded the Road No. 4 method (15) and rationalised some of the deficiencies observed in the Road Note No. 4 procedure.

Previous studies (3, 13, 14), carried out to investigate the suitability of D.O.E. method to local conditions, have revealed that neither the target mean strength nor the workability can be achieved with local materials. Certain modifications to the D.O.E. method have been proposed, to suit local materials, by the previous research. However, such modifications cater only to a limited range of materials; for example, aggregate falling into a certain category. Therefore, the information required and modifications to be made for certain other ranges have been studied in the present investigation.

2.0 Basic Design Parameters

Most of the mix design methods can be condensed to three steps of determination.

i. The water-cement ratio (W/C) for a given strength at a specified age.

ii. The water content or aggregate-cement ratio (A/C) for a given workability.

iii. The proportions of coarse and fine aggregate of given gradings.

Although the compressive strength of concrete is empirically a function of various factors (8), concrete technologists unanimously agree that the water-cement ratio has the highest influence on strength. The property workability is governed by the water content, aggregate properties such as grading, shape, size and the mix proportions. According to Neville (12), if the A/C ratio decreases while keeping the W/C ratio constant, the water content increases and consequently the workability also increases. Also for a given value of W/C, there is one value of the coarse/fine ratio that gives the highest workability. Increase in sand content causes a reduction in workability and vice versa. It is an apparent feature that lubrication action created by cement particles has a considerable effect on workability. However, increase of cement content in concrete increases the shrinkage cracking potential of concrete. Further, the increase in fineness of cement slightly improves the workability of a concrete mix (12).

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3.0 Performance of DOE Method Under Local Conditions

In order to study the suitability of DOE method with reference to local materials available in Sri Lanka a preliminary investigation was carried out on eight combinations of slump and strength after determining the relevant properties of available materials. Mixes were designed according to DOE method and tested under well controlled laboratory conditions. The results are shown in Table 1.

Table 1

Test Results of the Trial Mixes done according to DOE Method

Characteristic strength(N/mm^2)	20	25	30	40	40	30	25	20
Target mean strength(N/mm^2)	33	38	43	53	53	43	38	33
Specified slump range(mm)	0-10	10-30	30-60	60-180	0-10	10-30	30-60	60-180
Slump obtained(mm)	6	0	17	12	0	8	40	44
Strength obtained *7-day (N/mm^2)	29.5	34.5	27.0	41.7	37.6	34.6	24.7	21.0

Note: i. Fine aggregate grading - Zone 1

ii. Maximum size of coarse aggregate - 20mm

iii. Relative density - coarse aggregate - 2.85
- fine aggregate - 2.6

iv. Type - coarse aggregate - crushed
- fine aggregate - uncrushed

v. Mixing done manually

vi. Weigh batching is adopted and the water absorption of aggregate is of very neglegible order.

As it has been previously reported (3, 13, 14), neither the target mean strength nor the workability can be achieved by designing according to the DOE method. Failure modes of the cubes revealed that all the failure surfaces go through the binding layers indicating the aggregate are relatively higher in strength. Although the results shown in Table 1 seems to satisfy the characteristic strength requirement, it is not a satisfactory solution to a mix designer, because none of the mixes is capable of achieving its target mean strength which would take care of statistical variation of results.

Inability to achieve the design strength and workability is purely due to the difference in characteristic properties of materials used in this country and Britain. Cement and aggregate are the main constituent materials in concrete. Cement produced by the Cement Corporation of Sri Lanka is widely used for construction purposes which complies with BS 12-1978(4). However, cement manufactured in U.K. is found to be well above the BS-12 standards which yields high strength at early stages. Hence, whether the DOE method developed using cement available in U.K. is suitable to Sri Lanka is a matter of speculation. Further, since the failure mode of the cubes illustrated that the coarse aggregate is of good quality, it is apparent that quality of cement is greatly responsible for the lower strength of cubes.

It is believed, that the quality of aggregate is greatly responsible for the workability of fresh concrete. An extensive investigation done on aggregate quality has revealed the following :

a) Coarse aggregates used for local concrete production are produced by crushing of large boulders whereas fine aggregates are collected directly from river beds.

b) Surface texture is conducive to adherence of the binding paste (mixture of cement, sand and water).

c) Quality of the coarse aggregate is good strength-wise (relative density - 2.85).

d) Generally the grading of coarse aggregate falls in to 'single-size' category.

4.0 Influence of Coarse Aggregate Grading

To investigate the influence of coarse aggregate grading on the strength and workability, four trial mixes were made according to the DOE recommendations using coarse aggregate of 'well-graded' category. Since normally available aggregate falls into 'single-size' category, coarse aggregate samples were seived into single sizes on a vibrating screen and recombined to get the 'well-graded' category. Test results are reported in Table 2. It reveals not only an improvement but also satisfying the specified values in workability (except in one mix). However, it is quite evident that there is no improvement in strength by the change of coarse aggregate quality from 'single-size' to 'well-graded'.

Table 2

Trial mix results for the mixes done according to DOE method using well-graded coarse aggregate (maximum size 20mm)

Characteristic strength (N/mm^2)	20	25	30	40
Target mean strength (N/mm^2)	33	38	43	53
Specified slump range(mm)	0-10	10-30	30-60	60-180
Slump obtained	0	25	Collapse	115
Strength obtained (N/mm^2)	23.0	29.0	33.5	42.1

Note: i. Fine aggregate grading - Zone 1

ii. Relative density - coarse aggregate - 2.85 fine aggregate - 2.6

iii. Age at testing - 7 days

iv. Type of aggregate : coarse - crushed fine - uncrushed

v. Mixing done manually

vi. Weigh batching is adopted and the water absorption of aggregate is of very neglegible order.

5.0 Modifications Proposed to DOE Method to Achieve Workability

Comprehensive research carried out (3,14) previously to investigate the suitability of DOE method to local conditions has revealed that the water content and percentage of fine aggregate in a mix have a substantial effect on workability. Some of the conclusions drawn from those studies with regard to the workability can be summarised as follows.

a) Water contents given in DOE method are insufficient to get the desired workability.

b) Arbitrary increase in water content or reduction in fine aggregate percentage on the quantities computed from the DOE method improves the workability.

c) The different ranges of workability (slump ranges) stated in DOE method cannot be achieved by either increasing water content or decreasing fine aggregate percentage alone.

d) Alteration of fine aggregate percentage and water content must be done simultaneously to achieve intended slump range.

e) Although, the DOE method considers that workability solely depends on aggregate type and water content, the water-cement ratio also has a major role to play. Hence the Table 3 of the DOE method has been replaced by a graphical representation in which workability is a function of aggregate size and type, water content and water-cement ratio.

The above investigations have been limited to

i. 20mm crushed aggregate falling to 'single-sized' category.

ii. sand of grading zone 2.

The present investigation on mix design is aimed at obtaining required data for

i. 20mm crushed aggregate falling to 'well graded' category

ii. sand of grading zone 1.

Hence, the following procedure was adopted to get the relationship between water content and water-cement ratio for different workability ranges, using well graded coarse aggregate which is made by combining two 'single sized' aggregate samples (Appendix B).

a) For a particular water-cement ratio and slump range, a mix is designed using the water content given in DOE method.

b) The designed mix is tested and the slump is recorded.

c) By increasing the water content to a desired value arbitararily, mix is re-designed and slump is recorded.

d) This is repeated until the required lower and upper limits of selected workability range are achieved and corresponding water contents are recorded.

e) Similar procedure is carried out for other workability ranges.

f) The steps (a) to (e) are repeated for various water-cement ratios.

It was found that it is not possible to achieve very high workability (like 60-180mm slump) with very high water-cement ratios as a collapse slump is obtained. Hence, those ranges have been omitted here. The results are presented graphically in Figures 1, 2, 3 and 4 (detail results are shown in Table D1 in Appendix D).

FIG- 1 VARIATION OF WORKABILITY WITH WATER/CEMENT RATIO AND WATER CONTENT -

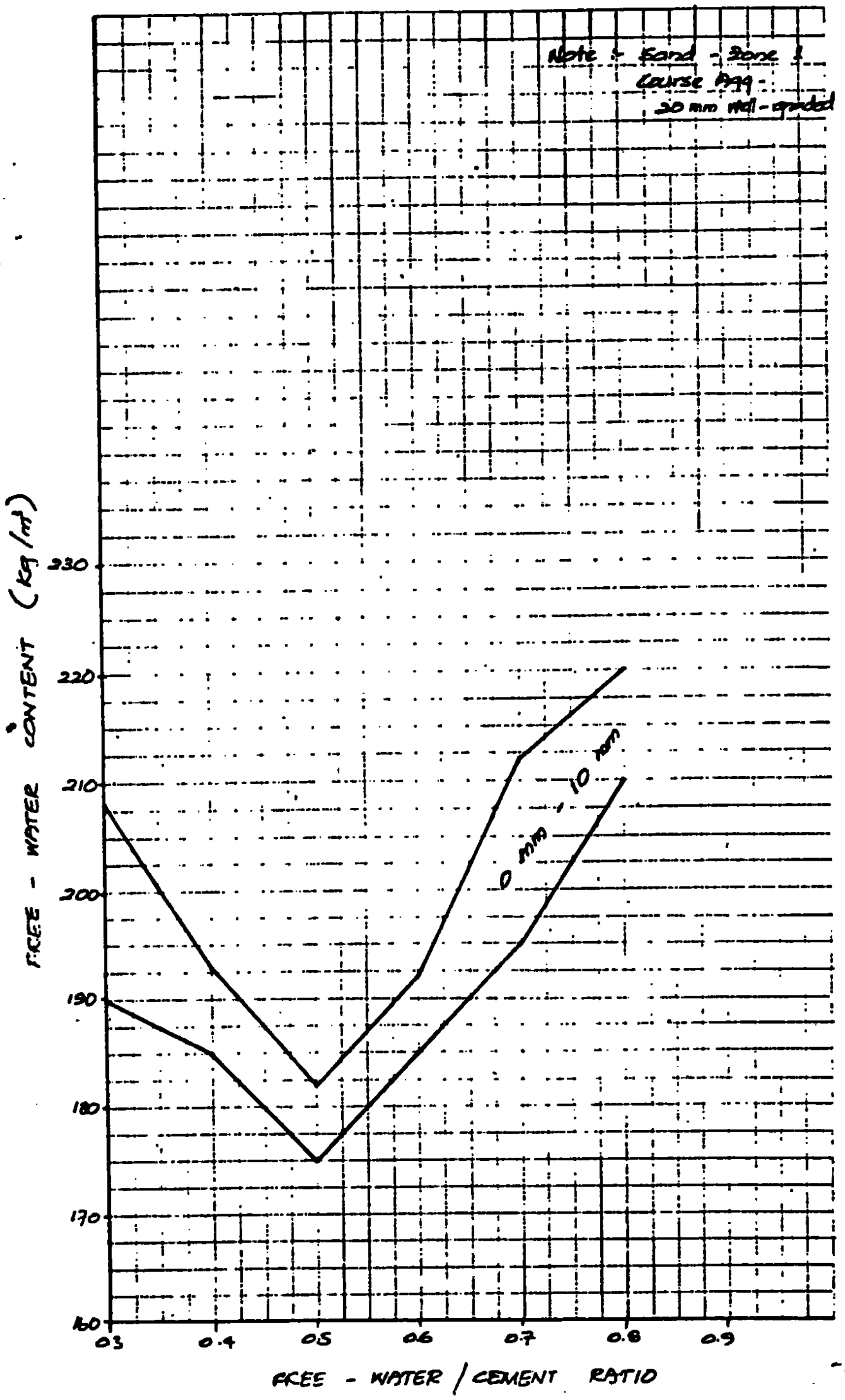


Fig. 2 VARIATION OF WORKABILITY WITH W/C RATIO AND WATER CONTENT

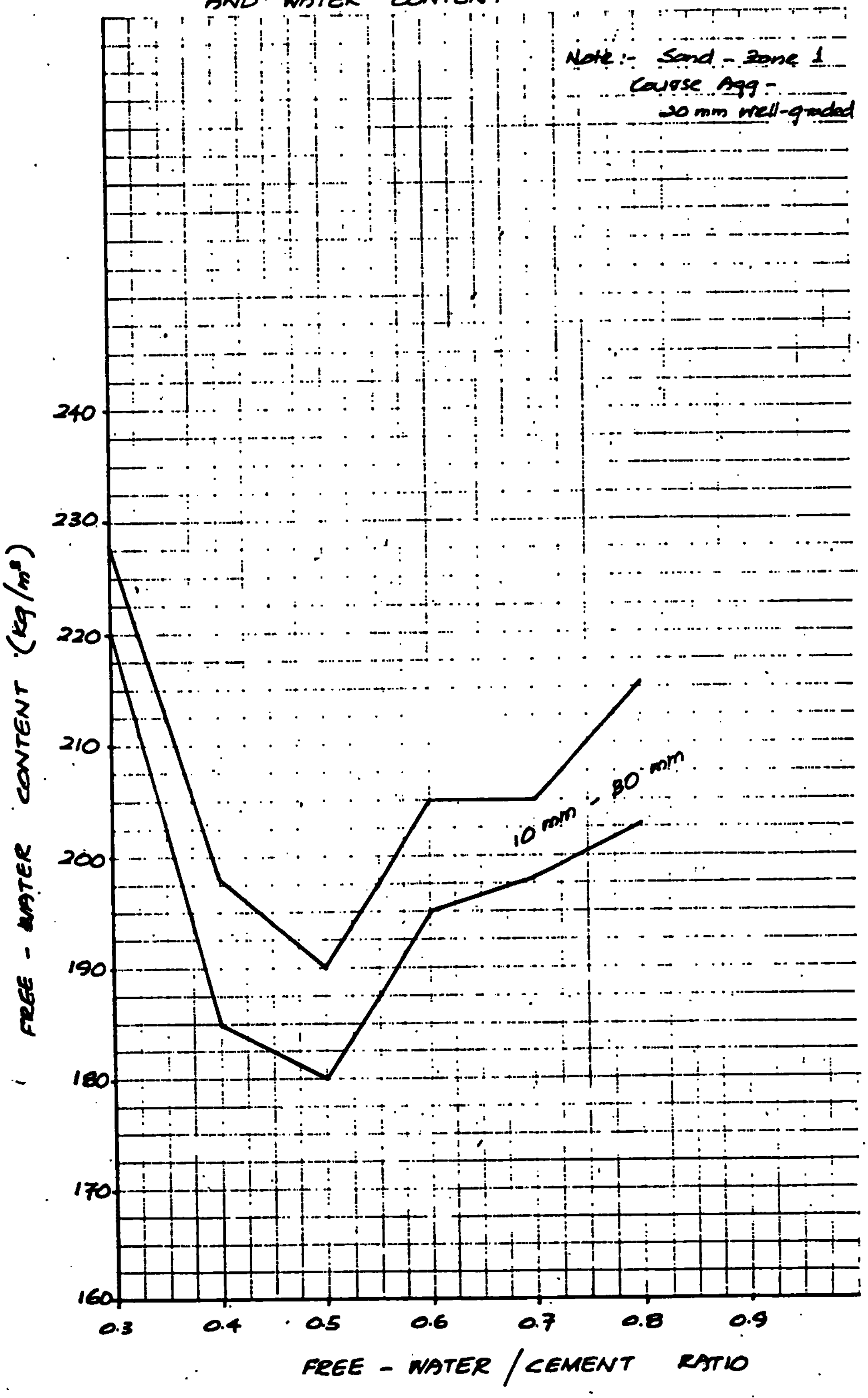


Fig. 3 VARIATION OF WORKABILITY WITH W/C RATIO AND WATER CONTENT

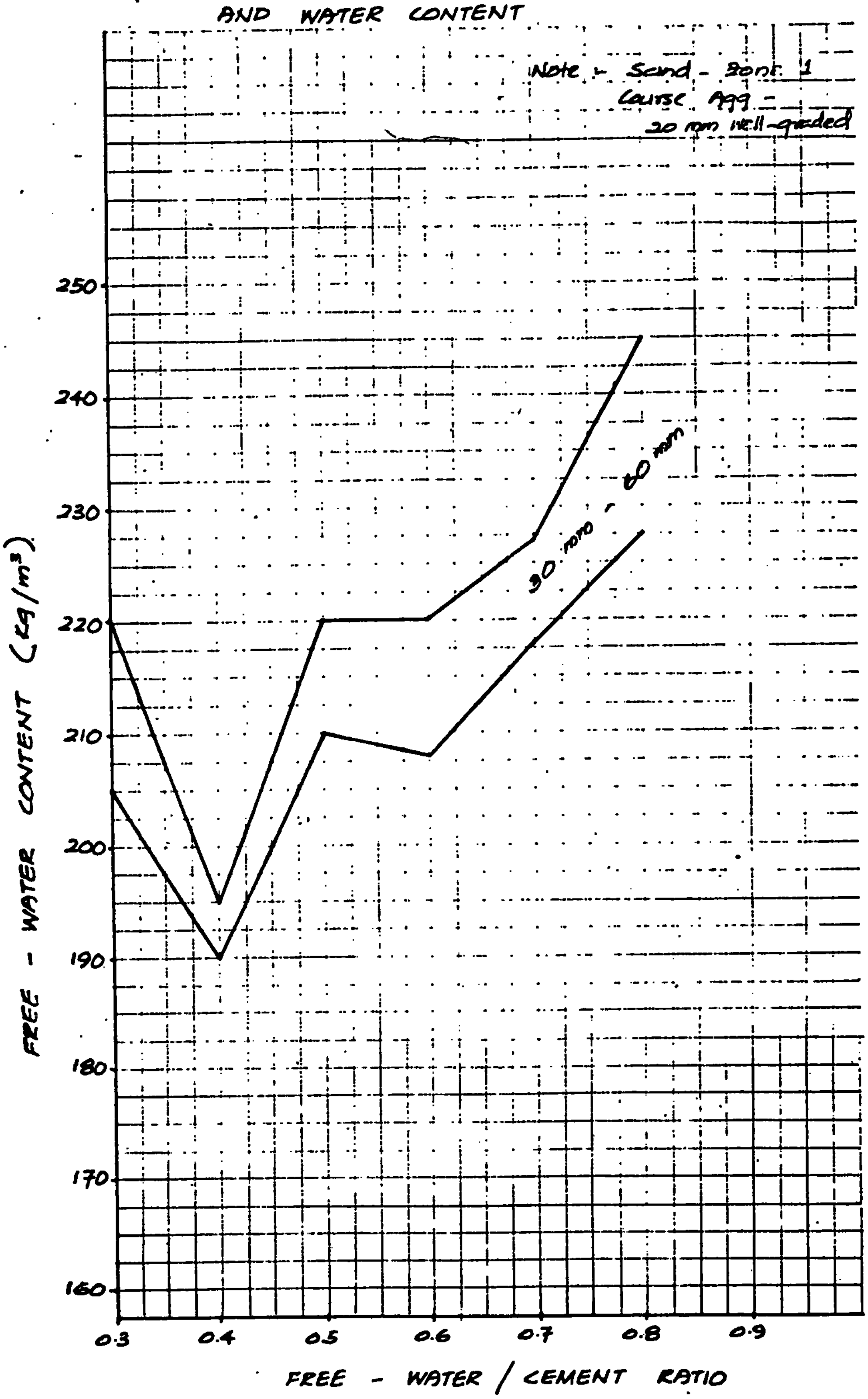
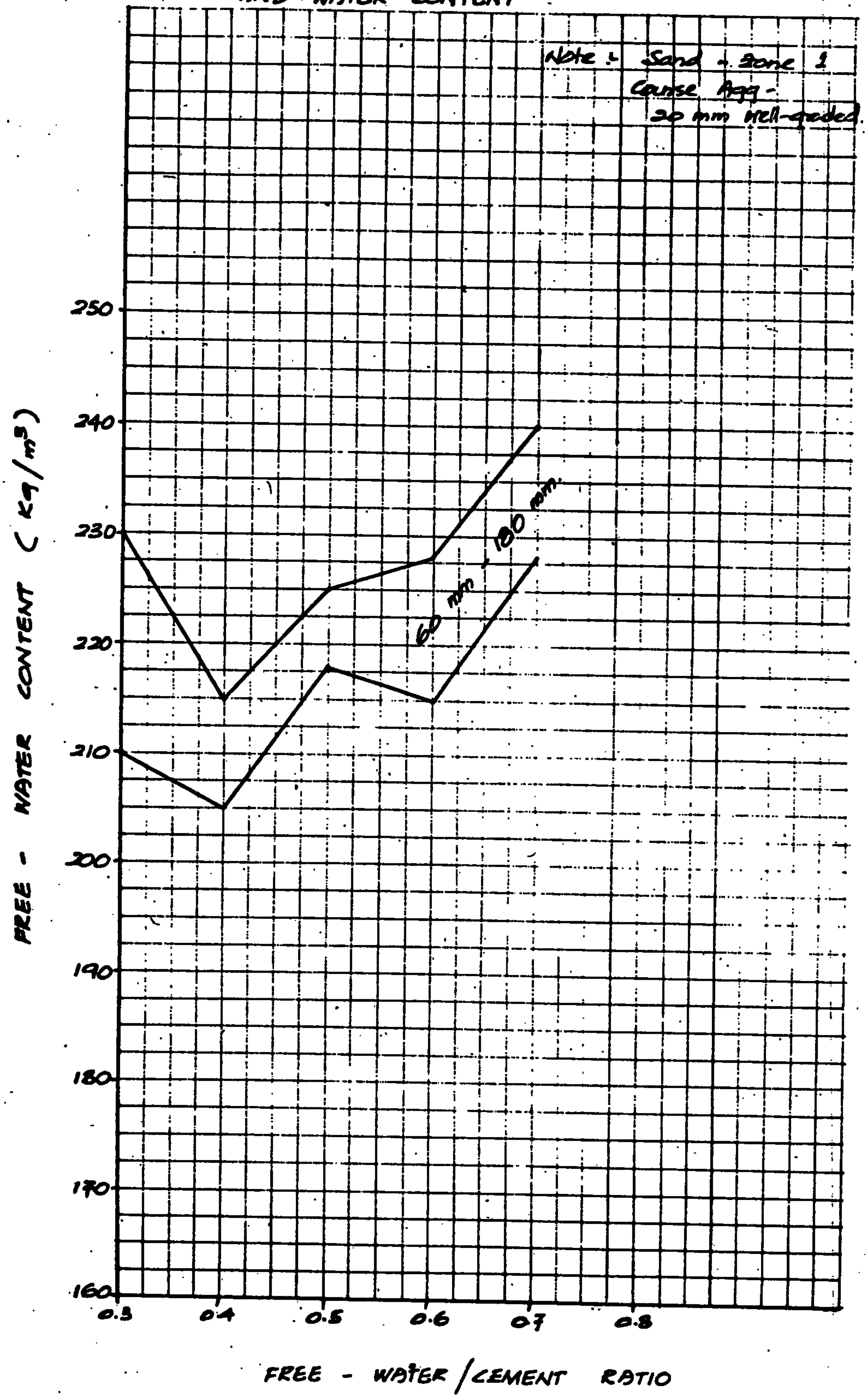


Fig - 4 VARIATION OF WORKABILITY WITH W/C RATIO AND WATER CONTENT



The effect of water-cement ratio on the workability is quite evident although it has been ignored in the DOE method. A similar pattern of behaviour, of concrete mixes at fresh state, can be observed when comparing with previously (3, 14) reported results for 'single sized' aggregate with sand of grading zone 2 category.

6.0 Modifications Proposed to DOE Method to Achieve Strength

Although the cement produced by the Cement Corporation of Sri Lanka conforms to BS12, it is inferior to the cement produced in United Kingdom. Hence, relationship between compressive strength of hardened concrete and water-cement ratio in DOE method needs modification.

It is well known that the strength of concrete is inversely proportional to water-cement ratio. Infact, this curve is valid only for a workable concrete in fresh state made out of particular cement batch with a specified composition. As a certain amount of variation is possible between two batches of cement, it has been postulated (6,7) that the relationship between strength and water-cement ratio must be depicted by a band curve rather than a single curve.

Therefore, the relationship between compressive strength and water-cement ratio has been developed for cement manufactured by the Cement Corporation, as stated below.

i. For different values of water-cement ratio ranging from 0.3 to 0.9, mixes were designed and nine cubes were cast for each composition of concrete mix.

ii. Compressive strengths at 3-day, 7-day and 28-day were obtained.

iii. Same procedure was repeated for different cement batches.

The results are reported in tabular form (Table 3) as well as in graphical form along with the DOE curve (Figures 5, 6 & 7). It is quite evident from the results that the local cement is of inferior quality compared to the British Cement. Further, it shows that cement taken from different batches could vary in composition marginally.

Table 3
Variation of Strength with water-cement ratio (graphically presented in Figures 5, 6 and 7)

a) For Cement Batch No. 2

W/C ratio	Obtained strength (N/mm^2)		
	3-day	7-day	28-day
0.35	32.0	47.7	59.5
0.45	21.8	32.3	47.4
0.55	13.2	22.0	33.5
0.65	8.2	17.1	25.0
0.75	6.0	11.9	19.4

b) For Cement Batch No. 3

W/C ratio	Obtained strength (N/mm^2)		
	3-day	7-day	28-day
0.3	35.0	49.0	61.6
0.4	22.5	35.0	50.1
0.5	13.6	22.5	34.5
0.6	8.5	16.2	25.6
0.7	5.6	11.6	18.5
0.8	4.5	8.1	12.6
0.9	3.5	5.4	7.4

c) For Cement Batch No. 4

W/C ratio	Obtained strength (N/mm^2)
	3-day
0.3	38.2
0.4	23.9
0.5	15.0
0.6	9.3
0.7	6.4
0.8	5.4
0.9	4.3

Fig - 5 RELATIONSHIP BETWEEN 8-DAY COMPRESSIVE STRENGTH AND FREE - WATER / CEMENT RATIO

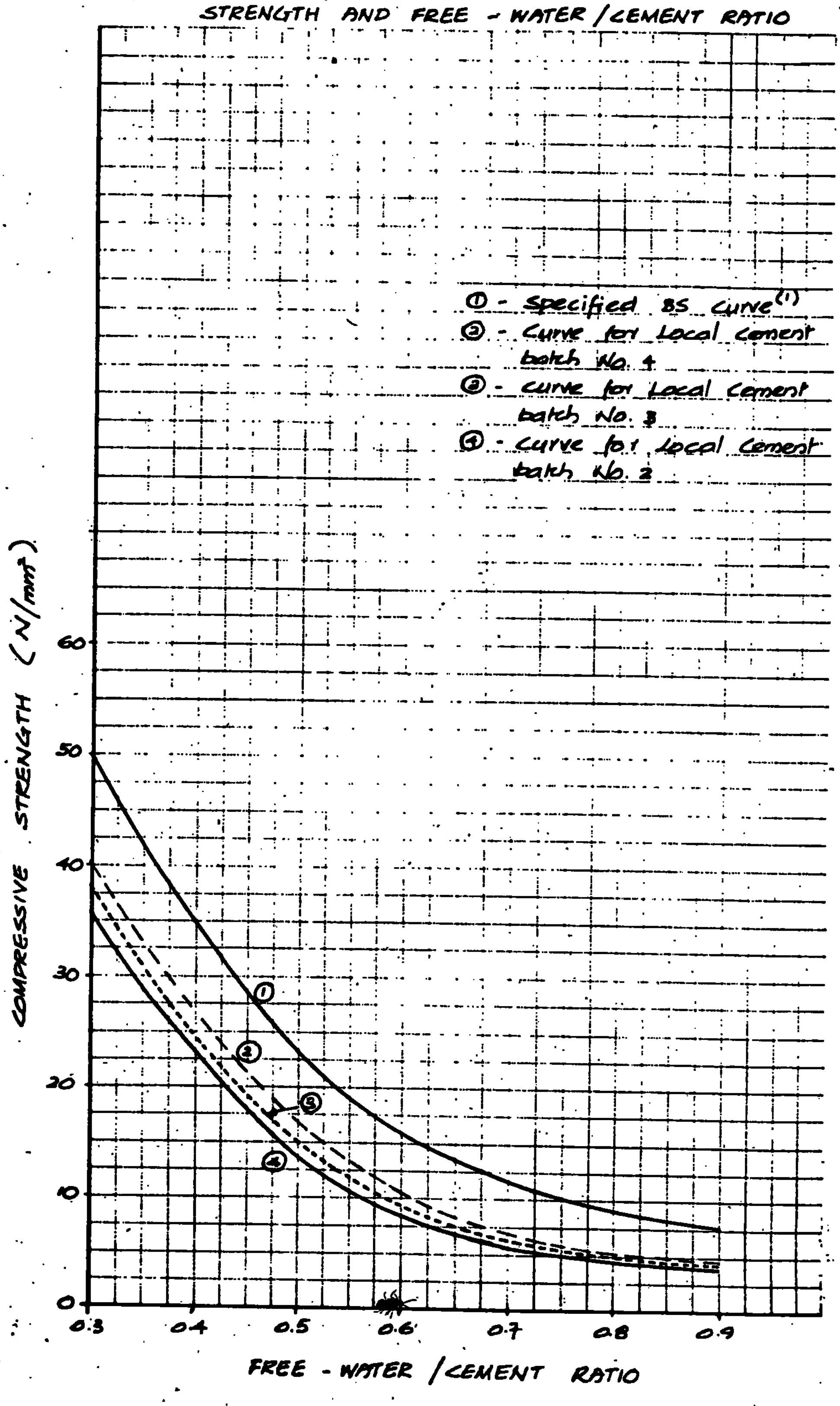


Fig - 6 RELATIONSHIP BETWEEN 7-DAY COMPRESSIVE STRENGTH AND FREE - WATER /CEMENT RATIO

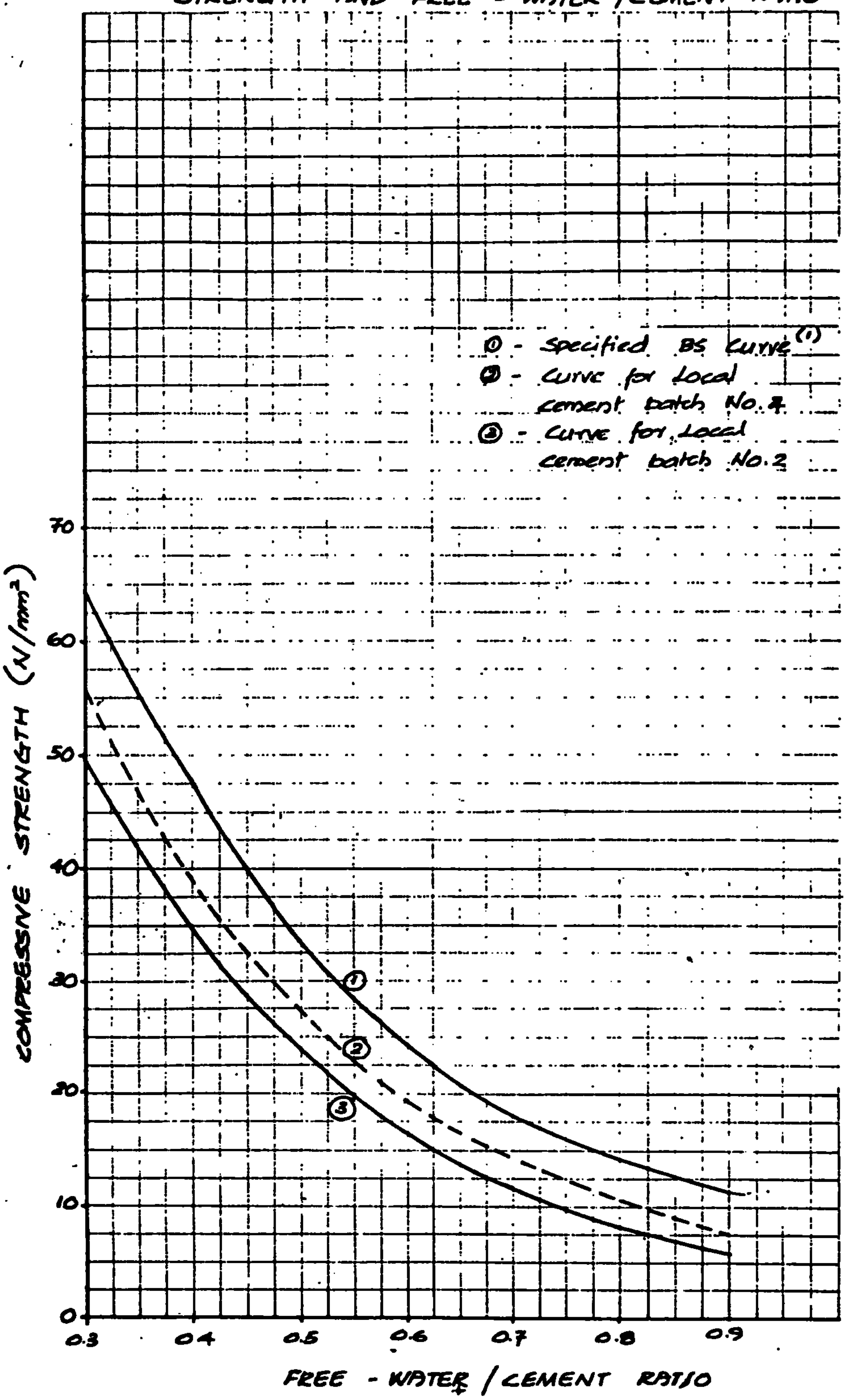
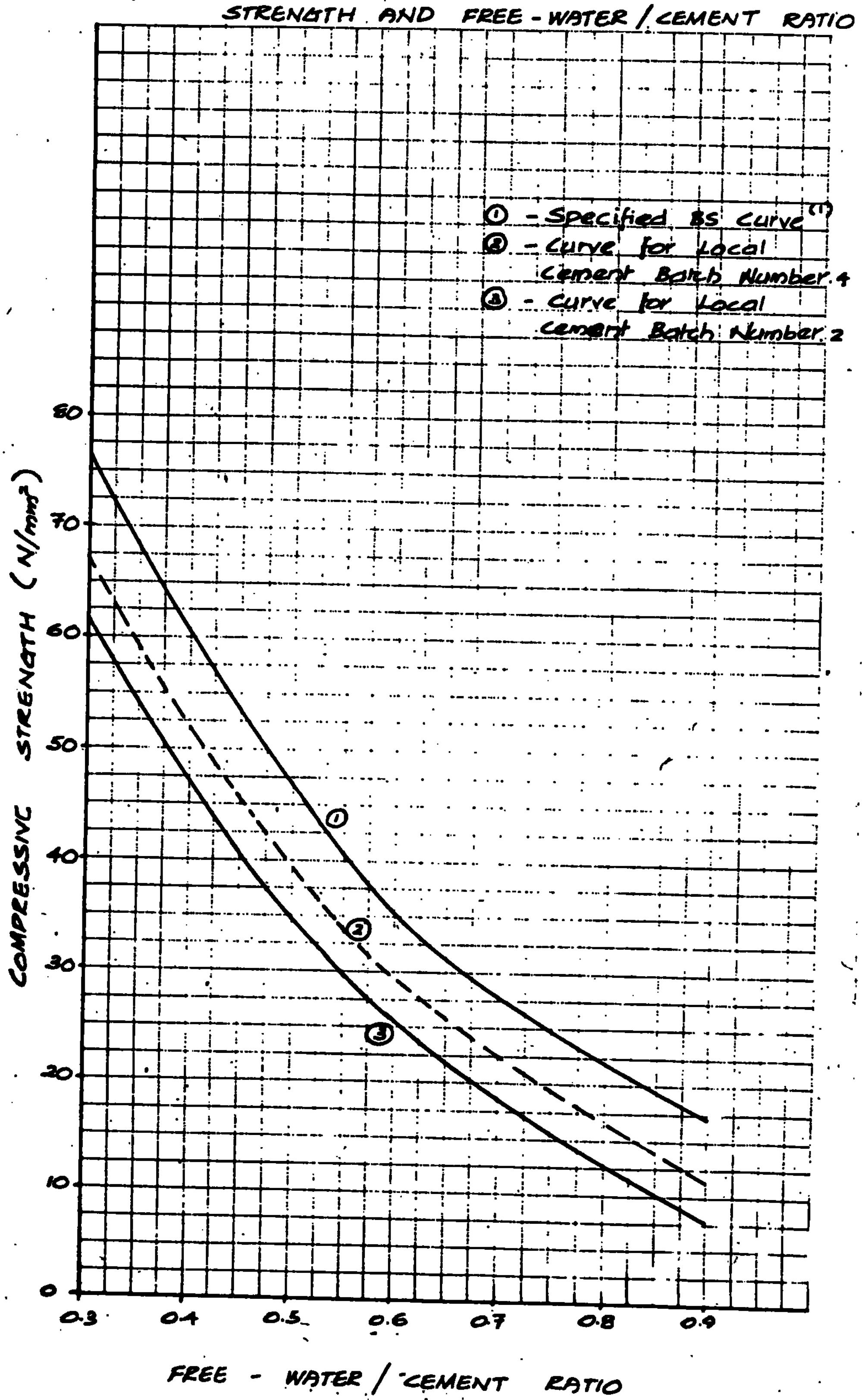


Fig - 7 RELATIONSHIP BETWEEN 28 - DAY COMPRESSIVE STRENGTH AND FREE - WATER / CEMENT RATIO



Since Sri Lanka adopts British Standard as the prescribed specification for cement, the upper most curve of the band may be selected as corresponding DOE curve, while taking the most conservative experimental curve (ie. for the worst cement batch) for the lower edge. Hence three band-curves proposed (3-day, 7-day and 28-day) replace the corresponding curve in DOE method. Hence, if the laboratory test data or experience records for the compressive strengths and water-cement ratio relationship cannot be obtained because of time limitations, the necessary water-cement ratio corresponding to a given strength can be estimated from the lower edge of the band curve as a conservative measure.

7.0 Wet Density of Concrete

In this investigation, special attention has been drawn to the actual wet densities of trial mixes. It is observed that the actual values are comparatively higher than the design values. However, this would require an in-depth investigation to modify the curves given in DOE method. It is estimated that the calculated amounts of materials per unit volume should be increased by about 15% to get the required volume.

8.0 Proposed Mix Design Method to Suit Local Conditions

As evident in the investigation results, some of the design data provided in DOE method, are not valid for local conditions. Hence these design data must be modified appropriately. Based on the extensive experimental investigation results, suggested method can be illustrated by the following flow chart (Fig. 16). The relevant mix design form, tables, figures and equations are given in APPENDIX 'C'.

Figure 16

Flow Chart for the Proposed Mix Design Process

Target mean strength

$F_m = F_c + KS$ .... D.O.E.

W/C ratio .... Figs.5,6,&7

Free water content (W) .... Figs.1,2,3 & 4 (for crushed agg.)

Cement content (C) = W

Proportion of fine .... D.O.E.

Wet density of concrete (D_w) .... D.O.E.

Total aggregate content = D_w-C-W

Proportions

Adjustment for completed volume of local materials

Adjusted proportion

9.0 Conclusions

(i) The design of concrete mixes by the British method (D.O.E.) is not suitable for local conditions. Neither the 'Target Mean Strength' nor the 'Workability' can be achieved and therefore the D.O.E. method needs to be modified to suit local materials.

(ii) The relationship of water-cement ratio and the compressive strength of concrete given in D.O.E. method is not valid for local materials. Provision of a band curve is found to be better to illustrate this relationship as the quality of cement produced by Cement Corporation of Sri Lanka varies from batch to batch. The determination of the most appropriate water-cement ratio, relevant to a specified target mean strength and for a particular set of materials, must be done by drawing a parallel curve on the band curve through a known point obtained from a trial mix. However, using the bottom edge of the curve is the most conservative assumption.

(iii) Water contents proposed in D.O.E. method are insufficient to get the desired workabilities. Increase in water content tends to decrease tremendously the stability of concrete made of single sized aggregate where as concrete made of well-graded aggregate possesses a better stability under high water contents.

(iv) As previous researchers have reported (3,14), the workability is a function of not only the aggregate size and type, and water content, but also water-cement ratio. A graphical illustration is shown in Figures 1, 2, 3 and 4 which comply with well graded coarse aggregate (maximum size 20mm) and uncrushed fine aggregate of Zone 1.

(v) Most of the aggregate delivered by the material suppliers comply with 'single sized' category. Generally well graded aggregate (20mm) can be obtained by combining 60% of 20mm and 40% of 10mm single size aggregates.

(vi) To account for the reduction in yield of concrete under local conditions, 15% increment on calculated material weights is recommended. However, further investigation on this issue is required.

(vii) Further investigations are required to study the behaviour of concrete with other sizes of aggregate and other sand grading zones.

10.0 Acknowledgement

We convey our sincere appreciation to the Head of the Department of Civil Engineering, University of Moratuwa for providing the facilities to work on this project.

We also thank the staff of the Building Materials Laboratory, University of Moratuwa, for their kind help.

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APPENDIX A

MATERIAL PROPERTIES

Relative density of fine aggregate	= 2.6
Relative density of coarse aggregate	= 2.85
Bulk density of fine aggregate	= 1614 kg/m³
Bulk density of coarse aggregate	= 1539 kg/m³

APPENDIX B

COMBINING OF AGGREGATE GRADINGS TO GET WELL-GRADED AGGREGATE

TABLE B1 Grading of aggregate (BS 882 : Part 2 : 1973)

Sieve size	Requisite grading (20mm coarse)	Percentage passing	
		20mm coarse	10mm coarse
37.5	100	100	--
20.0	97.0	92.5	--
14.0	--	--	100
10.0	45.0	12.5	92.5
5.0	5.0	2.5	12.5
2.36	--	--	2.5

Required combination of aggregate according to the graphical solution (Fig.B1):

10mm single-size aggregate	= 41%
20mm single-size aggregate	= 59%

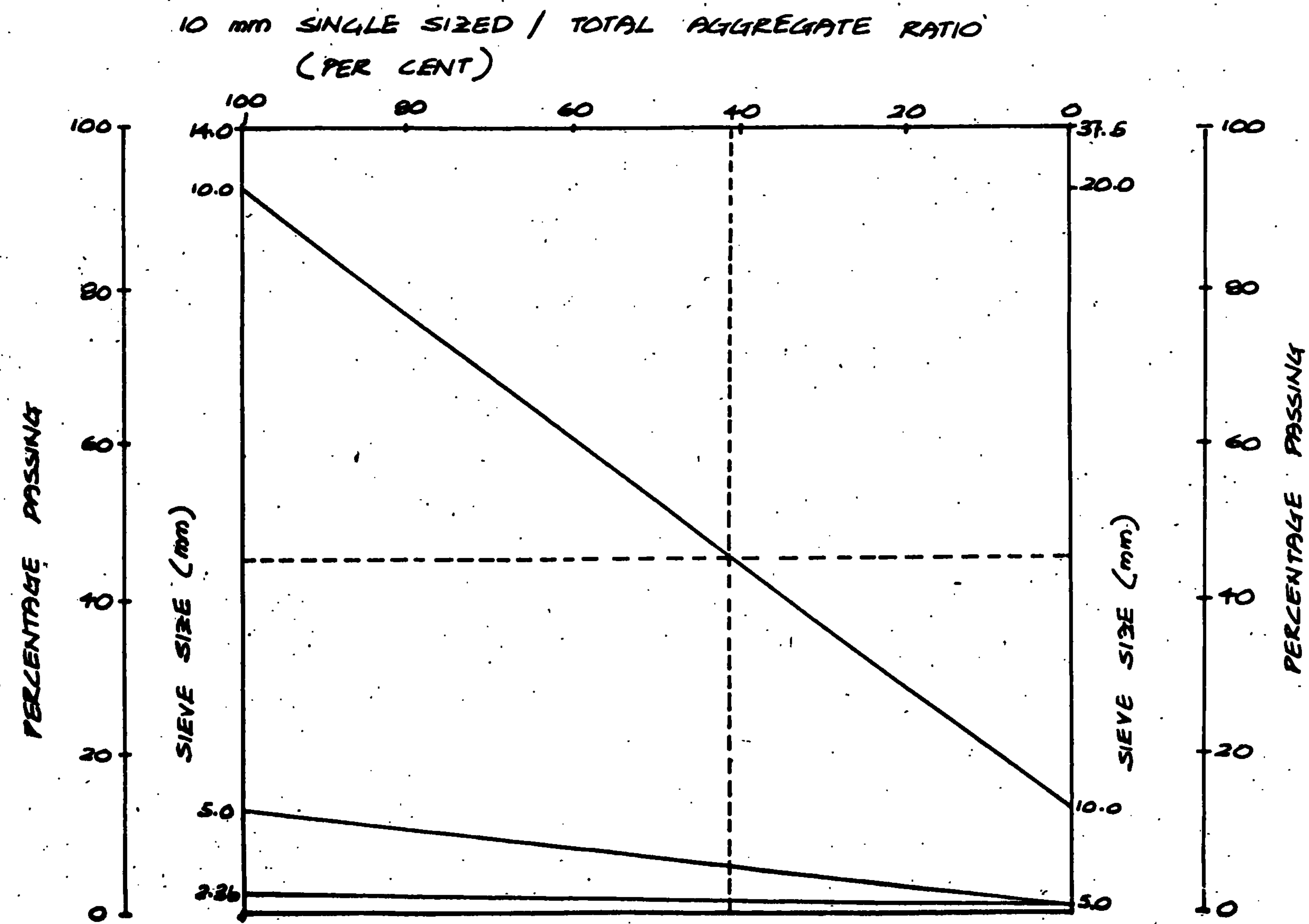

FIG. B-1 PROPORTIONING OF AGGREGATE
(10 mm SINGLE SIZED & 20 mm SINGLE SIZED)

APPENDIX C

MIX DESIGN FORM

ITEM	REFERENCE or CALCULATION	VALUES
1. Characteristic Strength	specified	....N/mm² at.....days Proportion of defectives. ..... %
2. Standard deviation	D.O.E	....N/mm² or no data....N/mm²
3. Margin	Eqn. C1	....x...=..N/mm²
4. Target mean strength	Eqn.C2	....+...=..N/mm²
5. Cement type	specified	OPC
6. Aggregate type	specified	coarse-crushed fine-uncrushed
7. Free water/Cement Ratio	Figs.5, 6, & 7.	.... use lower value
8. Maximum Free water/Cement Ratio	specified	....
9. Slump	specified	.....mm
10. Maximum aggregate size	specified	20mm
11. Free water content	Figs. 1,2,3, & 4.	......kg/m³
12. Cement content	Eqn.C3	...../....kg/m³
13. Maximum cement content	specified	......kg/m³
14. Minimum cement content	specified	.....kg/m³. use if greater than item 12 & calculate item 15
15. Modified free water/cement ratio		....
16. Grading of fine aggregate	BS 882	Zone 1
17. Proportion of fine aggregate	D.O.E.	.......%
18. Relative density of aggregate	Fine: Coarse:	....

APPENDIX C Cont./

ITEM	REFERENCE or CALCULATION	VALUES
19. Relative density of combined aggregate	Eqn. C4	....
20. Concrete density	Fig. C3	.......kg/m³
21. Total aggregate content	Eqn. C5	.......kg/m³
22. Fine aggregate content	Eqn. C6	.......kg/m³
23. Coarse aggregate content	Eqn. C7	.......kg/m³
24. Final Mix Proportions with 15% excess materials.		

Quantities	CEMENT (kg)	WATER (kg)	FINE AGGREGATE (kg)	COARSE AGGREGATE (kg)
	....	....	....	....

RELAVENT EQUATIONS

1. $M=K.S$ .... Eqn. C1

   where M = Margin

   K = Constant (D.O.E method)

   S = Standard deviation (D.O.E method)

2. $F_m=F_c+M$ ...... Eqn. C2

   where F_m = Target mean strength

   F_c = Characteristic strength

   M = Margin

3. $$\text{Cement content} = \frac{\text{Free water content}}{\text{Free water/Cement Ratio}}$$ .... Eqn. C3

4. Relative Density (R.D) of Combined Aggregate = R.D. of coarse aggregate X R.D. of fine aggregate .... Eqn. C4

5. Total Aggregate content = $D-D_c-D_{fw}$ .... Eqn. C5

where D = Wet density of Concrete (kg/m³)

D_c = Cement content (kg/m³)

D_{fw} = Free water content (kg/m³)

6. Fine aggregate content = Total aggregate content X Proportion of fines .... Eqn. C6

7. Coarse aggregate content = Total aggregate content - Fine agg. content .... Eqn. C7

APPENDIX D
TEST RESULTS ON MIX DESIGN

D1 INVESTIGATION ON WORKABILITY

TABLE D 1 Material quantities & results obtained for trial mixes produced with well-graded coarse aggregate

Expected slump range (mm)	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10
Target mean strength																					
*3 days (N/mm^2)	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	23.0	23.0	23.0	23.0	23.0	23.0	13.5	13.5	13.5	13.5	13.5	13.5
Free W/C ratio	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Free water content(kg/m^3)	147	160	170	180	185	190	200	205	208	147	170	180	185	190	195	147	160	170	175	180	182
Cement content(kg/m^3)	490	533	567	600	617	633	667	683	643	368	425	450	465	475	483	294	320	340	350	360	364
Fine aggregate(%)	34	34	34	34	34	34	34	34	34	36.5	36.5	36.5	36.5	36.5	36.5	39.0	39.0	39.0	39.0	39.0	39.0
Fine agg. content(kg/m^3)	650	626	622	585	574	567	545	534	527	739	717	679	669	657	653	813	794	776	766	757	754
Coarse agg. content(kg/m^3)	1263	1216	1206	1135	1114	1100	1038	1038	1022	1286	1248	1181	1163	1143	1136	1271	1241	1214	1199	1183	1180
Obtained strength																					
*3 days (N/mm^2)	--	--	--	--	--	--	--	--	37.0	--	--	--	--	--	24.1	--	--	--	--	--	14.5
Obtained slump(mm)	0	0	0	0	0	1	5	7	10	0	0	0	0	5	10	0	0	0	0	6	10

Expected slump range (mm)	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10
Target mean strength																					
*3 days (N/mm^2)	8.5	8.5	8.5	8.5	8.5	8.5	8.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	4.5	4.5	4.5	4.5
Free W/C ratio	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8
Free water content(kg/m^3)	147	160	170	180	185	190	192	147	160	170	180	190	195	200	205	210	212	147	160	180	190
Cement content(kg/m^3)	245	267	283	300	308	317	320	210	229	243	257	291	279	286	293	300	303	184	200	225	238
Fine agg. (%)	41.5	41.5	41.5	41.5	41.5	41.5	41.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	46.0	46.0	46.0	46.0
Fine agg. content(kg/m^3)	889	869	850	832	825	813	810	963	944	922	907	890	884	874	869	859	857	1007	984	952	932
Coarse agg. content(kg/m^3)	1254	1224	1197	1173	1162	1145	1200	1200	1150	1150	1109	1109	1802	1090	1083	1088	1088	1182	1156	1158	1095
Obtained strength																					
*3 days (N/mm^2)	--	--	--	--	--	--	8.9	--	--	--	--	--	--	--	--	--	5.9	--	--	--	--
Obtained slump (mm)	0	0	0	0	0	8	10	0	0	0	0	0	0	3	5	8	10	0	0	0	0

Expected slump range (mm)	0-10	0-10	0-10	0-10	0-10	0-10
Target mean strength						
* 3 days (N/mm^2)	4.5	4.5	4.5	4.5	4.5	4.5
Free W/C ratio	0.8	0.8	0.8	0.8	0.8	0.8
Free water content(kg/m^3)	200	205	210	215	218	220
Cement content(kg/m^3)	250	256	263	269	273	275
Fine aggregate (%)	46.0	46.0	46.0	46.0	46.0	46.0
Fine agg. content(kg/m^3)	915	910	898	888	885	881
Coarse agg. content(kg/m^3)	1075	1069	1054	1043	1039	1034
Obtained strength						
*3 days (N/mm^2)	--	--	--	--	--	4.1
Obtained slump (mm)	0	0	0	5	6	10

Expected slump range (mm)	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30
Target mean strength																					
*3 days (N/mm^2)	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	23.0	23.0	23.0	23.0	23.0	23.0	13.5	13.5	13.5	13.5	8.5	8.5
Free W/C ratio	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	05	0.6	0.6
Free water content(kg/m^3)	170	180	190	200	210	215	220	225	228	170	180	185	190	195	198	170	180	185	190	170	180
Cement content(kg/m^3)	567	600	633	667	700	717	733	750	760	425	450	463	475	488	496	340	360	370	380	283	300
Fine aggregate (%)	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	39.0	39.0	39.0	39.0	39.0	39.0	41.5	41.5	41.5	41.5	44.0	44.0
Fine agg. content(kg/m^3)	652	633	611	589	570	556	545	537	532	743	723	715	702	693	685	826	807	797	786	894	878
Coarse agg. content(kg/m^3)	1111	1077	1041	1004	970	947	927	913	905	1162	1132	1114	1098	1084	1072	1164	1138	1123	1109	1138	1117
Obtained strength																					
*3 days (N/mm^2)	--	--	--	--	--	--	--	--	36.4	--	--	--	--	--	24.4	--	--	--	14.6	--	--
Obtained slump (mm)	0	0	0	0	3	5	10	20	30	0	0	10	20	26	30	0	10	22	30	0	0

Expected slump range (mm)	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30	10-30
Target mean strength *3 days (N/mm²)	8.5	8.5	8.5	8.5	6.0	6.0	6.0	6.0	6.0	6.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Free W/C ratio	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Free water content(kg/m³)	190	195	200	205	170	180	190	198	200	205	170	180	190	195	200	205	205	210	215	218
Cement content(kg/m³)	317	325	333	342	243	257	271	283	286	293	213	225	238	244	250	254	256	263	269	273
Fine aggregate (%)	44.0	44.0	44.0	44.0	46.0	46.0	46.0	46.0	46.0	46.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0
Fine agg. content (kg/m³)	859	851	839	833	955	937	922	906	903	893	1029	1012	991	981	973	966	967	956	946	943
Coarse agg. content(kg/m³)	1094	1084	1068	1060	1122	1101	1082	1063	1061	1049	1073	1033	1031	1020	1012	1009	1007	996	985	981
Obtained strength *3 days (N/mm²)	--	--	--	8.3	--	--	--	--	--	6.3	--	--	--	--	---	--	--	--	--	4.3
Obtained slump(mm)	5	10	20	30	0	0	4	10	15	30	0	0	0	5	7	10	12	20	25	30

Expected slump range(mm)	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60
Target mean strength *3 days (N/mm²)	35.0	35.0	35.0	35.0	35.0	35.0	23.0	23.0	13.5	13.5	13.5	13.5	13.5	13.5	13.5	8.5	8.5	8.5	8.5	8.5	8.5
Free W/C ratio	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Free water content(kg/m³)	190	195	200	205	210	220	190	195	190	195	200	205	210	215	220	190	200	205	208	210	215
Cement content(kg/m³)	633	650	687	683	700	733	475	488	380	390	400	410	420	430	440	317	333	342	347	350	358
Fine aggregate (%)	40.0	40.0	40.0	40.0	40.0	40.0	40.0	42.5	45.0	45.0	45.0	45.0	45.0	45.0	45.0	47.5	47.5	47.5	47.5	47.5	47.5
Fine agg. content(kg/m³)	657	646	633	621	610	585	765	755	851	839	819	817	808	801	792	925	906	894	888	886	875
Coarse agg.content(kg/m³)	985	969	950	931	915	877	1035	1022	1039	1026	1001	998	987	979	968	1023	1001	989	982	979	967
Obtained strength *3 days (N/mm²)	--	--	--	--	--	37.2	--	23.8	--	--	--	--	--	--	14.9	--	--	--	--	--	--
Obtained slump(mm)	0	10	26	30	40	60	30	60	5	10	23	25	30	43	60	7	15	24	30	32	43

Expected slump range(mm)	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60	30-60
Target mean strength *3 days (N/mm²)	8.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Free W/C ratio	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Free water content(kg/m³)	220	190	195	200	210	215	218	220	225	227	190	200	210	220	230	240	245
Cement content(kg/m³)	367	271	279	286	300	307	311	314	321	324	238	250	265	275	288	300	306
Fine aggregate (%)	47.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	53.0	53.0	53.0	53.0	53.0	53.0	53.0
Fine agg. content(kg/m³)	864	996	983	972	958	949	940	938	927	970	1072	1049	1032	1015	990	973	979
Coarse agg. content(kg/m³)	954	994	983	972	958	949	940	938	927	970	950	931	915	900	877	867	850
Obtained strength *3 days (N/mm²)	8.8	--	--	--	--	--	--	--	--	5.9	--	--	--	--	--	--	4.0
Obtained slump(mm)	60	3	5	10	18	26	30	40	56	60	0	3	10	18	30	52	60

Expected slump range(mm)	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180	60-180
Target mean strength *3 days (N/mm²)	35.0	35.0	35.0	35.0	35.0	35.0	23.0	23.0	23.0	23.0	13.5	13.5	13.5	13.5	13.5	8.5	8.5	8.5	8.5
Free W/C ratio	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Free water content(kg/m³)	210	215	220	225	228	230	205	210	213	215	210	215	218	200	225	210	215	220	225
Cement content(kg/m³)	700	717	733	750	760	767	513	525	533	538	420	430	436	440	450	350	358	367	375
Fine aggregate (%)	46.5	46.5	46.5	46.5	46.5	46.5	48.5	48.5	48.5	48.5	51.5	51.5	51.5	51.5	51.5	54.0	54.0	54.0	54.0
Fine agg. content(kg/m³)	704	692	677	663	657	645	828	820	814	806	919	909	904	895	878	1002	989	974	964
Coarse agg. content(kg/m³)	811	796	780	762	755	743	879	870	865	856	865	856	852	844	827	853	843	829	821
Obtained strength *3 days (N/mm²)	--	--	--	--	--	37.5	--	--	--	24.3	--	--	--	--	--	--	--	--	--
Obtained slump (mm)	61	82	100	155	175	180	59	110	143	180	20	35	60	110	180	35	61	105	166

Expected slump range(mm)	60-180	60-180	60-180	60-180	60-180	60-180	60-180
Target mean strength *3 days (N/mm²)	8.5	6.0	6.0	6.0	6.0	6.0	6.0
Free W/C ratio	0.6	0.6	0.7	0.7	0.7	0.7	0.7
Free water content(kg/m³)	228	210	220	225	228	235	240
Cement content (kg/m³)	380	300	314	321	326	336	343
Fine aggregate (%)	54.0	56.0	56.0	56.0	56.0	56.0	56.0
Fine agg. content(kg/m³)	957	1064	1042	1030	1025	1010	1001
Coarse agg. content(kg/m³)	815	836	819	809	806	794	786
Obtained strength *3 days (N/mm²)	8.6	--	--	--	--	--	6.2
Obtained slump(mm)	180	105	35	52	60	152	180