DEVELOPMENT OF SOFTWARE FOR MIX DESIGN OF CONCRETE FOR METHOD OF ACI 211.1-91

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ABSTRACT

Concrete is much widely used all over the world as a building material. Because of difficulty in quantitative assessment of some properties of its ingredients, it is a very hard task to estimate suitable proportion by which these ingredients should be mixed (mix design) to obtain concrete of required strength, workability and durability. There are two methods most commonly used for this purpose. Both of these methods have their own features. In this paper, Computer programmes have been developed for concrete mix design of ACI 211.1-91.

INTRODUCTION

One of the ultimate aims of studying the various properties of the materials of concrete, fresh concrete and hardened concrete, is to enable a designer to design a concrete mix for a particular strength. In the broader sense strength is not the only criteria for design of mix however it is one of the most important properties of concrete.

Mix design of concrete can therefore be defined as the process of selecting suitable ingredients of concrete and determining their relative quantities with the purpose of producing an economical concrete which fulfils the requirements of workability, strength and durability.

However it should be kept in mind that design in strict sense of work is not possible owing to following factors:

The widely varying properties of constituent materials.

The properties of materials can not be assessed truly quantitatively so that it is really making no more than intelligent guess of optimum combinations of ingredients.

The complicated inter-relation between variables.

The conditions that prevailing at the site of work and conditions that are demanded for a particular work for which mix is designed.

However with better understanding of the properties, the concrete is becoming more and more an exact material than in the past. The structural designer stipulates certain minimum strength and properties of fresh concrete that are governed by the type of construction and by the technique of placing and transporting the concrete.

The definition of mix design in the preceding paragraph stresses two points.

(i) Concrete should have certain specified minimum properties.
(ii) It should be produced as economically as possible.

The object of producing concrete in the most economical manner depends primarily on two factors.

(i) Cost of material
(ii) Cost of plant, labour

The variation in the cost of material arises from the fact that cost of cement is many times more that the cost of other ingredients, so attention is mainly directed to use of as little cement as possible consistent with strength and durability.

In estimating the cost of concrete the variability of strength of concrete should also be considered, because it is the minimum strength that is specified by the designer of the structure and the actual cost of concrete is related to the materials producing certain mean strength. This is the problem where quality control comes into play. Quality control represents expenditure both on supervision and batching equipment. The decision on the extent of quality control often an economic compromise depend upon the size and type of the job.

The cost of labour is greatly influenced by the workability of the mix. Workability inadequate, for the available means of compaction results in a high cost of labour (or insufficient compacted concrete) even with efficient mechanical equipment.

SPECIFICATIONS

In the past, the specification for concrete prescribed the properties of concrete, and the fine and coarse aggregates certain traditional mixes were thus produced but, owing to the variability of mix ingredients, concrete having fixed cement/aggregates proportions and a given workability vary widely in strength. For this reason, the minimum compressive strength was later included in many specifications. This makes the specifications unduly restrictive when good quality materials are available, but else where it may not be possible to achieve an adequate strength using the prescribed mix proportion. This is why, sometimes, clauses prescribing the grading of aggregate and the shape of the particles have been added to other requirements.

However, the distribution of natural aggregates in many countries is such that these restrictions are often uneconomic. Furthermore, compliance with the requirements of strength, mix proportions and aggregate shape and grading leaves no room for economics in the mix design, and makes progress, in the production of cheap satisfactory mixes on the basis of a study, of the properties of concrete, impossible.

It is not surprising, therefore, that the modern tendency is for specifications to be less restrictive. They lay down limiting values but often give a1so as a guide the traditional mix proportions for the benefit of the contractor who does not wish to use a high degree of control. The limiting values may cover a range of properties, the more usual one are:

(i) minimum compressive strength necessary from structural considerations

(ii) Maximum water/cement ratio and/or maximum cement content and in certain conditions of exposure a minimum content of entrained air to give adequate durability.

(iii) Maximum cement content to avoid cracking due to temperature cycle in mass concrete.

(iv) Maximum cement content to avoid shrinkage cracking under conditions of exposure to a very low humidity.

(v) Minimum density for gravity dams and similar structures.

There are two well known methods which incorporate differently the factors influencing the mix design. These two methods are given below:

(i) Current British method

(ii) ACI method

This paper 'is concerned only with the development of software of mix design method of ACI code.

ACI METHOD OF MIX DESIGNING

The steps of mix designing of concrete are given hereunder.

(1) Find out the required average strength using table-I.

(2) From table-2, determine the w/c ratio.

(3) From table-3, determine the approximate mixing water content.

(4) From table-4 and 5, check the above w/c ratio against durability requirement, and use the lower one.

(5) From the formula given below

$$\text{Cement content} = \frac{\text{water content}}{\text{w / c ratio}}$$

Calculate the cement content.

(6) From table-6, determine the bulk volume of coarse ,aggregate.

(7) For each ingredient, calculate the absolute volume: Absolute volume is the mass divided by the absolute density of the material (kg/m^3). Absolute density is the specific gravity of the material multiplied by the density of water.

The absolute volume of fine aggregate is obtained by subtracting the sum of the absolute volumes of water, cement, entrapped air and coarse aggregate from the unit volume of concrete, that is, 1 m^3.

(8) The mass of fine aggregate is calculated by multiplying the absolute volume of fine aggregate by specific gravity of fine aggregate and density of water.

(9) If free moisture is present, the water content, and the contents of coarse and fine aggregates are adjusted as follows. Absorption of coarse and fine aggregate is subtracted from total moisture contents of coarse and fine aggregates respectively and this value taken as percentage is multiplied with the calculated coarse and fine aggregate contents to obtain the adjusted values. Adjusted value of water content is determined by subtracting the values of difference in coarse and fine aggregate from the calculated value of water content.

(10) Enlist all quantities

FLOW CHART OF SOFTWARE

For the above mentioned steps of method of mix design using ACI 211.1-91 method, a software is developed in FORTRAN-773.4. The flow chart of the software is given.

EXAMPLES SOLVED USING SOFTWARE

PROBLEM-I

Given data

Type of construction = Internal column
Type of cement = Ordinary Portland cement
No special exposure condition
Mean compressive strength = 2900 psi
Age = 28 days
Slump of concrete = 50 mm
Maximum aggregate size = 3/4 in.
Absorption of coarse aggregate = negligible
Absorption of fine aggregate = negligible
Moisture content of coarse aggregate = negligible
Moisture content of fine aggregate = negligible
Bulk density of coarse aggregate = 100 Ib/yd3
Bulk specific gravity of coarse aggregate = 2.60
Bulk specific gravity of fine aggregate = 2.60
Specific gravity of cement = 3.15

Solution:

Increase in strength, = 1000 psi
Required or target strength = 3900 psi
w/c ratio = 0.58
Mixing water content = 315 Ib/yd^3
Cement content = 315/0.58 = 543.1 Ib/yd^3
Entrapped air content = 2.0 %
Dry bulk volume of coarse aggregate = 0.64
No durability check since no special exposure condition are given.
Coarse aggregate content = 1728 Ib/yd^3
Fine aggregate content = 1297.6 Ib/yd^3

PROBLEM-2

Given data

Type of construction = Foundation
Type of cement = Sulphate resisting Portland cement
Type of concrete = Air entrained concrete
Exposure = Severe
Specified compressive strength = 3630 psi
Age = 28 days
Slump of concrete = 3.5 in.
Maximum aggregate size = 1.5 in.
Absorption of coarse aggregate = 0.5 %
Absorption of fine aggregate = 0.7 %
Moisture content of coarse aggregate = 2 %

Moisture content of fine aggregate = 6 %
Bulk specific gravity of coarse aggregate = 2.65
Bulk specific gravity of fine aggregate = 2.65
Fineness modulus of fine aggregate = 2.8
Bulk density of coarse aggregate = 100 Ib/yd^3

Solution:
w/c ratio =0.39
Water content = 275 Ib/yd3
Air content = 5.5 %
w/c ratio after durability check = 0.45
Therefore w/c ratio of 0.39 is OK
Cement content = 275/0.39 = 705.13lb/yd3
Bulk volume of coarse aggregate = 0.71
Coarse aggregate content = 1917 Ib/yd^3
Fine aggregate content = 980.2 lb/yd^3

Adjusted fine aggregate content = l032.2 lb/yd3
Adjusted coarse aggregate content = 1945 Ib/yd3
Adjusted water content = 195 Ib/yd3

REFERENCES

[1] A. M. Neville 1981 "Properties of concrete" Third edition, Pitman book Limited London.
[2] A. M. Neville & J.J. Brooks, 1990 Concrete Technology, First edition, English Language Book Society/Longman.

Table-I: Required increase in strength for specified compressive strength when no tests records are available [Data file-1 is made from this table]

Specified compressive strength		Required increase in strength	
Mpa	**Psi**	**Mpa**	**Psi**
Less than 21	Less than 3000	7	1000
21 to 35	3000 to 5000	8.5	1200
35 or more	5000 or more	10.0	1400

Table-2: [Part-A] Relation between water/cement ratio and average compressive strength of concrete, according to ACI 211.1-81 [Data file-2 is made from this table]

Average compressive strength at 28 days*		Effective water/cement ratio (by mass)	
Mpa	**Psi**	**Non-air-entrained concrete**	**Air-entrained concrete**
45	--	0.38	--
--	6000	0.41	--
40	--	0.43	--
35	5000	0.48	0.40
30	--	0.55	0.46
--	4000	0.57	0.48
25	--	0.62	0.53
--	3000	0.68	0.59
20	--	0.70	0.61
15	--	0.80	0.71
--	2000	0.82	0.74

* The values. given are for a maximum size of aggregate of 20 to 25 mm (3/4 to 1.0 in.) for concrete containing not more than the percentage of air shown in table-3 and for ordinary Portland (Type I) cement.

Table-2: [Part-B] Relation between water/cement ratio and specified compressive strength of concrete, according to ACI 318-83 [Data file-2 is made from this table]

Average compressive strength at 28 days*		Effective water/cement ratio (by mass)	
Mpa	**Psi**	**Non-air-entrained**	**Air-entrained concrete**
		concrete	
--	4500	0.38	--
30.	--	0.40	--
--	4000	0.44	0.35
25	--	0.50	0.39
--	3500	0.51	0.40
--	3000	0.58	0.46
20	--	0.60	0.49
17	--	0.66	0.54
--	2500	0.67	0.54

* Applicable for cements: ordinary Portland (Type I, lA, modified Portland (Types II, IIA) cement, rapid hardening Portland (Types Ill, IIIA), sulphate resisting Portland (Type V), also Portland blast furnace (Types IS, IS-A) and Portland-pozzolan (Types IP, P, I(PM), IP-A) including moderate sulphate-resisting cements (MS).

Table-3: Approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates according to ACI 211.1-81
[Data file-3 is made from this table]

Workability Or Air content	Water content, kg/m3 (lb/yd3) of concrete for indicated nominal maximum aggregate size							
	10mm (3/8 in.)	**12.5 mm (1/4 in.)**	**20mm (3/4 in.)**	**25mm (1 in.)**	**40 mm (1-1/2in.)**	**50mm (2 in.)**	**70mm (3 in.)**	**150 mm (6 in.)**
	Non-air-entrained concrete							
Slump								
30-50 mm	205	200	185	180	160	155	145	125
(1-2 in.)	(350)	(335)	(315)	(300)	(275)	(260)	(220)	(190)
80-100 mm	225	215	200	195	175	170	160	140
(3-4 in.)	(385)	(365)	(340)	(325)	(300)	(285)	(245)	(210)
150-180 mm	240	230	210	205	185	180	170	-----
(6- 7 in.)	(410)	(385)	(360)	(340)	(315)	(300)	(270)	
Approximate entrapped air content (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
Slump								
30-50 mm	180	175	165	160	145	140	135	120
(1-2 in.)	(305)	(295)	(280)	(270)	(250)	(240)	(205)	(180)
80-100 mm	200	190	180	175	160	155	150	135
(3-4 in.)	(340)	(325)	(305)	(295)	(275)	(265)	(225)	(200)
150-180 mm	215	205	190	185	170	165	160	-----
(6-7 in.)	(365)	(345)	(325)	(310)	(290)	(280)	(260)	
Recol1llnended average Total air content, (per cent)								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Extreme	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Table-4: Requirements of ACI 318-83 for concrete exposed to sulphate attack [Data file-4 is made from this table]

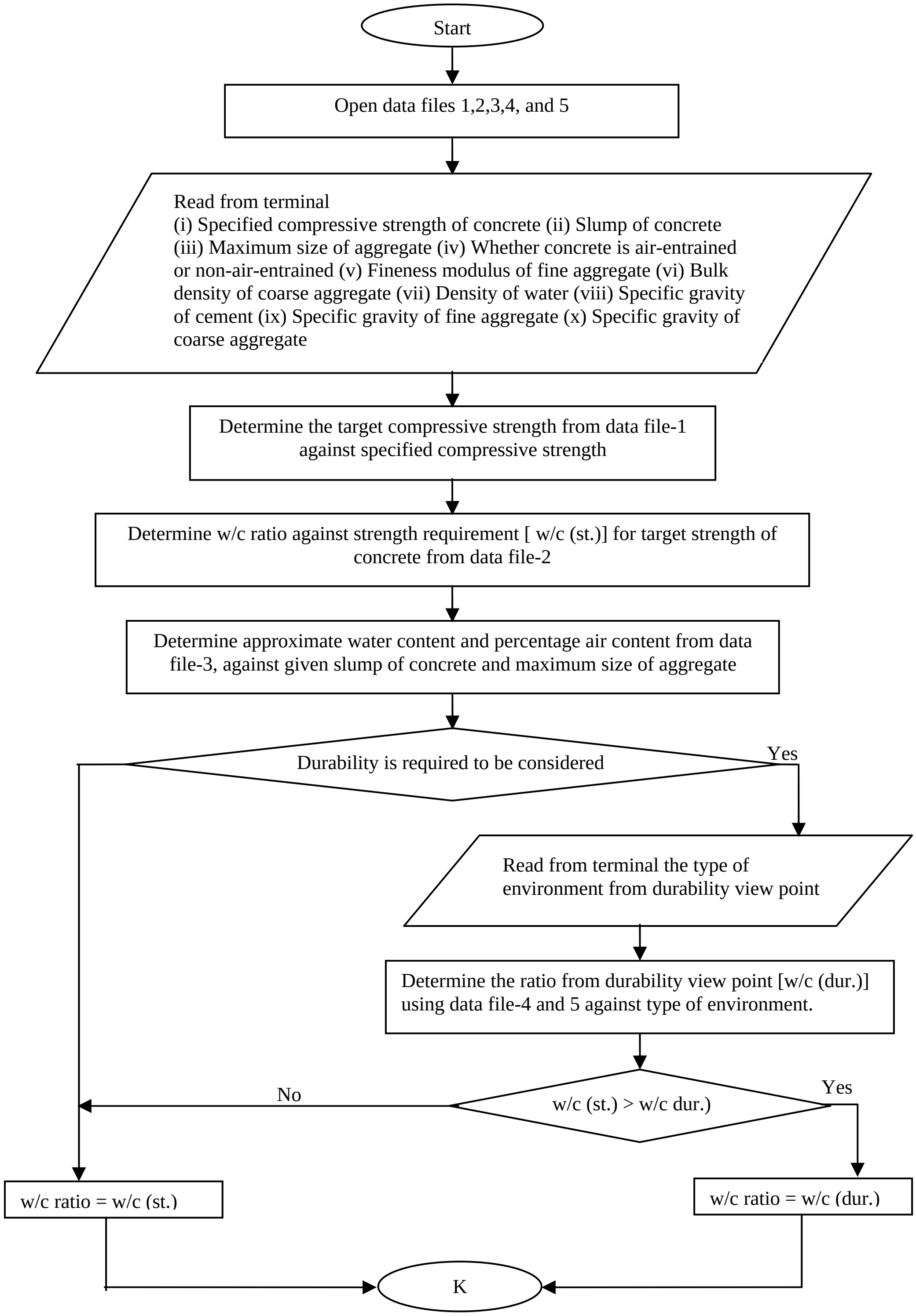
Sulphate Exposure	Water-soluble sulphate (SO^4) in soil	Sulphate (S04) in water	Type of cement	Normal weight aggregate concrete	Leightweight aggregate concrete
				Maximum free water/cement ratio	Minimum compressive strength in Mpa (psi)
Negligible	0.00-0.10	0-150	---	---	---
Moderate (seawater)	0.10-0.20	150-1500	Modified (Type-II), Portland- pozzolan (Type IP(MS)), Portland blast-furnace (Type IS(MS))	0.50	26 (3750)
Severe	0.20-2.00	1500-10,000	Sulphate-resisting Portland (Type V)	0.45	29 (4250)
Very severe	Over 2.00	Over 10,000	Sulphate-resisting Portland (Type V) plus pozzolan (fly ash or other suitable material)	0.45	29 (4250)
For corrosion protection of reinforced concrete exposed to de-icing salts, brackish water, sea water or spray from these sources				0.40	33 (4790)

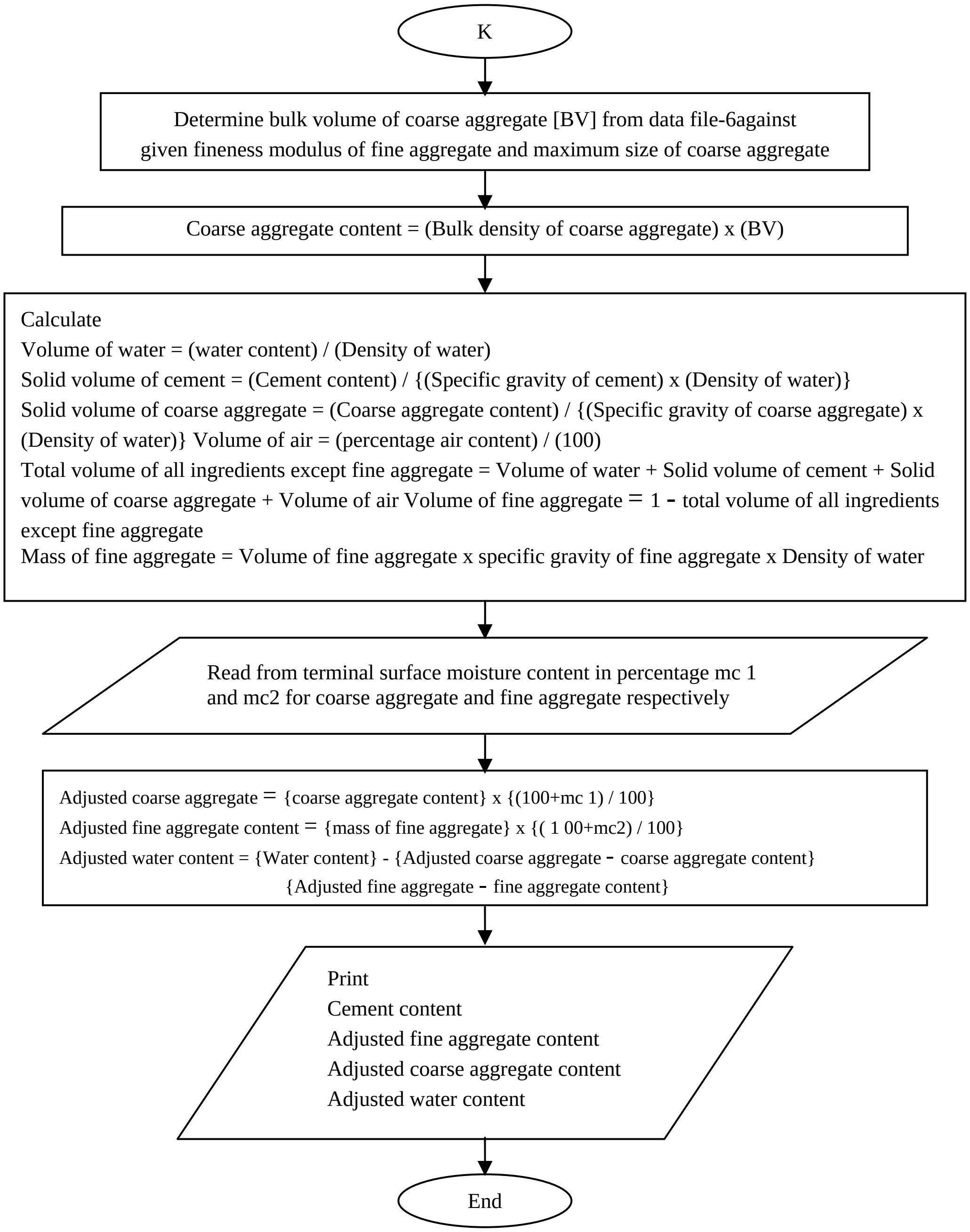
Table-5: Requirements of ACI 313-83 for water/cement ratio and strength for special exposure conditions. [Data file-4 is made from this table]

Exposure condition	Maximum w/c ratio, normal density aggregate concrete	Minimum design strength in MPa (psi), low density aggregate concrete
Concrete intended to be water tight		
(a) Exposed to fresh water	0.50	25 (3630)
(b) Esposed to brackish or sea water	0.45	30 (4350)
Concrete exposed to freezing and thawing in a moist condition		
(a) Kerbs, gutters, guardrails or thin sections	0.45	30 (4350)
(b) Other elcme.nts	0.50	25 (3630)
(c) In presence of de-icing elements	0.45	30 (4350)

Table-6: Bulk volume of coarse aggregate per unit volume of concrete
[Data file-5 is made from this table]

Maximum size Of aggregate		**Bulk volume of oven-dry rodded coarse aggregate per unit volume of concrete for finesses modulus of fine aggregate of:**			
mm	in.	2.4	2.6	2.8	3.00
9.5	3/8	0.50	0.48	0.46	0.44
12.5	Y2	0.59	0.57	0.55	0.53
20	%	0.66	0.64	0.62	0.60
25	1.0	0.71	0.69	0.67	0.65
37.5	1-1/2	0.75	0.73	0.71	0.69
50	2.0	0.78	0.76	0.74	0.72
75	3.0	0.82	0.80	0.78	0.76
150	6.0	0.87	0.85	0.83	0.81


Start
Open data files 1,2,3,4, and 5
Read from terminal
(i) Specified compressive strength of concrete (ii) Slump of concrete (iii) Maximum size of aggregate (iv) Whether concrete is air-entrained or non-air-entrained (v) Fineness modulus of fine aggregate (vi) Bulk density of coarse aggregate (vii) Density of water (viii) Specific gravity of cement (ix) Specific gravity of fine aggregate (x) Specific gravity of coarse aggregate
Determine the target compressive strength from data file-1 against specified compressive strength
Determine w/c ratio against strength requirement [w/c (st.)] for target strength of concrete from data file-2
Determine approximate water content and percentage air content from data file-3, against given slump of concrete and maximum size of aggregate
Durability is required to be considered
Yes
Read from terminal the type of environment from durability view point
Determine the ratio from durability view point [w/c (dur.)] using data file-4 and 5 against type of environment.
No
w/c (st.) > w/c dur.)
Yes
w/c ratio = w/c (st.)
w/c ratio = w/c (dur.)
K


K
Determine bulk volume of coarse aggregate [BV] from data file-6against
given fineness modulus of fine aggregate and maximum size of coarse aggregate
Coarse aggregate content = (Bulk density of coarse aggregate) x (BV)
Calculate
Volume of water = (water content) / (Density of water)
Solid volume of cement = (Cement content) / {(Specific gravity of cement) x (Density of water)}
Solid volume of coarse aggregate = (Coarse aggregate content) / {(Specific gravity of coarse aggregate) x (Density of water)} Volume of air = (percentage air content) / (100)
Total volume of all ingredients except fine aggregate = Volume of water + Solid volume of cement + Solid volume of coarse aggregate + Volume of air Volume of fine aggregate = 1 - total volume of all ingredients except fine aggregate
Mass of fine aggregate = Volume of fine aggregate x specific gravity of fine aggregate x Density of water
Read from terminal surface moisture content in percentage mc 1
and mc2 for coarse aggregate and fine aggregate respectively
Adjusted coarse aggregate = {coarse aggregate content} x {(100+mc 1) / 100}
Adjusted fine aggregate content = {mass of fine aggregate} x {(1 00+mc2) / 100}
Adjusted water content = {Water content} - {Adjusted coarse aggregate - coarse aggregate content}
{Adjusted fine aggregate - fine aggregate content}
Print
Cement content
Adjusted fine aggregate content
Adjusted coarse aggregate content
Adjusted water content
End