MEMBERS OF THE SPECIFICATIONS & STANDARDS COMMITTEE

1.	S.L. Kathuria (*Convenor*)	Addl. Director General (Roads), Ministry of Shipping & Transport
2.	R.P. Sikka (*Member-Secretary*)	Superintending Engineer (Stds.), Ministry of Shipping & Transport
3.	Maj. Genl. V.V. Bhide	Director General, Border Roads Organisation
4.	Brig. Harish Chandra	Director of Design, Engineer-in-Chief Branch AHQ
5.	R.C. Arora	Road Engineer, Hindustan Petroleum Corporation Ltd.
6.	Qazi Mohd. Afzal	Development Commissioner, Jammu & Kashmir
7.	M.K. Chatterjee	Chief Engineer, Calcutta Improvement Trust
8.	B.K. Choksi	'Shrikunj', Near Prakash Housing Society, Surat-395001
9.	E.C. Chandrasekharan	Chief Engineer (National Highways), Tamil Nadu
10.	Dr. M.P. Dhir	Head, Roads Division, Central Road Research Institute
11.	M.G. Dandavate	Engineer, Concrete Association of India
12.	J. Datt	Chief Engineer (Retd.), Greater Kailash, New Delhi-110048
13.	Dr. R.K. Ghosh	Head, Rigid Pavement Division, Central Road Research Institute
14.	I.C. Gupta	Chief Engineer, P.W.D., B & R, Haryana
15.	Dr. V.N. Gunaji	Chief Engineer (H) & Joint Secretary, Maharashtra B&C Department
16.	S.A. Hoda	Project Manager-cum-Managing Director, Bihar State Bridge Construction Corporation Ltd.
17.	M.B. Jayawant	Synthetic Asphalts, 13 Kant Wadi Road, Bombay-400050
18.	Kewal Krishan	Chief Engineer (Retd.), House No. 241-16A, Chandigarh
19.	D.R. Kohli	Commercial Manager, Bharat Refineries Ltd.
20.	P.K. Lauria	Superintending Engineer & Technical Assistant to Chief Engineer, P.W.D., B & R, Rajasthan
21.	H.C. Malhotra	Chief Engineer (S), P.W.D., Himachal Pradesh
22.	O. Muthachen	Poomkavil House, Punalur P.O. (Kerala).
23.	K.K. Nambiar	Chief Engineer, Cement Service Bureau, Alwarpet, Madras-18
24.	K. Sundar Naik	Chief Engineer, C & B, P.W.D., Karnataka
25.	T.K. Natarajan	Head, Soil Mechanics Division, Central Road Research Institute
26.	M.D. Patel	Secretary & Chief Engineer to the Govt. of Gujarat, P.W.D.
27.	Satish Prasad	Manager (Asphalts), Indian Oil Corporation Ltd.
28.	S.K. Samaddar	Engineer-in-Chief & Ex-officio Secretary to the Govt. of West Bengal, P.W.D.
29.	Dr. O.S. Sahgal	Head of the Civil Engineering Deptt., Punjab Engineering College
30.	N. Sen	Chief Engineer (Roads), Ministry of Shipping & Transport
31.	Dr. N.S. Srinivasan	Head, Traffic Division, Central Road Research Institute
32.	D. Ajitha Simha	Director, (Civil Engineering), Indian Standards Institution
33.	Dr. Bh. Subbaraju	Director, Central Road Research Institute
34.	C.G. Swaminathan	Deputy Director, Central Road Research Institute
35.	S.N. Sinha	49-B, Sri Krishna Puri, Patna
36.	Miss P.K. Thressia	Chief Engineer & Ex-officio Addl. Secretary, P.W.D., Kerala
37.	The Director (A. Annamalai)	Highway Research Station, Madras
38.	J.S. Marya	Director General (Road Development) & Addl. Secretary to the Govt. of India, Ministry of Shipping & Transport (*Ex-Officio*)

TENTATIVE GUIDELINES FOR DESIGN OF GAP GRADED CEMENT CONCRETE MIXES FOR ROAD PAVEMENTS

Published by
THE INDIAN ROADS CONGRESS
Jamnagar House, Shahjahan Road
New Delhi-110011
1976

Price Rs 5 Rs. 24
(plus Packing & Postage)

TENTATIVE GUIDELINES FOR DESIGN OF GAP GRADED CEMENT CONCRETE MIXES FOR ROAD PAVEMENTS

1. INTRODUCTION

These guidelines were approved by the Cement Concrete Road Surfacing Committee (Personnel given below) in their meeting held at Chandigarh on the 1st March, 1975.

K.K. Nambiar —*Convenor*
Dr. R.K. Ghosh —*Member-Secretary*

Members

D.C. Chaturvedi
Dr. M.P. Dhir
Brig. Gobindar Singh
C.L.N. Iyengar
P.J. Jagus
M.D. Kale
Brig. R.K. Kalra
Dr. S.K. Khanna
K.C. Mital
N.L. Patel
P.S. Sandhawalia
A.R. Satyanarayana Rao
S.B.P. Sinha
N. Sivaguru
Dr. H.C. Visvesvaraya
Director General (Road Development)—*ex-officio*
C.V. Padmanabhan (Co-opted)

These were processed by the Specifications & Standards Committee in their meeting held on the 12th and 13th December, 1975 and approved by the Executive Committee and the Council in their meetings held on the 22nd December, 1975 and 3rd January, 1976 respectively.

1.2. General

1.2.1. A significant criterion in designing cement concrete mixes is to ensure that the voids in the compacted coarse aggregate get filled with compacted fine aggregate and the residual voids in the total compacted aggregate structure with the cement paste of a given water-cement ratio to meet the strength requirement. Depending on the workability needed for a particular construction, it will be necessary to increase the amount of cement paste appropriately over that required to fill the residual voids. One way of achieving this desideratum is through gap-grading of aggregates with permissible maximum size of coarse aggregate followed by admissible maximum size of finer coarse aggregate or fine aggregate, as the case may be. The relationship between the permissible and admissible sizes constitutes the basis for compatible gradation required in the design of gap-graded concrete mixes.

1.2.2. The principle of gap-gradation of aggregates is that the voids in the larger aggregate particles are big enough to admit particles of the selected lower size without causing any interference to the larger particles or dilation thereof. The flow of concrete results from easy admittance of the finer fractions into the voids of coarser fractions. This may be explained as follows:

Assuming the maximum size of single-size coarse aggregates as D, the largest voids in the packing thereof will be able to accommodate smaller aggregates of size 0.414 D, which in turn will accommodate still smaller aggregates of size 0.225 D, all aggregates idealised as spheres. The residual voids can be geometrically filled with further smaller aggregates of size 0.155 D. This theoretical geometrical model can go on down to the extreme fines. Such arrangement is, however, possible only through very careful hand-packing, and in practice, the aggregates of sizes 0.414 D and 0.225 D cannot easily enter the side interstices after the single-size coarse aggregates of size D have been closely packed. Aggregates of size 0.155 D and lower alone can possibly slip into such side interstices without difficulty. Forcing any intermediate size of aggregate smaller than D but greater than 0.155 D with the aid of vibration, may result in wedging out the coarse aggregates of size D from contacting each other and thereby requiring considerably more quantity of mortar and hence more cement and water for any stipulated water-cement ratio. Properly designed gape-graded concrete mixes are, therefore, likely to require less quantity of cement for the same water-cement ratio and workability.

1.2.3. In general, if the requirements of gap-graded concrete are to be satisfactorily met from the practical point, it is necessary to eliminate from the continuous grading range, aggregates of at least two and at best three successive sizes, depending upon the shape, size and type of the coarse aggregates used. The suggested ranges of single-size coarse aggregates and aggregates of selected lower size for different maximum sizes of aggregates with a view to achieving compatible gradation as envisaged in gap-gradation are given in Table 1.

1.2.4. IRC: 15-1970 "Standard Specifications and Code of Practice for Construction of Concrete Roads" stipulates collection of coarse aggregates for paving concrete in different sizes. These are then combined in suitable proportions to obtain the stipulated continuous grading. In India, by and large, such continuous gradings are not produced from crushing operations. The elimination of a particular size from the grading range of coarse aggregate to

TABLE 1 : SUGGESTED COMPATIBLE GRADATION OF COARSE AND FINE
AGGREGATES FOR THE PURPOSE OF GAP-GRADING

Max. size of aggregate (mm)	Single size coarse aggregate (mm)	Number of gaps	Max. size of compatible finer aggregate	
			Small size coarse aggregate (mm)	Sand zo (IS: 383
63	63-50	2	20-10	II or
		3	10-4.75	III or
50	50-40	2	10-4.75	III or
		3	—	I or
40	40-20	2	—	I or
		3	—	II or
20	20-10	2	—	II or
		3	—	III or

* Foot Note : Fineness modulus of sand : Zone I-4.00 to 2.71
Zone II-3.35 to 2.11
Zone III-2.75 to 1.71
Zone IV-2.25 to 1.35

obtain gap-grading should, therefore, pose no problem. Since fractions of coarse aggregates are costlier than their coarser cou parts, such elimination may turn out to be cheaper from the of material costs also. Where, however, the all-in aggregates the crushers provide the stipulated continuous grading, purp eliminating a fraction therefrom by sieving to produce gap-gr aggregate may be uneconomical. For the same reason, fine ag gate should not be screened to obtain the desired fractions for grading. In many parts of the country, however, fine aggregat different granulometry are available and those with finer gra metry generally cost less. It is, therefore, imperative that before choosing between the continuous and gap-grading, the above aspects should be carefully considered and comparative economics of the two types of mixes worked out.

1.2.5. For gap-graded concrete mixes, the workability is required to be low from the point of segregation. It is desirable to specify a slump of 0-12 mm for gap-graded paving concrete mixes. Gap-graded concrete mixes should be compacted only through vibratory effort. Manual compaction should not be permitted.

2. GUIDELINES

2.1. The following are required to be specified in the design of a cement concrete mix:

(a) Minimum compressive/flexural strength of concrete in the field at 28 days.

(b) Maximum size of coarse aggregate to be used and its type.

(c) Degree of workability, related to the nature of construction and compaction equipment available.

(d) Degree of quality control expected to be exercised—'very good', 'good' or 'fair' and permissible co-efficient of variation or standard deviation.

(e) Accepted tolerance level.

The stipulations in respect of the above items shall generally conform to the requirements laid down in IRC: 15-1970, where the work pertains to concrete pavement. For other works, relevant standard specification may be consulted.

2.2. Tests for Materials

The materials used should conform to the relevant standard specifications. For mix design, it will be necessary to know the results of the following tests:

(a) Cement:
- (i) Compressive strength at 7 days (IS: 269-1967**)
- (ii) Specific gravity (IS: 269-1967**)
  (A value of 3.15 may be assumed, if test cannot be conducted).

(b) Aggregate:
- (i) Specific gravity (IS: 2386 Part III-1963@)

** Specifications for Ordinary, Rapid Hardening and Low Heat Portland Cements.

@ Methods of Test for Aggregates for Concrete — Pt. III, Specific Gravity, Density, Voids, Absorption and Bulking.

(ii) Bulk density of saturated surface-dry samples (IS: 2386-Part III 1963@).

(iii) Per cent water absorption (IS: 2386 Part 1963@)

(iv) Sieve analysis (IS: 2386 Part I-1963@@)

2.3. Aggregate Grading

2.3.1. As stated earlier, single-size coarse aggregate should be chosen as far as possible, (Table I.) If this size is large and after allowing for 2 or 3 gaps still a fraction of finer coarse aggregate is required as the next compatible size, then as per gap-grading principle a second set of 2 or 3 gaps are required to be provided between the finer coarse aggregate and the fine aggregate (sand). However, since the second set of gaps will result in eliminating almost all the coarser fractions of fine aggregate and only fine to very fine sand will be left in most cases, this may not be desirable from the point of water demand and shrinkage. Under such circumstances, the number of gaps in the second set may be reduced from 2 or 3 to 1 or even 0.

2.3.2. Fine aggregate should preferably be natural sand conforming to IS: 383-1970*, although crushed stone sand may also be used. In the latter case, the fine aggregate should conform to IS: 383-1970, excepting that in Grading Zone IV, the permissible percentage passing limits on 300 — and 150 micron sieves should be 15-55 per cent and 0-20 per cent respectively as per IRC: 15-1970 instead of 15-50 per cent and 0-15 per cent as stipulated in IS Specification. As far as possible, the size of the fine aggregate (Zone I, II, III or IV) should be as stipulated in Table I. Where there is practical difficulty in getting fine aggregate conforming to the stipulated Zone, the next coarser Zone might be adopted. There is no need of sieving the fine aggregate to obtain the desired Zone.

2.4. Design Strength of Concrete

2.4.1. As in continuously graded concrete, so also in gap-graded concrete the strength varies with the water-cement ratio. Higher the water-cement ratio, lower is the strength of gap-graded concrete. Studies have shown that for the same water-cement ratio, both continuously graded and gap-graded concrete mixes yield similar strengths for workable mixes.

@ Methods of Test for Aggregates for Concrete—Pt. III, Specific Gravity, Density, Voids, Absorption and Bulking.

@@ Same as @—Pt. I, Particle Size and Shape.

* Specifications for Coarse and Fine Aggregates from Natural Sources for Concrete

2.4.2. In order to get the specified minimum compressive or flexural strength in the field, the concrete mix has to be designed for somewhat higher average compressive or flexural strength depending on the degree of quality control (denoted through permissible co-efficient of variation or standard deviation) and the tolerance level. The average strength (S) at 28 days for which the mix should be designed is given by the equation:

$$S = \frac{\overline{S}}{1 - t.v/100} \qquad (1)$$

where, $\overline{S}$ = minimum compressive or flexural strength (Kg/cm^2) in the field at 28 days,

t = factor (dimensionless) depending on specified tolerance level, and

v = co-efficient of variation (per cent) specified.

2.4.3. The values of t in eqn. (1) for different tolerance level are given in Table 2.

Table 2 : Values of Tolerance factor (t)

Tolerance level / Number 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	1.70	2.04	2.46
∞ (infinite)	1.28	1.50	1.64	1.96	2.33

2.4.4. The average design compressive strengths of concrete for different combinations of specified minimum strength, tolerance level and coefficient of variation corresponding to an infinite number of samples have been worked out and are shown in Table 3. On smaller jobs where a finite number of samples is to be tested, the corresponding average design strengths could be obtained by application of appropriate tolerance factor in eqn. (1).

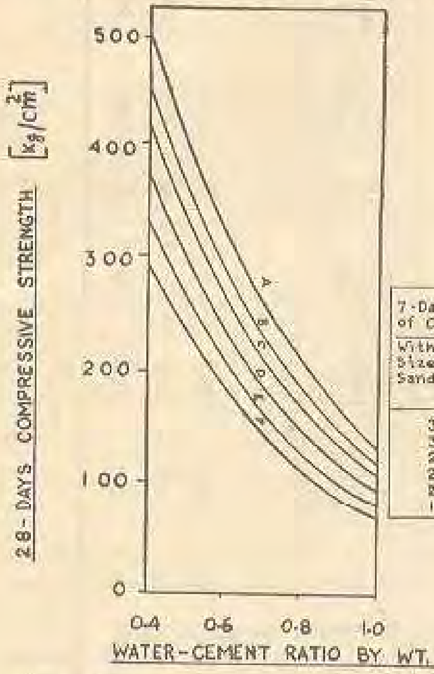
TABLE 3: AVERAGE DESIGN STRENGTHS OF CONCRETE FOR DIFFERENT DEGREES OF QUALITY CONTROL AND TOLERANCE LEVEL

Degree of Quality Control	Min. Specified concrete strength (Kg/cm^2) at 28 days											
	Compressive Strength = 200 Kg/cm^2 Flexural Strength = 20 kg/cm^2				Compressive Strength=275 kg/cm^2 Flexural Strength = 28 Kg/cm^2				Compressive Strength = 350 Kg/cm^2 Flexural Strength = 35 Kg/cm^2			
	Tolerance level	Coef. of variation	Av. design compr. str. (Kg/cm^2)	Av. design flex. str. (Kg/cm^2)	Tolerance level	Coef. of variation	Av. design compr. str. (Kg/cm^2)	Av. design flex. str. (Kg/cm^2)	Tolerance level	Coef. of Variation	Av. design compr. str. (Kg/cm^2)	Av. design flex. str. (Kg/cm^2)
Very good	1 in 15	10	235	23.5	1 in 15	7	310	31.3	1 in 20	7	400	40.0
Good	1 in 10	15	250	25.0	1 in 15	10	325	32.9	1 in 15	10	415	41.5
Fair	1 in 10	20	270	27.0	1 in 10	15	340	34.7	—	—	—	—

2.4.5. According to IRC: 15-1970, the permissible tolerance level and coefficient of variation for concrete road pavements are 1 in 15 (i.e., $t=1.5$ for infinite number of samples) and 10 per cent respectively.

2.5. Selection of Water-Cement Ratio

As the compressive strength of ordinary portland cements available in India varies considerably from factory to factory, it is not possible to have a single curve of correlation between water-cement ratio and compressive strength of concrete. A set of such curves with 7 days compressive strength of cement as the third parameter is given in IRC : 44-1972** and is reproduced here in Fig. 1 for the purpose of guidance. For a particular cement, knowing its compressive strength at 7 days, the water-cement ratio for the average compressive strength of concrete can be selected from



7-Days Compressive Strength of Cement (kg/cm²)		Curve for Cement Concrete Mix Design
With Single Sized Standard Sand (IS 269-1967)	With Regraded Standard Sand (IS 650-1966)	
350	440	A
315	396	B
280	352	C
245	308	D
210	264	E
175	220	F

Fig. 1. Design curve for cement concrete mixes in relation to 7-days compressive strength of cement

** Tentative Guidelines for Cement Concrete Mix Design for Road Pavements

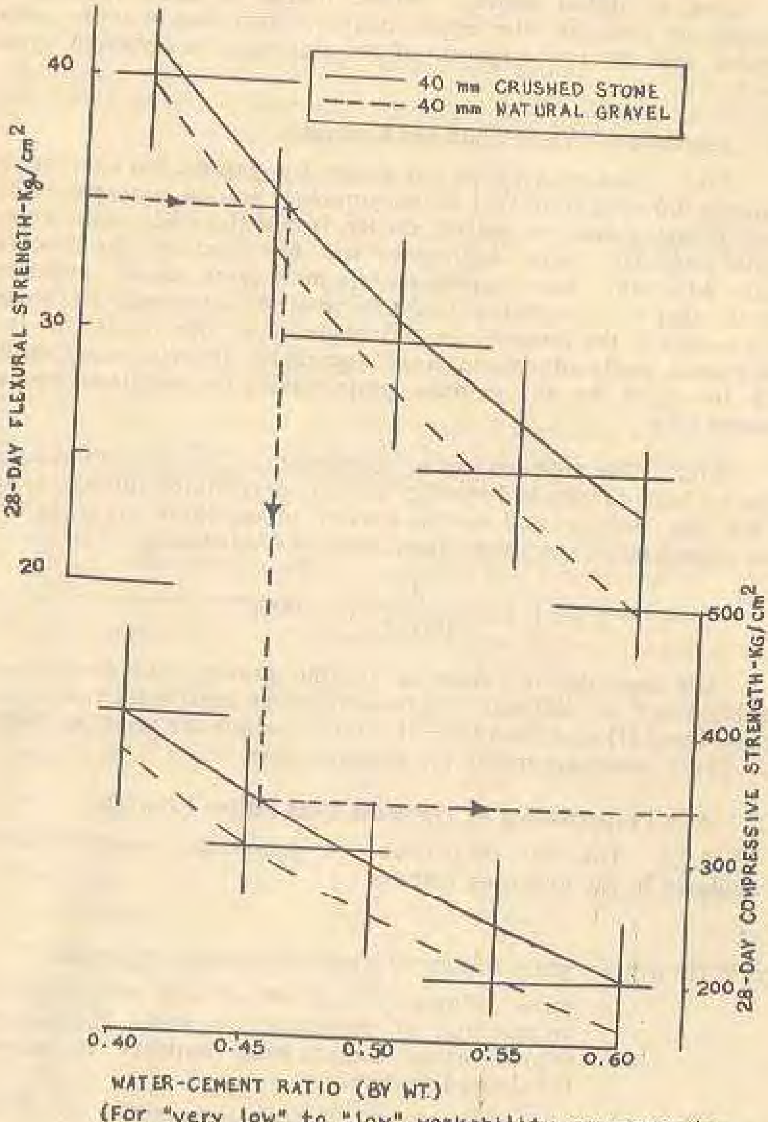


Fig. 2. Chart for assessment of flexural strength of concrete from its cube compressive strength

the curve as stated above. Where design is based on flexural strength of concrete, the approximate relationship between compressive and flexural strength of concrete may be obtained from Fig. 2.

2.6. Selection of Water Sand and Content

2.6.1. The principle of mix design for gap-graded concrete is radically different from that for continuously graded concrete. The basis of such design, as stated earlier, is that the voids in the compacted single-size coarse aggregates will be filled by the selected easily admissible finer aggregates (in most cases sand), meaning thereby that the compacted bulk volume of the latter will be equal to the voids in the former. In the same way, the voids in the compacted, easily admissible finer aggregates (in most cases sand) will be filled by the cement paste having the stipulated water-cement ratio.

2.6.2. The void content in aggregate can be easily calculated from its bulk density and specific gravity determined through tests. If the bulk density and specific gravity of aggregate are d (kg/m^3) and s (gm/cm^3) respectively, then the void content n is :

$$n = \left(1 - \frac{d}{1000\,s} \right) 100\% \qquad (2)$$

The approximate values of specific gravity, bulk density and void content in different single-sized coarse aggregates and coarse (Zone I and II) and fine (Zone III and IV) sands are given in Table 4. These values are meant for guidance only.

2.7. Mix Proportioning by Optimum Void-Filling Principle

2.7.1. The mix proportions of gap-graded concrete can be calculated in the following manner :

Let

(i) V (in m^3) = gross volume of single sized coarse aggregate

= gross volume ($\overline{V}$ = 1 m^3) of wet mix *minus* the volume (v_a) of entrapped air *minus* the volume (v'_p) of "extra" cement paste required to provide the desired workability.

(ii) v_f (in m^3) = gross volume of next compatible size of fine aggregate (in most cases sand)

= volume of voids in the single-size coarse aggregate

$= \frac{n_1 . V}{100}$, with n_1 denoting per cent of voids in single-size coarse aggregate,

and (iii) $\bar{v}_p$ (in m^3) = volume of cement paste required to fill the voids in finer aggregate

= volume of voids in finer aggregate

$= \frac{n_2 . v_s}{100}$, with n_2 denoting per cent of voids in finer aggregate

$= \frac{n_1 . n_2 . V}{10000}$

The total volume of cement paste is therefore $v'_p + \bar{v}_p = v_p$. Knowing v_p and water-cement ratio (r) by weight, the quantities of cement and water can be easily calculated.

TABLE 4. APPROXIMATE VALUES OF SPECIFIC GRAVITY, BULK DENSITY AND VOID CONTENTS OF COARSE AND FINE AGGREGATES

Size of aggregate	Specific gravity (g/cm^3)	Bulk density (kg/m^3)	Per cent void (%)
Coarse aggregate*			
63—50 mm	2.65	1650	37.7
50—40 mm	2.65	1620	38.6
40—20 mm	2.65	1600	39.6
20—10 mm	2.65	1520	42.6
10—4.75 mm	2.65	1520	42.6
Fine aggregate Coarse sand (Zone I & II)	2.65	1450	45.3
Fine sand (Zone III & IV)	2.63	1350	48.7

**Note*: The above values are average for both angular (manufactured) and rounded (natural) coarse aggregates.

2.7.2. The mix proportions by weight per m³ gross volume of wet concrete therefore are :

Water	Cement	Compatible finer aggregate (in most cases sand)	Coarse aggregate
kg/m^3 W_w	(kg/m³) W_c	kg/m³ W_s	kg/m³ W_a

where

(i) $$W_a = V.d_a = (1-v_e-v'_p)\, d_a \qquad (3)$$

(ii) $$W_s = v_s.d_s = \frac{n_1}{100}\,(1-v_e-v'_p)\, d_s \qquad (4)$$

(iii) $$W_c = \frac{1000\, v_p.\, s_c}{1 + r.s_c} = \frac{1000\, s_c}{1 + r.s_c}\left[v'_p + \frac{n_1\, n_2}{10000}\,(1-v_e-v'_p)\right] \qquad (5)$$

and (iv) $$W_w = r.W_c = \frac{1000\, r.s_c}{1 + r.s_c}\left[v'_p + \frac{n_1\, n_2}{10000}\,(1-v_e-v'_p)\right] \qquad (6)$$

with v_e = volume (m³) of entrapped air in 1m³ gross volume of wet concrete (see para 2.7.3.)

v'_p = volume (m³) of "extra" cement paste required for desired workability in 1m³ gross volume of wet concrete (see para 2.7.4),

n_1 = Per cent of voids in single-size coarse aggregate,

n_2 = Per cent of voids in finer aggregate,

d_a = bulk density (Kg/m³) of coarse aggregate,

d_s = bulk density (Kg/m³) of finer aggregate (in most cases sand),

s_c = specific gravity of cement, and

r = water-cement ratio by weight.

2.7.3. Approximate quantities (v_a) of entrapped air in wet concrete mixes having different maximum sizes of coarse aggregate are shown in Table 5.

TABLE 5. APPROXIMATE AMOUNT OF ENTRAPPED AIR IN NON AIR-ENTRAINED CONCRETE

Max. size of aggregate (mm)	10	20	40	50	63
Entrapped air (%)	3	2	1.0	0.5	0.4
Volume of air per 1 m^3 gross volume of wet concrete (m^3)	0.03	0.02	0.01	0.005	0.004

2.7.4. The amount (v'_p) of "extra" cement paste required in the concrete mix will depend on the degree of workability desired, which in turn will depend on the compactive effort intended to be applied and the amount of reinforcement proposed in the structure. In India, most concrete pavements are built without any reinforcement excepting dowel bars at expansion joints and sometimes tie-bars at longitudinal joints. The slump stipulated in IRC: 15-1970 is very low to low (0 to 25 mm) for paving concrete mixes when compacted by vibration. Since gap-graded concrete mixes should be dry to prevent segregation, the slump shall not be more than 12 mm. For this degree of workability, the amount (v'_p) of "extra" cement paste may be taken as equal to about 11 per cent of the gross volume ($\overline{V}$) of wet concrete on average basis. The quantity of "extra" cement paste will in reality depend on the shape and size of coarse aggregate as well as the grading of fine aggregate. Therefore, if greater refinement is desired, the volume of "extra" cement paste may be increased or decreased by 1 per cent (making it 12 per cent or 10 per cent of $\overline{V}$) depending on whether the coarse aggregate is angular (e.g., crushed stone) or rounded (e.g., gravel). Similarly, if sand available is such that the number of gaps between the lowest coarse aggregate fraction and the fine aggregate is required to be reduced to 1-2 or 0-1 instead of 2-3 (see para 2.3.1), the volume of "extra" cement paste may be reduced by 1 and 2 per cent (making it 10 and 9 per cent of $\overline{V}$) when the number of gaps is 1-2 and 0-1 respectively.

3. WORKED OUT EXAMPLE ON MIX DESIGN

An example illustrating the mix design procedure is worked out in *Appendix*.

4. TRIAL MIX

4.1. With mix proportions obtained from para 2.7.2. the mix is prepared and the workability measured. If the workability measured is different from the stipulated value, the "extra" cement paste (v'_p) shall be adjusted. To obtain maximum benefit from gap-graded concrete, the water-cement ratio of the mixes is kept low, usually between 0.40 and 0.60. For this range of water-cement ratio, for each 12 mm increase or decrease in observed slump, the amount of "extra" cement paste may be reduced or increased respectively by 5 per cent. For 1 m^3 gross volume of wet mix, $(\bar{V})$ this reduction or increase in "extra" cement paste ($v'_p = 0.1\ \bar{V} = 0.1\ m^3$) would mean an alteration by $\mp\ 0.05\ v'_p = \mp\ 0.005\ m^3$ for each 12 mm ncrease or decrease in the observed slump value.

4.2. The mix proportions are thereafter recalculated with the adjusted cement paste as per procedure given above for three water-cement ratios comprising the pre-selected water-cement-ratio and two other values, one higher and the other lower than the pre-selected ratio by 0.05. The strength of concrete with the three water-cement ratios is then determined in accordance with IS: 516-1969**. The values of strength obtained are then plotted against water-cement ratios and the appropriate water-cement ratio for the required strength chosen from the plot. The final mix proportions are then recalculated for this water-cement ratio, other parameters remaining the same.

** Methods of Test for Strength of Concrete

WORKED OUT EXAMPLE FOR CEMENT CONCRETE MIX DESIGN

(A) Design Stipulations

(i)	Minimum compressive strength required in the field at 28-days	: 260 Kg/cm²
(ii)	Maximum size of aggregate	: 40 mm (single-size, rounded aggregate)
(iii)	Degree of workability	: 12 mm (extra cement paste, $v'p=0.1$ m³/m³)
(iv)	Degree of quality control	: Good (co-efficient of variation 10%)
(v)	Accepted tolerance level (major work involving testing of a large number of samples i.e., t from Table 2=1.50)	: 1 in 15
(vi)	Entrapped air, v_a	: 0.01 m³/m³

(B) Test Data for Materials:

(i)	Compressive strength of cement at 7 days (I.S.: 269-1967)	: 308 Kg/cm²
(ii)	Specific gravity of cement	: 3.15
(iii)	Specific gravity of coarse aggregate and fine aggregate	: 2.65
(iv)	Water absorption: (a) Coarse aggregate	: 0.4%
	(b) Fine aggregate	: 0.6%
(v)	Free (Surface) moisture: (a) Coarse aggregate	: nil
	(b) Fine aggregate	: 2%
(vi)	Bulk density of saturated surface-dry coarse aggregate (d_s): 1600 kg/m³	(Table 4)
(vii)	Bulk density of saturated surface-dry fine aggregate (d_s): 1450 kg/m³	(Table 4)

(C) Design Strength of Concrete (S)

$$S=\frac{\bar{S}}{1-\frac{t.V}{100}}=\frac{260}{1-\frac{1.5\times 10}{100}}=\frac{260}{1-0.15}=\frac{260}{0.85}=306 \text{ kg/cm}^2$$

=say, 310 kg/cm²

(D) Selection of Water-Cement Ratio:

From Fig. 1, corresponding to 7-days cement strength of 308 kg/cm² and design strength of concrete of 310 kg/cm², water-cement ratio required=0.50.

(E) Calculation of Mix Proportions per 1 m³ of Wet Concrete

(i) $\overline{V}=1 \text{ m}^3$

Therefore $V=\overline{V}-v_a-v'p=1.00-0.01-0.10=0.89 \text{ m}^3$

(ii) $W_a=V.d_a=0.89\times1600=1424$ Kg

(iii) $W_s=\frac{n_1.V.}{100}.d_s.$

Since $n_1=(1-1600/1000\times2.65)\times100=39.6$ per cent

$W_s=\frac{39.6\times0.89\times1450}{100}=511$ Kg

(iv) $W_c=\frac{1000\ s_c}{1+r.\ s_c}\left(v'p+\frac{n_1.n_2}{10000}V\right)$

Since $n_2=(1-1450/1000\times2.65)\times100=45.3$ per cent

$W_c=\frac{1000\times3.15}{1+0.5\times3.15}\left(0.10+\frac{39.6\times45.3\times0.89}{10000}\right)$
$=317.7$ Kg

(v) $W_w=r.W_c$
$=0.5\times317.7=158.85$ kg

(vi) **Mix proportions**

	Water (Kg/m³)		Cement (Kg/m³)		Fine Aggregate (Kg/m³)		Coarse Aggregate (Kg/m³)
	158.85		317.7		511.0		1424.0
or	0.5	:	1	:	1.608	:	4.48

(F) Actual Quantities required for the mix per 50 kg bag of cement

(i) For cement=50 kg, net quantities of materials are: fine aggregate =80.40 kg, coarse aggregate=224.0 kg and water 25.0 kg=25.0 litre.

(ii) Extra water to be added to cater for absorption by coarse aggregate=224×0.4/100=0.896 kg=0.896 litre. Water to be deducted for free moisture present in fine aggregate=80.40×2/100=1.608 kg =1.608 litre. Actual quantity of water to be added is therefore =25.000+0.896—1.608=24.288 litre.

(iii) Actual quantity of fine aggregate required=80.400+1.608= 82.008 kg.

(iv) Actual quantity of coarse aggregate required=224.000—0.896= 223.104 kg.

Therefore, the actual quantities of the different constituents per bag of cement are:

Cement=50 kg
Water =24.288 litre
Sand=82.008 kg
Coarse aggr.=223.104 kg.