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(चौथा पुनरीक्षण)

Indian Standard

PLAIN AND REINFORCED CONCRETE — CODE OF PRACTICE

(Fourth Revision)

ICS 91.100.30

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PLAIN AND REINFORCED CONCRETE — CODE OF PRACTICE
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FOREWORD

This Indian Standard (Fourth Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

This standard was first published in 1953 under the title 'Code of practice for plain and reinforced concrete for general building construction' and subsequently revised in 1957. The code was further revised in 1964 and published under modified title 'Code of practice for plain and reinforced concrete', thus enlarging the scope of use of this code to structures other than general building construction also. The third revision was published in 1978, and it included limit state approach to design. This is the fourth revision of the standard. This revision was taken up with a view to keeping abreast with the rapid development in the field of concrete technology and to bring in further modifications/improvements in the light of experience gained while using the earlier version of the standard.

This revision incorporates a number of important changes. The major thrust in the revision is on the following lines:

a) In recent years, durability of concrete structures have become the cause of concern to all concrete technologists. This has led to the need to codify the durability requirements world over. In this revision of the code, in order to introduce in-built protection from factors affecting a structure, earlier clause on durability has been elaborated and a detailed clause covering different aspects of design of durable structure has been incorporated.

b) Sampling and acceptance criteria for concrete have been revised. With this revision acceptance criteria has been simplified in line with the provisions given in BS 5328 (Part 4):1990 'Concrete: Part 4 Specification for the procedures to be used in sampling, testing and assessing compliance of concrete'.

Some of the significant changes incorporated in Section 2 are as follows:

a) All the three grades of ordinary Portland cement, namely 33 grade, 43 grade and 53 grade and sulphate resisting Portland cement have been included in the list of types of cement used (in addition to other types of cement).

b) The permissible limits for solids in water have been modified keeping in view the durability requirements.

c) The clause on admixtures has been modified in view of the availability of new types of admixtures including superplasticizers.

d) In Table 2 'Grades of Concrete', grades higher than M 40 have been included.

e) It has been recommended that minimum grade of concrete shall be not less than M 20 in reinforced concrete work (*see also* **6.1.3**).

f) The formula for estimation of modulus of elasticity of concrete has been revised.

g) In the absence of proper correlation between compacting factor, vee-bee time and slump, workability has now been specified only in terms of slump in line with the provisions in BS 5328 (Parts 1 to 4).

h) Durability clause has been enlarged to include detailed guidance concerning the factors affecting durability. The table on 'Environmental Exposure Conditions' has been modified to include 'very severe' and 'extreme' exposure conditions. This clause also covers requirements for shape and size of member, depth of concrete cover, concrete quality, requirement against exposure to aggressive chemical and sulphate attack, minimum cement requirement and maximum water cement ratio, limits of chloride content, alkali silica reaction, and importance of compaction, finishing and curing.

j) A clause on 'Quality Assurance Measures' has been incorporated to give due emphasis to good practices of concreting.

k) Proper limits have been introduced on the accuracy of measuring equipments to ensure accurate batching of concrete.

m) The clause on 'Construction Joints' has been modified.

n) The clause on 'Inspection' has been modified to give more emphasis on quality assurance.

The significant changes incorporated in Section 3 are as follows:

a) Requirements for 'Fire Resistance' have been further detailed.

b) The figure for estimation of modification factor for tension reinforcement used in calculation of basic values of span to effective depth to control the deflection of flexural member has been modified.

c) Recommendations regarding effective length of cantilever have been added.

d) Recommendations regarding deflection due to lateral loads have been added.

e) Recommendations for adjustments of support moments in restrained slabs have been included.

f) In the detemination of effective length of compression members, stability index has been introduced to determine sway or no sway conditions.

g) Recommendations have been made for lap length of hooks for bars in direct tension and flexural tension.

h) Recommendations regarding strength of welds have been modified.

j) Recommendations regarding cover to reinforcement have been modified. Cover has been specified based on durability requirements for different exposure conditions. The term 'nominal cover' has been introduced. The cover has now been specified based on durability requirement as well as for fire requirements.

The significant change incorporated in Section 4 is the modification of the clause on Walls. The modified clause includes design of walls against horizontal shear.

In Section 5 on limit state method a new clause has been added for calculation of enhanced shear strength of sections close to supports. Some modifications have also been made in the clause on Torsion. Formula for calculation of crack width has been added (separately given in Annex F).

Working stress method has now been given in Annex B so as to give greater emphasis to limit state design. In this Annex, modifications regarding torsion and enhanced shear strength on the same lines as in Section 5 have been made.

Whilst the common methods of design and construction have been covered in this code, special systems of design and construction of any plain or reinforced concrete structure not covered by this code may be permitted on production of satisfactory evidence regarding their adequacy and safety by analysis or test or both (*see* **19**).

In this code it has been assumed that the design of plain and reinforced cement concrete work is entrusted to a qualified engineer and that the execution of cement concrete work is carried out under the direction of a qualified and experienced supervisor.

In the formulation of this standard, assistance has been derived from the following publications:

BS 5328 : Part 1 : 1991 Concrete : Part 1 Guide to specifying concrete, British Standards Institution

BS 5328 : Part 2 : 1991 Concrete : Part 2 Methods for specifying concrete mixes, British Standards Institution

BS 5328 : Part 3 : 1990 Concrete : Part 3 Specification for the procedures to be used in producing and transporting concrete, British Standards Institution

BS 5328 : Part 4 : 1990 Concrete : Part 4 Specification for the procedures to be used in sampling, testing and assessing compliance of concrete, British Standards Institution

BS 8110 : Part 1 : 1985 Structural use of concrete : Part 1 Code of practice for design and construction, British Standards Institution

BS 8110 : Part 2 : 1985 Structural use of concrete : Part 2 Code of practice for special circumstances, British Standards Institution

ACI 319 : 1989 Building code requirements for reinforced concrete, American Concrete Institute

AS 3600 : 1988 Concrete structures, Standards Association of Australia

DIN 1045 July 1988 Structural use of concrete, design and construction, Deutsches Institut für Normung E.V.

CEB-FIP Model code 1990, Comite Euro - International Du Belon

The composition of the technical committee responsible for the formulation of this standard is given in Annex H.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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SECTION 1 GENERAL

1 SCOPE

1.1 This standard deals with the general structural use of plain and reinforced concrete.

1.1.1 For the purpose of this standard, plain concrete structures are those where reinforcement, if provided is ignored for determination of strength of the structure.

1.2 Special requirements of structures, such as shells, folded plates, arches, bridges, chimneys, blast resistant structures, hydraulic structures, liquid retaining structures and earthquake resistant structures, covered in respective standards have not been covered in this standard; these standards shall be used in conjunction with this standard.

2 REFERENCES

The Indian Standards listed in Annex A contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated in Annex A.

3 TERMINOLOGY

For the purpose of this standard, the definitions given in IS 4845 and IS 6461 (Parts 1 to 12) shall generally apply.

4 SYMBOLS

For the purpose of this standard, the following letter symbols shall have the meaning indicated against each; where other symbols are used, they are explained at the appropriate place:

A – Area
b – Breadth of beam, or shorter dimension of a rectangular column
b_{ef} – Effective width of slab
b_f – Effective width of flange
b_w – Breadth of web or rib
D – Overall depth of beam or slab or diameter of column; dimension of a rectangular column in the direction under consideration
D_f – Thickness of flange
DL – Dead load
d – Effective depth of beam or slab
d' – Depth of compression reinforcement from the highly compressed face
E_c – Modulus of elasticity of concrete
EL – Earthquake load
E_s – Modulus of elasticity of steel
e – Eccentricity
f_{ck} – Characteristic cube compressive strength of concrete
f_{cr} – Modulus of rupture of concrete (flexural tensile strength)
f_{ct} – Splitting tensile strength of concrete
f_d – Design strength
f_y – Characteristic strength of steel
H_w – Unsupported height of wall
H_{we} – Effective height of wall
I_{ef} – Effective moment of inertia
I_{gr} – Moment of inertia of the gross section excluding reinforcement
I_r – Moment of intertia of cracked section
K – Stiffness of member
k – Constant or coefficient or factor
L_d – Development length
LL – Live load or imposed load
L_w – Horizontal distance between centres of lateral restraint
l – Length of a column or beam between adequate lateral restraints or the unsupported length of a column
l_{ef} – Effective span of beam or slab or effective length of column
l_{ex} – Effective length about x-x axis
l_{ey} – Effective length about y-y axis
l_n – Clear span, face-to-face of supports
l'_n – l'_n for shorter of the two spans at right angles
l_x – Length of shorter side of slab
l_y – Length of longer side of slab
l_0 – Distance between points of zero moments in a beam
l_1 – Span in the direction in which moments are determined, centre to centre of supports
l_2 – Span transverse to l_1, centre to centre of supports
l'_2 – l_2 for the shorter of the continuous spans
M – Bending moment
m – Modular ratio
n – Number of samples
P – Axial load on a compression member
q_0 – Calculated maximum bearing pressure

q_0 – Calculated maximum bearing pressure of soil

r – Radius

s – Spacing of stirrups or standard deviation

T – Torsional moment

t – Wall thickness

V – Shear force

W – Total load

WL – Wind load

w – Distributed load per unit area

w_d – Distributed dead load per unit area

w_l – Distributed imposed load per unit area

x – Depth of neutral axis

Z – Modulus of section

z – Lever arm

α, β – Angle or ratio

γ_f – Partial safety factor for load

γ_m – Partial safety factor for material

δ_m – Percentage reduction in moment

ϵ_{cc} – Creep strain of concrete

σ_{cbc} – Permissible stress in concrete in bending compression

σ_{cc} – Permissible stress in concrete in direct compression

σ_{mc} – Permissible stress in metal in direct compression

σ_{sc} – Permissible stress in steel in compression

σ_{st} – Permissible stress in steel in tension

σ_{sv} – Permissible tensile stress in shear reinforcement

τ_{bd} – Design bond stress

τ_c – Shear stress in concrete

$\tau_{c,max}$ – Maximum shear stress in concrete with shear reinforcement

τ_v – Nominal shear stress

ϕ – Diameter of bar

SECTION 2 MATERIALS, WORKMANSHIP, INSPECTION AND TESTING

5 MATERIALS

5.1 Cement

The cement used shall be any of the following and the type selected should be appropriate for the intended use:

a) 33 Grade ordinary Portland cement conforming to IS 269

b) 43 Grade ordinary Portland cement conforming to IS 8112

c) 53 Grade ordinary Portland cement conforming to IS 12269

d) Rapid hardening Portland cement conforming to IS 8041

e) Portland slag cement conforming to IS 455

f) Portland pozzolana cement (fly ash based) conforming to IS 1489 (Part 1)

g) Portland pozzolana cement (calcined clay based) conforming to IS 1489 (Part 2)

h) Hydrophobic cement conforming to IS 8043

j) Low heat Portland cement conforming to IS 12600

k) Sulphate resisting Portland cement conforming to IS 12330

Other combinations of Portland cement with mineral admixtures (*see* 5.2) of quality conforming with relevant Indian Standards laid down may also be used in the manufacture of concrete provided that there are satisfactory data on their suitability, such as performance test on concrete containing them.

5.1.1 Low heat Portland cement conforming to IS 12600 shall be used with adequate precautions with regard to removal of formwork, etc.

5.1.2 High alumina cement conforming to IS 6452 or supersulphated cement conforming to IS 6909 may be used only under special circumstances with the prior approval of the engineer-in-charge. Specialist literature may be consulted for guidance regarding the use of these types of cements.

5.1.3 The attention of the engineers-in-charge and users of cement is drawn to the fact that quality of various cements mentioned in **5.1** is to be determined on the basis of its conformity to the performance characteristics given in the respective Indian Standard Specification for that cement. Any trade-mark or any trade name indicating any special features not covered in the standard or any qualification or other special performance characteristics sometimes claimed/ indicated on the bags or containers or in advertisements alongside the 'Statutory Quality Marking' or otherwise have no relation whatsoever with the characteristics guaranteed by the Quality Marking as relevant to that cement. Consumers are, therefore, advised to go by the characteristics as given in the corresponding Indian Standard Specification or seek specialist advise to avoid any problem in concrete making and construction.

5.2 Mineral Admixtures

5.2.1 *Pozzolanas*

Pozzolanic materials conforming to relevant Indian Standards may be used with the permission of the engineer-in-charge, provided uniform blending with cement is ensured.

5.2.1.1 *Fly ash (pulverized fuel ash)*

Fly ash conforming to Grade 1 of IS 3812 may be used as part replacement of ordinary Portland cement provided uniform blending with cement is ensured.

5.2.1.2 *Silica fume*

Silica fume conforming to a standard approved by the deciding authority may be used as part replacement of cement provided uniform blending with the cement is ensured.

NOTE—The silica fume (very fine non-crystalline silicon dioxide) is a by-product of the manufacture of silicon, ferrosilicon or the like, from quartz and carbon in electric arc furnace. It is usually used in proportion of 5 to 10 percent of the cement content of a mix.

5.2.1.3 *Rice husk ash*

Rice husk ash giving required performance and uniformity characteristics may be used with the approval of the deciding authority.

NOTE—Rice husk ash is produced by burning rice husk and contain large proportion of silica. To achieve amorphous state, rice husk may be burnt at controlled temperature. It is necessary to evaluate the product from a particular source for performance and uniformity since it can range from being as deleterious as silt when incorporated in concrete. Water demand and drying shrinkage should be studied before using rice husk.

5.2.1.4 *Metakaoline*

Metakaoline having fineness between 700 to 900 m^2/kg may be used as pozzolanic material in concrete.

NOTE—Metakaoline is obtained by calcination of pure or refined kaolintic clay at a temperature between 650°C and 850°C, followed by grinding to achieve a fineness of 700 to 900 m^2/kg. The resulting material has high pozzolanicity.

5.2.2 *Ground Granulated Blast Furnace Slag*

Ground granulated blast furnace slag obtained by grinding granulated blast furnace slag conforming to IS 12089 may be used as part replacement of ordinary

Portland cements provided uniform blending with cement is ensured.

5.3 Aggregates

Aggregates shall comply with the requirements of IS 383. As far as possible preference shall be given to natural aggregates.

5.3.1 Other types of aggregates such as slag and crushed overburnt brick or tile, which may be found suitable with regard to strength, durability of concrete and freedom from harmful effects may be used for plain concrete members, but such aggregates should not contain more than 0.5 percent of sulphates as SO_3 and should not absorb more than 10 percent of their own mass of water.

5.3.2 Heavy weight aggregates or light weight aggregates such as bloated clay aggregates and sintered fly ash aggregates may also be used provided the engineer-in-charge is satisfied with the data on the properties of concrete made with them.

NOTE—Some of the provisions of the code would require modification when these aggregates are used; specialist literature may be consulted for guidance.

5.3.3 *Size of Aggregate*

The nominal maximum size of coarse aggregate should be as large as possible within the limits specified but in no case greater than one-fourth of the minimum thickness of the member, provided that the concrete can be placed without difficulty so as to surround all reinforcement thoroughly and fill the corners of the form. For most work, 20 mm aggregate is suitable. Where there is no restriction to the flow of concrete into sections, 40 mm or larger size may be permitted. In concrete elements with thin sections, closely spaced reinforcement or small cover, consideration should be given to the use of 10 mm nominal maximum size.

Plums above 160 mm and up to any reasonable size may be used in plain concrete work up to a maximum limit of 20 percent by volume of concrete when specifically permitted by the engineer-in-charge. The plums shall be distributed evenly and shall be not closer than 150 mm from the surface.

5.3.3.1 For heavily reinforced concrete members as in the case of ribs of main beams, the nominal maximum size of the aggregate should usually be restricted to 5 mm less than the minimum clear distance between the main bars or 5 mm less than the minimum cover to the reinforcement whichever is smaller.

5.3.4 Coarse and fine aggregate shall be batched separately. All-in-aggregate may be used only where specifically permitted by the engineer-in-charge.

5.4 Water

Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel.

Potable water is generally considered satisfactory for mixing concrete. As a guide the following concentrations represent the maximum permissible values:

a) To neutralize 100 ml sample of water, using phenolphthalein as an indicator, it should not require more than 5 ml of 0.02 normal NaOH. The details of test are given in **8.1** of IS 3025 (Part 22).
b) To neutralize 100 ml sample of water, using mixed indicator, it should not require more than 25 ml of 0.02 normal H_2SO_4. The details of test shall be as given in **8** of IS 3025 (Part 23).
c) Permissible limits for solids shall be as given in Table 1.

5.4.1 In case of doubt regarding development of strength, the suitability of water for making concrete shall be ascertained by the compressive strength and initial setting time tests specified in **5.4.1.2** and **5.4.1.3**.

5.4.1.1 The sample of water taken for testing shall represent the water proposed to be used for concreting, due account being paid to seasonal variation. The sample shall not receive any treatment before testing other than that envisaged in the regular supply of water proposed for use in concrete. The sample shall be stored in a clean container previously rinsed out with similar water.

5.4.1.2 Average 28 days compressive strength of at least three 150 mm concrete cubes prepared with water proposed to be used shall not be less than 90 percent of the average of strength of three similar concrete cubes prepared with distilled water. The cubes shall be prepared, cured and tested in accordance with the requirements of IS 516.

5.4.1.3 The initial setting time of test block made with the appropriate cement and the water proposed to be used shall not be less than 30 min and shall not differ by $\pm$ 30 min from the initial setting time of control test block prepared with the same cement and distilled water. The test blocks shall be prepared and tested in accordance with the requirements of IS 4031 (Part 5).

5.4.2 The *p*H value of water shall be not less than 6.

5.4.3 *Sea Water*

Mixing or curing of concrete with sea water is not recommended because of presence of harmful salts in sea water. Under unavoidable circumstances sea water may be used for mixing or curing in plain concrete with no embedded steel after having given due consideration to possible disadvantages and precautions including use of appropriate cement system.

Table 1 Permissible Limit for Solids
(*Clause* 5.4)

Sl No.		Tested as per	Permissible Limit, *Max*
i)	Organic	IS 3025 (Part 18)	200 mg/l
ii)	Inorganic	IS 3025 (Part 18)	3 000 mg/l
iii)	Sulphates (as SO_3)	IS 3025 (Part 24)	400 mg/l
iv)	Chlorides (as Cl)	IS 3025 (Part 32)	2 000 mg/l for concrete not containing embedded steel and 500 mg/l for reinforced concrete work
v)	Suspended matter	IS 3025 (Part 17)	2 000 mg/l

5.4.4 Water found satisfactory for mixing is also suitable for curing concrete. However, water used for curing should not produce any objectionable stain or unsightly deposit on the concrete surface. The presence of tannic acid or iron compounds is objectionable.

5.5 Admixtures

5.5.1 Admixture, if used shall comply with IS 9103. Previous experience with and data on such materials should be considered in relation to the likely standards of supervision and workmanship to the work being specified.

5.5.2 Admixtures should not impair durability of concrete nor combine with the constituent to form harmful compounds nor increase the risk of corrosion of reinforcement.

5.5.3 The workability, compressive strength and the slump loss of concrete with and without the use of admixtures shall be established during the trial mixes before use of admixtures.

5.5.4 The relative density of liquid admixtures shall be checked for each drum containing admixtures and compared with the specified value before acceptance.

5.5.5 The chloride content of admixtures shall be independently tested for each batch before acceptance.

5.5.6 If two or more admixtures are used simultaneously in the same concrete mix, data should be obtained to assess their interaction and to ensure their compatibility.

5.6 Reinforcement

The reinforcement shall be any of the following:

a) Mild steel and medium tensile steel bars conforming to IS 432 (Part 1).

b) High strength deformed steel bars conforming to IS 1786.

c) Hard-drawn steel wire fabric conforming to IS 1566.

d) Structural steel conforming to Grade A of IS 2062.

5.6.1 All reinforcement shall be free from loose mill scales, loose rust and coats of paints, oil, mud or any other substances which may destroy or reduce bond. Sand blasting or other treatment is recommended to clean reinforcement.

5.6.2 Special precautions like coating of reinforcement may be required for reinforced concrete elements in exceptional cases and for rehabilitation of structures. Specialist literature may be referred to in such cases.

5.6.3 The modulus of elasticity of steel shall be taken as 200 kN/mm^2. The characteristic yield strength of different steel shall be assumed as the minimum yield stress/0.2 percent proof stress specified in the relevant Indian Standard.

5.7 Storage of Materials

Storage of materials shall be as described in IS 4082.

6 CONCRETE

6.1 Grades

The concrete shall be in grades designated as per Table 2.

6.1.1 The characteristic strength is defined as the strength of material below which not more than 5 percent of the test results are expected to fall.

6.1.2 The minimum grade of concrete for plain and reinforced concrete shall be as per Table 5.

6.1.3 Concrete of grades lower than those given in Table 5 may be used for plain concrete constructions, lean concrete, simple foundations, foundation for masonry walls and other simple or temporary reinforced concrete construction.

6.2 Properties of Concrete

6.2.1 *Increase of Strength with Age*

There is normally a gain of strength beyond 28 days. The quantum of increase depends upon the grade and type of cement, curing and environmental conditions, etc. The design should be based on 28 days characteristic strength of concrete unless there is a evidence to

Table 2 Grades of Concrete

(*Clause* 6.1, 9.2.2, 15.1.1 *and* 36.1)

Group	Grade Designation	Specified Characteristic Compressive Strength of 150 mm Cube at 28 Days in N/mm²
(1)	(2)	(3)
Ordinary Concrete	M 10	10
	M 15	15
	M 20	20
Standard Concrete	M 25	25
	M 30	30
	M 35	35
	M 40	40
	M 45	45
	M 50	50
	M 55	55
High Strength Concrete	M 60	60
	M 65	65
	M 70	70
	M 75	75
	M 80	80

NOTES

1 In the designation of concrete mix M refers to the mix and the number to the specified compressive strength of 150 mm size cube at 28 days, expressed in N/mm².

2 For concrete of compressive strength greater than M 55, design parameters given in the standard may not be applicable and the values may be obtained from specialized literatures and experimental results.

justify a higher strength for a particular structure due to age.

6.2.1.1 For concrete of grade M 30 and above, the rate of increase of compressive strength with age shall be based on actual investigations.

6.2.1.2 Where members are subjected to lower direct load during construction, they should be checked for stresses resulting from combination of direct load and bending during construction.

6.2.2 *Tensile Strength of Concrete*

The flexural and splitting tensile strengths shall be obtained as described in IS 516 and IS 5816 respectively. When the designer wishes to use an estimate of the tensile strength from the compressive strength, the following formula may be used:

$$\text{Flexural strength, } f_{cr} = 0.7\sqrt{f_{ck}}\ \text{N/mm}^2$$

where f_{ck} is the characteristic cube compressive strength of concrete in N/mm².

6.2.3 *Elastic Deformation*

The modulus of elasticity is primarily influenced by the elastic properties of the aggregate and to a lesser extent by the conditions of curing and age of the concrete, the mix proportions and the type of cement. The modulus of elasticity is normally related to the compressive strength of concrete.

6.2.3.1 The modulus of elasticity of concrete can be assumed as follows:

$$E_c = 5\,000\sqrt{f_{ck}}$$

where

E_c is the short term static modulus of elasticity in N/mm².

Actual measured values may differ by ± 20 percent from the values obtained from the above expression.

6.2.4 *Shrinkage*

The total shrinkage of concrete depends upon the constituents of concrete, size of the member and environmental conditions. For a given humidity and temperature, the total shrinkage of concrete is most influenced by the total amount of water present in the concrete at the time of mixing and, to a lesser extent, by the cement content.

6.2.4.1 In the absence of test data, the approximate value of the total shrinkage strain for design may be taken as 0.000 3 (for more information, *see* IS 1343).

6.2.5 *Creep of Concrete*

Creep of concrete depends, in addition to the factors listed in **6.2.4**, on the stress in the concrete, age at loading and the duration of loading. As long as the stress in concrete does not exceed one-third of its characteristic compressive strength, creep may be assumed to be proportional to the stress.

6.2.5.1 In the absence of experimental data and detailed information on the effect of the variables, the ultimate creep strain may be estimated from the following values of creep coefficient (that is, ultimate creep strain/ elastic strain at the age of loading); for long span structure, it is advisable to determine actual creep strain, likely to take place:

Age at Loading	*Creep Coefficient*
7 days	2.2
28 days	1.6
1 year	1.1

NOTE—The ultimate creep strain, estimated as described above does not include the elastic strain.

6.2.6 *Thermal Expansion*

The coefficient of thermal expansion depends on nature of cement, the aggregate, the cement content, the relative humidity and the size of sections. The value of coefficient of thermal expansion for concrete with different aggregates may be taken as below:

Type of Aggregate	*Coefficient of Thermal Expansion for Concrete/°C*
Quartzite	$1.2 \text{ to } 1.3 \times 10^{-5}$
Sandstone	$0.9 \text{ to } 1.2 \times 10^{-5}$
Granite	$0.7 \text{ to } 0.95 \times 10^{-5}$
Basalt	$0.8 \text{ to } 0.95 \times 10^{-5}$
Limestone	$0.6 \text{ to } 0.9 \times 10^{-5}$

7 WORKABILITY OF CONCRETE

7.1 The concrete mix proportions chosen should be such that the concrete is of adequate workability for the placing conditions of the concrete and can properly be compacted with the means available. Suggested ranges of workability of concrete measured in accordance with IS 1199 are given below:

Placing Conditions	*Degree of Workability*	*Slump* (mm)
(1)	(2)	(3)
Blinding concrete; Shallow sections; Pavements using pavers	Very low	*See* **7.1.1**
Mass concrete; Lightly reinforced sections in slabs, beams, walls, columns; Floors; Hand placed pavements; Canal lining; Strip footings	Low	25-75
Heavily reinforced sections in slabs, beams, walls, columns;	Medium	50-100
Slipform work; Pumped concrete		75-100
Trench fill; *In-situ* piling	High	100-150
Tremie concrete	Very high	*See* **7.1.2**

NOTE—For most of the placing conditions, internal vibrators (needle vibrators) are suitable. The diameter of the needle shall be determined based on the density and spacing of reinforcement bars and thickness of sections. For tremie concrete, vibrators are not required to be used (*see also* **13.3**).

7.1.1 In the 'very low' category of workability where strict control is necessary, for example pavement quality concrete, measurement of workability by determination of compacting factor will be more appropriate than slump (*see* IS 1199) and a value of compacting factor of 0.75 to 0.80 is suggested.

7.1.2 In the 'very high' category of workability, measurement of workability by determination of flow will be appropriate (*see* IS 9103).

8 DURABILITY OF CONCRETE

8.1 General

A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service. The materials and mix proportions specified and used should be such as to maintain its integrity and, if applicable, to protect embedded metal from corrosion.

8.1.1 One of the main characteristics influencing the durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances. Impermeability is governed by the constituents and workmanship used in making the concrete. With normal-weight aggregates a suitably low permeability is achieved by having an adequate cement content, sufficiently low free water/cement ratio, by ensuring complete compaction of the concrete, and by adequate curing.

The factors influencing durability include:

a) the environment;

b) the cover to embedded steel;

c) the type and quality of constituent materials;

d) the cement content and water/cement ratio of the concrete;

e) workmanship, to obtain full compaction and efficient curing; and

f) the shape and size of the member.

The degree of exposure anticipated for the concrete during its service life together with other relevant factors relating to mix composition, workmanship, design and detailing should be considered. The concrete mix to provide adequate durability under these conditions should be chosen taking account of the accuracy of current testing regimes for control and compliance as described in this standard.

8.2 Requirements for Durability

8.2.1 *Shape and Size of Member*

The shape or design details of exposed structures should be such as to promote good drainage of water and to avoid standing pools and rundown of water. Care should also be taken to minimize any cracks that may collect or transmit water. Adequate curing is essential to avoid the harmful effects of early loss of moisture (*see* **13.5**).Member profiles and their intersections with other members shall be designed and detailed in a way to ensure easy flow of concrete and proper compaction during concreting.

Concrete is more vulnerable to deterioration due to chemical or climatic attack when it is in thin sections, in sections under hydrostatic pressure from one side only, in partially immersed sections and at corners and edges of elements. The life of the structure can be lengthened by providing extra cover to steel, by chamfering the corners or by using circular cross-sections or by using surface coatings which prevent or reduce the ingress of water, carbon dioxide or aggressive chemicals.

8.2.2 *Exposure Conditions*

8.2.2.1 *General environment*

The general environment to which the concrete will be exposed during its working life is classified into five levels of severity, that is, mild, moderate, severe, very severe and extreme as described in Table 3.

Table 3 Environmental Exposure Conditions

(*Clauses* 8.2.2.1 *and* 35.3.2)

Sl No.	Environment	Exposure Conditions
(1)	(2)	(3)
i)	Mild	Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal area.
ii)	Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wet
		Concrete exposed to condensation and rain
		Concrete continuously under water
		Concrete in contact or buried under non-aggressive soil/ground water
		Concrete surfaces sheltered from saturated salt air in coastal area
iii)	Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation.
		Concrete completely immersed in sea water
		Concrete exposed to coastal environment
iv)	Very severe	Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions whilst wet
		Concrete in contact with or buried under aggressive sub-soil/ground water
v)	Extreme	Surface of members in tidal zone
		Members in direct contact with liquid/solid aggressive chemicals

8.2.2.2 *Abrasive*

Specialist literatures may be referred to for durability requirements of concrete surfaces exposed to abrasive action, for example, in case of machinery and metal tyres.

8.2.2.3 *Freezing and thawing*

Where freezing and thawing actions under wet conditions exist, enhanced durability can be obtained by the use of suitable air entraining admixtures. When concrete lower than grade M 50 is used under these conditions, the mean total air content by volume of the fresh concrete at the time of delivery into the construction should be:

Nominal Maximum Size Aggregate (mm)	*Entrained Air Percentage*
20	5 ± 1
40	4 ± 1

Since air entrainment reduces the strength, suitable adjustments may be made in the mix design for achieving required strength.

8.2.2.4 *Exposure to sulphate attack*

Table 4 gives recommendations for the type of cement, maximum free water/cement ratio and minimum cement content, which are required at different sulphate concentrations in near-neutral ground water having *p*H of 6 to 9.

For the very high sulphate concentrations in Class 5 conditions, some form of lining such as polyethylene or polychloroprene sheet; or surface coating based on asphalt, chlorinated rubber, epoxy; or polyurethane materials should also be used to prevent access by the sulphate solution.

8.2.3 *Requirement of Concrete Cover*

8.2.3.1 The protection of the steel in concrete against corrosion depends upon an adequate thickness of good quality concrete.

8.2.3.2 The nominal cover to the reinforcement shall be provided as per **26.4.**

8.2.4 *Concrete Mix Proportions*

8.2.4.1 *General*

The free water-cement ratio is an important factor in governing the durability of concrete and should always be the lowest value. Appropriate values for minimum cement content and the maximum free water-cement ratio are given in Table 5 for different exposure conditions. The minimum cement content and maximum water-cement ratio apply to 20 mm nominal maximum size aggregate. For other sizes of aggregate they should be changed as given in Table 6.

8.2.4.2 *Maximum cement content*

Cement content not including fly ash and ground granulated blast furnace slag in excess of 450 kg/m^3 should not be used unless special consideration has been given in design to the increased risk of cracking due to drying shrinkage in thin sections, or to early thermal cracking and to the increased risk of damage due to alkali silica reactions.

Table 4 Requirements for Concrete Exposed to Sulphate Attack

(*Clauses* 8.2.2.4 *and* 9.1.2)

Sl No.	Class	Concentration of Sulphates, Expressed as SO_3: In Soil: Total SO_3	Concentration of Sulphates, Expressed as SO_3: In Soil: SO_3 in 2:1 Water: Soil Extract	Concentration of Sulphates, Expressed as SO_3: In Ground Water	Type of Cement	Dense, Fully Compacted Concrete. Made with 20 mm Nominal Maximum Size Aggregates Complying with IS 383: Minimum Cement Content kg/m^3	Dense, Fully Compacted Concrete. Made with 20 mm Nominal Maximum Size Aggregates Complying with IS 383: Maximum Face Water-Cement Ratio
		Percent	g/l	g/l			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	1	Traces (< 0.2)	Less than 1.0	Less than 0.3	Ordinary Portland cement or Portland slag cement or Portland pozzolana cement	280	0.55
ii)	2	0.2 to 0.5	1.0 to 1.9	0.3 to 1.2	Ordinary Portland cement or Portland slag cement or Portland pozzolana cement	330	0.50
					Supersulphated cement or sulphate resisting Portland cement	310	0.50
iii)	3	0.5 to 1.0	1.9 to 3.1	1.2 to 2.5	Supersulphated cement or sulphate resisting Portland cement	330	0.50
					Portland pozzolana cement or Portland slag cement	350	0.45
iv)	4	1.0 to 2.0	3.1 to 5.0	2.5 to 5.0	Supersulphated or sulphate resisting Portland cement	370	0.45
v)	5	More than 2.0	More than 5.0	More than 5.0	Sulphate resisting Portland cement or supersulphated cement with protective coatings	400	0.40

NOTES

1 Cement content given in this table is irrespective of grades of cement.

2 Use of supersulphated cement is generally restricted where the prevailing temperature is above 40 °C.

3 Supersulphated cement gives an acceptable life provided that the concrete is dense and prepared with a water-cement ratio of 0.4 or less, in mineral acids, down to *p*H 3.5.

4 The cement contents given in col 6 of this table are the minimum recommended. For SO_3 contents near the upper limit of any class, cement contents above these minimum are advised.

5 For severe conditions, such as thin sections under hydrostatic pressure on one side only and sections partly immersed, considerations should be given to a further reduction of water-cement ratio.

6 Portland slag cement conforming to IS 455 with slag content more than 50 percent exhibits better sulphate resisting properties.

7 Where chloride is encountered along with sulphates in soil or ground water, ordinary Portland cement with C_3A content from 5 to 8 percent shall be desirable to be used in concrete, instead of sulphate resisting cement. Alternatively, Portland slag cement conforming to IS 455 having more than 50 percent slag or a blend of ordinary Portland cement and slag may be used provided sufficient information is available on performance of such blended cements in these conditions.

8.2.5 *Mix Constituents*

8.2.5.1 *General*

For concrete to be durable, careful selection of the mix and materials is necessary, so that deleterious constituents do not exceed the limits.

8.2.5.2 *Chlorides in concrete*

Whenever there is chloride in concrete there is an increased risk of corrosion of embedded metal. The higher the chloride content, or if subsequently exposed to warm moist conditions, the greater the risk of corrosion. All constituents may contain chlorides and concrete may be contaminated by chlorides from the external environment. To minimize the chances of deterioration of concrete from harmful chemical salts, the levels of such harmful salts in concrete coming from concrete materials, that is, cement, aggregates water and admixtures, as well as by diffusion from the environment should be limited. The total amount of chloride content (as Cl) in the concrete at the time of placing shall be as given in Table 7.

The total acid soluble chloride content should be calculated from the mix proportions and the measured chloride contents of each of the constituents. Wherever possible, the total chloride content of the concrete should be determined.

8.2.5.3 *Sulphates in concrete*

Sulphates are present in most cements and in some aggregates; excessive amounts of water-soluble sulphate from these or other mix constituents can cause expansion and disruption of concrete. To prevent this, the total water-soluble sulphate content of the concrete mix, expressed as SO_3, should not exceed 4 percent by mass of the cement in the mix. The sulphate content should be calculated as the total from the various constituents of the mix.

The 4 percent limit does not apply to concrete made with supersulphated cement complying with IS 6909.

8.2.5.4 *Alkali-aggregate reaction*

Some aggregates containing particular varieties of silica may be susceptible to attack by alkalis (Na_2O and K_2O) originating from cement or other sources, producing an expansive reaction which can cause cracking and disruption of concrete. Damage to concrete from this reaction will normally only occur when all the following are present together:

a) A high moisture level, within the concrete;

b) A cement with high alkali content, or another source of alkali;

c) Aggregate containing an alkali reactive constituent.

Where the service records of particular cement/aggregate combination are well established, and do not include any instances of cracking due to alkali-aggregate reaction, no further precautions should be necessary. When the materials are unfamiliar, precautions should take one or more of the following forms:

a) Use of non-reactive aggregate from alternate sources.

Table 5 Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size

(*Clauses* 6.1.2, 8.2.4.1 *and* 9.1.2)

Sl No.	Exposure	Plain Concrete			Reinforced Concrete		
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 12 Bending Moment Coefficients
(*Clause* 22.5.1)

Type of Load	Span Moments		Support Moments	
	Near Middle of End Span	At Middle of Interior Span	At Support Next to the End Support	At Other Interior Supports
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	$+\frac{1}{12}$	$+\frac{1}{16}$	$-\frac{1}{10}$	$-\frac{1}{12}$
Imposed load (not fixed)	$+\frac{1}{10}$	$+\frac{1}{12}$	$-\frac{1}{9}$	$-\frac{1}{9}$

s_v = spacing of the stirrup reinforcement,

b_1 = centre-to-centre distance between corner bars in the direction of the width,

d_1 = centre-to-centre distance between corner bars in the direction of the depth,

b = breadth of the member,

σ_{sv} = permissible tensile stress in shear reinforcement,

τ_{ve} = equivalent shear stress as specified in **B-6.3.1**, and

τ_c = shear strength of the concrete as specified in Table 23.

ANNEX C

(*Clauses* 22.3.2, 23.2.1 *and* 42.1)

CALCULATION OF DEFLECTION

C-1 TOTAL DEFLECTION

C-1.1 The total deflection shall be taken as the sum of the short-term deflection determined in accordance with **C-2** and the long-term deflection, in accordance with **C-3** and **C-4**.

C-2 SHORT-TERM DEFLECTION

C-2.1 The short-term deflection may be calculated by the usual methods for elastic deflections using the short-term modulus of elasticity of concrete, E_c and an effective moment of inertia I_{eff} given by the following equation:

$$I_{\text{eff}} = \frac{I_r}{1.2 - \dfrac{M_r}{M}\dfrac{z}{d}\left(1 - \dfrac{x}{d}\right)\dfrac{b_w}{b}}; \text{ but}$$

$$I_r \le I_{\text{eff}} \le I_{\text{gr}}$$

where

I_r = moment of inertia of the cracked section,

M_r = cracking moment, equal to $\dfrac{f_{cr} I_{gr}}{y_t}$ where

f_{cr} is the modulus of rupture of concrete, I_{gr} is the moment of inertia of the gross section about the centroidal axis, neglecting the reinforcement, and y_t is the distance from centroidal axis of gross section, neglecting the reinforcement, to extreme fibre in tension,

M = maximum moment under service loads,

z = lever arm,

x = depth of neutral axis,

d = effective depth,

b_w = breadth of web, and

b = breadth of compression face.

For continuous beams, deflection shall be calculated using the values of I_r, I_{gr} and M_r modified by the following equation:

$$X_e = k_1 \left[\frac{X_1 + X_2}{2}\right] + (1 - k_1) X_o$$

where

X_e = modified value of X,

X_1, X_2 = values of X at the supports,

X_o = value of X at mid span,

k_1 = coefficient given in Table 25, and

X = value of I_r, I_{gr} or M_r as appropriate.

C-3 DEFLECTION DUE TO SHRINKAGE

C-3.1 The deflection due to shrinkage a_{cs} may be computed from the following equation:

$$a_{cs} = k_3 \Psi_{cs} l^2$$

where

k_3 is a constant depending upon the support conditions,

0.5 for cantilevers,

0.125 for simply supported members,

0.086 for members continuous at one end, and

0.063 for fully continuous members.

Ψ_{cs} is shrinkage curvature equal to $k_4 \dfrac{\varepsilon_{cs}}{D}$

where ε_{cs} is the ultimate shrinkage strain of concrete (*see* **6.2.4**),

$$k_4 = 0.72 \times \frac{P_t - P_c}{\sqrt{P_t}} \le 1.0 \text{ for } 0.25 \le P_t - P_c < 1.0$$

$$= 0.65 \times \frac{P_t - P_c}{\sqrt{P_t}} \le 1.0 \text{ for } P_t - P_c \ge 1.0$$

Table 25 Values of Coefficient, k_1

(*Clause* C-2.1)

k_2	0.5 or less	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
k_1	0	0.03	0.08	0.16	0.30	0.50	0.73	0.91	0.97	1.0

NOTE — k_2 is given by

$$k_2 = \frac{M_1 + M_2}{M_{F1} + M_{F2}}$$

where

M_1, M_2 = support moments, and

M_{F1}, M_{F2} = fixed end moments.

where $P_t = \frac{100\,A_{st}}{bd}$ and $P_c = \frac{100\,A_{sc}}{bd}$

and D is the total depth of the section, and l is the length of span.

C-4 DEFLECTION DUE TO CREEP

C-4.1 The creep deflection due to permanent loads $a_{cc\,(perm)}$ may be obtained from the following equation:

$$a_{cc\,(perm)} = a_{i,cc\,(perm)} - a_{i\,(perm)}$$

where

$a_{i,cc\,(perm)}$ = initial plus creep deflection due to permanent loads obtained using an elastic analysis with an effective modulus of elasticity,

$E_{ce} = \frac{E_c}{1+\theta}$; θ being the creep coefficient, and

$a_{i\,(perm)}$ = short-term deflection due to permanent load using E_c.

ANNEX D

(*Clauses* 24.4 *and* 37.1.2)

SLABS SPANNING IN TWO DIRECTIONS

D-1 RESTRAINED SLABS

D-1.0 When the corners of a slab are prevented from lifting, the slab may be designed as specified in **D-1.1** to **D-1.11**.

D-1.1 The maximum bending moments per unit width in a slab are given by the following equations:

$$M_x = \alpha_x \, w \, l_x^2$$

$$M_y = \alpha_y \, w \, l_x^2$$

where

α_x and α_y are coefficients given in Table 26,

w = total design load per unit area,

M_x, M_y = moments on strips of unit width spanning l_x and l_y respectively, and

l_x and l_y = lengths of the shorter span and longer span respectively.

D-1.2 Slabs are considered as divided in each direction into middle strips and edge strips as shown in Fig. 25 the middle strip being three-quarters of the width and each edge strip one-eight of the width.

D-1.3 The maximum moments calculated as in **D-1.1** apply only to the middle strips and no redistribution shall be made.

D-1.4 Tension reinforcement provided at mid-span in the middle strip shall extend in the lower part of the slab to within 0.25 l of a continuous edge, or 0.15 l of a discontinuous edge.

D-1.5 Over the continuous edges of a middle strip, the tension reinforcement shall extend in the upper part of the slab a distance of 0.15 l from the support, and at least 50 perccent shall extend a distance of 0.3 l.

D-1.6 At a discontinuous edge, negative moments may arise. They depend on the degree of fixity at the edge of the slab but, in general, tension reinforcement equal to 50 percent of that provided at mid-span extending 0.1 l into the span will be sufficient.

D-1.7 Reinforcement in edge strip, parallel to that edge, shall comply with the minimum given in Section 3 and the requirements for torsion given in **D-1.8** to **D-1.10**.

D-1.8 Torsion reinforcement shall be provided at any corner where the slab is simply supported on both edges meeting at that corner. It shall consist of top and bottom reinforcement, each with layers of bars placed parallel to the sides of the slab and extending from the edges a minimum distance of one-fifth of the shorter span. The area of reinforcement in each of these four layers shall be three-quarters of the area required for the maximum mid-span moment in the slab.

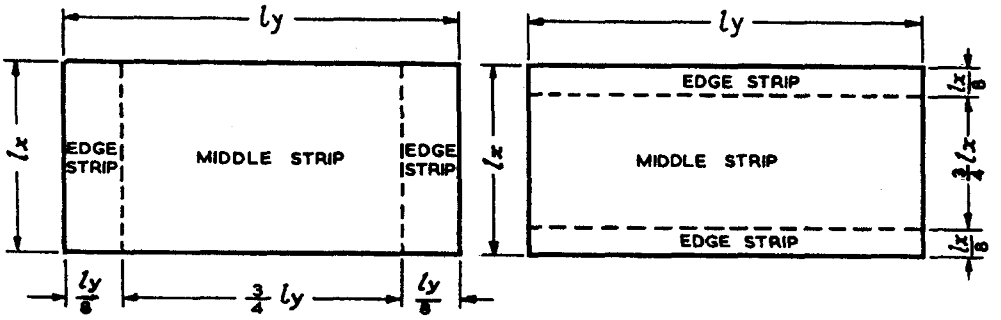
D-1.9 Torsion reinforcement equal to half that described in **D-1.8** shall be provided at a corner contained by edges over only one of which the slab is continuous.

D-1.10 Torsion reinforcements need not be provided at any corner contained by edges over both of which the slab is continuous.

D-1.11 Torsion l_y / l_x is greater than 2, the slabs shall be designed as spanning one way.

D-2 SIMPLY SUPPORTED SLABS

D-2.1 When simply supported slabs do not have adequate provision to resist torsion at corners and to prevent the corners from lifting, the maximum



25A For Span l_x 25B For Span l_y

Fig. 25 Division of Slab into Middle and Edge Strips

Table 26 Bending Moment Coefficients for Rectangular Panels Supported on Four Sides with Provision for Torsion at Corners

(*Clauses* D-1.1 *and* 24.4.1)

Case No.	Type of Panel and Moments Considered	Short Span Coefficients α_x (Values of l_y/l_x)								Long Span Coefficients α_y for All Values of l_y/l_x
		1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	*Interior Panels*:									
	Negative moment at continuous edge	0.032	0.037	0.043	0.047	0.051	0.053	0.060	0.065	0.032
	Positive moment at mid-span	0.024	0.028	0.032	0.036	0.039	0.041	0.045	0.049	0.024
2	*One Short Edge Continuous*:									
	Negative moment at continuous edge	0.037	0.043	0.048	0.051	0.055	0.057	0.064	0.068	0.037
	Positive moment at mid-span	0.028	0.032	0.036	0.039	0.041	0.044	0.048	0.052	0.028
3	*One Long Edge Discontinuous*:									
	Negative moment at continuous edge	0.037	0.044	0.052	0.057	0.063	0.067	0.077	0.085	0.037
	Positive moment at mid-span	0.028	0.033	0.039	0.044	0.047	0.051	0.059	0.065	0.028
4	*Two Adjacent Edges Discontinuous*:									
	Negative moment at continuous edge	0.047	0.053	0.060	0.065	0.071	0.075	0.084	0.091	0.047
	Positive moment at mid-span	0.035	0.040	0.045	0.049	0.053	0.056	0.063	0.069	0.035
5	*Two Short Edges Discontinuous*:									
	Negative moment at continuous edge	0.045	0.049	0.052	0.056	0.059	0.060	0.065	0.069	—
	Positive moment at mid-span	0.035	0.037	0.040	0.043	0.044	0.045	0.049	0.052	0.035
6	*Two Long Edges Discontinuous*:									
	Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.045
	Positive moment at mid-span	0.035	0.043	0.051	0.057	0.063	0.068	0.080	0.088	0.035
7	*Three Edges Discontinuous (One Long Edge Continuous)*:									
	Negative moment at continuous edge	0.057	0.064	0.071	0.076	0.080	0.084	0.091	0.097	—
	Positive moment at mid-span	0.043	0.048	0.053	0.057	0.060	0.064	0.069	0.073	0.043
8	*Three Edges Discontinuous (One Short Edge Continuous)* :									
	Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.057
	Positive moment at mid-span	0.043	0.051	0.059	0.065	0.071	0.076	0.087	0.096	0.043
9	*Four Edges Discontinuous*:									
	Positive moment at mid-span	0.056	0.064	0.072	0.079	0.085	0.089	0.100	0.107	0.056

moments per unit width are given by the following equation:

$$M_x = \alpha_x \, w \, l_x^2$$

$$M_y = \alpha_y \, w \, l_x^2$$

where

M_x, M_y, w, l_x, l_y are same as those in **D-1.1**, and α_x and α_y are moment coefficients given in Table 27

D-2.1.1 At least 50 percent of the tension reinforcement provided at mid-span should extend to the supports. The remaining 50 percent should extend to within 0.1 l_x or 0.1 l_y of the support, as appropriate.

Table 27 Bending Moment Coefficients for Slabs Spanning in Two Directions at Right Angles, Simply Supported on Four Sides

(*Clause* D-2.1)

l_y/l_x	1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	2.5	3.0
α_x	0.062	0.074	0.084	0.093	0.099	0.104	0.113	0.118	0.122	0.124
α_y	0.062	0.061	0.059	0.055	0.051	0.046	0.037	0.029	0.020	0.014

ANNEX E

(*Clause* 25.2)

EFFECTIVE LENGTH OF COLUMNS

E-1 In the absence of more exact analysis, the effective length of columns in framed structures may be obtained from the ratio of effective length to unsupported length l_{ef}/l given in Fig. 26 when relative displacement of the ends of the column is prevented and in Fig. 26 when relative lateral displacement of the ends is not prevented. In the latter case, it is recommendded that the effective length ratio l_{ef}/l may not be taken to be less than 1.2.

NOTES

1 Figures 26 and 27 are reproduced from 'The Structural Engineer' No. 7, Volume 52, July 1974 by the permission of the Council of the Institution of Structural Engineers, U.K.

2 In Figs. 26 and 27, β_1 and β_2 are equal to $\dfrac{\Sigma K_c}{\Sigma K_c + \Sigma K_b}$ where the summation is to be done for the members framing into a joint at top and bottom respectively; and K_c and K_b being the flexural stiffness for column and beam respectively.

E-2 To determine whether a column is a no sway or a sway column, stability index Q may be computed as given below :

$$Q = \frac{\Sigma P_u \Delta_u}{H_u h_s}$$

where

ΣP_u = sum of axial loads on all column in the storey,

Δ_u = elastically computed first order lateral deflection,

H_u = total lateral force acting within the storey, and

h_s = height of the storey.

If $Q \leq 0.04$, then the column in the frame may be taken as no sway column, otherwise the column will be considered as sway columnn.

E-3 For normal usage assuming idealized conditions, the effective length l_{ef} of in a given plane may be assessed on the basis of Table 28.

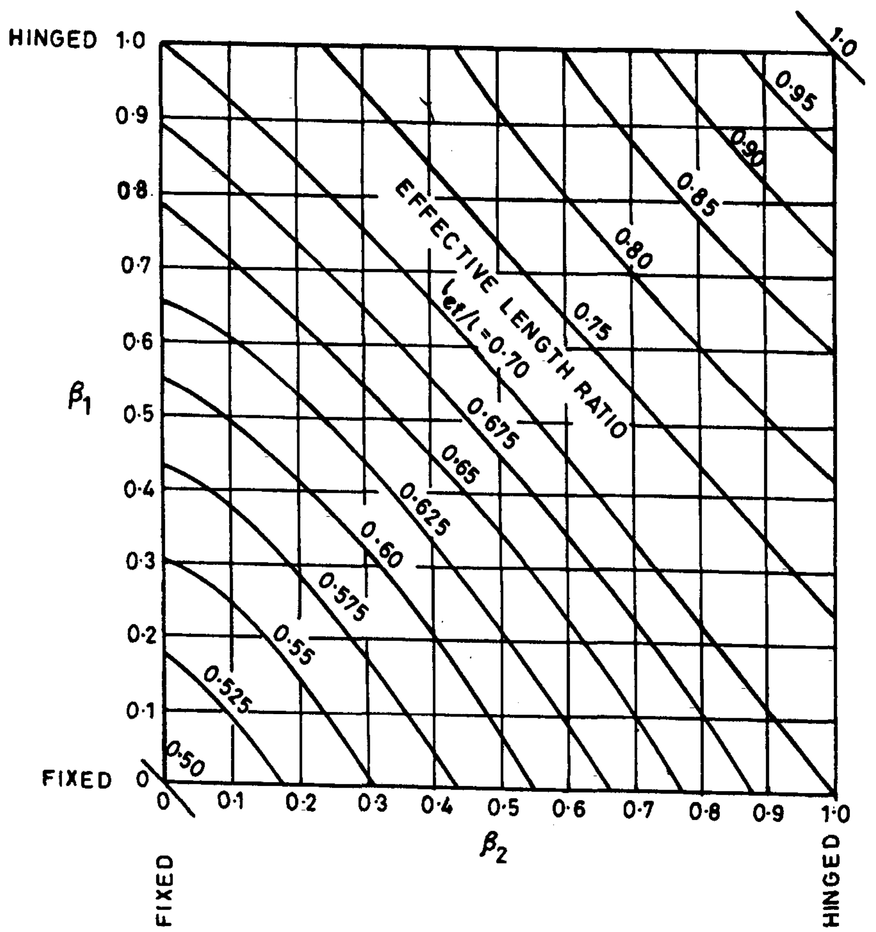


FIG. 26 EFFECTIVE LENGTH RATIOS FOR A COLUMN IN A FRAME WITH NO SWAY

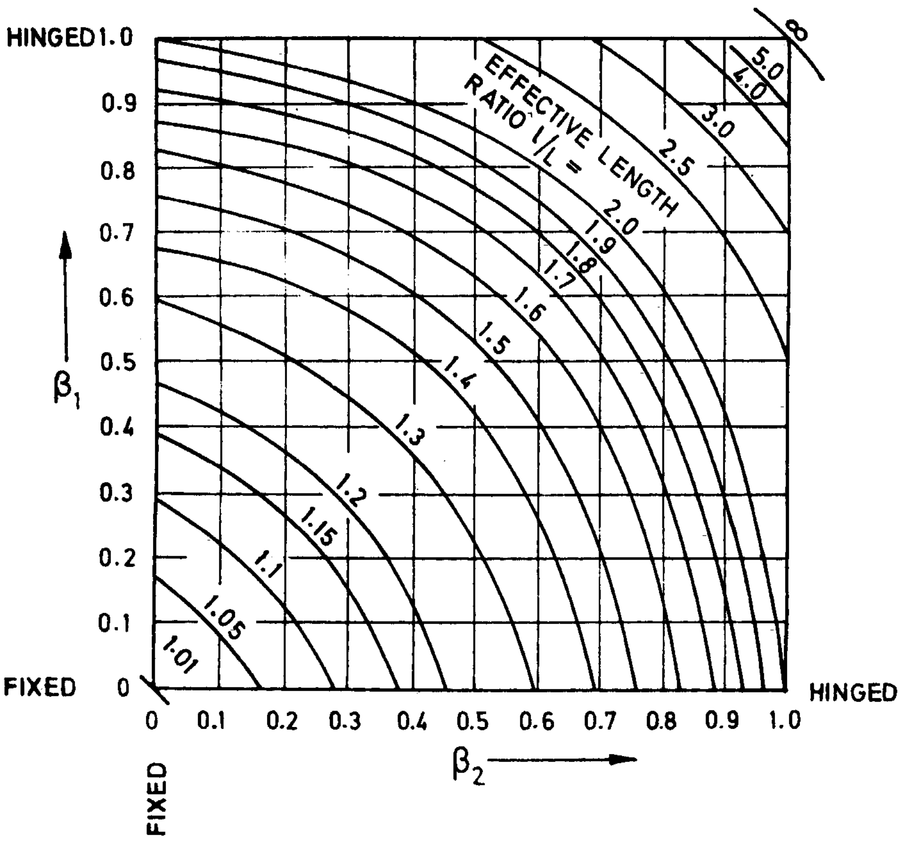
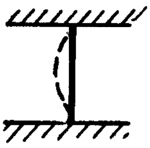
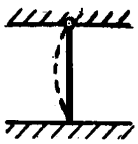
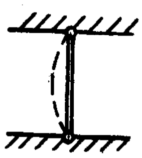
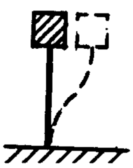
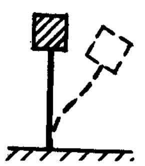
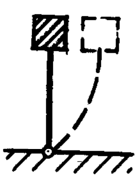
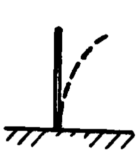


FIG. 27 EFFECTIVE LENGTH RATIOS FOR A COLUMN IN A FRAME WITHOUT RESTRAINT AGAINST SWAY

Table 28 Effective Length of Compression Members
(*Clause* E-3)

Degree of End Restraint of Compression Members	Symbol	Theoretical Value of Effective Length	Recommended Value of Effective Length
(1)	(2)	(3)	(4)
Effectively held in position and restrained against rotation in both ends		0.50 *l*	0.65 *l*
Effectively held in position at both ends, restrained against rotation at one end		0.70 *l*	0.80 *l*
Effectively held in position at both ends, but not restrained against rotation		1.00 *l*	1.00 *l*
Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position		1.00 *l*	1.20 *l*
Effectively held in position and restrained against rotation in one end, and at the other partially restrained against rotation but not held in position		—	1.50 *l*
Effectively held in position at one end but not restrained against rotation, and at the other end restrained against rotation but not held in position		2.00 *l*	2.00 *l*
Effectively held in position and restrained against rotation at one end but not held in position nor restrained against rotation at the other end		2.00 *l*	2.00 *l*

NOTE — *l* is the unsupported length of compression member.

ANNEX F

(*Clauses* 35.3.2 *and* 43.1)

CALCULATION OF CRACK WIDTH

Provided that the strain in the tension reinforcement is limited to 0.8 F_y / E_s, the design surface crack width, which should not exceed the appropriate value given in **35.3.2** may be calculated from the following equation:

Design surface crack width

$$W_{cr} = \frac{3\, a_{cr}\, \varepsilon_m}{1 + \dfrac{2(a_{cr} - C_{min})}{h - x}}$$

where

a_{cr} = distance from the point considered to the surface of the nearest longitudinal bar,

C_{min} = minimum cover to the longitudinal bar;

ε_m = average steel strain at the level considered,

h = overall depth of the member, and

x = depth of the neutral axis.

The average steel strain ε_m may be calculated on the basis of the following assumption:

The concrete and the steel are both considered to be fully elastic in tension and in compression. The elastic modulus of the steel may be taken as 200 kN/mm² and the elastic modulus of the concrete is as derived from the equation given in **6.2.3.1** both in compression and in tension.

These assumptions are illustrated in Fig. 28,

where

h = the overall depth of the section,

x = the depth from the compression face to the neutral axis,

f_c = the maximum compressive stress in the concrete,

f_s = the tensile stress in the reinforcement, and

E_s = the modulus of elasticity of the reinforcement.

Alternatively, as an approximation, it will normally be satisfactory to calculate the steel stress on the basis of a cracked section and then reduce this by an amount equal to the tensile force generated by the triangular distributions, having a value of zero at the neutral axis and a value at the centroid of the tension steel of 1N/mm² instantaneously, reducing to 0.55 N/mm² in the long-term, acting over the tension zone divided by the steel area. For a rectangular tension zone, this gives

$$\varepsilon_m = \varepsilon_1 - \frac{b\,(h-x)(a-x)}{3 E_s A_s (d-x)}$$

where

A_s = area of tension reinforcement,

b = width of the section at the centroid of the tension steel,

ε_1 = strain at the level considered, calculated ignoring the stiffening of the concrete in the tension zone,

a = distance from the campression face to the point at which the crack width is being calculated, and

d = effective depth.

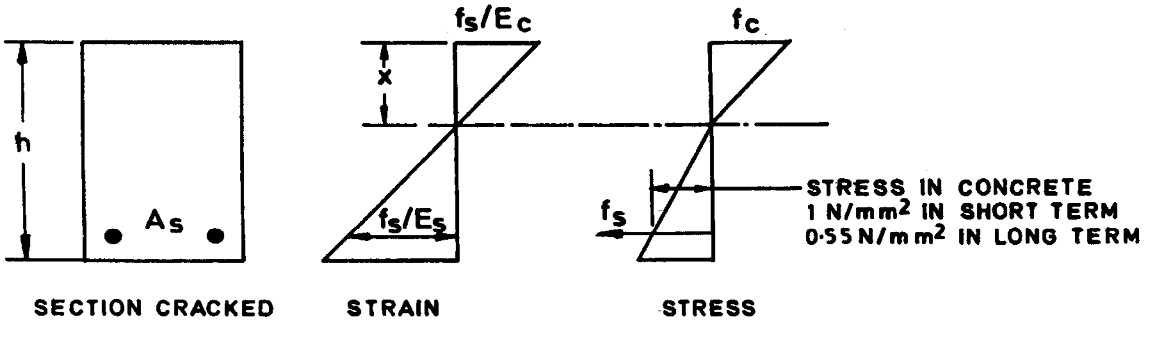


FIG. 28

ANNEX G

(*Clause* 38.1)

MOMENTS OF RESISTANCE FOR RECTANGULAR AND T-SECTIONS

G-0 The moments of resistance of rectangular and T-sections based on the assumptions of **38.1** are given in this annex.

G-1 RECTANGULAR SECTIONS

G-1.1 Sections Without Compression Reinforcement

The moment of resistance of rectangular sections without compression reinforcement should be obtained as follows :

a) Determine the depth of netutral axis from the following equation :

$$\frac{x_u}{d} = \frac{0.87 f_y A_{st}}{0.36 f_{ck} b.d}$$

b) If the value of x_u/d is less than the limiting value (*see* Note below **38.1**), calculate the moment of resistance by the following expression :

$$M_u = 0.87 f_y A_{st} d\left(1 - \frac{A_{st} f_y}{bd f_{ck}}\right)$$

c) If the value of x_u/d is equal to the limiting value, the moment of resistance of the section is given by the following expression :

$$M_{u,lim} = 0.36 \frac{x_{u,max}}{d}\left(1 - 0.42 \frac{x_{u,max}}{d}\right) bd^2 f_{ck}$$

d) If x_u / d is greater than the limiting value, the section should be redesigned.

In the above equations,

x_u = depth of neutral axis,

d = effective depth,

f_y = characteristic strength of reinforcement,

A_{st} = area of tension reinforcement,

f_{ck} = characteristic compressive strength of concrete,

b = width of the compression face,

$M_{u,lim}$ = limiting moment of resistance of a section without compression reinforcement, and

$x_{u,max}$ = limiting value of x_u from **39.1**.

G-1.2 Section with Compression Reinforcement

Where the ultimate moment of resistance of section exceeds the limiting value, $M_{u,lim}$ compression reinforcement may be obtained from the following equation :

$$M_u - M_{u,lim} = f_{sc} A_{sc} (d - d')$$

where

$M_u, M_{u,lim}, d$ are same as in **G-1.1**,

f_{sc} = design stress in compression reinforcement corresponding to a strain of

$$0.003\,5 \frac{(x_{u,max} - d')}{x_{u,max}}$$

where

$x_{u,max}$ = the limiting value of x_u from **38.1**,

A_{sc} = area of compression reinforcement, and

d' = depth of compression reinforcement from compression face.

The total area of tension reinforcement shall be obtained from the following equation :

$$A_{st} = A_{st1} + A_{st2}$$

where

A_{st} = area of the total tensile reinforcement,

A_{st1} = area of the tensile reinforcement for a singly reinforced section for $M_{u,lim}$, and

$A_{st2} = A_{sc} f_{sc} / 0.87 f_y$.

G-2 FLANGED SECTION

G-2.1 For $x_u < D_f$, the moment of resistance may be calculated from the equation given in **G-1.1**.

G-2.2 The limiting value of the moment of resistance of the section may be obtained by the following equation when the ratio D_f / d does not exceed 0.2 :

$$M_u = 0.36 \frac{x_{u,max}}{d}\left(1 - 0.42 \frac{x_{u,max}}{d}\right) f_{ck} b_w d^2 + 0.45 f_{ck} (b_f - b_w) D_f \left(d - \frac{D_f}{2}\right)$$

where

M_u, $x_{u,max}$, d and f_{ck} are same as in **G-1.1**,

b_f = breadth of the compression face/flange,

b_w = breadth of the web, and

D_f = thickness of the flange.

G-2.2.1 When the ratio D_f/d exceeds 0.2, the moment of resistance of the section may be calculated by the following equation :

$$M_u = 0.36 \frac{x_{u,max}}{d} \left(1 - 0.42 \frac{x_{u,max}}{d}\right) f_{ck}\, b_w d^2 + 0.45 f_{ck} (b_f - b_w) y_f \left(d - \frac{y_f}{2}\right)$$

where $y_f = (0.15\, x_u + 0.65\, D_f)$, but not greater than D_f, and the other symbols are same as in **G-1.1** and **G-2.2.**

G-2.3 For $x_{u,\,max} > x_u > D_f$, the moment of resistance may be calculated by the equations given in **G-2.2** when D_f/x_u does not exceed 0.43 and **G-2.2.1** when D_f/x_u exceeds 0.43; in both cases substituting $x_{u,\,max}$ by x_u.

ANNEX H

(Foreword)

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AMENDMENT NO. 1 JUNE 2001
TO
IS 456 : 2000 PLAIN AND REINFORCED CONCRETE — CODE OF PRACTICE

(Fourth Revision)

(*Page* 2, *Foreword, last but one line*) — Substitute 'ACI 318 : 1995' for 'ACI 319 : 1989'.

(*Page* 11, *clause* **4**) — Delete the matter 'L_w — Horizontal distance between centres of lateral restraint'.

(*Page* 15, *clause* **5.5**, *Title*) — Substitute '**Chemical Admixtures**' *for* '**Admixtures**'.

(*Page* 17, *clause* **7.1**) — Substitute the following for the existing informal table:

Placing Conditions	*Degree of Workability*	*Slump (mm)*
(1)	(2)	(3)
Blinding concrete; Shallow sections; Pavements using pavers	Very low	*See* **7.1.1**
Mass concrete; Lightly reinforced sections in slabs, beams, walls, columns; Floors; Hand placed pavements; Canal lining; Strip footings	Low	25-75
Heavily reinforced sections in slabs, beams, walls, columns;	Medium	50-100
Slipform work; Pumped concrete	Medium	75-100
Trench fill; *In-situ* piling	High	100 -150
Tremie concrete	Very high	*See* **7.1.2**

NOTE — For most of the placing conditions, internal vibrators (needle vibrators) are suitable. The diameter of the needle shall be determined based on the density and spacing of reinforcement bars and thickness of sections. For tremie concrete, vibrators are not required to be used (*see also* **13.3**).

(*Page* 19, *Table* 4, *column* 8, *sub-heading*) — Substitute 'Free' *for* 'Face' .

(*Page* 27, *clause* **13.5.3**) — Delete.

(*Page* 29, *clause* **15.3**):

a) Substitute 'specimens' *for* 'samples' in lines 2, 6 and 7.

b) Substitute 'IS 9013' *for* 'IS 9103' .

(*Page* 29, *clause* **16.1**) — Substitute 'conditions' *for* 'condition' in line 3 and the following matter for the existing matter against 'a)' :

'a) The mean strength determined from any group of four non-overlapping consecutive test results complies with the appropriate limits in column 2 of Table 11.'

(*Page* 29, *clause* **16.3**, *para* 2) — Substitute 'col 3' *for* 'col 2'.

(*Page* 29, *clause* **16.4**, *line* 2) — Substitute '**16.1** or **16.2** as the case may be' *for* '**16.3**'.

(*Page* 30, *Table* 11, *column* 3) — Substitute '$\geq f_{ck} - 3$' *for* '$\geq f_{ck}{}^{-3}$' and '$\geq f_{ck} - 4$' *for* '$\geq f_{ck}{}^{-4}$'

(*Page* 33, *clause* 21.3, *line* 2) — Substitute 'action' *for* 'section'.

[*Page* 37, *clause* 23.1.2(c)] — Substitute 'b_f' *for* 'b$_f$', 'l_0' *for* 'l$_0$', 'b' *for* 'b' and 'b_w' *for* 'b$_w$' in the formulaé.

(*Page* 46, *clause* 26.4.2) — Substitute '8.2.2' *for* '8.2.3'.

[*Page* 49, *clause* 26.5.3.2 (c) (2), *last line*] — Substitute '6 mm' *for* '16 mm'.

(*Page* 62, *clause* 32.2.5) — Substitute 'H_{we}^2' *for* 'H_{we}' in the explanation of e_a.

(*Page* 62, *clause* 32.3.1, *line* 4) — Substitute '32.4' *for* '32.3'.

[*Page* 62, *clause* 32.4.3 (b), *line* 6] — Insert 'τ_{cw}' between the words 'but' and 'shall'.

[*Page* 65, *clause* 34.2.4.1(a), *last line*] — Insert the following after the words 'depth of footing' :

'in case of footings on soils, and at a distance equal to half the effective depth of footing'.

(*Page* 68, *Table* 18, *col* 4) — Substitute '–' *for* '1.0' against the Load Combination *DL* + *IL*.

(*Page* 72, *clause* 40.1) — Substitute '*bd*' *for* 'b_d' in the formula.

(*Page* 83, *clause* B-4.3, *line* 2) — Delete the word 'and' .

(*Page* 85, *clause* B-5.5.1, *para* 2, *line* 6) — Substitute 'Table 24' *for* 'Table 23'.

(*Page* 85, *clause* B-5.5.2) — Substitute the following for the existing formula:

'$A_s = a_v b\,(\tau_v - 2d\,\tau_c / a_v) / \sigma_{sv} \geq 0.4\, a_v b / 0.87 f_y$'

(*Page* 90, *clause* D-1.11, *line* 1) — Substitute 'Where' *for* 'Torsion'.

(*Page* 93, *Fig.* 27) — Substitute 'l_{ef}/l' *for* '1/L'.

(*Page* 95, *Annex* F):

a) The reference to Fig. 28 given in column 1 of the text along with the explanation of the symbols used in the Fig. 28 given thereafter may be read just before the formula given for the rectangular tension zone.

b) Substitute 'compression' *for* 'campression' in the explanation of symbol '*a*' .

(*Pages* 98 *to* 100, *Annex* H) — Substitute the following for the existing Annex :

ANNEX H

(Foreword)

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