9. Arched structures
10. Shell structures
11. Cylindrical structures
12. Folded plate roofs.

1.4 NATIONAL CODES AND HANDBOOKS

Most of the developed countries have prescribed their specific national codes based on the extensive research and practical knowledge. These codes serve as guidelines for the design of reinforced concrete structures. The principal objectives of the codes can be summarized as:

1. Provision of adequate safety by ensuring strength, serviceability and durability codifying design procedure, design tables to facilitate easy computations.
2. Protection of structural engineers from any liability due to failure of structures caused due to inadequate design and improper materials and lack of proper supervision during construction.
3. To provide a uniform set of design guidelines to be followed by various structural designers and engineers in the country.
4. To provide simple design procedures, design tables and formulae for easy computations.

The national building codes are periodically revised to reflect the improvements in the quality of materials and design practices evolved as a result of comprehensive research investigations conducted in various institutions in the country and abroad.

In India, the design of reinforced concrete structures should conform to the Indian national code IS:456-2000[9]. The corresponding national codes of the leading countries generally referred to are listed as:

1. British code: BS EN:1992-1-1, Euro code-2, Design of concrete structure, general rules and rules for buildings, British Standards Institution, 2004[10].
2. American code: ACI:318M-11(metric), Building code requirements for structural concrete, American Concrete Institute, 2005[11].
3. AS:3800-1988, Concrete structures, Standards Association of Austraila, 1988[12].
4. CSA standard: A23.1-00/A23.2-00, Concrete materials and methods of concrete construction/methods of test for concrete, Canadian Standards Associations, Toronto, 2000[13].

In addition to the abovementioned codes, the following special publications and handbooks are very useful in the design offices of structural engineers:

1. SP:16-1980[14]: Design aids for reinforced concrete.
2. SP:34-1987[15]: Handbook of concrete reinforcement and detailing.
3. SP:10262-1982[16]: Recommended guidelines for concrete mix design.
4. Handbook of concrete engineering by Mark Fintel[17].
5. Reynolds' reinforced concrete designers' handbook[18].

1.5 PHILOSOPHY OF STRUCTURAL DESIGN

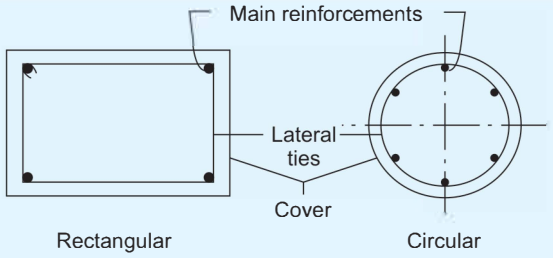
The design philosophy of structural concrete elements has seen significant changes during the last century due to the research investigations by several engineering

Table 1.2: Live loads on structures [(IS:876-1987 (part 2)]

Loading class	*Types of floors*	*Minimum live load kN/m²*
2	Floors in dwelling houses, tenements, hospital wards, bedrooms and private sitting rooms in hostels and dormitories	2
2.5	Office floors other than entrance hall floors of light workrooms	2.5–4.0
3.0	Floors of banking halls, office entrance halls and reading rooms	3.0
4.0	Shop floors used for display and sale of merchandise, floors of workrooms, floors of classrooms, restaurants, machinery halls, power station etc. where not occupied by plant or equipment	4.0
5.0	Floors of warehouses, workshops, factories and other buildings or similar category for light weight loads, office floors for storage and filling purposes. Assembly floor space without fixed seating, public rooms in hotels, dance halls and waiting halls	5.0
7.5	Floors of warehouses, workshops, factories and other buildings or parts of buildings of similar category for medium weight loads	7.5
10.0	Floors of warehouses, workshops, factories and other buildings or parts of buildings of similar category for heavy weight loads, floors of book stores and libraries	10.0
Garages (light)		
Floors used for garages for vehicles not exceeding 25 kN gross weight		
	Slabs	4.0
	Beams	2.5
Garages (heavy)		
Floors used for garages for vehicles not exceeding 40 kN gross weight		7.5
Stair cases		
	Stairs, landings and corridors for class 2, but not liable to overcrowding	3.0
	Stairs, landings and corridors for class 2 loading but liable to overcrowding and for all other classes	5.0
Balcony		
	Balconies not liable to overcrowding for class 2 loading	3
	Loading for other classes	5
	Balconies liable to overcrowding	5
Roofs		
Types of roofs		*Live load in plan kN/m²*
Flat, sloping or curved roofs with slopes upto and including 10 degrees		
	a. Access provided	1.5
	b. Access not provided, except for maintenance	0.75
	c. Sloping roof with slope greater than 10° – 0.75 kN/m² less 0.001 kN/m² for every increase in slope over 10° upto and including 20° and 0.002 kN/m² for every degree increase in slope over 20°	

1.6.5 Seismic or Earthquake Loads

Earthquake or seismic loads should be considered in the design of structures located in specific zones in the Indian subcontinent which experience earthquake resulting in lateral loads on the structures. Based on seismic studies, India has been divided into five zones depending upon the severity of the intensity of earthquake prevalent in the zone. Horizontal seismic forces induced due to the earthquake as specified in



Maximum reinforcement: $\leq 0.8\%$
Maximum reinforcement: $\geq 6\%$
Minimum number of bars: 4 in rectangular and 6 in circular sections
Diameter of bars: ≤ 12 mm
Minimum cover: 40 mm nor diameter of largest longitudinal bar nor < 5 mm
Pitch of lateral ties diameter: $\leq$ 1/4 diameter of largest longitudinal bar nor < 5 mm
Pitch of lateral ties shall not be more than the least of the following:
i. least lateral dimension of member
ii. 16 times the smallest diameter of longitudinal bars
iii. 300 mm
For effective arrangemet of lateral ties refer to Figs 8 to 10, IS:456-2000

Fig. 1.3: Reinforcement specifications in RC columns (IS:456-2000).

1.9 SPECIFICATIONS OF COVER REQUIREMENTS FOR STEEL REINFORCEMENTS

In reinforced concrete structures, sufficient cover of concrete is required to protect the steel reinforcements from exposure to aggressive environmental conditions and consequent rusting and deterioration of the cross-sectional area. Nominal cover is the design depth of concrete cover to all steel reinforcements including links.

Minimum values of the nominal cover for reinforcement depends upon the exposure conditions and the IS Code requirements for cover are given in Table 1.8. In case of columns, the nominal cover for longitudinal bars should be not less than the diameter of the bar. However, in the case of columns of minimum dimension of 200 mm or less and whose bars do not exceed 12 mm, a nominal cover of 25 mm may be used. In the case of RCC footings under the column, the minimum cover is prescribed as 50 mm.

The Indian standard code also provides for nominal cover requirements to meet specified period of fire resistance as shown in Table 1.9. The values indicate the minimum cover requirements for beams, slabs, ribs and columns for fire resistance varying from 0.5 to 4 hours.

Table 1.8: Nominal cover to meet durability requirements (IS:456-2000, Table 16)

Exposure	Nominal concrete cover in mm not less than
Mild	20
Moderate	30
Severe	45
Very severe	50
Extreme	75

Notes:
1. For main reinforcement up to 12 mm diameter bar for mild exposure, the nominal cover may be reduced by 5 mm.
2. Unless specified otherwise, actual concrete cover should not deviate from the required nominal cover by +10 mm.
3. For exposure condition 'severe' and 'very severe', reduction of 5 mm may be made, where concrete grade is M35 and above.

CHAPTER

2

Elastic or Working Stress Theory of Reinforced Concrete Sections

2.1 ELASTIC THEORY OF RC SECTIONS

The earliest codified design philosophy by various countries is based on the elastic or working stress theory proposed by Francois Coignet[1] of France, who acquired a patent for reinforced concrete in 1855. The concept of bond between steel rods and the surrounding concrete was propounded by the American lawyer, Thaddeus Hyatt as mentioned by Turneaure[2] in 1877. Later Koenan of Germany developed the design rules in 1886 as mentioned by Taylor and Thompson[3]. These fundamental concepts were incorporated by the French Commission as reported by Faber and Bowie[4] in their design rules for reinforced concrete in 1907 followed by the American Concrete Institute and the American Society of Civil Engineers, jointly developing the first design code for reinforced concrete in 1909 as reported by Adams and Mathews[5]. In the early 20th century, these design principles were recognized as the elastic or working stress theory of reinforced concrete sections[6,7].

The success of the elastic theory is attributed to the good bond[8,9] between concrete and steel resulting in the composite behaviour of the material in an elastic manner under service loads. Working stress method is used not only for reinforced concrete, but also for steel, timber and other metallic structures.

2.2 BASIC ASSUMPTIONS IN ELASTIC THEORY

In the elastic theory, the materials are assumed to behave in a linear elastic manner and the required safety of the structure is ensured by restricting the stresses in concrete and steel to permissible stresses obtained by applying suitable factor of safety to the characteristic strength of the materials. The resulting permissible or working stresses under service loads will be well within the linear elastic range of the materials. The basic assumptions incorporated in the elastic theory of flexure according to the Indian standard code IS:456-2000[10] are as follows:

1. At any cross-section, plane sections before bending remain plane after bending indicating that strain varies linearly over the depth of the section.

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