Training on
NBC and Structural Analysis & Design of Buildings

Load Calculation for A Building

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TYPES OF LOADS

Dead Loads

- Floor-wise calculated
- Consist of weights of:
  - Floors (slabs) Beams/Girders Partition walls
  - False ceiling Parapets Balconies
  - Fixed or permanent equipment Columns
- The variations in calculated dead load and actual dead loads are relatively small.
- NBC 102:1994 /IS:875(Part I) gives the unit weights of Materials.

DEAD LOADS OF MATERIALS

S.N.	Materials	Unit Wt. in kN/m³
1.	Reinforced Concrete	25 kN/m³
2.	Plain Concrete	24 kN/m³
3.	Brick masonry	18.85- 23.5 kN/m3
4.	Cement Sand Mortar	20.4 kN/m³
5.	Screed	20.4 kN/m³
6.	Marble	26.7 kN/m³
7.	Sand Stone	22.0 - 23.5 kN/m³
8.	Steel	78.5 kN/m³
9.	Timber - Sal	8.5 kN/m³
10.	Water	9.81 kN/m³
11.	Brick Ballast	6.85 - 14.30 kN/m³
12.	Earth - Dry	13.8 - 18.0 kN/m³
13.	Earth - Moist	15.7 - 19.6 kN/m³

Live load

- Depends upon type of occupancy of the buildings
- NBC 103:1994/IS 875-1987 Part 2 gives the values

- Reduction allowed for beam carrying load from an area greater than 50 sq.m.(-5 % for each 50 sq.m. area subject to a maximum reduxction of 25%)
- Reduction allowed for design of columns, walls, foundations.

LIVE LOADS ON BUILDINGS

S.N.	Occupancy Type	Examples
1.	**Residential Buildings**	one or multi-family dwellings, apartment houses, lodges, restaurants, hostels, dormitories, residential hotels
2.	**Educational Buildings**	school, colleges, day care centres, etc
3.	**Institutional Buildings**	hospitals, sanitoria, custodial institutions like jails, prisons & reformatories, etc
4.	**Assembly Buildings**	Theatre, cinema halls, assembly halls, city halls, marriage halls, town halls, exhibition halls, museaums, gymnasiums, places of worship, dance halls, passenger staions, bus terminal, airport terminal, etc
5.	**Business & office Buildings**	offices, banks, court houses, libraries, professional establishments, etc
6.	**Mercantile Buildings**	Shops, stores, markets with display 7 sale of merchandize either whole sale or retail
7.	**Industrial Building**	assembly plants, power plants, refineries, gas plants, mills, dairies, factories, workshops, etc
8.	**Storage Buildings**	warehouses, cold storages, freight depots, transit sheds, store houses, garages, hangers, truck terminals, grain elevators, barn and stables, etc

LIVE LOADS

S.N.	Occupancy Classification	UDL in kN/m²
1. Residential Buildings		
a) Dwelling houses, apartment houses		
1.	Rooms, kitchen	2.0
2.	Toilets, bathrooms	2.0
3.	Corridors, Store Room and staircases	3.0
4.	Balconies	3.0 minimum
b) Hotels, Hostels, Boarding Houses		
1.	Living Rooms, Bed Rooms, Dormitories	2.0
2.	Kitchen, laundries, corridors, passages, staircases	3.0
3.	Dining Rooms, restaurants	4.0
4.	Office Rooms	2.5
5.	Baths & Toilets	2.0
6.	Store Rooms	5.0
7.	Balconies	4.0 minimum
8.	Garage Floors for Passenger Cars	2.5 minimum

LIVE LOADS

S.N.	Occupancy Classification	UDL in kN/m²
2. Educational Buildings		
1.	Class Rooms, Lecture Rooms	3.0
2.	Dining Rooms, cafeterias	3.0
3.	Office, Staff Rooms, Lounges	2.5
4.	Projection rooms	5.0
5.	Store Rooms	5.0
6	Libraries and archieves	
a.	Stack room	6.0 for a minimum height of 2.2 m + 2.0 per m height beyond 2.2
b.	Reading rooms without separate storage	4.0
c.	Reading Rooms with separate storage	3.0

LIVE LOADS

S.N.	Occupancy Classification	UDL in kN/m^2
3. Business and Office Buildings		
1.	Rooms for general use with separate storage	2.5
2.	Rooms without separate storage	4.0
3.	Banking halls	3.0
4.	Computer Rooms	3.5
5.	Record/ File Store rooms, storage rooms	5.0
6.	Stationary Stores	4.0 for each m of storage height
4. Storage Buildings		
a.	Warehouses- to be calculated based on bulk density of materials to be stored but not less than:	2.5 per m of storage height with minimum of 7.5 kN/m^2
b.	Cold Storage- to be calculated but not less than:	5.0 per m of storage height with minimum of 15 kN/m^2

LIVE LOADS

S.N.	Occupancy Classification	UDL in kN/m^2
5. Roofs		
a) Flat, Sloping or Curved Roof with Slope < 10 degrees		
a.	access provided	1.5
b.	access not provided	0.75

Wind Load

- Wind is a highly dynamic phenomenon. It is a complex problem from a structural perspective.
- Wind forces fluctuate significantly and are influenced by the geometry of the structure, including the height, width, depth, plan & elevation shape, and the surrounding landscape.
- The basic building code approach is to treat wind as a static load problem, using the Bernoulli equation to translate wind speed into wind pressure. A semi-empirical equation is used to give the wind load at certain levels as a function of a number of factors representing such effects as wind gusts, topography and structural geometry.

Wind Load

Wind speed depends on :

- Density of obstructions in the terrain
- Size of gust
- Return period
- Probable life of Structure

Design wind speed, $V_z = V_b k_1 k_2 k_3$

k_1= probability or risk factor
k_2= terrain, height and structure size factor
k_3= local topography factor
V_b = basic wind speed in meters/sec at 10 m height

NBC 104:1994/IS:875 (Part 3)-1987 gives the details.

Wind Load … cont'd

- design wind pressure $p_z = 0.6 * V_z^2$ in N/m^2

Wind force on complete building, $F = C_f A_e p_z$

C_f = force coefficient

A_e = effective exposed area

p_z = design wind pressure

Basic Wind Speed Map of Nepal

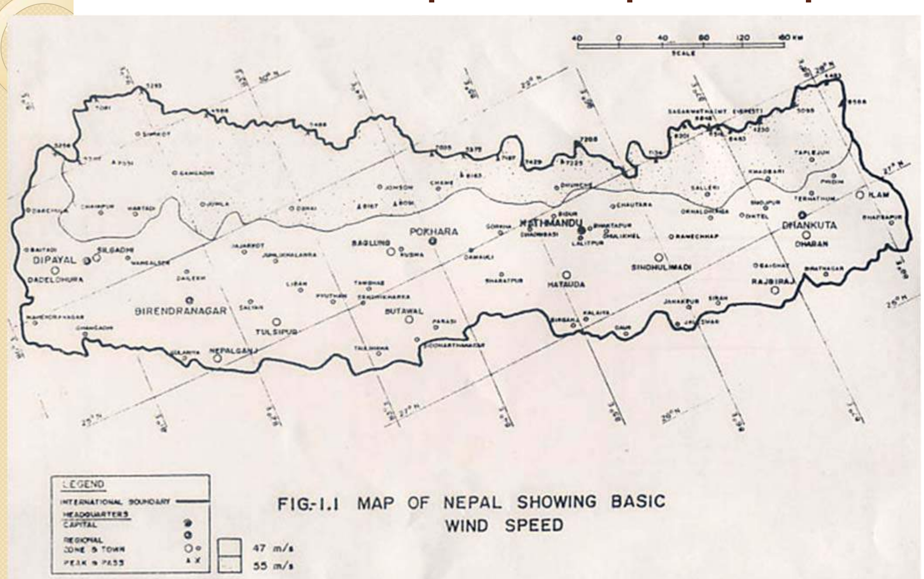


FIG-1.1 MAP OF NEPAL SHOWING BASIC WIND SPEED

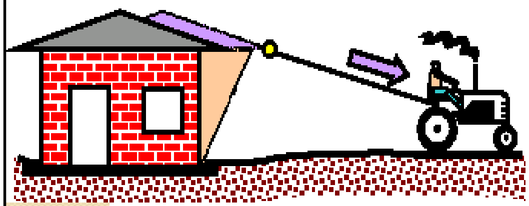
Seismic or Earthquake Load

- The treatment of seismic load effects is extremely complicated because of highly variable nature of this natural phenomenon and the many factors that influence the impact of an earthquake on any particular structure.
- For most buildings, it is sufficient to treat seismic effects through the use of an equivalent static load.
- Many characteristics of the problem must be quantified in order to establish the correct magnitude of this static load. these include such factors as the ground motion & response spectra for the seismic event and the structural and site characteristics for the specific project.

Earthquake Load

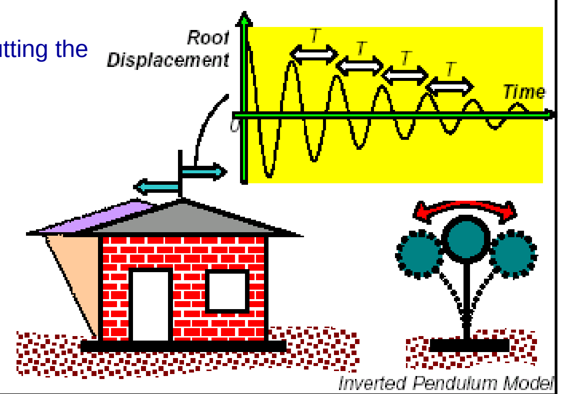
- Depends upon geographical location, lateral stiffness, mass
- It is reversible. Effect to be considered along both axes of a building taken one at a time.
- Wind and earthquakes assumed not to act simultaneously.

Fundamental period of Building



Building pulled with a rope tied at its rope

Oscillation of building on cutting the rope



Free vibration response of a building (The back and forth motion is periodic)

$$\omega_n = \sqrt{k/m}$$

$$T_n = 2\pi / \omega_n$$

Fundamental Time Period

- The time taken (*in seconds*) for each complete cycle of oscillation (*i.e.,* one complete *back-and-forth* motion) is the same and is called ***Fundamental Natural Period T*** of the building.
- ***"T"*** depends on the building flexibility and mass.
- More the flexibility, the longer is the *T*, and more the mass, the longer is the *T*.
- In general, taller buildings are more flexible and have larger mass, and therefore have a longer *T*.
- On the contrary, low- to medium-rise buildings generally have shorter T.

Natural Period of Typical Structures

Low rise building, T_n = 0.1-0.3 sec

Medium rise building, T_n = 0.5-1.0 sec

High rise buildings, T_n = 2.0 – 6.0 sec

- Taller, flexible structures have longer natural periods

Earthquake Load cont'd

Three methods:

- Seismic coefficient Method
- Response spectrum Method
- Time History Analysis

Equivalent Static Lateral Force

- Determine design base shear based on seismic hazard, building use group, total building mass, and building fundamental period
- Distribute base shear to building stories based on story masses and elevations
- Design for story forces applied in each orthogonal direction
- Also, ensure inelastic story drift does not exceed code requirement

EQ load Calculation

- Dead Load – preliminary member sizes, unit weights
- Live Load – Building occupancy
- Earthquake Load = Dead load + Appropriate imposed load

Design Live load	Percentage of Design Live load
Up to 3 kPa	25 %
Above 3 kPa	50 %
For roof	Nil

Earthquake Load as per NBC:105

- Horizontal Base Shear

$Vs = C_d * W$

W = Seismic Weight of the Building

= Dead Load + Appropriate % of Live Load

- The seismic weight at each level, W_i, shall be taken as the sum of the dead loads and the seismic live loads between the mid-heights of adjacent storeys

C_d = Design Horizontal Seismic Force Coefficient

= C Z I K

C = Basic Seismic Coefficient

Z = Zone factor

I = Importance factor

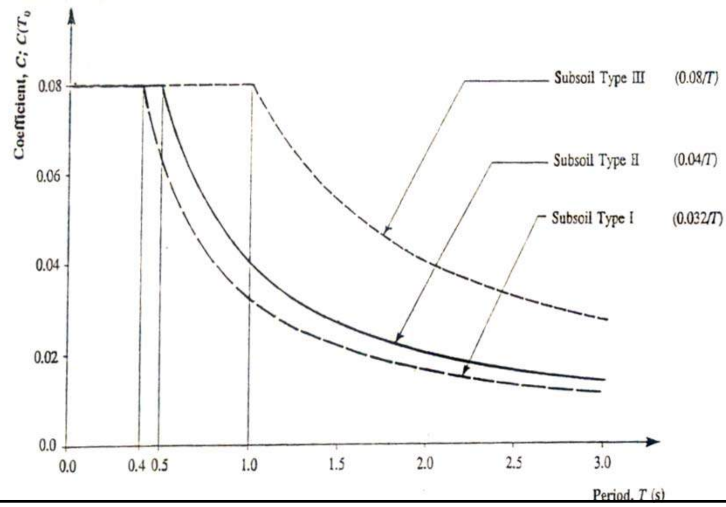
K = Structural performance factor

Periods of Vibration NBC:105

- The periods of vibration, T_i, shall be established from properly substantiated data, or computation, or both
- Where the Seismic Coefficient Method is used, the fundamental translation period in the direction under consideration, T_1, shall be determined from
  - T1 = 2 π √ Σ Wi di2 /g Σ Fi di
- For the purposes of initial member sizing, the following approximate formulae for T_i may be used
- For framed structures with no rigid elements limiting the deflection
  - T1 = 0.085 H ¾ for steel frames
  - T1 = 0.06 H ¾ for concrete frames
- For other structures Ti = 0.09*H/(√D)

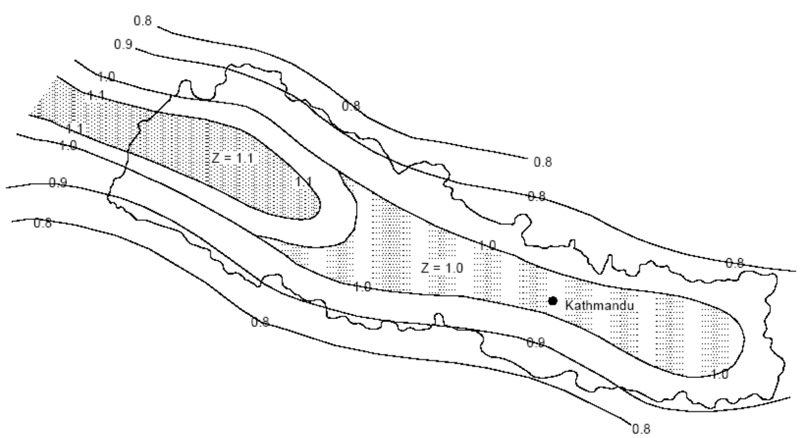
Basic Seismic Coefficient (C) NBC:105

The basic seismic coefficient, *C*, shall be determined from for the appropriate site subsoil category using the fundamental structural period determined



Seismic Zoning Factor (Z) NBC:105

- The seismic zoning factor, *Z*, shall be obtained from Figure for the appropriate location



Importance Factor

- The importance factor, I, for the structure shall be obtained from Table (1 – 2)

Type of Building	Importance Factor
(a)Monumental Buildings	1.5
(b)Essential facilities that should remain functional after an earthquake	1.5

Examples of these facilities would be :
Hospitals and other medical facilities, Fire and Police stations, Emergency vehicle shelters/garages, Food storage structures, Emergency relief stores
Power stations (including standby power-generating equipment for essential facilities)
Water works and water towers
Radio and television facilities
Telephone exchanges and transmission facilities
Offices and residential quarters for senior personnel
required for central and district-level rescue and relief operations
(ministers, secretaries, police and army chiefs; CDO, LDO and DDC chairmen, district-level army and police chiefs
Places of assembly (schools, colleges, cinemas, convention halls, temples, dharmsalas).

Importance Factor

Type of Building	Importance Factor
(c) Distribution facilities for gas or petroleum products in urban areas.	2.0
(d) Structures for the support or containment of dangerous substances (such as acids, toxic substances, etc.).	2.0
(e) Other structures	1.0

Structural Performance Factor K

- The minimum permissible value of the structural performance factor, K, and associated detailing requirements

Item	Structural Type	Minimum Detailing Requirements	K
1.(a)	Ductile moment-resisting frame	Must comply with the detailing for ductility requirements of IS4326 and for steel frames, the additional requirements of NBC 111-94	1.00
(b)	Frame as in 1(a) with reinforced concrete shear walls	For frames : as for 1(a). Reinforced concrete shear walls must comply with appropriate3detailing for ductility requirements.	1.00
2.(a)	Frame as in 1(a) with either steel bracing members detailed for ductility or reinforced concrete infill panels	For frames : as for 1(a). Steel bracing members must comply with the detailing for ductility requirements NBC 111-94. Reinforced concrete infill panels must comply with the detailing requirements of NBC 109-94.	1.50

Structural Performance Factor K

Item	Structural Type	Minimum Detailing Requirements	K
(b)	Frame as in 1(a) with masonry infills	Must comply with the detailing for ductility requirements of: IS 4326	2.00
3	Diagonally-braced steel frame with ductile bracing acting in tension only	Must comply with the detailing for ductility requirements of Nepal Steel Construction Standard	2.00
4	Cable-stayed chimneys	Appropriate materials Standard	3.00
5	Structures of minimal ductility including reinforced concrete frames not covered by 1 or 2 above, and masonry bearing wall structures.	Appropriate materials Standard	4.00

Distribution of EQ Load

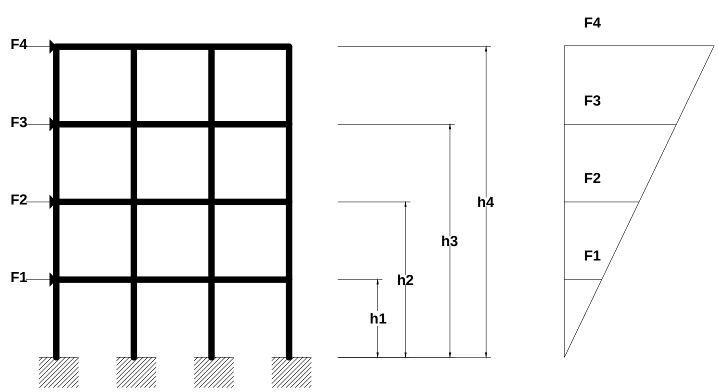
- Distribution of Base Shear

$$F_i = V * W_{i*} h_i / \Sigma W_{i*} h_i$$

Distribution of Story Shears into different frames

- Frame forces proportional to the stiffness of the frames
- Additional forces due to torsional effects
  - Eccentricity – difference in center of mass and center of rigidity

Calculation of Floor-wise Lateral Force



$F_i = (W_i h_i)*V/\Sigma(W_i h_i)$

$V = C_d * \Sigma W_i$

$C_d = C*Z*I*K$

Seismic Coefficient Method in IS 1893:2002

Total base Shear, $V_B = A_h * W$

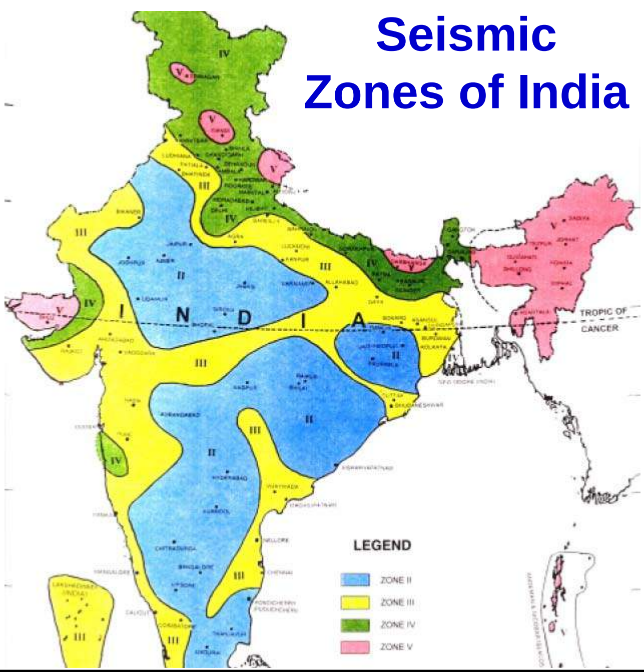
Where, design horizontal seismic coefficient

$$A_h = (Z/2)*(I/R)*(S_a/g)$$

Z = Zone factor

Seismic Zone	II	III	IV	V
seismic intensity	Low	Moderate	Severe	Very Severe
Z	0.10	0.16	0.24	0.36

Seismic Zones of India



Natural Period of Vibration T in IS 1893-2002

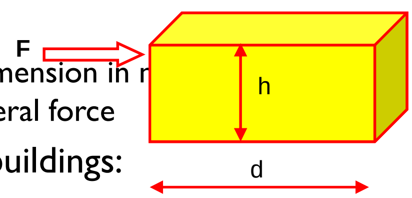
1. For Reinforced Concrete Moment resisting Frame Building without Brick Infill Panels:

   $T = 0.075*h^{0.75}$ in seconds, h = height of bldg. in meters

2. For All other building including moment resisting frames with brick infill panels and shear walls:

   $T = 0.09*h/\sqrt{(d)}$

   where, d = base dimension in r
   direction of lateral force



3. For Steel-framed buildings:

   $T = 0.085*h^{0.75}$

Spectral acceleration S_a/g in IS 1893-2002

1.	Hard Soil	S_a/g	1+15T	$0.00 \leq T < 0.10$
			2.50	$0.10 \leq T < 0.40$
			1.00/T	$0.40 \leq T < 4.00$
2.	Medium Soil	S_a/g	1+15T	$0.00 \leq T < 0.10$
			2.50	$0.10 \leq T < 0.55$
			1.36/T	$0.55 \leq T < 4.00$
3.	Soft Soil	S_a/g	1+15T	$0.00 \leq T < 0.10$
			2.50	$0.10 \leq T < 0.67$
			1.67/T	$0.67 \leq T < 4.00$

Spectral acceleration S_a/g in IS 1893-2002

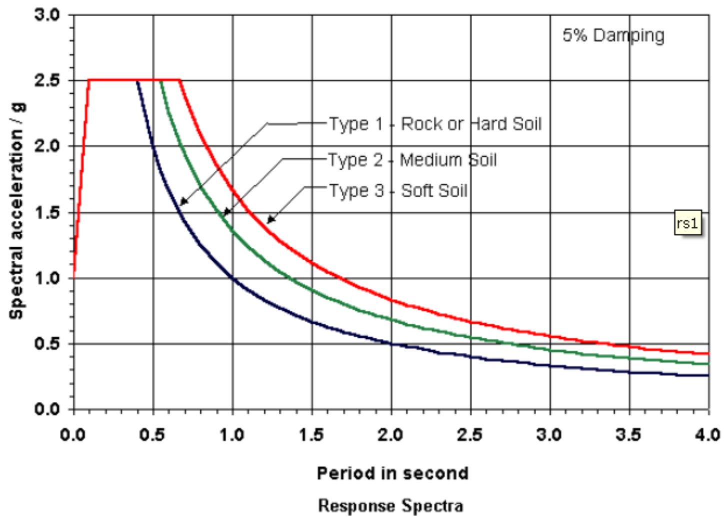


Fig. 1 Elastic response spectra IS:1893-2002

Importance Factor I in IS 1893-2002

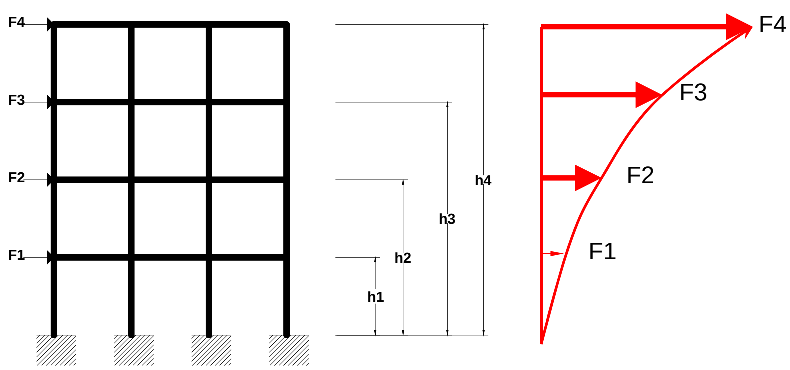
S.N.	Structure Type	Importance Factor
1.	Important service and community buildings, such as hospitals; schools; monumental structures; emergency buildings like telephone exchange, television stations, radio stations, railway stations, fire station buildings; large community halls like cinemas, assembly halls and subway stations, power stations	1.5
2.	All other buildings	1.0
Notes:		
i)	The design engineer may choose values of importance factor I greater than those mentioned above	
ii)	Buildings not covered in Sl No. (i) and (ii) above may be designed for higher value of I, depending on economy, strategy considerations like multi-storey buildings having several residential units	
iii)	This does not apply to temporary structures like excavations, scaffolding etc of short duration	

Response Reduction factor R in IS 1893-2002

Building with frames		
1.	OMRF	3.0
2.	SMRF	5.0
Bldg. with Dual System		
1.	Ductile Shear Wall with OMRF	4.5
2.	Ductile Shear Wall with SMRF	5.0
3.	Ordinary Shear Wall with OMRF	3.0
4.	Ordinary Shear Wall with SMRF	4.0

Load Bearing Masonry Wall Buildings with Shear Walls		
1.	Unreinforced	1.5
2.	Reinforced with Horiz. RC bands	2.5
3.	Reinforced with Horiz. RC bands+ Vertical Steel	3.0
4.	Ordinary RC Shear walls	3.0
5.	Ductile Shear Walls	4.0

Distribution of Base Shear VB in IS 1893-2002



$$F_i = V_B*(W_i h_i^2)/(\Sigma W_i h_i^2)$$

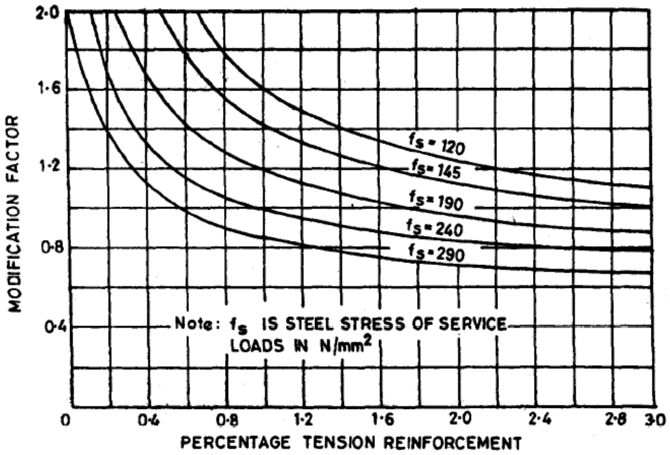
$V_B = A_h*W$, $A_h = (Z/2)*(I/R)*(S_a/g)$

Guidelines for Member Sizing

L/d ratio Approach for Controlling Deflection

- $(L/d)_{actual} < (L/d)_{permissible}$
- $(L/d)_{permissible} = \alpha * \beta * \gamma * \delta * \lambda$

<table>
<tr><th>S.N.</th><th>Items</th><th>Cantilever</th><th>Simply Supported</th><th>Continuous</th></tr>
<tr><td>1.</td><td>Basic values of span to effective depth ratio for spans upto 10 m (L/d) basic (α)</td><td>7</td><td>20</td><td>26</td></tr>
<tr><td>2.</td><td>Modification factor for spans >10 m (β)</td><td>Not applicable. Detailed deflection calculation reqd.</td><td colspan="2">10/span in m</td></tr>
<tr><td>3.</td><td>Modification factor for tension reinforcement (γ)</td><td colspan="3">From Fig. 4 of IS 456:2000</td></tr>
<tr><td>4.</td><td>Modification factor for compression reinforcement (δ)</td><td colspan="3">From Fig. 5 of IS 456:2000</td></tr>
<tr><td>5.</td><td>Modification factors for Flanged beam (λ)</td><td colspan="3">From Fig. 6 of IS 456:2000 depending upon b_w/b_f ratio, Area of section=b_f*d</td></tr>
</table>



$$f_s = 0.58\, f_y \frac{\text{Area of cross-section of steel required}}{\text{Area of cross-section of steel provided}}$$

FIG. 4 MODIFICATION FACTOR FOR TENSION REINFORCEMENT

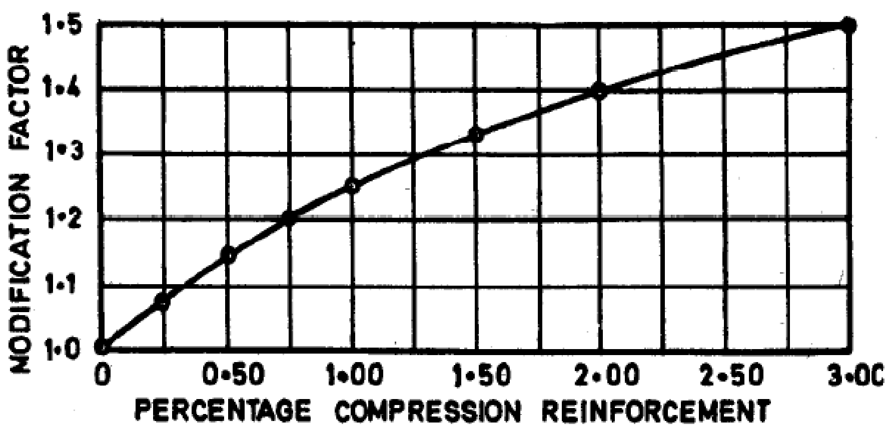


FIG. 5 MODIFICATION FACTOR FOR COMPRESSION REINFORCEMENT

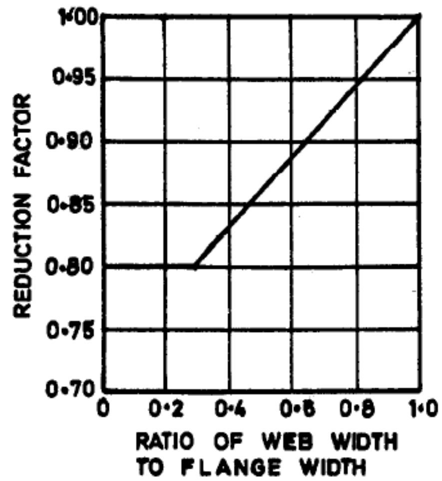


FIG. 6 REDUCTION FACTORS FOR RATIOS OF SPAN TO EFFECTIVE DEPTH FOR FLANGED BEAMS

) For flanged beams, the values of (a) or (b) be modified as per Fig. 6 and the reinforcement percentage for use in Fig. 4 and 5 should be based on area of section equal to $b_f d$.

NOTE—When deflections are required to be calculated, the method given in Annex C may be used.

Preliminary Size of Slab

- For Structural slab, minimum thickness for ease in construction= 100 mm
- Slab thickness is mainly governed by serviceability requirement.
- Total depth required = [span/Allowable L/d] + effective cover

  Where allowable L/d ratio = basic L/d ratio x modification factor for tension reinforcement

  pt = 0.7% to 1.0 %for Fe250

  pt = 0.3% to 0.45% for Fe415

  pt = 0.2% to 0.35% for Fe500
- Mod. Factor for tension = 1.4 for preliminary design with Fe415
- For simply supported, L/d = 20*1.4= 28, for continuous, L/d = 26*1.4 = 36.

Preliminary Size of Slab

- For span upto 3.5 m and loading class up to 3 kN/m^2, following basic L/d may be taken using mild steel reinforcement:
  - simply supported 2 way = 35
  - continuous two way slab = 40
- For span upto 3.5 m and loading class up to 3 kN/m^2, following basic L/d may be taken using HYSD bars of grade Fe415:
  - simply supported 2 way (35*0.8) = 28
  - continous two way slab (40*0.8) = 32

Preliminary Size of Slab

- for one way, a ratio of 25 and 30 may be taken.
- Normally safe in shear.
- Normally no compression reinforcement is provided.
- For cantilevers, greater depth may be required to be safe in deflection.
- Secondary beam may be provided to reduce slab thickness.

Preliminary Size of Slab

- Other detailing requirements:
  - The dia of main bar not greater than 1/8 of total thickness of slab
  - the amount of steel in any direction should not be less than 0.12 % of total cross sectional area when using Fe 415.
  - spacing of main steel not greater than 3d or 300 mm; secondary steel not greather than 5d or 450 mm.

Preliminary Size of Beam

- breadth not greater than width of column for effective load transfer.
- breadth of beam = 1/3 to 1/2 of the depth of beam.
- Depth of beam = L/10 to L/16.
- For heavy loads and/or large spans, provide D = L/10.
- for light load and/or small spans, provide D = L/16.
- Since D>L/20, deflection is normally satisfied.
- The rare possibility of design shear exceeding the permissible maximum shear is avoided by increasing the section of the beam.

Preliminary Size of Beam

- The usual widths of beam adopted in mm are 150, 200, 230, 250, 300 mm. These widths should be equal to or less than the dimension of the columns into which they frame. For example, 300 mm wide beams can frame into 300 mm or 400 mm dimensions of columns.
- In a simply supported or continuous beam, the clear distance between the lateral restraint should not exceed 60b or $250b^2/d$ whichever is less.
- For a cantilever, the distance between the free end of the cantilever and the lateral restraint should not exceed 25b or $100b^2/d$ whichever is less.

Other detailing Requirement of Beam

- Usually same size of beam is used for different spans to use same size of formwork from practical considerations
- Keep the beam width adequate to accommodate all bars with sufficient gaps and covers between rebars.
- at least two bars to be used as tension steel.
- dia of hanger bar not less than 10 mm. Dia of main tension bar not less than 12 mm. Dia used are 10, 12, 16, 20, 22, 25 and 32 mm.
- when using different sized bars in one layer, place the largest size bar near the beam faces. The areas of steel should be symmetrical about the centre line of the beam.
- The width of beam necessary to accommodate the required number of bars will depend upon the specification of the cover and minimum spacing between bars. The max. size of aggregate used is normally 20 mm and hence clear minimum distance between bars should be 25 mm.

Preliminary Column Sizing

- Approximate size may be calculated on the basis of axial load calculated from tributary area and then applying multiplication factor for possible bending moments.
- Dimension should be sufficient to accommodate beam within column rebars.

Column Size Approximation

Approximate Column Sizes

- equivalent Direct Load

  = K*Load based on static reactions

Position	Value of K		
	Top	Next to Top	Lower
Interior	1.0	1.0	1.0
Side	4.5	2.0	1.4
Corner	6.0	2.3	1.8

THANK YOU!