Structural Design
~~Of~~ of
Multi-Storeyed Buildings

~~Second~~ Third Edition

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1 Introduction

1.1. Need ~~Of~~ of Multi-Storeyed Buildings

Most of the existing buildings are multi-storeyed, in the sense that "multi-storey" means more than one storey. Single storey buildings may comprise of workshops, factory sheds, cinema halls, auditorium, etc. Even ordinary residences can be thought of as multi-storeyed buildings as presently ordinary residences are allowed to be built of two and a half storeys. With increasing pressure of population, commerce and trade, land costs in cities have risen very high. Often, there is no other alternative except building high on a given plot of land. Educational and commercial buildings are, in general, eight storeys high with lifts provided. Without lifts, a building has to be less than or equal to four storeys in Delhi, but not more than five storeys in Bombay. b/ These restrictions are imposed by the city bye-laws, keeping in view the pressure on the services like roads, water, electricity and sewage disposal. Some buildings are made extra ordinarily tall out of prestige. For example, Delhi Development Authoritys 's Vikas Minar is a 23-storey tower, while Hansalaya at Barakhamba Road in New Delhi, is a 22-storey building. ?Urban Arts Commission is one of the agencies which control the building height or the number of storeys of buildings in Delhi and New Delhi. Similar controls are exercised in all major cities in India.

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1.2. Structural Materials For Buildings

Traditionally, buildings have been built in brick (or stone) and mortar and also in timber in certain areas, where wood was available in plenty. Presently, wood has become scarce and prohibitively costly. Small buildings, particularly residences, are ideally built with load bearing brick walls. The horizontal members like slabs are built in reinforced concrete. In certain areas, brick walls may be replaced by random stone masonry walls, but these occupy more space in plan. Brick walls are, in general, 230 mm thick in plan, while stone walls may be 300 mm to 450 mm thick in plan. Concrete blocks, hollow or solid, are also available in the market, but these have not caught on for certain practical reasons, like difficulty in making notches for electrical conduits, etc. In framed buildings, structural steel and reinforced concrete are the two alternative materials. Structural steel frames were previously used in Calcutta area for multi-storeyed buildings. But now, for reasons of economy, reinforced concrete has replaced structural steel in the construction of multi-storeyed buildings of medium height. With the introduction of shear walls and shear cores, reinforced concrete systems are working out well for tall buildings as well. Further, a reinforced concrete structure has better fire resistance than that of a steel structure. So, in the present scene, brick and reinforced concrete are the two most prevalent structural materials in building construction.

pre-stressed?

1.3. Load

1.3.1. Vertical Loads

Structurally speaking, buildings are built to support loads. The load, which is ever present and ever acting on a building, is the dead load which consists of the self-weight of members, finishes, plaster, etc. Dead load should be calculated very accurately, as it

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comprises most of the building load. IS: 1911 − ~~1967^{1*}~~ gives a schedule of unit weights of building materials and it is used extensively to calculate the dead load.

imposed

Next in importance to dead load, is the live load, which is caused by the use of building. Live loads are given in IS:875. part 2 1987 Amendment 1 2 Live loads are generally high (150 Kg/$m^2$to 1000 Kg/m^2) on floors depending on the activity that is carried on there, while it is of a low value (75 Kg/$m^2$to 150 Kg/m^2) on a roof, which may or may not be accessible. Snow loads on roofs in hilly areas are also specified in IS:875. part 4 1987 In snow-incident areas, roofs are to be made sloping so that snow cannot get accumulated to a great height. IS:875 gives the loading due to snow at 2.5 Kg/m^2per cm depth of snow. With 30 cm 300 mm snow depth, the snow loading will work out to be 75 Kg/m^2, which may be reasonable for sloping roofs.

kN/m^2

Partition loads are also important to be considered. Wooden or similar light-weight partitions anywhere on a floor give a general loading of 100 Kg/m^2 font? of floor area. But in most buildings, 115 mm thick brick walls are arranged to divide space, this gives a heavier loading on the floor. IS:/b 875 -part 1 or 2? 2 gives the partition walls loading at one-third the weight of 1.0 m run of the partition wall. For 115 mm thick brick walls of 3.0 m height anywhere, the equivalent loading works out to be (0.115 ×1.0 ×3.0 ×1900)/3 = 218.5 Kg/$m^2$of the floor area. For 230 mm thick brick walls, we generally take care to provide beams to support directly such walls. In multi-storeyed buildings, 115 mm t hick brick walls anywhere add substantially to the load of the building and it affects the design of slabs, beams, columns and footings too. But in the present practice, for flexibility in the use of the building, this provision is made in most buildings and wherever possible, 115 mm thick brick walls should be replaced by wooden partitions to achieve lighter partition loading, which finally leads to economy in structural design. In practice, wooden partitions are provided in office buildings, while in hospitals and institutional buildings , 115mm thick brick walls arc used as partition walls.

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1.3.2. Temperature and Shrinkage Loading

degree in LaTeX?

reference 3

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Temperature and shrinkage also act on a building and these can also be regarded as a load on it. Shrinkage is equivalent to -15^0C, where negative stands for fall of temperature.3 The temperature differential is taken a $\pm\frac{2}{3}(t_1 - t_2)$, where t_1 and t_2 are the maximum and the minimum temperatures observed in a day (24 hours) for a given place or locality.(4) Fall of temperature together with shrinkage will govern the design, while the rise of temperature will be substantially reduced in effect by the action of shrinkage. The design temperature differential is given by the Indian Road Congress(5) at $\pm 17^0C$ for moderate climates and at $\pm 25^0C$ for extreme climates. The combined effect of temperature and shrinkage is given below:

$$\begin{array}{r} \text{For moderate climates : } \pm\ 17\ \text{-}\ 15 = +2\ \text{-}\ 32\ ({}^0C) \\ \text{For extreme climates : } \pm\ 17\ \text{-}\ 15 = +2\ \text{-}\ 32\ ({}^0C) \end{array}$$

-32 to 2
-40 to 10

2000 (6) (8)

IS:456 1978 (hereafter called simply the Code) states in its clause number 17.5.1 that "in ordinary buildings, effect due to temperature fluctuations and shrinkage and creep can be ignored in the design calculations". It is, however, not explained, what is meant by an ordinary building.(7?) It is, of course, clear that temperature and shrinkage loading has an effect on the design of long concrete buildings H which can be neglected if the length of building is restricted to 45 m (clause 20.3 of the Code). Thus, it can be surmised that temperature and shrinkage effect can be neglected in short length buildings. It is also seen that by providing minimum specified steel percentages in concrete members, temperature and shrinkage effects can be absorbed in short length buildings, while in long concrete buildings, these members have to be designed for this extra loading or a long building has to be cut up in two or more short length buildings. Further, this loading can be made use of in the evaluation of the gap of an expansion joint.

1.3.3. Wind Loading

Dead and imposed live loads are vertical or gravity loads, while wind and earthquake cause horizontal loads on a building. Temperature and shrinkage also result in a horizontal load on a building. Blast effects, earth and water pressures also cause horizontal loads on a structure. IS:875 /b part 3 gives values of wind pressures varying from 100 Kg/m^2 to 200 Kg/m^2 acting on building upto a height of 30m above the mean retarding surface, i.e. the mean level of the adjoining ground. For buildings of height upto 10.0 m, these wind pressure values can be reduced by 25%.

1.3.4. Earthquake Loading

Details of earthquake loading are given in IS:1893. year? India has been divided into five zones with basic horizontal seismic coefficient (α_0) varying from 0.01 to 0.08. The base shear (kb) V_B is given by

$$V_B = C\alpha_h KW \tag{1.1}$$

C = efficient defining the flexibility of structure, which depends on the time period of the building, which in turn, is a function of number of storeys

α_h = design seismic cofficent $= \dfrac{\beta}{\alpha_0}$

K = performance factor which is equal to unity for reinforced concrete framed building with detailing taking into account the requirements of ductility

W = total dead load g + appropriate amount of live load (25% to 50% LL)

P = coefficient depending on the soil-foundation system (varying from 1.0 to 1.5)

I = coefficient depending upon the importance of structure varying from 1.0 to 1.5 for buildings.

α_0 = basic horizontal seismic coefficient depending upon the zone in which the locality in question falls.

$$= \frac{a}{g} = \frac{\text{design acceleration in horizontal direction due to earthquake}}{\text{accleration due to gravity}}$$

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The vertical basic seismic coefficient is half the value of α_0 It has, in general,no effect on the structural design of buildings. All buildings, whether short ortall, shall be checked for horizontal effect of earthquake loading.

1.3.5. Blast Loading

In certain coal mine areas, where open cast methods of mining are used, blast is of regular occurrence. Buildings in these areas must be designed for blast effects. IS:6922 -1973 underground gives the blast effects

$$\frac{a}{g} = \frac{\text{design acceleration in horizontal direction due to earthquake}}{\text{acceleration due to gravity}}$$

$$= K_2 \frac{Q^{0.83}}{R^2} \qquad \textbf{(1.2)}$$

$where,\ K_2 = 4$

$Q =$ charge per delay in Kg.

$R =$ distance of structure from blast point in meters.

α_0

The calculated a/g value for blast may be taken as a fraction of earthquake effect given by Uo. The building can be analysed for, say, earthquake and the the blast effect can he evaluated by applying this fraction on the values obtained from the earthquake analysis. For a locality with α_0 = 0.04, Q = 20,000 kg, R1200 m. (Eq.3.1) gives,

=

$$\left(\frac{a}{g}\right)_{blast} = 4 \times \frac{(20,000)^{0.85}}{(1200^2)} = 0.01$$

This indicates that the blust effect is equivalent to (.01)/(.04) = .25, i.e. one-fourth the earthquake effect, in this particular case.

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1.3.6. Impact

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Live loads given in IS:K75 include the effect of impact and this is clearly mentioned in clause 3.1.1 of this code. But for a moving machinery, these loads should be increased

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by an allowance varying from 20% to 100%, as per clause 3.4. In a lift machine room above the roof of a multi-storeyed building, we generally consider a live loud of 1000 Kg/m^2together with an impact allowance of 100%, giving a loud of 2000 Kg/m^2.

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1.3.7. Earth and Water Pressures and Surcharge Load

Fig.

These loads act on a retaining wall. In 1.1, a basement retaining wall is shown under the action of these loads. The base pressures acting on a retaining wall are given as under

$$
\begin{aligned}
p_e &= \text{earth pressure} = \frac{1-\sin\phi}{1-\sin\phi}\gamma h && \textbf{(1.3)}\\
p_w &= \text{water pressure} = wh^{'} && \textbf{(1.4)}\\
p_s &= \text{surcharge pressure} = \frac{1-\sin\phi}{1-\sin\phi}w_s && \textbf{(1.5)}\\
where, \phi &= \text{angle of repose of earth}\\
\gamma &= \text{unit weight of earth}\\
w &= \text{unit weight of water}\\
w_s &= \text{surcharge loading} = 500kg/m^2\text{for pedestrain traffic}\\
&= 1000kg/m^2\text{for vehicular traffic}\\
h &= \text{height of the earth retained}\\
h^{'} &= \text{height of the subsoil water retained}
\end{aligned}
$$

/b ian

1.3.8. Load Combinations

The load which is ever acting on a structure is the dead load which includes the load of partitions also. Then the effect of live load, which may vary in intensity from 0 to 100% of its value, is additive to the effect of the dead load, as both these loads are gravity or

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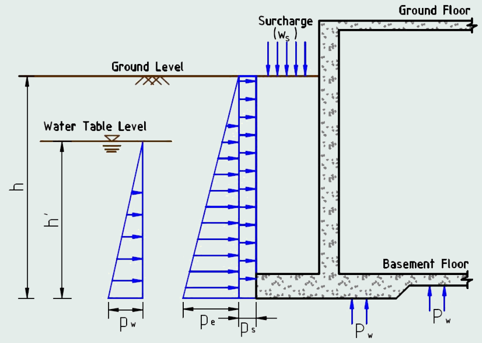

Figure 1.1: Pressures on a basement retaining wall

vertical loads. So, the structures should be designed by the limit state method for the dead and live load combination and it is given by the Code as

$$U = 1.5\,(D + L) \tag{1.6}$$

Then, horizontal loads of wind, earthquake and temperature will act on the building. It is assumed that the worst effects of the above three loadings will not coexist at the same time. Further, it is assumed that the worst effects of these loadings will act only for a short while on a building so that its load factor can be reduced by 25% (or allowable stresses in materials are increased by 33.33% in the working stress method, resulting in the same effect). Hence, the next load combination for checking the structure is given by the Code,

$$U = \overset{1.2}{1.5}\,(D + L \pm W or E or T) \tag{1.7}$$

where the value of 1.2 is derived from 0.75 ×1.5 = 1.125 or 1.2 and ± sign is added to take care of the reversal of direction of horizontal loads. For checking overturning of certain isolated tall structures, live load in equation 1.7 may be made zero and 10% reduction may be made in the dead load to account for any inaccuracy in the calculation of the dead load. This will give the following load combination lot for isolated tall structures,

$$U = 1.2\,(0.9D + W or E or T) \qquad \textbf{(1.8)}$$

For inclusion of the blast effect in structural design, we consider a load /b factor of 1 5 1.5 for blast loading, as it occurs frequently in the open-cast mining areas.So, for such areas, the governing load combination, in addition to those given above, is also,

$$U = 1.5\,(D + L or B) \qquad \textbf{(1.9)}$$

Also, ii it is assumed that the worst effect of blast will not take place together with the worst effects of earthquake or wind or temperature. The notation in Eq: 1.7 to 1.9 is explained below

$$\begin{aligned} U &= unlimitedload \\ D &= deadlove \\ L &= liveload \\ W &= windload \\ E &= earthquakeload \\ T &= temperatureandshrinkageload \\ B &= blastload \end{aligned}$$

The above write up is our explanation of Table 12 of the Code, which gives the relevant load combinations for structural design. The reader may take note of the changes called for in Table 12 of the Code, in the light of above explanation.

1.4. Building - A Result Of Combined Efforts Of Several Professionals

A client is one who has the necessary motivation and capital to make a building either for his own use or for sale. He engages an architect to prepare an architectural scheme and drawings and get these approved from the local municipal authority and these drawings

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form the basis on which the other professionals like structural, estimating, plumbing, electrical and air conditioning engineers work to prepare their own drawings and estimates. An architect is primarily concerned with the function and the area utilization of building. It takes care of the visual look of the building, its orientation and its position in the promulgation area. The structural engineer is to take care of the safety of the structure and he is to devise ways to support all the loads coming on the building in the most economical way. He is concerned with the design of both the superstructure and the sub-structure (i.e. foundations). A structural engineer is called upon, at an early stage, to work in close collaboration with the architect, to decide the structural grid and the sizes of structural members. An estimating civil engineer is also associated to prepare estimates and tender documents. After the tenders are called, these are compared and the client awards the work of construction of building to a contractor selected from the tenderer.

The role of the contractor and his engineers is of paramount importance in the construction of building. They have to ensure that the work at the site is carried out in accordance with the working drawings of the architect, the structural and other professional engineers. To supervise the work of the contractor, a separate agency or an individual (called clerk of works) is appointed, who coordinates the work of the. several agencies at the site and ensures quality and timely completion of work at the site. The author has the highest regard for the work of contractors site engineer, as he has to construct the building from both the architectural and the structural drawings. In cast-in-situ construction, there may remain, in practice, some gaps in these two sets of drawings and the site engineer, with the help of the clerk of works, closes up these gaps, reconciles these differences and gets the building constructed. The best site engineer is one who consults the architectural and the structural staff and with proper coordination, completes the building in accordance with the drawings. There are some site engineers who arrogate to themselves the powers of the design staff and these engineers, sooner or later, come to grief.

In some unusual structures, specialists or academic staff may be required to be associated with the structural design for consultation and/or checking as per the need.

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