# Earthquake Resistance and Design of Buildings

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**Abstract—** The abstract of the project is to structurally analyze and design an earthquake resistant multistoreyed building. During the execution of the project, we have acquired knowledge and skill to emphasis on practical application besides the utilization of analytical methods and design approaches, exposure and application of various available codes of practices. In the present context, in a developing city like Kathmandu, there is land crisis due to increasing population so as an engineer it will be challenging for us to minimize it. This can be solved upto some extent by designing/constructing high rise multistoreyd building for commercial, residential purposes, etc. Also our country lies in an earthquake prone area which may lead to loss of life and property which can be counteracted by seismic design of building

Keywords- Earthquake, Buildings, Resistance

## I. INTRODUCTION

One of the basic needs of a human being is shelter. Shelter being defined as a place giving temporary protection from bad weather or, danger. Long time ago people lived in temporary shelters as in caves. Later they built temporary shelters made from trees and bushes. With the evolution of humans, they started to build permanent houses consisted of masonry structures i.e. mud, stones, timber, straw, dongs etc. but these houses were not stable enough. As time passed and new methods of constructed were introduced humans started to build more stable and stronger houses for shelter. With the present context, just building houses is not enough. There is less space available for construction but the population is increasing day by day. Moreover, in Nepal's capital the land price has been hiked to a limit which cannot be afford to build residential houses for a small family. As the land available is less and the available land is overpriced the construction has to be carried out vertically instead of lateral expansion. This has mostly led to the constructions of high rise multistoreyed buildings in Kathmandu. Also with the occurrence of the recent Gorkha Earthquake occurred in 25th April, 2015 at 11:56:26 NST, it has added an extra attention in the design of a structure. The violent shaking occurred with a magnitude of 7.8 Richter with its focal point located 8.2 km downward with Mercalli intensity of grade IX. The total damage was estimated to be $5 billion with total deaths to be 8,959 with 23,447 casualties. Hundreds of thousands of people were made homeless with entire villages flattened, across many districts of the country. Centuries-old buildings were destroyed at UNESCO World Heritage sites in the Kathmandu Valley. The earthquake has created awareness among the people about the seismic effect on the structure, its unique loading patterns, bearing capacity of the subsurface and other effects like wind, storey drift for the seismic design and analysis of multistoreyed buildings. The building associated with out project lies in Kathmandu valley which is allocated as seismic zone "V" according to its seismic severity. In the context of Kathmandu, here the earthquake load dominates the wind load and governs the lateral design loading. This project has been undertaken as a partial requirement for B.E. degree in Civil Engineering. This project contains structural analysis, design and detailing of residential building located in Kathmandu district. All the theoretical knowledge of analysis and design acquired on the course work are utilized with the practical application.

## II. METHODOLOGY

Each building has its own purposes and importance. Basically, buildings were constructed based on client requirement, geographical condition of the site, safety, privacy, available facilities, etc. and designed as:

**Planning Phase:** Planning of building is grouping and arrangement of different component of a building so as to form a homogenous body which can meet all its function and purposes. Proper orientation, safety, healthy, beautiful and economic construction are the main target of building planning. It is done based on the following criteria:

**Functional Planning:**

- Client requirement is the main governing factor for the allocation of space required which is based upon its purposes. Thus, demand, economic status and taste of owner features the plan of building.
- Building design should favor with the surrounding structures and weather.
- Building is designed remaining within the periphery of building codes, municipal bylaws and guidelines.

**Structural Planning:** The structural arrangement of building is chosen so as to make it efficient in resisting vertical and horizontal load. The material of the structure for construction should be chosen in such a way that the total weight of structure will be reduced so that the structure will gain less inertial force (caused during earthquake). The regular geometrical shape building is designed as an earthquake resistant structure based on IS1893 (part1):2002.

**Load Assessment:** Once the detailed architectural drawing of building is drawn, the building subjected to different loads is found out and the calculation of load is done. The loads on building are categorized as below:

**Gravity load:** This includes the self-weight of the building such as structural weight, floor finish, partition wall, other household appliances, etc. To assess these loads, the materials to be used are chosen and their weights are determined based on Indian standard code of practice for design loads (other than earthquake) for buildings and structures: i. IS 875 (part I):1987 Dead Loads ii. IS 875 (part II):1987 Imposed Loads

**Lateral load**: Lateral load includes wind load and earthquake load. Wind load acts on roof truss while an earthquake act over the entire structure. Wind load calculation is based on IS 875 (part III):1987 and earthquake on IS 1893 (part I):2002. The dominant load is taken into consideration for design.

**Load Combination**: Combination of different loads is based on IS 875 (part V):1987 Load combinations.

**Preliminary Design:** Before proceeding for load calculation, Preliminary size of slabs, beams and columns and the type of material used are decided. Preliminary Design of structural member is based on the IS Code provisions for slab, beam, column, wall, staircase and footing of serviceability criteria for deflection control and failure criteria in critical stresses arising in the sections at ultimate limit state i.e. Axial loads in the columns, Flexural loads in slab and beams, etc. Appropriate sizing is done with consideration to the fact that the preliminary design based on gravity loads is required to resist the lateral loads acting on the structure. Normally preliminary size will be decided considering following points:

Slab: The thickness of the slab is decided on the basis of span/d ratio assuming appropriate modification factor.

Beam: Generally, width is taken as that of wall i.e. 230 or 300 mm. The depth is generally taken as 1/12-1/15 of the span.

Column: Size of column depends upon the moments from the both direction and the axial load. Preliminary Column size may be finalized by approximately calculation of axial load and moments.

## III. DESIGN AND DETAILING

**Limit State Method of Design for Reinforced Concrete Structures:** Design of Reinforced Concrete Members is done based on the limit state method of design following IS 456:2000 as the code of practice. The basic philosophy of design is that the structure is designed for strength at the ultimate limit state of collapse and for performance at limit state of serviceability. A check for these two limit states is done based on code of practice to achieve safe, economic and efficient design

**Working Stress Method of Design for Steel Truss Member:** The design philosophy of working stress method of design is to use working loads at service state and design the members to perform at characteristic loads with minimum factor of safety in material strength. This approach makes the design conservative and deterministic and quite obsolete compared to more logical Limit State Method of Design. Hence by using different philosophy, the design of beam, column, footing, staircase and other structural component are done.

## IV. LOAD ASSESSMENT AND PRELIMINARY DESIGN

The preliminary sizing of structural elements was carried out based on deflection control criteria and approximate loads obtained using the tributary area method. The gravity loads on the structural elements are taken as per IS 875 Part I (dead loads) and IS 875 Part II (imposed loads). The unit weights of materials taken for the calculation of dead load of the structure are as follows.

| S.N. | Material Used | Unit Weight | Type of Member |
|---|---|---|---|
| 1. | Cement Concrete for RCC | 25kN/m$^3$ | Beams, Columns, Slabs. |
| 2. | Common Burnt Clay Bricks | 20kN/m$^3$ | Infill & Partition Walls |
| 3. | Screed on floor 25mm | 20kN/m$^3$ | All flooring spaces |
| 4. | Finishing in step 30 mm | 20kN/m$^3$ | All flooring spaces |
| 5. | Floor finishing | 1.5 kN/m$^2$ | Load on Slab |

The imposed load on the floors and roof has been taken as follows.

| S.N. | Live Loads on Specified Spaces | Intensity of Load | Member Loaded |
|---|---|---|---|
| 1. | All rooms and kitchens | 2.0 kN/m$^2$ | Live loads from building are acted on floor slabs, roof slabs and staircase slab. |
| 2. | Toilet and bath rooms | 2 kN/m$^2$ | |
| 3. | Corridors, passages, staircases including tire escapes and store Rooms | 3 kN/m$^2$ | |

Preliminary Sizing of Slab The depth of slab is obtained from deflection control criteria. L/d = 32 for continuous two-way slab Or, d = L/32 = 4114.8 / 32=128.58mm Where, L = Longest Shorter span of all slabs=4114.8mm Adopt d = 125mm and D=150 mm with clear cover of 25mm. Load Intensity on Slab Self-weight = 25 * 0.150 = 3.75 kN/m2 Imposed live load = 2kN/m2 (for rooms, kitchens, toilet and bathrooms) = 3Kn/m2 (for corridors, passages, staircases, store rooms) Floor finish = 1.5 kN/m2 Total load intensity = 7.25 kN/m2 (for rooms, kitchens, toilet and bathrooms) = 8.25 KN/m2 (for corridors, passages, staircases, store rooms)

Preliminary Sizing of Beam Length of longest beam = 16'-6" = 5029.2mm Deflection Control For deflection control, as per IS456:2000, Clause 23.2.1, L/d ≤ αβγδλ Where, L = length of beam = 5029.2 mm d = Effective depth of the beam α = 26 for continuous beams β = 1 for spans below 10m γ = 0.8 (assuming the tensile steel percentage as 1.2%) δ = 1 for no compression steel λ = 1 for no flanged beams

Substituting, we get d = 242 mm Adopt d=300 mm and D=325 mm with clear cover 25mm. Adopt b=230mm

## V. IDEALIZATION OF STRUCTURE

Idealization of structure can be defined as the introduction of necessary constraints/restraints in the real structure as postulates to conform the design of this structure within the domain of available theories assuring required degree of performance to some probabilistic measure. This type of idealization helps us constrain infinite number of design variables to those that we can address properly with the available design philosophies. In design of RCC structures, chiefly two idealizations are employed namely: 1. Idealization of Load 2. Idealization of Structure Idealization of load has been dealt in detail in the previous chapter with necessary load diagrams. The idealization of utmost importance however, is the idealization of structure. This idealization imposes restraints/constraints to those variables which we are unable to address properly otherwise. Imploring the details of these idealizations, we need to start at the elemental level. Thus, we process with idealization of supports, slab elements, staircase element, beam and column element and the entire structural system.

**Idealization of Supports**: In general, idealization of support deals with the assessment of fixity of structure at the foundation level. In more details terms, this idealization is adopted to assess the stiffness of soil bearing strata supporting the foundation. Although the stiffness of soil is finite in reality and elastic foundation design principles address this property to some extent, out adoption of rigid foundation overlooks it. Elastic property of soil is addressed by parameters like Modulus of Elasticity, Modulus of Subgrade reaction, etc. addressing all these parameters are beyond the scope of this project. This is where idealization comes into play, equipping us with the simplified theory of rigid foundation in soil. As we have designed mat foundation as substructure, idealizations for RCC framed structure supported over the mat are used. The figure below explains the idealization of fixity of support for framed structure. This idealization is used in defining the fixed support of or building frame for modeling and analysis. For buildings with basement walls or underground storey, the idealization depends upon the connection of basement wall with the superstructure.

**Idealization of Slab:** Idealization of slab element is done in earthquake resistant design to perform as a rigid floor diaphragm. This idealization is done for slab to behave as a thin shell element subjected to out-of-plane bending only under the action of gravity loads. Due to infinite in-plane stiffness of the shell element, lateral loads are not taken by the floor slab and hence resisted completely by the columns. Idealization of slab element to thin plate member would have subjected the slab to behave as Kirchhoff’s plate inducing out-of-plane bending which is beyond our scope at Bachelor’s Level of Civil Engineering. Hence such an idealized slab is then modeled in SAP2000 program for analysis.

**Idealization of Staircase:** Open-well staircase used in the building is idealized to behave as a simply supported slab in case of upper and lower flights and also in case of intermediate flight. Detailing rules are then followed to address the negative bending moment that are induced on the joint of going and top flight in the staircase, the rigorous analysis of which is beyond our scope. Staircase being an area element is also assumed not to be a part of the integral load bearing frame structure. The loads from staircase are transferred to the supports as vertical reactions and moments.

**Idealization of Beam and Columns:** Beam Column idealization is one of the most critical aspects of structural idealization to achieve the desired behavior of the overall integrated structure. Beams and columns are idealized to behave as linear elements in 3D. Beam column joints in the structural planning are assumed to behave as perfectly rigid joints. In reality, perfect rigid joints do not exist. Effects of partial fixity can be addressed in modeling by rigorous analysis of sectional and material properties, which is beyond the limits of this project. Assumptions of rigid joints are also found to perform well in nature seen from years of practice. Another idealization is addressing the section of main beam as rectangular in shape despite being integrally connected with the slabs. The flange portions of these beams when subjected to reversal of loading during earthquakes become ineffective in taking the tension induced in them and hence we ignore their contribution in design. E. Idealization of the Structural System After idealizing individual elements, we idealize the structural system in its entirety to behave as your theoretical approximation for first order linear analysis and corresponding design. The building is idealized as unbraced space frame. This 3D space framework is modeled in the SAP2000 for analysis. Loads are modeled into the structure in several load cases and load combinations defined in the next section. The idealization of structure as 2D plane frame connected by links as shown in figure is used for lateral load analysis.

**Design of Beam:** Beams are structural members assigned to transmit the loads from slab to the column through it. Specially, flexure is more dominant than shear in the beam. There are three types of reinforced concrete beams: 1. Singly reinforced beams 2. Doubly reinforced beams 3. Singly or doubly reinforced flanged beams In singly reinforced simply supported beams, reinforcements are placed at the bottom of the beam whereas on top in case of cantilever beams. A doubly reinforced concrete beam is reinforced in both compression and tension regions. The necessity of using steel in compression region arises when depth of the section is restricted due to functional or aesthetic requirements. A complete design of beam involves consideration of safety under ultimate limit state in flexure, shear, torsion and bond as well as consideration of serviceability limit states of deflection, crack width, durability etc. Basically, two types of works are performed namely, analysis of section and design of section. In the analysis of a section, it is required to determine the moment of resistance knowing the cross section and reinforcement details.in the design of sections, it is required to determine the cross section and amount of reinforcement knowing the factored design loads.

## VI. CONCLUSION

The fact that Nepal lies in a hotspot for tectonic activities is a big factor to be accounted for in the design of any structure that aims to be safe, durable and serviceable. In this regard, the details of the structure we have designed for use as a residential apartment building, to the best of our team's knowledge, incorporate the required precautionary measures that allow it to overcome the perils that come with being situated in an earthquake prone zone along with the regular gravity loads that are expected in such a structure. Hence, we as the students of Civil Engineering hope that this project meets the expectations of our respected supervisor and the rest of our teachers to whom we owe the sum total of our knowledge in this subject.

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