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Flood Resistant Building Design in High Intensity Seismic Zone

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Abstract

Floods and earthquakes are among the most destructive natural hazards, and their combined effects significantly threaten the safety and durability of structures in high-risk regions. This study focuses on the design and analysis of a flood-resistant reinforced concrete (RC) residential building situated in a high seismic intensity zone of Kathmandu, Nepal. The research aims to integrate flood-induced forces—hydrostatic, hydrodynamic, and impact loads—alongside seismic loads within the structural design process to enhance multi-hazard resilience. A G+5 RC building model was developed and analysed using CSI ETABS 2022 in accordance with IS 456:2000, IS 1893 (Part 1):2016, and ASCE 7-2002 standards. The analysis incorporated realistic site parameters, including a 2.5 m flood level and Zone V seismic conditions. Comparative evaluation between conventional and flood-resistant models revealed that the inclusion of flood loads resulted in improved structural stability, reduced deformation, and enhanced foundation performance under extreme scenarios. The findings underscore the necessity of integrating flood load considerations into building codes and design practices for flood-prone and seismically active regions. This research contributes to sustainable, safe, and resilient urban infrastructure development through the adoption of multi-hazard design approaches.

Keywords: *Flood Resistant Design, High Seismic Intensity Zone, Multi- hazard Resilience, Reinforced Concrete (RC) Building, Structural Analysis.*

1. Introduction

The capital, Kathmandu, is extremely prone to earthquake and flood disasters based on its special geography, urbanization, and seismically active environment. The city lies in a bowl-shaped valley surrounded by the Himalayas and is underlain by extensive alluvial sediments that increase ground shaking during earthquakes. The Main Himalayan Thrust, one of the global hotspots for tectonic activity, passes near the area, and thus big-magnitude earthquakes are unavoidable. Two major events in the past established Kathmandu's disaster profile as per historical records: the 1934 Nepal earthquake (Mw ~8.0) and the 2015 Gorkha earthquake (Mw ~7.8). These two resulted in widespread structural damage, thousands of deaths, and extended socio-economic disruption. These occurrences highlight the ongoing seismic hazard and the necessity of earthquake-resistant structures. In addition to seismic risk, Kathmandu is subject to periodic monsoon floods. The tributaries and the Bagmati River itself regularly overflow during heavy rain, and uncontrolled urban expansion, land occupation of natural floodplains, and poor drainage infrastructure contribute to flooding. Major floods in 2019 and 2024 inundated major urban zones, affected transport and water supply infrastructure, and displaced thousands of city dwellers. Climate change is amplifying these hazards by raising the frequency of high-intensity rainfall events and modifying river flow regimes. This project responds to the twin threat of flood and earthquake risk in Kathmandu through the examination of historical data, determination of risk factors, and recommendation of engineering and planning interventions for disaster-resilient infrastructure. By using combined hazard assessment, structural design interventions, and community-based preparedness actions, the study hopes to contribute to safer urban growth. The outcomes are to inform policy makers, engineers, and local stakeholders in addressing vulnerability and making the city more resistant to subsequent natural disasters [1-3].

2. Motivation & Objectives of The Study

The following objectives will be achieved by studying the ‘Analysis & Design of Flood Resistant Building’

- Modelling and analysis of G+5 building.
- To study flood Load and evaluate flood load on the structure.
- Analyze building performance in different flood scenarios in addition with earthquake loads.
- Incorporate flood mitigation strategies in design.

3. Problem Statement

The problem objective is to address the vulnerability of RC buildings in Kathmandu’s high seismic and flood-prone zone by designing and analyzing flood-resistant structures with appropriate study of flood loads and load considerations in order to achieve safer, resilient, and stable buildings under combined hazards, Figure 1.

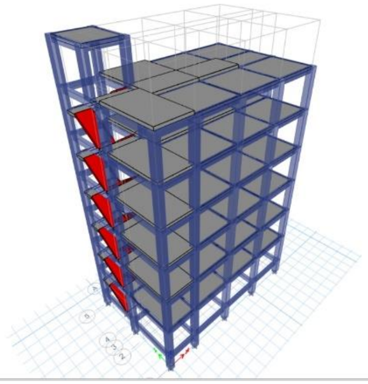

Figure 1 Typical 3D plan of G+10 RC Flat Surface Building.

The analysis and design of a flood-resistant residential structure was carried out using a systematic, software-based approach that incorporates modeling, simulation, and result interpretation. The project aims to study the structural performance of a G+5 storey residential building under flood loading conditions, including hydrodynamic forces. 456:2000, IS-3370, ASCE-7:2002 and relevant flood safety guidelines. In this study, the building is assumed to be located in the capital city of Nepal i.e. Kathmandu with medium soil type. The site-specific flood data, including expected water depth, flow velocity, and flood duration, are taken into account. The floor height is considered to be 3 m. The structure is modeled as a regular RC frame building with proper flood-resistant architectural measures such as raised plinth, minimum openings at ground level, and water-resistant material use in the lower portion. The site situated in the areas which is flood-prone and earthquake prone. The flood height in previous year record found to be 2.6 m from GL. The rainfall intensity of 2024 was 240 mm in 24 hours. The structural loads applied include dead loads, live loads, earthquake loads, flood-induced hydrodynamic loads wave loads and impact loads. Flood loads are manually calculated using ASCE-7-2002 and incorporated into the model using user-defined load combinations. The analysis is conducted to determine key performance parameters such as base shear, displacement, member forces, and support reactions, shown in Table 1 [4-7].

Table 1 Building Parameters

Floor height of building	3m
No. of bays in X direction	4
No. of bays in Y direction	3
Column size	400 mm X 450 mm
Beam size	250 mm X 350 mm
Slab thickness	150 mm
Total height of building	20.8 m above ground level
No of slab	6 Nos.
Walls (External and Internal)	230 mm &115 mm thick brick masonry walls

Ground beams	To be provided at 150 mm below G.L.
Material Properties	
Grade of Concrete	M25 for beam & M30 for column
Grade of Steel	Fe 500
Dead Load Intensities	
Lime mortar	0.041 kN/m^2
Plaster	0.49 kN/m^2
Tile load	0.2 kN/m^2
External wall load	11.489 kN/m
Plaster load on beam	0.734 kN/m
Internal wall load	6.244 kN/m
Live Load Intensities	
Live load	2 kN/m^2
Live load on staircase	3 kN/m2
Densities of the Material Used	
Density of Reinforced Concrete	25 kN/m^3
Density of Plain Concrete	24 kN/m^3
Density of Steel	78.5 kN/m^3

4. Need For the Research

The project is needed because Kathmandu lies in a high-risk zone where both floods and earthquakes can hit simultaneously, yet in the conventional design of buildings, the combined effects of such hazards are hardly considered. Ignoring flood-induced forces like hydrostatic, hydrodynamic, and impact loads creates major vulnerabilities in structural safety and performance. This research paper integrates seismic and flood loads into the design and analysis chain of an RC building, showing improvements regarding the stability, deformation control, and behavior of the foundation. Therefore, the project is relevant to ensure that multi-hazard-resilient design practices are promoted, safer urban development is supported, and it underlines the need to implement flood load considerations in building codes in countries prone to these extreme events, shown in Table 2.

5. Modelling

To compute the critical effect, the flood was assumed to act along the 8m side and has span of 13.4m. Two different models were put into modelling, namely

- ✓ DL + LL + EQ -X+EQ-Y+ WL
- ✓ DL + LL + FL (at 1m)
- ✓ DL + LL + FL (at 2m)
- ✓ DL + LL + FL (at 3m)

6. Flood Loads Calculation

6.1. Calculation of Hydrodynamic Forces (ASCE-7:2002)

dh = (Cd /2g) * V2
dh= Equivalent head due to low velocity flood flows (m). [Page-18]
Cd= Drag coefficient
V = velocity of flood water(m/s)
g = acceleration due to gravity

6.1.1. Drag Coefficient Cd by Calculating b/H

b= 7.2 m
b= width of building
H =1.3m
H = Flood Proofing Design Depth
b/H = 5.54 (since Cd value is less than 12)
Cd = 1.25
g = 9.81 m/s2
V= 2.9m/s
dh = 0.54
fdh = U w x dh x H x W
fdh = Equivalent hydrostatic force due to low velocity flood flows (KN/m).
Uw = Specific weight of water (9.8 KN/m3)
dh = Equivalent head
H = Flood proofing design depth (m)
W = width of the column.
W = 0.45 m

6.1.2. Calculations of Force due to Low Velocity Flood Flows

H = Flood Proofing Design Depth(m)
dh= Equivalent head due to low velocity flood flows

fdh = Uw x dh x H x W
€;

Table 2 Force due to Low Velocity Flood Flows

SL.NO.	H	dh	fdh	fdh acting at H/2
1	1.3	0.54	3.09	0.65
2	2.3	0.54	5.48	1.15
3	3.3	0.54	7.86	1.65

6.2. Calculation of Wave Load

Hb = 0.78 dS (page-19)
Hb = Breaking wave height
dS = Still water depth.
FD = Net wave force (KN).
CD = 2.25 (For Square Piles of Column)
D = Column diameter for circular section
D = 1.26 m
width of square section = 0.9 m

6.2.1. Calculations of Breaking Wave Load on Columns

Hb = 0.78(ds)
FD = 0.5U w x CD x D x Hb2
Still water depth from GL(m)

Table 3 Breaking Wave Load on Column

S.No	Hb	FD	Still water depth from GL
1	0.78	8.46	1
2	1.56	33.84	2
3	2.34	76.14	3

6.3. Calculation of Impact Load

Fi = W x V x CD x CB x CStr
Fi = Impact force (KN)
W = Weight of object (KN)
W = 5KN
V = Velocity of water = 2.9m/sec.
CD =Depth coefficient.
CB = Block coefficient.
CStr = Building structure coefficient.
Cstr = 0.8 (for RC and RM walls).
CD = 1; (flood depth > 5ft)
CB = 1; (flow path wider than 30 ft)
Fi = 11.6

6.3.1 Calculations of Resultant Force at Still Water Depth.

Resultant force (Fr) = FD + Fi (KN)

Table 4 Calculation of Impact Load

SL.NO	Resultant – Force (Fr)	Still Water depth from GL(m)
1	20.06	1
2	45.44	2
3	87.74	3

7. Analysis of Model

The procedure includes both linear static and linear dynamic analysis. In these methods, the seismic forces, load distribution along the building height, and resulting displacements are calculated using a linear elastic approach. The main steps involved in CSI-ETABS analysis are as follows, Figure 2:

- Modelling of frame sections.
- Defining and assigning material properties and section properties.
- Assigning support conditions.
- Defining and assigning load patterns and load cases.
- Assigning load combinations.
- Setting up of analysis option.
- Running analysis.
- Inferring the results.

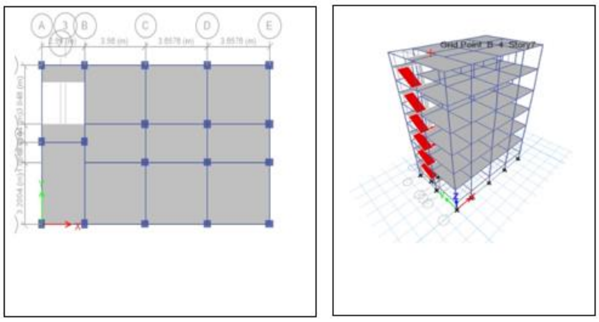

Figure 2 Plan and 3-D model for Regular Shape

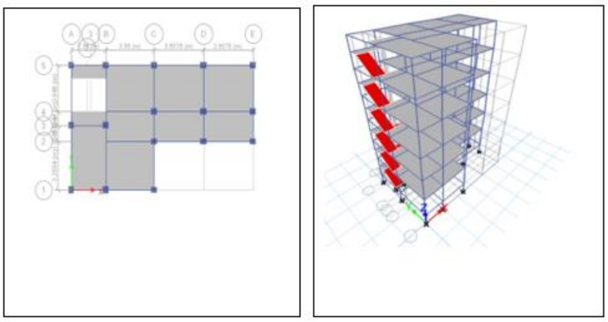

Figure 3 Plan and 3-D model for L-Shape

8. Result and Discussions

8.1. Bending Moment

From the analysis, we found out that regular building has more bending moment than L-shape building. The result shows that the B.M on regular building is greater by 6% to the B.M on L-shape.

Table 5 Comparing the Maximum Bending Moments.

Max. Bending Moment in KN-m	
MODEL	**MAX. BENDING MOMENT**
Regular Building with Flood & Earthquake loads	198.086 KN-m
L-shape Building with Flood & Earthquake loads	186.283 KN-m

8.2. Base Shear

Table 6 Comparing Base Shear Values

Base shear values in KN		
MODEL	**BASE SHEAR**	
	X– direction	**Y- direction**
Regular Building with Flood & Earthquake loads	1843.831 KN	1501.562 KN
L-shape Building with Flood & Earthquake loads	1515.319 KN	1234.00 KN

The base-shear comparison clearly shows that the regular building experiences the highest seismic demand, with a peak base shear of 1843.83 kN, indicating a more uniform and efficient transfer of earthquake forces to the foundation.In contrast, the L-shaped building exhibits slightly lower base shear in one direction, 1515.32 kN, and an even lower value, 1234 kN, in the other, reflecting how irregular geometry tends to distribute seismic forces unevenly and may cause torsional effects rather than purely translational resistance, shown in Table 3 to 6.

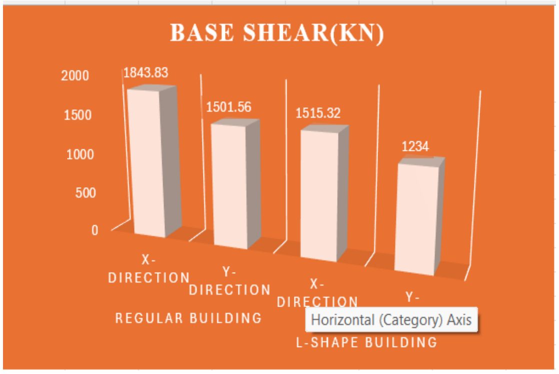

Figure 4 Comparing the Base Shear Values

The intermediate base-shear value of 1501.56 kN for the other case underlines the fact that irregular configurations generally attract less total base shear than regular buildings but often face greater structural vulnerability because of stress concentrations and uneven stiffness distribution, thus necessitating careful detailing and dynamic analysis for irregular structures.

8.3. Storey Displacement

The storey displacement comparison indicates that, under seismic loading, lateral displacements increase with height for both the regular and L-shaped buildings. This condition arises because of the flexible nature of the storeys located at higher elevations. From the displacement calculated for the regular building, slightly higher values can be seen for every storey: at Storey 1 it is 2.123 mm, while at the roof it is 83.033 mm. Displacement values of 1.946 mm at Storey 1 and 79.151 mm at roof level in the L-shaped building have been recorded. Although the general pattern of displacement is similar, marginally lower displacements within the L-shaped structure do not necessarily represent its good seismic performance. The results show that a regular building undergoes a slightly larger but more uniform deformation, while an irregular building, despite having a slightly lower peak displacement, requires careful evaluation of torsion, drift concentration, and stiffness irregularities, Figure 3 to 6.

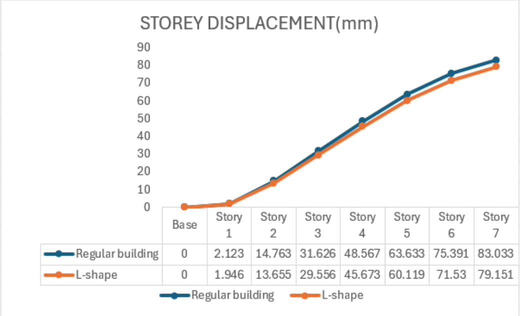

Figure 5 **Comparing the Storey Displacement Values**

8.4. Storey Drift

The storey-drift graph illustrates that both the regular and L-shape buildings follow a similar pattern in drift, which increases from the lower floors to attain peak drift around Storey 3–4.

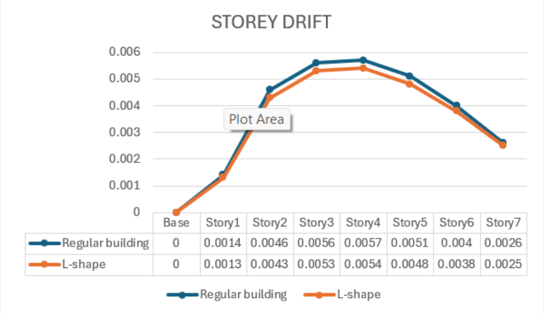

Figure 6 **Comparing the Storey Drift Values**

The regular building has slightly higher peak drift, about 0.0057, compared with the L-shape, suggesting a greater lateral deformation under seismic loading. Drift in both models gradually decreases toward the upper floors, showing a typical displacement profile in mid-rise buildings. Overall, even though the irregular L-shape structure attracts torsional effects, its drift values remain marginally lower than those of the regular building.

Conclusion

Based on the study the conclusions can be observed as follows:

- The building model was analyzed under various flood and seismic loading conditions using ETABS, where hydrostatic, hydrodynamic, wave and impact forces were applied along with earthquake loads. The analytical approach ensured that the combined effect of flood and seismic forces on the structure was accurately assessed.
- The comparison between regular and L-shaped plans showed that the regular building experienced 6% higher bending moments and also attracted higher base shear in both X and Y directions. This indicates that regular structures provide better load distribution, while irregular shapes require careful detailing due to torsional effects.
- The storey drift was higher in the regular model, with a peak value observed at about 0.0057, whereas in the L-shaped model, slightly lower drift was recorded. However, the irregular plan shape may still be responsible for concentration of drift and torsional rotation, making it more sensitive during seismic shaking.
- It was determined that the flood load effects—low-velocity hydrodynamic force, breaking wave pressure, and debris impact—showed a drastic rise with flood depth, thereby indicating that the essence of flood intensity, water velocity, and building geometry is quite vital in evolving structural response.
- The final outlook of the research work is that the design of high-rise or mid-rise structures in hazard-prone areas like Kathmandu should consider both flood and earthquake influences. Thus, flood depth, water velocity, seismic zone, and structural configuration must be considered

to provide a safe, resilient, and durable building designs

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