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Seismic Analysis of RC-Masonry Hybrid Residential Building

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Abstract: *Masonry structure is the oldest and popular mode of construction technology all over the world. During the seismic events, masonry buildings have shown their high vulnerability, RC frame elements have been introduced to improvement from seismic behavior, which transforms the original masonry into a combined RC-masonry structure. Since the 20th century in European, Mediterranean, southern American, and Asian countries including Nepal, combined RC-Masonry buildings have become more common. The hybrid structure suffered huge damage in major rural areas during the Gorkha earthquake. This paper describes the seismic analysis of RC-Masonry Hybrid residential buildings. Modeling of the building has been done in ETABS v18 software as per the Hybrid structure manual. As per the latest earthquake code IS1893:2016, the seismic analysis has been evaluated considering, story displacement, drift ratio, modal mass participation, fundamental period base shear, mass irregularity, and shell stress. From the analysis of the building, it is found that high-stress concentration at opening portion and the corner, hence recommended for seismic strengthening.*
Keywords: *RC-Masonry Hybrid Structure, Discontinuity of Structural System, Seismic Analysis.*

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I. INTRODUCTION

Masonry structure is the oldest and popular mode of construction technology all over the world, which has been constructed since the earliest day of civilization. For centuries, during seismic events, masonry buildings have shown their high vulnerability. For the improvement of the existing masonry structure from seismic behavior RC frame elements have been introduced transforming the original masonry into a combined RC-masonry structure. Since the 20th century, in European, Mediterranean, southern American, and Asian countries including Nepal combined RC-Masonry buildings have become more common.

Based on materials and structural load transfer methods buildings are classed as load-bearing masonry structures, reinforced concrete (RC), steel frame structures, and hybrid structures. Hybrid structures are known as structures featuring two or more separate lateral load-resisting systems. Hybrid structures might be conceived during the design process or as a result of changes or additions to existing structures (Gettu, 2012). Hybrid structures suffered huge damage in major rural areas during the Gorkha earthquake (NRA, 2017). As there is discontinuity, in both lateral and vertical load transfer mechanism the hybrid structure during the seismic response is different from other structural systems (Inderyas et al., 2019) i.e. lack of proper structural integration system, as a result, their behavior under seismic events is very critical. Even though today's modern computer software focused on modeling and analysis of tall buildings, bridges, and other major infrastructure to become earthquake-resistance structures, the study of the RC-Masonry hybrid building interaction effect is limited. The building model is analyzed as per the latest earthquake code IS 1893:2016. Base shear, top displacement, drift ratio at the different stories, and shell stress are presented from analysis results. It is found that stress concentration masonry shell at the opening of the building is higher than permissible value, hence recommended for seismic strengthening by applying horizontal and vertical bands at sill and lintel level, and using steel bar as post-tensioning material, which strengthened the brick masonry wall in their in-plane direction, allows masonry wall to dissipate energy against the lateral load.

II. LITERATURE REVIEW

Seismic analysis of RC-masonry Hybrid residential structure is the major objective of the research paper. Numerous research related RC-masonry hybrid structure was reviewed. The literature is mainly concerned with the modeling strategy of hybrid structure, material properties, seismic analysis method, software used, and code that has been followed during analysis. A few of them are discussed below.

1. (NRA, 2017) A hybrid structure (Mix structure) is a combination of two or more structural systems that are often built with various techniques and materials depending on the floor level. The hybrid structure is a huge demand in the rural village of Nepal during the Gorkha earthquake. As a result, creating a construction guideline, as well as suitable connection details and hybrid structural requirements, has become an essential effort to assure the safety of these buildings against earthquake and wind loads.
2. (Nardone et al., 2010) Despite the diffusion of RC-masonry combination building topology, the specific issues of this building typology are not exhaustive deal by international guidelines. For the study of interaction effects in combined RC-masonry buildings, the knowledge of numerical and experimental criteria is limited, despite the nonlinear analysis basis of masonry structures and RC frames being well-established.
3. (Gettu, 2012) Based on the materials and structural methods for load transfer buildings are classed as load-bearing masonry structures, reinforced concrete (RC), steel frame structures, and hybrid structures. Hybrid structures are known as structures that feature having two or more separate lateral load-resisting systems. Hybrid buildings might be conceived during the design process or as a result of renovations or additions to existing structures

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4. (Shrestha and Prajapati, 2015) The micro model produced somewhat better results than the macro model, but it took 10 times the resources. Physical testing included building displacement horizontally and vertically, as well as computational costs such as CPU time, storage, competency, human cost, and computer hardware. The comparison demonstrates that the macro model can predict a building's general response to ground movement.

III. METHODOLOGY

The effective and quick procedure to establish the actual structural layout and assess its characteristics that can affect its seismic vulnerability is done by preliminary evaluation. IS1893:2016 (Part 1) shall be used to compute the seismic base shear and stories shears for the building. It is a very approximate procedure to identify the potential risk of a building from the earthquake based on conservative parameters and can be used to screen for a detailed evaluation of buildings. Visual Assessment is a Collection of design and drawing, topographical information of the site, Site measurement of the main structural member, and Inspection of material used and it is quality.

Base Shear Calculations as per IS 1993(part1) (IS 1893 (Part 1), 2016)

Lateral load calculation, design base shear, fundamental period (Ta), and design horizontal seismic coefficient (Ah) can be found with the help of the following equation described in IS1893:2016 (part 1).

3.1 Building Details

The research is based on an analysis of a five-story residential building located at Bhaktapur. The building is constructed with a dual system i.e. RC-masonry combination. The building was located in seismic zone V, importance factor 1, and soil type medium. The plan of the building was 24.5ft*21ft. The total height of the structure is 35ft 8in. The floor height of the building was 7ft 6in. Site photographs were captured with mobile to prepare a plan, elevation, and section drawing in AutoCAD software which was further used in modeling software ETABS v1

Figure 1 Prototype Building at site

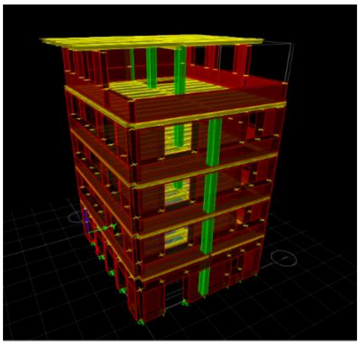
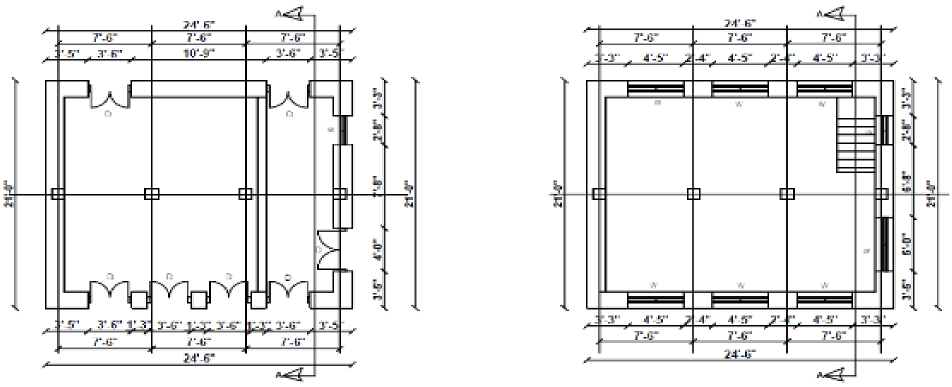


Figure 2 Modeling in ETABS



Ground Floor Plan **FIRST Floor Plan**

Figure 3 Plan of Building

SOUTH ELEVATION **EAST ELEVATION** **NORTH ELEVATION** **WEST ELEVATION**

Figure 4 Elevation View

3.2 The material properties for modal analysis.

For Brick masonry (IS 875 : 1987, 1989)
Unit weight of Brick masonry=18.85 KN/m^3
Unit weight of flooring = 14.7 KN/m^3
Unit weight of galvanized iron sheet= 81.875 KN/m^3
Concrete (IS 883:1994, 1994)
Concrete grade for beam, column= M20
Young's modulus (E_c) = 22360.67 N/mm2
Poisson's ratio = 0.2
Unit weight of concrete =25 KN/m^3
Timber (IS 883:1994, 1994)
Weight per unit volume (ϒ) = 8.05 KN/m^3
Modulus of elasticity (E) = 12600 N/mm^2

3.3 Building Modeling

The RC-masonry hybrid residential building chosen for study is modeled in Etab v18 software with a dual system i.e. RC-masonry combination. RCC frame element beam, the column is drawn in mid of y-direction parallel to x-direction. The masonry wall is model at the periphery of the structure with vertical rebar at the corner and a tie band at the floor level. Mud-topped timber floor structure for slab element. Here RCC and timber structural elements are models as frame elements and flooring and wall element are model as thin shell elements.

Timber joist is used for modeling mud-topped timber floor structure, a three-dimensional frame element. The connection between timber floor and wall is assumed to be resting on the wall so pin connections are assigned in joist at support connection (Maharjan et al., 2020). The connection between the lintel band and the vertical reinforcement bar is done by assigning a pin connection. A semi-rigid floor diaphragm was assigned at each floor level. Imposed load considered for modeling is as per IS 875.1.1987, live load taken was 2 KN/m2. Dimension of frame element used in modeling are column 300mm*300mm, beam 230mm*300mm, vertical reinforcement bar of 16mm, lintel band 450mm*150mm, and Timber joist 75mm*100mm. Similarly, dimension for shell element for the wall is 450mm and 230mm. CGI sheet is on the roof as a thin shell element.

3.4 Method of Analysis

After completion of modeling in Etab v18 software, seismic analysis of RC-masonry hybrid residential building was carried out. After modeling completion in ETABS v18 software, seismic analysis of RC-masonry hybrid residential building was carried out. The steps of the research methodology are summarized below:

- Etab V18 software was used for model analysis in this research
- First material properties and section properties as per building drawing were assigned in software. Similarly, the load was assigned regarding IS 875 (part-1,2).
- The analysis of the building was carried out from the following load combination.
  Dead load (DL) as per IS 875(Part 1)
  Live Load (LL) as per IS 875 (Part 2)
  Earthquake Load (EQ) as per IS 1893:2016
- The working stress method was used for load combination as per NBC 105.
  DL+LL
  0.7DL+EQ(X&Y)
  0.7DL- EQ(X&Y)
  DL+LL+EQ(X&Y)
  DL+LL-EQ(X&Y)
- RCC member beam, column, tie rod, and lintel is model as frame element and masonry wall as thin shell element.
- The mud-topped timber floor structure is used in the model, for this timber joist is assigned as frame element which rests on beam and masonry wall.

- Pin connection is assigned for timber joist resting on beam and wall. Similarly, rigid diaphragms have been assigned for floor level.
- From analysis, base shear, top displacement, drift ratio, shell stress, and mass irregularity at different stories were represented.

IV. RESULTS AND DISCUSSIONS

4.1 Modal Output

The output analysis result of the building model is as follows. Modal mass participation and period of various modes are given in the tabular form below. From analysis, modal mass participation ratio in mode 3 is 0.8551 and 0.7723 percent in sum UX and sum UY, similarly in mode 12 sum UX is 0.9849 and sum UY is 0.9788 percent. As per IS 1893:2016 table 6 "the first three modes together contribute at least 65 percent mass participation in each principle plane direction" and IS 1983:2016 clause 7.7.5.2 sum of total masses of this mode Nm considered is at least 90 percent" i.e. our analysis result satisfy both clauses

Table 1 Modal Mass Participation Ratio

Mode	Period (s)	Modal mass	Modal mass
		SumUX	SumUY
1	0.337	0.853	0.0015
2	0.265	0.8548	0.7638
3	0.163	0.8551	0.7723
4	0.113	0.9514	0.7725
5	0.097	0.9514	0.8752
6	0.068	0.9707	0.8777
7	0.067	0.972	0.9486
8	0.054	0.9722	0.9548
9	0.051	0.9815	0.9549
10	0.04	0.9815	0.978
11	0.039	0.9848	0.978
12	0.032	0.9849	0.9788

4.2 Inter-story drift

From the ETABS model inter-story drift of the building is obtained in X and Y directions. Story displacement check for EQx and EQy direction is shown in the table. (Due to the minimum specified story drift in any story design, the lateral force with a partial load factor of 1, shall not exceed 0.004 times the height of the story.)

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Table 2 Story Drift

Story	Location	DL+LL+Eqx	DL+LL+Eqx
		Max Drift X-Dir (mm)	Max Drift Y-Dir (mm)
Story5	Top	0.0007	0.0009
Story4	Top	0.0007	0.0005
Story3	Top	0.0008	0.0006
Story2	Top	0.0009	0.0006
Story1	Top	0.0009	0.0004
Base	Top	0.0000	0.0000

4.3 Story Displacement

From the analysis result, top displacement is found 8.008 and 6.424 mm in EQx and EQy direction which is less than the permissible value (43mm) i.e. 0.004h where "h" is the building height. This might be the result of a dual system of construction.

Table 3 Story Displacement

Story	Elevation	Location	Eqx	Eqy
	mm		X-Dir (mm)	Y-Dir (mm)
Story5	10820.4	Top	8.008	6.424
Story4	8686.8	Top	6.988	4.73
Story3	6553.2	Top	5.595	3.548
Story2	4419.6	Top	3.894	2.24
Story1	2286	Top	2.038	0.982
Base	0	Top	0	0

4.4 Story Response

Story response due to lateral earthquake force in EQx and EQy direction from the modal analysis.

Table 4 Story Response

Story	Elevation	Location	Eqx	Eqy
	m		X-Dir (kN)	Y-Dir (kN)
Story5	10.82	Top	217.78	217.78
Story4	8.69	Top	290.22	290.22
Story3	6.55	Top	166.68	166.68
Story2	4.42	Top	75.86	75.86
Story1	2.29	Top	19.47	19.47
Base	0	Top	0	0

4.5 Mass irregularity

Modal mass irregularity from the analysis is shown in the table below. As per IS 1893:2016 clause 7.1 "Building suffer mush less damage with uniformly distributed mass, simple regular geometry, and stiffness in plan and elevation, then building with irregular configuration". Mass irregularity is found regular up to the fourth floor and on the fifth floor due to large opening and terrace reduction of mass occur resulting in irregularity

Table 5 Mass irregularity

Mass		
story	Mass X	Mass Y
Story1	85791.03	85791.03
Story2	78971.22	78971.22
Story3	78850.07	78850.07
Story4	77961.18	77961.18
Story5	33676.4	33676.4

X Direction			
Mi	Check	Mi	Check
Mi+1		Mi-1	
-	-	-	-
-	-	1.002	Regular
0.998	Regular	1.011	Regular
0.989	Regular	2.315	Irregular
0.432	Regular	-	-
0.000	Regular	-	-

Y Direction			
Mi	Check	Mi	Check
Mi+1		Mi-1	
-	-	-	-
-	-	1.002	Regular
0.998	Regular	1.011	Regular
0.989	Regular	2.315	Irregular
0.432	Regular	-	-
0.000	Regular	-	-

4.6 Analysis results

As output results and numerical data obtained from the analysis are studied and verified with the actual capacity of the structural element resisting the expected horizontal shaking. The program analysis results obtained in the form of normal and shear stress are shown in fig below.

The wall density index (WDI) along x-direction is at ground floor, 1st, 2nd, 3rd floor is 7.8%, 6.5%, 6.5%, 6.5% and along y-direction at ground floor, 1st, 2nd, 3rd floor is 9.7%, 8.2%, 8.2%, 8.2% which is greater than 5% of Indian seismic zone V.(Brzev, 2007)

The maximum stress S11 due to vertical load combination is 0.15 Mpa in tension and 0.16 Mpa in compression, S22 is due to vertical and horizontal load combination is 0.19 Mpa in tension and 0.56 Mpa in compression, similarly, shear stress due to vertical and horizontal load combination is 0.29 Mpa in tension and 0.22 Mpa in compression. Stress concentration is high at the corner and the opening portion of the building. Stress concentration is high at the opening portion of the building and end corner. Stresses S11, S22, and S12 are greater than the permissible value.

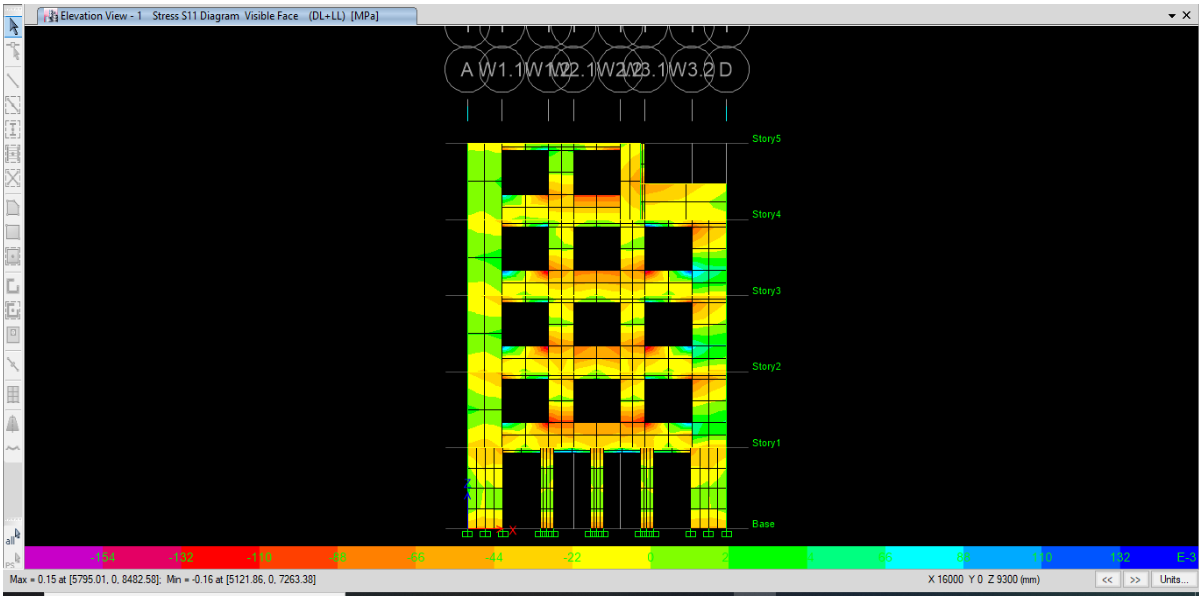

Figure 5 Stress Diagram S11 Due to DL+LL

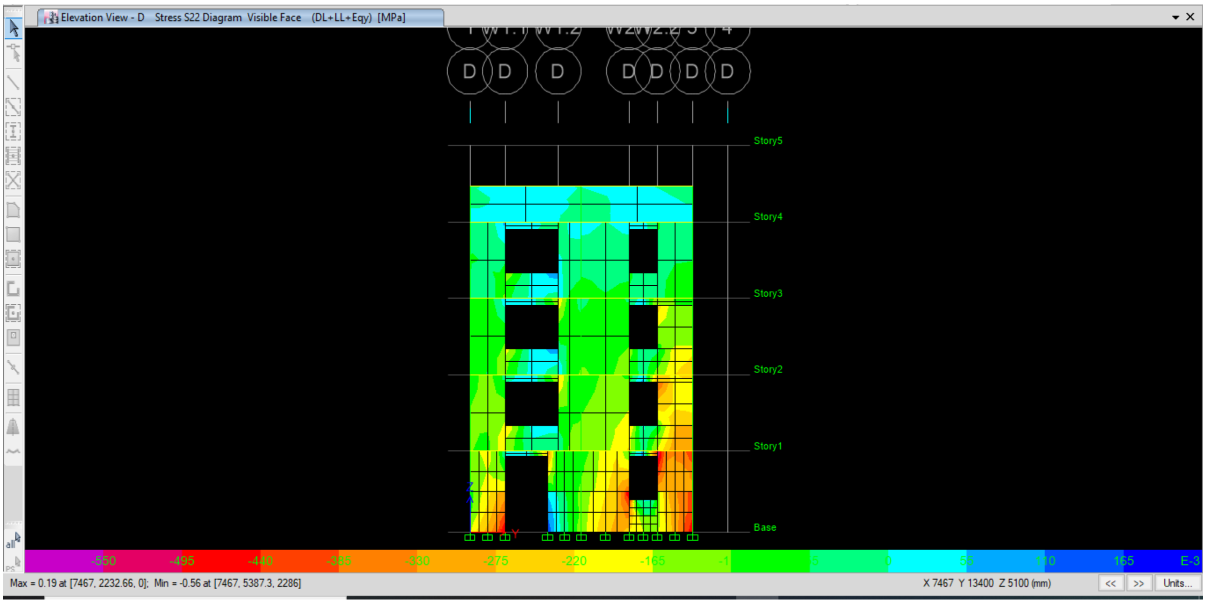

Figure 6 Stress Diagram S22 Due to DL+LL+EQy

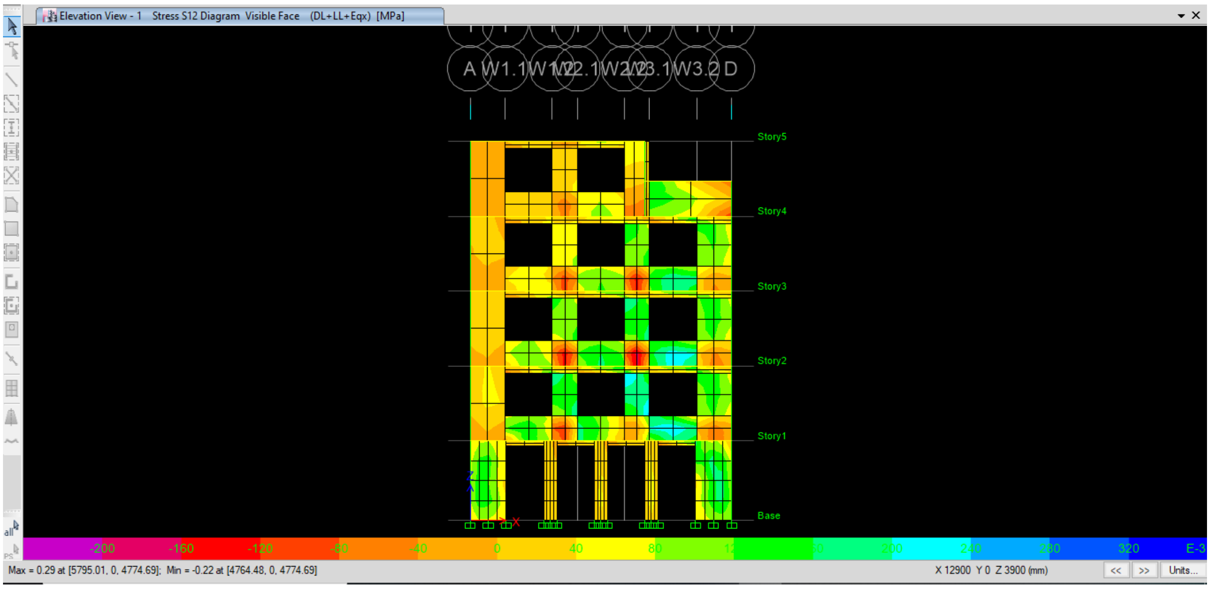

Figure 7 Stress Diagram Due S12 Due to DL+LL+EQx

V. CONCLUSION

The RC-masonry hybrid residential building is modeled in ETABS v18 software with a dual system i.e. RC-masonry combination. Where RCC and timber structure are model as frame elements and masonry structure as rectangular thin shell elements. Mud-topped flooring structures are model as timber joist supporting masonry flooring. From modal analysis story displacement, drift ratio, modal mass participation ratio of model found within the permissible limit as per IS 1893:2016. Wall density index along longitudinal and transverse is found greater than 5% which is safe for Indian seismic zone V. From the stress contour diagram it is found that stresses S11, S22, and S12 are greater than permissible, stress concertation is high at opening portion, and at the corner of the building. Hence recommended for seismic strengthening by reduction of the opening portion, applying horizontal and vertical band at sill and lintel level. Stress concentration at the opening portion of the structure can be reduced by steel bar as post-tensioning material, which strengthened the brick masonry wall in their in-plane direction, allows the masonry wall to dissipate energy against the lateral load. Furthermore, Time history analysis can be performed to know structural performance for different ground acceleration.

Conflict of interest

There is no conflict to disclose.

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