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Seismic Performance of Mixed RC-Steel Structure

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Abstract

Nepal is located at the boundary of the Eurasian and Indian plates, which are in constant motion, making it a tectonically active country. Therefore, it is essential for structures in Nepal to be earthquake-resistant. In Nepal, various concepts of earthquake-resistant structures are being adopted, including the mixed RC steel structure (MRSS). In MRSS, a certain number of stories are made of RC moment-resisting frames, while the remaining stories are made of steel moment-resisting frames. In this study, the seismic performance of MRSS was evaluated using response spectrum analysis. Three models with similar plans and elevations were considered: one made of RC moment-resisting frames (RCS), one made of steel moment-resisting frames (SS), and one made of RC moment-resisting frames for the first five stories and steel moment-resisting frames for the remaining three stories. The seismic response parameters of all three models were evaluated using response spectrum analysis in accordance with the NBC 105: 2020 code. The response parameters of MRSS were compared with those of the RCS and SS models, and the results showed that MRSS had better response compared to RCS but performed below the level of SS. MRSS had lower base shear, time period, and maximum story displacement compared to RCS, and higher values of responses compared to SS.

Keywords

Mixed Structure, Response Spectrum Analysis, Stiffness Modifier, NBC 105:2020

1. Introduction

A mixed RC-Steel construction is one in which the lower stories are made of reinforced concrete, while the upper stories are constructed using a steel structure. This is a new and emerging building technology in Nepal, where it is known as a vertically mixed structure. This type of building is commonly used in developed nations to construct high-rise buildings, and it typically consists of a lower story made of concrete and a higher story made of steel. The mixed RC-Steel structure has the potential to revolutionize the Nepalese construction industry.

The main objectives of this study are:

- To determine the seismic performance of mixed RC-Steel Structure.
- To compare the seismic performance of mixed RC-Steel Structure with RC Structure and Steel Structure.

Askouni and Papagiannopoulos (2021) conducted a study on the seismic behavior of a class of mixed reinforced concrete-steel buildings. They used a 3D numerical model and simulated five realistic mixed buildings with a combination of reinforced concrete and steel. The support condition of the lowest steel story was examined, with either a fixed or pinned connection to the upper reinforced concrete level. The study found that the maximum values of interstorey drift ratio (IDR) and residual interstorey drift ratio (RIDR) occurred in the reinforced concrete part of the building, while the maximum peak floor acceleration (PFA) mostly occurred in the steel part [1].

The study conducted by Das and Nau (2003) involved a comprehensive parametric analysis of 78 buildings with varying inter-story stiffness, strength, and mass ratios. The findings from the linear and nonlinear dynamic analyses of these engineered structures indicated that most of the buildings performed well when subjected to the design earthquake. As a result, the restrictions on the equivalent lateral force procedure for certain types of vertical irregularities are deemed unnecessary and overly conservative [2].

Bahri, Kafi, and Kheyroddin (2019) conducted analytical study of a 20 story and five span (in each direction) mixed structure building with a transition story at the 16th floor. As to specimen 1, failure begins with the yield in the anchor bolt and damage of grout under the column base in 3.3% drift, resulting in a loss in stiffness. No sign of a significant stiffness reduction is observed in the elastic region of the specimens 2 and 3. No significant strength loss is obtained in the specimens 3 and 4 up to 5.3% drift [3].

Fanaie and Shamlou (2015) found out that the response modification factor values of mixed structures are lower compared to those of steel or concrete ones with the same elevation. They suggested that such outcome is the result of irregularities of stiffness, mass, etc., at different height of the structure [4].

The mass and stiffness criteria of Uniform Building Code (UBC) result in moderate increases in response quantities of irregular structures compared to regular structures, however the strength criteria results in large increases in response quantities and thus is not consistent with the mass and stiffness requirements [5].

To construct earthquake-resistant high-rise buildings, the latest trend is to use lighter and stiffer materials. Steel is a better option as it is both lighter and strong, but obtaining larger steel sections may be difficult. In such cases, combining steel and reinforced concrete, i.e., a mixed RC-steel structure, can be a solution. This approach allows for the benefits of both materials to be utilized.

2. Analytical Modeling of Structure

2.1 Selected Building Properties

1. Structural configuration

   (a) Height of floor: 3.048 m

   (b) Number of storey: G+8

   (c) Grade of concrete: M30 for slab and beam, M35 for columns

   (d) Rebar: HYSD 500

   (e) Steel: Fe 250

   (f) Size of plan: 18m × 25m

   (g) No. of bay in X- direction: 3

   (h) No. of bay in Y- direction: 5

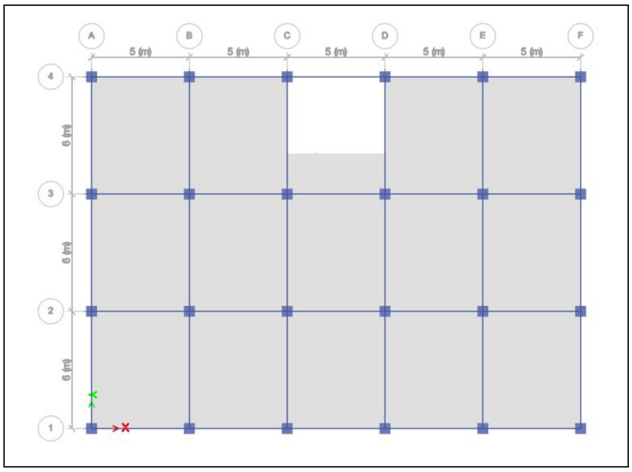

Figure 1: plan of the selected model

2. Loading Data

   (a) Wall Load: 8.88 kN/m

   (b) Live Load: 2.5 kN/m^2 for rooms, 3 kN/m^2 for staircase and lobby, 1.5 kN/m^2 for roof

   (c) Floor Finish: 1.5 kN/m^2

3. Section Properties
   The beam and column sections used in the models are mentioned in the table 1.

Table 1: Section Properties

Sections	RCS	SS	MRSS
Beam	355.6×609.6, 304.8×558.8	ISLB100, ISMB250, ISMB500, ISMB550	ISLB100, ISMB250, ISMB500, 304.8×558.8, 355.6×609.6
Column	558.8×558.8	2 ISMC 400 with batten plates	ISMC 300 with batten plates, 558.8×558.8

Note: All dimensions are in mm.

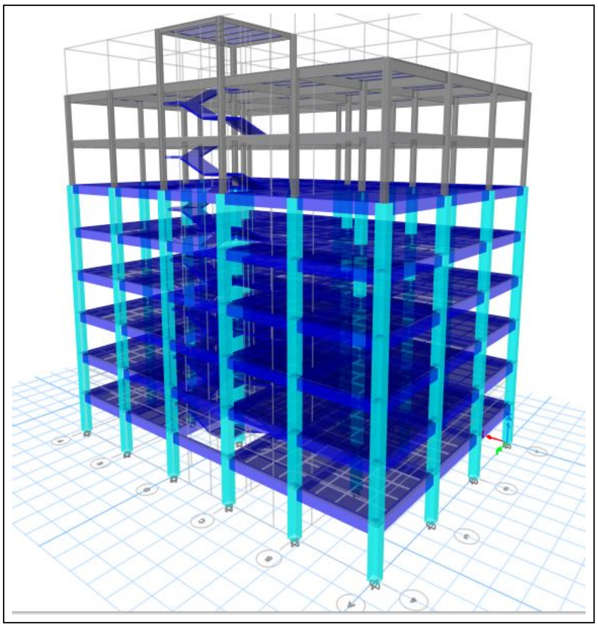

Figure 2: 3D view of MRSS model

2.2 Selected Site Characteristics

The site characteristics selected for this project are:

- Site Subsoil Category: Soil Type D (Kathmandu)
- Seismic Zoning Factor (Z): 0.35 (Kathmandu)
- Importance Class: II (Commercial Building)
- Importance Factor: 1.25

2.3 Connection between steel column and concrete column

During the modelling of MRSS model the connection between steel column and concrete column in 6th floor has been considered as rigid. The design of rigid connection was done following the Base plate and Anchor rod design published by American Institute of Steel Construction Inc. (AISC) [6]. Steel column is connected with the concrete column using the base plate and anchor rod assembly as shown in Figure 3.

3. Methodology

At first, the relevant literature was studied to get a general idea about the mixed RC-Steel structure. Then the appropriate building models were selected for the project. The deformation parameter indicating the behavior of the structure were chosen. After this, for analyzing the seismic performance of MRSS Response Spectrum Analysis was performed. Response Spectrum Analysis was also performed for other two models i.e., RCS and SS so as to compare the response of MRSS with these models. For this, a finite element software ETABS was used and NBC 105: 2020 [7] was followed throughout the analysis. The response parameters were extracted from analysis and eventually, the results were obtained based on observed parameters.

4. Results and Discussions

Response spectrum method was performed on the selected models as per the provision of NBC 105:2020 to analyze the seismic performance. The Seismic weight of the models are 39604.20 kN, 29345.63 kN and 37032.98 kN for RCS, SS and MRSS respectively.

Table 2: Base Shear Coeff., Base Shear and Time period comparison

S.N	Model	Base Shear Coeff.	Base Shear (kN)	Time Period (Sec)
1	RCS	0.164	6497.58	1.332
2	SS	0.164	4846.35	1.087
3	MRSS	0.164	6075.74	1.244

As shown in Table 2, the base shear value of the RCS model is higher than that of the MRSS and SS models regardless of it's base shear coefficient being similar. This is because the base shear of a structure is directly proportional to its seismic weight, and the RCS model has a higher seismic weight than the other two models. Therefore, the RCS model has the highest base shear value.

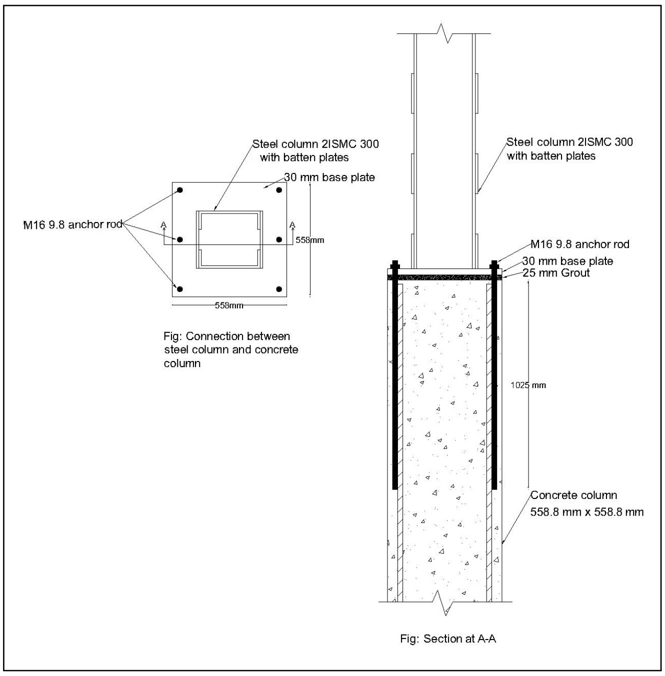

Figure 3: Connection detail between steel column and concrete column

The time period of a structure is directly proportional to its mass and indirectly proportional to its stiffness. In past studies, it was found that RC structures have a shorter time period compared to steel structures due to their stiffer nature and flexible nature of steel. However, recent building codes have included stiffness modifiers to model cracking phenomenon in concrete columns and beams, which reduces the flexural stiffness of RC sections, making them more flexible [8]. In this project, the effective stiffness of cracked section has been used for the concrete sections as prescribed by the NBC 105:2020. The effective stiffness used are:

Table 3: Effective stiffness of different components

S.N	Component	Flexural Stiffness	Shear Stiffness
1	Beam	0.35 EcIg	0.4 EcAw
2	Columns	0.7 EcIg	0.4 EcAw

According to the results in Table 2, the duration is greater for the RCS model than the SS and MRSS models because the mass of the RCS structure is heavier, and the story stiffness is lower than the other two models.

Figure 4, 5 and 6 illustrates the maximum story displacement and inter story drift ratio of three models respectively. As the story stiffness of the RCS model is lesser than the SS and MRSS model, the story displacement is larger. As disucussed earlier, due to consideration of stiffness modifier in RCS model, the effective stiffness of RCS model is lesser than the SS model. MRSS model has slightly lesser story displacement than the RCS model. Inter story drift ratio is also more in case of RCS and lesser in MRSS and SS model.

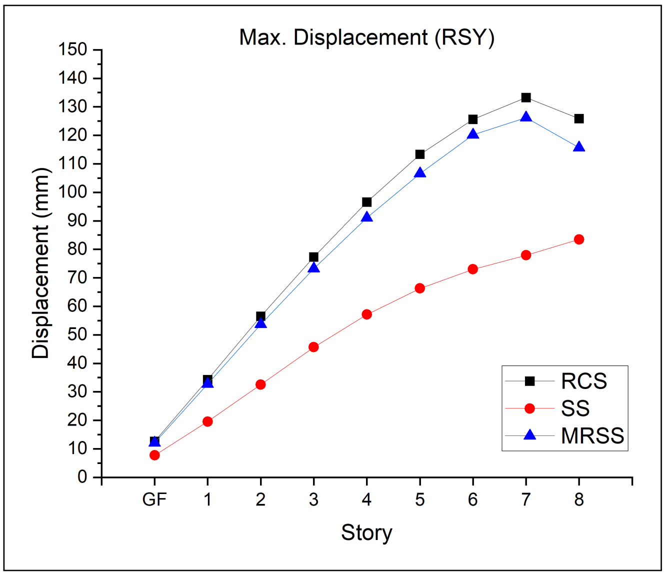

Figure 4: Maximum story Displacement

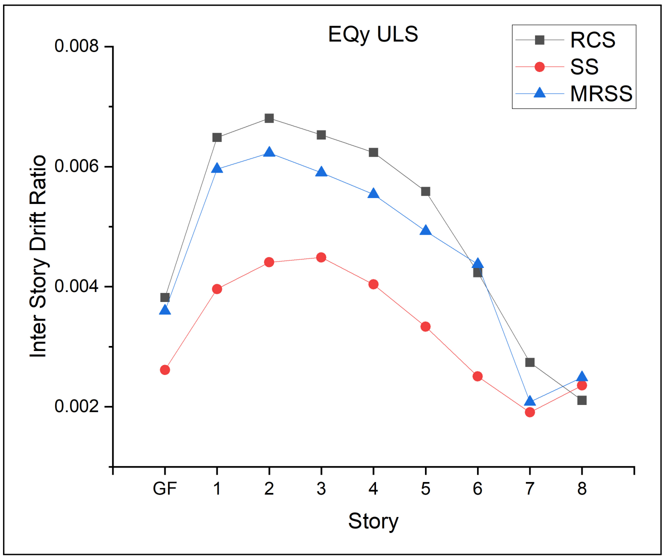

Figure 5: Inter story drift ratio for EQy ULS

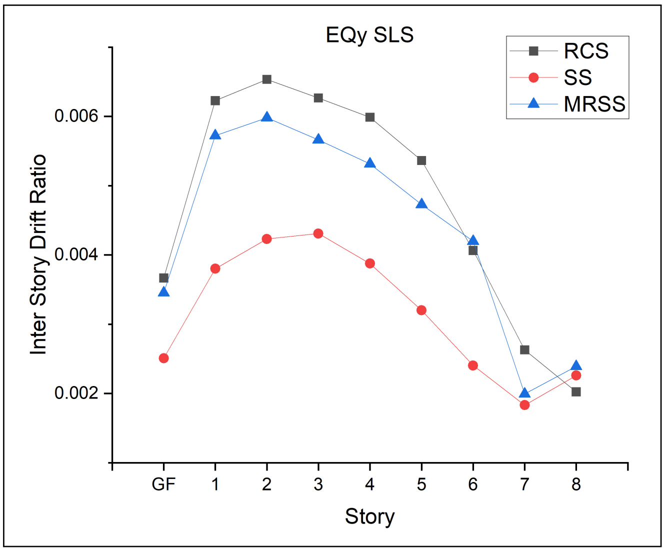

Figure 6: Inter story drift ratio for EQy SLS

5. Concluscion

Response spectrum analysis was done to find out the seismic performance of three moment resisting frame models i.e., Reinforced Concrete Structure (RCS), Steel Structure (SS) and Mixed RC Steel Structure (MRSS). The main aim of this study is to determine the applicability of vertically mixed RC Steel structure by comparing the seismic performance of the structure with the Steel structure and the Reinforced Concrete Structure. From the analytical results obtained from the study following conclusion can be made:

1. The base shear in the MRSS model is lower than the RCS model and higher than the SS model.
2. The fundamental period of the MRSS model is shorter than the RCS model and longer than the SS model.
3. The maximum story displacement of the MRSS model is smaller than the RCS model but larger than the SS model.
4. The inter-story drift ratio of the MRSS model is lower than the RCS model for all stories in both the ultimate limit state and serviceability limit state, except for the 8th story in the y-directional earthquake in both limit states.

Thus, from this research we can see that the MRSS model is performing slightly better than the RCS model during seismic activity and the SS model seems to be better of the three models. Since this study is done only for 8 storey building further research is required in various storied structure to decide in the applicability of mixed structure.

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