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# Performance Assessment of RCC-Steel Hybrid Structure

**Lalit Bhatt[1,2], Gokarna Kunwar[1], Manas Raj Ojha[1,*], Milan Chaulagain[1], Nabin Koirala[1], Ozone Rijal[1], Pradhyumna Poudel[1]**

[1] *Department of Civil Engineering, Thapathali Campus, Institute of Engineering, Tribhuvan University, Nepal*
[2] *Interdisciplinary Research Institute for Sustainability, Kathmandu, Nepal*
**Corresponding email: manasrajojha@gmail.com*
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## Abstract

This study presents a comparative evaluation of the seismic performance of three structural systems: Reinforced Cement Concrete (RCC), structural steel, and a vertically mixed RCC and steel hybrid frame. In the hybrid configuration, RCC is used in the lower two storeys and structural steel in the upper two, aiming to combine the strengths of both materials—concrete for its mass and stiffness, and steel for its lightness and ductility. Three building models of G+4 storeys each were developed in FEM tool ETABS and analyzed using the Equivalent Static Method, the Response Spectrum Method, and nonlinear Pushover Analysis in accordance with NBC 105:2020. Key performance parameters such as base shear, storey displacement, inter-storey drift, and pushover capacity were studied. The RCC model showed the highest base shear due to its heavier mass, while the steel structure exhibited better ductility and lower displacement but required larger sections and bracings to maintain structural stiffness. Steel model experienced 30% less base shear while RCC-Steel Hybrid Model experienced 17% less base shear compared to RCC model. The hybrid model exhibited drift and displacement responses that were intermediate to those of the RCC and steel structures. The hybrid model achieved a balanced performance, providing rigidity at the base and flexibility at the upper levels. The spectral acceleration value at performance point was highest for hybrid model (0.74g) compared to for RCC and Steel models (0.666g for both). Pushover analysis confirmed that the hybrid structure remained within acceptable life safety performance limits with no non-linear hinges formed at performance point indicating better seismic resilience than RCC and steel models. These findings suggest that RCC and steel hybrid systems offer a practical and efficient alternative for mid-rise construction, especially in regions like Nepal where staged construction is common, resources may be limited and high seismicity is found.

***Keywords:*** *RCC-Steel hybrid, seismic performance, performance assessment, pushover analysis, mixed structure*

## 1. Introduction

Reinforced Cement Concrete (RCC) is one of the most widely adopted construction methods globally, known for its strength, durability, and cost-effectiveness. The worldwide annual production of reinforced concrete exceeded 10 billion cubic meters in 2012 (Miller et al., 2016). Concrete is associated with significant environmental impacts, including substantial greenhouse gas emissions and the depletion of raw material resources (Eštoková et al., 2022). In contrast, steel structures are manufactured with consistent quality and offer better seismic performance. Steel structures provide a more economical option compared to RCC for multi-storey buildings (Gagandeep, 2021). The advantages of both construction systems can be combined by RCC and steel hybrid buildings which present a promising solution for Nepal.

Combining the strength and durability of RCC with the flexibility and ductility of steel, this hybrid approach may provide enhanced seismic resilience, faster construction, and cost efficiency. This combination is particularly beneficial for high-rise buildings, bridges, and commercial complexes, offering a balanced solution that addresses both Nepal's seismic concerns and the need for modern, sustainable infrastructure. An RCC and steel vertically hybrid structure (also referred to as mixed structure) is a hybrid construction system that combines reinforced cement concrete with structural steel to optimize strength, durability, and efficiency. The concrete component provides excellent compressive strength, while the steel enhances tensile strength, and ductility and their combination could allow for improved load distribution, accelerated construction timelines, and cost-effectiveness.

In Nepal, buildings are often constructed in stages, with lower floors built and occupied first, and upper floors added years later. The hybrid system could be an alternative for those buildings where lower stories are already built and the upper stories are yet to be built. However, due lack of code guidelines and knowledge, such construction practices aren't widespread.

Recent studies further highlight the importance of proper connection detailing and dynamic analysis in hybrid structures. Askouni and Papagiannopoulos (2023) investigated the nonlinear seismic behavior of hybrid RCC–steel frames and found that fixed-pinned connections between RCC and steel components resulted in higher structural vulnerability under strong ground motions. Dakshata and Sushma (2021) conducted a comprehensive review of high-rise hybrid structural systems. They highlight that hybrid structures are highly advantageous for tall buildings, offering reduced dead load, enhanced ductility, and reduced story drifts compared to pure RCC systems.

While advantageous in many ways, these structures must be carefully designed to ensure effectiveness. Hybrid structures have significant variation in the stiffness between RCC and steel components. Dynamic analysis is essential because equivalent static analysis isn't suitable for these types of structure (Kaveh, A., & Ardebili, S. R. 2023). Structure becomes vulnerable with increase in vertical irregularity (Kalibhat et al., 2014). Thus, a comprehensive study of their seismic behavior is necessary.

The applicability of such Hybrid structures is not fully understood. These hybrid structures which are commonly found in stadiums and buildings with lightweight steel additions, present unique challenges in seismic design that current codes often fail to address adequately (Papageorgiou & Gantes, 2010). Hybrid structures are highly diverse and complex, making it difficult to write general, standardized rules for their design and construction. The lack of standardized design procedures leads to several challenges during the design of such structures. So, a comprehensive study of such structures is necessary especially in seismically active zone like Nepal. This study seeks to address the existing gap in knowledge regarding such hybrid structural systems while exploring its suitability in Nepal.

To mitigate the identified challenges, this study focuses on the understanding their performance and applicability with an aim to fulfil the following objectives.

Objectives

- To assess seismic performance of RCC, steel and Hybrid structure using ETABS, with a focus on understanding their behavior through pushover analysis.
- To compare the performance of Hybrid RCC and steel structures with traditional RCC and pure steel structures.

## 2. Materials and Methods

At first, the relevant literature was studied and reviewed to understand past studies on hybrid structures. Then three building models were selected for the study: one made entirely of RCC, one made entirely of steel, and a hybrid model consisting of the lower two stories in RCC and the upper stories in steel. After that, the preliminary sizing of beam, column, and staircase was performed and the selected buildings were modeled using ETABS software. Parameters related to deformation, which indicate the structural behavior, were chosen. Response Spectrum Analysis was then performed as per the guidelines of NBC 105: 2020 to analyze the seismic performance of all three models. To study the non-linear properties of the modeled structures, pushover analysis was performed as per FEMA 440 guidelines. The response parameters were extracted from analysis and the results of pushover analysis were obtained. These were examined and the results were interpreted.

### 2.1 Structural Configuration

a) Height of floor: 3.2 m
b) Number of Storey: G+4
c) Size of plan: 13.1m x 26m
d) No. of bay in X- dir.: 2
e) No. of bay in Y-dir.: 4
f) Grade of Concrete: M25
g) Rebar: HYSD 500
h) Steel: Fe250

The selected configuration represents a typical building built in Nepal. NBC 206 classifies buildings up to 5 stories (G+4) as 'General Buildings', noting this category as the most common type of building. The materials selected are the typical construction materials in Nepal and are in accordance with NBC 105 code.

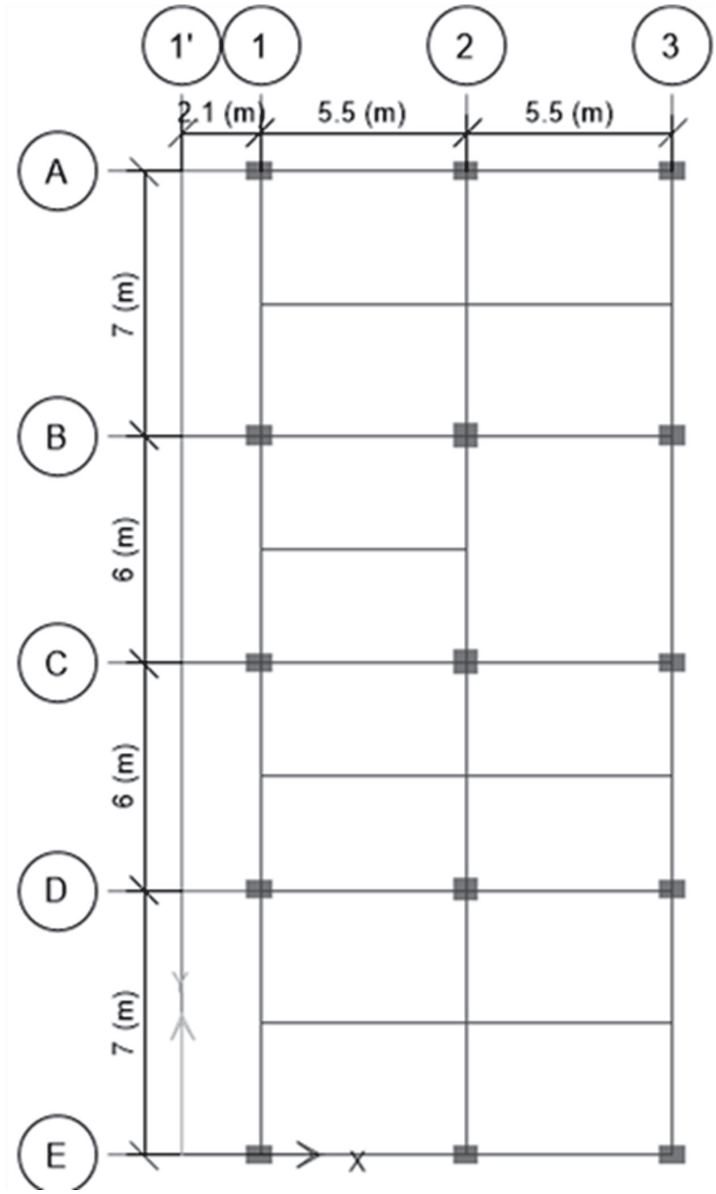


**Figure 1**: Plan of the selected building

Loading Data

a) Outer wall load: 12 kN/m
b) Partition wall load: 1.91 kN/m$^2$ on slab, 8 kN/m on beams
c) Live load: 3 kN/m$^2$ on rooms, 4 kN/m$^2$ on stair and passage
d) Floor finish: 1.55 kN/m$^2$

## 2.2 Section Properties

The beam (Primary and Secondary), Column and Bracing sections used in the models are mentioned in the table:

**Table 1**: Adopted size of Beam, Column and Bracing section in RCC, Steel and Hybrid models

| Member | RCC | Steel | RCC-Steel Hybrid |
|---|---|---|---|
| Primary Beam | 350×550<br>250×400 | ISMB450<br>ISMB400<br>ISMB300<br>ISMB250 | 350×550<br>ISMB400<br>ISMB300<br>ISMB250 |
| Secondary Beam | 300×425<br>200×300 | ISMB225<br>ISMB200<br>ISMB175 | 300×425<br>ISMB200<br>ISMB175 |
| Column | 625×625<br>700×500 | ISMC400 Battened<br>ISMC350 Battened<br>ISMC250 Battened | 550×500<br>ISMC400 Battened<br>ISMC350 Battened<br>ISMC250 Battened |
| Bracing | - | ISNB200H<br>ISNB175H<br>ISNB150H | ISNB175H<br>ISNB150H |

All dimensions are in mm

Note: Eccentric backward bracings were used in Steel model while Inverted-V bracings were used in mixed model.

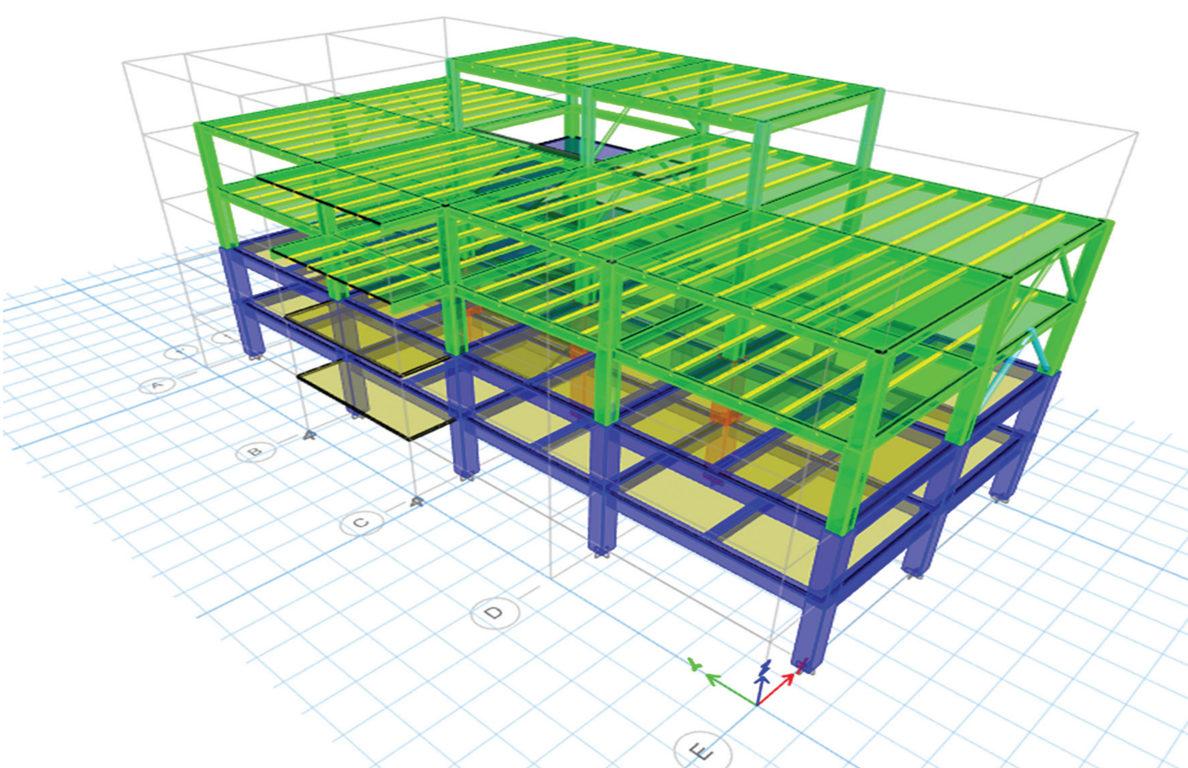


**Figure 2**: 3D view of RCC-Steel Hybrid model

### 2.3 Selected Site Characteristics

**Table 2:** Site Characteristics

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

### 2.4 Assumptions

1. The foundation is assumed to be fixed and the soil-structure interaction is not considered.
2. The connection between RCC and Steel Column of Hybrid structure is assumed to be fixed.
3. The infill walls are not considered in the model but their load have been distributed on beams.

While soil-structure interaction (SSI) is essential in capturing the actual seismic response of a building, its modeling requires knowledge of site-specific soil conditions, which are often highly variable and uncertain. Similarly, including infill walls in the model would increase the lateral stiffness of the structure, resulting in reduced deformations. These simplifications, while limiting accuracy, help to assess the structure's capacity under worst-case conditions.

In ETABS, the RCC–Steel column connection was modeled as a fully fixed joint. This rigid modeling ensures shear and bending forces transfer uninterrupted, assuring compatibility between materials and capturing composite behavior crucial for hybrid columns.

### 2.5 Selected Codes and Load Combinations

The three building have been designed in accordance to NBC 105: 2020 code which provides design guidelines for RCC and steel buildings constructed in Nepal. FEMA 440 is applicable for steel and concrete buildings. The lack of code-specified rules for hybrid systems is a modeling limitation. Thus, we have applied their factors and ductility parameters by analogy.

Load Combinations Specified in NBC 105: 2020 have been used for design of structures.

## 3. Results and Discussion

### 3.1 Base shear

The seismic analysis was conducted in all three models using Equivalent Static Method as well as Modal Response Spectrum Method as per NBC:105 2020 code. The base shear coefficients for RCC and Steel Models were both calculated to be 0.164. Since NBC:105 specifies no any values for RCC-Steel Hybrid structures, the same value of base shear coefficient was used.

**Table 3**: Structural Weight & Base Shear Coefficient

| Model | Seismic Coefficient (g) | Weight (kN) | Base Shear (kN) | Remarks |
|---|---|---|---|---|
| RCC | 0.164 | 16599.35 | 2723.95 | Maximum |
| Steel | 0.164 | 11468.92 | 1882.05 | 30%less than RCC |
| RCC- Steel Hybrid | 0.164 | 13650.71 | 2240.08 | 17% less than RCC |

The base shear is directly proportional to the weight of the building and the seismic coefficient. The three models have the same seismic coefficient; since RCC structure has highest weight, it experiences highest base shear. Steel structure has the lowest weight as well as base shear while the values for the hybrid model are intermediate between RCC and Steel models.

### 3.2 Modal Behavior

The use of braces in Steel and Hybrid models alter their modal behavior from the RCC model.

The 1$^{st}$ mode of RCC is along X-direction, while for Steel and Hybrid models it shifts to Y-direction. The 1$^{st}$ vibration mode is generally aligned with the weaker direction (or the direction where building finds easiest to deflect). The braces used in steel and hybrid models make it stiffer in X-direction, changing the 1$^{st}$ mode to Y-direction.

### 3.3 Drift and displacement

The drifts and displacement values obtained from response spectrum analysis are as shown below:

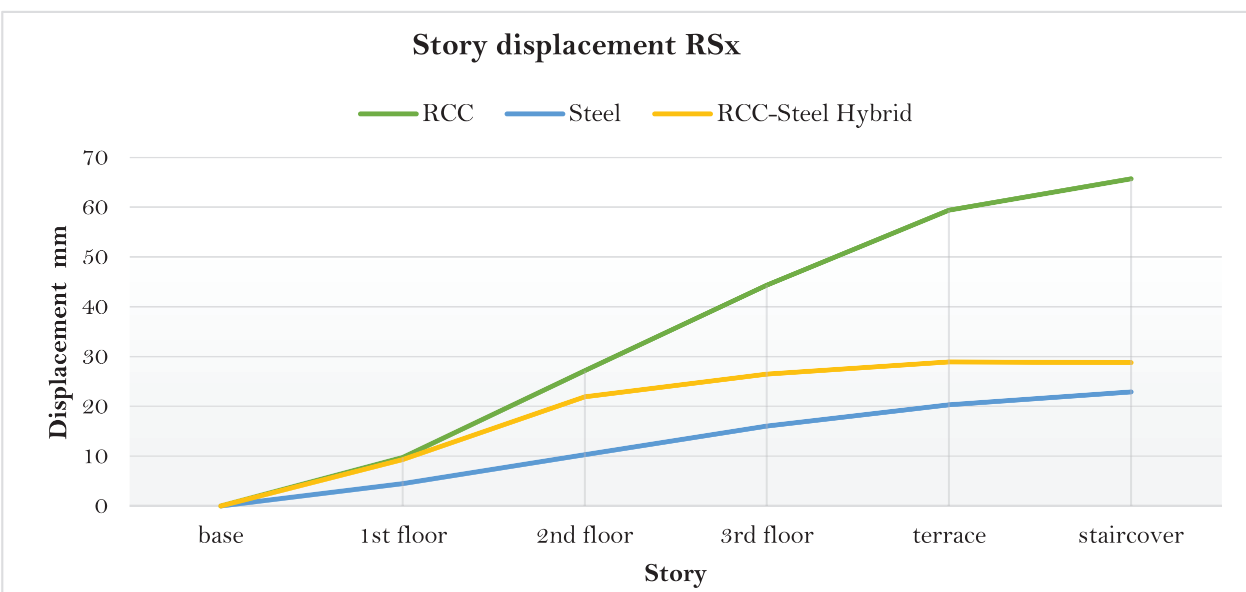


**Figure 3**: Storey Displacement Values for $RS_x$

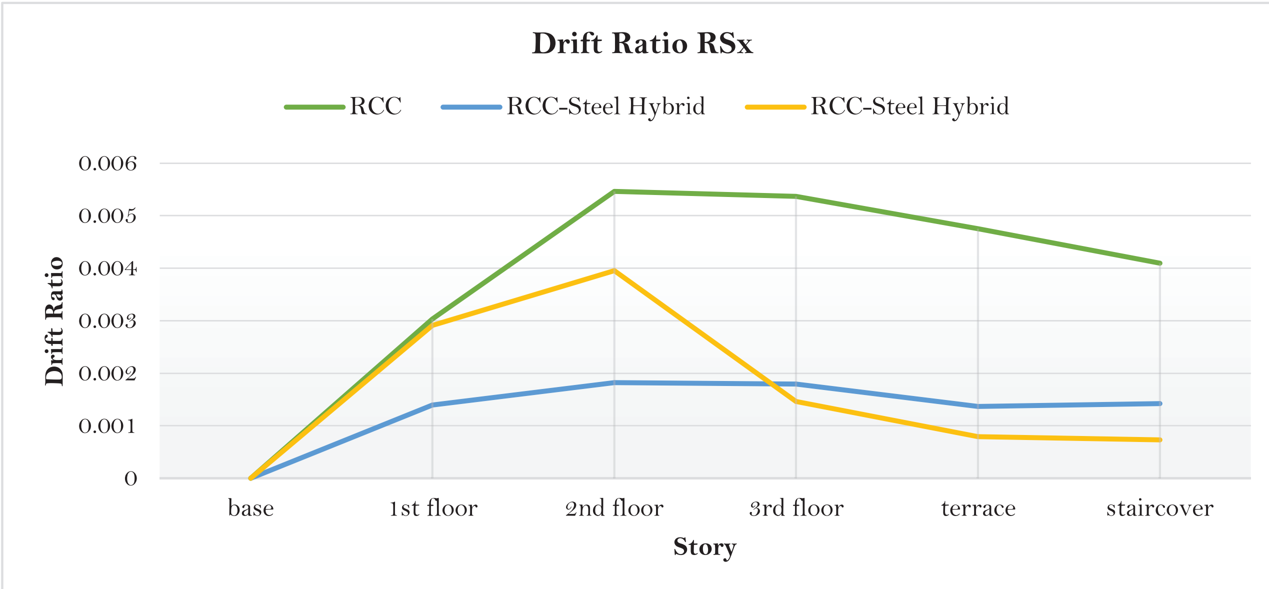


**Figure 4**: Interstorey drift ratio for $RS_x$

Along X-direction, the maximum displacement and maximum interstorey drift ratios are highest in RCC model lowest in Steel model while the RCC-Steel Hybrid model shows intermediate values. This can be attributed to the fact that braces used in the Steel and RCC-Steel Hybrid models make them stiff reducing the displacement and drift values.

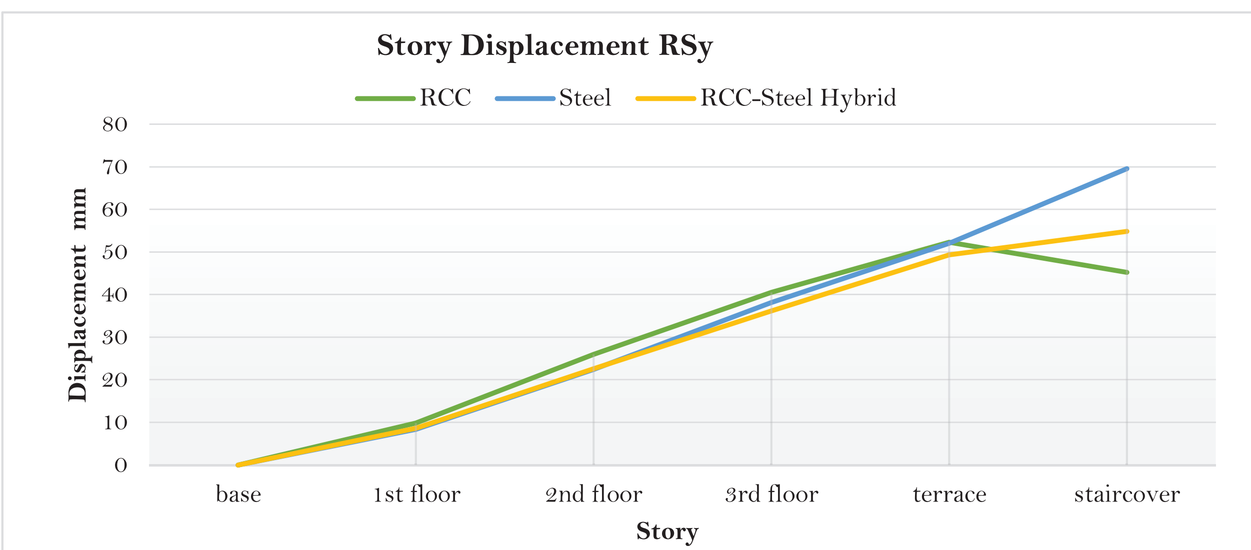


**Figure 5**: Storey Displacement Values for $RS_y$

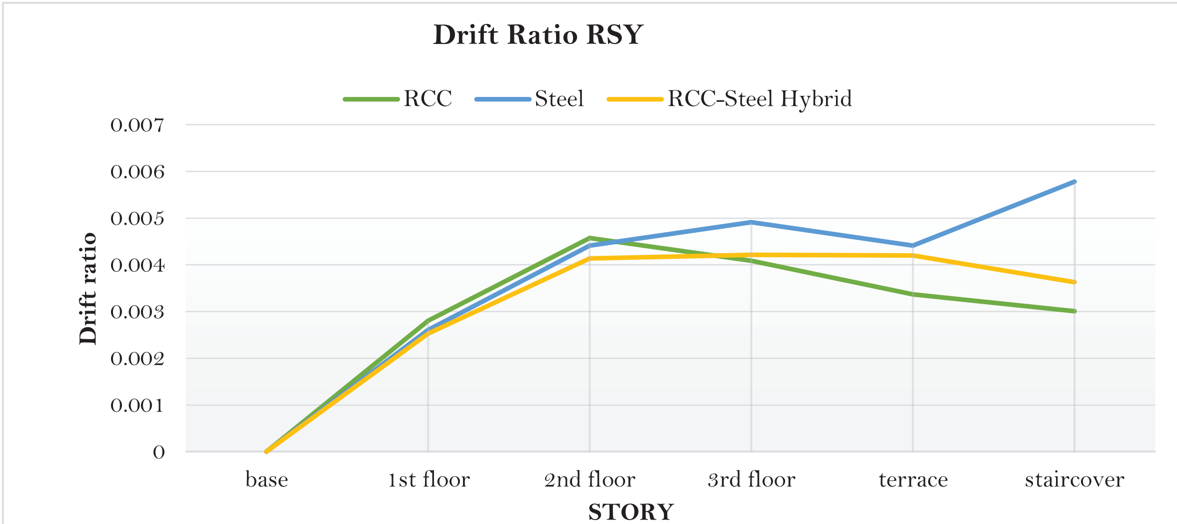


**Figure 6**: Interstorey drift ratio for $RS_y$

The maximum displacement and drift values under $RS_y$ are shown in figure 5 and 6. As in the case of $RS_x$ the displacement for RCC-Steel Hybrid model shows intermediate values between RCC and Steel Structures. But the maximum drift ratio for RCC-Steel Hybrid Model is least among three models.

## 3.4 Pushover analysis

Pushover analysis was performed on all three models to study the non-linear behavior of the buildings during earthquake. The performance point was determined using FEMA 440 Equivalent Linearization Method, NBC:105 response spectrum and appropriate scale factors.

The results from pushover analysis have been summarized in the table below:

**Table 4:** Performance point parameters

| Model | Base Shear (kN) | Displacement (mm) | Spectral acceleration (g) | Spectral Displacement (mm) | Number of hinges at IO level at performance point |
|---|---|---|---|---|---|
| RCC | 9322.67 | 186.063 | 0.666 | 123.97 | 15 |
| Steel | 6392.88 | 164.45 | 0.666 | 111.88 | 15 |
| RCC-Steel Hybrid | 7957.10 | 127.99 | 0.744 | 77.27 | 0 |

The spectral acceleration value was found to be highest for RCC-Steel Hybrid model. The spectral acceleration values were same for RCC and Steel models.

Additionally, the number and states of non-linear hinges at performance point were examined for each model. RCC and Steel models had 15 hinges each at IO level, whilst there were no hinges formed at performance point in RCC-Steel Hybrid model. This suggests that the hybrid model is still in elastic range at performance point and has further capacity to resist earthquake force.

These results of pushover analysis indicate that hybrid model has better earthquake resisting capacity compared to the RCC and Steel models.

## 4. Conclusions

The seismic performance of three structural model RCC, Steel, and RCC-Steel Hybrid was assessed through linear and non-linear analysis. The aim was to evaluate the applicability of RCC-Steel Hybrid model by comparing them with conventional RCC and Steel structures models.

Based on the analytical results, the following conclusions are drawn:

1. The base shear in the Hybrid model is lower than the RCC model and higher than the Steel model.
2. The storey displacement and drift of the Hybrid model lie between the RCC and Steel models.
3. Non-linear hinges in the Hybrid model form after the performance point, unlike RCC and Steel models.
4. The spectral acceleration at the performance point is higher in the Hybrid model than in RCC and Steel models.
5. The base shear at performance point are 3.4 times greater for RCC and Steel models and 3.5 times greater for Hybrid model.

Thus, the RCC-Steel Hybrid structure showed balanced and improved performance compared to both RCC and Steel models. Hybrid model can withstand stronger earthquakes while still in elastic region. Study shows that the hybrid structures are suitable for seismically active zones like Nepal. However, its effectiveness should be further verified for high-rise hybrid structures and the connections between RCC and Steel components.

## 5. Limitations

1. The connection between RCC and steel columns in RCC-Steel Hybrid structure is assumed to be rigid for the scope of this study. The effect of different connection types on the overall performance has not been verified.
2. The results obtained may not be directly applicable to high rise buildings where higher mode effects are significant.

## 6. Further scope of study

The connection between RCC and Steel components of the hybrid structure could be potential topic for future research and micro modeling.

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