Economic Earthquake Resistance Construction of High-Rise Buildings

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ABSTRACT

The economic perception of earthquake resistance construction for medium- to high-rise RCC buildings is examined in this paper. The conventional way of creating high-rise buildings is not financially viable without a shear wall to withstand seismic energy. Framed structures with irregular floor plans that vary in size, shape, and geometry are also expensive. Many studies have been conducted recently on the Coupling Ratio (CR). The current analysis investigates the behavior of the coupled shear wall and the CR for an affordable earthquake resistance construction including the shear wall within a range of 30 % to 45 %. The study shows that shear walls could be reduced at 40–50 % and at 60–70 % of the base height for regular and irregular buildings, respectively. The current study also comes to the conclusion that coupled shear wall earthquake-resistant construction is more practical than the conventional approach because couple beams can be repaired with ease.

Keywords-coupled shear wall; non-linear dynamic analysis; SAP2000

I. INTRODUCTION

In developing countries like India, the population density of cities is increasing rapidly. The most common used practice to mitigate the problem is the construction of low to medium rise load bearing structures or framed structures, mainly for economic reasons. Also, according to [1], the size of population has significant positive association with the fatalities during an earthquake [2]. The opted solution is to construct the maximum number of low cost, medium- to high-rise earthquake resistant structures that are affordable to the maximum number of people.

The study area of this paper is an Indian city near the Himalaya. The area has faced many significant earthquakes in the past, due to its proximity to the Himalayan mountain range [3, 4]. It was observed that after the 2015 Gorkha Earthquake, the RC frame buildings were less damaged than masonry infill and mud structures. Load bearing and frame structures for high-rise buildings are unfeasible against earthquakes because columns, beams, and slabs are not enough to provide the expected lateral stiffness. In this, paper we used a series of shear walls connected with beams. This system is known as coupled shear wall and the connecting beam is called the coupling beam. Properly detailed coupling beams can dissipate large amounts of energy at the ends of the beam by the formation of plastic hinges before any hinging occurs at the wall base. Damaged connected beams are easier to repair than walls. For developing countries, the process of urbanization is generally associated with the growth of vulnerable infrastructures and buildings [5], since the relearnt construction codes may be deficient [6]. The cities in developing countries are expending with very fast rates [7] and the location of these cities in earthquake-prone zones is up to the 31% of globally infrastructure built-up areas [8].

Many studies are available regarding the theoretical and experimental studies of coupled shear walls. Authors in [9] created curves from the continuum theory for the rapid evaluation of the stresses and maximum deflections. Authors in [10] developed a technique where the beams made using uniform openings having vertical arrangements inside the walls had been replaced by minute elastic laminas of similar stiffness. Authors in [11] presented a method that the connecting beams applied to develop axial, flexure, shear, and torsion resistance have been considered as slender elastic members. Authors in [12] studied the frame method application of nodal rotational degree of freedom and shear deformation while analyzing the coupled wall frame structures. Authors in [13] gave the idea of single band openings of asymmetrical coupled shear walls and two band openings of symmetrical arrangement. Authors in [14] present coupling beams used to transfer forces between wall piers. The upper limit of 66% Coupling Ratio (CR) was proposed in [15]. The CR range from 30 % to 45 % has been proposed in [16]. The competent design has been proposed [17] for 30-story reinforced concrete structure, with the structures having CR value of 67% and 78%.

The coupled shear wall concept for the earthquake resistance design of structures is very useful because the coupled beams fail before the rest of the building during an earthquake, and they can be easily repaired. The knowledge gap filled in this paper is the curtailment of shear walls to maintain the CR within the limit of 30-45 %, thus reducing the cost of the building. In this paper, we present the positioning of coupled shear walls of different shapes of RCC structure. The main objective of this paper to investigate the brittle failure of coupling beams and to show that the damage of buildings before the coupling beams depends on the CR. So, we can provide 40-50 % coupled shear walls for the regular sections and 60-70 % for the irregular sections of the total building height to maintain the CR within limits for good-performing and economical earthquake resistant structure design.

II. METHODOLOGY

We modeled a 10-story RCC building with 30 m × 30 m coupled shear walls, with coupled shear width of 14.5 m and thickness of 25 cm (Figures 1-2). The dimensions of the primary beams are assumed as 50 cm × 60 cm, of the secondary beam as 35 cm × 45 cm, of the columns as 50 cm × 50 cm, and of opening in the coupled shear wall as 4.5 m × 2 m. M25 concrete and Fe 500 TMT rebar were used. All the provisions laid down in IS 13920:2021 deals with the flexural strength and boundary elements required for shear walls.

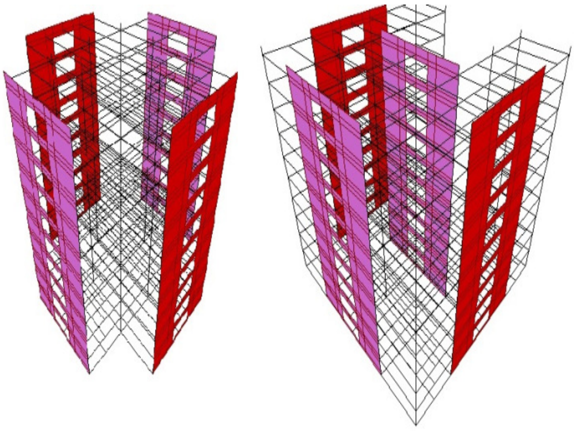

Fig. 1. Cross section and channel section.

The time history method was used. We have taken the ground motion of Patna, Bihar for non-linear dynamic earthquake analysis of different shape of structure from [18]. In this, the base shear (Vb) is obtained by SAP2000 and the shear at each floor is calculated manually as:

$$Q_i = \frac{W_i h_i^2}{\sum W_i h_i^2} \quad (1)$$

If the manually calculated force is greater than the forces calculated by SAP2000, then the ratio of the force calculated manually and the SAP2000 generated forces is multiplied by a Scale Factor (SF) and the building effects are observed.

The followed steps are:

- Distribute the base shear along the height of the building at various levels and calculate the Over Turning Moment (OTM).
- Calculate the equivalent triangular load on the coupled shear wall.
- Calculate the shear force and moment in coupling beams by using Figure 3.

The shear reactions at the bases of the wall piers are resisting the base shear. The proportion of overturning moment (OTM) resisted by the couple is defined as the CR.

$$CR = \frac{LXV_{beam}}{OTM} x100 \quad (2)$$

Over Turning Moment (OTM) = 61361.33 kN.m

$$M = \frac{WH^2}{3}$$

$$W = \frac{3M}{H^2}, \; W = 204.54 \text{ KN}$$

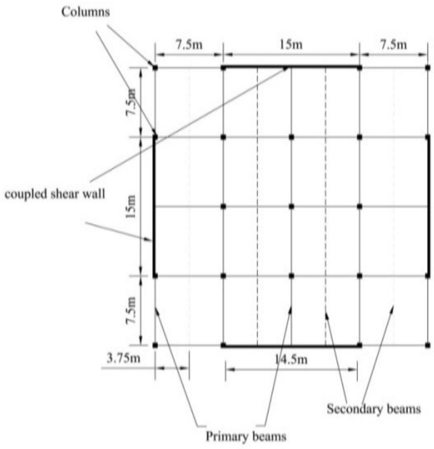

Fig. 2. Cross section plane.

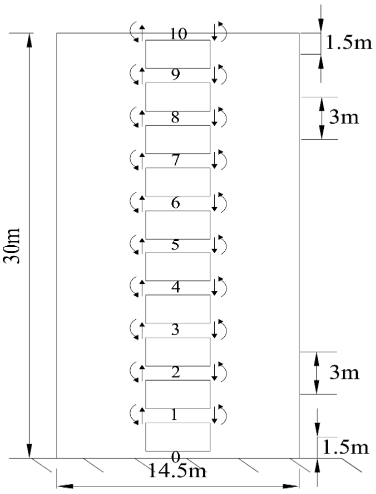

Fig. 3. Coupling beam.

TABLE I. STORY SHEAR AND LATERAL FORCES OF THE REGULAR SECTION

Floor weight (KN)	**Height (m)**	**Wixhi2**	**Storey shear (KN)**	**FXH (KNm)**
7107.19	0	0	0	0
7107.19	3	63964.71	6.904511177	20.71353
7107.19	6	255858.8	27.61804471	165.7083
7107.19	9	575682.4	62.14060059	559.2654
7107.19	12	1023435	110.4721788	1325.666
7107.19	15	1599118	172.6127794	2589.192
7107.19	18	2302730	248.5624024	4474.123
7107.19	21	3134271	338.3210477	7104.742
7107.19	24	4093741	441.8887153	10605.33
7107.19	27	5181142	559.2654053	15100.17

III. RESULTS

Table II shows the displacement and drift of the regular section, while Figure 4 exhibits the drift and displacement versus height.

TABLE II. HEIGHT, DISPLACEMENT, AND DRIFT OF THE REGULAR SECTION

Height (m)	Displacement (mm)	Drift (mm)
0	0	0
3	0.32	0.32
6	0.92	0.6
9	1.7	0.77
12	2.64	0.95
15	3.6	0.95
18	4.43	0.84
21	5.22	0.79
24	5.98	0.76
27	6.68	0.7
30	7.3	0.62

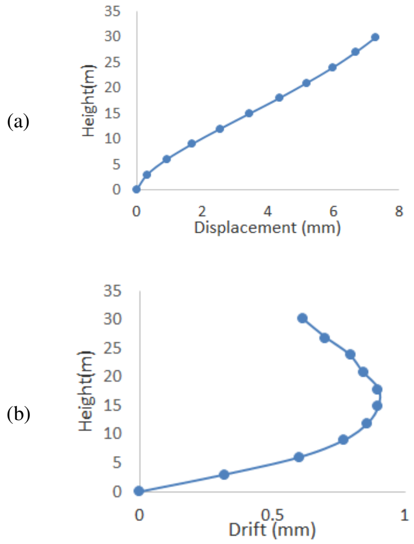

Fig. 4. Height vs (a) displacement, (b) drift (regular section).

The maximum drift of the stories of the regular section is 0.95 mm. So, the actual drift is less than the value of the allowable drift (12 mm).

Table III and Figure 5 and Table IV and Figure 6 show the displacement and drift of the cross section and channel section, respectively.

TABLE III. HEIGHT, DISPLACEMENT, AND DRIFT OF THE CROSS SECTION

Height (m)	**Displacement (mm)**	**Drift (mm)**
0	0	0
3	0.288	0.288
6	0.84	0.55
9	1.56	0.72
12	2.39	0.83
15	3.23	0.84
18	4.1	0.87
21	4.96	0.86
24	5.73	0.77
27	6.44	0.71
30	7.07	0.63

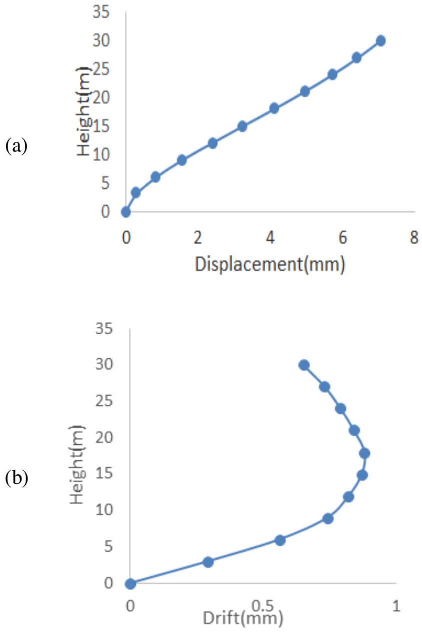

Fig. 5. Height vs (a) displacement, (b) drift (cross section).

TABLE IV. HEIGHT, DISPLACEMENT, AND DRIFT OF THE CHANNEL SECTION

Height (m)	**Displacement (mm)**	**Drift (mm)**
0	0	0
3	0.3	0.3
6	0.85	0.55
9	1.6	0.75
12	2.41	0.81
15	3.26	0.85
18	4.14	0.88
21	5	0.86
24	5.79	0.79
27	6.52	0.73
30	7.17	0.65

The maximum drift of the stories of the channel section is 0.88 mm. So, the actual drift is less than the allowable drift value (12 mm). The maximum story displacement in the regular structure was found to be equal to 7.3 mm, whereas relatively to the regular structure, the maximum displacement in the cross section and the channel section were 6.19 mm and 6.2 mm, respectively, but after separate analysis of the sections, the maximum displacement in cross section and channel section were found to be 7.07 mm and 7.17 mm, respectively. From this it can be concluded that the regular structure performed well during the earthquake as compared to the irregular structure and the performance of the cross section was better than that of the channel section during the earthquake.

IV. CONCLUSIONS

According to [16], systems with coupling ratios of 30 % to 45 % perform the best and are the most cost-effective since they need less steel and concrete. The traditional method for medium- to high- rise building construction and repairing are uneconomical without placing coupled shear walls against earthquake forces because the coupled shear walls reduce the moment. If an earthquake's force exceeds the design level, the connected beams will sustain damage first and withstand the structure collapse. Story drift is directly correlated with flexibility (Fs). Maximum story drift is 0.89 mm at a height of 12 m above the ground, 0.88 mm at 18 m, and 0.87 m at 18 m for the regular plan, channel section, and cross section, respectively. Therefore, the regular plan dissipates more energy than the irregular plan, and the cross section dissipates more energy than the channel section. Based on the limited study of the current paper, we can say that regular buildings performed well during earthquakes as compared to buildings with irregular plans. Regarding the performance with irregular plans, it was observed that the cross section structure performed better than the channel section. In order to keep the coupling ratio within acceptable bounds for effective earthquake resistance structure design and structure beam economy, we propose the use of 40–50 % coupled shear walls for the regular sections and 60–70 % for the irregular plans of the overall building height. If the CR is within the range of 30 % to 45 %, then the coupling beam will fail first. These beams can be repaired easily at a low cost. The findings of this paper may assist engineers, researchers, and designers in creating earthquake-resistant structures that are both efficient and cost-effective.

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