Seismic Performance of Multi-storey RC Building with Coupled Shear Walls

N. Y. Anjali and B. R. Beena

Abstract Earthquakes are one of the most dangerous disasters which cause severe threats to life and property. Lack of land availability and rising demands for better housing facilities have made vertical construction to gain significant importance. Nowadays, multi-storey buildings are being constructed even in high earthquake prone regions. Conventionally, buildings are made seismic resistant by constructing shear walls or by installing passive energy dissipating devices like dampers. The use of coupled shear wall (CSW) systems instead of conventional shear walls is an innovative technique that aims at enhancing the performance of buildings which are located even in high seismic zones. In the present study, a multi-storey RC building which is symmetrical in plan and having coupled shear wall system was modelled using ETABS software and it was assumed to be located in a region of high seismic activity. Response spectrum analysis was carried out on the building model and the results were compared with seismic responses of the same building having conventional shear walls instead of coupled shear walls. Therefore, improved performance of buildings having CSW systems and the use of such systems for better seismic resistance was understood.

Keywords Earthquake · Seismic resistance · Coupled shear walls · Response spectrum analysis · ETABS

1 Introduction

In the present era, construction of multi-storey structures have become widespread and highly important due to the increase in population and lack of availability of sufficient land. Nowadays, high-rise buildings are being constructed even in highly earthquake prone regions. Such practices can lead to severe damages during an

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G. C. Marano et al. (eds.), *Proceedings of SECON'21*, Lecture Notes in Civil Engineering 171, https://doi.org/10.1007/978-3-030-80312-4_18

earthquake scenario as the lateral seismic loads cause sway in the buildings which increases with increase in number of storey and due to this, it is necessary to make them seismic resistant. Thus it is important to counteract the lateral loads and to increase the strength and stiffness of the buildings so as to avoid huge damages to life and properties. Dynamic analysis methods are commonly adopted to conduct detailed studies on the behavior of multi-storey buildings during earthquakes in order to determine their maximum responses to various base excitations [1, 2].

The major concerns to be dealt with during the seismic analysis, design and construction of multi-storey buildings are to have their lateral storey drift, displacement and base shear values within the accepted limits as preferred by the codes, which is quite difficult in the case of seismic activities of high intensity. Conventionally, these requirements are satisfied by constructing shear walls in buildings for improving their lateral stiffness [3]. Nowadays, shear walls are extensively constructed in multi-storey structures as lateral force resisting members in the aim of reducing the responses of buildings to very high seismic forces. They are even used for retrofitting existing structures which does not comply with updating of codes or design practices [4].

Coupled shear walls are modifications of shear walls in which the wall piers are connected by coupling beams. In such systems, overturning moments are resisted by axial compression-tension couples due to accumulation of shear in the coupling beams, instead of lateral load resistance by individual flexural action in shear walls. They show excellent energy dissipation capacities and the dissipation of input energy is distributed along the coupling beams instead of concentrating at the bottom of wall piers [5, 6]. Under the action of large seismic loads, the coupling beams undergo degradation in strength and stiffness and their performance evolves from that of a coupled shear wall system to a system of linked wall piers which further resisted the seismic forces. This indicated the presence of reserve strength and stiffness in the wall piers even after the degradation in the capacity of coupling beams [7].

Nowadays, the concept of design codes have changed from strength-based to performance-based design and so, many researches are being carried out to determine the behavior and performance of coupled shear walls under severe earthquakes. Researches have shown that these structural systems not only provide large strength and stiffness to structures but they also control the horizontal deformation of buildings under large seismic loads [8, 9]. Hence, understanding the behavior of coupled shear wall systems on buildings that encounter high seismic forces are of great relevance for further upgradations in construction techniques as it will aid engineers in carrying out safer design and construction of building structures. This paper deals with understanding the seismic performance of a multi-storey structure which uses coupled shear walls over conventional shear walls as lateral load resisting members.

2 Methodology

A Model of multi-storey RC building was created in ETABS 2018 with shear walls which were provided along two of its bays in the X-direction, throughout the entire height. Another model of the same building was created in which the shear walls were coupled together by RC coupling beams at all storey heights, thereby forming a system of coupled shear walls. Design check was carried out for the models to ensure proper designing of all structural members. Linear dynamic analysis by response spectrum analysis was conducted to study the seismic responses of the structure under the action of both shear walls and couples shear wall systems when the building was located at a zone of high seismic activity. Analysis results were obtained in terms of storey displacement, storey drift and storey shear, and the results were evaluated to arrive at conclusions regarding response of the structure to high seismic forces.

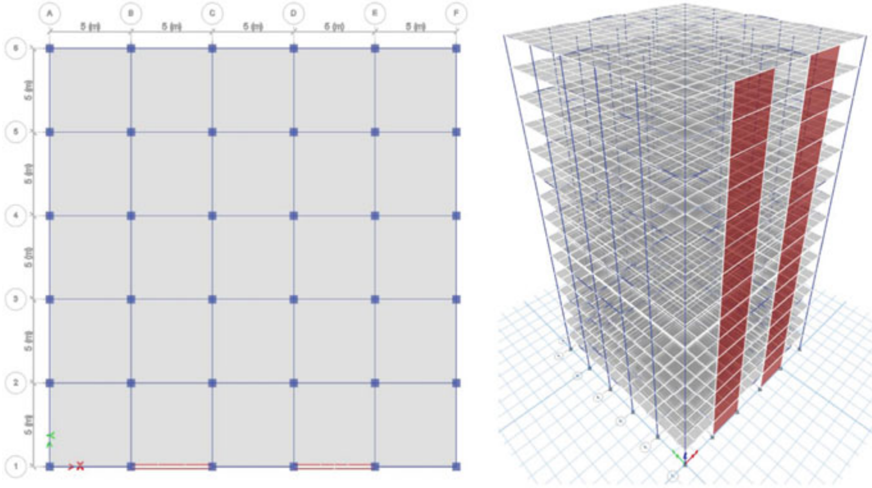
3 Model Description

For the study, a G + 15 storey RC residential building having square plan was modelled. The total height of the building is 45 m with a typical storey height of 3 m. It has 5 bays with 5 m spacing in each direction and a typical floor plan of 625 m^2 at all storey levels. Dimensions of columns were 500 mm × 500 mm and that of beams were 250 mm × 600 mm. The thickness of slabs were considered to be 150 mm. M30 grade concrete and Fe500 grade steel were used for the structural members, whereas Fe415 grade steel was used for the lateral ties in beams and columns.

In the first model, shear walls were provided in two bays along the x-direction and the wall piers have a thickness of 250 mm. In the second model, the shear walls were coupled together using coupling beams. The thickness of wall piers of the CSW system is 250 mm and the coupling beams were modelled as spandrels having size of 250 mm × 1000 mm. The floors were considered to be semi-rigid diaphragms. Figure 1a, b represent the plan view and 3D view of the model having shear walls. Figure 2a, b represents the plan view and 3D view of the model having coupled shear walls. The building was modeled in ETABS 2018.

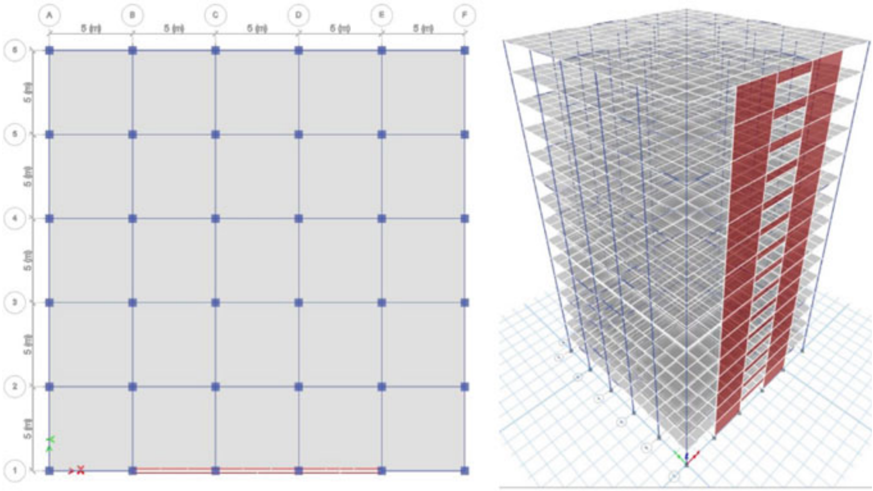
3.1 Loads

Live load of 2 kN/m^2 was applied as per IS 875 (Part II): 1987 and dead loads were assigned by the software. Wall loads were assigned to the beam elements as superimposed dead loads of 11.04 kN/m and 4.6 kN/m for parapets. Floor finish loads were taken to be 1 kN/m^2. Support conditions of the building were assumed to be fixed.



(a) (b)

Fig. 1 **a** Plan view and **b** 3D view of building with shear walls



(a) (b)

Fig. 2 **a** Plan view and **b** 3D view of building with coupled shear walls

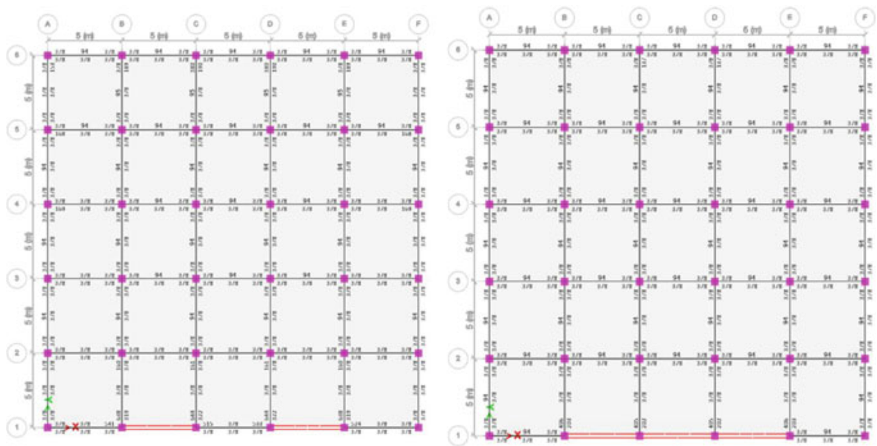
4 Response Spectrum Analysis

Response spectrum analysis is a linear-dynamic statistical analysis method that helps in the determination of response of a structure to seismic events. In this study, response spectrum function was set as per IS 1893: 2016 and was defined for seismic zone factor of 0.36, Medium (Type II) soil, importance factor of 1.5, response reduction factor of 5 and 5% damping.

4.1 Design Check

Design checks were conducted on the structure that was modelled to ensure that the beams and columns were not overstressed or had not undergone failure. Generally, after a design check, overstressed beams and columns will be indicated by red color and all the structural members that have passed the check will be indicated by pink color. In this study, all the structural members had passed the design check, indicating that they were sufficient to safely carry the assigned loads. Figure 3a, b show the plan view of design check result of models having shear walls and coupled shear walls respectively.

It can be seen that all members in both models passed the design check, indicating that they were safe to carry the assigned loads. Response spectrum analysis was carried out on the two models and results were obtained in terms of maximum storey displacements, storey drifts and storey shears. The seismic analysis results obtained from both models were compared to reach valid conclusions.



(a) (b)

Fig. 3 Design check of model with **a** shear walls and **b** coupled shear walls

4.2 Storey Displacement

Figure 4a shows maximum storey displacements in the X-direction versus elevation for buildings having shear walls and coupled shear walls. It was observed that the displacements increased with elevation of the building for both models and the displacement was maximum at the top storey. It was also observed that the model having coupled shear walls showed reduction in storey displacements at all storey heights when compared to the building having conventional shear walls.

4.3 Storey Drift

Figure 4b shows the maximum storey drifts observed in the response spectrum analysis conducted for the buildings having shear walls and coupled shear walls. The storey drift values were maximum at the third storey for both models and the drift versus elevation curve conformed to the general storey drift pattern observed for multi-storey buildings. Storey drifts were lesser for the building having coupled shear walls when compared to the same building when it had conventional shear walls.

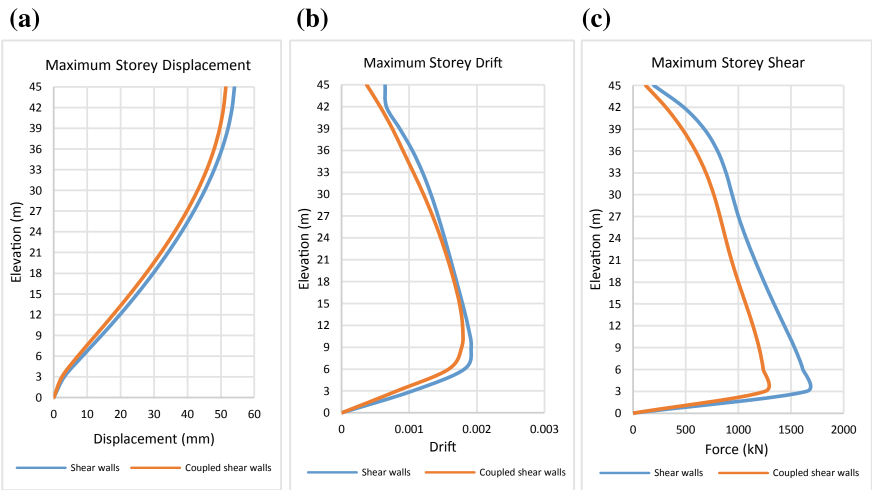


Fig. 4 **a** Maximum storey displacements, **b** maximum storey drifts and **c** maximum storey shear of building with shear walls and coupled shear walls

Table 1 Results of response spectrum analysis

Model	Building with conventional shear walls	Building with coupled shear walls	Inference
Maximum storey displacement (mm)	54.054	51.479	Decrease of 4.76%
Maximum storey drift	0.001916	0.001788	Decrease of 6.68%
Storey shear (kN/m)	1648.366	1252.785	Decrease of 24%

4.4 Storey Shear

Figure 4c shows maximum shear forces in the x-direction versus elevation of the building with conventional shear walls and coupled shear walls. Storey shear forces had a more pronounced effect at the bottom storeys of the building. The forces were maximum at the first storey for both models but the building with coupled shear walls showed considerable reduction in shear forces at all storey levels when compared to the same building with conventional shear walls.

5 Results and Discussions

The effect of coupled shear walls on the seismic performance of a 15-storey RC building was studied and the results were compared with that of the same building having conventional shear walls. Response spectrum analysis was conducted and the results are summarized in Table 1. The views on the results obtained are discussed in the conclusions.

From the response spectrum analysis results, maximum storey displacement of 54.054 mm, maximum storey drift of 0.001916 and storey shear forces of 1648.366 kN/m were observed for buildings having conventional shear walls and the corresponding values were reduced to 51.479 mm, 0.001788 and 1252.785 kN/m respectively, when the conventional shear walls were replaced by the coupled shear wall systems. Therefore, the building with coupled shear walls showed an overall reduction of 4.76% in storey displacement, 6.68% in storey drift and considerable reduction of 24% in storey shear forces, when compared to a similar conventional shear wall building, proving them to provide better seismic resistance to structures.

6 Conclusions

A detailed response spectrum analysis was conducted on two models of a G + 15 storey RC building having conventional shear walls and coupled shear walls in ETABS 2018 software based on IS 1893: 2016. Based on the seismic performance of the models, following conclusions were drawn:

- Coupled shear walls reduced the seismic responses by providing increased stiffness to the structure, when compared with the building having conventional shear walls.
- There was a reduction of 4.76% in maximum storey displacement and 6.68% in maximum storey drift values for coupled shear wall building when compared to the conventional shear wall building, owing to the increased stiffness of coupled shear walls and coupling action of the coupling beams.
- Coupled shear wall building showed considerable reduction in storey shear values by 24% when compared to the same building having conventional shear walls which indicates the improved seismic performance of Coupled shear walls.

Therefore, conventional shear walls can be adequately replaced by coupled shear walls in the present era of construction, which will help in improving the resistance of the structures to even very high seismic forces. This reduces the susceptibility of such buildings to severe damages induced by earthquake scenarios, further reducing possibilities of loss of lives and also preventing damages to adjacent buildings and hence proving them to be better lateral load resisting structural systems.

References

1. Ahamad SA, Pratap KV (2020) Dynamic analysis of G + 20 multi storeyed building by using shear walls in various locations for different seismic zones by using Etabs. Mater Today: Proc (Elsevier)
2. Khy K, Chintanapakdee C, Warnitchai P, Wijeyewickrema AC (2019) Modified response spectrum analysis to compute shear force in tall RC shear wall buildings. Eng Struct 180:295–309 (Elsevier)
3. Dahesh MA, Tuken A, Siddiqui NA (2015) Controlling the earthquake-induced lateral displacement of RC buildings using shear walls: parametric study. Arab J Geosci (Springer)
4. Cavdar O, Cavdar A, Bayraktar E (2017) Earthquake performance of reinforced-concrete shear-wall structure using nonlinear methods. J Perform Constr Facil (ASCE)
5. Lu X, Chen L (2005) Modeling of coupled shear walls and its experimental verification. J Struct Eng (ASCE)
6. Harries KA, Moulton JD, Clemenson RL (2004) Parametric study of coupled wall behavior—implications for the design of coupling beams. J Struct Eng 130(3) (ASCE)
7. Eljadei AA, Harries KA (2014) Design of coupled wall structures as evolving structural systems. Eng Struct 73:100–113 (Elsevier)
8. Asghari A, Zarnagh BA (2017) A new study of seismic behavior of perforated coupled shear walls. Int J Civ Eng 15: 775–789 (Springer)
9. Afefy HM (2020) Seismic retrofitting of reinforced-concrete coupled shear walls: a review. Pract Periodical Struct Des Constr 25(3) (ASCE)