

# Evaluation of the Dynamic Characteristics of Coupled Shear Wall System under Seismic Loads

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## ABSTRACT

The Coupled Shear Wall (CSW) is a widely used lateral resistance system in medium to high-rise buildings, known for its efficiency in mitigating seismic wind forces. Its features, including high shear stiffness, strong energy dissipation, enhanced ductility, and robustness, help minimize lateral deformations. This study investigates the dynamic properties of CSW systems, focusing on the fundamental vibration period, top lateral displacement, degree of coupling, and shear force distribution in coupling beams. The research analyzes various design parameters, such as wall thickness, wall length, building height, and coupling beam thickness across multiple CSW models. The results indicate that an optimal wall thickness effectively reduces fundamental period and top displacement while increasing shear force capacity in lower stories. Additionally, greater coupling beam thickness leads to maximum shear forces occurring lower in the structure, enhancing shear resistance, particularly in the lower third of the building. The percentage reduction in fundamental period and top displacement ranges from 30% to 60%, achieved by increasing coupling beam rigidity.

*Keywords-coupled shear wall; coupling beam; displacement; fundamental period; degree of coupling*

## I. INTRODUCTION

CSW are vertical structural elements consisting of two or more shear walls linked by coupling beams, typically found in high-rise buildings [1]. These beams, often associated with stair or elevator cores, transfer vertical forces between walls, resisting overturning moments caused by lateral loads [2]. The seismic performance of coupling beams is crucial to the overall structural behavior, with concrete beams being the most widely used [3]. In structural analysis, planar CSWs focus on deformations within the plane, while non-planar analyses consider additional in-plane, out-of-plane, and torsional deformations [4, 5]. Authors in [6] conducted experiments on Reinforced Concrete (RC) coupling beams, finding that diagonal and rhombic reinforcement layouts performed better

than traditional ones, with the rhombic layout offering enhanced rotational ductility and minimal strength degradation under varying loading conditions. A global study on sustainable civil structures highlighted the role of CSWs in high-rise RC buildings, emphasizing the challenges posed by thinner skyscrapers and the importance of efficient reinforcement strategies [7]. Diagonal reinforcement was identified as particularly effective in managing extreme lateral stresses. Authors in [8] studied four alternative CSW models using ETABS 2015, focusing on story displacement, shear, and drift through equivalent static and response spectrum analyses. Authors in [9] assessed CSW systems based on international building codes, while authors in [10] reviewed the seismic behavior of CSW systems and retrofitting strategies, emphasizing the selection of cost-effective retrofitting methods

based on performance requirements and economic factors. The use of lightweight concrete and linear-elastic Glass Fiber-Reinforced Polymer (GFRP) bars in floor construction reduces the geometric nonlinearity (P- $\Delta$  effects) and dissipates seismic energy, minimizing post-earthquake damage [11]. The method was experimentally validated through total station measurements, structural analysis, and displacement gauges on a RC beam [12]. The elastic nature of GFRP bars enhances the deformation capacity, leading to better seismic energy absorption and reduced structural damage and repair costs [13-15].

The present study examines the impact of coupling beam rigidity on the dynamic properties of CSW systems through a parametric analysis. The key parameters analyzed include the fundamental vibration period, overall seismic drift, and degree of coupling. Using SAP2000 software [16], the study provides insights into these properties and their influence on CSW performance. The findings aim to improve CSW system design, enhancing structural resilience and safety under seismic loads. The previous studies have not fully explored the combined effects of wall thickness, coupled beam rigidity, and height of the building on the dynamic behavior of CSW systems. The current study addresses this gap by providing a comprehensive parametric analysis that considers these factors simultaneously.

## II. PARAMETRIC STUDY AND METHODOLOGY

In this study, two U-shaped CSWs, functioning as elevator cores, were modeled and interconnected through coupling beams. The models were studied with different heights of 10, 15, 20, and 25 stories, with a story height being 4.0 m, and the length of the couple walls was 5.0 m and 7.0 m. The study parameters, categorized into two phases, are summarized in Table I. The initial phase includes the aspect ratio ( $H/L_w$ ), building height ( $H$ ), wall length ( $L_w$ ), and wall thickness ( $t_w$ ). The final phase focuses on the coupling beam cross-section ( $b$ ,  $h$ ) and the number of stories. The parameter ranges in Table I were chosen to cover typical design scenarios encountered in medium to high-rise buildings. The parametric analysis examines the CSW system, shown in Figure 1, analyzing coupling beam thickness, wall length in the plan, and the number of stories. A total of 120 models were examined, with seismic loads applied based on the International Building Code [17]. All CSW systems were modeled and analyzed using SAP2000 [16], chosen for its robust shear wall modeling capabilities, user-friendly interface, and widespread acceptance in structural engineering. In the model, shear walls were modeled as shell elements, while coupling beams were represented as frame elements. The study outputs include the fundamental period of vibration, top displacement, and shear force in coupling beams under seismic loads.

TABLE I. MODEL GEOMETRIC PROPERTY

Parameter	Values
Number of stories (building height)	10, 15, 20, 25
Wall thickness (mm)	300, 400, 500, 600
Story height (mm)	4000.0
Slab thickness (mm)	200
Coupling beam thickness (mm)	200, 400, 600, 800, 1000

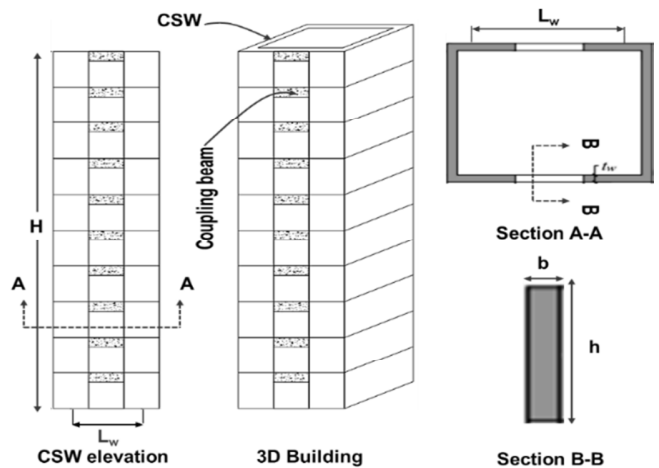


Fig. 1. Configuration of the used CSW.

## III. EFFECT OF COUPLED SHEAR WALL THICKNESS ON THE FUNDAMENTAL PERIOD OF VIBRATION

The relationship between the fundamental period of vibration (s) and wall thickness (mm) for CSW systems is illustrated in Figure 2 for 10-story, 15-story, 20-story, and 25-story buildings. The results show that increasing wall thickness reduces the fundamental period due to greater lateral stiffness, though the rate of reduction stabilizes beyond a certain thickness. Additionally, coupling beam cross-section affects the fundamental period, with smaller beams (e.g., CB300  $\times$  200) leading to higher periods due to lower stiffness, while larger beams (e.g., CB300  $\times$  1000) reduce periods by enhancing the coupling action and system stiffness. The Hinged-Hinged model exhibits the longest fundamental periods, as it lacks the stiffness contribution of coupling beams.

In Figure 2 (a), the period decreases significantly as wall thickness increases from 300 mm to 400 mm, followed by a gradual decline for thicker walls. Larger beams (e.g., CB300  $\times$  1000) result in notably lower periods compared to smaller beams (e.g., CB300  $\times$  200), emphasizing the role of beam stiffness in shorter buildings. Figure 2 (b) displays similar trends. However, the fundamental periods are higher than those in the 10-story model due to increased height and reduced global stiffness. In Figure 2 (c), the range of fundamental periods is broader, reflecting greater dynamic effects in taller buildings, with larger beams exhibiting a more pronounced impact by improving coupling action. Finally, in Figure 2 (d), the 25-story model has the longest fundamental periods owing to increased height and flexibility. The reduction in period with increasing wall thickness is less steep beyond 400 mm, suggesting diminishing stiffness benefits for very tall structures.

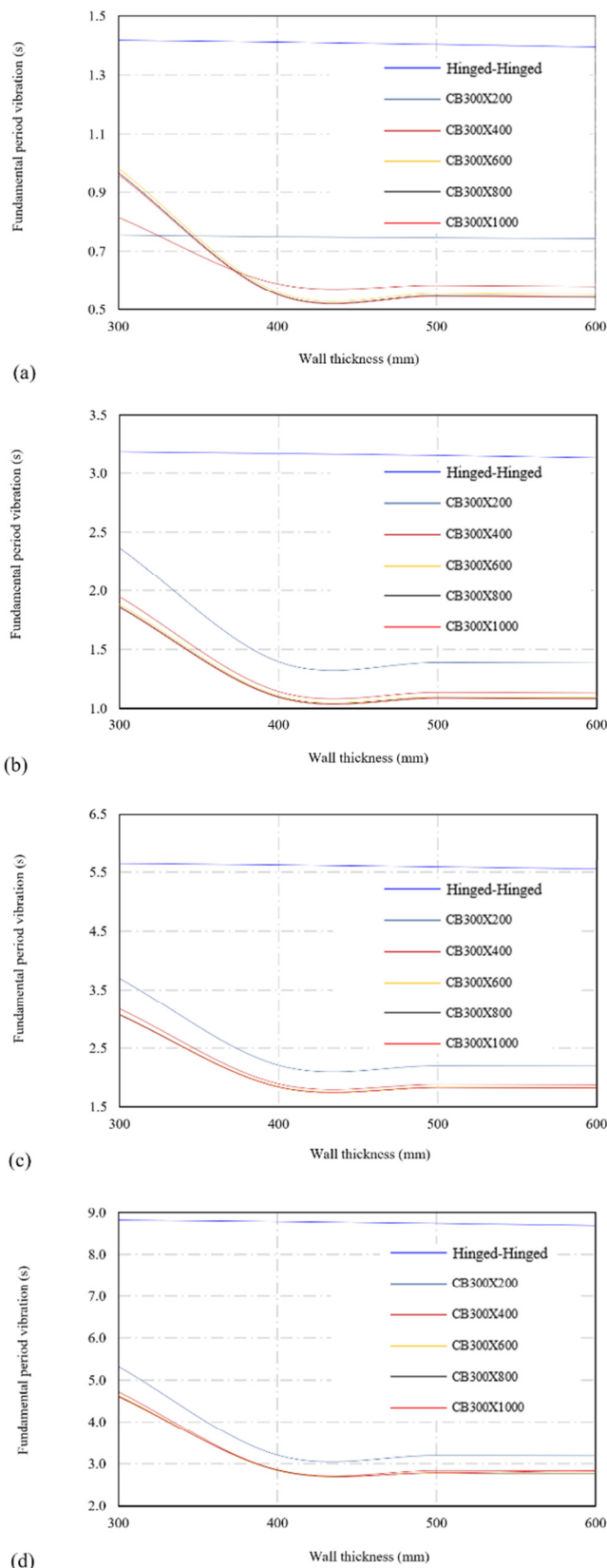


Fig. 2. Fundamental period vs CSW thickness for: (a) 10-story, (b) 15-story, (c) 20-story, and (d) 25-story models.

Overall, taller buildings exhibit higher fundamental periods due to reduced global stiffness, making coupling beam effectiveness more critical. Increasing wall thickness significantly lowers the fundamental period, particularly up to 400 mm, beyond which the effect diminishes. The inclusion and size of coupling beams play a vital role in enhancing CSW system stiffness, with larger beams reducing the fundamental period across all models. In contrast, Hinged-Hinged systems, which lack coupling beams, exhibit significantly longer vibration periods, highlighting the importance of coupling beam stiffness.

#### IV. EFFECT OF COUPLED SHEAR WALL THICKNESS ON THE TOP DISPLACEMENT

The relationships between top displacement (mm) and wall thickness (mm) for CSW systems in 10-story, 15-story, 20-story, and 25-story buildings are illustrated in Figure 3.

Each plot examines how increasing wall thickness and varying coupling beam dimensions affect lateral stiffness and top displacement under lateral loading. In all cases, increasing wall thickness significantly reduces top displacement, particularly for thinner walls (300–400 mm), though the rate of reduction slows beyond 400 mm, indicating diminishing stiffness benefits. Smaller coupling beams (e.g., CB300 × 200) lead to higher top displacements due to their lower lateral stiffness, while larger beams (e.g., CB300 × 1000) enhance stiffness and reduce displacements.

In Figure 3 (a), top displacement decreases rapidly as wall thickness increases from 300 mm to 400 mm, with a more gradual decline beyond 400 mm. Systems with larger coupling beams consistently exhibit lower displacements than those with smaller beams, and the displacement range remains relatively small due to the inherent stiffness of the 10-story model. In Figure 3 (b), displacement values increase compared to the 10-story model, reflecting reduced lateral stiffness in taller structures. Similar trends are observed, with significant displacement reductions for wall thicknesses up to 400 mm and smaller improvements beyond that. Larger beams continue to minimize displacements effectively. Figure 3 (c) demonstrates that for 20-story buildings, the displacement range broadens, with higher overall values than in the 10-story and 15-story models, as taller structures are more flexible. The effect of coupling beam size becomes more pronounced, particularly for thinner walls, with larger beams effectively reducing displacements even in taller buildings. In Figure 3 (d), the 25-story model exhibits the highest top displacements due to increased height and flexibility. The reduction in displacement with increasing wall thickness is more gradual for thicker walls (400–600mm), reinforcing diminishing returns for very tall structures. While larger coupling beams remain effective in reducing displacements, their benefits are slightly reduced compared to shorter buildings. As the height of a building rises, the importance of coupling beams grows. Larger beams enhance coupling effectiveness, leading to a substantial reduction in top displacements. To achieve the best design, it is essential to balance wall thickness with the size of the coupling beams, considering both the building's height and performance needs. Beyond certain limits, increasing wall thickness or beam size results in reduced structural advantages.

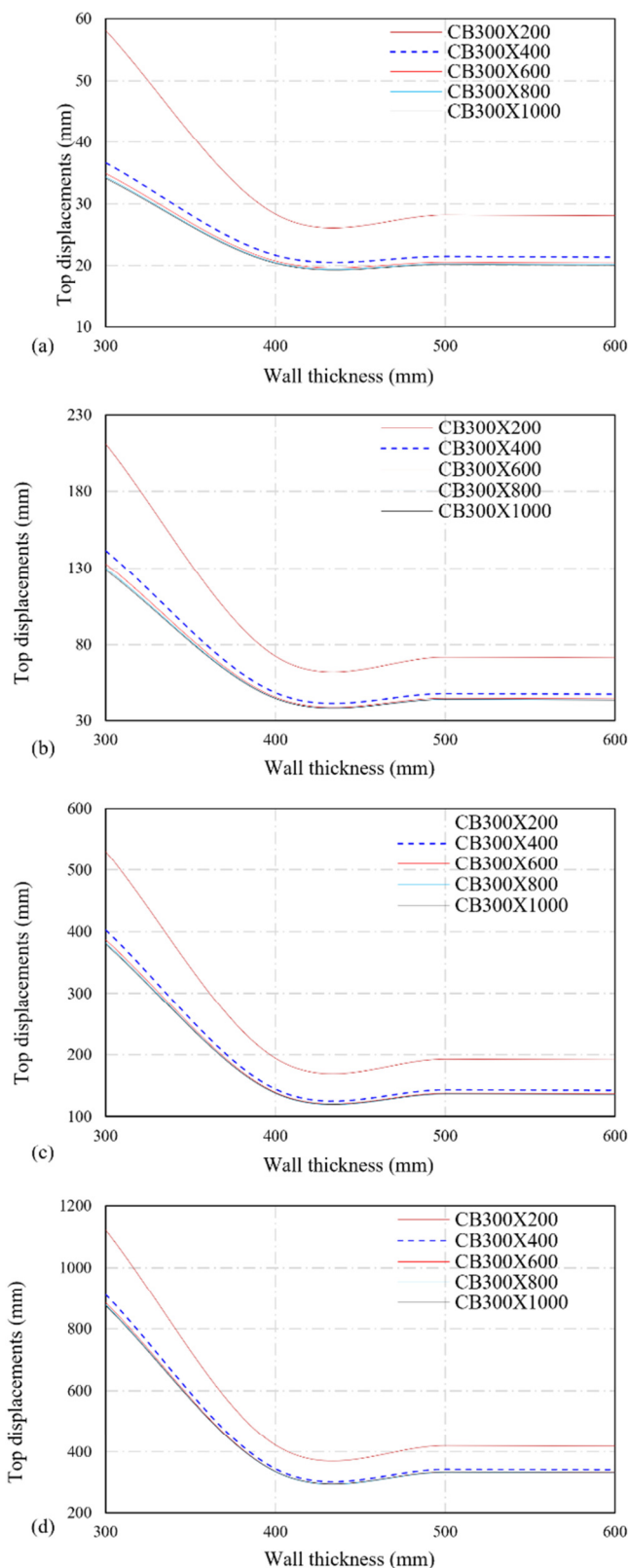


Fig. 3. Top displacement vs CSW thickness for: (a) 10-story, (b) 15-story, (c) 20-story, and (d) 25-story models.

### V. EFFECT OF COUPLED SHEAR WALL LENGTH ON THE DEGREE OF COUPLING

Figure 4 depicts the relationship between CSW length and the degree of coupling for high-rise buildings of different heights. In 10-story buildings, coupling efficiency decreases as shear wall length increases, suggesting that longer walls do not always improve coupling efficiency in low-rise structures. An optimal wall length may exist, beyond which additional length provides diminishing benefits. A similar decreasing trend is observed in 15-story buildings, though the slope is less steep than in the 10-story case, indicating that shear wall length continues to affect coupling efficiency as building height increases. In 20-story buildings, the trend persists but at a slower rate. The degree of coupling is generally higher across all wall lengths compared to 10-story and 15-story buildings, suggesting that mid-rise structures benefit more from longer shear walls up to a certain threshold. For 25-story buildings, the degree of coupling starts at a higher value for shorter wall lengths than for shorter buildings but decreases significantly as wall length increases. This may be due to the increased flexibility of taller buildings, where very long shear walls become less effective in coupling due to greater sway and potential changes in vibration modes. Overall, the results suggest that the relationship between shear wall length and coupling efficiency is influenced by building height. Although increasing wall length does not always improve coupling efficiency in low-rise buildings, longer shear walls are more effective in taller buildings up to a certain limit beyond which their influence diminishes.

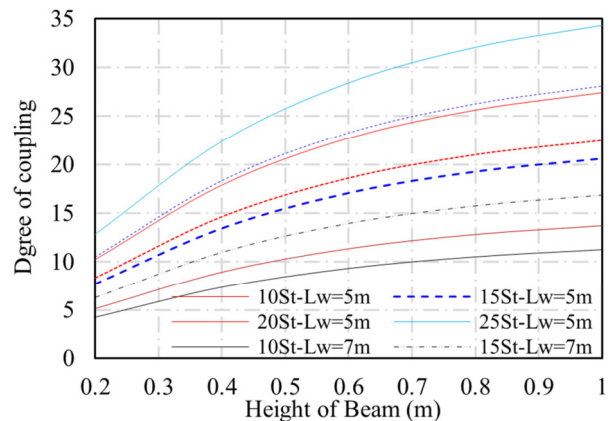


Fig. 4. Effect of CSW length on the degree of coupling.

### VI. EFFECT OF COUPLING BEAM THICKNESS ON THE SHEAR FORCE

Figure 5 portrays the distribution of shear force in coupling beams along the height of CSW systems in 10-story, 15-story, 20-story, and 25-story buildings. The graphs highlight how coupling beam dimensions influence shear force distribution. Shear forces are highest near the base, at around 40% of the structure height, and progressively decrease with height. This pattern reflects larger moments and lateral forces at the base due to higher overturning moments and smaller lateral

displacements at lower levels. Smaller coupling beams exhibit lower shear force capacities, as indicated by their curves shifting leftwards, while larger beams resist significantly higher shear forces, shifting curves rightwards due to increased stiffness and improved lateral load transfer.

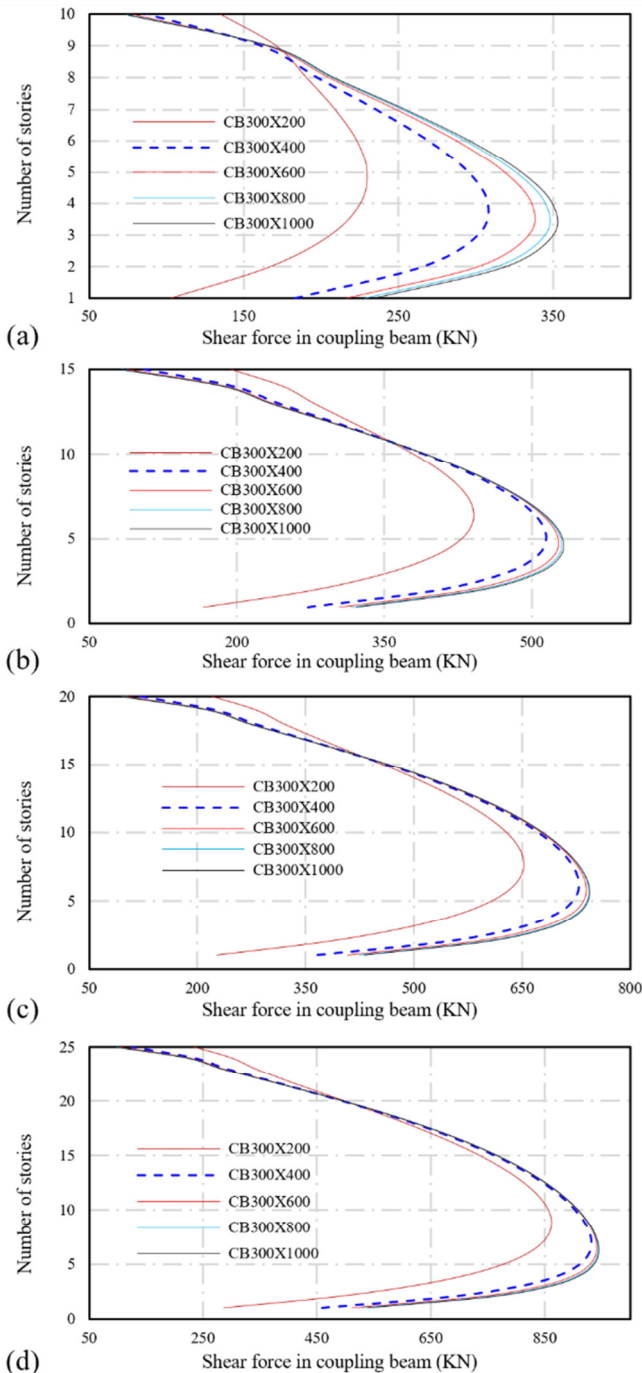


Fig. 5. Shear force generated in coupling beam for: (a) 10-story, (b) 15-story, (c) 20-story, and (d) 25-story (case of wall length = 5 m).

For the 10-story model in Figure 5 (a), the maximum shear force at the base is relatively small compared to taller models, given the shorter height and lower overturning moments. Shear

force capacity varies significantly across beam sizes, with CB300 × 200 displaying much lower resistance than CB300 × 1000, emphasizing the critical role of beam dimensions in resisting shear forces. In the 15-story model in Figure 5 (b), shear forces increase at the base due to the taller structure's greater overturning moments and lateral loading. While shear force decreases with height in all cases, the influence of beam size remains significant, with larger beams being able to resist higher forces. For the 20-story model in Figure 5 (c), base shear forces are significantly higher than in the 10-story and 15-story models, which is consistent with increased height and larger lateral loads. The difference in performance between small and large beams is more pronounced, as taller structures benefit more from the enhanced stiffness and strength of larger coupling beams. In the 25-story model in Figure 5 (d), the highest base shear forces are observed among all cases due to the structure's increased height and lateral load demands. The distribution pattern remains consistent, with shear forces steadily decreasing according to the height. Larger beams significantly outperform smaller beams, demonstrating their ability to handle higher shear demands in tall structures. The diminishing shear force with height suggests that beam dimensions could be optimized according to the height of the structure, with larger beams being used at lower levels and smaller beams at higher levels. These findings provide essential insights for designing and optimizing coupling beams in CSW systems, ensuring that they are adequately sized to resist shear forces while maintaining structural efficiency.

Figure 6 illustrates the shear force distribution in coupling beams for 10-story, 15-story, 20-story, and 25-story buildings with a CSW length of 7 m. The 7 m wall exhibits significantly higher shear force capacities than the 5 m wall for the same building height and coupling beam dimensions. This increase is due to the longer wall providing greater stiffness and lateral load resistance, redistributing more shear force to the coupling beams. Similar trends are observed for smaller coupling beam sizes (e.g., CB300 × 200, CB300 × 400) as in the 5 m wall, but the increase in shear force capacity is more pronounced in the 7 m wall due to improved load distribution efficiency. The overall distribution pattern remains consistent, with shear forces being the highest at the base and decreasing with height, though the maximum shear force values at the base are significantly higher for the 7 m wall, especially in taller structures.

Figure 6 (a) shows that the shear force at the base is approximately 20-30% higher for the 7 m wall than for the 5 m wall, while the difference becomes more pronounced as the building height increases from 10-story to 15-story. Figure 6 (b) highlights the greater impact of wall length in taller structures, where larger beams demonstrate better performance and a more uniform distribution of shear forces along the height. In Figure 6 (c), base shear forces for the 7 m wall are significantly higher, reflecting the increased overturning moments and lateral load resistance provided by the longer wall. The relative performance gap between smaller and larger beams widens, emphasizing the need for adequately sized beams in taller structures with longer walls.

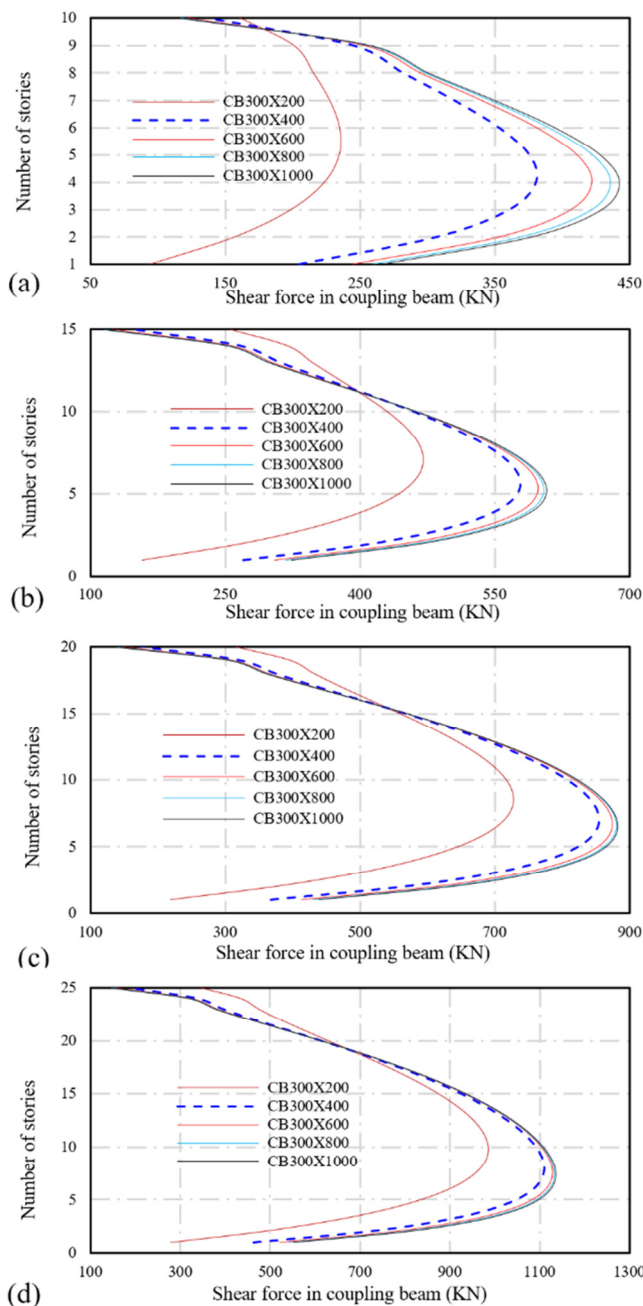


Fig. 6. Shear force generated in coupling beam for: (a) 10-story, (b) 15-story, (c) 20-story, and (d) 25-story (Case of wall length = 7 m).

The highest base shear forces are observed in the 7 m wall, with values nearly doubling in some cases compared to the 5 m wall. In Figure 6 (d), larger beams maintain high capacities and ensure smoother force distribution compared to smaller beams. The increase in wall length from 5 m to 7 m enhances the lateral stiffness of the system, enabling more shear force transfer to the coupling beams. While smaller beams are feasible for shorter walls, they struggle to accommodate the increased forces in longer walls, particularly in taller structures. Larger beams are more suitable for longer walls and taller buildings, providing the required stiffness and capacity to resist

higher shear forces. The choice of wall length significantly impacts shear force distribution, necessitating careful consideration during the design phase. Longer walls require larger coupling beams and more robust reinforcement and detailing. Optimizing wall length and beam dimensions for high-rise buildings can lead to more efficient load distribution and improved structural performance.

## VII. CONCLUSION

In this study, the dynamic characteristics of the Coupled Shear Wall (CSW) system are investigated considering the effect of numerous design parameters, through a parametric study that examines the impact of the coupling beam rigidity, building height, coupling shear wall thickness, and length on the dynamic properties of the CSW system. The results demonstrate that the rigidity of coupling beams significantly influences the dynamic behavior of CSW systems under seismic loads. Increasing coupling beam rigidity results in a 30-60% reduction in both the fundamental period and top displacement, depending on the building height and wall thickness. Additionally, greater wall thickness contributes to a decrease in the fundamental vibration period due to enhanced lateral stiffness, although this effect becomes less pronounced in taller buildings. Specifically, increasing wall thickness from 300 mm to 400 mm significantly reduces top displacement, but the benefits diminish beyond 400 mm. Using thicker coupling beams also improves shear force capacity, facilitating better load transfer in the lower stories, where maximum shear forces tend to occur. Furthermore, increasing beam rigidity enhances the degree of coupling between shear walls, leading to improved load sharing and overall lateral stiffness, particularly in shorter buildings. Finally, longer shear walls further improve coupling effectiveness, resulting in better load distribution and lateral stiffness, with a more significant impact observed in shorter buildings. Increasing wall thickness from 300 mm to 400 mm significantly reduces the top displacement of high-rise buildings. However, beyond a critical thickness of approximately 400 mm, the rate of displacement reduction diminishes, indicating diminishing returns. The study identifies an optimal range of wall thickness, where the reduction in the fundamental period is the most effective. Beyond this range, further increases in wall thickness have a minimal impact, especially in buildings above 20 stories.

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