Effect of Shear Walls Length on the Behavior of Reinforced Concrete Structures

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Abstract

On May 21, 2003, a powerful earthquake with a moment magnitude of Mw=6.8 struck the city of Boumerdes, which is located roughly 50 km east of Algiers, the capital city of Algeria. 2,278 people lost their lives as a result of the earthquake, which also caused several buildings and infrastructures to collapse. Structures with reinforced concrete (R/C) frames did not withstand the earthquake, according to post-seismic observations. In order to reduce risks related to this type of construction, the revised version of the Algerian Seismic Code (RPA 99 Version 2003) restricted the use of RC frame structures to two-story buildings or structures that were eight meters or taller. Over this threshold, shear walls must either fully or partially resist the earthquake loads. To comply with this new requirement, engineers adopted a new construction system by using small length shear walls arranged in L shape at the corners of the building. In order to assess the efficiency of this shear walls configuration, a series of numerical analysis has been performed using the finite element method where the shear walls length was varied from 0.60 m to 2.00 m. For the purpose of this study a typical three-story building constructed in Algeria's most seismically active region, Algiers and the surrounding area, has been selected for this investigation.

Keywords: *Shear Walls, RC Frame Structures, Earthquake, Nonlinear Analysis, Linear Analysis*

1. Introduction

The capital city of Algeria, Algiers and its around is renowned of being a high seismic area. It suffered a large number of seismic events such as Orleans Ville earthquake (Ms¼6.7) which caused over 1,200 deaths and damaged over 20,000 buildings in September 1954, El-Asnam earthquake (Ms¼7.2), which caused over 2,640 deaths and damaged more than 20,000 buildings in October 1980 and the 21st May, 2003 earthquake that occurred in Boumerdes and caused 2,278 deaths and 11,450 injuries, and left 250,000 people homeless [1]. The assessment mission conducted by the Algerian Housing Ministry after Boumerdes' earthquake estimated a direct economic loss of 5 billion U.S. dollars [2]. The most affected buildings were residential constructions with reinforced concrete frame structures and brick infill walls, according to assessments made of the state of various structures after these seismic events [3, 4, 5]. This was because of the following factors: (i) the first stories (ground floors) had very large openings, as they were used for commercial purposes and the gravity load-carrying elements of the second floor were insufficient; (ii) the exterior cavity walls consisted of an outer leaf that enveloped the R/C frame, and the inner shell had usually very low cohesion with the frame [6]. In order to mitigate risks related to this type of construction, the revised version of the Algerian seismic code, RPA 99 V 2003 [7], limited the usage of reinforced concrete frame structures with brick infill walls up to two stories, or 8 meters, and prohibited it for buildings with soft stories on the ground floor. In buildings that don't follow these requirements, shear walls have to be used to withstand all or some of the lateral seismic loads.

According to RPA 99 V 2003 [7], shear walls must have at least a maximum thickness of 15cm, the height of the story divided by 20 (Figure 1), and a length equal to four times its thickness (Figure 2). For a building with a story height of three meters, shear walls can have a thickness of 15cm and a length of 60cm. As a result of these new regulations, engineers adopted a new construction system where they use small-length shear walls arranged in L shapes at the corners of the building. However, after Fardis et al. [8], for a wall to play its intended role, the length dimension of its cross-section, l, should be large, not just relative to its thickness, a, but in absolute terms. To this end, and for the beam sizes commonly found in buildings, a value of at least 1.5 m for low-rise buildings or 2 m for medium- or high-rise ones is recommended for l. In this paper, a series of numerical analyses were performed to assess the effect of the shear wall length on the behavior of Reinforced Concrete (RC) frame structures.

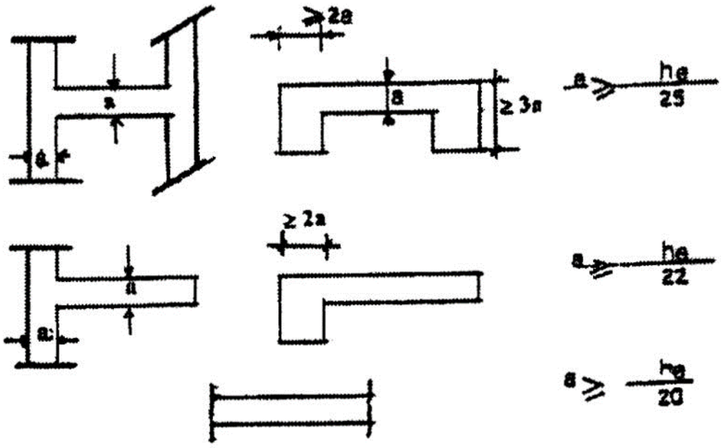


Fig. 1. Shear wall thickness [7].

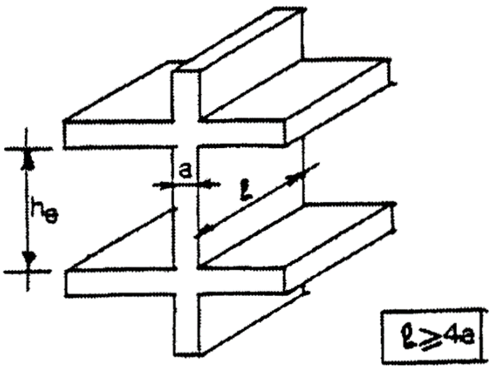
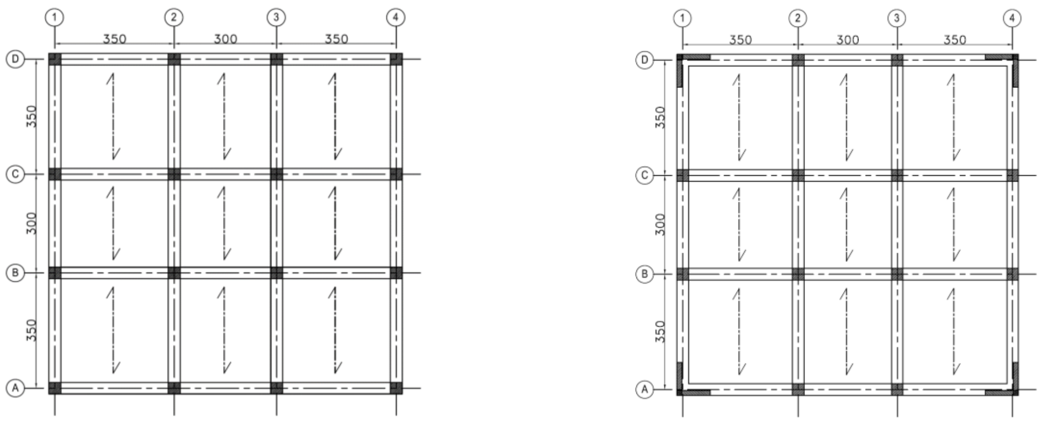


Fig. 2. Shear wall length [7].

2. Description of the Structure

In order to analyze the effect of shear wall length on the behavior of the R/C frame structure, a typical three-story building that is usually constructed in Algiers is considered. The layout of the building consists of three spans in the two principal directions (Figure 3). The columns have a square shape with a dimension of 30cm by 30cm and are reinforced with 8HA14 (Figure 4.a). However, the beams are rectangular with a dimension of 30cm by 40cm and reinforced with 6T14 (Figure 4.b). The floor height is 3 m, and the height of the structure is 12m.

To comply with Algerian seismic code RPA 99 Version 2003 [4], shear walls are added at the corners of the building, arranged in an L shape (Figure 3.b). The shear walls are usually reinforced with 4T14 on their extremities and T12 spaced 15cm in their middle (Figure 4.c).



(a) (b)

Fig. 3. Floor layout, a) frame structure, b) frame structure with shear walls.

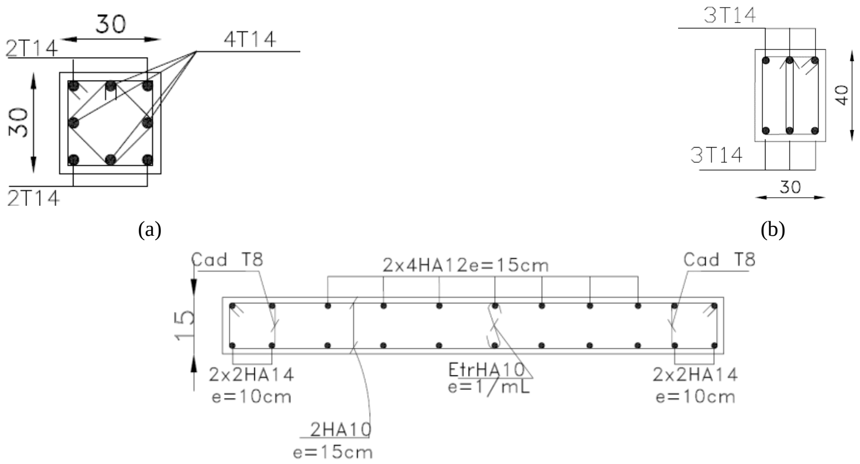


Fig. 4. Structural element reinforcement, a) Columns, b) beams, c) shear walls.

3. Numerical Analysis

The structure represented in Figure 3 was modeled in 3D using the finite element method. Columns and beams were modeled as frame elements. However, shear walls and floors, which are a one-way ribbed slab of 16+5cm, were modeled as shell elements. The floors were considered rigid. To assess the efficiency of the shear walls and to analyze the effect of their length on the behavior of the structure, two numerical analyses were performed: a linear analysis and a nonlinear analysis. The linear analysis consists of a seismic analysis using the equivalent static lateral force method. Whereas, nonlinear analysis is a pushover analysis method. Moreover, a parametric study has been performed for shear walls with a length of 0.60 m, 0.80 m, 1.50 m, and 2.00 m.

4. Results and Discussion

Figure 5 depicts diagrams of the base shear ratios taken by the columns and the shear walls for each of the four shear wall lengths using the equivalent static lateral force method. It can be observed that for a shear wall length of 0.6 m, the columns take more lateral loads than the shear walls. Indeed, the columns take 53% of the lateral load, and the shear walls take 47%. Whereas, when the length of the shear walls increases, the ratio of the lateral load taken by the columns decreases. Indeed, for a shear wall length of 0.8 m, the columns take 37% of the lateral load and the shear walls take 63%. For shear wall length of 1.5 m and beyond, the lateral load is mainly withstood by the shear walls.

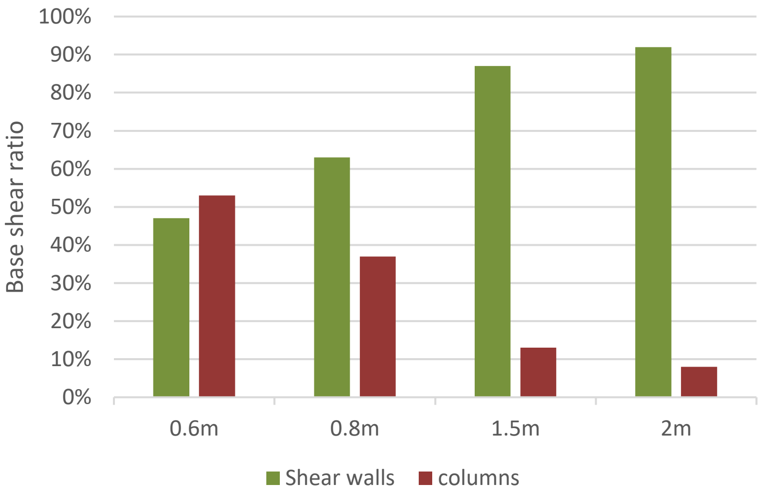


Fig. 5. Base shear ratio.

Figure 6 depicts the results of the push-over analysis for the frame structure, comparing scenarios with and without shear walls in terms of base shear ratio versus top displacement. It's been observed that the presence of shear walls enhances the frame structure's ability to withstand lateral seismic loads. This increase in lateral capacity is directly correlated with the length of the shear walls. Specifically, the shear walls with a length of 0.60 m increased the lateral capacity of the frame by 48%. However, for a length of 0.80 m, the increase in the lateral seismic load capacity is 142%, and it reaches 184% for a shear wall length of 2.00 m (Figure 7).

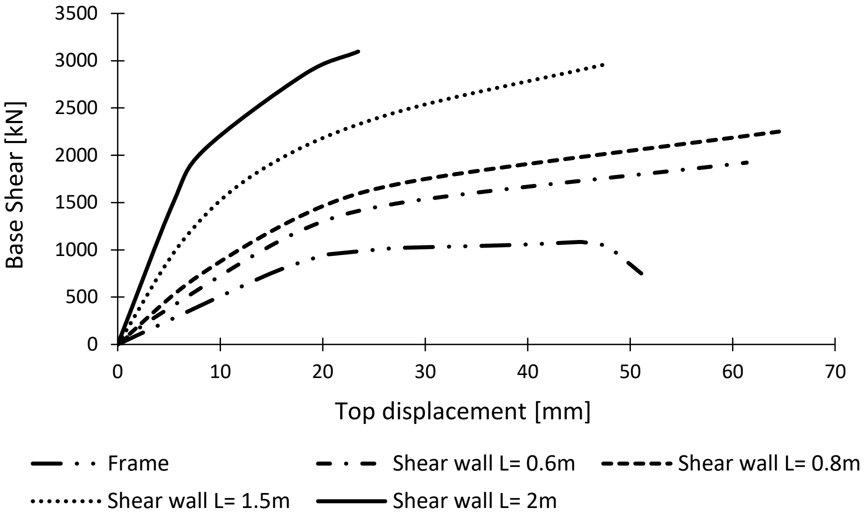


Fig. 6. Base shear curve in term of top displacement.

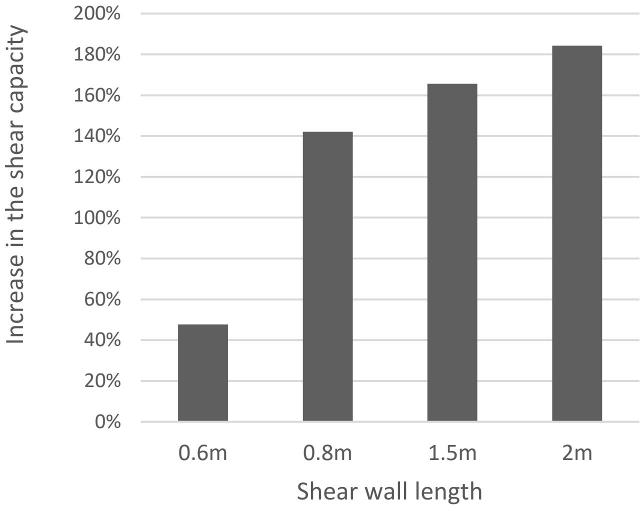


Fig. 7. Increase in the base shear capacity.

In order to assess the effectiveness of L-shaped shear walls placed at the corners of a building compared to a frame structure, a parametric analysis was conducted. This involved substituting the shear walls with columns of equivalent section area. The shear walls, ranging in lengths of 0.60 m, 0.80 m, 1.50 m, and 2.00 m, were replaced by square columns with side lengths of 42cm, 49cm, 67cm, and 77cm, respectively. These columns were reinforced with a reinforcement ratio of 0.9% of the column's section area [7].

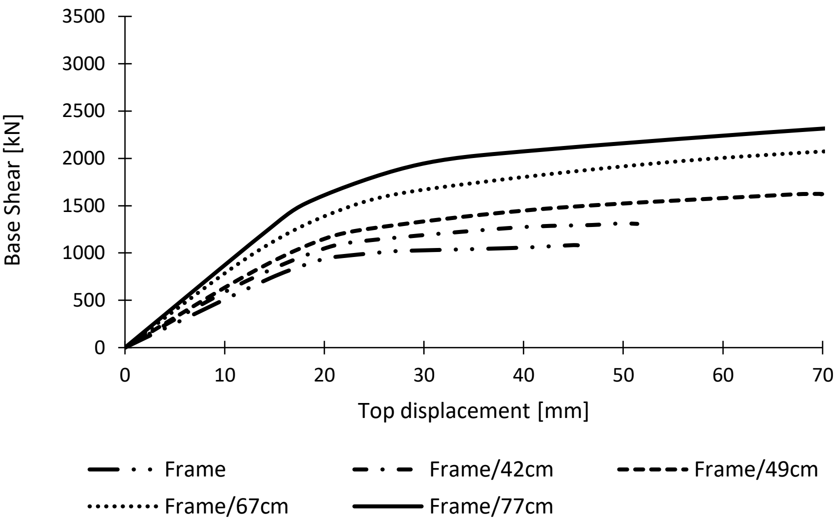


Fig. 8. Base shear curve in term of top displacement, equivalent frame.

Figure 8 depicts the base shear curve in term of top displacement for the four equivalent frame in term of section area. In one hand, it can be observed that the substitution of the shear walls by equivalent columns having the same section, decreased the capacity of the frame structure to resist lateral seismic loads. For instance, the frame structure with a 2 meter-length shear walls can withstand a lateral load of 3000 kN. However, the frame structure with 77cm squar columns placed at the corner of the structure, can withstand a lateral load of 2300 kN. In the other hand, replacing the shear walls by equivalent column increased the ductility of the structure and decreased its initial stiffness.

5. Conclusion

In this paper, a linear and nonlinear numerical analysis were performed to analyze the effect of shear walls length on the behavior of reinforced concrete structure. It was noticed that the shear walls which comply with the minimum length and thickness required by the Algerian seismic code RPA 99V 2003 [7], take less lateral loads than the columns. However, for shear walls that respect the mini-mum length given by Fardis et al. [8], the majority of the lateral loads is resisted by the shear walls. Furthermore, the Pushover analysis shows that the increase in the shear wall length increases the capacity of reinforced concrete frame structure to resist lateral loads. It reaches more 180% for a 2.00m shear walls length.

Replacing the shear walls by columns that have the same section area shows that columns are less efficient than shear walls to resist lateral seismic loads for this type of reinforced concrete structures.

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