Investigation of Seismic Behavior of Reinforced Concrete Shear Walls Rehabilitated whit Fiber Reinforced Polymer Sheets

R. Mousapour[1*], M. Rezvani Sharif [2], S.B. Beheshti Aval[3]

[1]M.SC.of Structural Engineering of K. N. Toosi University of Technology, Tehran, Iran.
[2] Assistant Prof., Faculty of Civil Engineering of K. N. Toosi University of Technology, Tehran, Iran.
[3] Associate Prof., Faculty of Civil Engineering of K. N. Toosi University of Technology, Tehran, Iran.

ABSTRACT

Reinforced concrete shear walls are the most commonly used lateral load-resisting systems in steel and concrete buildings, especially in case of mid- and high-rise structures. Investigations of buildings subjected to the last severe earthquakes have shown the robust performance of these walls in minimizing structural and non-structural damages and controlling the inter-story drifts. Accordingly, strengthening of concrete shear walls, as one of the common and reliable lateral load-resisting systems in concrete structures, particularly in areas with high risk of seismic hazard, and studying their seismic behavior are of significant importance. Strengthening, rehabilitation and retrofit of these structural elements will have remarkable effects on improvement of the structural response and behavior of the buildings. Using Fiber Reinforced Polymer (FRP) composite sheets is one of the practical and applicable methods for strengthening this type of walls. Nowadays, this technique is widely used as a reliable method in retrofit and renovation of buildings. In this regard, it is necessary to take a deeper look at FRP sheets and understand how they affect the seismic behavior of concrete shear walls. Indeed, it is vital for civil engineers to take these factors into consideration in retrofitting and strengthening structural elements. Literature review on recent researches has shown inadequate study of the behavior of high-rise shear walls which strengthening with FRP layers rather than short walls. As such, in this research, the seismic behavior of high-rise shear walls reinforced by FRP layers has been studied. The main purpose of this study is to numerically model sample shear walls utilizing the Finite Elements Method (FEM) and to evaluate their seismic responses. Three types of concrete shear walls used in high-rise buildings with different heights have been modeled and analyzed using the ABAQUS commercial software. The behavior of these types of shear walls has been investigated with two types of strengthening layers (CFRP & GFRP) and two different sets and arrangements. The results show an increase in load bearing capacity, ductility and energy absorption of high-rise shear walls reinforced with FRP layers.

KEYWORDS

Concrete Shear Walls, High-rise Shear Walls, FRP reinforcement.

* Corresponding Author: Email: Roya.Moosapoor@gmail.com

1. Introduction

Reinforced concrete shear walls are one of the most common lateral load-resisting systems in mid- and high-rise buildings. Application of FRP composite materials offers various benefits. Among the unique properties of FRP composites are ease of use, no change in aesthetics and architecture of members and high resistance to weight ratio. Accordingly, this method can be considered as one of the best techniques in strengthening of shear walls and; also, one of the important factors in improving their seismic behavior.

A survey in the literature shows that very limited number of studies deal with experimental and numerical investigations of shear walls strengthened with FRP composites in high-rise buildings. A summary of some research works is presented in the following.

For the first time, FRP composite materials were used for rehabilitation of shear walls in 2000 by Lombard [1]. In this study, sample walls with an aspect ratio of 1.2 were reinforced by vertical and horizontal FRP sheets and studied under cyclic loads. In this research, a steel angle anchorage system was used at the base of the walls. The results disclosed an increase in the load bearing capacity of shear walls. Paterson & Mitchell [2] strengthened four shear wall samples with an aspect ratio of 2.7 with horizontally spiral FRP sheets. They also reinforced the boundary elements with the intention of increasing the ductility, shear resistance and energy absorption capacity. Hiotakis [3] tested shear walls having similar dimensions and reinforcement scheme to Lombard's ones. However, unlike Lombard, he made use of tubular anchorage system and was able to provide a more appropriate rehabilitation design. Mostofinejad and Mohammadi Anaei [4] carried out a numerical study on two high-rise shear walls with aspect ratios of 3 and 7.49 . It is noteworthy that the boundary elements of the walls were strengthened with CFRP sheets. The results of their study showed an increase in the load bearing capacity and ductility of the shear walls.

In the present study, the behavior of three shear wall samples with heights of 16, 22.4 and 32 meters existing in old buildings has been investigated. These samples were reinforced with CFRP and GFRP sheets based on spiral and cross-shaped configurations. These shear walls have been modeled and analyzed using ABAQUS commercial software and the effects reinforcements on their load bearing capacity, ductility, stiffness and energy absorption have been studied. The results of this research demonstrate that all of these factors increase in rehabilitated samples and their seismic performance improves. The main focus of this research is to investigate the performance of reinforced high-rise shear walls subjected to a combination of axial load and monotonic lateral load.

2. Methodology

It is complicated to model the reinforced concrete medium using finite elements. In this study, the concrete damage plasticity (CDP) has been used to define the nonlinear behavior of concrete. The behavior of concrete in compression and tension was defined by the Hognestad modified model [4] and the crack width model proposed by Cornelisen [5]. The compressive strength of concrete and the tensile strength of steel rebars were considered equal to 25 MPa and 412 MPa, respectively.

Once the accuracy of simulation was verified, analytical samples were designed and modeled. These samples are weak shear walls with a low ductility level and aspect ratios larger than 2. They were designed in CSI ETABS commercial software as per the ACI-318-99 provisions [6]. They also satisfy the limitations imposed by the National Concrete Code of Iran. These shear walls were designed according to three categories with different heights as shown in table 1.

Table 1. Dimension characteristic of sample shear walls

Num. of story	Height of shear wall (H_w)-m	Length of shear wall (L_w)-m	Thickness of shear wall (t_w)-m	Aspect ratio (L_w/H_w)
5	16	5.6	0.3	2.86
7	22.4	5.6	0.3	4
10	32	5.6	0.35	5.71

As illustrated in Fig. 1, in all three categories, the shear walls are considered to be reinforced with FRP sheets according to two different reinforcement configurations, i.e. cross-shaped and horizontally spiral. In this way, there will be three walls in each category. One of these walls is the control wall, which is unreinforced and is used to compare the results. The remaining two walls are strengthened using the foregoing arrangements of FRP sheets.

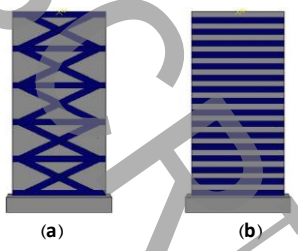

Figure 1. Reinforced shear wall model. a) With cross-shaped and horizontal sheets. b) With horizontally spiral arrangement of sheets.

3. Discussion and Results

In order to explore the effects of FRP sheets on seismic performance of the sample shear walls, the load-displacement curve of the samples was obtained and studied. Analysis of these curves leads to the conclusion that reinforcing the shear walls with FRP sheets increases their load bearing capacity. The maximum increase was observed in the samples reinforced spirally with CFRP sheets. Comparison of the results shows that the shear walls reinforced with horizontally spiral arrangement of sheets provide higher stiffness, load bearing and energy absorption capacities compared to the shear walls strengthened with cross-shaped configuration. Therefore, it can be claimed that horizontally spiral arrangements result in more confinement compared to the cross-shaped configuration. This in turn leads them to be more effective in improving the seismic behavior of the shear walls.

The maximum increase in ductility is observed in the specimens reinforced with GFRP sheets. The reason for this increase can be associated with the fact that glass fiber reinforced polymers fail at a higher ultimate strain compared CFRPs.

An increase in the height and aspect ratio of the shear walls is inversely proportional to the increase of their load bearing capacity and ductility. This observation can stem from the increased stiffness of the walls in its high elevations. The minimum increase in load bearing capacity is related to the SSW2-G10 sample (wall with a height of 32 meters and reinforced with spiral GFRP sheets), which experiences an increase of 2%. The lowest increase in ductility is observed in SSW1-C10 (wall with a height of 32 meters and reinforced with cross-shaped CFRP arrangement of sheets), which benefits from an increase of 0.4%. In this way, the reinforcing effects of the sheets on the highest shear wall is decreased.

4. Conclusion

In this research, the seismic behavior of FRP reinforced concrete shear walls in mid- and high-rise buildings was investigated using the ABAQUS commercial software. The outcomes of this study are summarized in the following:

• The load bearing capacity is increased in all of the specimens, although this increase is insignificant if only one reinforcement layer is used. The SSW2-C5 sample with 7.01% increase and SSW2-G10 with 2% increase represent the maximum and minimum effects on improvement of the load bearing capacity.

• The ductility is increased in all of the rehabilitated samples. The largest increase in ductility was 21.9%, which was observed in 7-story building's shear wall (SSW2-G7). This sample was reinforced with horizontally spiral GFRP sheets. Furthermore, the lowest improvement was 0.4%, which was observed in 10-story building's shear wall (SSW1-C10). It must be noted that that this sample was reinforced with cross-shaped arrangement of CFRP sheets.

• Application of FRP sheets has led to a slight increase in the stiffness of the specimens. This increase ranges between 0.3% and 10.6%, occurring in SSW2-G10 and SSW2-C7 specimens, respectively.

• FRP sheets have increased the energy absorption capacity of the shear walls. This increase ranges between 8.5% and 29.06%, occurring in SSW1-C10 and SSW2-G5 specimens, respectively.

• CFRP composites can be used if it is aimed to increase the load bearing capacity in a rehabilitation project. However, if an increase in ductility is preferred over increased load bearing capacity, it is recommended that GFRP sheets be used as they are more economically efficient than CFRPs.

• According to the results, it can be generally concluded that the effectiveness of a reinforcement layer in improvement of the seismic performance of reinforced concrete shear walls will decrease by increasing their height. This can be related to the higher stiffness of shear walls arising from their increased height.

5. References

[1] Lombard, J., et al. *Seismic strengthening and repair of reinforced concrete shear walls*. in *Proc., 12th World Conf. on Earthquake Engineering*. 2000.

[2] Paterson, J. and D. Mitchell, *Seismic retrofit of shear walls with headed bars and carbon fiber wrap.* Journal of Structural Engineering, 2003. **129**(5): p. 606-614.

[3] Hiotakis, S., *Repair and strengthening of reinforced concrete shear walls for earthquake resistance using externally bonded carbon fibre sheets and a novel anchor system.* 2004, Carleton University.

[4] Mostofinejad, D. and M.M. Anaei, *Effect of confining of boundary elements of slender RC shear wall by FRP composites and stirrups.* Engineering Structures, 2012. **41**: p. 1-13.

[5] Cornelissen, H., D. Hordijk, and H. Reinhardt, *Experimental determination of crack softening characteristics of normalweight and lightweight.* Heron, 1986. **31**(2): p. 45-46.

[6] ACI-318-99, *Building code requirements for structural concrete and commentary.* American Concrete Institute; Detroit (MI), USA., 1999.