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On the effect of GFRP fibers on retrofitting steel shear walls with low yield stress

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Abstract. In this article the non-linear behavior of the shear wall with low yield stress retrofitted with Glass Fiber Reinforced Polymer (GFRP) is investigated under pushover loading. The models used in this study are in ½ scale of one story frame and simple steel plates with low yield stress filled the frame span. The models used were simulated and analyzed using finite elements method based on experimental data. After verification of the experimental model, various parameters of the model including the number of GFRP layers, fibers positioning in one or two sides of the wall, GFRP angles in respect to the wall and thickness of the steel plate were studied. The results have shown that adding the GFRP layers, the ultimate shear capacity is increased and the amount of energy absorbed is decreased. Besides, the results showed that using these fibers in low-thickness plates is effective and if the positioning angle of the fibers on the wall is diagonal, its behavior will improve.

Keywords: steel plate shear wall; low yield stress plate; GFRP; shear capacity; energy waste

1. Introduction

High steel buildings are widely used in many countries and seismic areas. In such buildings to resist against lateral loads imposed by wind and earthquake to the structure, various resistant seismic systems are used including moment frames, concrete shear walls, various converging and eccentric bracing systems and steel shear walls. In the proposed systems, the steel shear wall systems have been used in steel buildings during the last four decades due to their high stiffness, ductility and energy waste, speed of construction and low structure weight compared with the other systems. Generally, the steel shear walls are classified into two groups: stiffened and unstiffened. Among all kinds of the steel wall, the steel plates used in these walls are classified into low-yield and high-yield stress with high strength in terms of stress (Petkune *et al.* 2012).

During the last four decades, many numerical and experimental studies have been done on the various kinds of the steel shear walls. One of the experimental studies done on the steel shear wall

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with low yield stress was Chen and Jhang (2006, 2011) study. They studied one-story frame under cyclical loading and the results showed that the steel shear walls with low yield point associated with simple and clamped boundary conditions have good load-bearing capacity, deformation, energy waste and adequate stiffness. One reason for efficiency of these systems is diameter stretch field phenomenon in plate of wall under lateral loads which increases their load-bearing capacity. However this phenomenon is associated with bulking out of wall and causes nonstrucural damage. One of the important issues in structure is retrofitting issue, using various methods such as the use of different types of steel braces system, concrete shear walls, all types of steel shear walls by using FRP polymer. Among these, FRP fibers are mostly used in different kind of structural systems. Using these fibers increases load-bearing capacity and improves the behavior of structural elements. One of the cases where these fibers are used is in steel structures which nowadays are used in retrofitting beam stretch wings and steel structural connections. Using FRP fibers in the steel shear walls instead of installing stiffener to improve wall behavior is one of the issues which recently have caught the researcher's attention (Nateghi and Khazaei 2013, Khazaei and Nateghi 2012, Maleki *et al*. 2012, Narmashiri *et al*. 2010, Kong *et al*. 2013, Mohamed *et al*. 2014, Yu *et al*. 2014, Zhu and lopez 2014).

In this area one can refers to Hatami and Rahai's work (Hatami and Rahai 2008). They put several steel one-layered shear walls retrofitted with CFRP fibers under cyclical loading and found that using these fibers decrease damages in plate connections with boundary elements, increases energy waste capacity, lateral stiffness and deformation. Alipour and Rahai (2011) have done a series of numerical studies on bulking and post-bulking behavior of the steel shear composite walls with FRP fibers and the results showed that this action increases bulking capacity and hardening of the walls and decreases out of plate deformations. Rahai and Alipour Tabrizi (2010) studied the direction and geometry of FRP fibers in the steel shear walls using finite elements method. It is worth mentioning that the idea of using FRP fibers in the steel walls is to replace stiffeners with these materials on the wall surface.

Considering the above mentioned issues, this article investigates the effect of GFRP on the behavior of the steel shear walls with low yield point so that after verification of the experimental model, the various parameters including plate thickness, the number of GFRP layers, fibers positioning angle and positioning of these fibers on the steel walls with low yield stress are studied using one story models.

2. The shear bulking capacity of the steel plates

The shear bulking capacity of the steel plates is a function of width-to-thickness ratio, boundary conditions and tangential module of the steel. Galambus proposed formula (1) to anticipate inelastic thin plates under within-plate loads as follows (Rahai and Alipour 2011, Alipour and Rahai 2011)

$$F_{cr} = \frac{K_v .\pi^2 .\eta .E}{12(1-\mu^2)} .(\frac{t}{b})^2 \tag{1}$$

where F_{cr} is shear bulking stress, E young elastic module, μ Poisson's ratio, t thickness of steel plate, $\eta = \sqrt{E_t / E}$ plastic reduction factor, E_t tangential module and k_v bulking coefficient of the plate which is obtained from the following equations

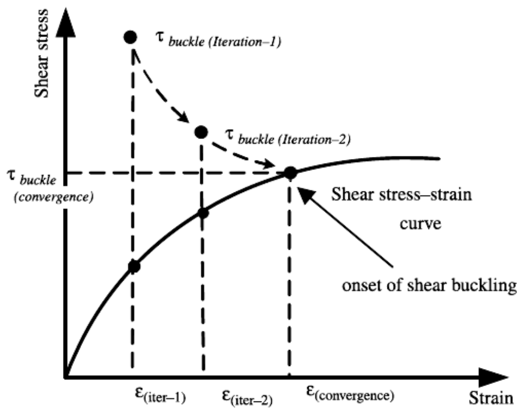


Fig. 1 Procedure of repeated calculations of shear bulking capacity

$$K_v = 5 + \frac{5}{(a/b)^2} \qquad a > b \qquad \text{simply support} \tag{2}$$

$$K_v = 8.98 + \frac{5.6}{(a/b)^2} \qquad a > b \qquad \text{clamped - clamped} \tag{3}$$

In the above equations, parameters a and b are panel height and width which are embraced by boundary members or hardeners. It should be mention that after yielding, the steel with low yield point gains a high strain hardening. Plastic reduction factor η is used to consider post-bulking resistance of the steel wall with low yield point. To calculate bulking tensions F_{cr}, there is a need for a series of repeated processes which calculate critical tension F_{cr} with a preliminary assumption for η and through a repeated process so that it converges to a value as shown in Fig. 1.

3. Validating and introducing numerical models

In this paper nonlinear samples have been analyzed using finite elements ANSYS software. To verify the software performance in the analysis of studied models, (Chen and Jhang 2011) experimental model has been used. They used a model of one- story steel shear wall with plate having a low yield point which has been shown in Fig. 2(a).

In this model beam to column connections has been of bone connection type with reduced section under cyclical loading. In this model the sections H250×250×9×14 are used in the column and H244×175×7×11 in the beams and a plate of 8 mm thickness as the span filler. Also, in this model the steel A572 Gr. 72 is used in the steel materials of the boundary members and connections and the steel LYP100 as the plate. The diagram of the stress-strain of the steel materials is shown in Fig. 2(b).

To verify the experimental model in the finite elements software, elements of group Shell have been used and the element Shell143 in modeling the boundary members and the element Shell181 in the steel plate. These two elements are four-node and have six degrees of freedom: *Ux*, *Uy, Uz*,

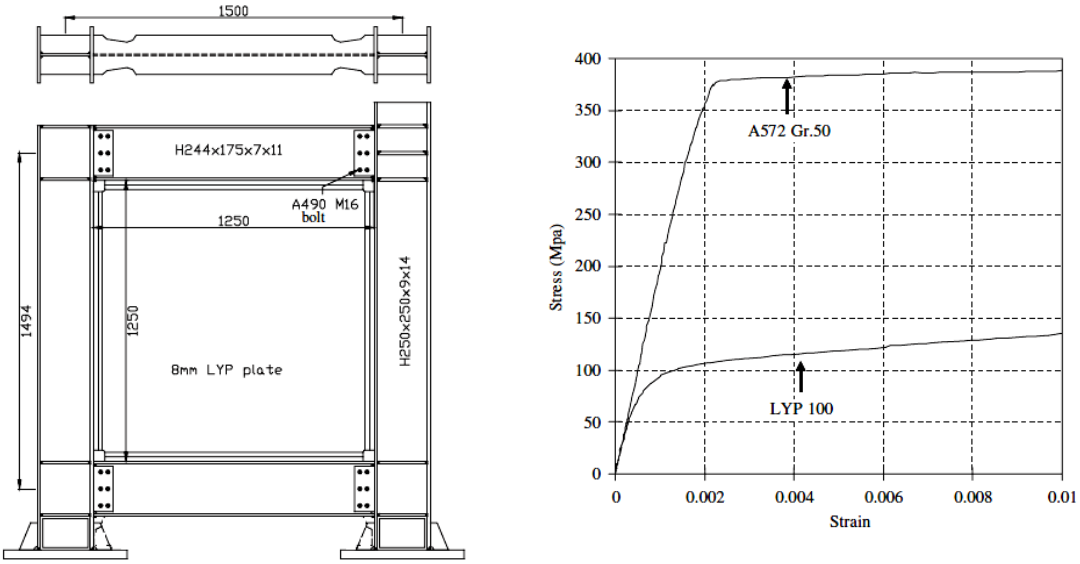


Fig. 2 (a) The schematic figure of Chen *et al.* laboratory model (b) The diagram of the stress-strain of the steel used in examined models (Chen and Jhang 2011)

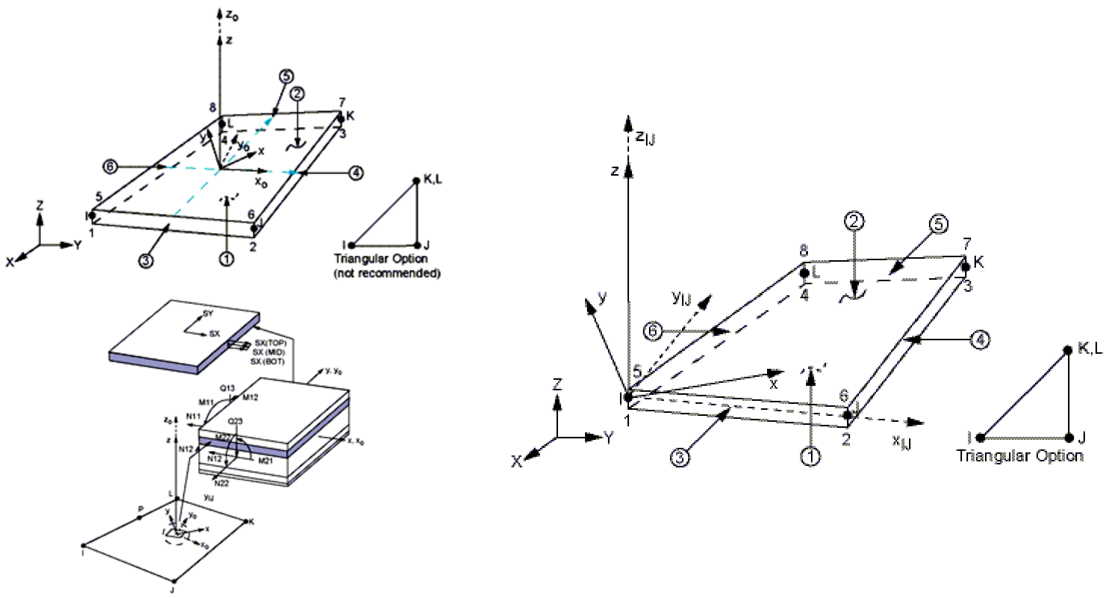
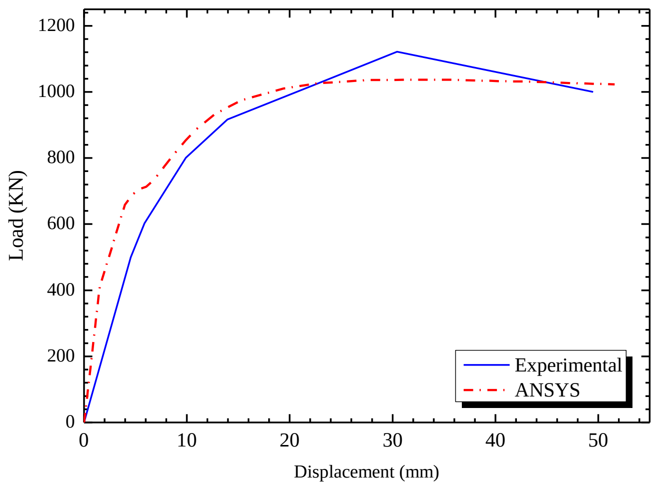


Fig. 3 Geometric characteristics of (a) Shell Element 181 (b) Shell Element 143

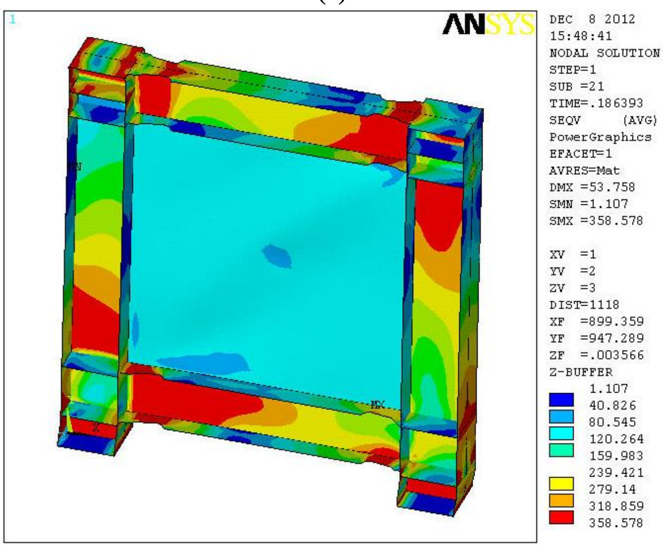
Rotx, *Roty* and *Rotz*, they have plasticity, creep, stress hardening, large deformation and small strain properties and are very suitable for thin structures with thin and moderate thickness under non-linear conditions. The only difference between the two is that the element Shell181 is also applicable in the layered and composite models and it is capable to model until 250 layers. Fig. 3 shows geometric characteristics of these two elements.

After modeling the respective sample, the model was analyzed non-linearly using the length of arc method considering the large deformations under lateral pushover loading. The results of this analysis, shown in Fig. 4(a), show that the models constructed in the software have a relatively good precision. Fig. 4(b) shows Von-Misez's tention levels in the software model.

After verification of the results of experimental model and software sample, the one-story steel shear wall models with low yield tension were retrofitted with GFRP fibers and then analyzed. The analyses include the number of layers, position of the fibers in one or two sides of the wall, and the fibers angle in respect to the steel plate.



(a)



(b)

Fig. 4 (a) Results of the laboratory model validation and (b)Von Misez's stress counter in the software model

Table 1 Material properties of GFRP fibers (Mpa)

Mat	*Ex*	*Ey*	*Ez*	υ_{xy}	υ_{xz}	υ_{yz}	G_{xy}	G_{xz}	G_{yz}	G_{yz}
FRP	2.3e5	0.2e5	0.2e5	0.22	0.22	0.3	1.31e4	3.77e4	1.31e4	1.31e4

Table 2 The effect of thickness in the models with and without GFRP fibers

Thickness of the plate	The angle of three-layered fibers	Thickness of one-layered fibers	Bearing capacity		Displacement		Energy waste	
			With GFRP	Without GFRP	With GFRP	Without GFRP	With GFRP	Without GFRP
4	45, -45, 90	0.13	1170.95	399.28	108.27	3.79	62.97	1.2
6	45, -45, 90	0.13	1204.66	915.47	78.96	117.82	49.26	4.06
8	45, -45, 90	0.13	1223.42	960.46	73.43	124.28	49.38	62.52
10	45, -45, 90	0.13	1228.86	1022.50	65.58	126.15	46.24	62.93

4. Analysis of the results of the software models

In this section, the results of the analysis of the mentioned cases are presented. It should be mention that the thickness of the layers of GFRP fibers used in the studied samples is 0.13 mm and the characteristics of its materials are shown in Table1.

4.1 The effect of the number of the layers of GFRP fibers in one and two sides of the wall

To investigate the effect of the number of the layers of GFRP fibers, one, two and three fiber layers are used in the wall surface which were installed in one side of the wall in a series of models and in the two sides in the other ones. The results show that installing the fibers on the wall, the load-bearing capacity follows an upward trend considering the increase in hardening. This increase in walls where the fibers are installed in two sides and one side is 23% and 13% respectively. Besides, the amount of hardening and energy waste has been increased relatively.

4.2 The effect of the thickness of wall plate on FRP behavior

To investigate this case in the steel walls with low yield stress retrofitted with GFRP, the walls with 4,6,8 and 10 mm thickness were used which were installed in two sides of the plate by 3 fiber layers with angles 45, -45 and 90. The results of the models under lateral load, shown in Table 2, show that the increase in the plate thickness leads to increase of the load-bearing capacity and decrease of the amount of deformation and energy waste due to increase of the hardening. Then, the above models were put under loading in the absence of fibers to compare the efficiency of GFRP fibers in thin and thick plates. The results, shown in Table 2, show that the use of these fibers is more effective in low-thickness walls.

4.3 The effect of GFRP fiber layers' angles on the wall

GFRP fibers can be installed in various directions and angles on the structure elements. Here, the effects of positioning angle of these fibers on 8 mm wall are discussed. These fibers were

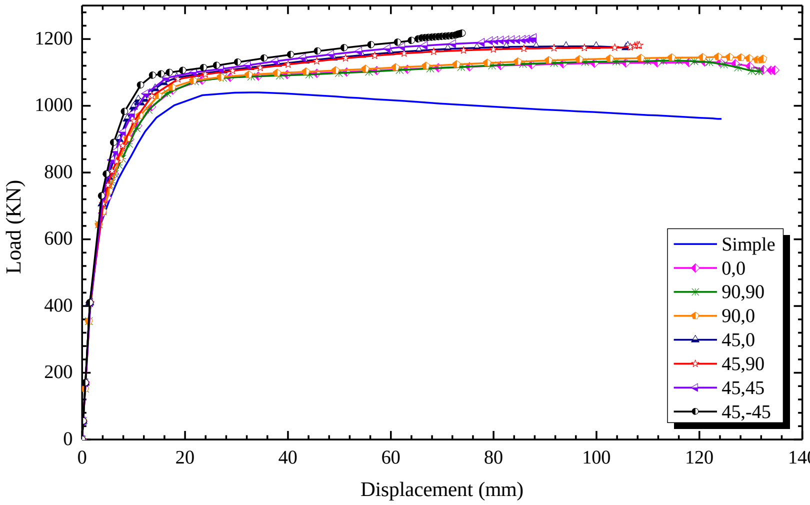


Fig. 5 Load-displacement diagram of models with different angles of GFRP fibers

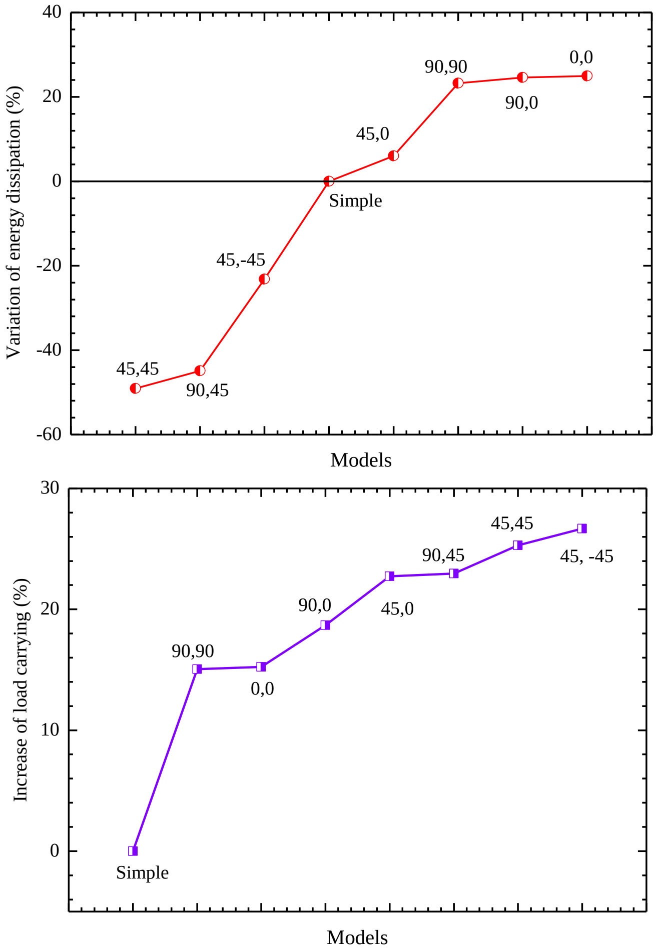


Fig. 6 Results of the effect of GFRP fibers' angles on load-bearing and energy waste capacity of the models

installed in angles 0, 45 and 90 on the two sides of the wall. The results show that if the fibers are installed in the angle 45, they show the best behavior and have the maximum load-bearing capacity, as shown in Fig. 5.

The results of the study of this parameter show (Fig. 6) that the models with the angle 45 have the maximum load-bearing capacity and compared with the unretrofitted model, they have less energy waste capacity. In contrary, the models with vertical and horizontal angles have the maximum energy waste.

5. Conclusions

In this article, the steel shear one-layered walls with low yield stress in which the beam-column connection was reduced beam section were retrofitted with GFRP fibers. The models were studied using finite elements model under pushover load. The following results were obtained:

• Installing GFRP fibers on the steel plate shear wall increases its load-bearing and energy waste capacity. The better results are obtained from the models retrofitted in two sides.

• An increase in the thickness of steel plates leads to increasing the amount of the load-bearing capacity in the models retrofitted with GFRP, but their deformation and energy waste decreases.

• Using GFRP in models with low-thickness plates leads to more effective results than high-thickness one.

• Installing GFRP fibers in the angle 45 leads to a better behavior than vertical and horizontal angles, because it increases the load-bearing capacity but decreases the amount of energy waste compared with unretrofitted mode.

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