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Nonlinear Lateral Behavior of Coupled Shear Walls Having Different Link Beams

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Analytical results from two coupled shear walls under cyclic loads are presented in this paper. The objective of the analyses is to find the best link beam in coupled shear walls. Link beams are of two types depending on material: concrete or steel for coupled concrete shear walls in reinforced concrete buildings. The results indicate that in the presence of lateral loads, the link beams have a significant effect on the strength, ductility, displacement and failure mechanisms of the coupled shear walls. Finite element analyses show that steel link beams behave better than concrete ones. For example, displacement is 2.57 cm in coupled shear walls with steel link beam, 5 mm less than that in concrete model. Also, nonlinear behavior of steel link beam shows that crack, shear absorption and pressure and tension control are equivalent. Finally, three composite link beams are modelled and analyzed by finite element program. The total volume of each model is fixed, such that when steel thickness is increased in model, concrete volume is decreased. The results indicate that composite link beam performs better than those with only steel or concrete link beams.

1 INTRODUCTION

Architectural aspects require the existence of windows and/or doors, and thereby engineers should design openings in walls. When it comes to shear wall, special considerations shall be made to position openings within the shear wall. However, openings may split the shear wall and create a dual system interconnected via a link beam termed as coupled shear wall. A coupled shear wall usually consists of two shear walls and a link beam for their connection. Link beams are mostly made of concrete or structural steel. Paulay and Priestly (1992), have suggested using concrete link beams. They investigated such coupled shear wall under the cyclic loading (Figure1) where they investigated the effects of concrete link beam with diagonal rebar. They also concluded that concrete link beam had better behaviour, less crack and higher shear absorption once reinforced with diagonal rebar (Figure 2). Zahrai and Khatami (2009) conducted a research on negative shear in concrete shear walls. They analysed a coupled shear wall model using a nonlinear finite element program. They indicated that coupled shear wall is able to control negative shear in concrete tall buildings.

Figure 1. Coupled shear wall with concrete link beam

Figure 2. Concrete link beam with diagonal rebar

Haries (2001) tested several specimens with steel link beam, and concluded that steel link beam is better than concrete type. He made some coupled shear walls in laboratory, and tested them under lateral loadings, using steel link beam instead of the concrete type. Crack pattern, displacement and hysteretic curve showed steel link beam has better behaviour in comparison with other types. In another research studied by Kheyroddin and Mahzarnia (2006), steel link beam with finite element program NONLACS2 (1996) was modelled. This research indicates that crack occurs in intersection of the link beam and the shear wall. They compared their findings with experimental results, and found that steel link beam absorbs more energy.

2 ANALYTICAL MODEL

A reinforced concrete residential building in ten floors was modelled where lateral resisting system is moment frame, and shear walls of intermediate level of ductility. In horizontal X and Y directions, this building consists of five spans of 4 meter, and three 4-meter spans respectively. Also floor height is 3 meters, and gravity loads are input as per Iranian code of gravity loads for building (2009) consisting of 600 kg/m² dead load and 200 kg/m² live load on the floors. Concrete compressive strength is 25MPa, and yielding strength of steel is 400MPa. Iranian code for the seismic loads (2800 standard) is applied for seismic design of the structure. Shear walls are in middle direction as can be seen in Figure 3, whereas openings are located in 3 upper floor shear walls. Since shear force is high in these floors, the results of the analyses can be investigated more efficiently.

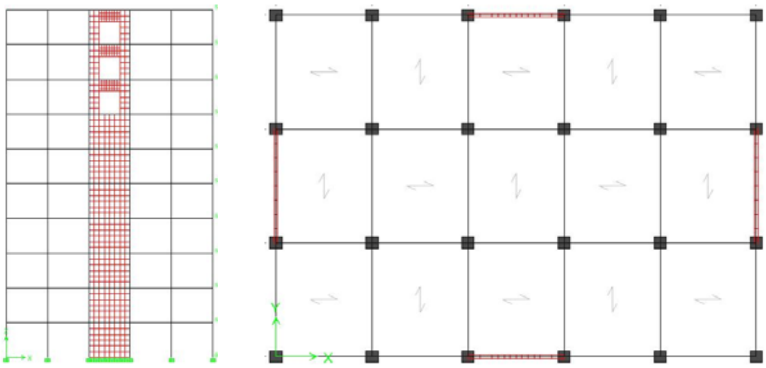


Figure 3. Plan and elevation of numerical model of 10 story reinforced concrete building

Beams and joists (small beam) have rectangular sections, and all building columns are reinforced with the 16#20 rebar. Sizing of reinforced concrete beams and columns are selected in a way that moment frame in the first floor of the building absorbs %25 of the earthquake force. Dimensions of columns, beams are given in Table1.

Table 1.Details of reinforced concrete building column and beam sections

Story	Column dimension(cm×cm)	Beam dimension(cm×cm)
9-10	50×50	35×35
7-8	55×55	35×40
5-6	60×60	40×40
3-4	65×65	40×45
1-2	70×70	45×45

Link beam was modelled by concrete. In a later part of analysis, link beam will be of steel material. Couple wall and its forces can be seen in figure4.

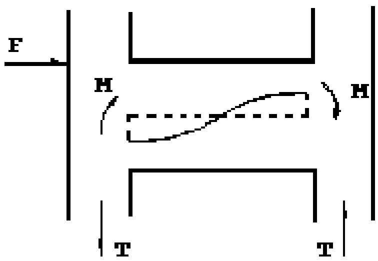


Figure 4.Forces in couple shear wall with lateral force

Link beams are made of concrete and steel material which is shown in Figure 5.

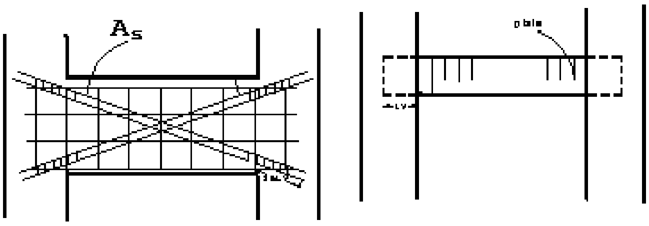


Figure 5.Conerete link beam with diagonal rebar and steel link beam with plate

3 ANALYSES OF THE NUMERICAL MODEL

Deformation energy is absorbed by link beam in coupled shear wall. That is, link beam functions similar to a damping system and it transfers shear forces and controls the displacements. Investigation on the linear behaviour of the link beams in coupled shear wall showed that steel link beam exhibits better behaviour than concrete link beam in shear absorption and displacement.
Table 2 show the comparison between concrete link beam and steel link beam.

Table2. Models analysis results

Type of link beam	Shear story(kN)	Shear in shear walls(kN)	Shear in link beam(kN)	Displacement(cm)
Concrete	2064.6	1121.7	552.0	2.62
Steel	2064.6	1121.7	572.0	2.57

Results of analysis showed that lateral strength resisted by steel link beam is more than concrete link beam. Also, displacement in steel link beam is 5 mm less than in that of the concrete model. Finite element program was utilized to model the link beam made of eight-node concrete elements (Figure 6).

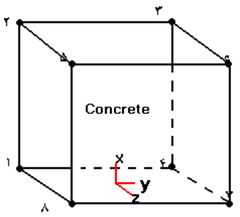


Figure 6. Eight-node element used in numerical model

The two input strength parameters, ultimate diagonal tensile and compressive strengths, were required to define a failure surface for the concrete. The Poisson ratio for the concrete was assumed to be 0.25. The shear transfer coefficient of closed crack is 0.9 and that of open crack is 0.25.
Stress-strain relationship of used concrete is shown in figure 7.

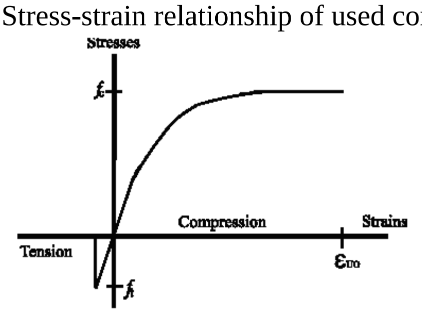


Figure 7. Concrete stress-strain curve used in finite element program

In this study, five different finite element models were generated to analytically predict the response of structures under lateral load. Concrete of the shear wall models were meshed with rectangular elements of dimension 20 mm.
Seismic load is imposed as pressure in the upper slab. Stress contours are shown in coupled shear wall with concrete link beam in Figure 8.

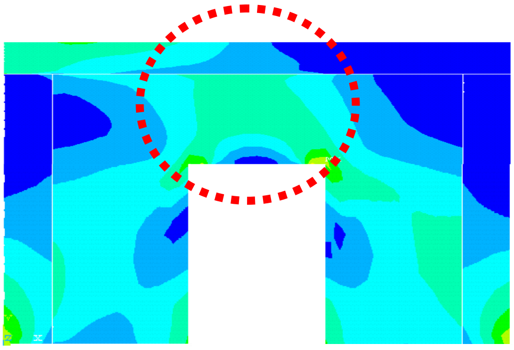


Figure 8. Stress in concrete link beam (CSW)

Since part of the lower link beam is in tension, stresses are very high. This model, therefore, showed some cracks in concrete link beam. Also, displacement is 6.2 mm and lateral strength is 192 kN in this model. Second model was made by steel link beam. Seismic load is imposed as pressure in the upper slab. Stresses are shown in coupled shear wall with concrete link beam (Figure 9). It can be clearly seen that the rate of tension decreases in the shear wall, and ultimate load is 202 kN. In this model, final displacement is equal to 6.90 mm which indicates ductile behavior of this shear wall model.

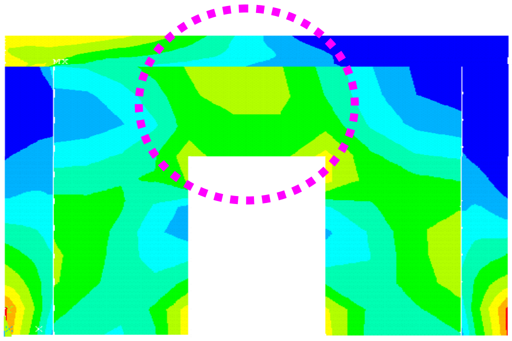


Figure 9. Stress in steel link beam (SSW)

The load-displacement curve for two shear walls are captured well by the numerical simulation. The difference between the finite element results is mainly due to the better behaviour of the coupled shear wall with steel link beam comparing to concrete link beam in displacement, shear absorption and crack pattern. For instance, lateral strength resisted by shear wall with concrete link beam is 192 kN which is 10 kN less compared with steel link beam.

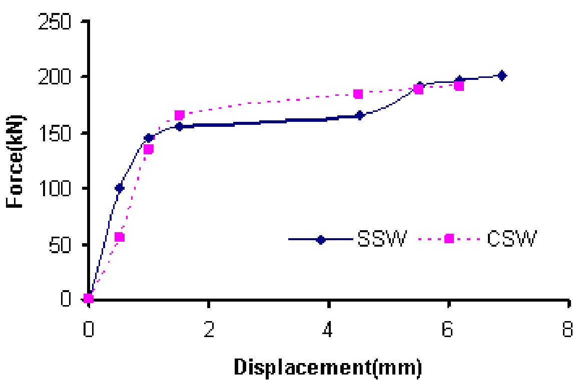


Figure10. Force-displacement comparison for two models

Table 3. Dimension of finite element models

Name	Steel dimension(mm)	Concrete dimension(mm)
2.5SSW	25×500	200×500
3SSW	30×500	150×500
3.5SSW	35×500	100×500

Three coupled shear walls with link beams are analyzed using the finite element program to investigate the influence of steel on the results of the finite element analysis of the link beam. Three types of link beam configurations with 2.5,3,3.5 cm steel are used to analyze the coupled shear walls, as shown in figure 11.

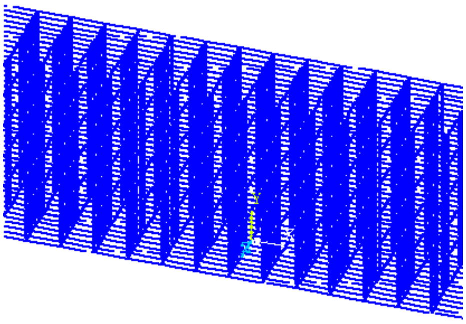


Figure 11. Composite link beam in finite element program

The shear walls with these link beams are analyzed with no provision to account for the steel of link beam. In this case the value of steel thickness is given as an input value by the user. The computed results are influenced by the steel thickness. The load- displacement curve for the three models is shown in Figure 12, which presents the results for the models with three types of link beam.

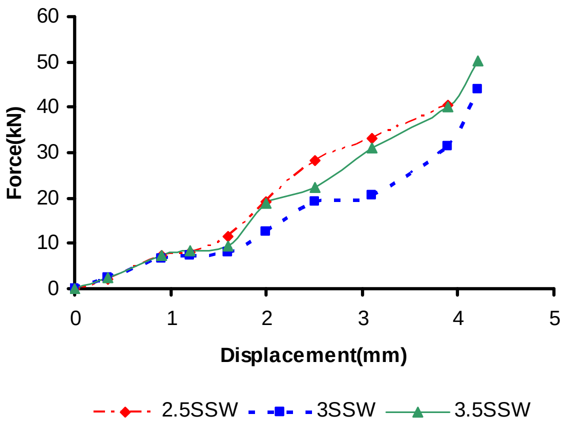


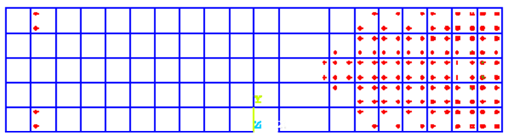
Figure12. Load- displacement curve of composite models

The steel thickness of 3.5SW resists an ultimate load value of 50 kN, which is very good. While the medium steel thickness of 3SW results in an ultimate load of 44 kN, and the finer steel thickness of 2.5SW underestimates the ultimate load 40 kN. When steel thickness is used, the structure exhibits a stiffer behavior compared with other models. It can be seen in fig 8. with an increase in the steel thickness, the structure is slightly more flexible than in the case with steel thickness idealization, and the coupled shear wall tends to be less ductile. In fact, the deflection at the ultimate load decreases with a decrease in the steel thickness. The pre-cracking behavior and the cracking load are the same and equal to 7 kN for the different models. The yielding and the ultimate loads for the different link beams are compared with each other in table 4.

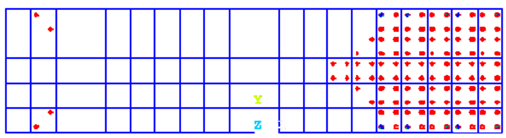
Table 4. Results of finite element analysis in composite link beam

Name	Force(kN)	Deflection(mm)
2.5SSW	40.32	3.9
3SSW	43.9	4.15
3.5SSW	50.35	4.2

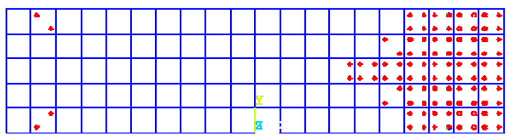
This table shows that the ultimate load for the three link beams dependents on the steel thickness used in the analysis. It should be noted that the ultimate load for this link beam decreases with an decrease in the thickness of steel. The computed results are influenced by the steel thickness, and it emphasizes the sensitivity of the computed responses to the mesh characteristics. From energy considerations standpoint, a decrease in the thickness of the steel increases the rate of crack propagation in the structure, and consequently, its energy dissipation capacity decreases. In Figure 13, crack pattern is shown in the three models.



2.5SSW



3SSW



3.5SSW

Figure13. Crack pattern in composite models

Minimum crack is in 3.5SSW model. Also, shear absorption is 50.35 kN.

4 ANALYTICAL RESULTS

Results of analysis showed different responses in each models. For the first model, 2.5SSW. The analytical value of the first crack load is 7.25 kN. As shown in figure 13, the value at the failure is 40.32 kN. This amount is minimum value among three models for failure. The displacement value at the ultimate force is 3.9 mm. In second model, 3SSW, first crack occured at 6.75 kN. Load-displacement curve shows that the ultimate load is 43.9 kN while model is displaced 4.2 mm. In this model resisting and yielding in 34.5 kN, ultimate load is 11 percent higher than the that of 2.5SSW.

Thickness of 3.5SSW has 35 mm length. In this model included 841 rectangular mesh., yield strength and displacement are 7.45 kN and 0.9 mm, respectively. The ultimate load of 3.5SSW is 50.35 kN, %12 higher than thats of the 2.5SSW and 2 percent higher than thats of 3SSW. Load-displacement curve in 3.5SSW shows that ultimate deflection occurs in 4.2 mm.

5 CONCLUSION

Investigation of link beam material showed that steel link beam behaves more effective than concrete link beam. Shear absorption is 3 percent less than in concrete link beam versus that of the steel link beam. The load-displacement responses in steel link beam for two walls were captured accurately by numerical simulation by finite element program. The results in this study indicate that steel was effective in shear force absorption, and concrete had significant effects in energy dissipation by developing the cracks within the member. The results of finite element models showed that composite link beam could have better behaviour versus other link beams with one material. Crack patterns and value of shear, displacement and ductility are key parameters for this study. The finite element models of three link beams in this study could provide wide-range information useful to investigate the behaviour of shear walls. Composite link beam in this paper offered a new approach to study coupled shear walls, which can help the designer to have a better understanding of the performance of coupled shear wall structures.

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