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Evaluation and comparison of seismic behavior of composite and steel shear-walls in construction frames with semi-enclosed composite columns

S. F. Sajedi[1], M. Harizavi[2,*]

[1]Department of Civil Engineering, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran
[2] Department of Civil Engineering, Abadan Branch, Islamic Azad University, Abadan, Iran

ABSTRACT: The research purpose is to evaluate and compare the seismic behavior of composite and steel shear-walls in construction frames with semi-enclosed composite columns. The numerical behavior of composite and steel shear-walls with semi-enclosed columns was investigated and then the parameters affecting the seismic behavior of the composite shear-walls under cyclic loading were analyzed with the Abaqus software. Software validation was performed with two laboratory samples. The results showed that the use of Semi-enclosed columns increased by 48% and 56% in the ultimate strength of the composite shear-walls with unilateral and bilateral concrete. These columns improved ductility and energy depletion. The semi-enclosed columns caused a 15% increase in the ultimate strength of the steel shear-walls and had a limited impact on energy absorption. The increase in steel plate thickness of the composite shear-walls from 2 to 4 and 4 to 6 mm, resulted in 16% and 14% improvement in the ultimate strength and energy depletion, respectively. The gap of 11.3 mm between the steel frame and the concrete wall was optimum. By reducing the diameter of the gap to 6.5, the strength decreased by 1.5% and with increasing the diameter of the gap to 9.16 mm, strength dropped by 7%. By increasing the thickness of the cross-section of the composite columns from 2 to 5 and from 5 to 8 mm, the strength increased 25.3% and 12.1%, respectively. With an increase in strength of concrete from 30 to 72.5 MPa (142% increase), the structural strength increased by only 15%.

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1. INTRODUCTION

Up to 45 years ago, the only concrete wall was used, but there were always concerns about the local strength and ductility of these systems in areas with high seismic risk. The use of this system in high-seismic areas leads to disadvantages such as the extension of stretching cracks and the crushing of concrete in compression areas. In the 1970s, steel shear-walls were introduced as a seismic performance system, especially in high-rise buildings. This system has considerable stiffness and strength. The environmental integrity of this system increases the ductility and energy depreciation of the structure; according to economic calculations, this system saves about 50% of the steel consumption compared to the flexural frame system. In the thin-walled steel shear-walls, with a steel plate buckling, a diagonal stretch of field is formed in the wall, with two general solutions to prevent this: a) Use of stiffener: One of their disadvantages is considerable costs and workshop problems. b) The use of reinforced concrete on one side or on two sides of the steel wall, which is connected to the steel plate through the cutters. This proposal led to the creation of a composite shear wall. Composite shear-walls are a good seismic system adopted by the AISC-2005 standard as a side-impact resistant system. Based on current records on the use of conventional shear-walls for concrete and steel, against seismic loads, each has disadvantages and defects. Considering the existing developments, in order to overcome these disadvantages, the tendency to use the composite shear-walls to improve the seismic behavior of structures has increased. According to previous studies, the system requires boundary components such as high stiffness columns to yield a shear.

Due to the high importance of the column in this system, it is necessary to maintain the column under various loading in the elastic zone, since, until the formation and development of a diagonal pulling field, the plate is a function of the geometric characteristics of the perimeter frame, especially the column. On the other hand, more studies on the behavior of composite and steel shear-walls with ordinary columns have been made so far, and fewer studies have been done on the performance of these types of walls in construction frames having composite columns. Therefore, in this study, the seismic behavior of composite and steel shear-walls was investigated in construction frames with semi-enclosed composite columns and their behavior was compared. Also, an evaluation of the effective parameters on the behavior of these types of systems was carried out which is defined as an innovation.

In 2016, Shafai et al. simulated several composite shear walls by Abaqus software. The results showed that increasing

*Corresponding author's email: sajedi@iauahvaz.ac.ir

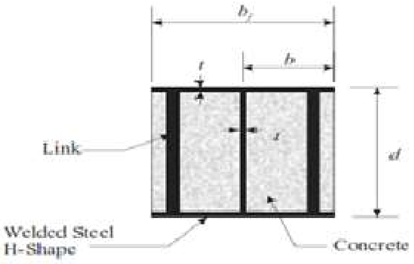

Fig. 1. Cross-section of semi-enclosed composite column

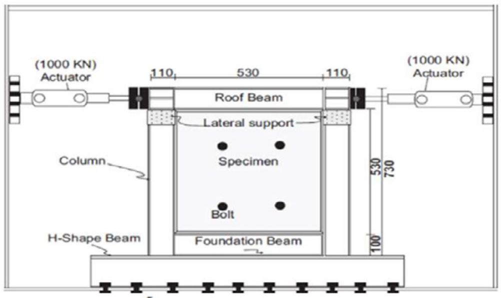

Fig. 2. An overview of the laboratory model of Arabzadeh et al. [7]

the thickness of the steel plate, the shear capacity and the ultimate strength increase significantly. Also, increasing the thickness of the reinforced concrete wall to a certain extent increases the ultimate strength [1]. In the years 1998 to 2001, separate investigations were carried out by Astana-Asl on the behavior of conventional and composite steel shear-walls. The study aimed to determine the seismic design recommendations in this field. The results of the studies, as mentioned above, indicated that the steel shear-wall was very suitable for use as well as the high capabilities of the composite shear-wall to enhance the ductility and control of the formation of the diagonal-tensile field [2-4]. Astane-Asl and Zhao in 2004 examined the effect of the gap between concrete panels and boundary components by constructing two laboratory samples under seismic loads (there was a gap in the new sample and not in the old one). The results of the studies showed that the new composite shear-wall is more versatile than the old one, and the damage to the concrete wall in the relatively large loading cycles was much less than the damage to the concrete wall in the old system [5]. Yahyaei and Mobaraki-Moghaddam in 1394, studied the seismic behavior of composite frames, including composite columns and concrete-filled steel shear-walls. The results showed that the shear-wall with composite frame has better seismic behavior than steel systems and bending frames. Also, the effect of the ratio of span to height in different states on the system response was studied, which was the ratio of 1 to 6 of the most suitable ratio for this variable [6].

Table 1. Sample laboratory characteristics for simulation [7]

CS1	specimens
2IPE100 + 2PI100 × 5	columns
2IPE100	beams
2	Steel pl. thick. (mm)
5×40	Fish plate (mm)
4	No. of cutters
6	Diameter of cutters (mm
3	Rebar radius (mm)
1	Reinforcement ratio (%
30	Concrete thick. (mm)
11.3	Concrete gap (mm)

Table 2. Specifications of steel in a laboratory sample [7]

Section type	Yield strength (MPa)	Ultimate strength (MPa
IPE100 beam flange	308	**479**
IPE100 beam web	285	**446**
Fishplate	297	**406**
Steel plate	268	**415**
Bolt	900	**1000**

2. INTRODUCING THE LABORATORY MODEL OF ARABZADEH ET AL.

Before presenting the numerical results, it is necessary to ensure the correctness of the numerical solution method. So, before simulating the desired models and to ensure the work' correctness, modeling the experimental model of Arbzadeh et al. and comparing the results of the software with the experimental results. After assuring the accuracy of the simulated model, the model was developed. Arabzadeh et al. performed experiments on a composite shear-wall under cyclic loading. An overview of this laboratory model is shown in Fig. 2.

In interactions, shear wall modeling is of particular importance. The system of composite shear-walls includes a steel frame, steel plate, fish plate, reinforced concrete wall, rebar, and cutter. Specifications of laboratory samples for simulation and specification of steel in the laboratory model are presented in Tables 1 and 2, respectively.

Properties of materials are presented in the text of the article. Nonlinear static analysis was used to analyze the behavior of composite shear-walls under cyclic loads. Shell element was used for the steel plate and also for the fish plate; the Solid element was used for the reinforced concrete wall

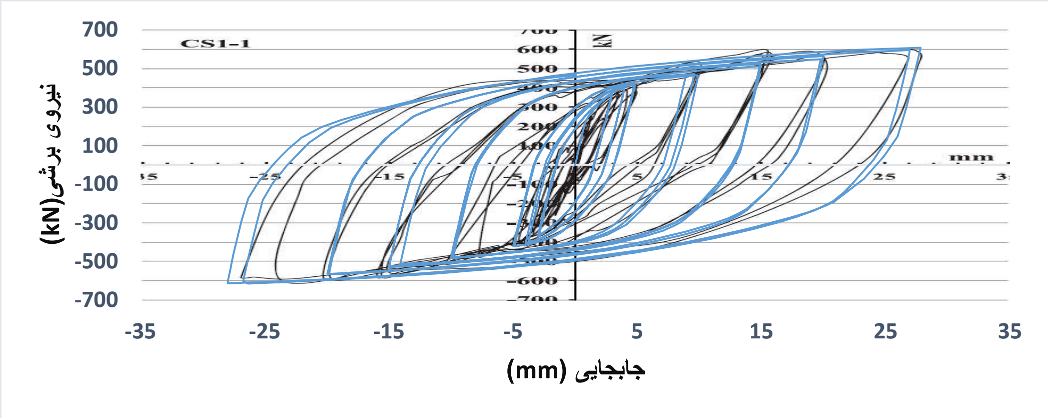

Fig. 3. Comparison of sample hysteresis curve in laboratory and software models

and the Wires used for the reinforcement and the cutters. After assembling the parts and determining the geometric shape of the composite shear wall, the solvers and simulation methods were determined. The interface between the components of the shear composite wall Tie was defined. For the contact surface between the reinforcement and the concrete wall, where the Region embedded was used. The friction coefficient between steel and concrete was 0.3. To carry out loading, it is possible to apply two methods of applying force and displacement.

In the first method, the amount of force applied to the structure and the software will give the corresponding displacement amount, and in the second method, the amount of displacement is introduced into the structure, and the software provides the amount of force required for the displacement entered. In this example, the transfer procedure was used to load. To do this, according to the ATC24 loading instructions, the amount of displacement was applied to the shear wall. To validate the numerical model, a composite shear wall sample was placed under cyclic loading and the load-displacement curve was plotted and compared with the results of a similar laboratory sample. As shown in Fig. 3, the curves obtained from numerical and experimental models are very similar. In Fig. 3, black and light blue lines are related to laboratory and software, respectively.

3- COMPARISON OF THE RESULTS OF NUMERICAL AND LABORATORY MODELS

A comparison of the hysteresis curve of the simulated model with the laboratory sample (shown in Fig. 2) shows that the ultimate strength of the laboratory sample under displacement of a maximum of 27 mm is 595 kN and in the simulated model, this value is 606 kN. This result shows that the difference between the simulated model and the experimental model is 2%, so the accuracy of the modeling is confirmed.

4- RESULTS

The key results of the research are as follows:

- The composite shear-walls have higher resistant, more ductility and higher energy absorption than steel one. The presence of a reinforced concrete wall on both sides of the steel plate reduced somewhat off-plate displacement but limited the margin of lateral space inside the plate and the ultimate strength of the system.
- Semi-enclosed composite columns increased the ultimate strength of 48% and improved the ductility and energy depreciation of the composite shear-walls.
- By increasing the thickness of the steel plate in the composite shear-wall, the plate's strength increased and the plate buckled under greater force; this increased the strength, energy depreciation, and total wall ductility. Based on the results, it can be said that the increase in the thickness of the steel plate up to 4 mm resulted in increased strength, energy depreciation, and shear wall thickness; and more than this, in the strength of the composite shear-wall negatively affects.
- The use of the gaps between the reinforced concrete-walls due to the reduction of concrete damage improves the behavior of the system and is acceptable; but it should be noted that if the gap diameter exceeds a certain and/or lower limit, the strength, ductility, and energy depletion of the system is decreased. The gap of 11.3 mm diameter was determined as the optimal mode gap.
- An increase of 142% in the compressive strength of concrete resulted in only a 15% increase in the ultimate strength of the system, and therefore, increasing the compressive strength of the concrete has little effect on the ductility and the energy loss of the composite shear-walls.

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