A Study on the Seismic Behavioral Parameters of the Composite Steel Plate Shear Wall (CSPSW) in The Building Frame System Using Incremental Dynamic Analysis (IDA)

Shahrokh Golpayegani[1], Majid Gholhaki[2*]

1- Faculty of Civil Engineering, Semnan University, Semnan, Iran
2- Faculty of Civil Engineering, Semnan University, Semnan, Iran

ABSTRACT

Due to the advancements in lateral force-resisting systems, there is a growing need to study other modern systems further. To investigate the behavior of structures from linear to nonlinear and static to dynamic, analysis and design methods such as incremental dynamic analysis offer researchers more accurate results. Given the absence of a specified behavior factor for the lateral force-resisting system of composite steel plate shear walls in Iranian standards, the primary objective of this research is to analyze the seismic coefficients and, consequently, determine the behavior factor using the incremental dynamic analysis method for the systems in question. This research initially validated a laboratory model to achieve optimal networking. Subsequently, three structural models representing short (7 stories), medium (14 stories), and tall (21 stories) buildings were designed using ETABS software. Finally, a two-dimensional frame was extracted from the mentioned structures and analyzed using Abaqus software for modal, nonlinear static, and incremental dynamic responses. The results demonstrate an increase in the overstrength factor coefficient as the height of the structure increases, rising from 4.942 to 5.213. This indicates a direct correlation between the overstrength factor and the height of the structure. Conversely, a decrease in the ductility coefficient, from 1.266 to 1.496, confirms the inverse relationship between ductility and the height of the structure. In the section on the behavior coefficient, the values of 7.396, 6.742 and 6.6 were obtained in the extreme state and 10.355, 9.438 and 9.24 in the admissible stress state respectively for short, medium and tall structure.

KEYWORDS

Composite Steel Plate Shear Wall, Incremental Dynamic Analysis, Overstrength Factor Coefficient, Ductility Coefficient, Behavior Coefficient.

---

[*] Corresponding Author: Email: mgholhaki@semnan.ac.ir

1. Introduction

The composite steel plate shear wall (CSPSW) consists of a steel plate and concrete panel on one or both sides of it, and the connection between the concrete and steel will be provided with shear studs. This system is referred to as the CSPSW in AISC [1] seismic design criteria.

The concrete panel confines the steel plate and prevents its buckling prior to the in-plane shear yielding. The shear yield capacity of the sheet is much higher than its capacity in facing the shear resulting from the yield caused by the diagonal tensile field.

Therefore, if there is a gap between the concrete panel and the boundary elements, this system is called a new system, but if there is no gap, it will be an old type [2].

some of the valuable studies by some researchers in this field are as follows:

In 2002, Astaneh-asl et al. [2] investigated the behavior of a novel CSPSW system under cyclic loading and compared it with the common system. It should be noted that the difference between these two types of walls concerns the gap between the concrete panel and the boundary element. The results exhibit less severe damage in the connection bolts and concrete panel under the same lateral displacement, and due to the gap, the new system will incur less intense damage compared to the old system in relatively large loading cycles.

In 2018, in order to estimate the stiffness of the CSPSW system, Movahedinia et al. [3] separated the steel plate from the frame and calculated the stiffness by considering the interaction between them. The results confirm that the involvement of the concrete panel with the boundary elements and the use of low strength steel plate and thickness equivalent to a normal plate will increase the stiffness of the system.

Additionally, in 2020, Rahimikhah et al. [4] parametrically investigated the buckling-restrained SPSW with the gap between the concrete panel and the steel plate ranging from 0 to 15 mm. The results show that the initial strength and stiffness of the system decreases with the increase of the gap. Hence, the R factor will be 8.11 on average in the case without gap and 11.21 with gap. The existence of a concrete panel in a gapless state and on both sides of the steel plate will increase the initial stiffness of the system by 45%.

In 2021, Rahimi et al. [5] studied the effect of steel plate thickness and concrete panel as well as width-to-height (W/H) ratio of 0.75, 1, and 1.5 on the behavior of the CSPSW. The results illustrated that the 6 mm thick plate will absorb more energy in all W/H ratios. Furthermore, while presenting a semi-empirical relationship to calculate the thickness of the concrete panel according to the thickness of the steel plate in order to prevent the plate buckling, the R factor of 13.5 was obtained for this system.

In 2023, Munesi et al. [6] investigated the behavior of the BRSPSW subjected to the cyclic loading. According to the obtained results, the SPSW without concrete panel has the lowest energy absorption due to local and lateral buckling, and in contrast to the specimens with concrete panel and with a gap width of 20 and 40 mm, the energy absorption capacity increased by 6 times. Moreover, the shear capacity of the specimen with the concrete panel will be enhanced by about 50%.

Considering the studies conducted in the field of composite shear walls, some of which were listed above during the last two decades, as well as the progress of structural analysis methods from linear to nonlinear and from static to dynamic, the need to study seismic coefficients and provide a specific behavior coefficient using modern structural analysis methods such as incremental dynamic analysis, especially in domestic regulations and standards due to the lack of a specific behavior coefficient for the lateral load-bearing system of composite steel shear walls, has been felt more and more, and the present study will be carried out with the aim of convincing the above-mentioned cases.

2. Methodology

In this research, first, a laboratory model was validated to obtain optimal meshing. Then, three structural models (7, 14, and 21 stories) representing short, medium, and tall structures were designed in the ITBS software, and finally a two-dimensional frame of the aforementioned structures was separated and analyzed in the Abaqus software (modal, nonlinear static, and incremental dynamic).

3. Results and Discussion

1- The growth of the design base shear values with increasing structure height, which is reasonable due to the approximate decrease in the ductility coefficient as the structure height increases and the subsequent decrease in the behavior coefficient (the inverse ratio between the behavior coefficient of the structure and the base shear is dominant).

2- Due to the decrease in the stiffness of structural models with increasing height and also the inverse ratio of the stiffness of the structure and the cycle time, the cycle time values will grow with increasing structure height.

3- The increase in the overstrength factor coefficient with increasing structure height, which indicates a direct ratio of the overstrength factor coefficient to the height of the structure. The opposite of the above is true regarding the ductility coefficient, and previous studies will confirm the aforementioned relationship. In this study, a slight difference is observed between the above explanations and the values obtained in the 14- and 21-story model range, which can be due to factors such as the typification of structural sections in the design stage, etc. In general, the above relationship will be true.

4- According to Section 3-4-2 of Standard 2800, Fourth Edition, if three pairs of accelerograms are used for analysis, the final reflectance of the structure will be equal to the maximum reflectance obtained from the analysis of each model under three pairs of accelerograms. The explanations of this section were also used in calculating the behavior coefficient for the three ranges of short, medium and long-range structures.

4. Conclusions

1- Obtaining an optimal 30 mm mesh for the composite steel plate shear wall system after validating the laboratory model of Arabzadeh et al.

2- Increasing the design base shear from 1048.26 kN in the 7-story model to 1496.5 kN in the 21-story model.

3- Increasing the cycle time values from 1.856 seconds in the 7-story model to 3.425 seconds in the 21-story model.

4- Increasing the overstrength factor coefficient from 4.942 to 5.213 with increasing the height of the structure.

5- Obtaining the behavior coefficient of 7.396, 6.742 and 6.6 in the limit state and 10.355, 9.438 and 9.24 in the allowable stress state for short, medium and tall structures, respectively.

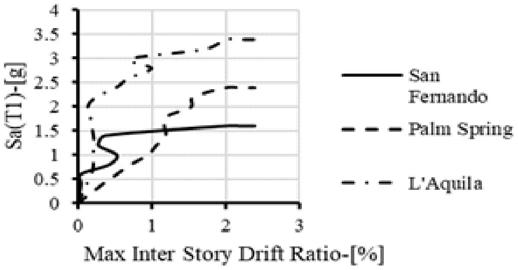

Figure 1. IDA Curves of the 7-storey model

5. References

[1] Seismic Provisions for Structural Steel Buildings, ANSI/AISC341-16, American Institute of Steel Construction, Chicago, Illinois, (2016).

[2] Astaneh-Asl A. Seismic Behavior and Design of Composite Steel Plate Shear Walls: Structural Steel Educational Council Moraga, CA, USA; (2002).

[3] Gholhaki M, Movahedinia M, Rezaeifar O. Providing Analytical Relationship to Calculate the Stiffness of Composite Steel Shear Walls. Amirkabir Civil Engineering Journal. 50(3) (2018) 607-16.

[4] Gholhaki M, Rezayfar O, Rahimikhah MS. Provide Analytical Relationship to Calculate the Strength of Composite Steel Shear Walls by Abaqus software. Journal of Structural and Construction Engineering. 8(3) (2021) 42-55. (In Persian).

[5] Gholhaki M, Rahimi T, Kheyroddin A. An Analytical and Numerical Study on Effect of Thickness and Concrete Type of Panels on Behavior of Composite Steel Plate Shear Walls. Amirkabir Journal of Civil Engineering. 53(9) (2021) 3623-48.

[6] Munesi A, Gholhaki M, Sharbatdar MK, Pachideh V. Study on the Gap Width Between the Steel Plate and Concrete Panels on Behavior of the Buckling-Restrained Steel Plate Shear Walls. Structural Concrete. (2023).