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Research Review on the Performance of Double Steel Plate Composite Shear Walls

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Abstract: Double steel plate composite shear walls are characterized by their lightweight, thin wall structure, high ductility, and construction convenience. These walls are widely used in the field of engineering. This paper focuses on double steel plate composite shear walls and summarizes the current state of research on their static load-bearing and seismic performance both domestically and internationally. The paper highlights the deficiencies in current research and points out the future direction for the study of double steel plate composite shear walls.

Keywords: Double steel plate combined shear wall; Seismic; Static load.

1. Introduction

In recent years, with the economic growth of our country, the demand for building land has continued to increase, leading to a shortage of land resources. To alleviate this issue, the construction height of buildings has been continuously increased. A plethora of high-rise and super high-rise buildings have sprung up, and their numbers have become an important indicator of the level of urbanization. Unlike low-rise buildings, the design key for high-rise and super high-rise buildings lies in lateral displacement of the structure. During the design process, structures must not only have sufficient strength to resist vertical loads but also possess adequate lateral stiffness to counteract horizontal loads caused by seismic and wind forces.

In current high-rise and super high-rise buildings, the majority of lateral force-resisting systems are still reinforced concrete shear walls. However, as building heights increase, the shortcomings of reinforced concrete shear walls in terms of seismic resistance are becoming more apparent. Double steel plate composite shear walls, as a new type of efficient lateral force-resisting structural component, effectively address this problem.

The wall body of a double steel plate composite shear wall is composed of external steel plates, internal concrete infill, and the connectors between them. The connectors include stud connections, T-shaped stiffener connections, stitch plates, or through-tie bolts, and these four types of connections can be used in combination. Double steel plate composite shear walls have advantages such as lightweight, thin wall profile, and high lateral stiffness. Additionally, the steel plates of the shear wall are fabricated in the factory and can be directly poured with concrete on-site, eliminating the need for manual formwork, making it both economical and convenient.

2. Status of Research on Double Steel Plate Composite Shear Walls

2.1. International Research Status

In the 1980s, engineer Tomlinson proposed a double steel plate composite structure in pipeline engineering. In 1995, Wright conducted static load performance studies on ordinary profiled steel plate concrete composite frame shear walls, as shown in Figure 1. During axial compression tests, it was discovered that the absence of effective connection measures between the external steel plates and the reinforced concrete frame resulted in a reduction of the structure's axial load-bearing capacity. This finding provided direction for subsequent research.

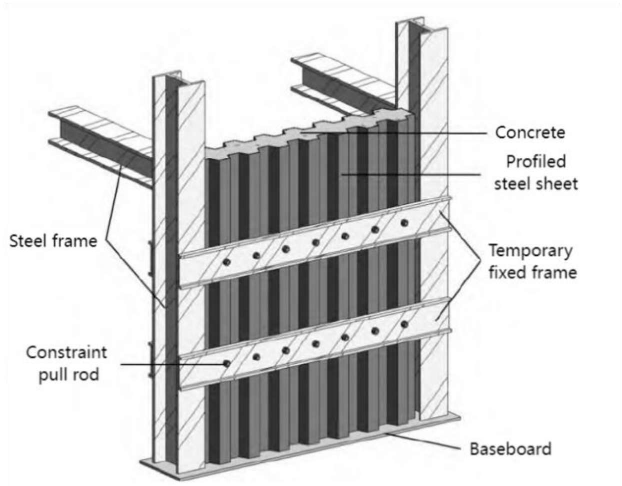

Figure 1. Profiled Steel Plate Composite Shear Wall

In the same year, Link [3] conducted out-of-plane performance tests and finite element analysis on double steel plate composite shear walls used in marine protection. The study found that the double steel plate composite shear walls exhibited good bearing capacity and ductility under out-of-plane loads.

In 1998, M. Takeuchi [4] studied the static load performance of double steel plate composite shear walls used in the nuclear engineering field, mainly focusing on their axial compression, shear, and bending performance through experiments. The shear walls were welded with shear studs on both sides of the steel plates, and then connected with tension steel bars. The test results showed excellent mechanical performance of the shear walls with this connection method, and the overall integrity of the steel plates and concrete was greatly improved.

In 2004, Zhao et al. [5] conducted seismic tests on three-layer composite steel plate shear walls. The experimental research showed that the steel plate shear walls exhibited good ductility. However, in the later stages of the test, local buckling occurred in the external steel plates of the steel plate shear walls, which could be effectively mitigated by increasing the bolts.

In 2009, Eom et al. [6] conducted seismic tests on double steel plate composite shear walls with different cross-sectional types, studying the wall failure, and the influence of section shape and steel plate thickness on the seismic performance of the walls.

In 2016, Rassouli et al. [7] conducted shear tests on lightweight concrete double steel plate shear walls, with ordinary concrete shear walls set as the control group. The experiments showed that there was little difference in shear performance between lightweight concrete double steel plate shear walls and ordinary shear walls, but the lower self-weight of lightweight concrete shear walls led to a decrease in their seismic performance.

In 2018, Huang et al. [8] studied the seismic performance of a new type of double steel plate composite shear wall with transverse stiffeners. The experimental variables were axial compression ratio and shear span ratio. The results showed that this type of shear wall had strong bearing capacity and good energy dissipation capability, and a lateral bearing capacity calculation formula considering the steel plate confinement effect was derived.

2.2. Research Status in China

Research on double steel plate shear walls in China started relatively late, but up to now, numerous scholars have conducted research on various aspects of the performance of double steel plate shear walls. This section briefly summarizes these studies.

In 2011, Nie Jianguo et al. [9-12] conducted experimental research on the mechanical properties of double steel plate shear walls, as shown in Figure 2, and analyzed them using finite element software. The experimental variables were axial compression ratio and shear span ratio. The experimental study found that: the larger the axial compression ratio and the smaller the shear span ratio of the shear wall, the better its hysteretic performance; shear walls with smaller shear span ratios mostly failed in flexural shear; double steel plate shear walls connected by bolted connections had higher bearing capacity than those connected by restrained tie rods; bolted connections improved the overall integrity between the two side steel plates and the middle concrete; when the axial compression ratio of the shear wall was relatively large, its ductility decreased, and the axial compression ratio had no significant effect on the peak load and stiffness of the shear wall.

In 2013, Ji Xiaodong et al. [13] conducted experiments on double steel plate shear walls with rectangular steel tube concrete columns to study their seismic performance. Five specimens were designed for testing. The experimental results showed that most specimens failed in flexural compression, and the length of the constrained edge components significantly affected the deformation and energy dissipation capacity of the wall.

In 2014, Luo Yongfeng, Li Jian, etc. [14-15] conducted scaled seismic tests based on the design of the Yancheng Radio and Television Tower, studying the stiffness degradation law and failure modes of different structural types of specimens. The experimental content analyzed the influence of different materials, axial compression ratios, and height-to-width ratios on seismic performance. The hysteretic performance of specimens was also compared. The results showed that reasonable openings could effectively improve the ductility of specimens, and the initial stiffness of specimens was significantly affected by the height-to-width ratio.

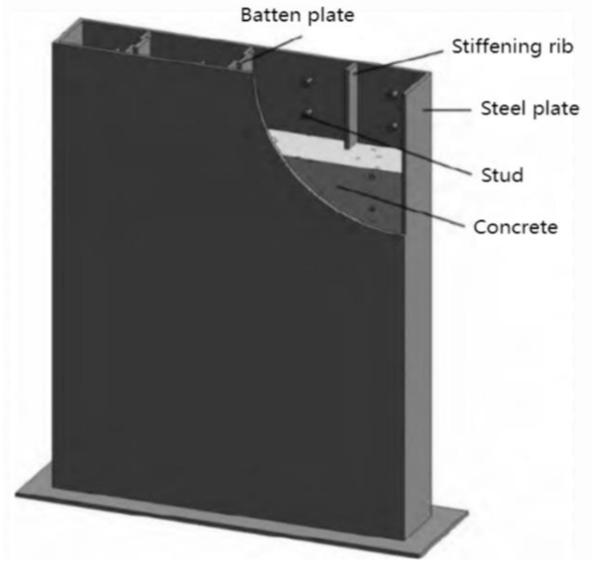

Figure 2. Double steel plate shear wall

In 2016, Zhang Youjia et al. [16-17] conducted axial compression tests on double steel plate shear walls with different axial compression ratios to better study the deformation and bending performance of steel plates connected by bolted connections. They also conducted finite element analysis to fully study the deformation, bearing capacity, and failure modes of specimens and derived calculation formulas for double steel plate shear walls, which could accurately calculate the ultimate bearing capacity and initial stiffness, and then deduced the formula for elastic buckling strain of steel plates.

In 2016, Li Xiaojun, Li Xiaohu, etc. [18-21] conducted experiments on double steel plate shear walls applied in nuclear power projects, mainly studying the seismic performance of shear walls and the influence of horizontal loads and planar bending stiffness on bearing capacity. Calculation formulas for flexural bearing capacity were derived based on the experimental results.

Based on the above research content, whether it is static loading tests or seismic tests of double steel plate shear walls, the selected experimental variables are almost always axial compression ratio, shear span ratio, etc. The failure of shear walls starts with the failure of steel plates. With the continuous increase of load, concrete begins to fail, leading to specimen failure. The larger the axial compression ratio and the smaller the shear span ratio of the shear wall, the more stable its hysteretic performance and the better the ductility of the specimen.

3. Shortcomings and Prospects

Based on the current research results, numerous scholars believe that the double steel plate shear wall structure has good bearing capacity and ductility performance. However, in the research of scholars and the application in engineering, some problems still need to be addressed. Therefore, it is necessary to conduct in-depth research on double steel plate shear walls to meet the application needs of double steel plate shear walls in the engineering field.

According to the existing research results, the following two suggestions are proposed:

(1) Theoretical research: Although some scholars have derived calculation formulas for the bearing capacity of double steel plate shear walls, the determination of their constitutive relationship is not clear in relevant specifications. Double steel plate shear walls are mostly used in the field of nuclear engineering. When installing some special equipment, it may involve opening and multiple opening treatments of the wall, and the specifications do not clearly specify the treatment methods of the openings and the calculation of the bearing capacity after opening, which requires in-depth research.

(2) Construction: The connection method of the two side steel plates of double steel plate shear walls currently used in engineering mostly adopts through-bar reinforcement, which increases the connection strength of the two side steel plates to a certain extent. However, the spacing of through-bar reinforcement is small, and there are many arrangements in the entire wall, while the wall thickness is limited, resulting in extremely inconvenient construction. It is necessary to develop new connection methods to solve this problem.

4. Conclusion

This paper focuses on double steel plate shear wall structures and summarizes the research status of the static and seismic performance of double steel plate shear walls. At the same time, it also points out the problems in theoretical research and construction research of double steel plate shear walls, providing reference for future specification formulation and engineering application.

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