Experimental Study on a New Type of Earth Pressure Measurement Device for Retaining Structures

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Abstract. To address the challenge of precision in existing earth pressure measurement techniques, this study introduces the use of rebar strain gauges. This novel approach utilizes the tensile forces in reinforcing bars to accurately determine the earth pressure on retaining structures. Employing a bespoke experimental framework, the investigation assesses earth pressure on retaining structures under various states, including stasis, non-limit, and active limit conditions. It also documents soil dynamic changes under non-limit states through imaging, with empirical data analyzed alongside theoretical forecasts. The results highlight that rebar strain gauges enhance measurement accuracy by ensuring a clear distinction between the sensor and soil, thus reducing errors from soil characteristics and sensor positioning. Compared to traditional methods, this approach significantly narrows the gap in earth pressure readings under static and limit conditions by factors of 2.23 and 2.49, respectively. This system promises to validate standard retaining structure designs and support the empirical and theoretical exploration of innovative retaining solutions, offering broad application potential.

Keywords: Earth Pressure Measurement; Rebar Strain Gauge; Model Apparatus; Separation; Sensor.

1 Introduction

Amid rapid economic progress and urban expansion, the scope of subterranean construction has grown, delving into more complex environments. This change has redefined the role of retaining structures beyond soil retention to prioritize efficiency, economic feasibility, sustainable material use, and environmental adaptability[1]. Innovations in retaining structure design are becoming crucial in underground development, with earth pressure—a key design factor—significantly influencing structural dimensions, cost, and material requirements[2]. Thus, precise earth pressure measurement is

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change the connection method to improve the energy consumption, ductility, and earthquake resistance of the specimen. Yan Guiyu^{n}[1]et al. studied the seismic performance of steel connected prefabricated shear wall with repairable earthquake damage. Meng Bao[2]et al. improved the design of the new energy-dissipating plate, which effectively improved the bearing capacity, deformation and energy dissipation capacity of the steel frame node under earthquake and continuous collapse conditions. Fan Yujiang[3]et al. tested the seismic performance of this new prefabricated shear wall with energy dissipation and shock absorption through the combination of loading test and numerical simulation of finite element software. Wu Dongyue[4]et al. proposed a large-size reinforced cogging prefabricated shear wall, which resists the joint shear force and adversely affects the seismic performance of the prefabricated shear wall. Wu Zhiping[5]et al. used perforated plug welding to connect the connecting parts of anchor plates, webs, end plates and stiffener plates with anchor ribs with prefabricated shear wall members to test and study the seismic performance.

The common connection forms of prefabricated concrete shear walls mainly include: bolted connections, welded connections and other dry connections; Grouting sleeve connection, grouting anchor connection and other wet connections. In this paper, the connection types, new construction methods and related test results of prefabricated shear wall are reviewed in literature, the seismic performance of related specimens is analyzed, and the research direction of seismic performance of prefabricated shear wall connection joints is prospected.

2 Prefabricated shear wall dry connection

The dry connection form can be divided into horizontal connection and vertical connection. The prefabricated shear wall is used vertically for horizontal joints in the upper and lower wall panels, and the horizontal connection is used for vertical joints in the left and right wall panels.

2.1 Bolt connection

Zhong Xun et al. designed two types of prefabricated concrete shear wall specimens connected by box bolts with round holes and square holes in the bottom plate of the box[6] . The ductility of the specimen is good, friction and pin bolt are the main factors affecting the bearing capacity of the horizontal joint, and reasonable design can ensure that the tensile end of the connecting steel frame does not yield during the whole test[7-8]. The joint action of bolts and steel plates can avoid brittle failure, and have high bearing capacity and structural ductility, as well as good energy dissipation and deformation capacity[9].The diameter, pre tension, and flange thickness of high-strength bolts are the main factors affecting the bearing capacity of steel frames[10].

To sum up, through reasonable bolt connection structure design, it has good bearing capacity, ductility and energy dissipation capacity, basically meets the seismic requirements, and can realize the same mechanical properties of prefabricated shear walls and cast-in-place concrete shear walls, fulfill the prerequisites for robust joints and fragile members.

2.2 Solder connection

The both layouts exhibit excellent deformation ability, side resistance performance and energy dissipation ability. Corresponding design formulas are proposed for the two layouts of prefabricated T-shaped dry-type connection shear walls[11] .Zhang Shuyun et al. studied the seismic performance of prefabricated shear walls with concealed column steel welded connections. The results showed that increasing the diameter of the longitudinal reinforcement of the edge members can improve the seismic performance of prefabricated shear walls. When the diameter of the steel bars increases to a certain extent, the bearing capacity of the shear wall increases slowly[12]. All specimens were bending failure, with excellent ductility, energy dissipation capacity, and gradual stiffness degradation. Increasing the axial compression ratio can improve the rigidity and load-bearing capacity of prefabricated shear walls[13].When designing steel box connectors, nuts should be avoided Slipping should also be checked for welding quality in the connection of the steel box, while increasing the horizontal direction Reinforcement can help improve the energy dissipation capacity of columns[14].

In summary, the welded connection prefabricated shear wall has good bearing capacity, basically meets the seismic requirements, and the construction period is short, but to ensure the performance of the joint, a higher welding level is required to ensure the quality of the weld. So connection mode need to be further improved.

3 Seismic Performance Optimization Design of Prefabricated Shear Walls

3.1 Optimization Design of Prefabricated Shear Walls

3.1.1 Model Establishment.

The prefabricated wall is composed of loaded beams, hidden columns, intermediate walls, and bottom beams. The dimensions of the wall are 1900×1000×200, the dimensions of the loaded beam are 1200×300×300, and the dimensions of the bottom beam are 1800×600×400. An axial compression ratio of 0.2 is used.

3.1.2 Material Constitutive Relations.

The ABAQUS finite element software offers a plastic damage model that facilitates the simulation of concrete cracking and crushing, ensuring exceptional convergence and applicability across both static and dynamic analysis scenarios. This enables users to accurately capture the non-elastic behavior of concrete under cyclic loading conditions. Based on the test data of specimen GB2-5-3 and in conjunction with the “Code for Design of Concrete Structures” (GB50010—2010), the concrete material’s strength parameters are listed in Table 1.

Table 1. Main Material Parameters of Concrete

fcu,k/MPa	fck/MPa	ftk/MPa	Ec/MPa	VC
82.37	58.58	3.85	38150	0.2

All concrete is of C40 grade, with a density of 2500kg/m^3, Young's modulus of 3.25×1010N/m^2, and Poisson's ratio of 0.2. All steel components in the test use Q235B steel, with stirrups of HPB300, longitudinal reinforcement of HRB400, steel density of 7850kg/m^3, Young's modulus of 2.1×1011N/m^2, Poisson's ratio of 0.3, and the use of Q235B shims.

3.1.3 Grid Division and Model Loading.

The grid division uses C3D8R for concrete and T3D2 for reinforcement. All connection surfaces are bound, and all steel bars are internally constrained. The wall is highlighted in the grid division, with a partition size of approximately 100mm, while the remaining concrete grid sizes are approximately 400mm.

The finite element simulation uses displacement-controlled loading. Initially, horizontal displacement is cycled in increments of 3mm, with 3 cycles per level, until a displacement of 18mm is reached. Then, the loading is continued with increments of 6mm per level, again with 3 cycles per level, until a maximum displacement of 48mm is reached, based on the test results.

3.2 Finite Element Model Simulation Analysis

3.2.1 Hysteresis Curve Analysis.

The hysteresis curve is full and exhibits good energy dissipation capacity. In the initial stage, the hysteresis curve is approximately linear, with almost no residual deformation, stress, or displacement, indicating an elastic working stage. As the displacement increases, the height and the enclosed area of the hysteresis loop also increase, creating a more complete hysteresis curve. The gradual decrease in the slope of the curve indicates a reduction in the stiffness of the shear wall, whereas the increasingly larger residual deformation observed at the unloading point of the hysteresis loop indicates that the shear wall has progressed into the elastic-plastic stage. After unloading, all test specimens exhibit different degrees of residual deformation and a significant "pinching" phenomenon.

3.2.2 Skeleton Curve Analysis.

In the initial stage of loading, the stiffness of the test specimen degrades rapidly, and the skeleton curve is basically linear, the specimen is currently in the elastic phase, characterized by a gradually inclined skeletal curve towards the horizontal axis with increasing displacement. This slope reduction signifies a decline in the specimen's stiffness, indicating its transition into the plastic deformation stage. Stiffness degradation begins to slow down, and finally, the stiffness degradation curve of the specimen tends towards the horizontal axis. Even after exceeding the maximum elastic-plastic interlayer displacement angle, the skeleton curve continues to exhibit an upward trend, indicating that the bearing capacity escalates alongside the increment in loading displacement, until the specimen ultimately sustains failure. In the late stage of loading, its bearing capacity almost does not increase, but it maintains a stable bearing capacity.

3.2.3 Energy Dissipation Capacity.

The test specimen still exhibits good energy dissipation capacity and has practical significance in actual engineering. As the loading displacement increases, the equivalent viscous damping coefficient of the test specimen also rises, indicating an enhancement in the specimen's yielding reinforcement, concrete or grouting crushing, and overall energy dissipation capacity.

4 Conclusions

Shear walls play an important role in the seismic performance of civil engineering. It is worth emphasizing that when selecting the connection method, we must deeply consider the specific requirements of site conditions, building functions and seismic fortification. Through this method, we can effectively prevent and mitigate disasters in the design and construction process, and reduce the impact of natural disasters such as earthquakes on civil engineering structures.

In this paper, the research results of precast shear wall in recent years are analyzed, and the research progress of the seismic performance of the precast shear wall in different connection forms is emphasized. List the main connections for discussion:

1)The bolt specimen has good bearing capacity, ductility and energy dissipation capacity, and the diameter, pre-tension and flange thickness of the high-strength bolt connected to the steel frame are the main factors affecting the bearing capacity;

2) The structural performance of the welded connection of the specimen is good, but it is not conducive to the energy dissipation effect of the vertical joint, and the welding quality is difficult to ensure, and the concrete and steel bars in the T-shaped shear wall may produce large thermal expansion deformation when the temperature changes, resulting in stress changes in the wall. Long-term thermal expansion may lead to cracks and deformation of the wall, so we propose the following improvement methods:

Preheat the welding parts before welding, so that the heat generated in the welding process is dispersed. Hammering in the hot state during the welding process, hammering between layers, so that the weld is extended, and heat treatment of the welding part after welding, such as overall heat treatment or local heat treatment, can eliminate or reduce the welding residual stress.

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