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A Review of Seismic Performance of Infill Wall Frame Structures under Flexible Connections

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Review Article

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ABSTRACT

With the continuous improvement of seismic-resistant technology and the development of social and economic level, the research on seismic performance of infill wall frame structure has been deepened, and the flexible connection between walls and frames has been gradually emphasized. The purpose of this paper is to systematically elaborate the experimental research and finite element analysis method research on the seismic performance of infill wall frame structure under flexible connection according to the research results of scholars from various countries, point out the key technical problems that need to be solved in the research process of the seismic performance of infill wall frame structure under flexible connection, and put forward the outlook of the future research.

Keywords: Flexible connections; infill wall frame structures; seismic performance.

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1. INTRODUCTION

Masonry infill walls are the most commonly used partition and enclosure elements in reinforced concrete frame structures. At present, the frame and infill wall will not be separated in actual projects, and this rigid connection between the wall and frame has numerous advantages, such as: easy construction, improving the overall lateral stiffness of the structure, and participating in seismic energy consumption as the first line of defense against structural earthquakes. However, there are many problems that have not yet been considered, such as: the masonry infill wall rigidly connected to the frame will limit the deformation of the main frame structure to a certain extent, affecting the generation of plastic hinges, which can easily cause shear damage at the top of the frame column. And due to the masonry infill wall stiffness than the frame body is much smaller, rigid connection leads to the frame body extrusion masonry infill wall, so that the masonry infill wall in the first time of the earthquake cracking or even collapse. Research on previous earthquakes found that the frame structure shows good seismic performance, but most of the damage occurs in the infill wall, and the frame is prone to column hinge damage, short column damage and other super-expected earthquake damage under the action of the wall [1-4] The frame is prone to column hinge damage, short column damage, and other unexpected damage under the action of walls. Non-structural exterior walls, partition finishes, non-structural partitions and ceilings, and appurtenant elements are the first to show damage and are most likely to be damaged in multiple earthquakes [5]. The most likely damage will occur during a multiple-occurrence earthquake. Damage that is difficult to repair can result in serious economic losses, and in the case of critical buildings such as hospitals, which are required to maintain specific functions, serious damage can directly hinder the normal maintenance of the building's functionality [6]. The damage can be severe enough to impede the normal maintenance of the building's function.

The proposal of flexible connection between wall frames can well avoid the premature damage of infill wall members and make up for the deficiency of rigid connection. According to the research results of domestic and foreign scholars on the seismic performance of infill wall frame structure under flexible connection, this paper summarizes the current research status of the seismic performance system of infill wall frame structure under different connection configurations in terms of experimental research and finite element analysis, analyzes the key technical problems existing in the current research, and puts forward a prospect of the future research on the seismic performance of infill wall frame structure system under flexible connection. It provides reference basis for the research and development and application of flexible connection of infill wall frame structure.

2. OVERVIEW OF FLEXIBLE CONNECTIONS BETWEEN WALL FRAMES

The connection between the infill wall and the frame can be roughly divided into rigid connection and flexible connection. When rigid connection is used, the specific practice has filler wall slanting masonry top tight frame beams and columns masonry, set up tie reinforcement between the filler wall and the frame, and so on. In view of the many disadvantages of the traditional rigid wall and frame connection, researchers and scholars have proposed the use of disconnection between the frame and the infill wall for connection. Numerous studies have shown that the flexible connection with the frame disconnected from the traditional rigid connection has a better performance of the energy consumption [7-8]. In order to realize the rapid restoration of urban functions in the disaster area after the earthquake on the basis of the original seismic defense requirement of "not falling down after a big earthquake", to reduce the casualties and economic losses caused by the destruction of infill walls and structures, and to solve the problems of high cost, long time and serious waste of materials in the post-earthquake restoration.

Provisions for flexible connection of wall and frame are given in Chinese codes, "Code for the Design of Masonry Structures" (GB50003-2011) [9]. Article 6.3.4 of the Code for Masonry Structures (GB50003-2011) stipulates that: the connection between infill walls and frames can be disengaged or not disengaged according to the requirements of the design. If there is seismic defense requirement, it is appropriate to use the method of disconnecting the infill wall and the frame. Code for Seismic Design of Buildings (GB50011-2010) [10]. Article 3.7.4 stipulates that: for the enclosing walls and partition walls of frame structures, the adverse effects of their setting on the seismic resistance of the structure should be estimated, so as to avoid the damage of the main structure caused by irrational setting, and it is suggested in the corresponding provisions that the two should be connected flexibly or disconnected from each other. In the earthquake codes of New Zealand and the United States [11-12], whether the infill wall and the frame are disconnected or not is an option. Many scholars through the flexible connection of infill wall frame structure in-plane, out-of-plane seismic performance of experimental research and theoretical analysis, concluded that the infill wall and frame using reasonable flexible connection. Specific practices of flexible connection between wall and frame include: disconnecting the gap between the infill wall and the frame, filling with filler material, setting up structural columns in the infill wall, setting up horizontal tie beams in the infill wall, and setting up cross diagonal reinforcement in the infill wall. However, the current specification has not formed a unified flexible connection construction process, which makes the promotion and development of flexible connection are hindered.

3. EXPERIMENTAL STUDY ON SEISMIC PERFORMANCE OF INFILL WALL FRAME STRUCTURES UNDER DIFFERENT CONNECTION MEASURES

Riddington et al. [13] conducted low-cycle reciprocating loading tests on 6-bay masonry infill wall frames to investigate the effect of different degrees of disengagement between the wall frames on the seismic performance of the structure, and the results showed that even if the degree of disengagement between the wall frames is small, it can effectively reduce the initial stiffness of the structure and improve the seismic performance of the structure.

Borujeni et al. [14] carried out proposed static tests to investigate the seismic performance of the structure with 4 bays of masonry infill wall frames with different connection methods, which were flexibly connected by disconnecting the infill walls from the frames on three sides and setting up mechanical connectors. The results show that this flexible connection reduces the initial stiffness and peak bearing capacity of the structure, minimizes the damage of the infill walls and improves the structural integrity.

M.M. Erdem et al. [15], presented three different flexible connectors (as Fig. 1 shown in), experimental and numerical analyses were carried out to compare the seismic performance under rigid and flexible connections. The results of the study show that; the frame maintains its lateral resistance even under extreme drifts. In addition, the flexibly connected infill wall can achieve a displacement angle of 4% with little or no damage. The adoption of this flexible connection can significantly reduce the negative impact of ACC masonry infill walls on the frame structure.

Saheb Ali Asadzadeh et al. [16], conducted proposed static tests of steel frames for 6-bay masonry infill walls and proposed five different flexible connectors, which were shown to be V-shaped (Fig. 2) and T-type (Fig. 3) connectors showed good synergetic behavior in terms of safety. The deficiency of Mainstone's formula in estimating the ultimate strength of AAC block-filled steel frames was also found.

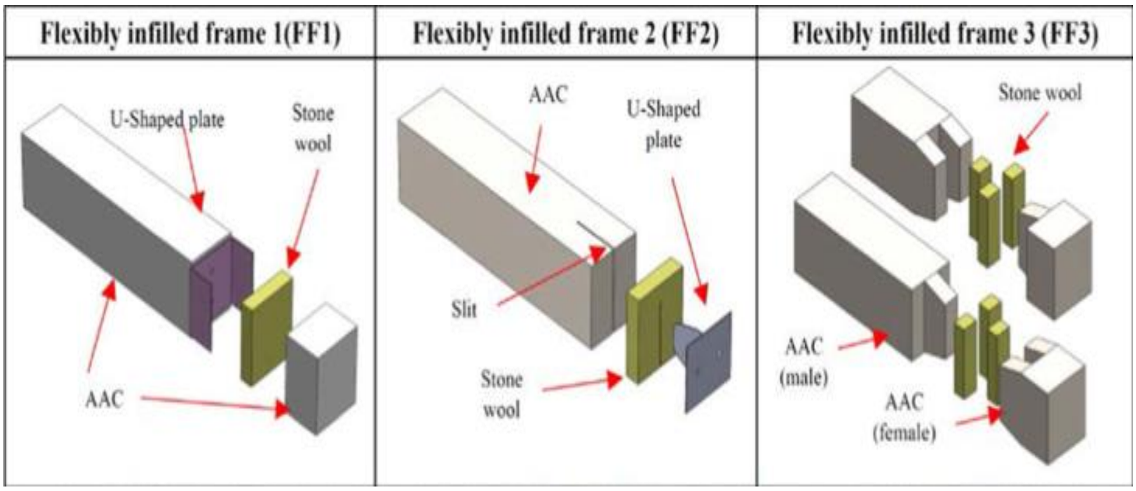

Fig. 1. Flexible connectors

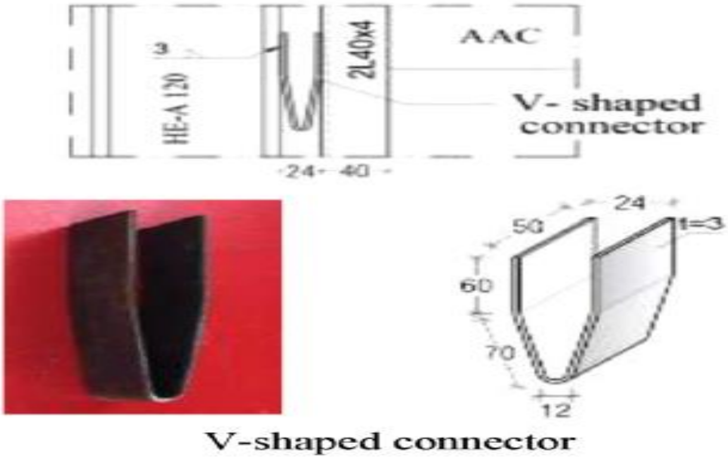

Fig. 2. V-connector

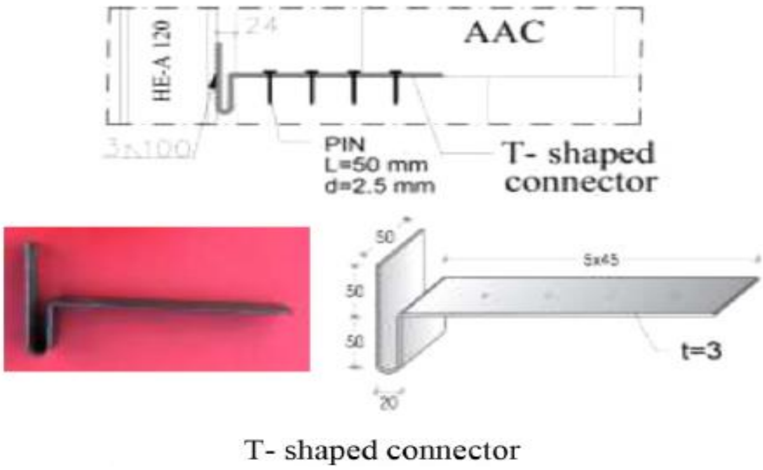

Fig. 3. T type connector

Aristomenis V et al. [17], in order to study the in-plane cyclic response of steel frames of infill walls coming with cellular flexible material (foamed polyethylene), four sets of tests were conducted on steel frames of single-story, single-span hollow clay brick masonry infill walls with nearly 1/3 reduction in size. The relationship between factors such as the location of the flexible material arrangement and thickness and the in-plane response of the infill wall was also analyzed. Pachappoyil et al. [18], Proposed a new type of hysteretic energy dissipation infilled wall RC frame structure. Considering the influence of openings, the seismic performance of the energy dissipation hysteretic infilled wall RC frame structure was evaluated under uniaxial in-plane, out of plane and in-plane and out of plane loads. Hao lyu et al. [19] used high toughness concrete as the covering layer of the infilled wall, and the gap between the frame column and the infilled wall was filled with polystyrene foam board. The results show that the isolation infilled wall scheme can effectively reduce the interaction between infilled wall and column, and has better deformation and energy dissipation capacity than the traditional infilled wall frame.

Jianhui Li and Yantao Xue [20] investigated the effects of wall-frame connection construction and the construction measures of the wall itself on the overall seismic characteristics of the frame by means of foot-size modeling experiments. Zhenyu Xiao [21] analyzed the effects of wall-frame column tie of U-bar tie and wire rope tie, flexible connection of filled polystyrene foam board and rigid connection of unfilled polystyrene foam board on the in-plane seismic performance of the structure through 1:2 foot-size reduction experiments and numerical simulation results.

Mingyuan Liu [22] proposed a new type of flexible connection with U-type connectors pre-buried into the frame and U-type catches inside the wall for cinder block walls and assembled frame structures. With the gradual increase of block size, the bearing capacity of the overall structure shows a gradual decrease in the law. At the same time, the lateral stiffness of the structure decreases as the height-to-width ratio of the block size increases. Lu Xiao, Cha Shumin et al. [23] mitigated the damage of wall under seismic action by rationally installing vertical joints and connectors in the wall. Zhang Yongbing, Guo Xinhua et al. [24] investigated rubber as a flexible connection material and considered variables such as the connection between the infill wall and the frame, the type of block, and the strength of the mortar. The results show that the type of rubber has a certain effect on the seismic performance of frame structures, but the effect is not significant. Different types of infill wall blocks have a greater effect on the load carrying capacity, stiffness degradation, and energy dissipation capacity of the structure. Wenjun Bian [25] used extruded polystyrene foam board as a flexible connection material at the connection of infilled wall and frame beam and column. Through low cycle repeated loading tests of reinforced concrete frame with composite wall panel infilled wall under different connection modes, the influence of different connection modes on the seismic performance of the structure was studied. The results show that the flexible connection has good seismic performance. Junnan Ding [26] proposed a new type of flexible connection based on the use of polystyrene foam plastic plate as flexible material in the gap between the wall and frame. The channel steel track was used to make a reliable connection between the infilled wall and the RC frame structure. The results show that when the damage degree in plane is the same, the peak bearing capacity and stiffness of the new flexible connection RC frame structure with opening infilled wall are 119.8% and 104.2% higher than that of the ordinary flexible connection RC frame structure with opening infilled wall, respectively.

In summary, it can be seen that the frame is greatly affected by the connection method between the wall and frame and the type of block, and the researchers used the experimental methods such as simulated seismic shaking table, horizontal static low-circumference reciprocating load and horizontal proposed dynamic force to study the seismic performance of infill wall steel frame structure and other experimental methods to study the seismic performance of infill wall frame structure with different connecting measures, and to find out the synergistic performance of the force between the wall and the frame, the action mechanism and the influence law of the wall and the frame with the proposed new type of flexible connection. mechanism and influence law of the proposed new flexible connection.

4. RESEARCH ON FINITE ELEMENT ANALYSIS METHODS FOR SEISMIC PERFORMANCE OF INFILL WALL FRAME STRUCTURES UNDER DIFFERENT CONNECTION MEASURES

The finite element analysis method has been widely used in the research in the field of engineering, which has the advantages of fast, easy to implement, and effective shortening of the test cycle [27], and it is a good supplement for the experimental research. The researchers used the finite element analysis method to study the seismic performance of infill wall frame structure system under flexible connection.

Holmes [28] proposed to replace the infill wall with equivalent articulated diagonal bracing, with diagonal bracing having the same material as the infill wall and 1/3 the width of the diagonal length of the infill wall.

Durrani and Luo [29] proposed the following semi-empirical formula for calculating the equivalent support width based on empirical compliance with finite element results and comparison with other models:

$$\frac{w}{d} = \gamma \sin 2\theta \quad (1)$$

included among these

$$\gamma = 0.32\sqrt{\sin 2\theta \left(\frac{h^4 E_W t_W}{m E_c I_c h_w} \right)^{-0.1}} \quad (2)$$

$$m = 6\left(1 + \frac{6 E_b I_b h}{\pi E_c I_c L} \right) \quad (3)$$

It has been reported by many researchers that the use of a single diagonal diagonal brace does not adequately represent the bending moments and shear forces in frame members. More complex macro-models have been proposed and the typical model is still based on many diagonal braces.Thiruvengadam [30] proposed the use of a multi-braced model to simulate the effect of an infill wall. The model consists of a flexural frame and a large number of articulated diagonal and vertical braces.Gabriele Milani et al. [31] investigated the out-of-plane force performance of masonry infill walls by using a combination of homogenization modeling and limit analysis, and proposed to divide the unit lattice in the homogenization into a number of layers along the thickness as a simplified model, and also summarily delineated the damage modes of the wall, and derived the wall's out-of-plane bearing capacity parameters such as damage load and ultimate load. Lihua Liu [32] used nonlinear spring units to simulate the flexible materials between the wall frames and established a finite element model of infill wall frame structure with flexible connections, which better reflected the interaction between the wall frames. Xiaojie Zhou [7] Two kinds of two-dimensional models of flexibly connected infill wall frames were established. One is to simulate the flexible connection with a spring unit, the infill wall with a plane stress unit, and the frame with a beam unit; the second is to convert the infill wall into a brace and simulate it directly with an equivalent spring unit. Guangqing Wang [33] Simulation of inter-block mortar by face-to-face bond contact in ABAQUS to make the mechanical properties of the model closer to the experimental model. Yingnan Hu [34] used the finite element analysis method to simulate the flexible connection structure between the wall and the frame by setting the linear spring unit with specified stiffness between them, and the seismic performance of RC frame structure with foam concrete infill wall was investigated.

In summary, for the flexible connection between infill walls and wall frames, scholars at home and abroad mainly simulate it by equivalent diagonal brace model, solid model, linear or nonlinear spring unit and defining interface contact properties, and change the stiffness of flexible connection or flexible material by adjusting the elastic modulus, spring stiffness and friction coefficient of the contact surface of the solid unit.

5. MAIN ISSUES FOR REFLECTION

(1) With the popularization of new blocks, the synergistic stress performance of the wall frames under flexible connections is still unknown.

(2) The lack of unified construction technology for flexible connection and the lack of scientific design methods have seriously hindered the research and development of flexible connection.

(3) In the past, most of the flexible connections between infill walls and frames were simulated by spring units, but it is difficult to simulate the failure of flexible materials in the loading process.

6. CONCLUSION AND OUTLOOK

6.1 CONCLUSION

Based on the research results of the current researchers on the seismic performance test and finite element analysis of the infill wall frame structure system under flexible connection, the following summary is made:

(1) The flexible connection setting can effectively enhance the deformation capacity of the structure, improve the ductility of the structure, effectively reduce the additional stiffness of the infill wall to the structure, prevent the infill wall from premature destruction, and enhance the seismic performance. The change of its seismic performance changes with the different gap widths between the wall frames, the category of flexible materials between the wall frames, and the special flexible components.

(2) For the simplified calculation model of the flexible connection has its own advantages and disadvantages, different studies to take the appropriate simulation method can get more accurate results.

6.2 Outlook

Although scholars at home and abroad have done various relatively in-depth researches on the seismic performance of infill wall frame structure system under flexible connection and obtained some remarkable results, the research direction and method have not yet been perfected. In this regard, this paper makes the following outlook:

(1) The design of the flexible connection must not affect the design of the later decoration

of the structure, and must not be concerned only with how much seismic performance is added to the structure, while ensuring that the construction is simple.

(2) With the popularization of new types of blocks, there is a need to carry out research on the seismic performance of such new types of infill walls with underfill flexible connections.

(3) There is less research on the susceptibility of infill wall frame structures under flexible connections, and research on the susceptibility of flexible connections to infill walls and frames is needed.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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