A Review on the Seismic Performance of Assembled Steel Frame-precast Concrete Facade Panels

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Abstract. Assembled steel structure housing has the advantages of low cost, light weight and flexible space arrangement, which has been largely used in government-subsidized housing in China. Meanwhile with the rising of assembled steel structure housing, precast concrete facade panels have been widely used. In this paper, the research on the seismic performance of assembled steel frame with precast concrete facade panels in China is summarized and discussed, including the influence of precast concrete facade panels, flexible connections and the seismic performance of steel frame influenced by precast concrete facade panels. According to the research status, the mechanical characteristic of the precast concrete facade panels following the deformation of steel frames; the seismic performance influence of the main structure in rare earthquakes because of the flexible connections are analysed. This paper provides a reference for seismic theory establishment of assembled steel structure housing envelope system.

1. Introduction
China is an earthquake-prone country, between the circum-Pacific seismic belt and the Eurasia seismic belt. The market share of steel structure buildings in the civil construction market is far lower than that of industrial buildings and long-span spatial structures market [1]. There are three design principles of assembled buildings: “Modularized” basing on basic module design; “Standardized” basing on less variety, high production efficiency, and more combinations design; “Integrated” basing on whole process and whole system details pre-design [2]. It is imperative to put assembled steel structure housing system into industrialization, because of which can perfectly make building construction more collaborative and integrated. With the development of assembled steel structure housing system, the seismic performance of non-structural components has been attracted more attention.

Assembled steel structure housing system includes structure system, building envelop system and interior decoration system. The building envelop system increases the lateral stiffness of the steel frame structure and participates in the horizontal force. The building envelop system includes interior wall panels, external wall panels, doors, windows and roof panels. The research on the interior wall panels was carried out earlier, mainly discussed about infilled walls [3-7]. The theoretical research on the external wall panels [8] is also in the process of digging.
The installation forms of external panels include embedded building and external hanging. The research on the embedded panels were carried out earlier by foreign researchers, the design of many non-structural components is still based on these earlier foreign research results. However, with the improvement of China’s science and technology, the research on the bearing capacity of precast concrete facade panels in recent years is being studied deeply by domestic researchers [9-14]. The calculation method of precast concrete facade panels bearing capacity mainly refers to the current Chinese standard Code for Design of Concrete Structures GB50010 [15], Standard for Design of Steel Structures GB50017 [16], Code for Seismic Design of Buildings GB50011 [17], Technical Standard for Assembled Buildings with Concrete Structure GB/T51231 [18] and Technical Specification for Precast Concrete Structures JGJ1 [19]. Technical Standard for Application of Precast Concrete Facade Panels JGJ/T485 [20], as an industry standard, was promulgated on December 27, 2018.

If precast concrete facade panel designed unproperly, it will easily lead to a secondary disaster, the panel will possibly fall off or even collapse. Hetao H [21-22] and Youdong C [23] pointed out that future research directions of precast concrete facade panels should focus on the following aspects: the improvement of wall panels design theory, the improvement of joint connection forms and the manufacture of new materials. In this paper, aiming to point out the further research direction and approach of seismic performance of precast concrete facade panels system, the research results of seismic performance of assembled steel frame-precast concrete facade panels system are classified and summarized by Chinese experts and scholars in recent years.

2. Precast concrete façade panels

2.1. Design formulas

The calculation of bearing capacity of precast concrete facade panels includes load combination calculation and ultimate bearing capacity checking calculation. Reference [20] clearly stipulates that the load combination should consider the influences of the precast concrete facade panels self-weight, wind load, earthquake action, thermal action and the deformation of the main structure. According to reference [19], the horizontal seismic action calculation of precast concrete facade panels follows the regulation of seismic analysis method for equivalent lateral force, which means that the critical direction of horizontal seismic action is related to influence coefficient of frequent earthquakes, gravity and dynamic magnification coefficient, as shown in formula (1). Guowei Z [12], Jiasen L [13], and Jinhu W [24] calculated wind load and seismic action when carrying out load combination, and seismic action was calculated according to the above method.

\[
F_{Ehk} = \beta_E \alpha_{\text{max}} G_k \tag{1}
\]

where, \(F_{Ehk}\) is the standard value of horizontal seismic action applied to the gravity center of the precast concrete facade panels; \(\beta_E\) is the dynamic amplification factor, value 5.0; \(\alpha_{\text{max}}\) is the maximum influence coefficient of horizontal earthquakes. \(G_k\) is the standard value of gravity load (kN) of precast concrete facade panels.

According to reference [17], the value of amplification coefficient is related to the function, category, state and floor position of non-structural components, and the horizontal seismic action is shown in formula (2).

\[
F = \gamma \eta \xi_1 \xi_2 \alpha_{\text{max}} G \tag{2}
\]

where, \(\gamma\) is the function coefficient for non-structural components, for precast concrete facade panels should be 1.4 times the design deflection of the main structure components; \(\eta\) is the classification coefficient of non-structural components, for retaining wall \(\eta\) is 0.9; \(\xi_1\) is 2.0 of a prefabricated component as a state factor; \(\xi_2\) is position factor, taking with an interval of 1.0 to 2.0.

2.2. Test and finite element analysis

Hongchao G [25], in order to study the force transfer path of precast recycled concrete facade panels, conducted a pseudo-static test with axial compression on three trusses of one-story one-span full-scale flat model. The steel column height was 1275mm. The seismic performance of the steel frame was
evaluated according to the horizontal bearing capacity, lateral stiffness, displacement ductility and energy dissipation capacity. Research showed that the force transferring path of precast recycled concrete facade panels started from the connection and passed along the bottom edge of the diagonal.

Besides the traditional concrete materials, the precast concrete facade panels also derive various materials, such as light weight panels and composite panels. 2 spatial full-scale models of three stories, three span full-scale steel frame-precast concrete facade composite panels was carried on the shaking table test by Wei W [26]. The deformation characteristics of the precast concrete facade composite panel were studied. The precast concrete facade composite panel was composed of ceramist concrete sandwich panel and EPS panels. The working conditions of the model included frequent earthquakes, seismic fortification earthquakes, rare earthquakes and aftershock. Models can be easily repaired and finally accepted by the super-large seismic waves. Research suggested that the main structure of the residual displacement was less than 0.5% when precast concrete facade composite panels could be better to follow the main structure deformation. The precast concrete facade panels had a good ability to adapt to the deformation of the main structure during the test vibration process. On the basis of the experiment in reference [27], Mingji F [28] drew a comparison diagram of the acceleration response of each floor between the floor and the precast ALC facade panels at peak time to prefabricate the acceleration response of the precast ALC facade panels. ALC means Autoclaved Lightweight Concrete. Studies showed that precast ALC facade panels would produce independent acceleration to steel frame. Independent acceleration related to the independent deformation and energy dissipation of flexible connection.

Jianyao G [29] used SAP2000 to analyse the time history response of middle, low and high-rise steel frame structures under different earthquake working conditions respectively. The results had shown that in the rare earthquake, the dynamic response of the precast concrete facade panels to meet twice than the frequent earthquake. Basing on the reference [25], Lijian S [30-31] compared strain curve of the precast recycled concrete facade panels and joint connections. They also found that the deformation coordination performance between steel frame and the precast recycled concrete facade panels was good. It was suggested that the upside connections of precast recycled concrete facade panels should get involved with deformation and energy dissipation, while the downside connections should bear stress.

In the newly issued reference [19], the calculation of horizontal seismic effects of the panels was more clearly specified: the amplification coefficient of the precast concrete facade panels in case of frequent earthquakes was set at 5.0. However, in the actual study for precast concrete facade panels of the seismic response did not reach 5.0 times yet [31]. According to different forms of precast concrete facade panels taking with proper amplification coefficient is still a problem need to be studied further.

3. Prefabricated steel frame-precast concrete facade panels joint connections

3.1. Design formulas

Precast concrete facade panels can be applied to different forms of main structures [32-33]. Flexible connection can ensure that the precast concrete facade panels can dissipate energy through the rotation or displacement by using the joint connections when the main structure deforming. This chapter mainly introduced the design criteria of joint connections and Chinese research progress when the assembled steel frame as the main structure flexibly connected with the precast concrete facade panels.

The connections between precast concrete facade panel and steel frame are divided into flexible connection and rigid connection. Figure 1 and figure 2 in reference [20] is a schematic diagram of the connection form of the precast concrete facade panel. Both of them have different advantages. The flexible connection is a typical point support form, which has the ability to adapt to deformation. The rigid connection is a typical linear support form, which can increase the structural stiffness and participate in bearing force. According to the different roles of joint connections, the point-supported precast concrete facade panel can be divided into displacement type, rotation type and fixation type.
Regularly, the connections of a precast concrete facade panel should be set on the upside and downside, but the bearing joint and non-bearing joint should not be set on the same side.

When bearing capacity is calculated, it is necessary to consider the stress condition of joint connections under different loads, and the stress form is shown in Figure 3 [24]. Self-weight of precast concrete facade panel should be designed at the position of the load-bearing joint; Wind load was equally divided by load-bearing joint and limitation joint [29]. The horizontal seismic action outside the panel made the joint connections under pressure (or tension), and its size is divided equally by load-bearing joint and limitation joint. The horizontal seismic action inside of the precast concrete facade panel made the joint connection bearing shear force, and each load-bearing joint bears the 0.5 times of horizontal seismic action. Each limitation joint bear 0.25 times of the horizontal seismic action. The calculation method of earthquake action of precast concrete facade panel refers to formula (1). According to reference [20], when the dynamic amplification coefficient of the joint connections of precast concrete facade panel were designed depending on the seismic fortification intensity of the region or the rare earthquake, it could be set as 4.0 or 5.6 according to the building type.

![Figure 1. Flexible Connections](image1)

![Figure 2. Rigid Connection](image2)

![Figure 3. Stress diagram of joint connections](image3)

3.2. Test and finite element analysis

Guoqiang L [28] [34-35] deduced the maximum shear stress of joint connections based on the inertia force of precast concrete facade panel from the shaking table test data. It was found that the moment and bending stress will be regenerated by the shear force when the joint connection was under stressed. It was suggested that the non-uniform coefficient of stress on precast concrete composite external wall panel should be considered in the joint design. After the 9-degree earthquake, the joint connection between the precast ALC facade panel and the steel frame was subjected to the inertia force, which was determined by the mass and acceleration of the ALC facade panel. The full-scale shaking table test carried out by Wei W [26]. The test results showed that under the action of super-large earthquake, the damage of the ALC facade panel was the maximum damage at the joint connection and embedded parts.

Yong J [36-37] summarized and tested the bearing capacity of four types of flexible joint connections. The upside load-bearing type joint meant the upside joint bear all vertical loads. Shi C [38] carried out checking calculation and static simulation of finite element model for a new form of steel frame-precast concrete facade panels joint connection. The amplification coefficient of horizontal seismic action was set at 5.0. The bearing capacity of bolts, welded joints under tensile force, shear force and bending moment were checked. The research verified the available mechanical performance of this new form.

At present, the design of flexible connection is mostly in the form of elliptic bolt hole, which is convenient for deformation and energy dissipation of precast concrete facade panels. Xueqin W [39]
proposed a new type of connection, in which 4 trusses of one-story and one-span assembled steel frame-precast concrete facade panel models were tested by pseudo-static test to verify the good deformation performance of the joint connection. Under the horizontal load, the concrete at the bolt joint was crushed and the expansion of bolt hole leaded to different displacement between the precast concrete facade panels and the main structure. The research showed that the joint connection was an important link for precast concrete facade panel to adapt to the deformation of steel frame. Jianyao G [29] suggested strengthening the connection between precast concrete facade panels and the main structure. Ailin Z [40] put forward a new type of assembled form suitable for the precast concrete facade panel. ABAQUS finite element model was established for the steel frame with precast concrete facade panels. The hysteretic curve was obtained by static and pseudo-static finite element analysis, and the feasibility of the new assembly was evaluated by ductility and energy dissipation capacity.

The existing structure design of connections is easy to cause stress concentration, and the slender bolt of joint connections will be the first failure area under the earthquake action, which reduces the bearing capacity of precast concrete facade panels.

4. Influence on seismic behaviour and deformation following ability of steel frame
This chapter mainly discusses the seismic performance of steel frame structure with precast concrete facade panels, and the deformation following ability of precast concrete facade panels while steel frame deforming, which are carried out according to shaking table test, pseudo-static test and finite element simulation.

4.1. Shaking table test
Guoqiang L [34-35] conducted shaking table tests on two two-story spatial steel frame-precast concrete facade panels models respectively in order to study the dynamic characteristics of precast concrete composite facade panels and precast ALC facade panels and the stress characteristics of flexible joint connections. The research showed that the higher the floor was, the greater the deformation was, and the inter-story displacement of the steel frame under the 0.6 g El-Centro earthquake was 1/54. Qiaoling X [41] carried out a shaking table test on a two-story full-size steel frame-precast concrete composite facade panel and found that after connecting the precast concrete facade panel, the natural vibration frequency decreased significantly because the increase of structure gravity. As the inter-story displacement of the steel frame-precast concrete facade panels was smaller than that of the steel frame, it was considered that the precast concrete facade panel had a good following deformation performance, but the following performance had little relationship with the tightening moment of the connection bolts. Yuliang Z [42] conducted a reduced scale shaking table test on a spatial steel frame-precast concrete facade panels model, and found that the increased precast concrete facade panels significantly reduced the amplification coefficient generated by the structure delivering from the opposite side seismic waves, so that it was obvious that precast concrete facade panels increased the lateral stiffness of the steel frame.

4.2. Pseudo-static test
The research objects include precast ALC wall panel, precast concrete composite facade panel and precast recycled concrete facade panel.

Guoqiang L [43] carried out static and pseudo-static tests on three trusses of steel frames and six trusses of two-story single-span steel frames with precast ALC panels, in order to study the influence of precast ALC panels and installing forms on the stress deformation and lateral stiffness of the main structure. The top angle on both ends of prefabricated ALC panels started to fall off while the load increasing. The results showed that the embedded ALC panel was superior to the external ALC panel in twice stiffness and improving 76.9% bearing capacity of the structure. The external ALC panel owned a better deformation ability.

Hetao H [44-45] carried out pseudo-static tests on 8 trusses of one-story one-span precast concrete composite facade panel steel frame model respectively. The specimens were all destroyed by the
fracture of welding seam at the connections, and the spalling of precast concrete composite facade panel starting from the connections. He studied the influence of energy-saving composite panels and joint connections on the reciprocating performance of the main structure, evaluated the seismic performance of steel structure, and gave the recommended value range for equivalent damping coefficient in different stress circumstances. In order to study the seismic performance of the structure, Jian Z [46] conducted a pseudo-static test on the plane model of 4 trusses of one-story and one-span steel frame-precast composite facade panels, and found that the cross-bracing steel plate support of precast composite facade panels can improve seismic performance of the main structure. The hysteretic performance of precast concrete composite XPS panel with cross-bracing steel plate supporting the steel structure system was studied. The cross-steel plate is used to maintain stability of the precast concrete composite facade panel. According to the hysteretic pinching phenomenon of the specimens, it was found that the shear slip at the connection between the wall panel and the steel frame could slow down the structural damage. By comparing the stiffness degradation curve of pure steel frame, steel frame with composite panels, steel frame with composite panels and cross-bracing steel plate and the energy dissipation capacity of the structure, it was found that the composite panels with cross-bracing steel plate system improved the ultimate displacement of the whole structure and has better hysteresis performance. The independent slip deformation of the precast concrete composite facade panels in the post-loading period of the pseudo-static test reduced the damage of the steel frame, and the lateral stiffness increased by 1.2-2.9 times.

Hongchao G [25] conducted horizontal reciprocating test with axial compression on 3 trusses of one-story one-span scale model respectively, and obtained the effect of precast recycled concrete facade panel on the improvement of structural strength. During the test, the inter-story displacement, shear deformation at the top of the precast recycled concrete facade panels, the section and joint strain of structural components and the deformation at the joint connections of structural components were measured. The influence of precast recycled concrete facade panels and beam-column joints on the seismic performance of steel frame structures were studied. The seismic performance of the steel frame was evaluated according to its horizontal bearing capacity, lateral stiffness, displacement ductility and energy dissipation capacity. The steel frame with precast concrete facade panels had a 17% increasing in peak load capacity and a 16.7% increasing in displacement ductility and seismic performance at the later loading period.

4.3. Finite element simulation

Finite element model includes spatial model and flat model. SAP2000 finite element software is mainly used for finite element simulation of spatial steel frame-precast concrete facade panels model. ABAQUS and ANSYS finite element software is used for finite element simulation of flat model of flat steel frame-precast concrete facade panels and the details of the flexible joint connections.

In order to set up the finite element model of spatial steel frame-precast concrete facade panels, Yuliang Z [42] calculated SAP2000 for a two-story spatial model. The research showed that the top floor of spatial steel frame with precast concrete facade panels reduced the acceleration response of the top floor by about 16%, and the precast concrete facade panels produce lateral stiffness, precast concrete facade panels was beneficial to the seismic resistance of the main structure. In order to study the seismic performance of precast concrete facade panels and joint connections, Jiupeng L [47] conducted pseudo-static simulation of a two-story and two-span flat steel frame by ANAYS finite element software, and set up ground motion simulation of the spatial steel frame by using SAP2000. The inter-story displacement and the displacement response of the top floor under different working conditions were extracted.

Dianshen Z [48] carried out a numerical analysis using ANSYS finite element software based on the pseudo-static test of embedded and external precast ALC panels in reference [43]. The friction coefficient, which was more suitable for aerated concrete, was used in the simulation to build the aerated concrete constitutive model with descending section. The joint connections were presented as orthogonal duplexing spring in the simulation model. The finite element model had a high degree of
fitting with the test results, and can reflect the internal crack development of ALC panels when it was damaged. The hysteretic curves showed that the pure steel frame was at elastic stage, and the steel frame with precast concrete composite facade panel had obvious ductility and yield point. Minglei W [49] used ABAQUS for numerical simulation of a single-story and single-span flat model. Shell elements were used to build the model, and full hysteretic curves were obtained. The stiffness degradation was 85.7\% and the energy dissipation coefficient is 0.4. If the hysteretic curves of pure steel frame and steel frame with precast concrete composite facade panels could be compared, the energy dissipation comparison would be more ideal. Lijian S [50-51] carried out finite element simulation of pseudo-static test including axial load on the flat model of precast recycled concrete facade panel made of full-scaled steel frame with one-story and one-span on the basis of the test in reference [25]. The study doubted that the model did not show the crack and aggregate friction of precast recycled concrete facade panels accurately, so that the simulation results amplified the energy dissipation capacity of precast recycled concrete facade panels on the main structure.

At present, the influence of precast concrete facade panels on the seismic performance of the steel frame is mainly evaluated by the hysteretic curve, skeleton curve and other parameters obtained through experiments. In the test process, the failure of precast concrete facade panels and joint connections is the mark of test finishing. However, the deformation and bearing capacity of the connection area between the structural components and the precast concrete facade panels are not analysed in detail. The seismic response of the whole structure cannot be detected by the pseudo-static loading of the flat steel frame structure. The seismic performance evaluation should consider the acceleration response of the model.

5. Conclusion

This paper introduces the mechanical characteristics of assembled steel frame-precast concrete facade panels and summarizes the related research and exploration of Chinese scholars in recent years. The conclusions and suggestions are as follows:

(1) At present, the shaking table test of assembled steel frame-precast concrete facade panels model cannot be carried out until its failure, and the pseudo-static test cannot more accurately reflect the actual seismic performance. From one-span assembled steel frame-precast concrete facade panels flat model for pseudo-dynamic test, it is easy to compare with the main structure and displacement response of the acceleration response, as well as the deformation and bearing capacity differences of structures and precast concrete facade panels connection area. Pseudo-dynamic test could be better for precast concrete facade panels seismic performance research.

(2) The joints of flexible connection are bolted, which is easily lead to stress concentration. Design optimization should be carried out for bolt joints of flexible connections, such as thickening plates, reducing bending and avoiding irregular areas. The flexible connection can adapt to the deformation coordination of steel frame and reduce the degree of weakening of the rigidity of the precast concrete facade panels.

(3) The finite element simulation of assembled steel frame-precast concrete facade panels focuses on the analysis of SAP2000 as a spatial model and the analysis of ABAQUS and ANSYS as a flat model. However, there is no unified classification on the constitutive relation of precast concrete facade panels with different structures and the interaction relation of different forms of connectors. Assembled structure building for different situation, will produce different materials, different shapes of panels. How to find a more suitable form of precast concrete facade panel, how to find the common characteristics from the personality, will be the majority problem to solve in the future.

6. References

[1] Han J, Lihua C, Zuochao L and Yu L 2018 Structural System and Practical Case of Assembly Buildings (Nanjing: Southeast University Press) pp 93-105
[2] Jie W, Ning L, Han J, Yi Z, Dunjun W, Xuefei W, Liujin W, Leqi C and Jian Z 2018 The Design and Application of Prefabricated Concrete Building (Nanjing: Southeast University Press) pp 26-29
[3] Emad F G, Adrian M C, Colin F D and Graeme S 1999 J. Struc. Eng 125 32-39
[4] Xiangdong T, Jerome F Hajjar, Arturo E S and Carol K S 2005 J. Constructional Steel Research 61 531-552
[5] Guohua S, Ruoquan H, Gu Qiang, and Youzhen F 2011 J. Const. Steel Research 67 1821-1834
[6] Zheng L, Minjian H, Xijun W and Minghao L 2018 J. Const. Steel Research 140 62-73
[7] Lei W, Zhenyung Tang, Yue L and Kai Q 2019 Construction and Building Materials 211 756-770
[8] Takuya N, Hideo F, Kunio F and Shirou K 2010 Performance of an exterior metal curtain wall in seismic responses of a high-rise building J. Technology & Design 16 535-540
[9] Zhenbao L, Leiling J, Lida T and Dongyan W 2017 Study on the structural properties of lightweight microporous concrete wall panels 17th National Symposium on Modern Structural Engineering Conf. Industrial Construction (Tianjin) pp 66-70
[10] Shengcai L, Jianjing J and Qingrong Y 2001 An Inquiry into Calculation Approaches of Bending Strength about Composite Shear Wall Slab Structural Engineers 3 35-40
[11] Hetao H, Xiaojing H, Guoqiang L and Yanming W 2009 Ultimate Load-Bearing Capacity of the Energy-Saving Composite Sandwich Panels Journal of Building Materials 12 106-111
[12] Guowei Z, Boshan C, Xiao W, Qisong M and Hui W 2016 Research on the flexural behavior of autoclaved aerated concrete external panel Building Structure 43 97-102
[13] Jiasen L, Chenggong Z, and Zhengzhen P 2013 Analytical Methods of Precast Outer-Wall Hanging Panels Chinese & Overseas Architecture 1 105-107
[14] Yanbo L, Weiqi G, Xiaodun W, Qing M and Qiong H 2018 Experimental Research on Wind Resistance and Finite Element Analysis of Reinforced Concrete Composite Insulation Wall Plate Journal of Tianjin University (Science and Technology) 51 95-102
[15] Code for Design of Concrete Structures GB50010-2010
[16] Standard for Design of Steel Structures CHN Standard GB50017-2017
[17] Code for Seismic Design of Buildings CHN Standard GB50011-2010
[18] Technical Standard for Assembled Buildings with Concrete Structure CHN Standard GB/T51231-2016
[19] Technical Specification for Precast Concrete Structures CHN Standard JGJ1-2014
[20] Technical Standard for Application of Precast Concrete Facade Panels CHN Standard JGJ/T485-2018
[21] Hetao H, Bosheng L, and Jinwen L 2007 Problems on Measures About Energy-saving Composite Wall of Steel Residence Steel Construction 22 41-44
[22] Bosheng L, Jinwen L, and Hetao H 2007 Study on Energy-saving Composite Panel in Steel Residence Houses Steel Construction 22 9-12
[23] Youdong C, Yuanrong J, Weiqi F, Yongchao L, Hetao H, Canxing Q and Yanming W 2017 Current Issues and Suggestions for Sandwich Composite Panels of Steel Structure Residence Industrial Construction 47 52-57
[24] Jinhui W, Jiasen Lu, Zhengdong X and Zhenpeng Z 2014 Upper Load-bearing Joint Design Method of the Precast Concrete Wall Panels Building Structure 44 47-51
[25] Hongchao G, Lijian S, Yunhe L, Jiping H and Zhenshan W 2017 Journal of Building Structures 38 63-73
[26] Wei W, Yueshi C, Yiyi C and Hetao H 2019 Full-scale Shaking Table Test of a Floor-by-floor Assembled Steel Braced Frame with External PC Composite Wall Panel Journal of Building Structures 40 88-96
[27] Guoqiang L, Mingji F, Yijing L and Ye L 2005 China Civil Engineering Journal 38 27-32
[28] Mingji F, Jingfeng W and Guoqiang L 2013 Shaking table test of steel frame with ALC external wall panels J. of Constructional Steel Research 80 278-286
[29] Jianyao G 2016 Seismic Analysis of Prefabricated Exterior Board of the Assembled Frame Structure M.S. thesis, Dept. Architect. and Civil Eng., Southwest Jiaotong Univ. China

[30] Lijian S, Hongchao G, Yunhe L and Changwei J 2017 Chinese Journal of Applied Mechanics 34 742-747

[31] Lijian S 2016 Study on Seismic Behavior of Flexible Steel Frame with Recycled Concrete External Wall M.S. thesis, Dept. Structure Eng., Xian Univ. of Tech. Xian China

[32] Jingfeng W and Beibei L 2017 Cyclic testing of square CFST frames with ALC panel or block walls J. Constructional Steel Research 130 264-279

[33] Jingfeng W, Beibei L and Jinchao L Experimental and analytical investigation of semi-rigid CFST frames with external SCWPs J. Constructional Steel Research 128 289-304

[34] Guoqiang L., Xin Z, Feifei S., Wenli G, Zunquan Y and Shiwen J 2003 Earthquake Engineering and Engineering Vibration 23 64-70

[35] Mingji F, and Guoqiang L 2008 Experimental research on seismic behavior of ALC external wall panels and masonry wall Building Structure 38 55-58

[36] Yong J, and Caiyuan C 2008 Structures Units & Units Architecture 4 42-46

[37] Yong J, and Caiyuan C 2009 Construction Wall Innovation & Building Energy-Saving 4 42-46

[38] Shi C, Ganping S, Kunhong L, Shenggang F and Hong G 2017 Building Structure 47 46-52

[39] Xueqin Wang, Xuechun L, Lin M and Xiaojun Z 2017 Experimental Research on Seismic Behavior of Prefabricated ALC External Panels Steel Construction 32 22-26

[40] Ailin Z, Lin M, Xuechun L and Zinqin J 2016 J. of Building Structures 37 suppl. 1 152-157

[41] Qiaolong X, Yuanhui L, Zhenxi H and Zhong Y 2010 J. Earthquake Engineering and Engineering Vibration 30 72-79

[42] Yuliang Z 2009 Shaking Table Test and Numerical Simulation of Steel Frame Assembled House with Exterior Wall M.S. thesis, Dept. Structure Eng., Harbin Ins. of Tech. China

[43] Guoqiang L and Cheng Wang 2005 The Hysteretic Behaviour of Steel Frames with ALC Out-hung and In-filled Walls Steel Construction 20 52-56

[44] Hetao H, Canxing Q, Guoqiang L, and Jingfeng W 2012 Cyclic Test on Steel Frames with Energy-saving Sandwich Composite Panels Engineering Mechanics 29 177-184

[45] Hetao H, Jian Z, Haitao Z, Jingjing L, Haining L, Zhonglong L and Xiping W 2014 Engineering Mechanics 31 85-91

[46] Jian Z, Haitao Zang, Jingjing L, Minglei W and Zhonglong L 2014 ISSF pp 481-488

[47] Jiupeng L 2009 Study on Vibration Damping Properties of External Wall Panels of Industrialized Housing M.S. thesis, Dept. Structure Eng., Tianjin Univ. China

[48] Diansheng Z, Liang C and Weiwei W 2010 Hysteretic Behavior Analysis of Steel Frame Structure with ALC Walls Journal of Zhejiang University of Technology 38 448-452

[49] Minglei W, Hetao H, Yanfei S and Qian W 2012 Parametric Analysis on Hysteretic Behavior of Steel Frame Structure with Energy-saving Composite Wallboard ISSF pp 433-440

[50] Lijian S, Hongchao G, Yunhe L and Yanan L 2017 Earthquake Engineering and Engineering Dynamics 37 67-76

[51] Lijian S, Hongchao G and Yunhe L 2017 Construction and Building Materials 157 790-808

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