Study on seismic behavior of separated anti-buckling low yield point steel plate shear wall

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Abstract

In this paper, we propose a new type of steel plate shear wall that is composed of steel frame lattice and embedded steel plate, in which the steel frame lattice is composed of ribbed beam and ribbed column with smaller size, and the embedded steel plate is scattered in multiple small frame lattices. Because steel plate is separated into smaller sizes, it is easy to meet the requirements of thickness-to-height ratio of steel plate to anti-buckling.These steel plate walls are earthquake-resisting elements that are connected to moment frames by high strength friction bolts. The steel plate wall is only connected with the frame beam, it is simple to make and install, and easy to replace and repair after the earthquake.

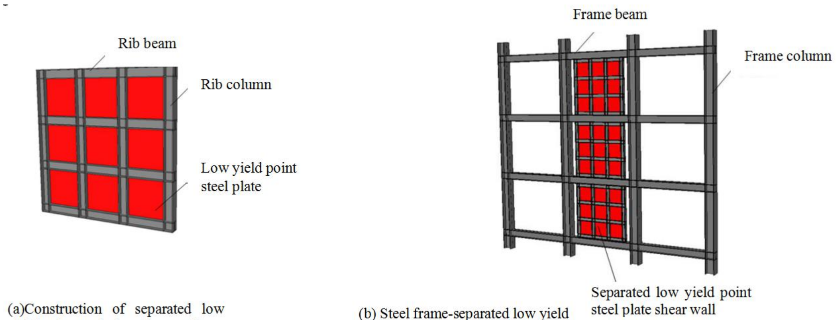
The analysis models of steel frame-steel plate shear wall structure were established by using software ABAQUS. The embedded steel plate used the low yield point steel LYP100, the steel frame lattice used ordinary low carbon steel Q235B, and the steel frame used low alloy steel of Q345B. In the calculating, the cyclic constitutive model including the isotropic and the kinematic hardening was adopted, which can accurately simulate the phenomenon of buckling, cumulative damage degradation, cyclic strengthening and so on under cyclic load.The hysteretic performance, bearing capacity and energy dissipation as well as stress, deformation and fracture damage characteristics were studied. The results showed that the separated steel plate wall structure has reasonable damage failure mode and energy dissipation mechanism to meet the multi-fortification requirements of seismic system, the steel frame lattices can effectively prevent or delay the out-of-plane buckling of the embedded steel panels, and greatly improve the lateral stiffness, bearing capacity and energy dissipation capacity of structure.There is good cooperative working performance between the separated low yield point steel plate shear walls and steel frames.These results provide the data on general seismic performance of the steel plate walls, and provide a research basis for further understanding of the new steel plate wall.

Keywords: separated; low yield point steel plate shear wall;anti-buckling;steel frame;seismic performance

1. Introduction

Low yield point steel plate shear wall has the dual advantages of lateral force resistance and damping energy dissipation,which has been more and more widely used in seismic and wind resistance design of high-rise and super-high-rise buildings.However,the most prominent problem of steel plate shear wall is the out-of-plane buckling of embedded steel plate,which affects the performance of steel plate.The width-to-thicknes ratio of steel plate is a key parameter to its buckling behavior,while the traditional steel plate shear wall is mostly integral, the size is large,it is difficult to meet the requirement of buckling-restrained width-to-thicknes ratio. A approach employs heavily stiffened steel plate shear walls to ensure that the steel plate achieves its full plastic strength prior to out-of-plane buckling.Thus stiffened, the wall panels can resists large lateral forces and dissipates energy from earthquakes.Such systems are current practice in Japan [1],where the high-fabrication cost is tolerated in order to guarantee small transverse deformations and stable hysteresis loops out to large story drafts. Astaneh-Asl (2002) proposed steel plate-coated concrete wall panels. The test results show that the concrete wallboard can prevent the buckling of steel plate, and the improved wall has good stability and ductility[2]. Toko Hitakaet et al.(2007) employs pre-cast reinforced mortar panels instead of vertical edge stiffeners to stiffen transversely steel plate shear wall with slits [3]. Keh-Chyuan Tsai et al.(2007) proposed buckling-restrained steel plate shear wall, using precast concrete slabs to suppress the out-of-plane deformation of embedded steel plates[4]. Guo Yanlin et al.(2009) proposed an anti-buckling steel plate shear wall composed of embedded steel plate and precast concrete slab on both sides,which can slip relatively between embedded steel plate and precast concrete slab[5]. Li Guoqiang et al.(2012) disclosed a concrete wallboard constrained low yield point steel plate energy-consuming shear wall, the concrete slab is made of semi-precast,which can fully prevent the out-of-plane buckling of the steel plate[6]. Hao Jiping et al.(2015)proposed an all-steel anti-buckling steel plate shear wall with low yield point steel for embedded steel plate and a common steel ribbed mesh plate on both sides of the steel plate,in which main function of the ribbed mesh plate is to provide sufficient out-of-plane constraints for the steel plate[7-8].

As above, the main anti-buckling approach is to provide additional constraints on both sides of the integral steel plate. Based on the idea of reducing the width-to-thicknes ratio of steel plate for buckling, the authors (2015) proposed a new type of separated anti-buckling low yield point steel plate shear wall [9].The separated low yield point steel plate shear wall is composed of common steel ribbed frame lattice and embedded low yield point steel plate (see fig.1), and the frame lattice is composed of ribbed beam and ribbed column with smaller size, the steel plate is scattered in multiple small frame lattices. the steel plate size is smaller and it is easier to meet the requirements of the width-to-thicknes ratio of steel plate anti-buckling. Different from the traditional reinforced rib or stiffener, the rib beam and rib column of the separated steel plate shear wall are the main load bearing members.The lateral stiffness and bearing capacity of the low yield point steel plate shear wall are improved by the function of frame lattice.The embedded low yield point steel plate bears a certain lateral force in the small earthquake, and is the energy dissipation shock absorber in the large earthquake. In addition, due to its unique construction, the stiffness and strength of the separated low yield point steel plate shear wall can be adjusted, and it is easy to replace and repair after the earthquake. In this paper, the separated low yield point steel plate shear walls were installed in steel frame, the seismic performance of the structure was studied by using ABAQUS.



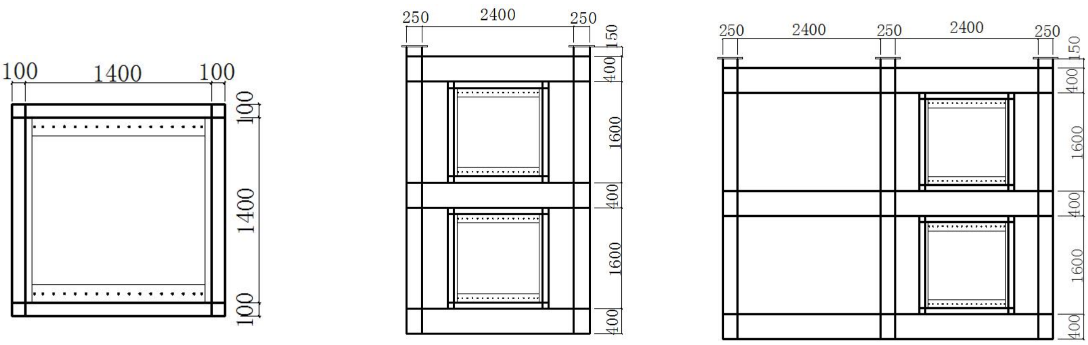
(a)Construction of separated low yield point steel plate shear wall

(b) Steel frame-separated low yield point steel plate shear wall structure

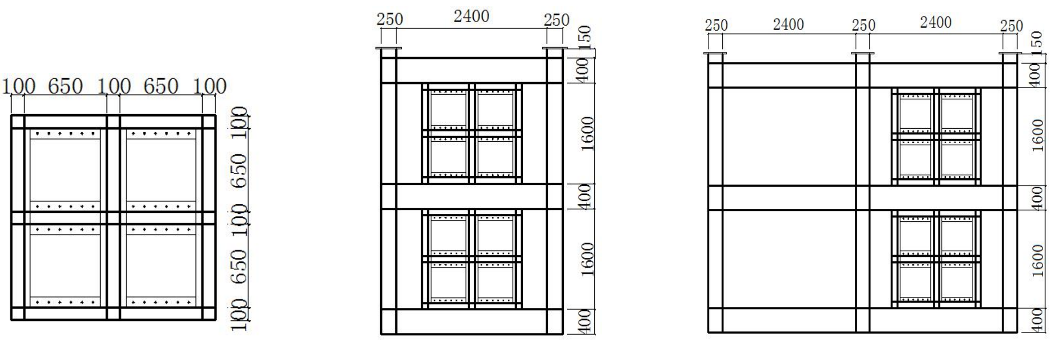
Fig.1 Separated low yield point steel plate shear wall structure system

2. Computational Analysis Model

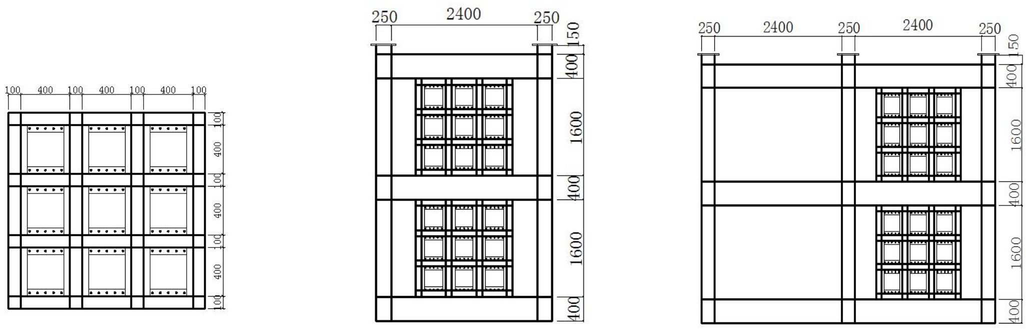
There are five basic structures in the separate low yield point steel plate shear wall: a two-beam two-column type, a three-beam three-column type,a four-beam four-column type, a four-beam three-column type and a three-beam four-column type, which are arranged respectively in the bilayer single-span and bilayer dual-span steel frame, as shown in figure 2. The bilayer single-span model is respectively called SDDSPW-1, SDDSPW-2,SDDSPW-3,SDDSPW-4 and SDDSPW-5, where SDCKJ is a pure steel frame for comparative analysis.The bilayer dual-span model is respectively called SSDSPW-1,SSDSPW-2,SSDSPW-3,SSDSPW-4 and SSDSPW-5, where SSCKJ is the pure steel frame.In the model calculation, the parameters used the H-section steel made from China Laigang, which the frame beam is HN400×200×8×13, the frame column is HW250×250×9×14, the ribbed beam and the ribbed column are HW100×6×8. The embedded steel plate used the low yield point steel produced by China Angang with a thickness of 10mm. The steel frame is Q345B with a yield strength of 390MPa; the steel frame lattice is Q235B with a yield strength of 300MPa; and the embedded steel plate is LYP100 with a yield strength of 114MPa.



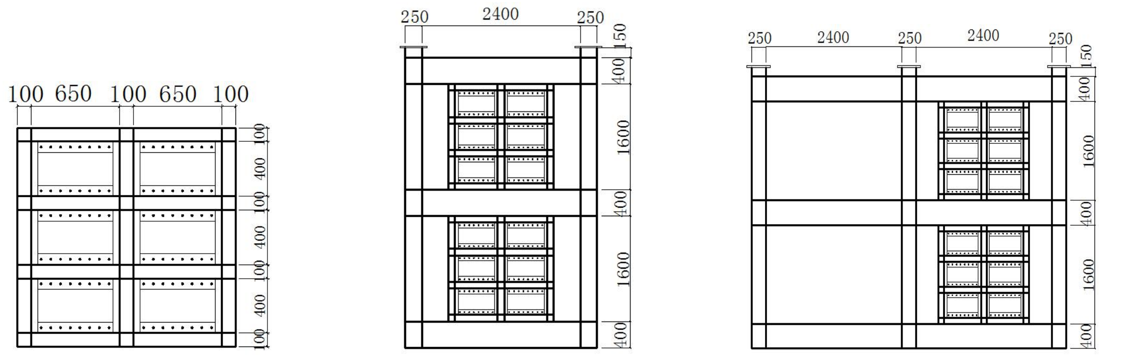
A two-beam two-column type SDDSPW-1 SSDSPW-1



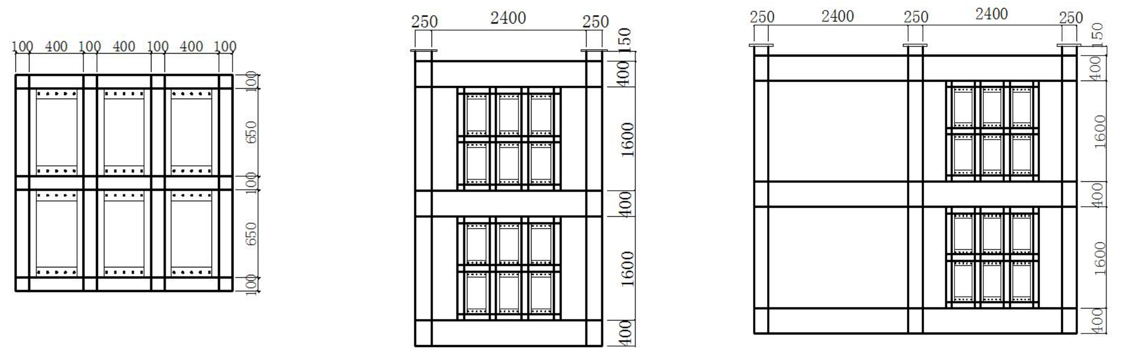
A three-beam three-column type SDDSPW-2 SSDSPW-2



A four-beam four-column type SDDSPW-3 SSDSPW-3



A four-beam three-column type SDDSPW-4 SSDSPW-4



A three-beam four-column type SDDSPW-5 SSDSPW-5

Fig.2 Computational analysis model

The finite element model was established by using the finite element analysis software ABAQUS,which the beam and column of the frame,ribbed beam and ribbed column of the frame lattice, and the embedded steel plate were all simulated by the S4R shell element. For the convenience of calculation, the influence of fishtail plate and residual stress were not considered in the finite element model.

In this paper, the cyclic constitutive model proposed by Chaboche[10-11] was adopted. The model is a mixed model, including the isotropic model and the kinematic hardening model, which can accurately simulate the phenomenon of buckling, cumulative damage degradation, cyclic strengthening and so on under cyclic load, as the parameterized HARDENING=COMBINED model in ABAQUS. On the basis of the cyclic constitutive model of steel proposed by Chaboche, Shi Yongjiu et al[12-14] calibrated the isotropic strengthening and the kinematic hardening parameters of Q345B, Q235B and LYP100 steels based on a large number of material properties tests to determine the material parameters of the steel cyclic constitutive model.The parameters calibrated by Shi Yongjiu et al were used in the calculation in this paper.

When calculated,initial defects were first applied,and vertical loads as large as 20% of the compressive strength of the frame column were first applied to the models.The top storey drift angle was used to control horizontal loading.Except for the fist two cycles of 0.25%,the storey drift angle was increased by 0.5% after completing two cycles of loading until 5% of storey drift angle was achieved.

2. Analysis of results

2.1 Hysteretic performance

The hysteresis curves calculated for each bilayer single-span and bilayer dual-span structure are respectively shown in fig.3 and fig.4.

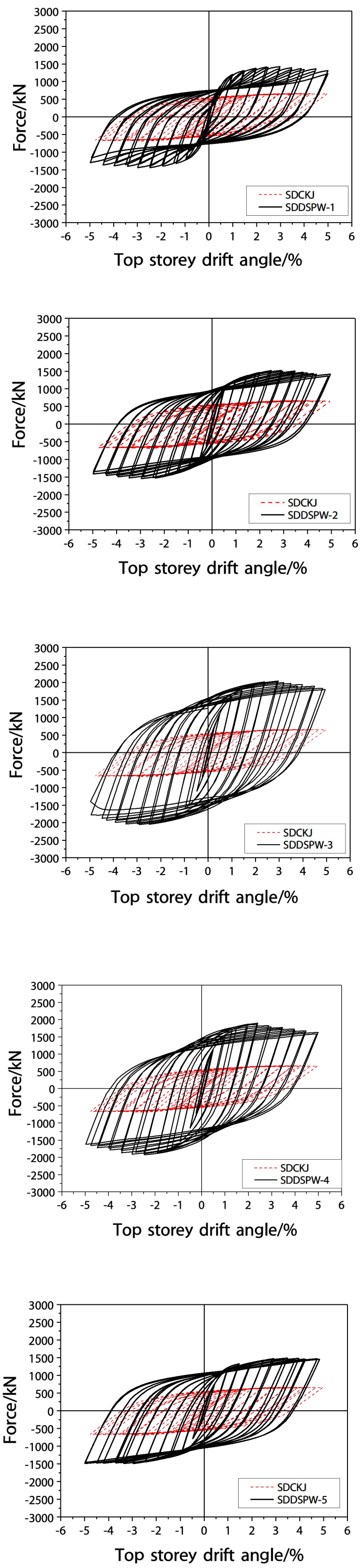


Fig.3 Hysteresis curves of single-span model

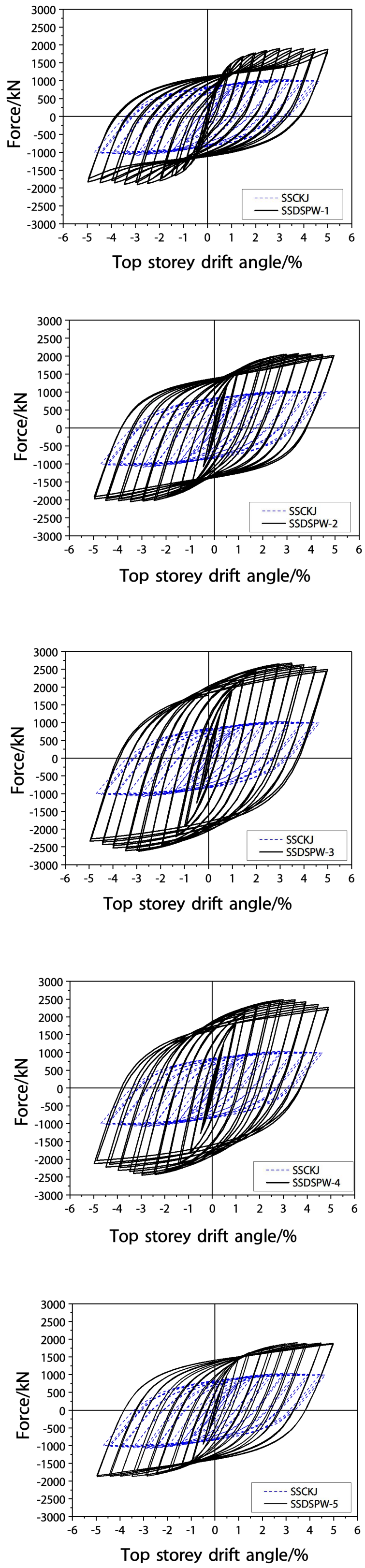


Fig.4 Hysteresis curves of dual-span model

The hysteretic curves of the model are full, showing good hysteretic energy dissipation. The hysteretic area of steel plate shear wall structure has greatly increased than the hysteretic area of steel frame, which greatly improves the energy dissipation capacity of the structure. The hysteretic curves of SDSPW-3 and SSDSPW-3 are more full than the other four models, indicating that the increasing of rib beam and rib column can reduce the pinching phenomenon of hysteretic curves and have greater hysteretic energy dissipation capacity. According to the energy dissipation distribution analysis, the energy dissipation of the separated low yield point steel plate shear wall accounts for about 60%~80% of the total energy dissipation, and the steel frame accounts for about 20%~40%.

3.2 Skeleton curve

Figure 5 and figure 6 are the skeleton curves calculated for each bilayer single-span and bilayer dual-span structure, respectively. It can be seen that the response of the structural model in the push and pull direction is basically consistent and has good symmetry. As the number of ribbed beams and ribbed columns increases, the initial stiffness and the lateral resistance of the steel plate shear wall structure increase accordingly, SDDSPW-3 and SSDSPW-3 are able to provide greater stiffness and lateral force. With the increasing of storey drift angle of loading, the degradation of stiffness and bearing capacity of the separated low yield point steel plate shear wall structure is not obvious. From the shear distribution analysis of the steel plate shear wall and the steel frame, it can be seen that the separated low yield point steel plate shear wall can bear about shear force of 60% to 80%, and the steel frame can bear about 20% to 40%.

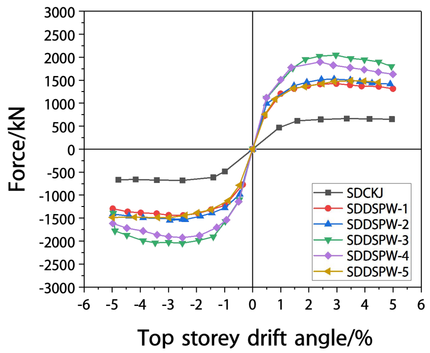


Fig.5 Skeleton curves of single-span model

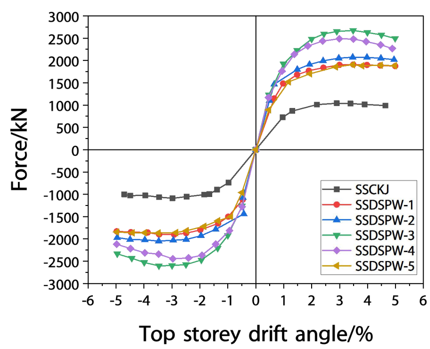


Fig.6 Skeleton curves of dual-span model

3.3 Energy dissipation

The accumulated hysteretic energy dissipation of the model structure is shown in fig.7 and fig.8. it can be seen that the structural models have large energy dissipation.The accumulated hysteretic energy dissipation of each structural model increases with the increasing of cycles, and the energy dissipation value(the ratio of the cyclic energy dissipation to the hysteretic loop of the unloading) can reach 2~2.5, The equivalent viscous damping coefficient (energy dissipation value divided by 2π) can reach about 0.3~0.4, indicating that the separated low yield point steel plate shear wall structure has a good hysteretic energy dissipation capacity.

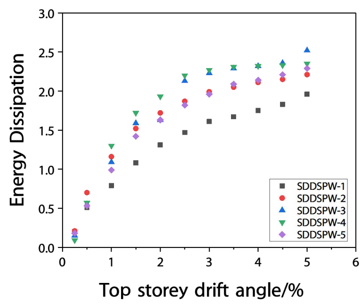


Fig.7 Energy dissipation of single-span model

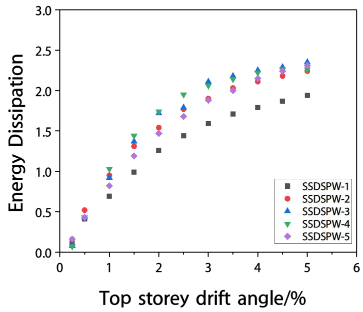
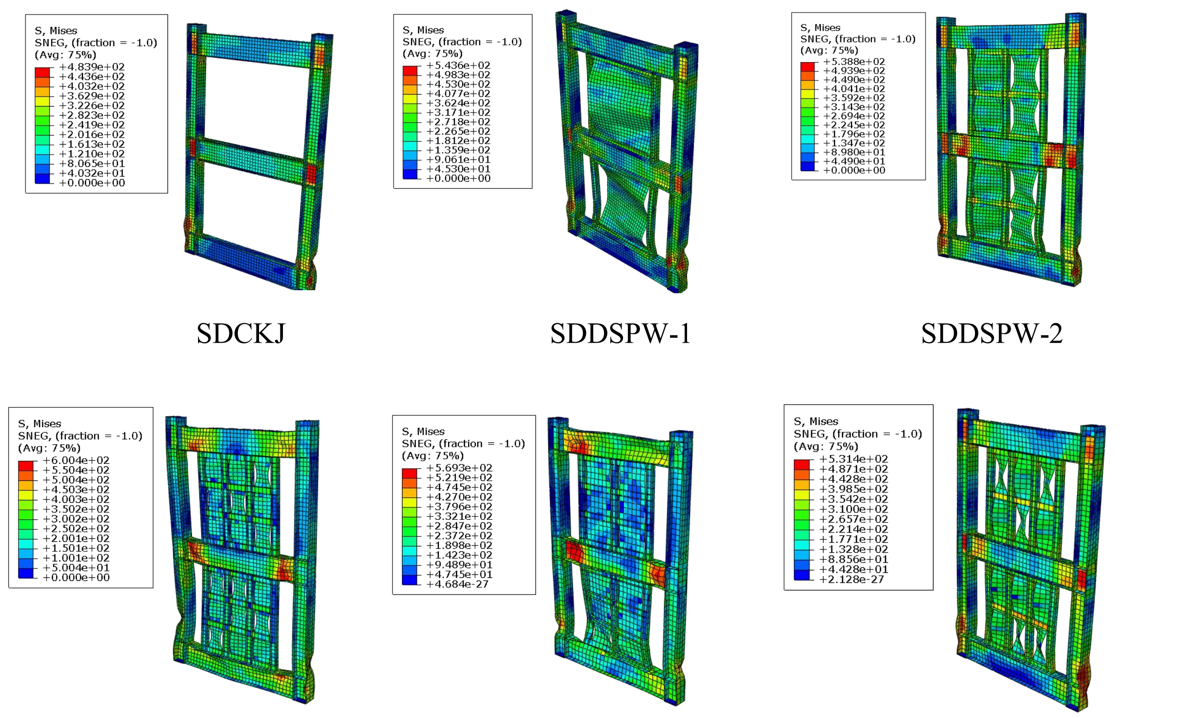


Fig.8 Energy dissipation of dual-span model

3.4 Analysis of stress, deformation and PEEQ

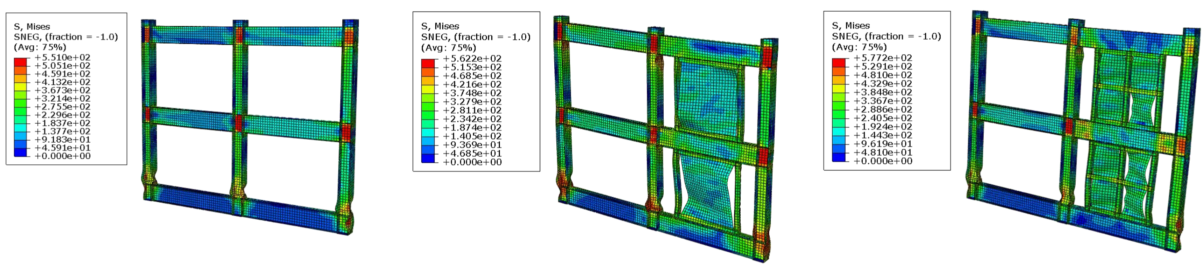
3.4.1 Stress analysis

The calculating results showed that the stress of each single-span and dual-span structure model was developing with the step-by-step loading. Because of the lower yield strength of low yield point steel, the embedded steel plate first produced large area yield, followed by the ribbed beam and ribbed column reaching the yield stress, and finally the beam and column of the steel frame yield until the beam and column of the steel frame formed plastic angle failure.In the whole loading process, the structure presented the failure mode of graded failure and graded the energy dissipation, which meet the multi-fortification requirements of the seismic structure system. Fig.9~Fig.10 is the Mises stress cloud diagram of the structural models loading up to a storey drift angle of 5%. The stress at the joints of frame lattice ribbed beam and ribbed column as well as at the joints of steel frame beam and column was large,which was the weak part of the structure.

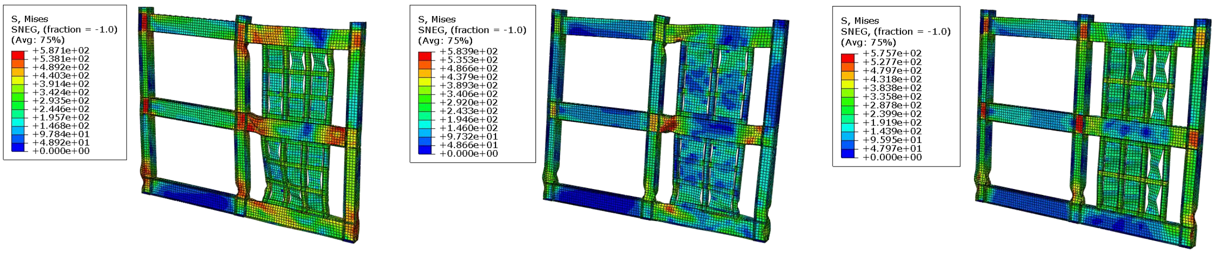


SDDSPW-3 SDDSPW-4 SDDSPW-5

Fig.9 Mises stress cloud diagram of single-span model(MPa)



SSCKJ SSDSPW-1 SSDSPW-2

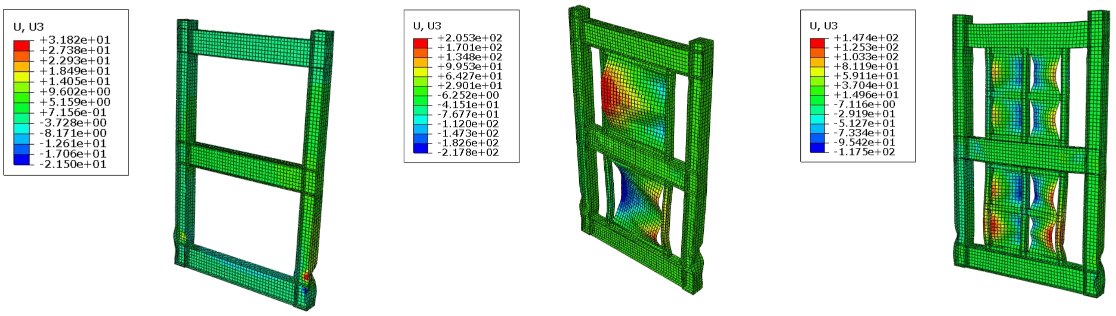


SSDSPW-3 SSDSPW-4 SSDSPW-5

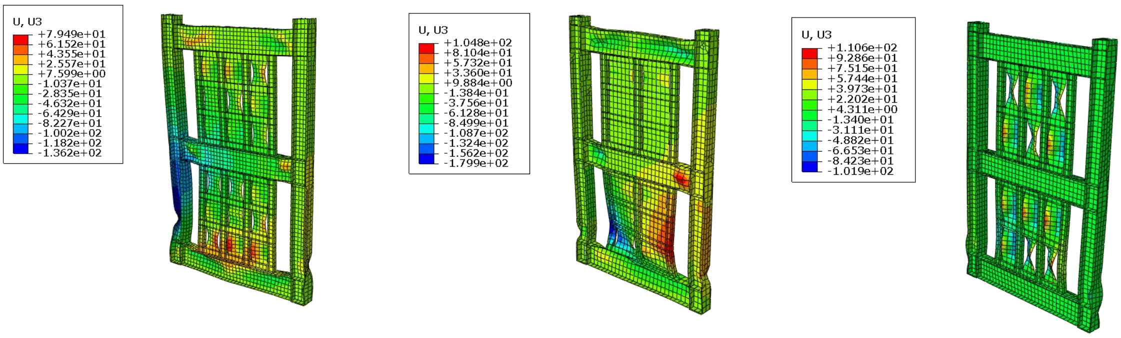
Fig.10 Mises stress cloud diagram of dual-span model(MPa)

3.4.2 Deformation analysis

Fig.11~Fig.12 is the deformed cloud diagram of the structural model loading up to a storey drift angle of 5%. The embedded steel panels in SDDSPW-1 underwent severe out-of-plane buckling. Because of presence of the frame lattice, and as the number of ribbed beams and ribbed columns increased, the width-to-thicknes ratio of the steel plate became smaller, which effectively prevented the out-of-plane buckling of the embedded steel plate. Expect for the local column foot, the whole steel frame lattice and the steel frame were basically kept in the plane deformation,there was no sudden collapse appearance of the structure under large storey drift angle, showing good stability.In addition,it showed that the embedded steel plate with the steel lattice as well as the steel shear wall with the steel frame had good cooperative working performance.



SDCKJ SDDSPW-1 SDDSPW-2



SDDSPW-3 SDDSPW-4 SDDSPW-5

Fig.11 Deformation cloud diagram of single-span model(mm)

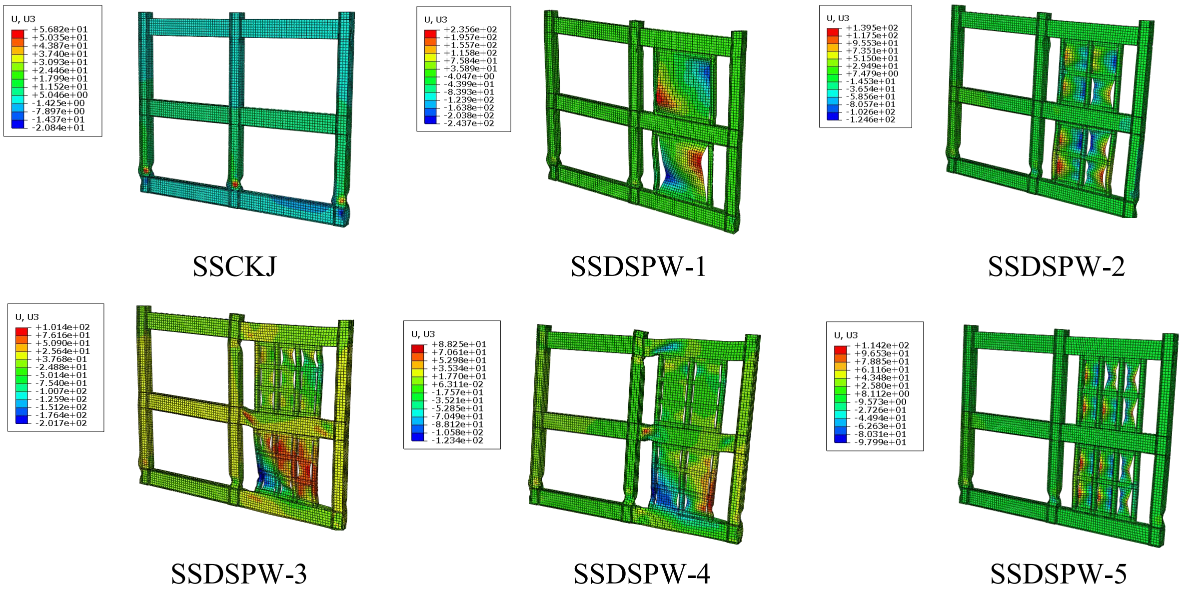


Fig.12 Deformation cloud diagram of dual-span model(mm)

3.4.3 PEEQ analysis

Fig.13~Fig.14 is the PEEQ cloud diagram of the structural models loading up to a storey drift angle of 5%. The large PEEQ values were found at the embedded steel plate, the joints of the ribbed column and ribbed beam as well as the joints of the frame beam and column, which indicated that these parts were a vulnerable part of the fracture damage.The structural fracture damage and energy dissipation occurred firstly in the embedded low yield point steel plate during large earthquake, which can effectively reduce or delay the damage degree of major structure of the model.

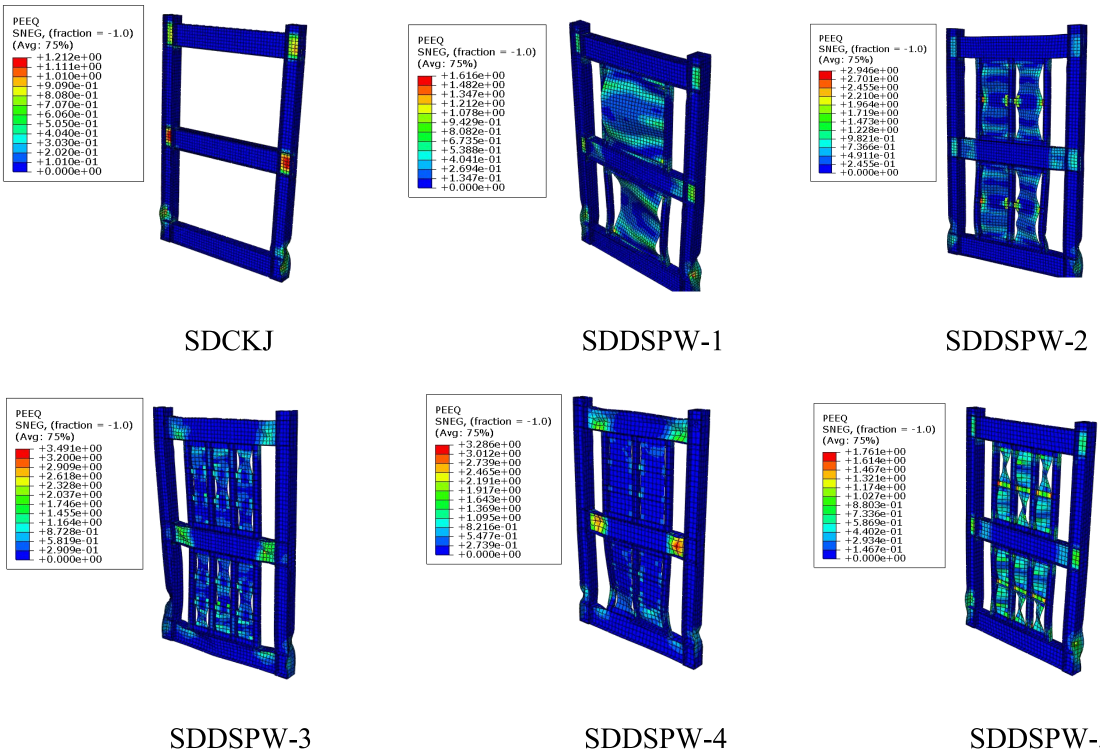


Fig.13 PEEQ cloud diagram of single-span model

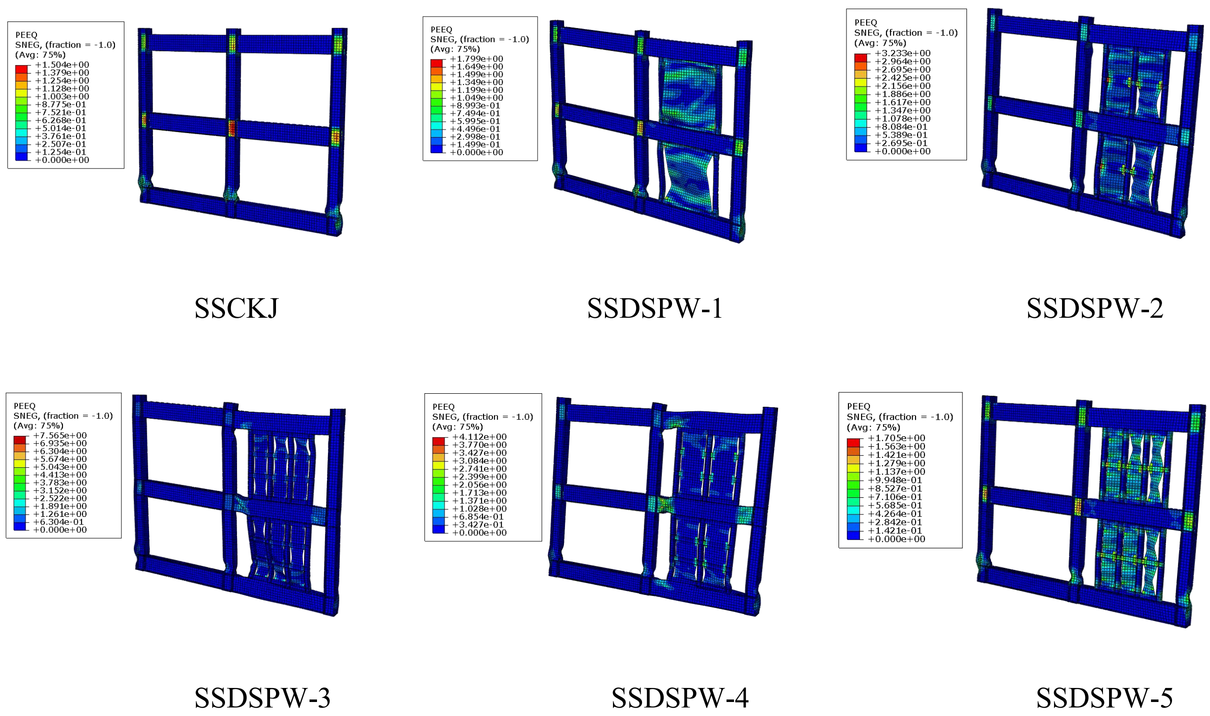


Fig.14 PEEQ cloud diagram of dual-span model

4. Conclusion

A new type of separated low yield point steel plate shear wall is proposed, which is applied to steel frame structure, and the seismic performance of the structure is calculated and analyzed by using finite element software ABAQUS. The main conclusions are as follows:

(1) Separated low yield point steel plate shear wall, due to the existence of its frame lattice, and with the increasing of the number of beam ribs and beam columns, the width-to-thicknes ratio of steel plate decreases, which can effectively prevent or delay the out-of-plane bending of steel plate, and improve the lateral stiffness, bearing capacity and energy dissipation capacity of the structure. The equivalent viscous damping coefficient of structure can reach about 0.3~0.4.

(2) There is good cooperative working performance between the separated low yield point steel plate shear walls and steel frames.The steel plate shear wall can bear about 60%~80% shear force, and the steel frame bears about 20%~40% shear force. The energy consumption of the steel plate shear wall accounts for about 60% to 80% of the total energy consumption, and the steel frame accounts for about 20% to 40%.

(3) Steel frame-separated low yield point steel plate shear wall structure can be graded failure, graded release of energy, with reasonable failure mode and energy dissipation mechanism, to meet the multi-fortification requirements of seismic system.The embedded steel panel of the steel plate shear wall is the main damage and energy dissipation part during the large earthquake, which can effectively reduce or delay the damage degree of major structure.

5. Acknowledgements

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