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Study on Seismic Performance of Damage-Protected Precast Frame

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ABSTRACT

A computational study of precast concrete 3D bean-column joint and frame designed with damage-protected rocking connections is presented. Prestress system is implemented whereby high-strength unbonded thread-bars running through the beams are anchorage on the column side. The thread-bars are post-tensioned and supplemental energy dissipation devices are also installed. Both wet and dry joint solutions are considered. First, a computational model of the prefabricated concrete frame joints are established using finite-element software ABAQUS. Comparisons between wet and dry joints under monotonic and low-cyclic reversed loading are made. On the basis of the joints analyses, the nonlinear finite element analyses on both wet and dry frames are conducted considering seismic performance related to force-displacement hysteresis curves, the mises stress cloud, skeleton curves and stiffness degradation curve. Results indicate that the bearing capacity and energy dissipation capacity with respect to dry connection are weaker slightly than wet ones, but the residual deformation and the damage of components are reduced in the meanwhile. The study shows the dry subassembly frame could protect beams and columns from severe damage reduction and reduce restoration cost after moderate earthquake.

KEYWORDS: *damage-protected Precast Frame; nonlinear finite element analyses; rocking connections; seismic performance*

1. GENERAL INSTRUCTIONS

Damage-Protected rocking Frame has been aroused widespread interests and heated discussions in recent years. Structures with dry connection can acquire rigid body rotation without obvious bending deformation, which thanks to releasing the constraint between structural components, or the structure and foundation. Besides, the structure applied with prestressed tendons has the self-centering capacity, which aims for reducing the residual deformation after moderate earthquake. Numerical analysis on seismic performance of precast frames was based on the joint and a one-bay and one-story framework by finite-element software ABAQUS.

2. FINITE ELEMENT ANALYSIS MODEL OF JOINTS

2.1. The Basic Information

One self-centering prefabricated frame joint JD-1 with prestressing tendon was proposed. In the meanwhile, a model of JD-2 of post-cast prefabricated concrete frame, whose dimensions and reinforcement are all the same as the JD-1, was presented for comparison.

A dry method is used to splice joint JD-1. 4 steel strands are put in the corrugated pipe, which are embedded in the joint before pouring the concrete. Longitudinal reinforcement and stirrup are also used connection method of reserving channel then grouting. However, JD-2 is constructed by traditional method. A distance from the joint core region is left for cast concrete in place.

The distance between inflection points is 3.6m, between the inflection of beams and the lateral edge of columns is 2.4m. The column section is 400mm×400mm, longitudinal reinforcement is 4Φ20, stirrup is Φ8@100. The beam section is 250mm×400mm, longitudinal reinforcement 3Φ18+3Φ18, stirrup of beam sectional uses Φ8@100. Beam-column longitudinal reinforcement are HRB400 rebar, the stirrups are HPB335 reinforced, and the strength grade of concrete is C45.

Nominal diameter of tendons are 15.2mm, tensile strength is 2000Mpa. 1000Mpa was applied to tendons in the pre-tensioning stage.The number of ordinary steel bar of JD-2 is the same as the prestressed tendon of JD-2. It also means there is no different in the reinforcement ratio between JD-1 and JD-2.Size and reinforcement details of JD-1 and JD-2 are shown in Figure2.1 and 2.2.

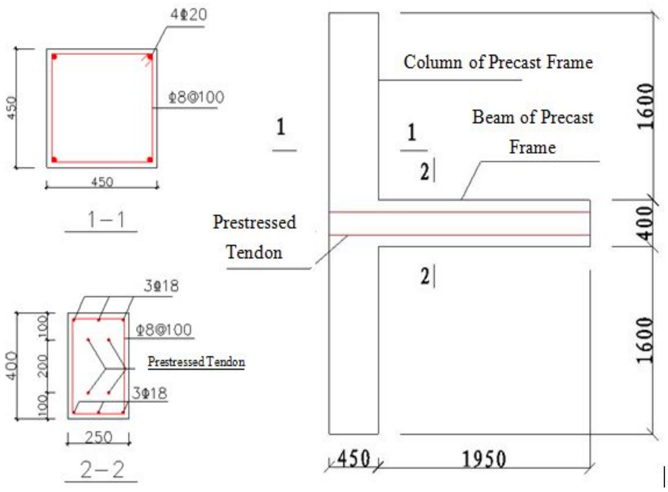


Figure 2.1Size and reinforcement details of JD-1

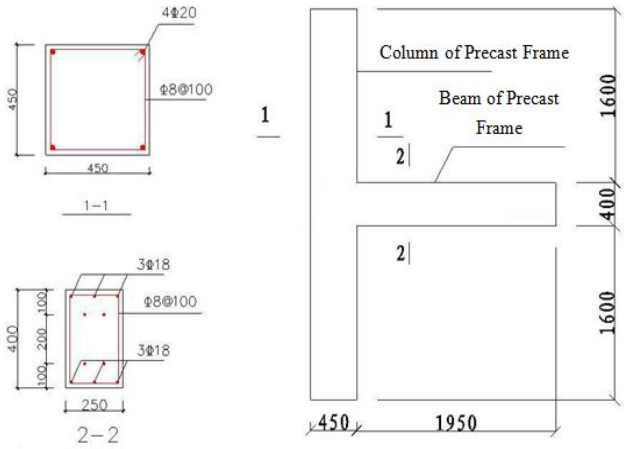
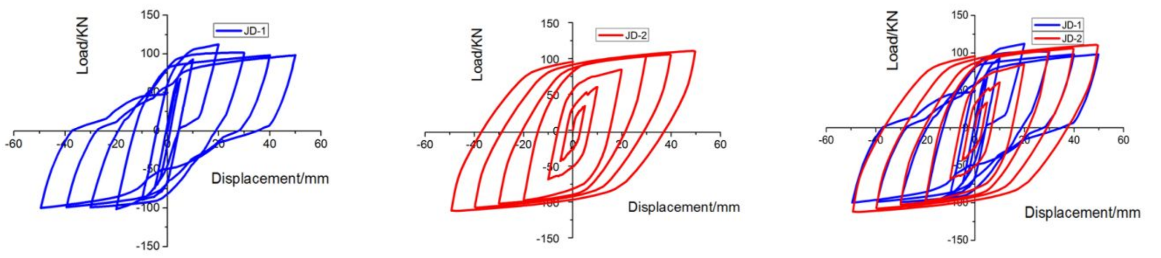


Figure 2.2Size and reinforcement details of JD-2

3. ANALYSIS OF THE RESULTS OF JOINTS FINITE ELEMENT CALCULATION

3.1. Hysteresis Curves

The hysteresis curves of JD-1 and JD-2 are shown in Figure3.1. It indicates that the hysteresis curve of post-cast prefabricated JD-2 is in spindle type under cyclic loading. The hysteresis curves of is stable and full, showing that the energy dissipation capacity are relatively good. Although the curve of JD-1 is not as plump as JD-2, the displacement always returned to zero after each cycle, showing that JD-1 has a better displacement restoring capacity. On the other hand, the curve of JD-1 shows a clear "double flag" shape, which indicates good energy dissipation performance. It results from the steel in joints. The beam and column became separated when the load increased, and then the steel in beam-column joints got to be in plastic stage immediately. In other words, steel did make the difference in the energy dissipation under cycle loading.

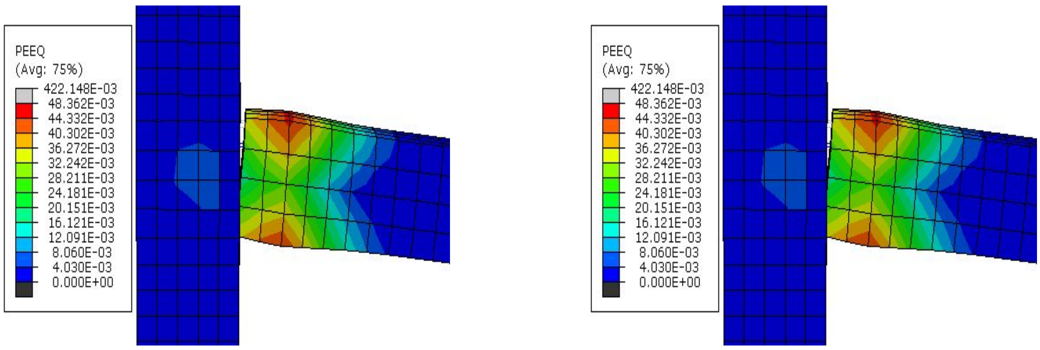


(a) Hysteresis curves of JD-1 (b) Hysteresis curves of JD-2 (c) Comparison of hysteresis curves

Figure 3.1Hysteresis curves of JD-1& JD-2

3.2 Analysis of the Strain and Stress

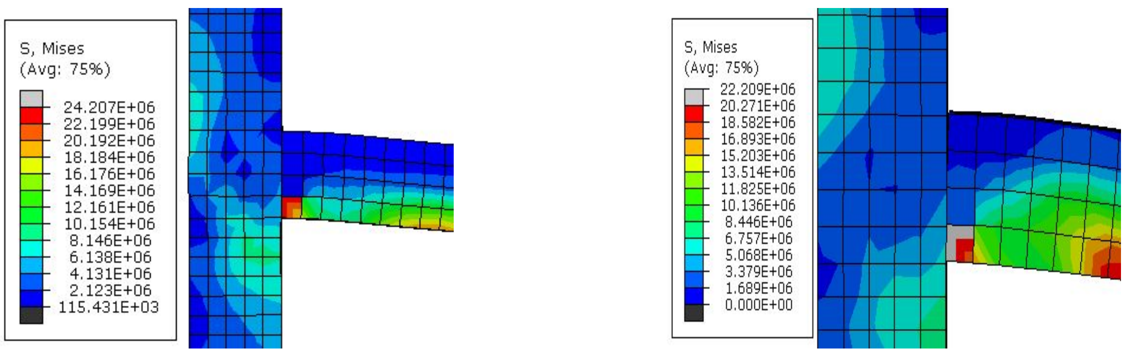
PEEQ equivalent plastic strain contours of JD-1 and JD-2 under the monotonic load are shown in Figure3.2, and Von Mises equivalent stress contour is shown in Figure3.3.



(a) Plastic strain contours of JD-1 (b) Plastic strain contours of JD-2

Figure3.2 PEEQ equivalent plastic strain contours under the monotonic load

As shown in figure3.2, for JD-1, dry joints, at the top of joints between beams and columns, the rotation effect can be seen when loading to some degree. The concentration of stress appeared at the bottom, and tensile stress concentration occurred at the top of joints, while stress and strain of other parts were small in contrast. For JD-2, wet joints, plenty of obvious plastic deformation was produced in a large range of core area. A conclusion can be drawn that JD-1, which have the self-centering capability, made a contribution to protecting the joint areas from severe damage under the monotonic loading. In addition, the problem of stress concentration of JD-1 can be settled by rubber pad and angle steel.



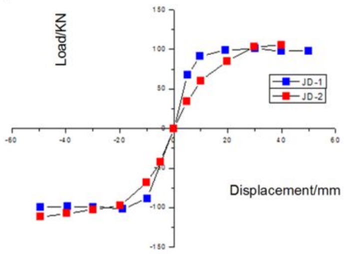
(a) Mises stress cloud of JD-1 at 3△y (b) Mises stress cloud of JD-2 at 3△y

Figure3.3 Equivalent stress cloud of F-1 & F-2 under cyclic loading

It could be seen that, for JD-1, stress concentration came up at the bottom of beam, and the junction between the beam and column was separated gradually when the deformation reached into 3△y. At the same time, for JD-2, significant tensile deformation turned up at the bottom of beam, which indicated that crack must have shown up. From the change of stress in the whole process of loading we can see that the rotation of the beam around the joint area protect main structure from severe damage.

3.3 Analysis of Skeleton Curve and Stiffness Degradation Curve

The skeleton curve and stiffness degradation curve of JD-1 and JD-2 are as shown in Figure3.4 and Figure3.5.



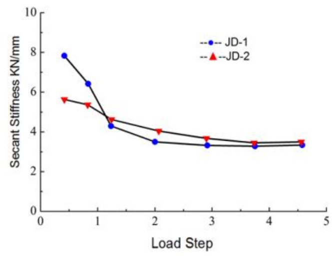


Figure3.4 Skeleton curve of JD-1&JD-2

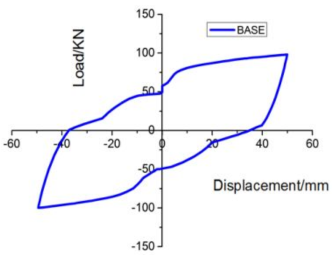
Figure3.5 Stiffness degradation curve of JD-1&JD-2

Figure3.4 suggests that there is no obvious difference between JD-1and JD-2 in the skeleton curve and load-displacement curves under monotonic loading. Almost components are in elastic stage at the beginning of loading.Crack will emerge in post-cast JD-2 when load is increasing.Stiffness decreased significantly, and curve slope amplitude mitigated.The drop of stiffness of JD-1 was small at the beginning, while both joints were gradually yielding with increase of the load, and the slope of the curve tends to be horizontal.

Figure3.5 shows that JD-1 has larger initial stiffness than JD-2 owing to the prestressed reinforcement, but the stiffness degradation is more rapid than JD-2 with the increase of load. Moreover, stiffness of both them reaches unanimity in the end, which indicates the self-centering joints do well in maintaining stiffness.

3.4 Analysis of Energy Dissipation Capacity

Hysteresis loop of JD-1 and JD-2 under cyclic loading are shown in Figure3.6 and Figure3.7. It' s obvious that the area of Hysteresis loop is more larger means better energy dissipation capacity, which is beneficial for structure. The figure suggests that the energy dissipation capacity of self-centering JD-1 is slightly poorer than JD-2, it still have enough and favorable energy dissipation effects.



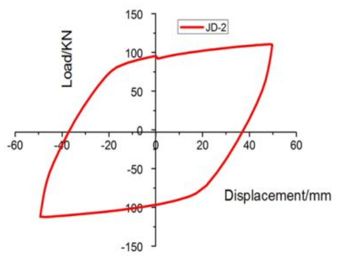


Figure 3.6Hysteresis loop of JD-1

Figure 3.7Hysteresis loop of JD-2

4 FINITE ELEMENT ANALYSIS MODEL OF FRAME

4.1 The Basic Information

One precast concrete frame F-1 with prestressed tendons was presented in this research. Relax the constraint on columns from the foundation in the joint. Set a certain number of tendons with prestressing force in the column in order to make the column have the self-centering capacity after the earthquake. Seam construction was designed in the joint between the prefabricated beam and column, which was called "dry type" connection.

Prestressed steel strand was inserted in the prefabricated beam with prestressing force and anchored in the outside of the column which was located in the node domain. On this condition,the beam and column can be connected with each other closely by the prestressing force which can provide the capability of transferring shear through the frictional force by the contact surface. In addition, a model of cast-in-place concrete frame F-2, whose dimensions and reinforcement are all the same as the precast concrete frame F-1, was also discussed meanwhile for comparison. Details are as follows: The span of the frame is 5m, and the storey height is 4m. The column section is 400mm×400mm, and the beam section is 250mm×500mm. Furthermore,axial compression ratio is 0.3.

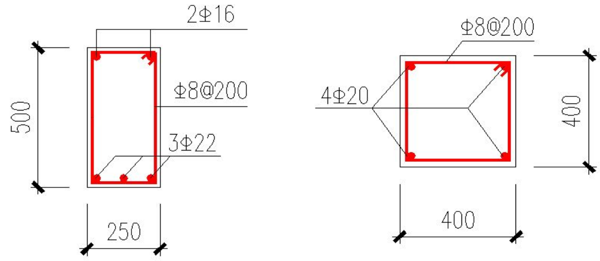
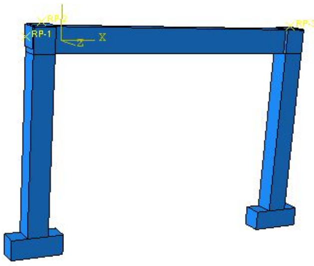
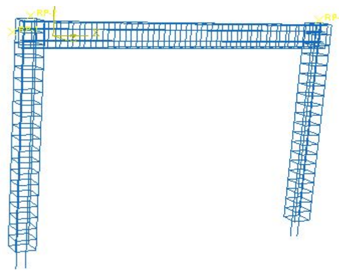


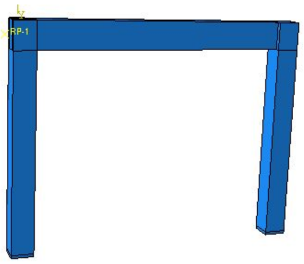
Figure 4.1Size and reinforcement of the beam and column



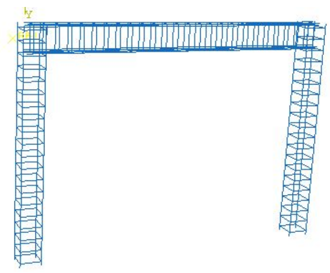
(a)The concrete model of F-1



(b)The steel model of F-1



(c)The concrete model of F-2



(d)The steel model of F-2

Figure 4.2 The basic framework model of F-1&F-2

4.2 The Arrangement of Prestressed Tendons

Prestressed tendons are set in beams and columns at the same time,as shown in Figure4.3. Nominal diameter of tendons are 15.2mm, and tensile strength is 1860Mpa. 1000Mpa was applied to tendons in the pre-tensioning stage.

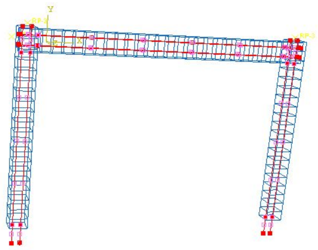


Figure4.3 Prestressed tendons of frame F-1

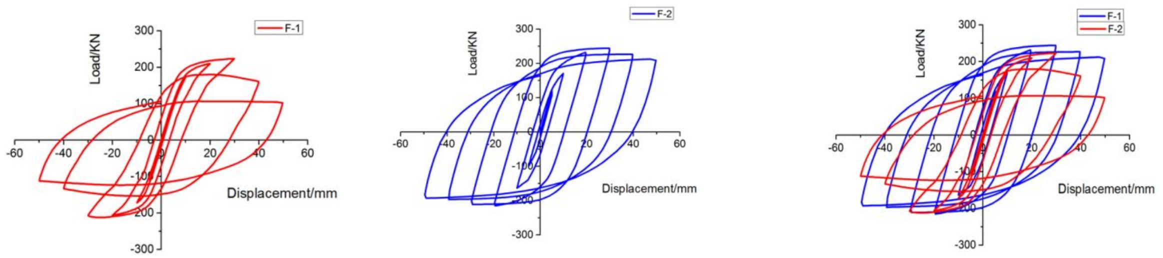
4.3 Boundary Conditions

For the frame F-1, the contact unit is designed on the contact surface between the beam and column. What's more, on the border of pedestal and foundation, the horizontal and vertical displacement of the bottom of columns are limited, but the rotational degree of freedom is relaxed, which means the rotation is allowed at the bottom of columns. On the contrary, for F-2, consolidation was adopted in the joints of beams and columns, as well as in the connection between the bottom of the building and foundation by means of command— " Tie " .

5 ANALYSIS OF THE FRAME RESULTS OF FINITE ELEMENT CALCULATION

5.1 Analysis of Low-cyclic Loading

The hysteresis curves of F-1 and F-2 under the monotonic and low-cyclic loading are shown in Figure5.1. It can be seen that the hysteresis curve of F-2, cast-in-place frame, is in spindle type under cyclic loading. This graphics type indicates large energy dissipation effects and good seismic performance. Although the curve of F-1 is not as plump as F-2, the displacement returned to zero after each cycle, indicating that F-1 has a better displacement restoring capacity. The bearing capacity reduced, and energy-dissipation ability weakened when the deformation reached into 4△y.

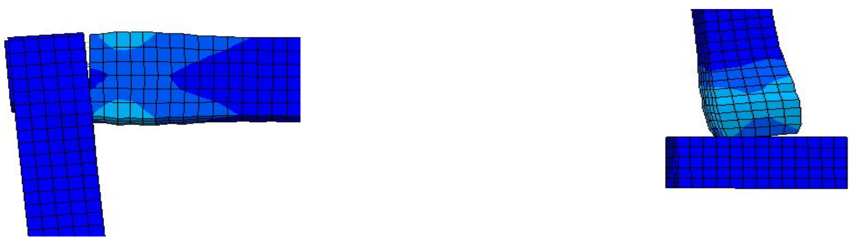


(a)Hysteresis curves of F-1 (b) Hysteresis curves of F-2 (c) Comparison of hysteresis curves

Figure 5.1Hysteresis curves of F-1& F-2

5.2 Analysis of the Strain and Stress

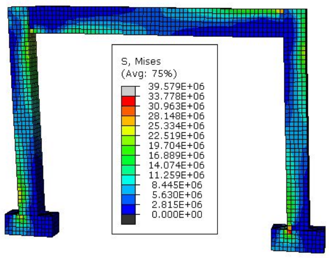
The deformation of the beam-column joints and the joints at the bottom of column under cyclic loading are as shown in Figure5.2, and the Mises stress cloud in Figure5.



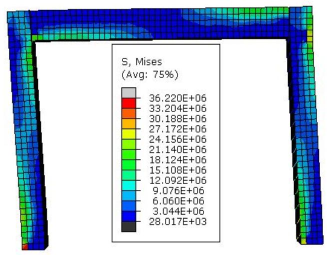
(a) Deformation of the beam-column joints in F-1 (b) Deformation at the edge of the column in F-2

Figure5.2 Deformation of F-1 & F-2

The figure showed that the beam, which got to be separated from the column, began to rotate slightly as load increased for a while owing to the “dry type” connection. Similarly, the rotational deformation was produced between the column and the foundation, and the fame began to rock in the left-right direction integrally. As The Mises stress cloud shown, the concrete at the edge of the column and beam were both in the elastic stage largely because the stress in the core area of joints was small at the beginning of loading. And the stress at the edge of the column and beam in F-1 was smaller than F-2 when the yield displacement occurred. Concentration of stress appeared at the lower end of the beam and the bottom of the column on the left because of extrusion when the displacement is 3 times of the yield displacement, while the stress for other parts were small relatively. But for F-2, the cast-in-place frame, wide range of sections at the edge of the column and beam came to the elastic stage. Obviously, in terms of F-1, components were protected from excessive damage by rocking in the left-right direction under cyclic loading. Moreover, damage produced by partial extrusion can be improved by taking some measures like setting more rubber pads. In the matter of the cast-in-place frame F-2, larger bending deformation emerged in the beam and column under cyclic loading which increased step by step leading to permanent plastic damage.



(a) Mises stress cloud of F-1 at 3△y



(b) Mises stress cloud of F-1 at 3△y

Figure5.3 Equivalent stress cloud of F-1 & F-2 under cyclic loading

5.3 Analysis of skeleton curve and stiffness degradation curve

The comparison of skeleton curve and stiffness degradation curve are shown in Figure5.4 and Figure5.5. What can be seen is that there is no much difference between F-1 and F-2 in the initial stiffness. But the stiffness degradation is rapid and the bearing capacity is reduced significantly for Self-Centering frame F-1 when yield displacement emerges.

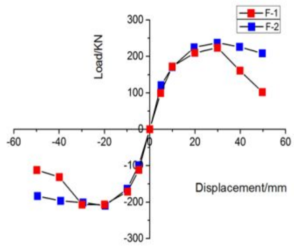


Figure 5.4Skeleton curve comparison

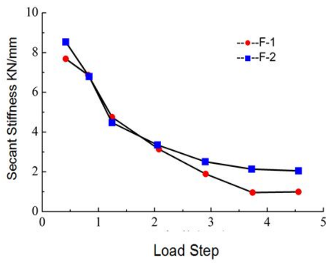
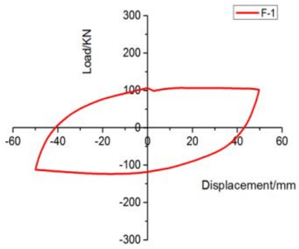


Figure 5.5Stiffness degradation curve comparison

5.4 Analysis of Energy Dissipation Capacity

Hysteresis loop of F-1 and F-2 are shown in Figure5.6 and Figure5.7. It is obvious that the dissipation energy in Self-Centering frame F-1 is smaller than the cast-in-place frame F-2. However, F-1 still have enough and favorable energy dissipation effects.



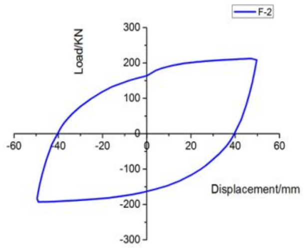


Figure 5.6Hysteresis loop of F-1

Figure 5.7Hysteresis loop of F-2

6. CONCLUSIONS

(a)The bearing capacity and energy dissipation capacity with respect to dry connection are weaker slightly than wet ones, but the residual deformation and the damage of components are reduced in the meanwhile. Moreover, the “double flag” shape of the hysteresis curves of JD-1 suggests excellent energy dissipation capacity.

(b)For post-cast JD-2 and cast-in-place F-2, the plastic deformation of beams and columns were obvious and severe damage emerged in the process of loading, while for self-centering JD-1 and F-1, the main structure of beams and columns has no significant damage, which means self-centering joints and frames have influence on protecting main structures.

(c)JD-1 has larger initial stiffness and the stiffness degradation is more rapid than JD-2. Moreover, stiffness of both them reaches unanimity in the end, which indicates the self-centering joints do well in maintaining stiffness.

(d)There is no much difference between the Self-Centering frame F-1 and the cast-in-place frame F-2 in the initial stiffness.However,for F-1, the stiffness degradation is more rapid, the bearing capacity is weaker slightly and come to be plastic early. JD-1 have the capacity of self-centering owing to prestress after unloading. In other words, it can make residual deformation decrease which is in favor of restoration after earthquake.

(e)Through the analysis of energy dissipation capacity, the result shows that the dissipation energy of self-centering joint JD-1 is smaller than JD-2 and the dissipation energy of self-centering F-1 is smaller than F-2. However, JD-1 and F-1 still have enough and favorable energy dissipation effects. It means both self-centering joints and frames have significant advantages in seismic performance.

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REFERENCES

1. Lieping Ye, Xuchuan Lin, Xunliu Wang. Fourteenth National Conference of concrete and prestressed concrete. (2007), p.345-350.
2. Palermo A, Pampanin S, Calvi G M. Journal of Earthquake Engineering. Vol. 9(2005), p.899-921.
3. Garlock M M,Sause R, Ricles J M. Journal of Structural Engineering. Vol. 133(2007), p.239-299.
4. Zhenhua Pan. Study of Self-centering Steel Moment Frames[D]. Tsinghua University (2010).
5. Zhenhua Pan, Peng Pan, Lieping Ye. Journal of Building Structures. Vol. 32(2011), p.35-42.
6. Lieping YE, Xuchuan LIN, Xunliu WANG: Self-centering performance and seismic performance of prestressed concrete structures[C](IN CHINESE)."Development of green technology, construction managing structure "academic of the 14th national conference on concrete and prestressed,concrete.2007.
7. Zhenhua PAN: Research on self-centering capacity of steel frame system[D](IN CHINESE).Tsinghua University.2010.
8. Zhenhua Pan. Study of Self-centering Steel Moment Frames[D]. Tsinghua University (2010)
9. Palermo A, Pampanin S, Calvi G M. Journal of Earthquake Engineering. Vol. 9(2005), p.899-921