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STUDY ON A NEW TYPE OF FRICTIONAL PLASTIC HINGE

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ABSTRACT

The plastic deformation of the steel structure takes place at the end of the beam or in the connecting area under the action of an earthquake. By forming the plastic hinge, the energy can be effectively dissipated. Plastic hinge commonly used traditional methods of steel structure to strengthen or weaken the connector or strengthen and weaken the connector. The goal of the above details is to relocate plastic hinges to avoid brittle failure of the beam-column joints. The existing method is difficult to precisely control the position of the plastic hinges and is difficult to repair after the earthquake. Therefore, based on the energy dissipation principle of the Friction pendulum bearing and the automobile braking device, a new friction "quick repair plastic hinge" structure with high safety and low cost is proposed. The theoretical analysis and numerical analysis were carried out. The nonlinear finite element analysis and calculation model was esTablelished by using ABAQUS finite element analysis software. The energy dissipation mechanism and design parameters of ductile joints were studied. The results show that the structure can quickly repair the structure after the earthquake, and can determine the position of the plastic hinge to move out, which can precisely dissipate energy and has better hysteresis energy dissipation effect.

Keywords: Friction plastic hinge; Friction pendulum bearing; Automobile brake device; Ductility; Hysteresis energy dissipation

1. INTRODUCTION

In recent years, the performance-based seismic design of steel structures has drawn more and more attention and is one of the hot topics in structural engineering. In the performance-based design, the performance requirements of the building are clearly defined, and different performance measures can be implemented in different ways to make the application of new materials, new structural systems and new design methods easier.

Based on the performance of the structure that the structure as long as there is sufficient energy capacity to meet the energy needs, we can resist the earthquake. Furthermore, it is proposed that the precise control of the structure energy consumption can be realized, that is, the energy consumption position and the energy consuming components can be specified. When an earthquake occurs, it is possible to use specific components to dissipate energy at a specific location, keeping the rest of the structure resilient. When an earthquake occurs, it is only necessary to replace the damaged energy consuming components and keep the structure body components unchanged. That is, ductility criteria to achieve "large earthquake does not fall", the seismic fortification goals.

For the study of the development of steel structures, scholars from various countries pay more attention to the seismic behavior of the joints and the effect of ductility on the structure and carry out a large number of experiments (Chen 2001, Lee 2003).The test pieces of strong beam and weak joints can play the plastic bearing capacity of the beam and form the failure mechanism of the beam hinge, thus having great deformation ability and energy dissipation capacity, which means that it has good seismic performance(Shen 2000, Cai Yiyan 2004). In this study, the steel and plastic hinge is studied by weakening or strengthening the cross section of steel girder, so as to avoid brittle failure during reorientation of beam plastic hinge column (Wang Xiuli 2005, Wang Yan 2006). Although the plastic hinges can be effectively moved out to achieve the purpose of protecting the beam-column joints, there

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are still some defects that the energy consumption is hard to control and cannot be repaired after the earthquake. Based on the research status of the steel plastic hinge and the seismic performance evaluation of the new energy dissipation components, this paper puts forward a new concept and structure of the new friction plastic hinge, and improves the ductility of the structure, so as to realize the precise control of the structural energy dissipation and the aseismatic fortification target of "large earthquake can be repaired".

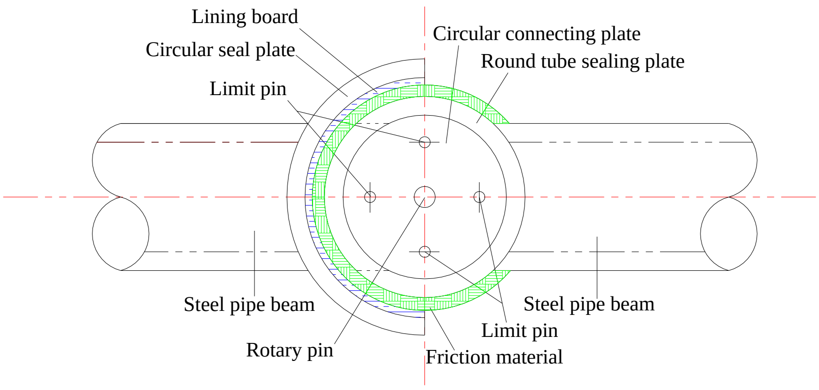
2. THEORETICAL RESEARCH

2.1 Structure principle

The new type of friction of the plastic hinge structure design is based on the energy dissipation principle of friction pendulum isolation bearing and combined with the structure of the automobile brake mode, which can be widely applicable to truss structure and steel frame structure. When small earthquakes and mid-earthquakes occur, the "plastic hinge" area is maintained in the elastic range of the component and can be considered as a rigid connection node. In the event of a large earthquake, the member of the structural part is withdrawn from the work as a result of the lateral displacement of the column. At this time, the ductile joints enter the semi-rigid connection state by rigid connection and generate frictional energy dissipation with the interaction between the members.

2.2 Structural design

The new friction "plastic hinge" structure consists of structural unit, energy-dissipating unit and connecting unit. Its basic structure is shown in Figure1(a). In this structure, the circular curved sealing plate and the circular tube seal plate (with connecting plate groove) are welded with the steel tube beam on the left and right sides respectively, and the circular seal plates (with lining plates) and non-circular joint plates are welded together, as shown in Figure1(b)(c). The circular tube sealing plate (outer surface setting friction material) and two circular sealing plates are welded, as shown in Figure1(d)(e); The connecting plates are connected by the limit pins and a rotary pin.



(a)

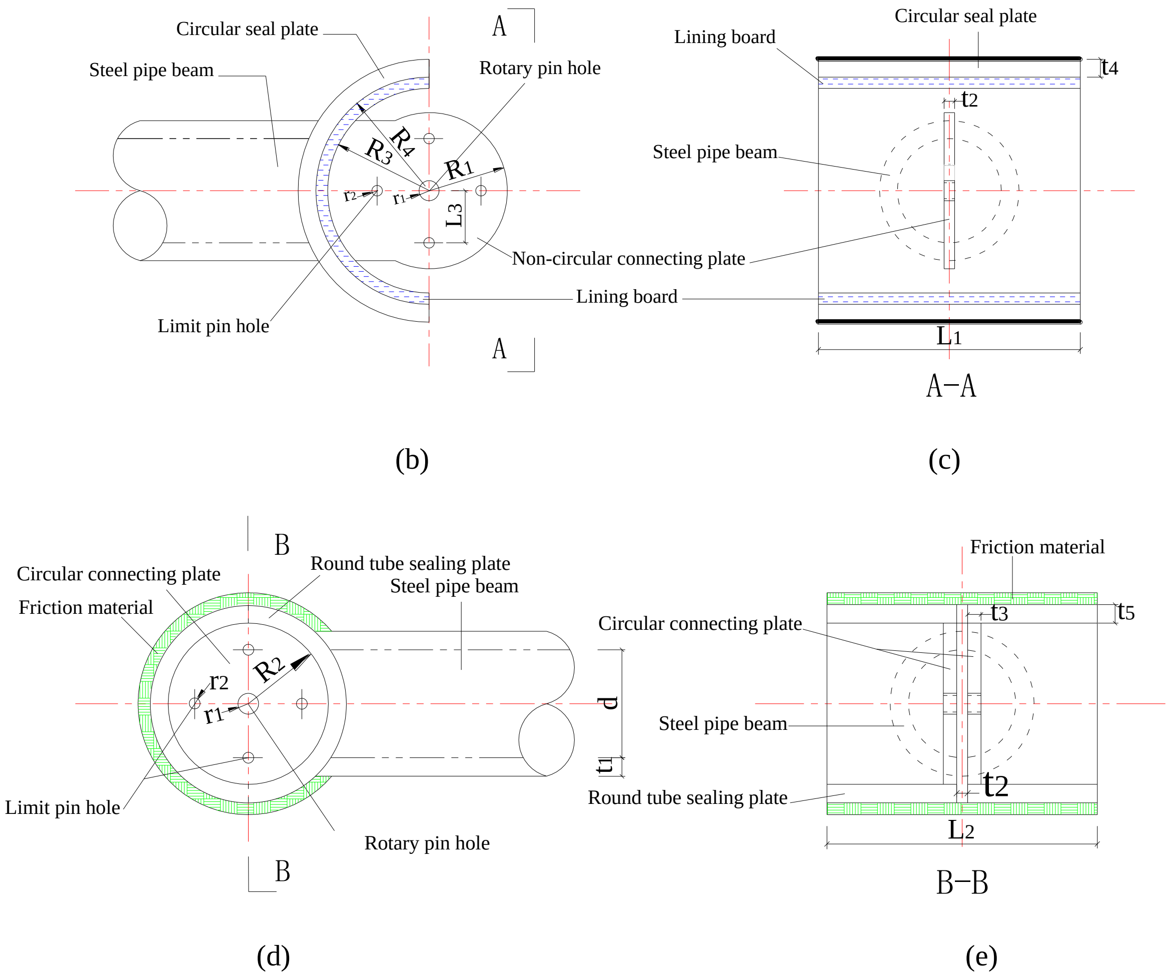
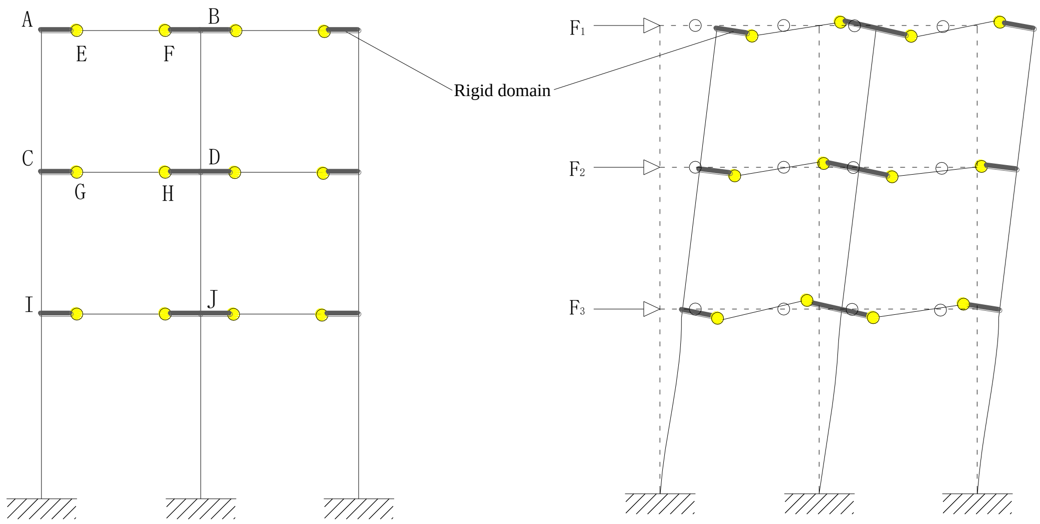


Figure 1. The new friction plastic hinge detailed structure

2.3 Theoretical study

According to the working principle of the friction type plastic hinge structure, it is applied to the structural system, based on the study of the lateral stiffness of the structure (Zhou Xuhong,2004). In the structural system under the load, the plastic hinge is arranged and the connecting part of the beam segment with the plastic hinge is the new domain, and the plastic hinge of the ABCD structure is arranged in E, F, G and H, as shown in Figure2(a)(b). The new friction "plastic hinge" structure in friction contact surface between the loaded assembly friction material to a normal extrusion stress, when structure under horizontal load and vertical uniformly distributed load, with lateral column under horizontal load by the elastic deformation to plastic deformation occurred rotation to friction energy dissipation. When the structure system is under the horizontal load and the vertical uniformly distributed load, the lateral displacement of the column under horizontal load is transformed from elastic deformation to plastic deformation and it turns to friction dissipation. Based on the principle of structural mechanics, it is assumed that the stress deformation of beam AB and column AC is shown in Figure2(a)(b). In the case of column AC, beam AB is equivalent to rotate the anti-twisting spring at both ends of the column AC(Figure2(b)).



(a) (b)

Figure 2. Plastic hinge in the structure of the layout and function

According to the principle of superposition, the structure system is subjected to horizontal load Fi and vertical uniformly distributed load q.

When only the horizontal load is applied, the torsional spring stiffness is:

$$m_1 = \frac{6i_{AC} \cdot i_{AB}}{i_{AC}} = 6i_{AB} \quad m_2 = \frac{6i_{AC} \cdot i_{CD}}{i_{AC} + i_{CI}} \tag{1}$$

From the column AC moment equation and geometric boundary conditions available:

$$\theta_1 = \frac{\left(2EI_{AC}h_1 + m_2 h_1^2\right)V}{2m_1 m_2 h_1 + 2EI_{AC}m_1 + 2EI_{AC}m_2} \quad \theta_2 = \frac{\left(2EI_{AC}h_1 + m_1 h_1^2\right)V}{2m_1 m_2 h_1 + 2EI_{AC}m_1 + 2EI_{AC}m_2} \tag{2}$$

At this time, the angle of the end of the horizontal load is θ.

Where m_1 and m_2 are the rotational stiffness of the torsion spring; i_{AB} and i_{CD} are the line stiffness of the beam; i_{AC} and i_{CI} are the line stiffness of the column; θ_1 and θ_2 are the column end angle; E is the elastic modulus; I_{AC} is the column moment of inertia; V is the column end shear force ; h_1 is the height of the column.

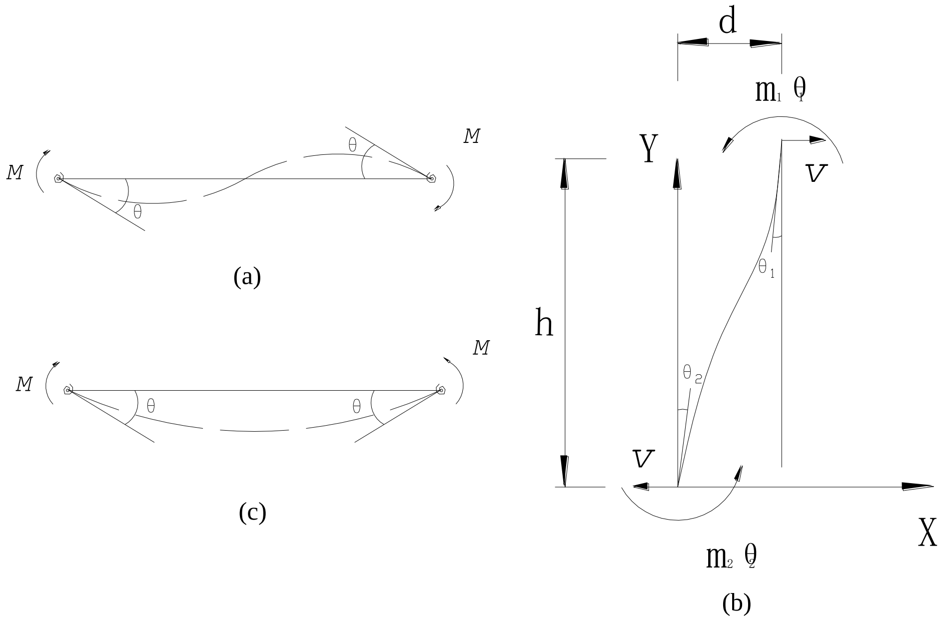


Figure 3. Stress deformation analysis of beam column

When the structural system is only acting on the vertical uniform load, the beam end bending moment : $M_{AB} = i_{AB} \cdot \theta^{'}$, as shown in Figure3(c), then $\theta_{AB} = \theta_1 + \theta^{'}$ is the rotation angle of the AC beam (ignoring the AE section beam angle changes).

When the rotation angle is greater than the plastic hinge E occurs relatively rotating elastic limit angle [θ], based on the plastic properties of the metal material and the analysis of yield condition, the new plastic hinge "friction" some artifacts occurred plastic deformation, the limit pin was cut short, construct rotate around the pin, pressure type friction relative slide between the contact surface occurs (Figure4).

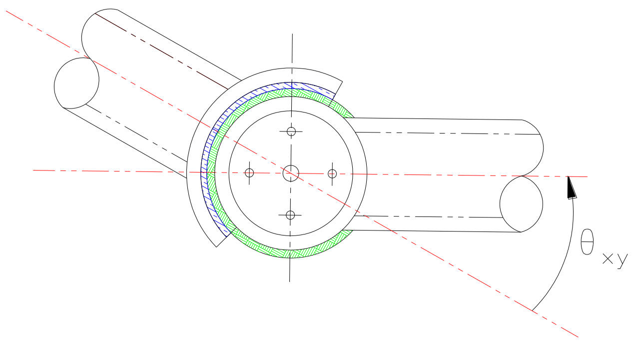


Figure 4. The new friction plastic hinge deformation

When the new "friction plastic hinge" structure rotation angle θ, and θ≥[θ], its energy consumption is as follows:

The maximum rotation arc length: $l = \int \frac{\pi}{180} \cdot r \cdot d_\theta$ (3)

The contact friction: $F_f = N_0 \cdot \mu$ (4)

Where N_0 is the friction material suffered confined compressive prestress between the contact surfaces; μ is the coefficient of friction of the friction material.

The friction energy dissipation: $M_f = F_f \cdot l \cdot \alpha = \int \frac{\pi}{180} \cdot r \cdot N_0 \cdot \alpha \cdot \mu \cdot d_{\theta_{AB}}$ (5)

Similarly, for the beam CD: $\theta_{CD} = \theta + \theta'$ (6)

the friction energy dissipation: $M_f = \int \frac{\pi}{180} \cdot r \cdot N_0 \cdot \alpha \cdot \mu \cdot d_{\theta_{CD}}$ (7)

Where M_{AB} is beam bending moment; θ is a plastic hinge rotation angle; α is reduction factor; θ_{CD}, θ_2 and θ' are sides effect of the beam angle; r is the radius of rotation of the plastic hinge structure; d_θ is the integral variable of the rotation Angle; M_f is the friction energy consumption.

3. NUMERICAL ANALYSIS

3.1 Finite element modeling and analysis

According to the formation of the known plastic hinge and its development law (Wang Yan, 2012), a numerical analysis model was esTablelished by using the finite element ABAQUS structure analysis software. In the finite element elastoplastic analysis, the mises yield criterion and related flow rules are adopted, and the reinforcement phase is adopted by the multi-linear with dynamic strengthening rule, and the linear reduction integral unit (C3D8R) is used to divide the grid. The model defines a contact interference (v) simulation of the frictional contact surface is applied to the prestressing, the contact of the interference amplitude profile (Figure 5).
The friction coefficient of the contact surface is defined as μ, and other influencing factors of friction material are ignored. The structure on the left side of the steel beam on the free end section of the vertical displacement of the coupling, the right side of the steel beam free end section simulation beam-column rigid connection constraints, different parameters adjustment model, through the low cycle reciprocating load verify its hysteretic energy dissipation factors that influence the performance and functions of the beam end displacement coupling loading amplitude curve as shown in Figure6.

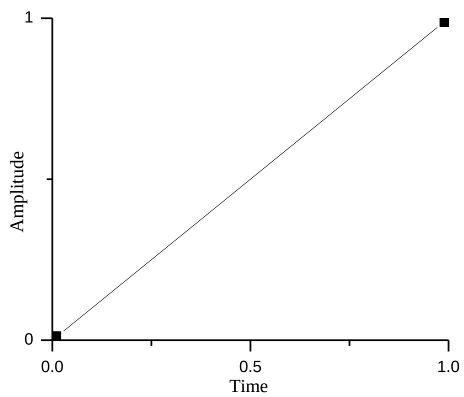


Figure 5. Define the interference contact amplitude curve

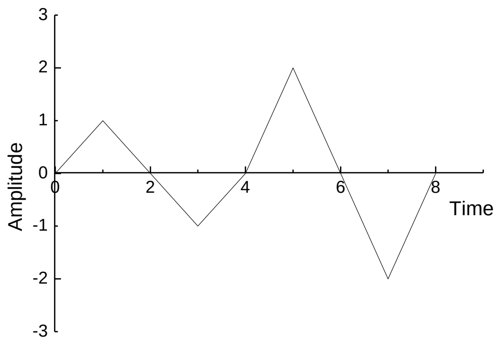


Figure 6. Beam displacement coupling load amplitude curve

The material of the analytical specimen was made of steel, elastic modulus E= 2.1e11N/m^2, poisson's ratio u = 0.3, the plastic stress-strain curve of the material (Figure7). The parameters of each component (Table 1).

Table 1. The plastic hinge model design-related parameters (mm)

Model	d	L_1/L_2	L_3	ν	r_1	r_2	μ	t_1	t_2	t_3	t_4	t_5	R_1	R_2	R_4
M-1	60	80	35	0.10	15	2.5	0.45	10	20	15	12	10	48	50	70
M-2	60	80	35	0.08	15	2.5	0.45	10	20	15	12	10	48	50	70
M-3	60	80	35	0.05	15	2.5	0.45	10	20	15	12	10	48	50	70
M-4	60	80	35	0.08	15	2.5	0.35	10	20	15	12	10	48	50	70
M-5	60	80	35	0.08	15	2.5	0.25	10	20	15	12	10	48	50	70

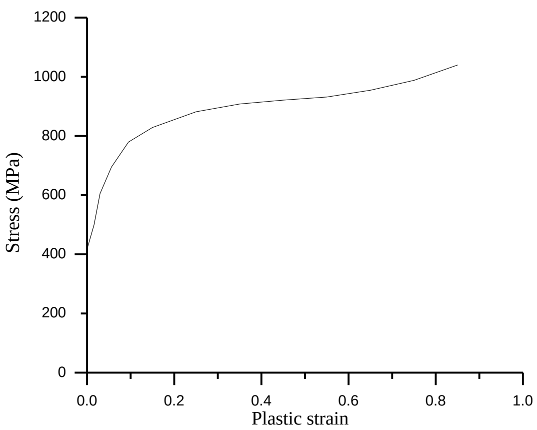


Figure 7. Relationship between steel yield stress and plastic strain

3.2 The finite element calculation results and analysis

According to the theoretical research and the working principle of the model, the plastic hinge is divided into two phases.

(1) The relationship between the bearing capacity and the limit pin of the beam: the bearing capacity of the beam is connected with the radius of the limit pin to the center of the connecting plate and the radius of the limit pin. As the range of L_3 and r_2 increases, the bearing capacity of the beam increases. With the structural movement, the limit pin is greatly deformed to the shear,

and the plastic hinge starts to play a role(Figure8).

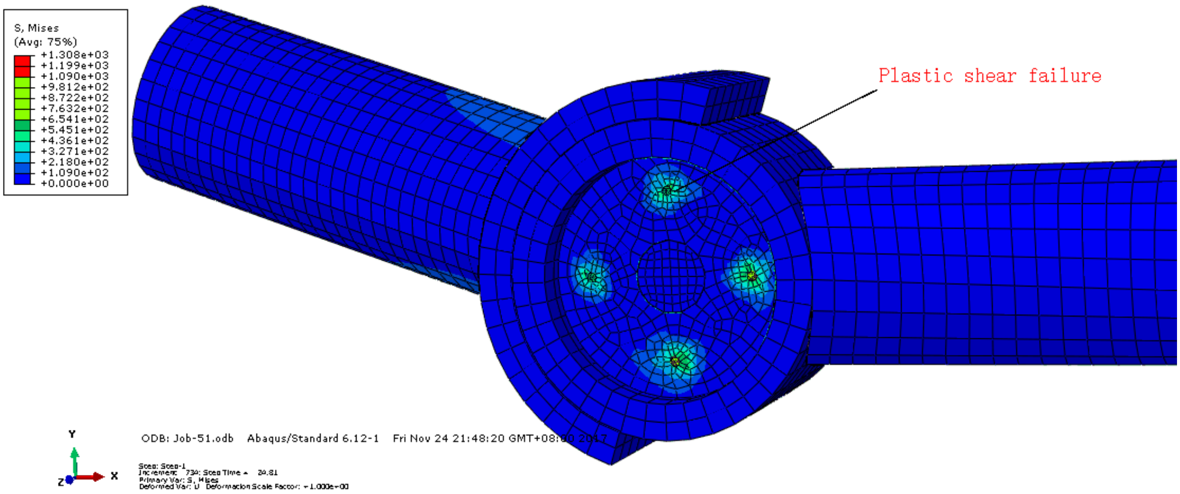
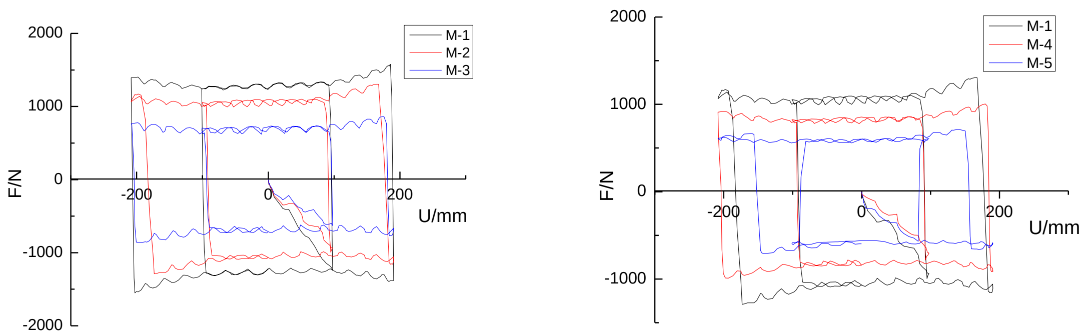


Figure 8. Shear damage deformation cloud pattern of plastic hinge pin shear

(2) The hysteresis performance of plastic hinge is the main research object.

Hysteresis curve is a comprehensive reflection of the seismic performance of the structure. By adjusting the interference (ν) and the friction material properties of the contact friction surface, the area of the hysteresis loop increases and the curve is full with the increase of the normal prestress of the contact friction surface and the friction coefficient of the friction material (F-U), as shown in Figure 9(a) (b). With the structure of the loading process and the friction energy curve (E-T) in Figure 10(a) (b). This shows that the plastic hinge energy consumption is better, can achieve precise positioning energy consumption, help to reduce the destruction of the structure.



(a) (b)

Figure 9. Hysteresis curves for different conditions

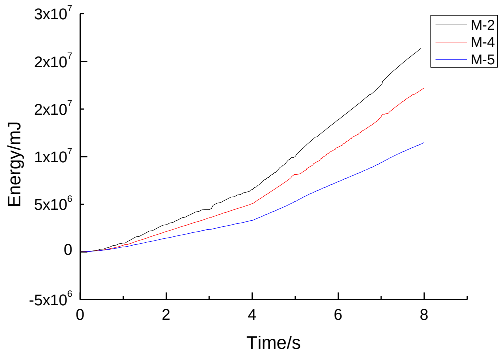


Figure 10. Friction energy cures for different conditions

4. CONCLUSIONS

Based on the idea of structure performance and ductility node design, introducing the theory of plastic hinge can realize offshoring in the plastic hinge node ductility, resistance and avoid brittle failure of beam-column joints under the earthquake action, effectively solve the seismic design of the high-rise steel structure of beam-column connections. Through the study of the new friction plastic hinge, it can effectively realize the external shift of plastic hinge points, and adjust the structural parameters to achieve accurate energy consumption, and the hysteresis performance is better. After the large earthquake, the structure only needs more partial damage to the components, can realize the target of quick repair after the earthquake.

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