A NEW TYPE OF EARTHQUAKE RESISTANT SHEAR WALL STRUCTURE WITH SLIDABLE HORIZONTAL FRICTION JOINTS

Li Ying (I)
Wei Lian (II)
Song Reihua (I)
Liu Zhengchang (III)
Jiang Jingkai (III)
Presenting Author: Li Ying

SYNOPSIS

This paper presents a new type shear wall structure. The precast shear wall panels are installed by means of vertical prestressing, horizontal friction slide joints are formed between the top of the panels and the bottom of the beams. Test results of a single-storeyed reinforced concrete specimen and a three storeyed timber model are introduced. Design of a five-storeyed experimental building with new type shear wall is also presented.

INTRODUCTION

As a result of strong earthquake motion, irregular destructive crack will appear in the shear wall structure. In this test, cracks of structure are expected to be controlled within definite joints and occur in regular sequence. For this purpose, a horizontal friction joint is formed between the top of the shear wall and the bottom of the beam, which is pressed tightly against the wall by means of post-tensioned force. Under seismic loading, the shear wall will move back and forth along the friction joint, and the structural rigidity will change depending on the seismic response. The amplitude is attenuated by the frictional damping and the seismic loading is reduced by degradation of structural rigidity. Adequate behavior of energy dissipation is thus obtained.

TEST OF A SINGLE-STOREYED REINFORCED CONCRETE SPECIMEN (Ref.1)

Figure 1 shows a single-storeyed reinforced concrete friction slide shear wall specimen SG2-2, which is assembled by precast members, the connection between the beam and the column is analogus to the Yuogoslavian IMS system, the structural integrity is obtained by means of prestressing.

Figure 2(a) shows the force-displacement curve measured at the center line of the beam located on top of the specimen under cyclic horizontal loading. Figure 2(b) is the force-displacement curve of the friction joint measured at the same time. Except that the former horizontal displacement is somewhat more than that of the later, the behaviors of hysteresis and energy dissipation are quite similar.

(I) Engineer, Beijing Institute of Architectural Design, Beijing, China

(II) Senior Engineer, Chinese Academy of Building Research, Beijing, China

(III) Engineer, Chinese academy of Building Research, Beijing, China

1. Foundation beam;
2. Column;
3. T-beam;
4. Shear wall panel;
5. Sliding friction joint;
6. Vertical prestressing strand;
7. Horizontal prestressing strand;
8. Built in ducts at both sides of shear wall panel;
9. Gap between the column and the panel;

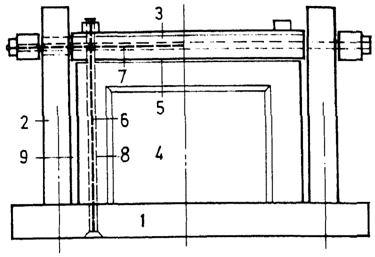

figure1. specimen SG2-2

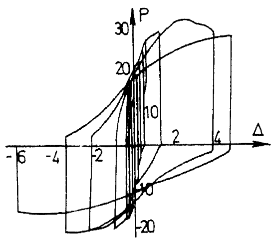

figure 2(a)

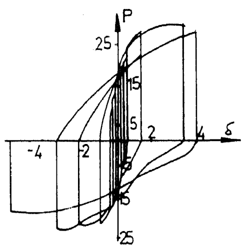

figure 2(b)

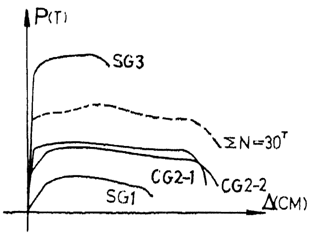

figure 3

This shows that in the process of friction slide, the structural integrity is adequately maintained.

For comparision, tests of a bare frame and a solid shear wall without friction joint were carried out. The specific content is shown in table1.

Table1

Specimen No.	SG1	SG2-1	SG2-2	SG3
Characteristic of specimen	Bare frame	Friction slide shearwall		Solid shear wall
Type of Construction	Precast beam and column	Precast beam, column and panel		Precast beam and column, panel cast in situ
Concrete strength of column and beam kg/cm^2	500	520	450	530
Concrete strength of wall panel kg/cm^2	——	520	450	400
Longitudinal reinforcement of column	$E = 2.5\times10^6 kg/cm^2$ $P = 2,700 kg/cm^2$ $P = 100 kg/cm^2$			
Prestressing strand	$E = 1.8\times10^6 kg/cm^2$ $P = 16,000 kg/cm^2$			
Prestressing force	Vertical $N_y = 2\times7.5 = 15^T$, Horizontal $N_x = 2\times10 = 20^T$			

Figure 3 is the envelope curves of the maximum displacements measured at the top of model SG 1, SG 2-2 and SG 3, if the normal pressure (i. e the vertical prestressing force) on the friction joint increases; the strength of specimen SG 2-1 and SG2-2 will increase;to the dotted line position.

Based on the test result, an ideal degrading quadri-linear model of restoring force characteristics is suggested as shown in figure 4, it can be used to analyze the structure theoretically. The mechanical characteristics of the restoring force model can be described in three stages (Ref.2).

1. Before slide of the friction joint — under external load, owing to the shear force in the joint is less than the friction force, the joint does not move, the structure is in elastic condition.

2. During slide of the friction joint — the shear force in the joint equals to the friction force produced by the prestressing force and vertical load, the friction joint starts to slide. The structural displacement is mainly caused by the column drift, structural rigidity reduces obviously, but the structure is still in elastic condition.

After crack occur on the frame, loading increases with larger displacement until yielding, the structural rigidity is further reduced. If loading starts, the rigidity will be close to the initial rigidity till reverse slide begins, while the shear force in the joint equals to the friction force.

3. After yielding of the frame, the displacement of the frame increases with cônstant loading, a certain amount of residual deformation will occur after unloading, and the structural rigidity will be close to the initial rigidity. With reverse loading the friction slide will take place in its loading direction, path of displacement obviously points to the foregoing position of maximum displacement.

With respect to the restoring force model shown in Fig.4 the parameter of transition points may be computed with following formulas:

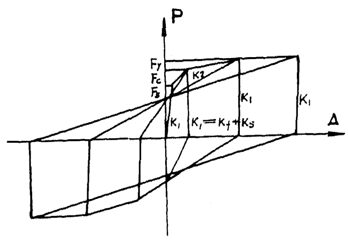

figure.4 restoring force computation model for structure with friction slide joints between stories.

1. Horizontal force F_s of friction joint when slide begins

$$F_s = \mu_f (N + N_L) + K_f \Delta_s \qquad (1a)$$

$$F_s = \mu_f (N + N_L)\left(1 + \frac{K_f}{K_s}\right) \qquad (1b)$$

$$\Delta_s = \frac{\mu_f (N + N_L)}{K_s} \qquad (2)$$

$$K_s = \frac{2.4 E I_s A_s}{H (7 I_s + H^2 A_s)} \qquad (3)$$

2. Cracking strength F_c

$$F_C = \mu_f\ (N + N_L)\ + K_f \Delta_C \tag{1a}$$

$$F_C = \frac{\Sigma M_C}{H} + F_S - K_f \Delta_S \tag{1b}$$

$$\Delta_C = \frac{\Sigma M_C}{H \cdot K_f} \tag{5}$$

$$K_1 = \frac{F_C - F_S}{\Delta_C - \Delta_S} \tag{6}$$

3. Yielding strength F_Y

$$F_Y = \frac{\Sigma M_Y}{H} + F_S - K_f \Delta_S \tag{7a}$$

$$F_Y = \frac{\Sigma M_Y}{H} + \mu_f\ (N + N_L) \tag{7b}$$

The yielding displacement can be estimated with the following formalae:

$$\Delta_Y = \frac{\Sigma M_Y}{H \alpha_Y K_f} \leqslant \left(\frac{1}{80} \sim \frac{1}{100}\right) H \tag{8}$$

$$\alpha_Y = 0.035\ \left(1 + \frac{a}{h}\right)\ + 0.27\eta_0 + 1.65 n \mu_f \tag{9}$$

$$K_2 = \frac{F_Y - F_C}{\Delta_Y - \Delta_C} \tag{10}$$

$$\eta_0 = \frac{N}{0.83 b h R}$$

where:

K_f — storey rigidity of the frame;
μ_f —coefficient of friction at the joint;
N —vertical prestressing force;
N_L — vertical loading;
A_S — cross-sectional area of the panel;
I_S — moment of inertia of the panel section;
H — clear height of the column;
ΣM_C — sum of cracking moments of the top and bottom sections of the column;
ΣM_Y — sum of yielding moments of the top and bottom sections of the column.

$$n = \frac{E_g}{E_h}$$

$$\mu = \frac{A_g}{bh}$$

bh — sectional area of the column
a/h — shear to span ratio;
Eg.E_h — elastic modulas of steel and concrete;
Ag — tensile steel area;
R — compressive strength of concrete.

Mc and My of column section may be cacullated according to related formulas. Based on above restoring force model and computation, the multi-storeyed shear and shear-bending structures may be analyzed by the following equation, using method of step by step integration.

$$[M]\{\ddot{X}\}+[C]\{\dot{X}\}+[K]\{X\}=-[M]\{\ddot{U}_0\} \quad (11)$$

where:

$\ddot{U}_0$ — acceleration of ground motion.

TEST OF A THREE-STOREYED TIMBER MODEL (Ref.3)

In order to investigate the friction slide mechanism of prestressing multi-storyed shear wall with friction slide joints, load-displacement curves have been measured under cyclic loading for a three-storeyed timber model. The 1:5 model is made of white pine, details of beam and column connection mimics IMS system, the test model is shown in figure 5.

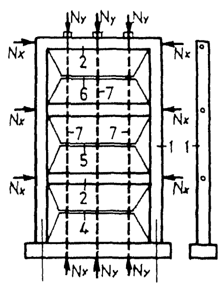

figure.5 three-storeyed test model

where:

1 — column;
2 — beam;
3 — wall panel;
4 — bottom storey friction joint;
5 — middle storey friction joint;
6 — top storey friction joint;
7 — vertical prestressing tie rods;
8 — friction controller;
Nx — horizontal prestressing force;
Ny — vertical prestressing force

Figure 6(a), 6(b) and 6(c) are the hysteretic loops corresponding to the sliding of bottom, middle and top storeys. A,B and C represent the measuring points on friction joints of different storeys.

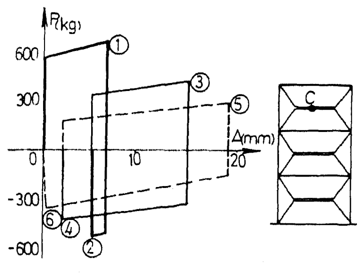

figure 6(c)

load-displacement curves of the top storey friction slide joint

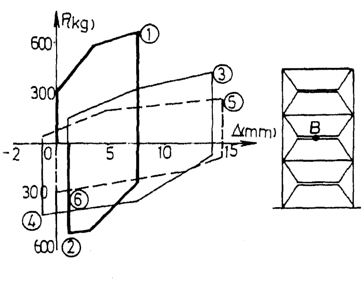

figure 6(b)

load-displacement curves of the middle storey friction slide joint

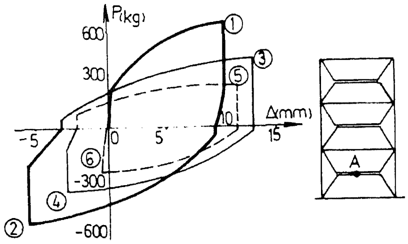

figure 6(a)

load- displacement curves of the bottom storey friction slide joint

①—⑥ denotes the sequence of loading. The shapes and enclosing areas of the hysteretic loops represent the regularity of friction slide and the characteristics of energy dissipation. During the process of loading, sliding begins from the bottom friction joint, then the middle storey friction joint, thus impelling the bottom joint to reduce its rigidity. Finally, the top friction joint slides, at this stage the rigidities of friction joints in the middle and bottom storeys are both reduced. This characteristics of friction sliding can not be seen in the test of a single-storeyed model. The above test results present a wider train of throught for designing multi-storeyed structure.

EXPERIMENTAL BUILDING

Base on the experimental results and the structural principles of Yugoslavian IMS system, a five-storyed frame building with friction slide shear walls and prestressed slab-column connections has been designed and put into construction. The structural plan is shown in figure 7 .

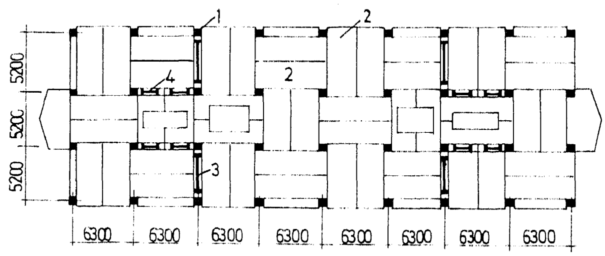

figure7 structural plan

1 — column;
2 — pretensioned precast slab;
3 — prestressed friction slide shear wall in transverse direction;
4 — prestressed friction slide shear wall in longitudinal direction;
Nx — tranverse prestressing force of the floor;
Ny — longitudinal prestressing force of the floor;

In order to enlarge the bearing area of the slab-column connection and improve the torsion resisting behaviour of the corner column, the floor arrangement of IMS system is replaced by a mat shape floor assemblage. Two kinds of slab-column connection details are shown in figure 8 .

The front view of prestressed friction slide shear wall is shown in figure 9 .

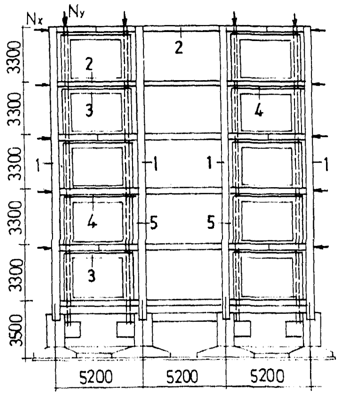

figure 9.
prestressed friction slide shear wall

1 — column;
2 — slab (beam);
3 — shear wall panel;
4 — friction slide joint;
5 — gap between slab and column;
Nx— horizontal prestressing force;
Ny— vertical prestressing force.

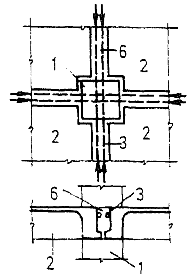

figure 8.(a)
slab-column connection of the IMS system

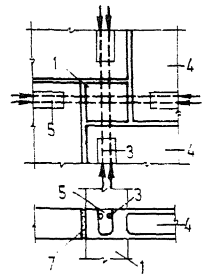

figure 8(b)
slab-column connection of experimental building

1 — column;
2 — prestressed slab of the IMS system;
3 — prestressing wire strand;
4 — prestressed slab of experimentsl building;
5 — slot on slab;
6 —open slot between slabs;
7 — dry mortar packing between slab corner and column.

Adopting the above mentioned restoring force model and analysis method, comparative designs are made for this building. Figure 10(a) and figure 10(b) illustrate three schemes corresponding to bare slab-column frame, monolithic shear wall and slab-column frame with friction slide shear wall, computed with EL-CENTRO NS component of May 18, 1940, the peak value of acceleration is taken as 200 gal.

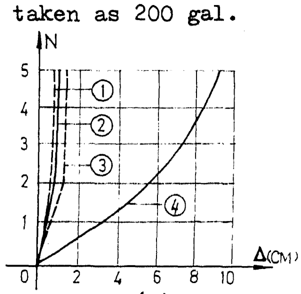

figure 10(a) story displacements

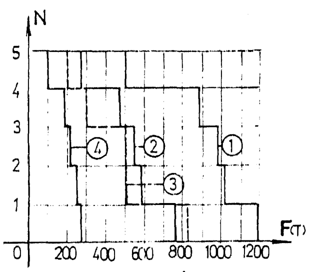

figure 10(b) shear diagrams

N —STORY NO.

Δ —STORY DISPLACEMENT

F —STORY SHEAR

where:

1 . shear wall;
2 . friction slide shear wall, slide occurs on the second story;
3 . friction slide shear wall, slide occurs on the second and fourth stories;
4 . bare frame.

The analysis shows clearly that the horizontal displacement of frame structure with friction slide shear walls is far less than the bare frame structure, its shear values lie between those of shear wall structure and bare frame structure.

Computing with earthquake accelerograms of Tianjin and TAFT, considering friction slide occurs on the second and fourth stories, the results are shown in figure 11(a) and 11(b).

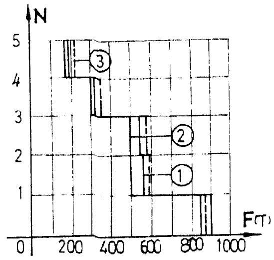

figure 11(a) shear diagram

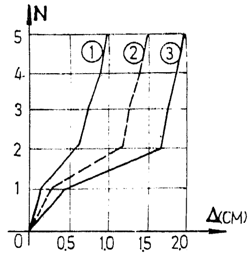

figure 11(b) story displacements

1 EL-CENTRO
2 TAFT
3 TIANJIN

CONCLUSION

1. The prestressed friction slide shear wall is an effective aseismatic structure. Under cyclic loading, through the slide of friction joint, the structural rigidity varies systematically, it possesses adequate behaviour of ductility and energy dissipation. The rigidity and strength of the structure can be adjusted through rational choice of vertical prestressing force.
2. During the slide of friction joints, the frame will play most important role on the structural behaviour. Rational proportioning of column section and detailing of reinforcement are extremely important to provide necessary ductility and avoid early cracking.

REFERENCES

1. Li Ying, Liu Zhengchang et al. The experimental research of prestressed reinforced concrete friction slide shear wall. July, 1982.

2. Wei Lian, Li Ying et al. Earthquake response of multistoried prestressed friction slide shear wall structures. August,1982.

3. Li Ying and Wei Lian, The experimental research of the prestressed friction slide shear wall. Jan,1982.