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Research of sliding shock absorbing of multi-storey brick buildings

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ABSTRACT: Based on a series of analytical and experimental studies, this paper presents a convenient and economical method to significantly improve the anti-collapse behaviour of superstructure. A sliding shock absorbing system using materials with low friction coefficient such as graphite,etc. is suggested. This paper is of importance to improving buildings' safety esp. to China and other third-world countries, where multi-storey brick buildings are the common construction option.

1 INTRODUCTION

Loading-bearing wall multi-storey brick structures are the common option in China. They are seismically designed according to "Seismic Design Code" and ensured safety subjected to design earthquake intensity. But in today's science level, it's difficult to accurately divide earthquake intensity zones. It is proved by several severe earthquakes which occured in China in recent years, such as Haicheng(1975) and Tangshan (1978) earthquake. These earthquakes caused most damage. Therefore, it's an important subject for seismic engineers to find a simple、economical and conveniently executed structure to improve anti-collapse behaviour of multi-storey brick buildings. This paper describes a research program in which shock absorbing sliding joint is used for this purpose. A horizon joint made of low frition material is set at the bottom of the masonry structure. When a strong earthquake occurs, the superstructure above the joint slides opposing to lower base, then earthquake energy transmitted to the superstructure is prevented or limited. As a result, the superstructure is protected from damage or collapsing. The sliding joint acts like a fuse in a circuit to ensure buildings safety subjected to strong earthquakes.

2 EXPERIMENTAL STUDIES AND RESULTS

2.1 Sliding joint tests

Specimen compression and shearing tests of various low friction materials joints are undertaken. Graphite, paraffin wax and screened gravel are selected as sliding joint materials.

2.2 Behaviour tests of wall with sliding joint

Horizon load and distortion tests of walls with and without sliding joint under various vertical loads are made. Results show that the horizon loads of ordinary wall when slant cracks start forming is two times larger than that of wall with sliding joint. Therefore, the sliding effect of the shock absorbing joints protect superstructures safety in earthquake.

Curves of horizon load and relative motion between superstructure and substructure of wall with and without sliding joint are shown in Fig.1、Fig.2 and Fig.3 . These experiments supply basis for dynamic analysis of multi-storey buildings with sliding joints.

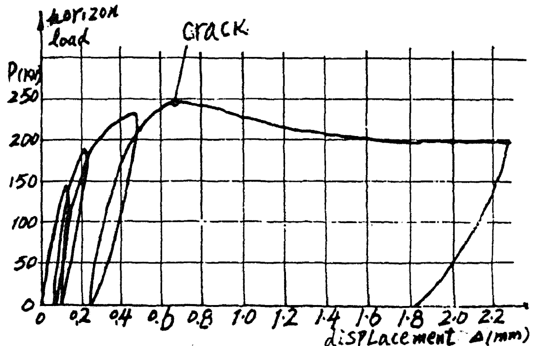
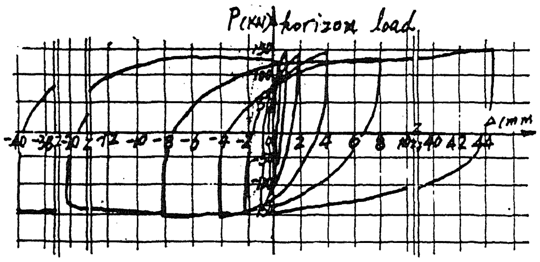
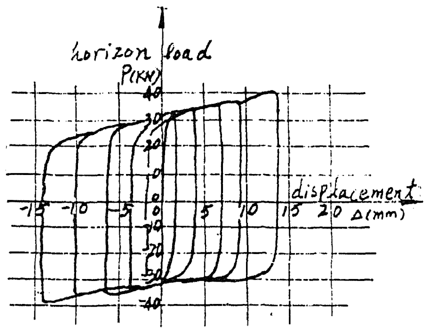


Figure 1. Load-displacement curve of common brick wall
1. Mortar strength 3.41 MPa
2. Vertical load 240 KN

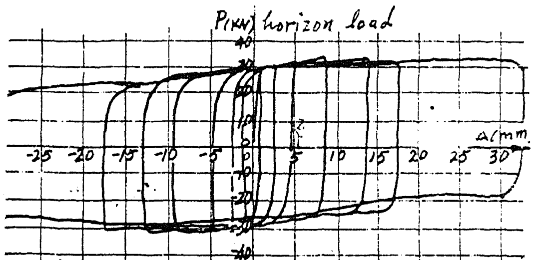


1. Vertical load 240 KN
2. With guy outside joint

Figure 2. Load-displacement curve of screened gravel sliding joint



(1) With guy outside joint



(2) Without guy outside joint

Figure 3. Load-displacement curve of graphite sliding joint.

2.3 Shaking table tests of various sliding joint specimens

The test model has a I-shaped cross section and is composed of upper and lower parts. According to different purposes, sliding joint material、joint structures between superstructure and substructure and height of superstructure are different. Thirty-two tests of two models are run according to test requirements. Results are shown in the following.

1. Graphite is an ideal low frition material to make sliding joint. It has low cost、good endurance and great load bearing. It maintains stable behaviour in dry or wet sliding and after several sliding. When the sliding surface is concrete, the joint start sliding table acceleration is 0.2g~0.3g. As the table acceleration goes on increasing, the superstructure will maintain to be in start sliding acceleration.

There is a layer of asphalt felt above the graphite layer. It has similar sliding behaviour to concrete surface. This structure simplifies actual construction by making asphalt felt as bottom formwork of reinforcement concrete bottom-beam. Therefore, this is a more practical sliding joint.

2. Screened gravel or fine sand are also low friction materials. They have low cost、good endurance and great load bearing. But after several sliding, sand breaks and sliding surface is ground rough. This makes friction coefficient increase considerably. The start table acceleration is 0.3~0.6g according to the smooth of sliding surface.

3. Parffin wax is not suitable as sliding material. Its condensation cohesiveness easily leads to swing vibration before sliding.

4. The relative displacement of sliding joint relates to the joint material, but has nothing to do with whether having joint-piece between upper and lower part. Subjected to a harmonic ground motion of 1.0g maxium acceleration, the maxium displacement of graphite joint is ±7mm and for screened gravel is ±6mm.

5. Spacing by filling up the horizon hollow joint with rubber cudes. This will sharply resists superstructure from sliding and cause swing vibration. Therefore, this spacing method is unfeasible.

6. Using graphite and screened gravel as sliding material with height-width(H-W) ratio of 1.85, the specimen only slides without swing vibration; With H-W ratio of 2.57, the specimen will swing and vibrate severely; Common seven-storey buildings' H-W ratio is 1.85, Therefore, swing vibration will not occours.

3 DYNAMIC ANALYSIS

3.1 Restoring force pattern

According to test results and several internal references, Fig. 4 and Fig. 5 show restoring force pattern of walls with and without sliding joint.

The following symbols are used in Fig. 4、Fig. 5 and other equations.

Pu —— Wall limit horizon load causing shearing crack;

Py —— Sliding horizon force of wall or wall with sliding joint;

K_o —— Stiffness of wall in elestic phase;
σ_o —— Average compression stress;
A —— Cross section of wall;
E —— Masonry elastic modulus;
H —— Height of wall;
$\Delta 1$ —— Wall initial crack displacement
For common wall $\Delta 1 = Pu/K_o$
For wall with sliding joint $\Delta 1 = Py/K$
R_j —— masonry shearing strength

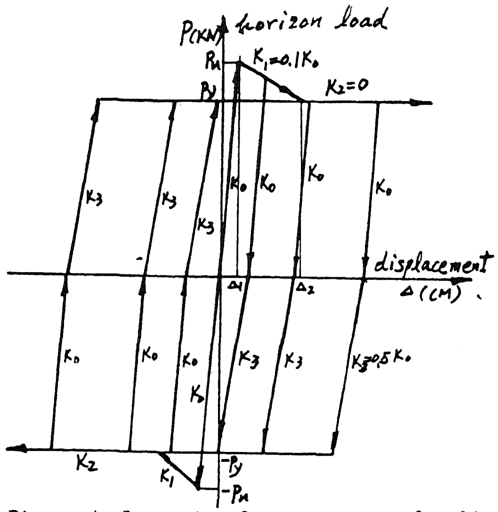


Figure 4. Restoring force pattern of wall

a. $Pu = Rj\sqrt{1+\sigma_o/Rj}\ A/1.2$, $Py = f\sigma_o A = 0.6\sigma_o A$
b. Diagram for wall with moveable superstructure and substructure
$K_o = 0.65Et/((H/B)^3 + 3H/B)$ or $K_o = 0.21EA/H$
c. Diagram of wall with fixed substructure and free superstructure $K_o = 0.65Et/(4(H/B)^3 + 3H/B)$ or $K_o = 0.2EA/H$

3.2 Mathematical model for dynamic analysis of multi-storey brick building

As multi-storey brick buildings are mainly damaged from shearing distruction subjected to earthquake, they are simplified as series multi-degree-of-freedom interlayer shearing model to calculate, neglecting effect of floor rotational inertia. The wall mass of every stories are assumed to be lumped at floors, respectively.

The equation of motion is as follow:

$$[M]\{\ddot{Y}\}+[C]\{\dot{Y}\}+[K]\{Y\}=-[M]\{E\}\ddot{X}g(t) \quad \cdots(1)$$

where Mi is the mass of No.i floor, Ki is floor displacement and $\ddot{X}g$ (t) is input acceleration of earthquake.

in which mass matrix is

$$[M]=\begin{bmatrix} M1 & & \\ & M2 & \\ & & \cdots \\ & & & Mn \end{bmatrix} \quad \cdots(2)$$

Horizon displacement、velocity and acceleration row vectors are

$$\{Y\}=\begin{bmatrix} Y1 \\ Y2 \\ Y3 \end{bmatrix},\ \{\dot{Y}\}=\begin{bmatrix} \dot{Y}1 \\ \dot{Y}2 \\ \dot{Y}3 \end{bmatrix},\ \{\ddot{Y}\}=\begin{bmatrix} \ddot{Y}1 \\ \ddot{Y}2 \\ \ddot{Y}3 \end{bmatrix} \quad \cdots(3)$$

Story-side stiffness Ki is the sum of walls' stiffness in this story.

$$[K]=\begin{bmatrix} K1+K2 & -K2 & & 0 \\ -K1 & K2+K3 & -K3 & \\ & \cdots\cdots & & \\ 0 & & -K2 & Kn \end{bmatrix} \quad \cdots(4)$$

As Ki=Qi/Xi, then story shearing is:

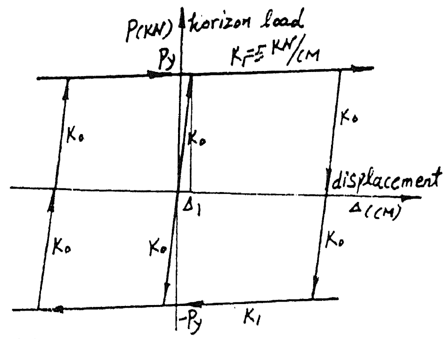
$$Qi=Ki/Xi=Ki(Yi-Yi_{-1}) \quad \cdots(5)$$

Story earthquake force is:

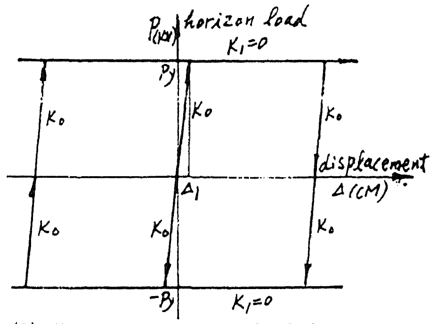
$$Pi=Qi-Qi_{-1} \quad \cdots(6)$$

which can be written as:

$$\{P\}=[K]\{Y\} \quad \cdots(7)$$



(1)With guy outside joint



(2) Without guy outside joint
Figure 5. Restoring force pattern for wall with sliding joint
a. $Py = f\sigma_o A$
b. Two-degree-of-freedom superstructure
$K_o = 0.2EA/H$

In calculation, damp vector [C] is adopted in Rayleigh damp mode. Damp vector is determined by mass vector [M] and stiffness vector [K].

$$[C]=\alpha[M]+\beta[K] \quad \cdots(8)$$

where [K] is general stiffness vector assuming whole system to be in elastic phase; α、β are constant and can be directly given. It can be also given by following equation with given any sec-order vibration mode damp ratio λi、λj.

$$\alpha=2(\lambda j\omega i-\lambda i\omega j)\omega i\omega j/(\omega i^2-\omega j^2) \quad \cdots(9)$$
$$\beta=2(\lambda i\omega i-\lambda j\omega j)/(\omega i^2-\omega j^2) \quad \cdots(10)$$

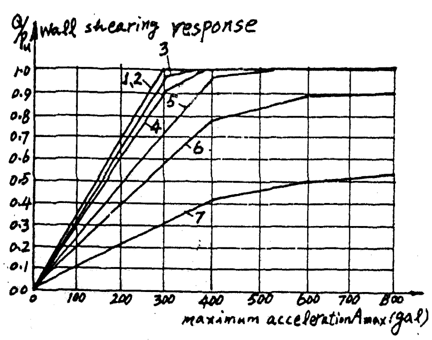
where λi、λj are damp ratio of No.i、No.j vibration mode; ωi、ωj are circular frequency of system No.i、No.j vibration mode (calculated by computer), respectively.

Noncondition stable Wilson-θ integral method is adopted to solve dynamic equation, in which $\theta=1.4$.

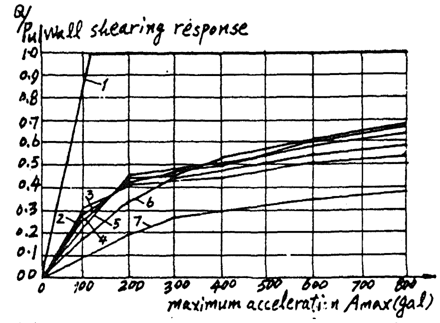
3.3 Example

For seven-storey brick concrete residence with seismic design of intensity 7 which is common in North China, comparison calculate analysis is taken between middle units (of all five units) with and without sliding joints. The unit is 16.2 m long、10.7m wide、19.8m height. The exterior and middle staircase pier are 370mm thick, other cross-wall and pier are 240mm thick. Graphite(f=0.23) and screened gravel(f=0.4) are used as sliding joint materials. El-centro(1940/NS) and Taft(1952) ground motion are used as modulation input. Calculation results give out the ratio of floor shearing to wall shearing strength when they are subjected to ground motion, calling it wall shearing response(WSR). When WSR value Q/Pn=1, it means the wall starts cracking or sliding. Fig. 6 shows the calculation results. It shows that for general seven-storey brick concrete buildings with seismic design of intensity 7 when the ground acceleration reaches 0.28~0.31g(corresponding to earthquake intensity 8.5), walls start cracking; When ground acceleration reachs 0.4g (corresponding to earthquake intensity 9), majority walls crack and the building is severely damaged.

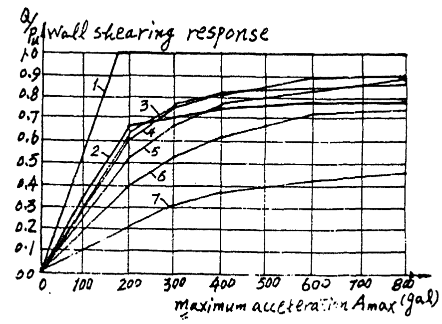
For multi-storey brick buildings with sliding joints and different sliding materials, when the ground acceleration is 0.1~0.18g, the superstructure starts sliding and the joints come into effect. When the ground acceleration reachs 0.8g(corresponding to earthquake intensity 10), the superstructure can also maintain security.



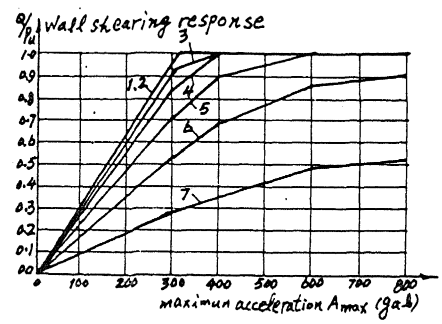
(1) Common brick building



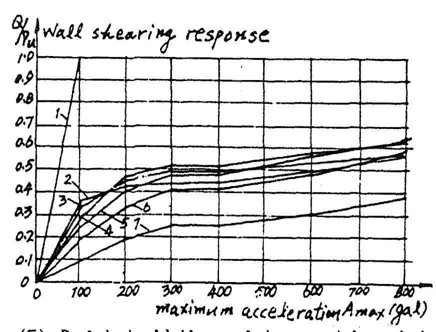
(2) Brick building with graphite joint



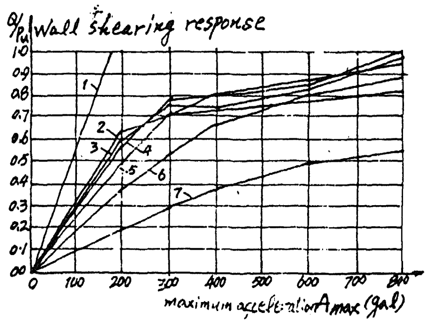
(3) Brick building with screened gravel joint



(4) Common brick building



(5) Brick building with graphite joint



(6) Brick building with screened gravel joint
Figure. 6 Wall shearing response of every floor subjected to various ground motion
a. Fig. 1~Fig. 3 El-centro ground motion
b. Fig. 4~Fig. 6 Taft ground motion

4 CONCLUSIONS

Sliding joints made of graphite or screened gravel are set at the bottom of multi-storey brick building. Because of the sliding effect in earthquake, the superstructures' earthquake response(acceleration and shearing) is significantly limited. As a result, the building is safe. Therefore, shock absorbing joint can significantly increase superstructures' anti-collapse behaviour.

REFERENCES

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