BASE ISOLATION MEASURE FOR ASEISMIC BUILDINGS IN CHINA

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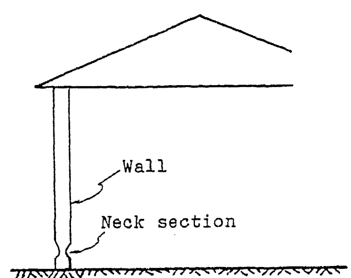
SUMMARY

If a horizontal crack occurs at the root of wall, some buildings may survive strong earthquake. An artificial horizontal slit is constructed as the base isolation measures, and it is verified by model test on shaking table and blast ground motion. Four buildings have been constructed awaiting test of the coming natural earthquake.

INTRODUCTION

In 13th April 1960 a strong earthquake hit Tuqiao village, Jilin province, most houses collapsed, only one survived. In that small village farmhouses were all built of earth (adobe or tamping soil wall). Examined this old house, we found a neck section at the root of the wall as a result of weathering. (Fig.1) Owing to this crack, the upper part of the house might slide on it, thus survived the strong ground motion. The old house survived, while all of the new houses were collapsed, why? It is the merit of the horizontal crack, i.e. the strength of the house exceeds the shaking force transmitted from the sliding surface. So there come up two concepts:



(Fig. 1)

1. If this horizontal crack may prevent the earth house from damage during strong earthquake, then other houses which build of bricks, woods, reinforced concrete etc. may survive in strong earthquake, because these houses are all stronger than earthen house.

2. If an artificial horizontal slit is constructed at the root of the wall, intensity of strong earthquake may be reduced due to sliding.

The first concept is verified in several earthquake investigations.

1. Xintai earthquake (intensity 9) of 8th March 1966. Strong earthquake induced a horizontal crack in the upper part of a flour mill brick building, which survived during subsequent strong earthquake.

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2. Bohai earthquake (intensity 8.5) of 18th July 1969. To make wall moisture-proof many adobe dwellings had been laid with a layer of reed (about 10cm thick) at the root of wall, which survived strong earthquake but were not durable, some of them were collapsed following decay of reed.

3. Tangshan earthquake (intensity 10) of 26th July 1976. Two dormitories No. 3 & No. 4 on Wenhua Road of Tangshan city only 10m apart, which were all 3-story brick buildings and under the same soil condition, but after strong earthquake dormitory No.3 survived and No.4 was reduced to rubble. Inspecting dormitory No.3, we found a through horizontal crack around the root of the wall, which might be induced at the beginning of earthquake, since then the whole building slided on the crack, traces of sliding might be observed at the crack. Between the upper and lower parts of brick wall there was a residual displacement about 6 cm.

Thus the first concept has been verified by the aforementioned cases. The second concept will be discussed later.

In 1909 an English doctor Calantariants was the first to make the suggestion, followed by researches of scholars in Japan, U.S., France, New Zealand etc. They used rubber pad, graphite, round or ellipsoid ball support, Gapec system, polytetrafluoroethelene plates etc, which being neither ecinomic, durable nor easy to apply are all unpractical for our country, we should select other materials.

In China the most severely damaged during earthquake are houses of peasants of lower living level which, usually built with earth wall and straw roof, are low in cost and seismic resistance. To protect their lives and property, earthquake engineers should study aseismic measures of their houses. Cost of houses being low, they are unwilling to pay much money for aseismic purposes. On the other hand, most of the adobe houses are built by peasants themselves, without being designed by structure engineers, so that sliding measure should be cheap, easy to apply, effective and durable.

To fulfill these four requirements, sand grains are selected as sliding material.

1. Sieve the cleaned sand, take only the grains of diameter 1-1.2 mm. Then spread the grains on a glass plate inclined 20° to the horizontal, collect the round grains rolled down, while discarding grains of other shapes left on the inclined plate. This kind of sand grains are rather cheap, for a 15 $m^2$ house only 200-300 gram of grains is needed and cost less than 0.1% of the overall cost of the house. Consequently, the material may be approved by peasants and workers of lower living level, especially people of developing countries.

2. Sand composed of $SiO_2$, is a stable material, not corroded by moisture, its working life being over 100 years and even longer than the earthen house.

The sand is compressed on an universal testing machine. A thin layer of selected sand is spread between two terrazzo plates to test its bearing capacity, results are shown in table 1.

Table 1

| Pressure $^{kg}/_{cm^2}$ | Crushed sand % | Smooth surface of terrazzo plate |
|---|---|---|
| 1 | few | no indentation |
| 2 | 1 | no indentation |
| 4 | 2 | little indentation |
| 8 | 5 | little indentation |

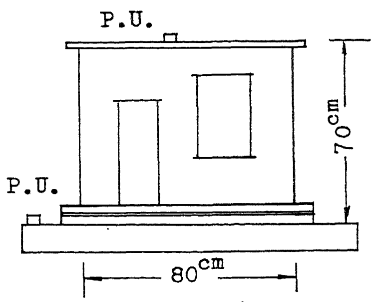
In farmhouses, the compressive stress of wall does not exceed $1^{kg}/_{cm^2}$ even in a four-story brick building the pressure at the root of the wall does not exceed $3^{kg}/_{cm^2}$, hence the sand used as the material for sliding measure is durable and applicable.

3. The measure is easy to apply. Lay down wall footing in an ordinary way up to 10 cm below the floor level, then cover a terrazzo plate with smooth surface upward, spread a thin layer of sand grains and cover another terrazzo plate with smooth surface downward. It is preferable to pour reinforced concrete wall beam on the latter, or lay several layers of brick with high strength cement mortar, with the upper part of the hous built as usual.

4. The measure is effective in isolating horizontal strong ground motion, which is the most destructive force on the damage of building. Dynamic frictional coefficient of the sand grains equals to 0.2, which is a statistical value obtained from shaking table tests. The force transmitted by friction causes no damage of the upper part of the building.

## MODEL TESTING AND ENGINEERING PRACTICE

To verify the second concept, i.e. isolating effect of the measure, house models were tested on shaking table. Dimensions of the model are shown in Fig.2. Two layers of small brick were laid with cement mortar on shaking table, upper surface was levelled and made smooth, then a thin layer of selected sand grains was spread as sliding material, on which two layers of small brick were laid with cement mortar and the upper part were built with adobes. After drying, the table was shaked. when acceleration reached 0.2g, the upper part slided without collapse. The tests were repeated five times, five models with slight differences all survived the shaking.



(Fig. 2)

Later, the effect of isolatic measure was verified by blast-induced strong ground motion. The house were built with underfired brick of low strength, which may be broken off with fingers and thumb. Wall is built with lime mortar had been rain-drenched for over three months in the rainy season, house models survived the blast test, but the whole house slided a little distance. Ground near the house cracked, it was identified corresponding to intensity 8 from field inspection.

Following shaking table test and blast test, all of the models survived, the second concept is thus probably verified. Then we built dwellings in the regions where strong earthquake prediction is available awaiting the coming natural earthquake.

Four buildings with the base isolation measure were built in China:

a. A 16 $m^2$ adobe house with straw roof built at Huaping County, Yunnan Province in 1975;

b. A 16 $m^2$ house with tamped wall and tile roof was built at Xichang City, Sichuan Province in 1975;

c. A 12 $m^2$ weight bridge house was built with brick wall and tile roof at Anyang Steel Plant, Anyang City, Henan Province in 1980;

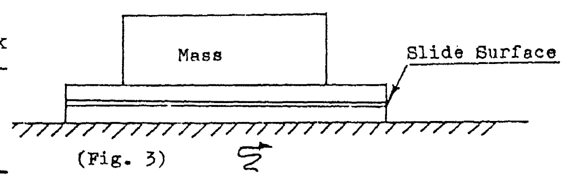
d. A four-story dormitory was built for Strong Earthquake Observation Center, Beijing in 1981.

Some photos were taken during construction are shown in later, so far these buildings have not experienced strong earthquake.

## RELATIVE DISPLACEMENT

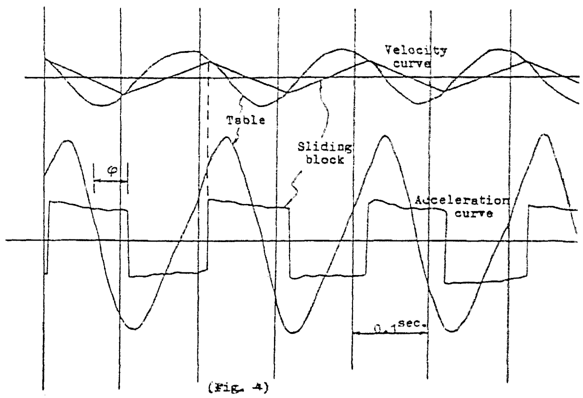
A matter of vital concernment is the distance the upper part may slide on the foundation during earthquake, Now let us discuss this problem.

A rigid block is placed on a sliding surface (Fig.3), which is vibrated with a certain frequency, the amplitude is increased gradually. When $|\ddot{X}_0|>0.2g$, the block slides on its foundation. Acceleration and velocity curves of shaking table and rigid block are shown in Fig. 4. When $|\ddot{X}_0|=0.2g$ the block starts to slide. If $|\ddot{X}_0|>0.2g$, acceleration curve of the block becomes a cut-off curve. The maximum acceleration equals to dynamical frictional coefficient multiplied by g. later the acceleration of shaking table is reduced to $|\ddot{X}_0|=0.2g$, due to momentum the block does not stop immediately and still slides forward, which is called the "lagging slide". When the velocity of the block equals to that of shaking table, sliding stops (see Fig. 4). Then sliding takes place in opposite direction under the above conditions. Change in frequency does not vary the characteristics, i.e. maximum acceleration of



(Fig. 3)

rigid block keeps 0.2g, which follows Coulomb's law of friction.



(Fig. 4)

Then displacement curve may be computed. Dynamic equilibrium equation is written as:

$$M(\ddot{Y} + \ddot{X}_0) = F$$

Where $F$— frictional force
$\ddot{Y}$— acceleration of block relative to the ground
$\ddot{X}_0$— ground acceleration

When block slides on its foundation

$$F = \text{SIGN}(\dot{Y})\cdot f\cdot M\cdot g$$

Where $f$— frictional coefficient

The initial discrimination conditions are:
$|\ddot{X}_0| \leqslant f\cdot g$ block vibrates with its foundation, i.e. $Y=\dot{Y}=\ddot{Y}=0$.
$|\ddot{X}_0| > f\cdot g$ block slides on its foundation.

While block is sliding, $\ddot{X}_0$ is gradually reduced to the limit($f\cdot g$), but $\dot{Y}\neq 0$, block may slide continuously, which is the lagging slide. A phase angle $\varphi$ is lagged. Relative acceleration of rigid block is:

$$\ddot{Y} = -\ddot{X}_0 + f\cdot g\cdot \text{SIGN}(\dot{Y})$$

Following these equations with the aid of electronic computer, maximum and residual displacement of block are given in Table 2:

If the foundation inclines a small angle $\alpha$, the dynamical equation of the block becomes:

$$\ddot{Y} = -\ddot{X}_0 + \left\{\frac{\text{SIGN}(\dot{Y})\cdot f + \text{Tan}\,\alpha}{1-\text{SIGN}(\dot{Y})\cdot f\ \text{Tan}\,\alpha}\right\}\cdot g$$

and the sliding condition may be written as :

$|\ddot{X}_0| \leqslant f\cdot g - \text{Tan}\,\alpha$ does not slide;

$|\ddot{X}_0| > f \cdot g - \mathrm{Tan}\,\alpha$ slide.

Taking the effect of vertical component of earthquake $\ddot{V}_0$ into consideration, equation may be written as

$$\ddot{Y} = -\ddot{X}_0 + \mathrm{SIGN}(\dot{Y}) \cdot f \cdot (g + \ddot{V}_0)$$

Discriminant equations are

$|\ddot{X}_0| \leq f \cdot (\ddot{V}_0 + g)$; or $|\ddot{X}_0| > f \cdot (\ddot{V}_0 + g)$.

Results are shown in Tables 3 and 4.

Maximum and residual displacement of block Tab. 2

| f | El Centro (NS) 1940 | | Qian-an (NS)X2 1976 | |
|---|---|---|---|---|
| | $D_{max}$ | $D_{res}$ | $D_{max}$ | $D_{res}$ |
| 0.2 | 1.01 cm | 0.92 cm | 0.037 cm | 0.021 cm |
| 0.18 | 1.215 cm | 1.05 cm | 0.077 cm | 0.025 cm |
| 0.16 | 1.246 cm | 0.674 cm | 0.138 cm | 0.033 cm |
| 0.14 | 1.452 cm | 0.358 cm | 0.189 cm | 0.036 cm |
| 0.12 | 2.413 cm | 0.337 cm | 0.260 cm | 0.055 cm |

When vertical component is considered Tab. 3

| f | 0.20 | 0.18 | 0.16 | 0.14 | 0.12 |
|---|---|---|---|---|---|
| $D_{max}$ | 0.044 cm | 0.113 cm | 0.147 cm | 0.216 cm | 0.269 cm |
| $D_{res}$ | 0.001 cm | 0.002 cm | 0.018 cm | 0.013 cm | 0.051 cm |
| Qian-an earthquake (NS+UD)X2 1976 is used | | | | | |

When ground inclines an angle Tab. 4

| Tan | 0.000 | 0.003 | 0.005 | 0.010 |
|---|---|---|---|---|
| $D_{max}$ | 1.01 cm | 1.06 cm | 1.09 cm | 1.19 cm |
| $D_{res}$ | 0.92 cm | 0.98 cm | 1.02 cm | 1.13 cm |

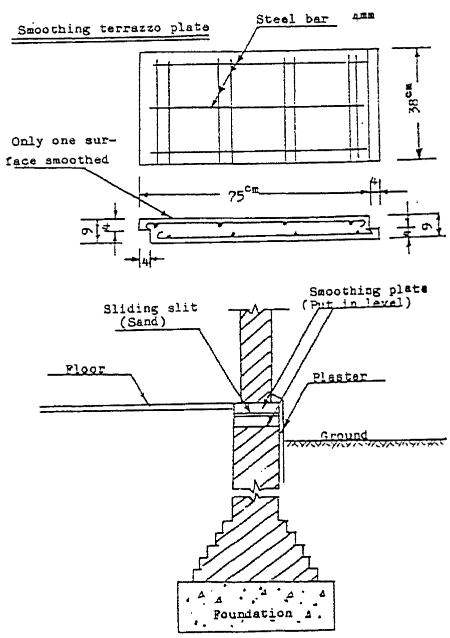
Obviously, with sliding isolation measure taken, responses of the upper part are greatly reduced.

## PROSPECTS

It is not until resent years that extra attention has been paid to base isolation measures in earthquake engineering, but some advantages have been shown. In the past, only "earthquake resistance" has been studied, the more "resist", the larger the inertia force results, i.e. the more stiff the building, the larger the seismic force will be, hence it is neither economic nor reasonable. Apparently, with base isolation measure taken, seismic force may not exceed a certain limit, it is effective, especially for strong earthquake. It is certain that base isolation measure has broard prospects.

Participating in this study are Li Baoxi, Sun Shangcai, Gao Zhi, Liu Dexin, Fu Yuan and I.

Finally, let me express my hearty respect and deep gratitude to my friend Mr. Pong Kezhong who encouraged me many times to work on this topic and appreciate his help on my career.

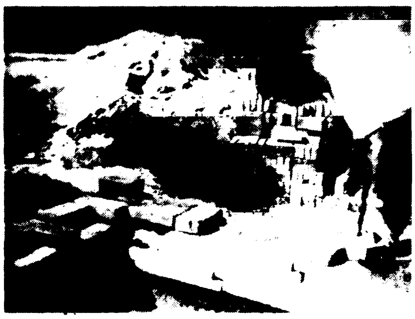



Detail drawing of sliding slit.

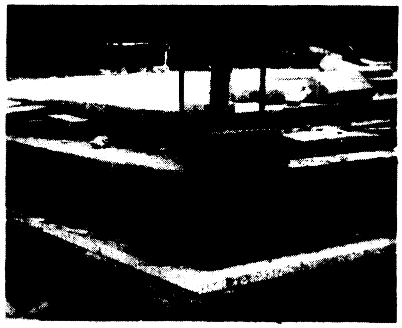
Four-story dormitory building for SEOC.

Weight Bridge house at
Anyang Steel Plant.

Spread sand grains on
the terrazzo plate.

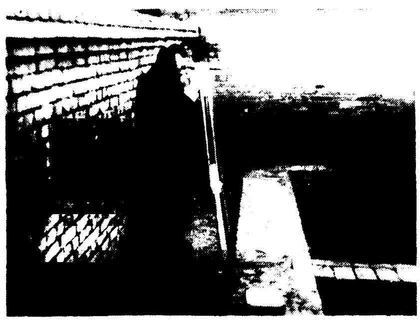


Lay down the brick wall
on terrazzo plate.



Sliding slit details.

Lay down a terrazzo plate.



Leveling the slide surface.