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THE WORK IN PROGRESS CONCERNING ASSISMIC EARTHEN HOUSING IN CHINA

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ABSTRACT

Earthen housing is the main kind construction of residential and public buildings in rural area of south and southwest China. In this paper, the damage to earthen buildings and lessons from recent China's strong earthquakes, the aseismic design requirements, the mechanical characteristics of earthen materials and elements, the testing work on earthen housing are described. It shows that the earthen buildings can be used in seismic region provided the buildings are consistant with the requirements of aseismic design code.

THE WORK IN PROGRESS CONCERNING ASEISMIC EARTHEN HOUSING IN CHINA

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ABSTRACT

Earthen housing is the main kind of construction for residential and public buildings in rural area of the south, the southwest and the northwest China. In this paper, the damage to earthen buildings and lessons from recent China's strong earthquakes, the aseismic design requirements, the mechanical characteristics of earthen materials, as well as the testing work on full scale earthen housing are described. It shows that the earthen buildings can be used in seismic region provided the buildings are consistant with the requirements of aseismic design code.

INTRODUCTION

Earthen housing is widely used for residential and public buildings in rural area of the south, the southwest and the northwest China. It has had thousand years historical record. Most of them are single story buildings. A few earthen buildings, up to four stories, have been constructed in some cities and towns. The earthen walls also used as cladding walls in some industrial factory buildings. The earthen cave dwellings are used in loessic region of the northwest China.

The Yunnan Tonghai Earthquake of January 5, 1970, was one of the remarkable seismic events experienced in rural area of China in recent decades. The main shock had its epicentre near Tonghai county town of Yunnan Province. It had a Richter magnitude of 7.7. The focal depth of this event was about 1 3km. The peak intensity was over grade X according to the Chinese Seismic Intensity Scale which is similar to the Modified Mercalli(MM) scale. The Isoseismal lines of the event are shown in FIG. 1 (1). The intensity in Osan county town was grade IX. There were many earthen buildings in Osan county. However, the buildings that existed there before the earthquake were not designed to resist the vertical and lateral loads produced by strong ground motion. Many earthen walls and buildings damaged or collapsed, but some of them still stood well. The authors inspected survived walls and buildings and get a lot of usefull ideas.

In this paper, the damage to earthen buildings and lessons from Tonghai earthquake, the aseismic design requirements, the mechanical characteristics of earthen materials, as well as the testing work on full scale earthen housing are described. It shows that the earthen buildings can be used in seismic region provided the buildings are consistant with the requirements of aseismic design code.

CLADDING WALLS

The advantages in earthquake resistance were found from survived earthen walls after Tonghai earthquake. The following are some typical examples:

1. The warehouse of productive brigade NO.1 of Osan county town was a two stories timber frame building in Chinese type. In which, both adobe gable wall and longitudinal exterior adobe walls were built in the way tied by wooden ring beams which was not connected with the wooden columns. At the eaves level, the two purlins were purposely arranged so that they were capable to press the top of the adobe wall from both sides (FIG.2). The height of the gable wall attained to 6.5m. Although the gable wall was somewhat convex outward, it didn't collapse in the earthquake.

2. The office building of Osan county town was built as of Chinese type of three bay, two stories wooden frame building with adobe cladding walls. The two purlins were arranged on both sides of the front exterior wall at the eaves level for holding the top of the wall. The two ring beams were placed in the middle part of the walls. The surfaces of walls were plastered with mixture of mud and straw (FIG.3). As the result of wooden columns which were placed on stone footings of 40cm high fell down in the earthquake, the building inclined. Although the wall tilted, it still stood.

3. The house belonging to productive brigade NO.2 of Osan county town was a two stories wooden frame building in Chinese type and with cladding adobe walls. The front wall, held by purlins at its top, was 45cm thick, 5m wide and 4.8m high. A log of 10cm in diameter was installed in the wall at the level of 3.3m high. The wall was plastered with mixture of mud and straw, and stood well after the earthquake.

4. The house owned by productive brigade NO.4 of Osan county town was constructed as of Chinese type of three bay, two stories timber frame building. The gable wall of the building was 46cm thick, 5.2m high, and plastered with mixture of mud and straw and finished

with white lime. A wooden rod of 13 x 10cm cross section was placed in the middle part of the gable wall and was tied with wooden column (FIG.4).

5. In a two stories timber frame office building, the wooden ring beam was placed underneath the windows of the second story. Although the gable wall of the building collapsed, the longitudinal exterior walls still stood.

6. The warehouse of productive brigade NO.4 of Osan county town was a Chinese type, single story timber frame building with adobe cladding walls. The eaves level was 2.45m high. The top of the surrounding walls had been held by purlins. The walls were plastered with mixture of mud and straw. There were two longitudinal tie rods to connect the columns, and through them the building was tied together to respond as a unit. The front exterior wall had two gates and three small windows. The dimension of each gate and window was about 200cm by 210cm and 110cm by 80cm respectively. The rear exterior longitudinal wall had only three small windows. After Tonghai earthquake, it was found that except there appeared spalling on the gable walls, all others sustained well.

7. It has been found that the meeting hall of productive brigade NO.1 of Osan county town was intact. This building was built as of two stories Chinese type timber frame, which had survived in the strong earthquake occured 57 years ago. The adobe cladding walls plastered with mixture of mud and straw were used for the first story, and being thin at its top but thicker at its lower part (FIG.5). The walls of the second story were made of board.

8. The house of a commune member of productive brigade NO.1 of Osan county town was a single story frame building with earthen flat roof and with infilled adobe walls (FIG.6). After the earthquake, this house including adobe walls was found still in good condition.

The another house, a three-bay Chinese type of wooden frame building, is located in Xiaojie village of Xiaojie commune. There were four frames in total. After earthquake, it was found that three of them inclined, while one infilled adobe wall as a gable sustained during the earthquake and had remained in proper position just since there was a infilled adobe wall in the frame. The house as a whole didn't collapse, because of the fact that the uninclining frame tied the other frames.

9. A rammed fencing wall of a height by 2m locating in Xiaojie village of Xiaojie commune had strengthened with bamboo reinforcement at corners of the wall. Minor cracking was taken place at corners during the earthquake, but the wall didn't collapse.

10. In a warehouse of Osan county town, a adobe fencing wall of 30cm thick, 2.4m high and 20m long had been plastered both sides by mud with straw, and finished by lime-white mixture, and had both side 10cm thick ribs of 4m spacing. This fencing wall still stood after earthquake except there occurred horizontal bent cracks at lower part of the wall.

From above examples, it follows that:

1. Following measures are recommended to be taken to prevent collapse of non-load-bearing adobe walls in seismic zones:

— Installing timber ring beam tied to the columns with wooden connecting rods.

— Utilizing purlins at the eaves level to hold the top of the adobe wall.

— Designing the wall with varied cross section, upper thin and lower thick.

— Adding ribs or buttresses to adobe walls.

— Plastering wall surfaces by mud with straw.

— Placing the reinforcing materials, such as bamboo strips, chaste twigs, or straw at the intersections of the adobe wall to tie them together.

— Decrease dimension of apertures (e.g. gates and windows).

2. The adobe wall infilled within a timber frame can increase the lateral earthquake resistant capacity of the frame and prevent collapse of the house.

3. The adobe walls can be used in earthquake-prone areas provided necessary aseismic measures are taken.

SINGLE STORY BUILDINGS

For the single story earthen housing, the walls generally are the rammed earthen walls or the walls laid with adobes. The thickness of the walls is 30cm to 50cm, and the height of eaves is about 3m. The purlins are directly supported on the earthen wall. The roof may be covered by mud, tiles or straw. This kind of building is schematically illustrated in FIG. 7.

The recent China's destructive earthquake had shown that the performance of earthen housing which is not specially designed by the aseismic design code can be summarized as below in the earthquake.

— In the area where seismic intensity is VII, the light damage was found. The small cracks were taken place on the intersections of the walls and the corners of the windows and doors only. The buildings are not need to repair and still could be used.

— In the area where seismic intensity is VIII, the damage was moderate or severe. Some exterior walls were tilted to outside. Some walls were cracked or collapsed.

— In the area where seismic intensity is IX, most of the earthen buildings were severely damaged or collapsed.

The survived earthen buildings still can be found in the area where seismic intensity is grade VII to IX. The following are some typical examples:

1. The house of Osan Hotel was built as a single storey building with load-bearing adobe walls. The walls being supported by rubble footing with its top at level 30cm above the ground. The height of the eaves was about 2.9m, the thickness of walls 30cm, the width of the building in plan 4.8m and the length of each bay 3.8m. A timber ring beam was installed at the level above the window and four logs were inserted into two adjacent gable walls at the ceiling level. It was found after the earthquake that the wall cracked but both the walls and the roof didn't fall down Those beside it, however, a multi-storey building of timber structure with triangular roof trusses and columns partially collapsed, and another multi-storey building with timber roof trusses, brick columns and adobe infill walls was severely damaged.

2. A dormitory house locating in Osan County town which was built as a single storey and single bay earthen house of 4m by 3.3m in plan and height of the eaves 2.9m, was found after the earthquake that there were cracks on the earthen walls, but the house didn't collapse. Beside this house, the partition walls of a single storey building of brick timber structure severely damaged with cracks as wide as 8cm.

3. A factory building was constructed with load-bearing earthen walls, 49 x 49cm load-bearing brick columns and trianglar timber roof trusses. Dimensions of the building: 8m in span, 4m in each bay, 40m in total length, 3.5m as the height of the eaves, 20cm as the height of the stone footing above the ground, and 33cm as the thickness of earthen walls. The earthen walls were plastered with mud and straw. It was found after the earthquake that earthen walls sligntly cracked and only the adobe walls underneath the wooden cantilever of eaves had spalled.

4. An office building near the above-mentioned factory was built in 1967 with 6m by 76m in plan and 4m in each bay. This building was constructed with some load-bearing earthen walls 50cm thick, longitudinal walls with 55cm in thickness, wooden roof trusses supported by brick columns, wooden purlins supported by the wooden block placed on earthen walls and with a lightened ceiling. Although it was found after the earthquake that some corner columns displaced slightly, while the earthen walls had small cracks and had spalling underneath the wooden cantilever of the eaves, this building is capable of to be used.

5. Eleven single storey buildings, each having 4—12 bays and with 33 bays in total, were constructed of load-bearing earthen walls, timber triangular roof trusses and brick columns. The buildings were with 2.8m as the height of the eaves, 4m as the bay and 7m as their width. Only two bays collapsed during the earthquake, while some of these buildings are still being employed at present.

6. The tobacco baking tube structure of a commune was so constructed that it was with 7.65m as the height of the eaves, 5.2x5.8m in plan and 65cm as the thickness of the earthen walls, purlins at the eaves held the top of the earthen wall, within the wall there were two ring beams made of rectangular timber of 10 x 15cm and there was a floor at the height of 2.2m. Some logs for tobacco baking use which were horizontally inserted into the walls had been all cut off before the earthquake. This building was found almost in good codition after this earthquake, except that some adobes over the doors came down.

From the above six examples, it follows that the single story buildings with load-bearing earthen walls have a good performance in strong earthquake. It is recognized that those buildings survived just since they had the following advantages:

— Relisbility of foundations.

— Adequate protective measures to the earthen wall, such as higher stone footing, proper sewage canal and plastering with a mixture of mud and straw.

— Ring beam installed in the wall.

— Wall top held by purlins at the eaves level.

— Logs inserted into the two adjacent load-bearing gable walls tieing the walls together.

— Smaller aperture (e.g. door and window).

— More transversal walls.

— Good quality of the wall construction.

TWO-STORY BUILDINGS

There were few two-story buildings with load-bearing earthen walls in the 1970 Tonghai earthquake effected area, damages to four buildings of them were following(2):

1. The Dormitory House of the Highway Station of Tonghai County was built in 1967. Where the seismic intensity was evaluated as a grade of VII. This building was built with its plan as 36x10.8m, the height of the first and the second story as 2.8m and 2.5m respectively, and the thickness of the walls as 30-40cm. At the level of the top of the windows of the first story, a reinforced brick ring beam has been installed and at the level underneath the windows of the second story, a timber ring beam has been installed. The purlins had timber blocks underneath them, and the roof had outstanding eaves at four sides. The house had rubble foundations with a depth of 70-100cm under the ground surface and had the footings with a height of 50cm. The building was slightly damaged after the earthquake, horizontal cracks occurred on the walls, the vertical cracks at the intersections of the exterior and the transverse walls of the second story was about 3mm and roof tiles slided somewhat downwards.

2. The Office Building of the People's Hospital of Tonghai County was built in 1967. There the seismic intensity was evaluated as a grade of VII. This building was built with its plan as 3[illegible].5x11.0m, the height of the first and the second story as 3m and 2.8m respectively, and the thickness of the walls as 40cm. The reinforced brick ring beam was installed at the top of windows of the exterior walls, and the roof had outstanding eaves at four sides. The foundations were made of rubble and buried 60cm under the ground surface, and the footing was built as 40cm high. It was found after the earthquake that the house was slightly damaged (e.g. small cracks on walls and sliding of roof tiles).

3. The Office Building of Epidemic Prevention Station of Tonghai County was constructed in 1968. Where the seismic intensity was evaluated as a grade of VII. This building was built with its plan as 25.9 x 11 m, the hight of the first and the second story as 3m and 2.8m respectively, and the thickness of the adobe walls as 40cm. Reinforced brick ring beams were installed above and underneath window aperture of both stories, and eaves at four sides of the roof was built with overhanging. The foundation was made of rubble buried 60cm under the ground surface and the footing was built as 45cm high. The house was damaged slightly in the earthquake, cracks occurred on the walls, the width of some cracks attained to 5cm.

4. The Building of Tax Office of Tonghai County was built in 1968 with its plan as 10.5 x 7m, the thickness of the walls as 40cm. The foundations on soft soil was made of rubble. The reinforced brick ring beams were installed above windows of the exterior walls of both stories. This building locating in the area of IX grade seismic intensity was collapsed during the earthquake.

The floor structures of the second floor of all above mentioned four buildings were built of timber. It was found that some aseismic measures, such as profitable construction site, harder subsoil, adequate foundation, higher footings, regular configuration in plan and in elevation, installing ring beams and installing tie logs both at the eaves level and underneath the floor beams etc. had been considered only when in the three buildings locating in the area of VII grade seismic intensity.

As what has been from above illustrations it is concluded that one stories buildings with load-bearing adobe walls might be permitted to be constructed in the areas of VII grade seismic intensity.

MECHANICAL PROPERTIES OF LIME-EARTH

Lime-earth is a mixture of slaked lime and earth. Slaked lime is produced by slaking quicklime in water two days before to be use. Green lime blocks, earthen blocks and miscellaneous materials should be silted out from the lime and earth. The volume ratio of lime to earth is uselly in the range of 1:1 to 1:6, and the lime content approximately equals to 6-25%. According to experimental data, the mechanical properties of lime-earth can be summarized as below (3):

Compressive Strength

1. The compressive strength of lime-earth increases with the plastic index (FIG.3).

2. The compressive strength of lime-earth increases with lime-earth ratio within a certain extent. The optimum lime-earth ratio is approximately 10 to 15 percent for the weight and is inversely proportional to the plastic index.

3. The compressive strength of lime-earth increases with its age. The compressive strength of the lime-earth less than one day old, is the same as that of pure earth. It will be increased over 250% when the lime-earth is 28 days old. Some testing reports show that the compressive strength of lime-earth is increased from 15kg/cm^2 at the age of 1 0 days to 65kg/cm^2 at the age of 10 years.

4. The compressive strength of lime-earth increases with its

density. For example, for the lime-earth with volume ratio of 3:4, the compressive strength can be raised [illegible] at the age of 10 days if rammed once more.

7. The homogeneous degree for mixture of lime and earth has significant effect on the compressive strength. For some lime-earth, it still remained about 2kg/cm^2 at the age of 21 years due to non-homogeneity.

<u>Shear Strength</u>

1. The shear strength raises with increase of lime content, but there is a limit of lime content, beyound which, it will decrease somewhat. The optimum lime-earth volume ratio which gives the maximum shear strength is 1:3 or 1:4 when earth is made of sand clay and 1:2 when earth is made of sand with clay particles.

2. The shear strength increases with the plastic index. For example, for the lime-earth with volume ratio of 1:4, the shear strength is 1.44kg/cm^2 and 1.6kg/cm^2, if the plastic index is 7.9 and 14.9 respectively.

3. The shear strength increases with the age, but the internal fraction angle varies slightly.

4. Higher the density of the lime-earth, higher the shear strength.

<u>Bending Strength</u>

1. The bending strength of the lime-earth is about one third of the compressive strength. For the lime-earth made of clay, it is little higher than that made of sand.

2. The bending strength of the lime-earth is raises with increase of the age. The rate of increase is the same with that of the compressive strength.

Modulus of Deformation

For the lime-earth mixture with a volume ratio of 3:7 when earth is made of sand clay (dry unit weight 1.55g/cm^3) or clay (dry unit weight 1.45g/cm^3), the modulus of deformation of the mixture is 100-150kg/cm^2 after 7 days curing and 48 hours soaking and 320-400 kg/cm^2 after 28 days curing and 48 hours soaking.

FIELD TESTING OF FULL SCALE EARTHEN HOUSE

In autumn 1970, Institute of Engineering Mechanics (IEM) of Chinese Academy of Science conducted a field explosive earthquake simulating experiment of a full scale earthen house in Tonghai county, Yunnan province. FIG.9 shows the plan and the sectional drawing of the testing house.

The tested house had two rooms, the adobe walls were laid with local technique (the adobes were laid vertically) for one room, and with improved technique (the adobes were laid horizontally) for another. Vertical joints in the wall were filled with mud mortar. A layer of straw was placed in the walls every two courses.

The tested house had rubble foundations with 60cm below ground surface and a mud roof to simulate the tiles. The walls were plastered with mud and white-lime. The house had fundamental natural periods of 0.1 - 0.2 sec in different directions as actually measured.

The underground multi-hole explosion at a deepth of 5-7m was used as the vibration sources in the test. They conducted the test three times with total filling explosives 46.5kg, 228kg and 630kg for each time. The explosive sources had distances of 20 - 30m from the house.

First, the house was tested in single hole explosion, the induced maximum ground velocity was nearly of 7.6cm/sec, and the house was intact.

Second, the house was tested in four successive explosions of seven holes with explosive filling. The induced maximum ground velocity was about 20cm/sec. After explosion, the cracks with width of 0.5cm on the walls laid by local technique were found, but they couldn't find any apparent crack in the walls laid by improved technique, mud layers on the roof slided, and cracks occurred on the roof ridge.

Third, the house was tested in simultaneous explosion of three holes with explosive filling, the induced maximum ground velocity was about 78cm/sec. Most of the walls collapsed, and the roof fell down.

The above tests show that the earthen house had a certain capacity of earthquake resistance and the improved technique for laying adobe is better than the local one.

It should be noted that the ground motion excited by explosion was significantly different with that of natural earthquake, and it can be characterized as more content of high frequency waves, rapid decay of the amplitudes, higher amplitude of ground accelerations and the shorter duration. These remained problems shoud be study in detail in the furture.

LESSONS FROM EARTHQUAKES

According to the reports of recent Chinese destructive earthquakes, the damage to earthen buildings and aseismic constructive measures can be summarized as following:

Subsoil

1. Where the subsoil is soft or the subsoil in the bearing layer associate with a soft and hard distribution, such as sections with abandaned and filled river bed and fracture belt of fault, hidden swamp, creek, gully and pit as well as partially cutting and filling subsoil, and where the distribution of the walls is severely unsymmetrical, the non-uniform settlement is easily taken

place, and can be led to cracks or collapse of the walls (FIG.10). Therefore, in order to prevent the nonuniform settlement, we have to pay more attention to the site selection and the arrangement of the walls.

<u>Wall</u>

2. Owing to the ravages of rain and wind, the thickness of the footing of a wall may be gradully dereased, and the wall is vulnerable to collapse in earthquake. Therefore, for safty, the wall should be plastered by mud with straw, and the house should be surrounded by sewage escape canal.

3. In earthquake, gables are very dangerous when they are made of adobe. For improving the aseismic capacity of a wall, the following measares can be used:

—— Elongating purlins supported by a gable towards outside in certain length, i.e. using outstanding eaves (FIG.11).
—— Putting bearing beams underneath the purlins. The beams are tied with rod and anchored with bolts. (FIG.12).
—— Setting wall ties in a gable wall (FIG.13).

4. In earthen buildings with brick columns in corners and intersections of walls (FIG.14), during earthquake, the brick column can be separated with attached earthen wall, and led it to collapse. Therefore, this structural solution is not recommended.

5. For earthen wall with brick in exterior surface, the bricks are vulnerable to fall, and led to collapse of the wall in the earthquake. Therefore, in earthquake-prone area, the wall with brick in its exterior surface is not recommended.

6. Owing to lack of the ties in intersections of earthen walls, during the earthquake, the vertical cracks were taken place in intersections, and in some cases, the walls were collapsed due to tilt of them. Therefore, at intersections of walls, bamboo ribs, straw, wooden battens and chaste twigs should be placed for

strengthening (FIG.15). The wooden ring beams should be installed in the walls for better integrity.

7. The clay with little impurity should be selected for making an earthen wall. Mud should be mingle with wheat straw, sorghum stalks or rice straw to strengthen an adobe or an earthen wall.

8. Inserting 3-5 logs into two adjacent transverse lod-bearing walls at the ceiling level, the two walls will be tied together. These logs can be used as suport beams for the ceiling and attic (FIG.16).

9. The earthen walls, which were rammed layer by layer using mud with wheat straw, had good performance in 1966 Xingtai earthquake. This kind of wall have an advantage in prevent the ravages of rain and flood.

10. It is a good solution to hold the top of the wall by purlins at the eaves level.

11. A wall, which is very long and has no transverse walls connected with it, is vulneable to collapse in earthquake. In such case, the pilasters, buttresses or ribs may be added to the wall for increasing its stability (FIG.17).

12. For a house, in which the roof is the one with two sides and the purlins are directly supported by earthen gable walls, the upper trianglar part of gables may collapsed during an earthquake. In such case, adding buttresses laid on longitudinal wall to triangular part of gables was recommended (FIG.18).

Eaves

13. The cantilever for eaves of a earthen house may be displaced and led to cracks or collapse of the wall. Elongating the rafter instead of the cantilever to make eaves can be avert this kind of damages (FIG.19).

Purlin

14. Vertical cracks may occur on the wall underneath the purlin due to stress concentration in the earthquake, if the purlin is placed directly on the top of the wall (FIG.20a).This damage can be avoided by inserting a bearing block under the purlin (FIG.20b).

15. If there is no mutual connection between purlins and no connection between the wall and purlins, some purlins could be drawn out from the wall, consequently, the wall would collapse and the roof would fall down. Therefore, the purlins should be connected among themselves and be connected with the wall (FIG.21).

Roof

16. An earthen house having a heavy mud roof is liable to collapse in the earthquake since the increased lateral force from the heavy roof. Such heavy mud roof, whose thickness may attained to 40cm, is usually formed in water-proof repairing by adding more mud to the roof from year to year. Therefore, the old mud should be taken off in repairing.

17. The best roof for an earthquake-prone area is the one with four inclined sides because it distributes its weight better and eliminates the neccessity to use gable walls(FIG.22).

ASEISMIC DESIGN REGULATIONS

Aseismic design requirements for buildings with lime-earthen load-bearing walls are specified in Section 7, Chapter 4 Aseismic constructive requirements, of the Aseismic Design Code for Industrial and Civil Buildings (TJ 11-78). The full text of this section reads as follows (4):

Section 7 Buildings With Lime-Earth Load Bearing Walls

Article 91

For buildings with lime-earth load bearing walls, the settlements of walls should be as even as possible. Generally, transverse walls shall be installed in each bay and brick columns for open corridors should not be used. Staggered floors and abrupt change of the elevation of building should be avoided, and the number of stories must be the same in a building.

Note: The lime-earth wall generally indicates the rammed earth (mixed with lime) wall and the wall laid with lime-earth adobes.

Article 92

Where design intensity is 7, the height of the building shall not greater than 6m. The lime-earth load bearing wall is not recommended for design intensities of 8 and 9.

Article 93

Different materials for masonry walls should not be used for a building.

The compressive strength of lime-earth walls shall not be less than 15 kg/cm^2. The dry unit weight should not be less than 1.6 ton/m^3. The adobes should be laid with lime mortar.

Article 94

The layers of interior and the exterior walls shall be rammed alternatively and adobes of walls shall be laid with racking.

At quoins of exterior walls and intersections of exterior and interior walls, reinforcing materials, such as bamboo ribs, wooden battens and chaste twigs, should be placed at every 30cm spacing along the height with both ends extending into the wall not less than 1m.

The minimum thickness of the wall is 25cm.

Article 95

A stepped buttress should be built on the top surface of inner longitudinal walls on both sides of the exterior and interior gables. The purlins should be supported by blockwood.

Article 96

The ring beams shall be placed on longitudinal exterior walls and all transverse walls at each floor. The depths of ring beams are:

For reinforced concrete ring beam	8-12cm
For reinforced brick masonry ring beam	4-5 courses
For wooden ring beam	6-10cm

ACKNOWLEDGEMENT

The authors express apreciation to Prof. Zhang, Qiubo for his assistance, and also to Mrs. Zhu, Zaiwang for typewriting.

REFERENCES

1. IEM, "Seismic Intensity Distribution and Site Effect of Tonghai Earthquake", Research Reports on Earthquake Engineering of IEM, Vol.III, (1980).

2. IEM, "Inspection and Testing Research Work for Buildings with Load-Bearing Earthen Walls in Tonghai County", Research Reports on Earthcuake Engineering of IEM, Vol.III, (1980).

3. Yung, Hai, "Properties of Lime-Earth and its Aplication", Spread of Construction Scientific Knowledge, NO.3, (1980).

4. Aseismic Design Code for Industrial and Civil Buildings(TJ 11-78), Beijing, (1979).

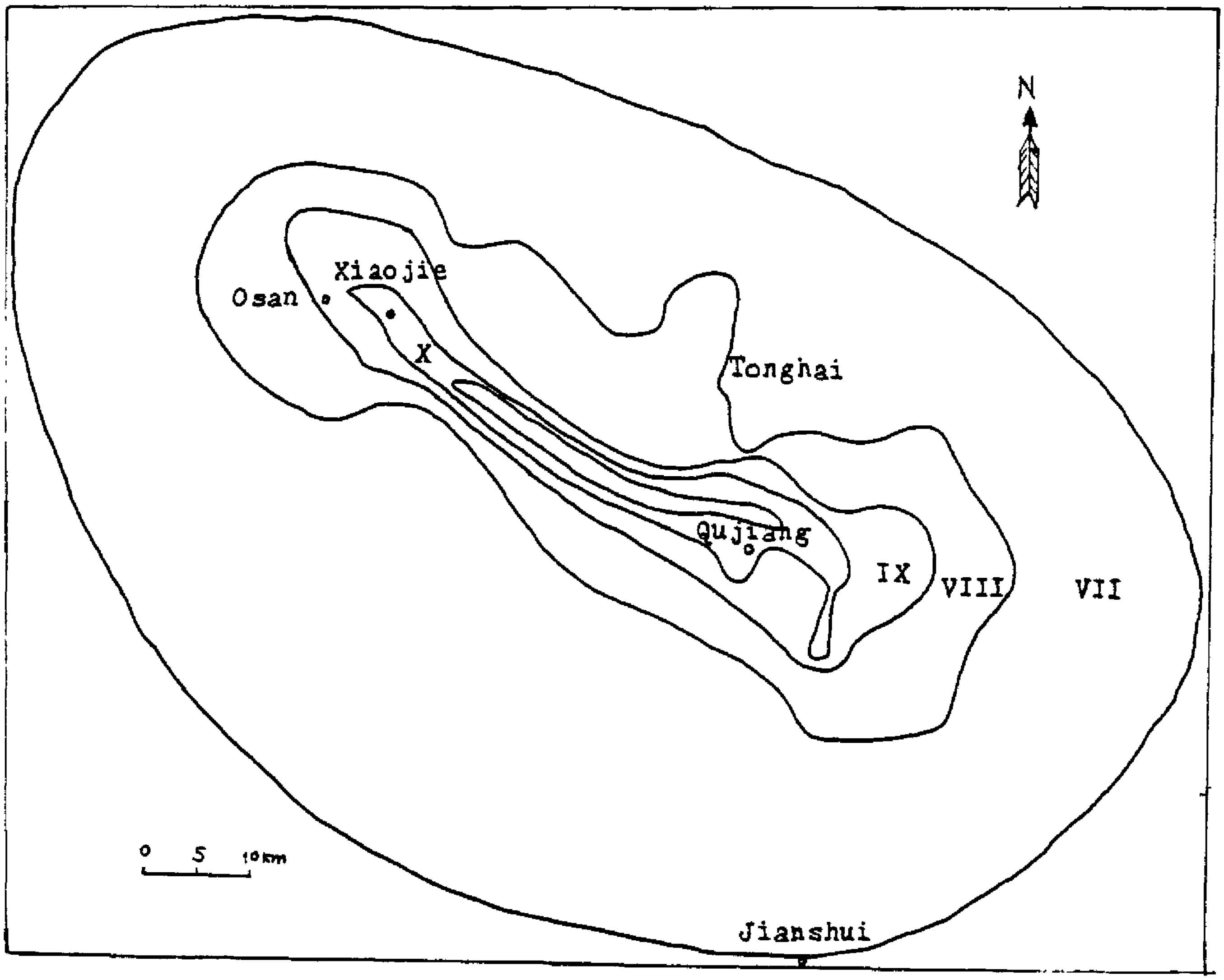
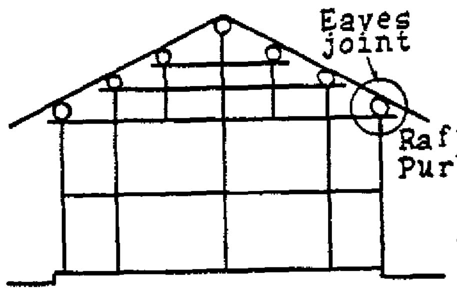
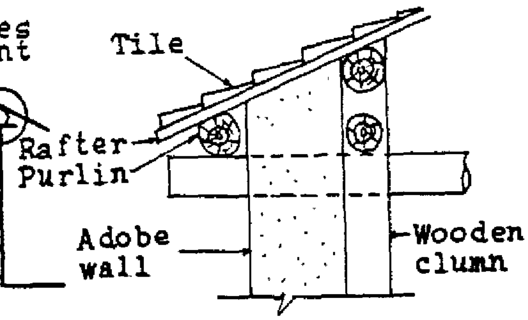


FIG.1 Intensity map of 1970 Tonghai Earthquake



Sectional elevation of wooden frame in Chinese type



Eaves joint

FIG.2 Utilizing two purlins to press the top of the adobe wall from both sides

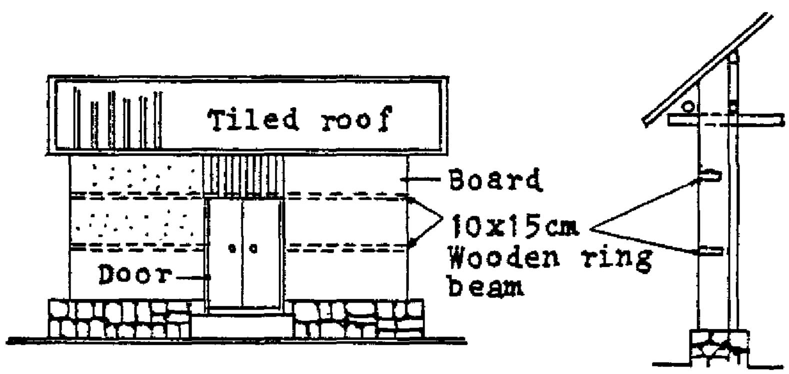


FIG.3 Earthen wall with ring beams

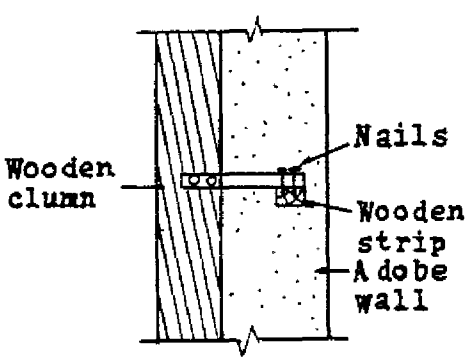


FIG.4 Wooden rod in the wall and its conection

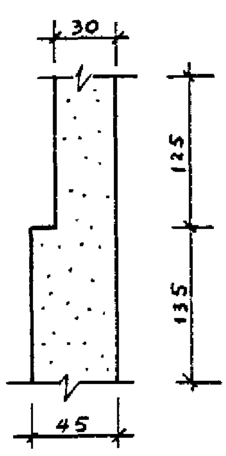
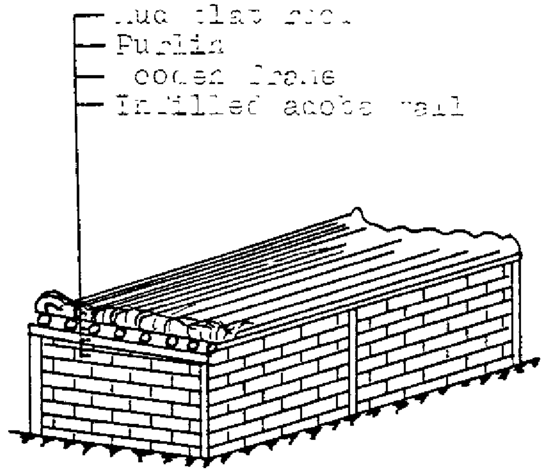


FIG.5 Earthen wall with varies cross section

FIG.6 Single storey frame building with earthen flat roof and with infilled adobe walls



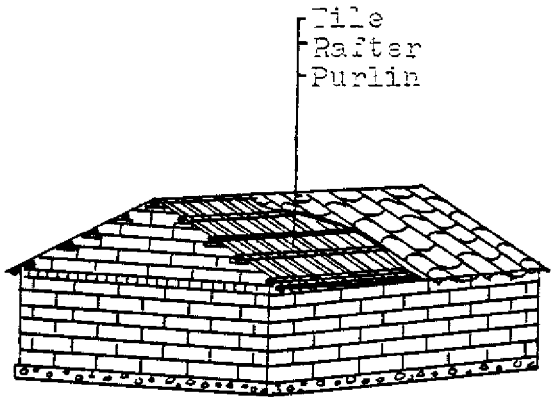


FIG.7 Single storey building with load-bearing earthen walls

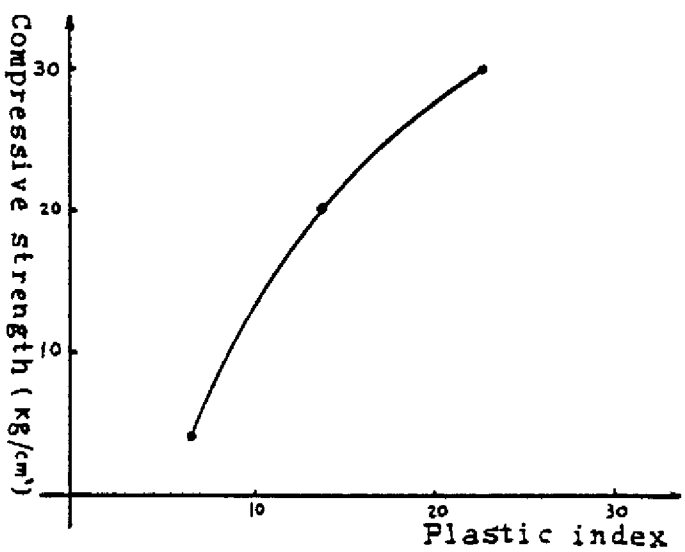


FIG.8 Compressive strength vs. plastic index

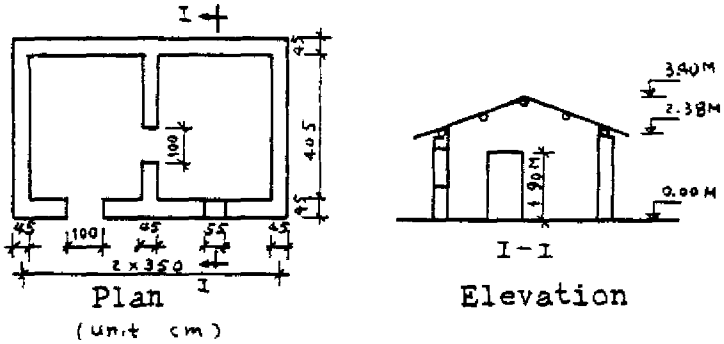
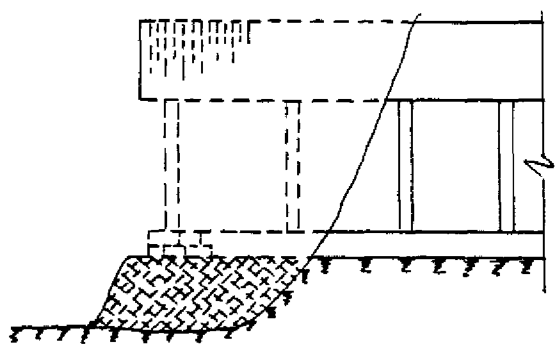
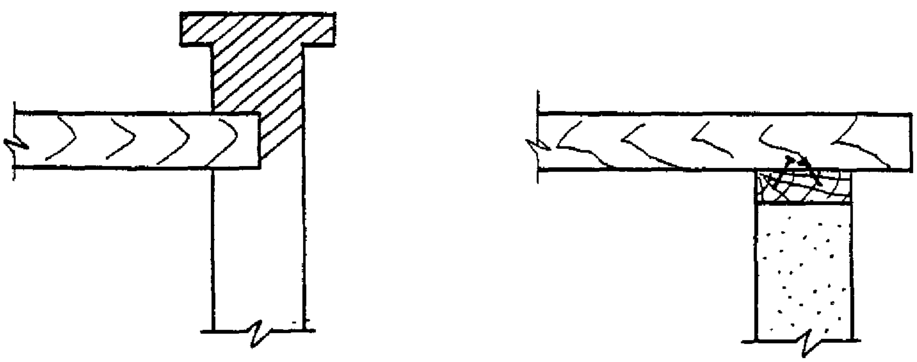


FIG.9 Full scale tested house

FIG.10 Building built on partially cutting & filling subsoil, the part with dashed lines shows it may be collapsed in an earthquake



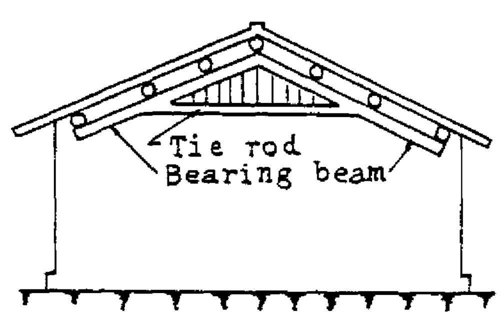


a. Without outstanding eaves, shaded part may be came down in an earthquake

b. Outstanding eaves by elongating a purlin outwards

FIG.11 Eaves

FIG.12 Bearing beams and tie rod within the gable wall



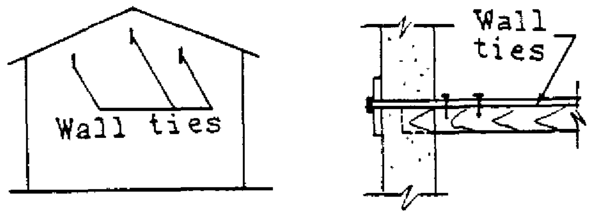


FIG.13 Wall ties

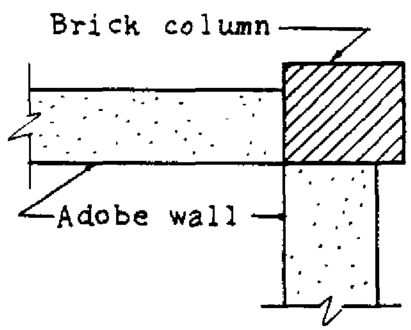


FIG.14 Earthen wall with brick column

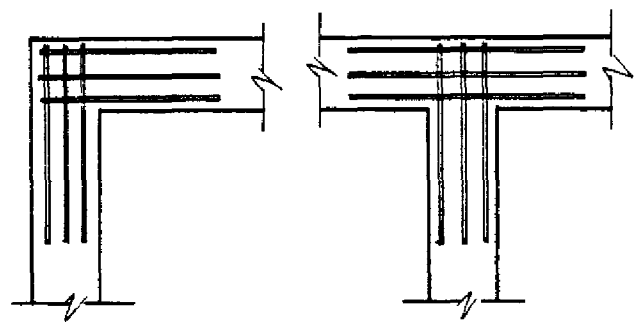


FIG.15 Reinforcing materials in the intersections of walls

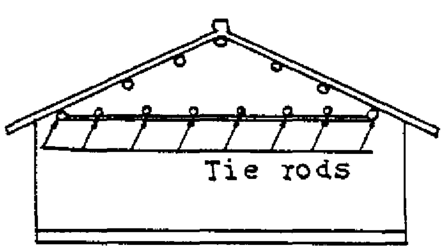


FIG. 16 Tie rods between load-bearing walls

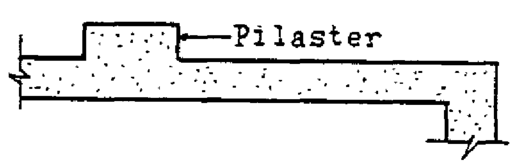


FIG.17 Pilaster

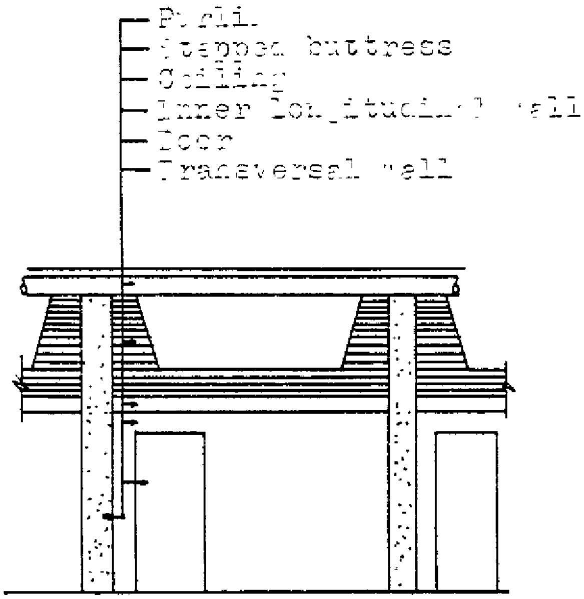


FIG.18 Stepped buttresses built on the top surface of inner longitudinal walls at both sides of the exterior and interior gable walls

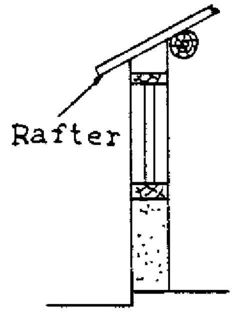


FIG.19 Outstanding eaves by elongating a rafter outwards

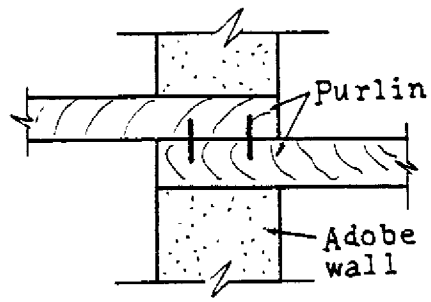
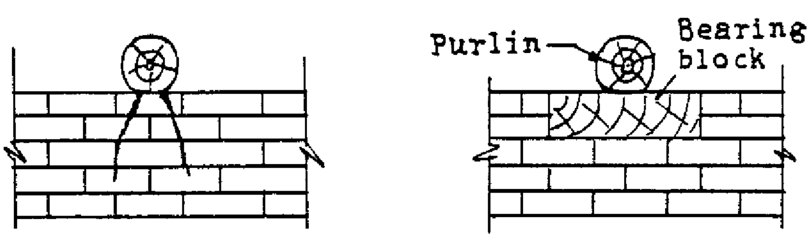


FIG.20 Connection of purlins on the wall



a. Without bearing block b. With bearing block

FIG.21 Purlins suported on walls

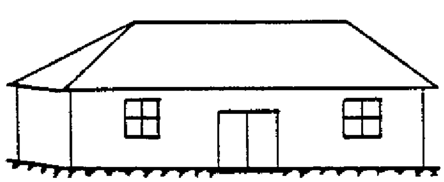


FIG.22 Building with four sides inclined roof