REPORT ON THE 1951 EARTHQUAKE IN TAIWAN

By

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I Description of The Earthquake

The island Taiwan lies right on a main seismic belt in the Pacific Ocean where earthquakes are frequent and oftentimes with disastrous results. According to the records of Taiwan Weather Bureau, there are probably one destructive, 327 felt and 1080 unfelt earthquakes per year in average. In other words, in Taiwan district and its surrounding sea bottom area there are one felt and three unfelt earthquakes daily in average.

Based on the statistics Hwalien city had a monthly max. of 498 felt earthquakes in June 1925. Taitung rated next with 86 earthquakes in September, 1919. Daily max. in the record of earthquakes reached 149 in number at Hwalien on June 14, 1925.

A comparison has been made among the record of earthquakes occurred at different districts in the Island Taiwan. It shows that Hwalien stands 37% the highest; the northern part takes the next, stands 23% and Hengchun stands 2% the least in frequency.

Since the establishment of a network for seismological observations throughout this Island, 65 destructive earthquakes had been recorded since 1900. In view of seismic intensity and damages, there were 6 most disastrous earthquakes in record. The latest one happened a Hwalien, on the eastern part of this Island in 1951. The main shock occurred on October 22nd at 5:34 a.m. and a series of after-shocks continued until the end of the year, 1951.

This report will be confined to the study of the important occurrences during this great earthquake. During the period of this earthquake in latter part of the year 1951, we found some important records at 4 stations (see Map attached):

1) Earthquake at Chengkung town, Taitung, occurred on Oct. 22nd, at 5:34 a.m.

2) Earthquake in Hwalien city, occurred on Oct. 22nd, at 11:30, a.m.

3) Earthquake in Taitung Longitudinal Valley, occurred on Nov. 25th, at 2:47, a.m.

4) Earthquake at Taitung, occurred on Dec. 5th, at 2:58, p.m.

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The important features of the above-mentioned 4 earthquakes will be briefed separately in following:

1) Earthquake at Chengkung town.

The extension of sensitivity of earthquake was the greatest one. As far as 600 km. away from the epicenter such as Hongkong and Kowloon there was remarkable felt earthquake recorded. After this occurrence, there was a series of after-shocks of which some were even strong ones.

Based on the destructive force to the structures and the changes of land surface, the intensity in the central region of the earthquake is estimated as grade 6, according to the scales 0 to VI adopted in Taiwan, the epicenter of earthquake was located in the region of Chengkung town or Hsinkong and its vicinity. The intensities are reported as the following:

Chengkung town:	Grade 6 (disastrous)
Hwalien & Taitung:	Grade 5 (very strong)
Suao, Taipei, Hsinchu, Taichung & Chiayi:	Grade 4 (strong)
Most of other parts of this Island:	Grade 3 (rather strong)

Consequently the degree of damages on the super-structures in Chengkung town was the worst, most of highways and bridges, even the reinforced concrete structures were destroyed, other districts such as Hwalien, Taitung as far as Tainan also suffered some damages. From the extension of the sensitivity of earthquake, it seemed that the depth of focus (Hopocenter) of this earthquake was deeper than that of the other great earthquakes occurred on this Island. According to the information from Taiwan Weather Bureau the depth was 10 km.

The after-shock of the earthquake at Chengkung town commenced from 5:49 a.m. on Oct. 22nd and was followed by another disastrous earthquake at Hwalien at 11:30 a.m. on the same day, within a period of 6 hours. There had been 42 after-shocks, of which 5 were confined to a small district, one quite remarkable and the others local in nature.

2) Earthquake at Hwalien.

As mentioned above six hours after the earthquake at Chengkung town in the early morning another major earthquake followed at Hwalien round noon. It was so strong as to have caused the greatest destruction in recent 50 years. Due to the short interval between the shocks, the Hwalien earthquake may be considered either as the strong after-shock or felt earthquake from that at Chengkung town. The epicenter of this earthquake was located ENE 30 km. to the east of Hwalien; depth of focus was 20 km. The sensitivity of earthquake over this Island was as following:

Disastrous earthquake at Hwalien;
strong earthquake at Taitung, Ilan & Sun-moon Lake,

Rather strong earthquake in Taipei, Taitung & Hsinchu;
Moderate earthquake at Hengchun;
Slight earthquake at Kaohsiung.

The vertical movement of Hwalien earthquake at its initial period on ground surface was very remarkable and strong horizontal movement later continued; most structures overturned during the trembles of horizontal movement which was mainly in a direction of NE - SW. Many buildings were overturned along this direction. At the movement of maximum shock, man finding difficulty to walk on the street had the feeling of being in a boat rocking on a rough sea. Meanwhile, certain earthquake sound was heard by many people but its source and direction could not be ascertained. Duration of the shock was about 4 minutes.

Fault, fissures and subsidences or sink holes brought about topographical changes on land surface after the earthquake at Hwalien. Fault discovered in the northeastern part of Hwalien city was seven kilo-meters in length; strike of the fault was N40-70E; max. displacement was 2 meters horizontally and one meter vertically. Zone of earthquake fissure occurred in the downtown of Hwalien city and the western side of Milun-shan, which is situated in the northeast of the city. The position of this zone appeared to be situated at the southern end on the extension of earthquake fault. Openings of these fissures were measured at about 10-20 cm., strike in a northwest direction. Subsidences were found both at the southern end of airfield and on the dike along the southern sea beach. The depth of the subsidences at both places was measured 50 cm and 100 cm respectively.

In general, most damages caused by this earthquake were in the downtown of the city. The monetary loss was estimated to be over US$ 2,000,000. Casualties and destroyed buildings are as follows:

Casualties		Buildings destroyed	
Dead	Wounded	Completely destroyed	Partially destroyed
45	120	522	1,004

After the earthquakes at Chengkung town and Hwalien city, after-shocks followed continuously in East Taiwan till the end of 1951. 91 after-shocks were recorded on the day of the Hwalien city earthquake, 48 on the next day and 42 on the third day. From Oct. 25th to the end of Oct., there were 145 after-shocks.

3) Earthquake at Taitung Longitudinal Valley

One month after the earthquake at Hwalien, i.e. in November 1951, after-shock was still active. A number of 196 felt after-shocks was recorded till Nov. 24 th, 1951. On Nov. 25th, 1951, at 2:47 a.m. another destructive earthquake broke out and set a record of the third destructive earthquake after the shock at Chengkung town. The epicenter was located at 20 kms SE of Peinanshan of East Taiwan. Depth of focus was 5 km. The region of strongest sensitivity of the earthquake was at the middle section of Taitung Longitudinal Valley. The intensity was of grade 6. Deformation of land surface in this earthquake was reported extensively. The intensity at Taitung, Hwalien, Suao, Tainan and Kaohsiung was all of grade 5, but most districts in West Taiwan were reported with a shock of grade 4.

The widespread land surface deformation and magnitude of extension were the main features of the earthquake at Taitung Longitudinal Valley. This earthquake is considered to be the greatest in East Taiwan during the last 50 years, also surpassing the intensities of the greatest earthquake in West Taiwan.

The direction of earthquake fault was parallel with the Longitudinal Valley. Phenomena of subsidences, fissures, sand craters, change of ground water, blowing out of natural gas were found during the time of the earthquake. Other phenomena such as earthquake sound, luminous light flash were also reported in the region of Taitung Longitudinal Valley.

The direction of the movement was most remarkable in a S-N direction and matched with the general direction of the overturned buildings. The intensity of this earthquake in Taitung Longitudinal Valley was of grade 6 and even stronger than that of Hwalien city as mentioned above. Due to the fact that the population in this valley is not so dense, the damage suffered was not too serious. The damages are listed in the following table.

Casualties		Buildings destroyed	
Dead	Wounded	Completely destroyed	Partially destroyed
13	126	399	1.669

The number of after-shocks of this earthquake was 40 during the first day, 6 on the next and third day respectively. From Nov. 26th to Nov. 30th, 1951, there were 23 after-shocks.

4) Earthquake at Taitung

One month after the earthquake at Taitung Longitudinal Valley, i.e. in December 1951, many after-shocks again happened in East Taiwan. The sensitivity of earthquake was remarkable in all region of East Taiwan. A total of 105 felt after-shocks was recorded. The strongest one with a grade 5 intensity took place on Dec. 5th, at 5:58 p.m. Center of focus was located at sea bottom 20km. ENE of Taitung. Depth of focus was 20km.

The damage on land surface was limited to the Taitung city and its vicinity. 17 persons were wounded, 31 buildings were completely overturned and 773 buildings partially destroyed.

A year after the earthquake at Taitung i.e. in 1952, the number of felt earthquake within a year was greater than the average number of earthquake during the period from 1947 to 1951. In 1952 the number of felt earthquakes on this Island was 22 per month, while the monthly average was 8 for the period from 1947 to 1951. This seems to show that more after-shocks follow great earthquakes than normal ones.

II Description and Study of Damage on Buildings

The damages caused by the earthquake at Hwalien on the buildings were rather heavy but they were different on buildings of different materials and methods of construction. In order to make a brief study and comparison, the buildings are divided into three catagories and discussed accordingly.

A. Wooden house of Japanese type

There were many wooden houses in Hwalien city suffering worst damages. The following are some records of damages on different parts of the buildings:

1) Mat foundation with concrete wall

Usually under the wooden building there was a platform as mat foundation surrounded by low concrete walls*. The space within the walls is paved or filled with gravel and sand. The dimensions of these walls are about 15 cms in thickness and 30 to 60 cms in height.

After the overturning or destruction of the wooden superstructures, most of these mat foundations were in good condition. Investigation revealed that some were destroyed owing to the unproper mixing of concrete of walls or of pavement. Some were destroyed where short wooden posts with frames were used instead of concrete walls. This shows that a well constructed concrete mat foundation can withstand earthquake, otherwise it will be unsafe.

2) Columns

There were columns of different materials:

(a) Brick coumn

The section of brick columns was about 2 1/2 bricks or 2 bricks in

* Cost of brick in Hwalien is very expensive, so low concrete wall is popularly used instead of brickwall.

square. The height was about 2.8m. Because the brick is rather heavy and its tensile strength is lacking, almost all the brick columns collapsed throughout the district affected by the earthquake. This seems to show that ordinary brick columns are not safe in earthquake regions.

(b) Concrete column

Well-designed concrete columns and structures proved to be safe. Some wooden houses with concrete columns were also found to be safe; others were destroyed owing to shallow footing only 3 to 30 cms. in depth where the columns collapsed before the whole wooden houses.

(c) Wooden post

All the wooden posts properly braced were found to be safe. In order to keep the wood in dry condition adn to prevent decay, care should be taken on the following points:

Bracing should be strong enough;
Joints should be fastened with iron bars or spikes;
Dimensions of wooden member should be large enough;
Proper drainage should be provided around the foot of timber post, especially where the post is embedded in concrete block in which water is easily collected.

3) Roof truss

The king post trust was commonly adopted in buildings throughout the city and all is provided with shear brace and horizontal knee bracing. There had been cases where-in houses were destroyed, but trusses remained in good condition. This proved that this type of truss was safe enough. But for the building with greater span it appeared to be safer to use knee braces in order to reduce the bending moment of the column.

4) Walls

In wooden house of Japanese type wooden posts and main wooden girder are used to form a frame. The space within the frame is weaved with bamboo as mattress on which mud is paved to form the wall. This kind of construction was proved to be economical and practical in non-earthquake regions. But from the experience of the earthquake at Hwalien, it was found that all the walls made of mud on the mattress fell down, even when the frame stood still. Therefore it should be better to replace the mud and mattress by wood lath or plywood to make the inner wall. Furthermore the frame should be strengthened by diagonal bracing for safety.

5) Roof

In general it is desirable to use light material as roofing such as aluminun sheet or asbesto sheet to reduce the damage from earthquake.

This practice is proved to be true from the observation of the earthquake at Hwalien. Of course for certain buildings it may still be necessary to use tile or cement tile for roofing after the truss is reasonably strengthened.

B. Wooden hall or plant

The investigation work after earthquake covered various kinds of public buildings such as theaters, school dormitories and classrooms, officer buildings, public meeting halls, plant buildings and ware-houses.

With the exception of two new well-designed theaters and some internally well-braced office buildings which suffered no damage and stayed. Completely intact, all other buildings were either overturned completely or inclined badly. The main causes seemed to be due to design defects as illustrated in the following examples:

(a) There were two warehouses newly built with identical designs. They were completely overturned toward the direction of NE. Damage was bad. Careful investigation revealed the causes to be: 1) wooden member was under-sized; 2) four wooden posts under a truss were not firmly connected, resulting in the truss being inadequately supported; 3) in the front and rear panel of the buildings there were diagonal bracings for the wooden posts but no provision was made for the side panel the direction of verturning was just along the side.

(b) A 9m x 36m classroom of a primary school and some other similar buildings were completely overturned. After investigation it was found that failures were generally due to the following reasons: 1) the connections of the posts and roof beams were not fastened firmly; 2) there were too many windows on the walls which were without bracing in the inner face; 3) the joints of posts and mat foundation were too weak and pedestals or wood spikes broke under vibration; 4) some sections of the wooden,posts were too small.

C. Brick buildings

There are very few brick buildings in Hwalien city, because the brick is comparatively expensive there. Only a few brick buildings were investigated after the earthquake and the findings were as follows:

1) One two-story brick building with wall of 1 1/2 bricks in thickness was completely overturned. Even concrete beam was destroyed.

2) Big cracks were found on all brick arches on the lintel of some buildings and some of them were beyond repair. This seems to prove that it is not advisable to use brick arches in earthquake regions.

3) A plain motar brick wall without concrete beam in a building had many cracks before the earthquake. These cracks were so greatly widened by the earthquake as to make the house un-reparable.

4) There were some brick buildings with concrete beams on the upper

parts of their walls. Despite the existence of many cracks these buildings survived the earthquake.

From the above findings it would seem that beams and columns made of bricks and plain concrete are not reliable in the earthquake region, if they are not properly strengthened. Brick work with plaster only should be entirely avoided.

III. Suggestions

After the disastrous earthquake happened at Hwalien city in 1951, a great deal of investigation was conducted by different organizations, social, technical, civil and governmental, besides the carrying out of many necessary emergency remedies. From this investigation, there were made some suggestions with certain measures to be taken for ensuring the safety of the people and lessening earthquake damages in the future.

A. Planning of new city

Hwalien city is situated at the junction of Papaya stream and Hwalien stream.

The formation of the land surface is classified as alluvium with foundation of loose and soft materials which shows subsidence and changes during the earthquake. The characteristics of the land are shown particularly remarkable themselves during the earthquake 1951. At the same time the elevation of the city is rather low, being about 60m lower than the bottom of the neighboring Papaya stream only nine kilometers away. From the geological and topographical point of view it seemed that the basic solution for the safety of the city is to relocate a new city.

It is suggested to plan a new city in the area of Mi-lun, NE of the present downtown. Mi-lun situated at a higher elevation than the old city Hwalien. The foundation in this mountain district is by far better than that of the old downtown. From the experiences of 1951 earthquake, the district of this suggested site for new city was very slightly affected.

Furthermore due to its high elevation, this new location of the city may be free from inundation or flood damages.

B. Technical suggestions

Besides the relocation of the city as a whole for the prevention of damages from earthquake, there were made many suggestions of technical nature which may be considered in the design and construction of structures in the future.

1) Foundation

Hwalien city being situated on an alluvian formation, its foundation material is very soft and does not meet the requirements of high buildings. New buildings to be constructed should keep as low as possible and perhaps be limited to 3 stories.

The excavation for foundation work should go deeper than the present practice and the foundation should preferably be constructed as a whole mat or raft foundation. The usual practice adopted in Taiwan, making a mass mat by filling the space within the low concrete walls with gravel and sand generally cemented as concrete, is found to be quite adaptable for the residential buildings. Because the posts are fastened on the mat, so the plain concrete foundation in certain parts of houses such as bathroom and kitchen, where the drainage is essential, should be raised a little higher to facilitate the drainage and to prevent the decay of wooden mambers by moisture.

2) Wall and frame

Brick wall proved to be easily collapsable during the earthquake, even as low as one meter in height. Its use should be avoided as much as possible. If it is necessary to use brickwalls in some cases, then reinforced concrete column should be adopted and the walls should be strengthened on the top with reinforced concrete beams. The purpose of the concrete beam is to act as a bearing beam of the roof on one side and to form the brickwall as a frame on the other side. Furthermore the footings of brickwalls should be reasonably widened and deepened.

Well-designed wooden frames are proved to be safe and stay firm during the earthquake, but local-produced timbers are usually found to be too short owing the limitation of the transportation facilities in the forest, commonly the length is not longer than 6 meters. Shorter timber length would necessitate increased numbers of joints or connections in the frame-works which are apt weak points and mainly responsible for the collapse of the frame-works during an earthquake. The remedies are to use longer timber and to assure proper strength of the joints or connections for designed loads.

The safety of the wooden structure, however, depends upon the quality of the timber used. It would be desirable to use cypress (Hinoyi) for main members and to use zelkova for timber plank and bolt lash for connections of wooden structures. For the inner parts of decoration which are not subjected to moisture and presure lanmu is adoptable.

Timber member should be of adequate dimension and consequently strong enough; some too small dimensions used on the joints or connections as in the past should be avoided.

Reinforced concrete and steel structures are found to have good resistance to earthquake if properly designed.

3) Plan and arrangement of buildings

From the records of the earthquakes, the amplitudes of earthquake are different in different direction, such as EW or NS; it would seem that building plan in the shape of D, L, E, T or U would be better than that of a square or rectangle in the viewpoint of resistance to earthquake. Meanwhile the big buildings with more footings seemed to show better resistance to earthquake than small ones.

4) Bracing

From the investigation made after the earthquake at Hwalien bracing played a very important role in resisting the shock of earthquake. Footings of columns should be fastened or connected strongly to the foundation structures to avoid the movement or separation of footings and foundation as happened in many cases in the earthquake 1951 at Hwalien. Besides the ordinary horizontal beams there should be provided additional bracings between frameworks or between vertical posts within a frame-work in order that the frame would act as a whole unit. These bracing would be provided on the upper or lower part, in the left or in the right side, on the front or in the rear, to be designed as necessary.

As the buildings of old Japanese type in Taiwan provided sliding door and window in each side of the buildings, there left no space for placing the bracing. This seemed to be one of the weak points in respect to safety against earthquakes. It should be improved accordingly.

5) Roof material

From observations in Hwalien, light roof materials suffered slight damages during the earthquake. It may be advisable to consider the use of light material, such as asbesto sheet, aluminum sheet for roofing materials for smaller or temperary buildings. But for permanent and well-designed structures the tile or cement tile should be used as usual.

6) Inner decoration

During the earthquake of 1951 at Hwalien, almost all the walls made of bamboo strips plastered with mud fell down or were badly stripped. It would be better to use plywood or begasse board or to use wooden strips instead of bamboo (bamboo would easily decay). All the wooden materials should be dried before using. Any green timber used would loosen after drying and be destroyed during an earthquake.

IV Conclusion

Besides the damage the buildings suffered as stated above, there was also much damage to railways, highways, bridges and other structures. But owing to the fact that we do not have a special organization to dealing with the general problems of earthquake engineering, available records are dispersed - especially for the earthquake of 1951, and it is not easy to collect and correlate all the useful data for a more complete and satisfactory study and report as the author much desires, we do hope, however, that after this meeting of the Second World Conference on Earthquake Engineering, to which for the first time a Chinese delegate participates, there will be established in each country a standing organization incorporated with the Society of Civil Engineering and with the Society of Seismography of the country to devote itself to the study of the problems concerned. The author believes that under such a set up, not only can we increase our knowledge in the field of earthquake engineering, but also may amplify the application of relevant technology. Economical and safe design for earthquake-proof structures may consequently result.

Map of Taiwan