

EARTHQUAKES AND ASEISMIC DESIGNS IN PAKISTAN

Abdual Qadir Khan*

Introduction

Most of the earthquake belt of the Himalayas is uninhabited. Still large populations have been affected occasionally by big earthquakes occurring in this belt, for example, earthquakes of Assam (1897), Kangra (1905), Bihar (1934) and Quetta (1935). Of these, the last mentioned earthquake which occurred in Baluchistan, is of greatest importance and interest, since after the destruction of Quetta it was completely rebuilt with specially designed earthquake resistant buildings.

Baluchistan is the most seismic region of Pakistan and is one of the principal active regions of the world. Earthquakes in this region have been of fairly frequent occurrence in the past. Small shocks are felt from time to time every year. During the last 100 years about 20 destructive earthquakes are reported to have occurred in this region. Of these, the earthquakes of Chaman (1892), Mach (1931), and Quetta (1935) are perhaps the best known. The magnitudes of these three earthquakes were between $7 \frac{1}{2}$ and 8.

Considering the magnitudes of other Baluchistan earthquakes recorded during the period 1928 to 1955 the position is as follows:

4 earthquakes of magnitude $7 - 7 \frac{1}{2}$
6 earthquakes of magnitude 6 - 7
9 earthquakes of magnitude $5 \frac{1}{2} - 6$

This means that, in all 19 earthquakes of magnitudes $5 \frac{1}{2}$ to $7 \frac{1}{2}$ have occurred in the last 27 years. Therefore on the average we can expect one earthquake of magnitude 6 and above every 3 years and another one of magnitude $5 \frac{1}{2}$ to 6 in the same period.

Prior to 1930, when the number of seismological instruments was very limited, probably some other big earthquakes of this region went unnoticed because their epicenters were far away from the inhabited areas. Though Baluchistan as a whole is the least populated area in the whole of the Indo-Pakistan sub-continent (Quetta is its biggest city with a population of about 75,000 people) yet the three biggest earthquakes already mentioned struck points which were the most thickly populated in the region.

At the time of its creation in 1947, Pakistan had no facilities for seismological and other geophysical investigations. The great surge of building activities and other development programs which followed immediately afterward (the creation of the nation) focused attention on the earthquake problem. Therefore on the initiative of the Pakistan

* Chief, Seismological Section, Geophysical Observatory, Quetta.

DEVELOPMENT OF ASEISMIC CONSTRUCTION

Meteorological Service, a project for the establishment of a Geophysical Observatory at Quetta was signed between the Government of Pakistan and Unesco. In implementation of this agreement, Unesco experts arrived in 1951 and by 1954 a full fledged geophysical observatory was functioning at Quetta in addition to two subsidiary seismological observatories at Lahore and Chittagong.

Quetta before 1935

Till 1935 there was no official building code for the construction of earthquake resistant buildings. Most of the houses were made of sun-baked mud bricks or burnt bricks cemented by means of mud or lime mortar. Construction work was generally very inferior and the buildings were comparatively tall. Village houses were mostly made of thick mud walls with heavy irregular branches of trees as beams on which were laid heavy mud roofs.

It is estimated that 20,000 people lost their lives in Quetta alone during the 1935 earthquake. Total destruction of the southwestern part of the city, which was due to inferior construction and the disproportionate heights of the buildings, contributed to most of the deaths. Narrowness of the streets was another factor which increased the mortality because people who rushed out of their homes safely were soon buried under falling houses from the two sides of the streets. Another contributing factor for the high mortality was the incorporation of wire netting within the plaster of the walls of many houses. This wire netting proved to be a death-trap in many cases making it impossible even for those who were not seriously injured to escape out of their ruined houses.

A very interesting fact about the distribution of damage sustained at Quetta during this earthquake was the rapid decrease in intensity towards the northeast. The intensity at any particular place is a function of distance from the epicenter, the nature of the ground and the type and orientation of the construction with respect to the direction from which the shocks come. The northeastern part of the city was, no doubt, slightly away from the epicenter as compared to southwestern part and was also comparatively better constructed. The southwestern part of Quetta is built on water bearing alluvium whereas the northeastern part is on dry alluvium and mountain fan gravels.

It was rather difficult at that time to say whether the nature of ground or better construction and greater epicentral distance was responsible for the smaller amount of damage in the northeast. But the recent Quetta earthquake (18th February 1955) whose epicenter was comparatively nearer to northeast has indicated that it is perhaps the nature of ground which is responsible for the degree of damage. During this earthquake many old and poorly constructed compound walls (oriented in all directions) in the northeast remained intact, whereas much better constructed compound

KHAN on Experience and Practice in PAKISTAN

walls (oriented in all directions) in the southwest fell down. Similarly, damage to buildings was also comparatively greater in the southwest.

On the basis of the experience of the Mach earthquake of 1931, the railway authorities had by 1935 built a few earthquake resistant buildings at Quetta. These were of two types: The earlier design consisted of vertical and horizontal iron rails with non-reinforced brick 4 1/2 inches thick in 1:3 cement-mortar panels up to 8 ft. long by 6 ft. high. The residents of such houses were so shaken by the 1935 earthquake that they could hardly stand, yet the structure sustained no damage whatsoever, though all buildings surrounding these were completely destroyed. The disadvantages of this type of construction, however, were (i) use of steel rails which were very costly as well as not easily available and (ii) thin walls which made the structures very cold in winter. In the second design, walls were made thicker and necessary rigidity was obtained by means of reinforced cement concrete. In spite of the fact that one of such building was still under construction and the roof not yet on, it withstood the 1935 shocks remarkably well. These two types of structures were given a seismic factor of $g/10$. The construction engineers, therefore, inferred that if the buildings constructed in Quetta were given a seismic factor of $g/10$, they would be reasonably safe from the destructive effects of future earthquakes. This conclusion of theirs was entirely arbitrary as neither the acceleration of the 1935 earthquake nor the probable values of the future earthquakes were known. But judging from Gutenberg's Intensity - Acceleration formula ($\log a = I/3 - 0.5$; a being acceleration and I intensity in Modified Mercalli Scale) it appears that the acceleration was of the order of 150 - 200 gals.

Quetta after 1935

The designs of buildings to resist earthquake in the past have been based on two opposite principles. One aims at keeping the structure so light and flexible that even if it is shaken badly during an earthquake it does not fall to pieces. The other design requires a structure so firm and rigid that it moves as single unit during the earthquake and thus escapes undamaged. The latter design, besides being superior, suits Baluchistan from the climatological stand point as well. But the earning capacity of over-whelming majority of people in this part of Pakistan makes it almost impossible to erect a rigid type of structure requiring steel bars, cement etc. which are not only costly but also not easily available. Keeping this point in view the Municipal Committee Quetta permitted construction of both rigid and flexible (less rigid) types of structures. Moreover, to be on the safe side the seismic factor for such constructions was raised to $g/8$ from the $g/10$ used by railway authorities. A further restriction imposed was that they should have only one story. As the availability of land is no problem at present, this restriction did not offer any hardship to the people.

DEVELOPMENT OF ASEISMIC CONSTRUCTION

In the building code, eight types of structures were allowed to suit people of all income groups. Of these, two types are described below:

(a) Structure of burnt bricks or concrete block masonry reinforced vertically and horizontally. Foundations shall consist of a continuous frame of reinforced cement concrete, of mix not weaker than 1:2:4, the reinforcement being two 5/8 inch steel bars laid in center of thickness and 2 inches from the outer and inner faces.

Plinth masonry shall not be less than 18 inches in thickness and shall be finished off with a reinforced concrete band of 1:2:4 mix not less than 6 inches in thickness and of the width of the masonry. The reinforcement for this band shall consist of two 5/8 inch bars as above.

Superstructure masonry shall consist of walls not less than 13 1/2 inches in thickness set in cement mortar and reinforced with suitable welded fabric in every fourth course or two 1/2 x 1/8 inch iron flats in every eighth course, the flats to be spaced 1 inch from each face.

A reinforced concrete band not less than 6 inches in depth and of full width of walls and containing two 5/8 inch rods shall be laid just above all door and window openings.

If the roof is not of reinforced concrete, a third similar reinforced concrete band shall be laid on the top of walls to form a continuous wall plate to which the roof trusses whether of wood or steel must be firmly bolted. Should the roof be of reinforced concrete, this top band will not be necessary as the roof, complete with its reinforcement, must be carried right over the outside walls and can be made to project so as to form a string-course, this projection not exceeding 4 1/2 inches.

At every corner and in every door and window jamb and throughout all the walls at intervals not exceeding 5 feet, vertical reinforcement in the form of two round bars not less than 5/8 inch diameter must be placed. This must be connected with the reinforcement in the concrete band at the top of the plinth and with that in the reinforced concrete band at the top of the building. In the event of this band being omitted owing to roof being of reinforced concrete these vertical reinforcement bars must be hooked and firmly buried in the reinforced concrete roof.

The height of the building of this type shall not exceed 15 ft. from ground (first) floor to top of roof. Rooms should not have a length greater than 30 feet without a suitably designed transverse wall with a big archway in it, but any wall exceeding 22 feet in length must be strengthened by steel stanchions, reinforced concrete pillars, or masonry pilasters suitably reinforced.

KHAN on Experience and Practice in PAKISTAN

(b) Timber frames with corrugated iron sheets. Foundation for this class of building shall consist of cement concrete 1:3:6 or good lime concrete under the dwarf walls. The superstructure should consist of a timber framework. The vertical members of the superstructure must invariably be in one piece without any large knots which will weaken them. They shall not be less than 4 1/2 x 3 inch in section, the latter dimension being in the plane of the wall, and shall be firmly connected by horizontal members of the same section. The vertical and horizontal members must be so placed as to form panels not exceeding 4 x 4 feet.

The lower portion shall be filled in with a burnt brick wall, 9 inches thick and not exceeding 4 feet in height. This should be finished off with a reinforced concrete band not less than 5 inches in thickness and of the full width of the walls. This band must contain two iron bars not less than 3/8 inch in diameter.

The outer covering above this brick wall shall be corrugated iron sheets not thinner than 24 gauge properly attached by galvanized iron screws. The interior lining can be of timber planking or any suitable lining board or plaster provided that in the latter case the plaster does not exceed 3/4 inch in thickness.

The roof shall be carried on properly framed timber roof-trusses, the joints of which are secured by iron straps and bolts. The roof covering should be of corrugated iron sheets, lined on the underside by timber planking or by lining board or ply-wood but not by plaster. The height of buildings of this type shall not exceed 12 feet.

Both of the above mentioned types are for one story buildings, (a) being most rigid while (b) is least rigid of all the types in force. Specifications for the intermediate types of buildings are naturally in between these two extremes.

A two story structure is allowed only in the case of a building having a steel frame which is able to safely resist a lateral force on any member equal to 1/8th of the load, both live and dead, taken by that member. In such a case the thickness of walls should not be less than 13 1/2 inches for the lower story and 9 inches for the upper. Also, the second floor should be of reinforced concrete or of transverse steel beams forming part of the steel framework on which may be laid timber rafters and plank flooring. The total height of a building of this class must not exceed 30 feet. The maximum width of rooms without internal columns will be 25 feet. For width greater than this (but not exceeding 50 feet) columns will have to be employed as a support to the second floor or roof.

While building any aseismic structure, the foundation has to be designed in such a way that the pressure on the soil does not exceed one ton per square foot anywhere.

DEVELOPMENT OF ASEISMIC CONSTRUCTION

Effect of subsequent shocks

All buildings within the limits of Quetta Municipality, after 1935 were built according to the building code already mentioned. In 1941 an earthquake rocked Quetta and cracks occurred in several new buildings, but no detailed information is available about the damage. The earthquake of February 18, 1955, whose epicenter was 8 miles from the north-east and 9 miles from the southwest of Quetta was the first earthquake to really test the aseismic designs of the buildings. Immediately after the earthquake a thorough investigation of the damage was undertaken. In the city itself, the greatest damage noticed was to the non-reinforced compound walls. Many minarets (spires) of mosques which were not sufficiently reinforced came tumbling down or were bent. Several of the heavy decorations also were thrown down. Balconies of some of the buildings which were not properly bonded cracked from the sides. In a few cases differential settlement between two parts of a building was noticed by this was not sufficient to cause any serious damage to the building itself. Some of the buildings which at the time of construction lacked proper supervision or used poor materials were very badly damaged. But for these damages all aseismic designs stood the earthquake well.

Two reinforced concrete buildings about 4 1/2 miles from the epicenter were also examined. One of them, Kalat Palace, generally resisted the earthquake well but unnecessary decorations and additions were badly damaged. In addition to this some balconies which were again not properly bonded to the main building cracked from the sides and were bent down. On the other hand the second building, a fruit factory, very close to the first one did not suffer at all. This building was of much bigger dimensions. Its central hall having a basement under it (this is the only building in Quetta with a basement) was 80 x 40 feet. The heights of roofs of basement and the ground story, both of which were supported by reinforced beams and pillars were, 8 and 16 feet respectively, the thickness of walls being 1 1/2 feet. This shows that a clear functional design though of bigger dimensions is better and safer as compared to designs having unnecessary additions and decorations.

It will be interesting to compare the magnitudes of earthquakes of 1935 and 1955, the distances of their epicenters and their intensities at Quetta. According to Gutenberg and the International Seismological Summary, the epicenter of the 1935 earthquake was about 50 miles southwest of Quetta. But judging from the isoseismal lines drawn by West, the distance cannot be greater than 25 to 30 miles. The latter seems to be more reasonable. The epicenter of the 1955 earthquake was about 8 to 10 miles NNW of Quetta. The magnitudes of the 1935 and 1955 earthquakes were 7 1/2 and 6 respectively. Intensities on the Modified Mercalli Scale at Quetta during these earthquakes is estimated to be 8 (or slightly greater) in 1935 and 7 (or slightly greater) in 1955. From Gutenberg's Intensity - Acceleration formula already mentioned these intensities are equivalent to accelerations of about 150-200 and 70-90 gals respectively. The latter value is also supported by evidence obtained from the fall of a few free objects during the earthquake.

KHAN on Experience and Practice in PAKISTAN

Villages of Baluchistan

It is not the properly designed cities and towns which are Pakistan's main worry in her earthquake areas. It is the villages. The problem is negligible in East Pakistan where nearly every village is unconsciously built in accordance with one type of earthquake resistant design: wood or bamboo frame, light panel walls and roof. But in Baluchistan the problem is acute, for the available material, mud, is the worst material to use in earthquake areas. Can a village house built of mud and reinforced with local materials be designed to withstand moderate earthquakes of Baluchistan and not cost more than at present?

The villagers in this area are fully aware of the earthquake problems and the few who can buy timber have built their houses on earthquake resistant designs. But, for the overwhelming majority of the people in the villages timber is an expensive material. For them mud is the only available material for constructing houses. Experiments are therefore necessary to see if mud can be strengthened with local materials for use in the village dwellings. For example, to determine whether the branches of Khaira, a local willow, if woven into panels, can be used as earthquake resistant material for walls and roofs?

Overall Building Code

At present, only Quetta has a building code. But before it is extended to other seismic areas of Pakistan we should know their seismicity in terms of accelerations already experienced. Toward this end, data on all earthquakes (shallow focus) of known magnitudes which occurred in or near West Pakistan during the last 30 years or so were collected. Chaman earthquake of 1892 and Kangra earthquake of 1905 (each of magnitude 8) were also included. Assuming depth of such earthquakes to be nearly same as that in California, acceleration at the epicenters was determined from Gutenberg's formula ($M = 2.2 + 1.8 \log a_0$, M being magnitude of the earthquake and a_0 acceleration at the epicenter). Plotting these values of acceleration at the respective epicenters, an isoacceleration map was drawn. This map has clearly brought out four areas with accelerations reaching the value of 'g' or more. These four areas are (i) Northeast Arabian Sea (ii) Central Baluchistan (iii) Hindu Kush and (iv) Kangra Area.

We cannot, however, be certain about the accuracy of the value of acceleration obtained from the above formula. If the Hindu Kush earthquakes (shallow focus) have depth of focus greater than California earthquakes, the value obtained is high and vice versa. In the case of Central Baluchistan, where it is now almost confirmed that the depth of the focus is of the order of 8 kms., Gutenberg's formula gives lower value of acceleration. Thirty years data surely is not enough for drawing isoacceleration lines but, handicapped as we are at present, we have to

DEVELOPMENT OF ASEISMIC CONSTRUCTION

depend at least for the time being on this alone. As more and more earthquakes are recorded in these regions, their epicenters and depths precisely determined and magnitudes known, we shall be able to revise the iso-acceleration map and make it more accurate.

Above is the indirect method of determining the acceleration of the earthquakes. We recently obtained 4 three-component Wenner accelerographs from the United States. One of these has been installed in the Seismic vault of the Geophysical Observatory while the other has been installed in East Pakistan at Sylhet (bordering Assam). The third one is being installed on the second floor of a two-story building at Quetta, the last one being earmarked for Drosh (bordering Hindu Kush area). In addition, a simple shock recorder using smoked paper or driven by an alarm clock has been designed in the Observatory Workshop. Fifty of such instruments are now being manufactured in our Headquarters Workshop at Karachi. Before being distributed in Pakistan, they will be calibrated in terms of acceleration. Plans for manufacturing a simple falling spindle type of accelerometer as used by Department of Scientific and Industrial Research of New Zealand are in progress. These will be sited where use of the smoked paper type presents technical difficulties.

Conclusion

During the last 4 years a great deal of practical experience has been gained particularly with respect to earthquakes in Central Baluchistan. Furthermore the Quetta Earthquake of February 18, 1955 gave us an opportunity to see the effect of earthquakes on the aseismic designs. From the results obtained it appears that the two-story problem has been solved. We have little experience as yet with tall and multistory buildings, and with special structures such as bridges, dams etc. The village problem also remains to be solved. The Quetta seismology group have given these problems the first priority. As this conference is our first contact with scientists who have been engaged for many years with similar problems, their advice and suggestions will be most welcome. These suggestions, we are sure, will be very useful for this new seismological service, started primarily with the object of being useful to the common man and also to be associated with other sister seismological services of the world for the purpose of investigating earthquake problems.

Acknowledgement

The author wishes to thank Dr. H. E. S. Thirlaway for his many useful suggestions. The author also thanks Mr. S. J. Ahmed, Meteorologist In charge Geophysical Observatory and his colleagues in Seismological Section for going through the manuscript.

KHAN on Experience and Practice in PAKISTAN

Bibliography

1. West, W. D., "The Baluchistan Earthquake of August 25th and 27th 1931". The Geological Survey of India, XLVII (Part I); 1 - 82, (1934).
2. West, W. D., "Preliminary Geological Report on the Baluchistan (Quetta) Earthquake of May 31, 1935". The Geological Survey of India, LXIX (Part 2); 203 - 240, (1935).
3. Quetta Municipality, "Building Code", (1937).
4. Gutenberg, D., and C. F. Richter, "Earthquake Magnitude, Intensity Energy, and Acceleration", Bull. Seism. Soc. Am., 32; 163 - 191, (1942).
5. Gutenberg, B., and C. F. Richter, "Seismicity of the Earth", (1954).