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Geotechnical and Strong Motion Aspects of Recent Indian Earthquakes

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SYNOPSIS: India had many strong earthquakes in the past. The paper describes some strong motion and geotechnical aspects of Indian earthquakes.

INTRODUCTION

India has had several strong earthquakes in the last one century, six of them having a magnitude greater than 8 and 55 with magnitude between 6.5 and 8. Most of them have resulted from the strain released in the Himalayas extending from Assam in the east to Kashmir in the north and 70% of this release has taken place in North-East India i.e. Assam and the surrounding region (Fig.1). All earthquakes have damaged poorly designed buildings but some of them have also liquefied alluvial soil, caused fissures and subsidence, and resulted in widespread landslides, failure of bridges through overturning or unequal settlements and leaning of piers. It will be seen that this area is one of the most seismically active areas of the world, and offers a typical case to study the effects of an earthquake. It is proposed to describe in this paper some of the geotechnical and strong motion aspects in this region.

Figure 1

STRONG MOTION

First of all, let us examine what the strong motion has been like during Indian earthquakes. Since there were no strong motion instruments installed in India before 1963, the strongest ground motion that was actually recorded here was the accelerogram for Koyna Earthquake of December 11, 1967 (Magnitude 6.7), which recorded a peak acceleration of 0.63g (Fig.2).

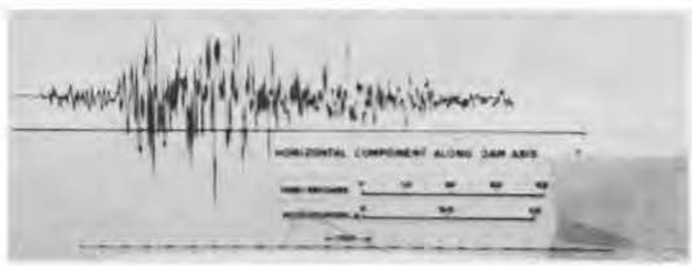

Figure 2. Accelogram Recorded at Block 1-A of Koyna Dam on December 11, 1967 at 04-21 IST

This was the highest acceleration recorded upto that time anywhere. Indications were, however, given by Oldham (1) when describing Assam Earthquake of June 12, 1897(Magnitude 8.6) that stone boulders deposited on the hill slopes were thrown up in the air which means that the acceleration was more than 'g' (Fig.3).

Figure 3. Displaced Boulders Near Kanchi Khasi Hills

This story was not always believed till the accelerogram on the Pacoima Dam during San Fernado earthquake of February 9, 1971 (Magnitude 6.6)(2) showed a peak greater than 'g' (Fig.4). Some evidence is available that during Bihar earthquake of January 15,1934(3) (Magnitude 8.4) some houses in the epicentral region were observed to have been lifted upwards by thuds under the ground surface and then dropped suddenly and collapsed. Obviously ground acceleration has exceeded 'g' at times.

Figure 4. Pacoima Dam, California - San Fernado Earthquake of February 9, 1971

Bihar and Assam earthquakes are two of the biggest shocks in History but even San Fernado shock, moderate by usual standards, recorded an acceleration bigger than 'g'. It will thus be seen that it is not the size of an earthquake that determines the peak value. A very large value can be recorded in a moderate size of an earthquake since acceleration is the rate of change of velocity of motion and if the change is large over a short period of time (fraction of a second), its value can be quite large. For Koyna, the peak of 0.63g lasted only about 1/15th of a second and in Pacoima record 1/10th of a second. The contribution of this one peak of the Koyna earthquake to the stresses in Koyna Dam has been calculated to be negligible in the total stress at that instant. That shows Koyna Dam would have cracked even if this particular peak was half its recorded size.

These significant observations have led to corelate damage to a structure more to velocity and consequently to total energy transmitted over a period of time than to peak acceleration. There are, however, certain instances where an instantaneous pulse can twist or overturn as shown by the overturning of the girders shown in Fig. 5 during Bihar earthquake of January 15, 1934 (Magnitude 8.4). Although no one has observed the mechanism of actual overturning of these 350 ft. span girders yet it is quite likely that duration of the impulse which led to the overturning was not the determining factor but it was its magnitude. Alternatively, it may be the successive build up of amplitudes of vibration, which may have caused it, but since the girders did not have much energy absorbing capacity in that direction, the overturning must be more or less an instantaneous action.

Figure 5. Overturning of Girders of a Railway Bridge During Bihar Earthquake of January 15, 1934.

In the midst of vast destruction caused by the Bihar 1934 earthquake, there were interesting structures that were not damaged whereas everything around them collapsed. Stone columns carrying idols (Fig. 6) stood unaffected since their foundation was deep, joints were tight-fitting sockets and generally the workmanship was good. There were many other structures of this kind which escaped damage. Experience has shown that good workmanship, good quality of materials and good anchorage of foundations lead to considerable safety much beyond what normal analysis would predict. Obviously it has a good deal to do with the special features of an earthquake ground motion, which changes in direction, magnitude and duration several times a second besides the shortcomings of analysis to estimate the actual strength of materials at the time of an earthquake and the inherent capacity of a structure to share the distress with the less stressed of its portions before final collapse.

Figure 6. Stone Columns Carrying Idols Unaffected During Bihar Earthquake of January 15, 1934.

Another observation in recent earthquakes (Pithoragarh, May 21, 1979)(4) and (Dharchula July 29, 1980)(5) affecting hilly areas in Western Himalayas is that buildings constructed on hill tops on firm rock but without much depth of foundations were damaged much more than similar buildings standing at the foothills with fairly deep foundation in sandy soil. It is indicative of the energy absorption effect of the foundation soil underneath rigid structures. It is, however, fortunate that the buildings covered small areas, otherwise unequal settlement of soft material may have resulted in failure even if the acceleration effect was less marked than for buildings on hill tops.

This observation may seem to contradict the usual understanding that when a wave passes from rock to soft material, its parameters get amplified as reported by Housner (6). Actually damage being a function of acceleration or velocity or unequal (or excessive) settlement, no general conclusions could be drawn on the effect of soil under a structure. Each situation seems to need special examination. One conclusion, however, appears to be reasonable that some earth cushion between rock base and foundation of rigid structures is of advantage in reducing the effects of earthquakes. This can be used as a safety device. As the thickness of soft material increases, the settlement and amplification of wave parameters have greater effects on structure, as it has been evidenced by lot of damage to buildings on alluvium or the foothills with substantial river deposit. It is not feasible to give quantitative values to these qualitative observations since it is rare that construction of identical specification may be built over different soil covers so that relative performance could be observed. Data available from Indian earthquakes in this respect is very meagre but these are some observations on the performance of stone or brick buildings during recent earthquakes.

GEOTECHNICAL ASPECTS

Landslides

Most of the earthquakes occurring in the hilly regions have not caused significant geotechnical effects excepting landslides. The most spectacular landslides were caused by Assam earthquake of August 15, 1950 (Magnitude 8.6) which blocked the main tributaries of the huge river Brahmaputra such that they changed their courses and flooded towns and huge areas on their banks (7).

All along the Himalayas, which are supposed to be geologically growing mountains, there are innumerable spots where there is constant sliding and even a moderate size earthquake triggers big landslides, breaking roads and causing considerable dislocation to life in the region.

This is more serious in the middle and lower Himalayan ranges, which have a large number of shear zones, and hills slide even due to heavy rain leave alone an earthquake shaking. If the slide is confined to blocking the road, the consequences are not so serious but when they block a river flow, store water for some time and flood downstream later the damage caused is considerable. That was the main source of loss due to several earthquakes in Assam region. In 1950 shock, water front rose upto 30 feet height on failure of an "instant" dams. No solution has yet been found to the problem of landslides, particularly because such spots are too numerous and expense involved in treating them prohibitive. Plantation is one of the stablisation methods being attempted.

Liquefaction

Bihar earthquake of January 15, 1934 (Magnitude 8.4) had its central tract over an alluvial region. The depth of alluvium was several kilometers deep, which was deposited by heavy silt bearing rivers and was charged with water almost to saturation. In several areas the silt deposit liquefied due to intensive shaking and threw up "mud fountains" and deposited mud in small mounds with an overall sinking of the land over the area (Fig. 7). In fact the earthquake compacted the alluvial deposit and caused significant sinking over an area of about 4700 square miles. Precise levelling after the earthquake showed sinking upto 2.7 feet - a situation similar to that caused by New Madrid earthquake west of Mississipi River about 150 years ago slumping huge areas.

Figure 7. Mud Fountains During Bihar Earthquake of January 15, 1934.

The problem of liquefaction of alluvial and sandy deposits during earthquakes was of great importance to India since building dams for irrigation and power purposes over silty-sandy beds of rivers is unavoidable. Three such projects Tenughat (8) Obra(9) and Ukai(10) were investigated from this point of view. Earth dams have been built on these sites. Tenughat lies in the area shaken by Bihar earthquake of 1934 and but it has not been visited by an earthquake since. Obra also had no shaking. Ukai dam has been shaken by an earthquake of magnitude 5.4 (peak acceleration 0.33g) with no adverse effects. These dams have been provided with stone aprons on the toes to prevent sinking and extra freeboards to allow for compaction settlements due to earthquakes. Similarly, a nuclear power plant on the banks of an alluvial river in a seismic zone, which had a history of moderate size earthquake, although not very frequent ones, had to be investigated carefully for liquefaction effects. It was found that unless properly confined and weighted , the soil will liquefy and would lead to excessive settlements and serious damage to the power plant if a strong earthquake occurs in the area. Thus the vulnerable area needed to be properly confined and foundation laid well below the ground surface so that liquefaction may not occur below the foundation of the power plant.

In studying liquefaction problems, reliance has been placed on vibration studies on saturated sands deposited with same relative density as measured at site, on a sinusoidal vibration table. Blast experiments in the field also provided some information which guided the design of earthen dams and foundations of important structures.

Other geotechnical aspects of Bihar earthquake were fissures over huge areas due to the failure of saturated alluvial soils to stand the intense vibrations.

Northern India with the unstable Himalayas and the alluvial deposits of Indo-Gangetic river systems provide an outstanding example, where strong motion occurs quite frequently and, besides structural engineering effects, typical geotechnical failures of all descriptions take place. With the increasing density of strong motion instruments over the region, much more can be learnt in future shocks corelating liquefaction threshold with ground acceleration in real situation. Laboratory and blast experiments have obvious shortcomings, and analytical solutions also will be based on field samples which are not likely to give thoroughly reliable information.

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