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Liquefaction During Two Moderate-Recent Earthquakes in India

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SYNOPSIS: The observations of liquefaction during the Cachar earthquake of N.E. India in December 31,1984 (M=5.6) and the Great Nicobar earthquake of January 20,1982 (M=6.3) have been reported. These observation, at short epicentral distances where duration of sustained motion was insufficient to postulate induced dynamic increase in porewater pressure, have been explained as quick-sand phenomena due to disturbance of soil structure under the influence of imipulsive force associated with rupture at source. The proposed physical mechanism also explains well the bending of ceiling fan blades in Cachar earthquake and upthrow of objects during earthquakes in general.

The discussion presented is expected to widen the scope of the explaination for ground failure, i.e., liquefaction in epicentral region particularly during moderate and shallow earthquakes.

INTRODUCTION

Damage during two earthquakes, namely the Cachar earthquake of 5.6 magnitude in N.E. India on December 30, 1984 at 23^{h} 33^{m} 35.7^{s} GMT with epicentre at 24.70° N, 92.85° E and the Great Nicobar earthquake of 6.5 magnitude in the Bay of Bengal on January 20, 1982 at 04^{h} 25^{m} 12.7^{s} GMT with epicentre at 6.94° N, 94.03° E was surveyed and ground failure including liquefaction was observed. The observation of liquefaction are reported here. The observed phenomena could not be explained by the usual approach where decrease in volume, undrained condition, increase in porewater pressure and resulting reduction of effective stress to zero during a sustained cyclic motion (Seed, 84) are visualised. The bending of ceiling fan blades due to their hitting cieling in dynamically very different buildings **(See Figures 1 and 2)** during the Cachar earthquake drew the attention to the possible role of impulsive force associated with rupture at source. Simplified physical mechanisms have been proposed to explain this and the so called upthrow of the objects **(Bolt and Hansen; 77 Psycharis and and Jennings, 85)**. Further, the impulsive force may be able to disturb the soil structure and pressurise water such that the observed liquefaction may truely be quicksand phenomena.

CACHAR EARTHQUAKE

The earthquake was very shallow with less than 1 sec S-P times for the aftershocks (Agrawal, 86.a). Naturally it caused sever but localised damage. The damage resulted in complete collapse of mud houses, human deaths, rendered two reinforced concrete bridges out of use and extensive ground failure (Agrawal, 86 b). The region is comprised of very thick sequence of folded tertiary sedimentary rocks overlain with layers of loose soil. The landsat photographs show presence of a younger NW-SE trend which cuts across the lineaments paraparallel to the Arkan-Yoma folded zone. The intersection of these two trends in the region is marked by the presence of a number of small lakes (abondoned meanders), changes in topographic maps, complex meandering of river courses and extensive ground failure during the earthquake under report. Presence of very thin layers of fine soil at different depths, shallow water table, poor drainage condition and artesian wells manifesting hydraulic gradient are some important features of the region inter related to the observed ground failure at focal distance of about only 8-10 km. The ground liquefaction resulted in number of individual sand boils independent of each other where the top soil was relatively compact as seen in Fig. 3 and reinforced with roots of grass and weeds. In well tiled fields under cultivation sub-parallel linear fissures extending to a few hundred meters had developed and sand boils were located in them at irregular spacing **(See Fig. 4)**.

GREAT NICOBAR EARTHQUAKE

This earthquake also was of shallow focal depth with its epicentre off the coast line. The estimates of focal depth on the basis of (S-P) times of the aftershocks recorded close to epicentre and USGS reports are 18 and 28 km respectively. The earthquake caused damage to Campbell Bay Jetty **(Figure 5)**, Maggar Nallaha Timber Bridge **(Figure 6)** various single and double storey buildings, construction by Harbour-Works, hollow block masonry construction by army, and wide spread liquefaction along the east coast of Great Nicobar. The coast is characterised by Coralbeds and Fringing Reef formations. The dominant rock is the Andaman Flysh - grey small sandstones, slates and shales. The

Fig. 1 Bending of blades of a ceiling fan in a timber frame building at Sonaimukh during Cachar earthquake.

Fig. 2. Bending of blades of a ceiling fan in a building with reinforced concrete columns and beams, near the one in Fig. 1.

Fig. 3. Individual sand boils in relatively compacted and weed reinforced soil during the Cachar earthquake.

Fig.4. Long fissure esxtending upto 500 m, housing sand boils in well tiled fields during Cachar earthquake.

Fig. 5 Campbell Bay jetty at Great Nicobar and the close up the distressed column, i.e. the location of liquefaction.

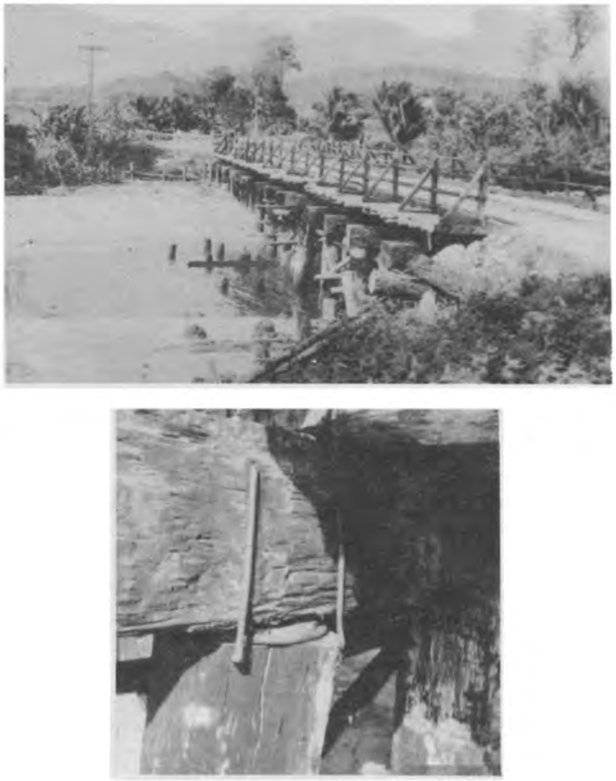

Fig. 6. Maggar Nallah bridge at Great Nicobar and the close up of the tilted timber column, i.e., the location of liquefaction.

Fig. 7 Individual sand boils in compacted and weed reinforced soil during Great Nicobar earthquake.

Fig. 8. Fissure housing sand boils in loose sand, near high tide level during Great Nicobar earthquake.

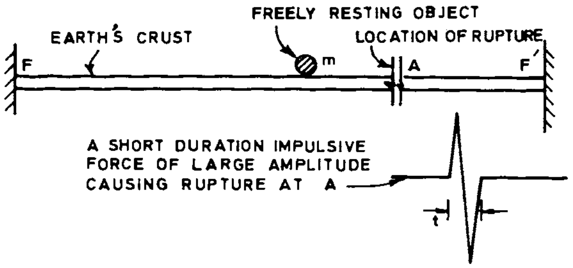

Fig. 9. A diagram representing the earth's crust very close to the epicentre before rupture during an earthquake.

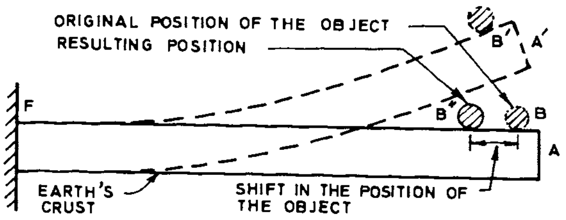

Fig.10. Deflection of the crust due to impulsive force after rupture at A and its effect on a freely resting object.

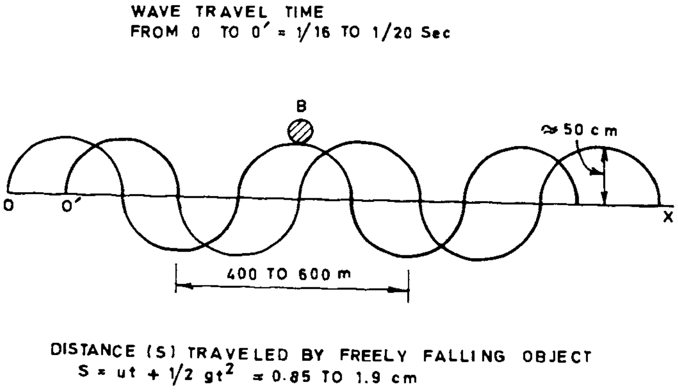

Fig.11. Undulations of ground surface in the wake of the passage of large amplitude wave at relatively more distance.

sediments are silty mudstones, clay and limestones. Our crops of ultrabasic rocks of late Cretaceous to Eocene are exposed at placed on the east coast of the island. The region is seismically very active and earthquakes of upto 8 magnitude have occurred in the past. Generally epicentres are below the sea but tidal waves are not generated, foreshocks are not associated whereas as aftershocks are well known for the activity. The tilting of RC and timber coloumns of Campbell Bay Jetty and Maggar Nallah Bridge respectively at some distance in the water, as seen in Figures 5 and 6, was attributed to liquefaction. Otherwise the sites of liquefaction were inland, well drained and close to high tide level. Either individual sand boils in the soil compacted and reinforced with grass, or a series of sand boils in loose sands were observed. The Figures 7 and 8 show these observations. These observations were at an epicentral distance roughly equal to focal depth and perhaps the predominent direction of resultant impulsive force associated with the rupture could be considered at about 45° from the vertical. Observed dislodging of empty 2700 litre capacity oil tankers from their well designed supports during Great Nicobar earthquake (Agrawal, 83) was phenomena similar to bending of blades of ceiling fans in the Cachar earthquake.

PROPOSED PHYSICAL MODEL

To explain these observations a simplified model as shown in Figure 9 comprising of an elastic beam/plate fixed at two ends FF' may be considered as an idealised representation for the earth's crust before an impending rupture at A during earthquake. We shall consider two cases namely, Case I - the deflection of beam/plate (more flexible) after rupture at A is large and that, Case II - the impulsive force is large but the deflection of beam (more stiff) is small.

Case - I

The response of the earth's crust, after rupture could be approximated by deflection of the beam or a rectangular plate fixed at one end and free at the other, as is also the basis for elastic rebound theory. It may be clarified that being close to the focus, where ground response is dominantly nonlinear, we will consider deflection of beam under impulsive force responsible for the rupture, and not its forced or free vibration. Let us consider a freely resting object on the ground close to rupture, i.e., the free end A of the beam as in Figure 1. The beam which was initially held under stressed state at A would deflect to A'. During upward travel of the ruptured crust the object will move alongwith the crust while during return to equilibrium it would tend to lag behind the ground due to its inertia of rest. The lag will be if the stiffness of the ruptured crust is more (hard rock). The object after loosing contact with the ground will freely fall vertically whereas its initial point of contact with ground will move along the same arc along which it had travelled upward. The representation in Figure 2 has been done to enhance this effect. The distance between new and original location of the object will depend on its distance from the point of rotation. For equal length arcs of small and large radius circles the curvature and therefore the dislodging of the object will be more for small radius.

Further, for the same angular deflection the height through which the object will be dropped freely will be more for large radius. Thus the effect considered could be observable under some favourable and critical conditions and not always. Additional conditions like the normal faulting, being on upthrown block, shallow focus and others will be required for the explained phenomena to occur. This simple mechanism explains the possible loss of contact between ground with freely resting objects and their occupying new positions in the wake of earthquakes.

Case - II

Let the intense impulse causing rupture may impart a velocity v to a ground layer of effective mass M. Let us consider an object of mass m initially resting freely on the ground and moving with a velocity v_o after rupture. The conservation of momentum will require

$$M.v = m\ v_o \text{ or } v_o = M.v/m$$

Normally M will be much greater than m and thus v_o will be much greater than v. This should not be mixed up with the larger dynamic response of top layer compared to hard rock as we are refering to the action of an impulsive force. The contact between the object, moving with higher velocity than the ground, will be lost or in the other words the object will be tossed over the ground. Only if the object is tossed at an angle from the vertical it may occupy a new position after fall. For the suspended objects like ceiling fans to swing and hit the ceiling the force will have to be at about 45° from the vertical which may be so at an epicentral distance equal to focal depth. The observation during Cachar earthquake as in Figures 1 and 2 where ceiling fans in very different type of building could exhibit identical response could be easily explained by the foregoing mechanism. The short duration of shaking with high frequency at short focal distance of about 10 km and in structures of very different dynamic characteristics could not be explained by usual consideration of resonance.

After having considered the possible mechanism of loss of contact with ground of freely resting objects at very short focal distances during moderate earthquakes and to explain the liquefaction during two earthquakes under consideration to complete the discussion on overthrow of objects, we shall now consider a possible mechanism for this phenomena at comparatively larger epicentral distances during major and great earthquakes. The classical example of such observations is from Assam Earthquake of June 12, 1897. Several reports of rapid passage of ground waves undulating the the ground to heights comparable to heights of individuals and making it difficult for the observers to keep standing without taking support are available from the region where boulders were found dislodged from their original locations. Let us examine some details of these waves by taking probable emperical estimates of various parameters. A sinusidal wave is shown in Fig. 11 as ox. Typically the wave amplitude, velocity, frequency and wave length may be taken as 0.5 m , 2000-3000 m/sec, 4 to 6 Hz and 400 to 600 m respectively. The position of a freely resting object on the ground is marked when it is at the crest of the wave. The time taken for the crest to move away from the position of object to as shown in Figure 11 will be 1/16 to 1/24 sec. During this rapid, vertical and downward motion of ground the object because of its inertia of rest will loose contact with it and start falling freely. The height through which the object will fall during say 1/20 sec will be 0.0123 m which is very small compared to 0.5 m which will be displacement of the ground below it during the same time. Thus the object will come in contact with ground again when the wave is not at its crest but in some other random phase. The object may be made to roll down due to its having acquired some velocity and coming in contact with slanting ground and after the ground shaking has stopped it will rest in equilibrium at some new location.

EXPLANATION OF THE OBSERVED LIQUEFACTION

The freely resting object will in general possess more complex forms, and may be taken as a layer of cohesionless soil layer resting on a stiff substratum. The phenomena explained would cause decoupling of the top soil layer from the substratum, moblise the intergranular contact, disturb its soil structure, reduce its shear strength to zero and break its original role as membrane to hold pre-existing hydraulic gradient, if any. Thus, the action of impulsive force may cause quick-sand phenomena. The pre-existance of a hydraulic gradient as in the case of Cachar earthquake may further facilitate the phenemena.

The explaination being considered here is the loss of shear strength due to disturbance of soil structure by the impulsive force in the wake of rupture at short focal distance, and not the dynamic loading and that is why it is prefered to describe it as quick-sand phenomena and not liquefaction. Naturally observations for such a phenomena which can be triggered at short focal distances in moderate eathquake may appear and have been described as liquefaction but are not well explained as observations extend to areas where the soils are well drained, as in case of Great Nicobar earthquake, duration of shaking is too small to induce significant pore water pressure changes and peak ground acceleration is also not large.

Even the phenomena considered for loss of contact during large earthquakes at greater distances coupled with small but rapid changes in the value of gravity, inducing significant changes in body forces of light soil grains, may also be capable of disturbing the soil structure and may contribute to the liquefaction phenomena in addition to the development of porewater pressure.

CONCLUSIONS

The discussion presented here was to explain specific observations and has to some extend widened the scope of the explaination of the liquefaction phenomena under special circumstances. Inspite of the earthquake loading being dynamic in character at very short focal distances where duration of shaking is small the accompanying ground failure may be explained as quick-sand phenomena. The paper also proposes simple but physically acceptable mechanism for the loss of contact with ground of freely resting objects in epicentral region during shallow and moderate size earthquakes and hitting of objects with ceiling without resonance. Another explanation for this phenomena during major earthquake at some what larger epicentral distances has also been disucssed. Simple experimental demonstration of the proposed mechanism seems feasible, but has not been done, and will perhaps be required to make these ideas fully acceptable.

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