ABSTRACT: The paper discusses the geotechnical aspects of natural disasters and presents an approach to geotechnical investigation for disaster management. The relevant fields of landslides and earthquake have been given the main focus in the discussion. It is, however, believed that the approach should also be applicable to other areas of natural disaster which are triggered by geological phenomena.

1. INTRODUCTION

Geotechnical engineering is a discipline of civil engineering that deals with soil, rock and ground water and their relation to design, construction and operation of engineering projects. It also goes by the name of soil engineering, ground engineering or geotechnics. The subject is closely related to engineering geology which deals with the nature and formation of natural materials existing on or below the earth. Most civil engineering structures are supported on or built in the ground, and thus require major application of geotechnical engineering in their design and construction.

Soil conditions need to be known in advance in order to adequately support structures during their life time so that no disaster occurs during their life time. The leaning tower of Pisa—although a great tourist attraction—would not be something which one would like to see happening to one’s own construction however big or small it may be, Figure 1.

Building settlement and tilt of the type occurring in the Tower of Pisa are not uncommon. There are many instances of adjacent buildings on soft soil tilting towards each other. This famous picture, Figure 2, shows two grain silos built on Lake Agassiz clay in the Red River valley south of Winnipeg, Manitoba. The silos were built too close to each other and the pressure bulb under the footings overlapped causing higher stresses and therefore larger settlement under the parts of the ring foundations that were too close to one another. The net result was tilting of the structures which touched one another and eventually led to structural failure.

2. LANDSLIDE DISASTERS

Natural disasters such as landslides on hill slopes or large dams may involve movement of large quantities of earth. Figure 3 shows a simulation of the San Francisco bay area landslide which caused widespread destruction in 1997. On October 9, 1963, a landslide broke loose and filled the reservoir behind the Viont Dam in Italy. This in turn caused a huge wave of water to surge over the top the dam, flooding towns downstream, Figure 4.

A situation that occurred to a railroad failure after a landslide is shown in Figure 5.
The above instances of failure point to our lack of understanding of the response of soil to extreme loading conditions which were either not known at the time of design and construction or ignored, knowingly or unknowingly. Such disasters, when they occur, may lead to widespread loss of life and property which no amount of restoration work can ever bring back.

Natural disasters—in a wider context—involve large scale destruction of life and property which causes enormous hardship to the people. Natural disasters, e.g., earthquakes, landslides, cyclones and tsunamis are vividly engrossed in our mind today. We have seen many such instances of the fury of nature in recent years which needed large scale mobilization of resources, manpower and technological skill to ensure their proper management in terms of giving the affected people the kind of relief that would be required for their long and short term rehabilitation. Disaster management has become a major thrust area which pools together all our material and scientific resources to meet the challenges of nature’s fury when we confront them. In the context of India, some recent disasters, like the Orissa cyclone 2002, the Bhuj earthquake 2004, the Indian Ocean Tsunami 2005, and the numerous landslides in the Himalayas left us with no alternative but to wake up to the need for working out an effective management strategy for meeting the challenges posed by such disasters.

3. GEOTECHNICAL INVESTIGATION OF LANDSLIDES

Landslides are caused by rock, earth, or debris flow on slopes due to gravity. They can occur on any terrain given the right conditions of soil, moisture, and the angle of slope. Also known as mud flows, debris flows, earth failures, slope failures, etc., they can be triggered by rains, floods, earthquakes, and other natural causes including man-made causes, such as grading, terrain cutting and filling.

Landslides are natural hazards that affect large parts of India in geodynamically active domains in Himalayas in the north and northeastern parts of the country as well as relatively stable domains in Western Ghats and Nilgiri Hills in the southern part. In all 21 States and parts of Union Territory of Pondicherry are affected by this hazard mostly during monsoon. Landslides had disastrous consequences causing enormous economic losses and affecting the social fabric in the affected areas for a long time. In 2005 alone, more than 500 lives were lost due to this hazard in our country.

Landslides occur as natural phenomena in hilly terrains. They also occur due to disturbances caused by construction activities, e.g., housing and transportation. Natural slopes which have established a balance with the geological and geotechnical features of the area get disturbed by human actions like mining, deforestation and road construction which perforce are required to fulfill the development needs of the area.

Landslides fail to attract as widespread attention as earthquake or cyclone because landslides usually occur in “remote” areas on the hills, often far away from the urban growth centres. Yet instances are plenty where landslides have killed thousands of people and the resulting economic loss to the region has been no less than that from a major earthquake or cyclone.

While it is true that a number of factors, such as hill movement, rainfall, river flow and local and regional geology have important bearing on the landslide, at the time of actual movement it is basically the interplay of the forces of
instability with the resistance offered by the soil or rock that controls the ultimate slide. Geotechnical investigation, therefore, forms an integral part of a landslide management programme.

3.1 Requirements

The factors affecting landslides can be geophysical or man-made. They can occur in developed areas, undeveloped areas, or in any area where the terrain had been altered for roads, houses, utilities, and even for lawns in one's backyard. Investigation of landslides requires considerable judgment because natural slopes are seldom homogeneous and the shear strength of the soil is difficult to determine. While the mathematical analysis of stability can be done with the help of software it is often difficult to establish the shear strength of the soil or rock mass and the boundary conditions that are relevant at the time of failure.

Geotechnical investigation of landslides requires clear appreciation and understanding of the following:

(a) Failure mechanism of the slide
(b) Geometry of the failure plain
(c) Shear strength of the soil and rock along the failure surface
(d) Hydrological and geological features.

In homogeneous clay and clay shale the slip surface is often circular. But if, bedding planes or weak strata exist the slip surface may resemble a combination of various shapes or be even straight. The slip surface may be detected by field survey, test pits, trenches etc, Figure 6. The hydrogeologic condition at the time of a landslide is important, yet often unknown. Knowledge of the groundwater table and its flow, including seepage flow, if any, is required the analysis of a slide.

![Fig. 6: Depth and Length of Landslide (Skempton 1953)](image)

3.2 Stability Analysis

Slope stability analysis by the limit equilibrium method is the most common method of determining the stability of a landslide. The total disturbing force on the failure surface is compared to the stabilizing force due to shearing resistance along the same surface to obtain the factor of safety. This requires prior evaluation of the following:

(a) The geometry of the slip surface or the potential slip surface
(b) Soil parameters
(c) Water table and seepage condition
(d) Artificial loading, if any.

3.3 In-situ Shear Strength of Clays

While the different types of triaxial test have got their applications in specific field problems the most important strength parameters required for the analysis of short-term stability in cohesive soils are those obtained from the quick Unconsolidated Undrained (UU) triaxial test. For standard clays this shear strength is given by the undrained cohesion $C_u$ when $\phi_u$ should theoretically be zero. Therefore, the shear strength of the clay in this condition may be expressed as,

$$C = C_u$$

The major factors that are believed to cause such discrepancies are the stress release due to sampling, rate of testing, anisotropy and sample size.

3.4 Effective Stress Analysis

The effective stress method is used where the shear strength parameters of the soil in terms of effective stress, $c'$ and $\phi'$, are known along with the pore pressure developed along the failure surface. The pore pressure can be determined by using Skempton’s pore pressure parameters,

$$\Delta u = B[\Delta \sigma_3 + A(\Delta \sigma_1 - \Delta \sigma_3)]$$

where $A$, $B$ are the pore pressure parameters and $\Delta \sigma_1$ and $\Delta \sigma_3$ are the increase in major and minor principal stresses for the axi-symmetric case. The effective stress method is valid for all situations and takes into account the pore pressure while the total stress method gives the stability for sudden changes of loading.

3.5 Landslide Management Strategy

Landslide risk assessment involves a geological study followed by detailed geotechnical investigation. In order to have systematic study for development of standard codes and in planning capacity building for geological and geotechnical investigations, a few major landslides may be identified for carrying out detailed investigations. Organizations having expertise and knowledge in such investigation may be assigned the task of carrying out pilot studies to develop scientific methods of landslide investigation with the objective of:

- Standardization of LHZ mapping and site specific studies
- Understanding the mechanics of a landslide and working out remedial measures
- Design of surface and subsurface drainage Systems for stabilization of slopes
- Instrumentation for Geotechnical Investigation for detailed study of landslides
- Development of Early Warning System.
In India most landslides occur during the monsoon barring those that owe their origin to earthquake. Pore water pressure plays a major role initiating landslide events. Toe erosion by rivers or nalas and scouring of hill slopes by high velocity streams descending from the crown of the landslide gives rise to debris flow/slide. Hence, surface and sub-surface water management on the slopes or in the catchments forms an effective measure for controlling landslides.

Reinforcing techniques like nailing, bolting, anchoring and tie backs have all provided solutions to landslide problems and numerous examples of stabilization of problematic slopes bear ample testimony to the great potential of reinforcing technologies.

3.6 Instrumentation and Monitoring
Instrumentation for monitoring and prediction of landslide has not been a general practice in India. A detailed slope stability analysis and modeling of a landslide require instrument generated data. Monitoring shows acceleration of movement and development of pore pressures at different locations within the slide mass. It is, however, not practicable to monitor all landslides by the installation of instruments considering the prohibitive cost. Nevertheless, judicious monitoring can be used for warning the people about an impending disaster.

3.7 Geological Study
The area to be covered by geological mapping and the extent of subsurface geological investigation are guided by the geological complexity of the site. Detailed investigation should be planned and executed with close cooperation between geologist and geotechnical engineers.

After completion of surface geological mapping, the behavior of surface material and other features are required to be explored. The subsurface explorations should aim to establish:

- Depth to bedrock and thickness of overburden and weathering.
- Lithological characters of various rock units and their significance.
- Nature, spacing and continuity of joints, slip surface, minor and major shear zones, etc.
- Depth of ground water table.
- Permeability of strata and
- If possible, the depth and disposition of plane along which failure has taken place.

The above parameters can be determined by employing geophysical techniques that are easily available. Geophysical exploration should be done especially in the areas covered by debris or river-borne material/terrace deposits. Geophysical surveys including, resistivity surveys and seismic refraction surveys have been found helpful in determining above parameters. With developments in electronic and software technologies, the results are becoming more and more accurate and dependable.

Ground Penetrating Radar (GPR) can be initially employed in such surveys for evaluating depth and nature of bedrock and also ground water conditions. GPR surveys are very quick and provide results quickly. Other geophysical surveys like seismic (reflection) and resistivity surveys can follow the initial GPR Surveys.

3.8 Geotechnical Investigation
Preliminary studies and investigations, detailed geological mapping and planned geophysical surveys give a fair assessment of severity of the hazard, the dimensions and geometry of landslide and rough idea about the type and shape of plane of failure. The data thus obtained can be utilized to plan and conduct further subsurface exploration and for designing and implementing mitigation measures.

The investigations indicated below are required to be carried out at this stage:

(a) Detailed engineering and geological mapping on suitable scale.
(b) Supplementary or confirmatory subsurface exploration including drilling should be done at this stage. Standard Penetration Test (SPT) may be carried out concurrently with drilling.
(c) Collection and testing of samples involved in sliding is to be done to determine the physical and engineering properties of the soil involved in the landslide. Geo-hydrological characteristics of the slide mass and adjacent in situ mass should be defined.

The data obtained from preliminary and detailed geological and geotechnical investigations of the slide area may be analyzed to determine the status of stability of landslide or slope. It can also be used for developing a numerical model for determining the hazard potential and evolving a comprehensive, effective and economically feasible treatment plan to stabilize the landslide depending upon its risk potential.

4. EARTHQUAKE EFFECT ON SOILS AND FOUNDATION
Earthquakes can cause extensive damage to foundations and structures built on them. Earthquake motions are initiated in the soil and they are instantaneously transmitted to the foundation causing adverse effect on structure. Damage may occur due to rapid ground movement including differential movement. While structural damage is ultimately manifested in tilt or damage or even collapse of the superstructure the initiating cause is often identified as the adverse response of the soil-foundation system to seismic forces.

Geotechnical considerations are, therefore, important in the development of an earthquake resistance design. It is not only the type of soil that determines the kind of response to be expected during a strong earthquake. The type of structure also influences the seismic response. The field of
Geotechnical earthquake engineering is quite complex. Much of its application is based on empirical studies made on the basis of case studies which illustrate the effect of earthquake on engineering structures.

4.1 Earthquake Characterization

4.1.1 Magnitude of Earthquake

The most widely used magnitude scale to define the severity of an earthquake was developed by Richter (1958). Accordingly to this the magnitude of an earthquake is given by the logarithm of the amplitude on a Wood-Anderson torsion seismogram located at a distance of 100km from the earthquake source. Thus,

\[ M = \log \left( \frac{A}{T} \right) + f(\Delta, h) + C_s + C_r \quad (3) \]

where,
- \( A \) = Amplitude in (.001) mm
- \( T \) = Period of seismic wave (seconds)
- \( f \) = Correction factor for epicentral distance (\( \Delta \)) and focal depth (\( h \))
- \( C_s \) = Correction factor for seismological station
- \( C_r \) = Regional correction factor

4.1.2 Energy Release

The energy released by an earthquake has been related to the magnitude (M) by the equation,

\[ E = 10^{4.8+1.5M} \text{ (Joule)} \quad (4) \]

This energy is comparable to that of nuclear explosions. For example, a nuclear explosion of one megaton releases energy of \( 5 \times 10^{15} \) joule. An earthquake of magnitude 7.3 would also release the energy equivalent of one megaton nuclear explosion.

4.1.3 Intensity

The magnitude of an earthquake as obtained by the Richter’s scale gives measure of the amount of energy released by the earthquake. The intensity of an earthquake is a measure of the effect of an earthquake at a given location. Several intensity scales have been proposed; the most widely used being the modified Mercalli Scale (MM), Table 1. The value assigned to the MMI scale gives qualitative description of the damages based on physical verification at site. The equivalent value of the magnitude by Richter’s scale is given alongside the MM in Table 1 (See also Rao 2001).

4.2 Ground Acceleration

The intensity of ground motion during an earthquake is represented by the horizontal ground acceleration produced. The predominant effect of an earthquake is the horizontal forces that are produced in a structure. The horizontal ground acceleration (\( \alpha \)) gives a measure of this force, which can be expressed by \( \alpha W \) (where, \( W \) = weight of the structure) and acts at the centroid of the structure, Figure 5. I.S. 1893 gives the earthquake zones of India based on the horizontal ground acceleration and vulnerability to earthquakes.

<table>
<thead>
<tr>
<th>[MM]</th>
<th>Evaluation</th>
<th>Description</th>
<th>Magnitude [Richter]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Insignificant</td>
<td>Only detected by instruments</td>
<td>1</td>
</tr>
<tr>
<td>II.</td>
<td>Very light</td>
<td>Felt by sensitive persons—oscillation of hanging objects</td>
<td>2</td>
</tr>
<tr>
<td>III.</td>
<td>Light</td>
<td>Small vibratory motion</td>
<td>3</td>
</tr>
<tr>
<td>IV.</td>
<td>Moderate</td>
<td>Felt inside buildings; noise produced by moving objects</td>
<td>4</td>
</tr>
<tr>
<td>V.</td>
<td>Slightly strong</td>
<td>Felt by most persons; some panic; minor damages</td>
<td></td>
</tr>
<tr>
<td>VI.</td>
<td>Strong</td>
<td>Damages to non seismic resistant structures</td>
<td>5</td>
</tr>
<tr>
<td>VII.</td>
<td>Very Strong</td>
<td>People running; some damages in seismic resistant structures and serious damages to masonry structures</td>
<td></td>
</tr>
<tr>
<td>VIII</td>
<td>Destructive</td>
<td>Serious damage to structures in general</td>
<td>6</td>
</tr>
<tr>
<td>IX.</td>
<td>Ruinous</td>
<td>Serious damage to structures; almost total destruction of nonseismic resistant structures</td>
<td></td>
</tr>
<tr>
<td>X.</td>
<td>Disastrous</td>
<td>Only seismic resistant structures remain standing</td>
<td>7</td>
</tr>
<tr>
<td>XI.</td>
<td>Disastrous in extreme</td>
<td>General panic; almost total destruction; the ground cracks and opens</td>
<td>8</td>
</tr>
<tr>
<td>XII.</td>
<td>Catastrophic</td>
<td>Total destruction</td>
<td>9</td>
</tr>
</tbody>
</table>
4.3 Response Spectrum

Response spectra are typically used to portray the characteristics of the earthquake shaking at a site. The response spectrum shows the maximum response induced by the ground motions in damped single-degree-of-freedom structures of different fundamental periods. Each structure has a unique fundamental period at which the structure tends to vibrate freely without any external excitation. The response spectrum indicates how a particular structure with its inherent fundamental period would respond to an earthquake ground motion. For example, measurement of ground motion in the 1985 Mexico City earthquake, Figure 2, shows that a low-period structure (say, $T = 0.1$ s) experienced a maximum acceleration of 0.14g, whereas a higher-period structure (say, $T = 2.0$ s) experienced a maximum acceleration of 0.74g for the same ground motions.

The Uniform Building code of USA recommend the response spectrum, Figure 7, to determine the peak ground acceleration for a given fundamental period T for different soil conditions. For $T > 0.5$ seconds ground acceleration for deep soil strata is considerably higher than that for rock and hard soils. It is to be noted that the period of ground motion at a particular site is important in determining the effect of earthquake motion on the structure. If the fundamental period of a building is close to that of the site a resonant condition is created. This amplifies the shaking and increase the potential to damage.

4.4 Geotechnical Investigation of Earthquakes

The major effects of earthquake on soils are:

(a) Loose granular soils are compacted by ground vibration which causes large subsidence of the ground.

(b) Compaction of loose granular soil may result in development of excess pore water pressure to cause liquefaction of the soil and lead to settlement and tilting of structures.

(c) Combination of dynamic stress and induced pore water pressure may result in reduction of soil strength and cause bearing capacity failure and landslides in the earthquake area.

(d) Ground vibrations and shaking may cause structural damage even though the soils underlying the structure may remain stable during the earthquake.

4.4.1 Ground Settlement

Vibration has long been recognized as a means of compacting granular soils. However, such compaction is associated with volume change of the soil and associated ground subsidence. A measure of the ground subsidence caused by earthquake was obtained in the Alaska earthquake in 1964. A combination of 1.3 m settlement of rock due to tectonic movement and 1.3 m due to compaction of overlying soil led to a ground settlement of more than 2.6 m. Similar subsidence was noticed in other earthquakes also, Table 2.

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>Year</th>
<th>Rock subsidence (m)</th>
<th>Ground subsidence (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homer, Alaska</td>
<td>1964</td>
<td>0.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Portage, Alaska</td>
<td>1964</td>
<td>1.3</td>
<td>2.6</td>
</tr>
<tr>
<td>Validina, Chile</td>
<td>1960</td>
<td>1.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Niigata, Japan</td>
<td>1964</td>
<td>–</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Ground settlement due to compaction of granular soil often leads to differential settlement of structures. A differential movement of more than a metre was noticed between a railroad bridge abutment, founded on deep piles, and the backfill placed directly on the ground surface during the Niigata earthquake of 1964, Figure 9. The bridge abutment, being founded on piles did not undergo much settlement but the granular backfill experienced major subsidence due to compaction by seismic vibrations. Field measurements have shown that vibrations induced by earthquakes are often responsible for causing significant structural damage resulting from differential settlement in a building frame. Field observations of earthquake-induced settlement in saturated sandy soil are summarized in Table 3.

<table>
<thead>
<tr>
<th>Location &amp; year</th>
<th>Magnitude of earthquake</th>
<th>Site</th>
<th>Thickness of sand layer (m)</th>
<th>Observed settlement (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mexico, 1957</td>
<td>7.5</td>
<td>Mexico City</td>
<td>–</td>
<td>40</td>
</tr>
<tr>
<td>Tokachioki, 1968</td>
<td>7.9</td>
<td>Hachinohe</td>
<td>5.0</td>
<td>35</td>
</tr>
<tr>
<td>Niigata, 1964</td>
<td>7.5</td>
<td>Niigata C</td>
<td>9.0</td>
<td>20</td>
</tr>
<tr>
<td>Mieiken-oki, 1968</td>
<td>7.4</td>
<td>Arahama</td>
<td>9.0</td>
<td>20</td>
</tr>
</tbody>
</table>

4.5 Liquefaction

Major damage to structures during earthquakes is caused by liquefaction in saturated fine sand and silt. This is seen as ‘sand boils’ or ‘mud spouts’ with associated ground cracks and development of quicksand—like condition over wide areas. Liquefaction is caused in sand by ground vibration which tends to compact the sand and decrease its volume. If drainage does not occur the tendency to decrease in volume results in increased pore water pressure. If the pore pressure builds up to an extent which is equal to the overburden pressure the effective stress becomes zero and the soil loses its strength completely and gets into a liquefied state. Once liquefaction occurs at some depth the excess pore pressure tends to dissipate by upward flow of water which, in turn, induces liquefaction in the upper layers of the soil. (See Ambreseys & Sarma 1969). The recent Bhuj earthquake in India give vivid illustrations of liquefaction Figure 10.

4.5.1 Liquefaction Potential

The liquefaction potential of a soil depends on the relative density, percentage of fines present in the soil, effective confining pressure, depth of water table and the ground acceleration produced by the earthquake.

For practical use, the liquefaction potential may be studied from a comparison of the shear stress developed in the soil at a given depth by an earthquake and the shear stress required to cause liquefaction, the latter being related to the relative density of the of the soil as measured by the SPT blow count \(N\) (blows/30 cm). Based on the above, a procedure for evaluating liquefaction potential of a soil has been proposed by Seed (1988). The analysis involves determination of average cyclic shear stress caused by the earthquake and the cyclic shear stress required to cause liquefaction. Table 4 gives the data on grain size of the soil and depth of liquefaction in some well-known earthquakes.

In appears that liquefaction generally occurs in fine to medium sand within a depth of 10 m from ground surface. With increasing overburden the chances of liquefaction usually decreases.

<table>
<thead>
<tr>
<th>Location &amp; year</th>
<th>Magnitude of earthquake</th>
<th>Grain size (D_{10}) (mm)</th>
<th>Depth of liquefaction (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niigata, 1964</td>
<td>7.5</td>
<td>0.07–0.25</td>
<td>5</td>
</tr>
<tr>
<td>Mino-Owan, Japan, 1969</td>
<td>7.4</td>
<td>0.05–0.25</td>
<td>9</td>
</tr>
<tr>
<td>Jaltipan, Mexico, 1959</td>
<td>6.9</td>
<td>0.01–0.10</td>
<td>7</td>
</tr>
<tr>
<td>Alaska, 1964</td>
<td>7.0</td>
<td>0.01–1</td>
<td>8</td>
</tr>
</tbody>
</table>

4.5.2 Measures to Prevent Liquefaction

It is evident from the foregoing that liquefaction occurs in loose fine to medium sand and silt with particle size varying
from 0.01–0.25 mm and N value less than 15. Further, liquefaction occurs mostly in the top 10–15 m of the soil. At greater depth increasing overburden pressure causes natural compaction of the soil and the liquefaction potential decreases. It is necessary to ascertain the liquefaction potential of a site for the design earthquake magnitude and the probable depth of liquefaction by appropriate analysis. The extent to which the ‘N’ value is to be improved may then be determined by suitable trials. Measures to prevent liquefaction in the field may, therefore, be summarized as follows:

- Compaction of loose sand by compaction with vibratory rollers, compaction piles, vibroflotation and blasting and grouting, chemical stabilization, application of surcharge and drainage by coarse blanket.
- Field compaction to densify the soil to prevent liquefaction has the added advantage of compacting the soil sufficiently to prevent ground subsidence during earthquake.

5. SUMMARY AND CONCLUSION

Natural disasters are common phenomena which occur in all parts of the world causing widespread destruction of life and property. Landslides, earthquake, cyclone and tsunami affect the life of people in vulnerable areas almost in regular occurrences. With the advances in science and technology it is no longer possible to leave these occurrences to the realm of unforeseen tragedies. The cause of all natural disasters is now well known. All that is required is timely intervention for organizing remedial measures to minimizing hardship and to work out forecasting techniques for future management of such natural disasters.

Geotechnical engineering plays an important role in most natural disasters because ground contour, geology, engineering behaviour of soils, ground water characteristics, land use pattern, coastal engineering and earthquake effect on soils etc. play dominant roles in the understanding of the behaviour of all natural disasters. Systematic study is required to evaluate the extent of disaster and to work out appropriate remedial measures. Geotechnical investigation and monitoring play dominant roles in all these. Being very much a practical science dealing with the welfare of people it is necessary to work in tandem with field personnel and government departments to work out a management strategy which will not only be scientifically appropriate but cost effective too.

REFERENCES


