GEOTECHNICAL ASPECTS OF LANDSLIDES AND CONTROL OF LANDSLIDE HAZARDS

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Achieved balance with geological and geotechnical features of the hill slope.

Disturbed by natural phenomena e.g., heavy rainfall, earthquake etc.

Disturbed by human actions, e.g., mining, deforestation, road construction etc.
Landslide on hill slope (diagrammatic)
Monitoring landslide
MAJOR FACTORS

- Hill movement
- Rainfall
- River flow and toe erosion
- Local and regional geology

Frequent occurrence of landslides during heavy rainfall
(Zaruba and Mencl 1976)
# Classification of Landslides

<table>
<thead>
<tr>
<th>Type</th>
<th>Maximum depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface slide</td>
<td>&lt; 1.5</td>
</tr>
<tr>
<td>Shallow slide</td>
<td>1.5 – 5.0</td>
</tr>
<tr>
<td>Deep slide</td>
<td>5.0 – 20.0</td>
</tr>
<tr>
<td>Very deep slide</td>
<td>&gt; 20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely rapid</td>
<td>&gt; 3 m / sec</td>
</tr>
<tr>
<td>Very rapid</td>
<td>0.3 m / min – 3m / sec</td>
</tr>
<tr>
<td>Rapid</td>
<td>1.5m / day – 0.3m / min</td>
</tr>
<tr>
<td>Moderate</td>
<td>1.5m / month – 1.5m / day</td>
</tr>
<tr>
<td>Slow</td>
<td>1.5m / year – 1.5m / month</td>
</tr>
<tr>
<td>Very slow</td>
<td>0.06m / year – 1.5m / year</td>
</tr>
<tr>
<td>Extremely slow</td>
<td>&lt; 0.06 m / year</td>
</tr>
</tbody>
</table>
CAUSES OF LANDSLIDES

- Toe erosion – river, stream, glaciers
- Tectonic movement
- Rains and melting slow
- Shrinkage and drying
- Rapid draw down - dams
Active stream within a landslide
Rock – cum debris slide
TYPES OF LANDSLIDE

- Fall
- Translational slide
- Topple
- Mud flow
- Rotational slide
- Debris flow
INVESTIGATION OF LANDSLIDES

Necessary data

- Failure mechanism
- Geometry of failure plan
- Shear strength of soil & rock
- Hydrogeological features
STABILITY ANALYSIS

- Geometry of slip surface
- Soil parameters
- Water table and seepage condition
- Artificial loading, if any

Total stress analysis
Effective stress analysis
Determination of in-situ strength from analysis of existing slopes

For stable slopes:
$$F_D < F_S$$

For slopes at failure
$$F_O = F_S = S_U L$$
The short-term stability of a clay slope is generally determined by the total stress method. The undrained shear strength of the clay is determined in the laboratory from quick unconsolidated undrained (UU) triaxial tests on 38mm dia x 75mm, long specimens trimmed from undisturbed samples of larger diameter.
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.
FACTORS AFFECTING $C_u$

- Sampling disturbances
- Stress release due to sampling
- Rate of testing
- Anisotropy
- Sample size
SAMPLING DISTURBANCES

- Mechanical disturbances
- Type of sampler
  - Open – drive sampler
  - Piston sampler
- Area ratio : 15 %
SOIL PARAMETERS

1. Method of analysis
   a) Total stress \( \phi_u = 0 \)
   b) Effective stress \( C' = \phi' \)

2. In – Situ strength and Laboratory strength

3. Stress path effect
INFLUENCE OF SOIL TYPE

The type of failure surface in a landslide movement is significantly dependent on the type of soil in which the failure occurs:

Soft normally consolidated clays are generally intact and homogeneus and the failure surface is often circular. Such clays may be sensitive and the strength is affected by sampling disturbances. Mesri (1981) and Aas (1981) suggest that the in-situ strength of such clays may be taken as:

\[ C_u = 0.22 \sigma_{v'} \]

Where \( \sigma_{v'} \) is the effective overburden pressure.
**Residual soils** are formed by the weathering and decomposition of in-situ rocks. The soil or the rock gets fully decomposed at the surface but gradually changes into the parent rock at some depth. The soil near the surface is more homogeneous than the rock at depth because of the absence of folds, fissures and joints. Shallow transnational slides are common.
The **in-situ strength of rocks** is difficult to determine from laboratory tests because of the presence of joints and fissures. The stability of rock slopes is seldom governed by the strength of the intact rock. Slides generally occur along joints and fissures or along the bottom of the rock fragments of the surface as debris flow.

![Debris flow in steep slope](image)
EFFECTS OF EARTHQUAKE

A) Loose granular soils are compacted by ground vibration which cause large subsidence of the ground surface.

B) Compaction of loose granular soil may result in development of excess hydrostatic pressure to cause liquefaction of the soil and lead to settlement and tilting of structures.

C) The dynamic stress in the soil and induced pore water pressure may result in reduction of soil strength and cause landslides.

D) Ground vibrations and shaking may cause structural damage even though the soils underlying the structure may remain stable during the earthquake.
Ground settlement around well casing at Homer in Alaska earthquake 1964
<table>
<thead>
<tr>
<th>Earthquake</th>
<th>Year</th>
<th>Rock Subsidence (Tectonic)</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>
Differential settlement between bridge abutment and backfill in Niigata earthquake, 1964
LIQUEFACTION

A major damage to structure during earthquakes is caused by liquefaction in saturated sand. This is seen as ‘sand boils’ or ‘mud spouts’ with associated ground cracks and development of quick sand – like condition over wide areas. When liquefaction occurs, buildings may sink into the ground. Lightweight structures may even “float” up to the ground surface. A most vivid illustration of liquefaction was found in Niigata earthquake, Japan in 1964. Extensive liquefaction of the soil caused water to flow out of cracks and boils. Structures settled more than 1m accompanied by severe tilting.
Liquefaction in Niigata Earthquake, Japan, 1964
Liquefaction in Niigata Earthquake, Japan, 1964
Liquefaction in Bhuj Earthquake, India, 2001
Liquefaction in Bhuj Earthquake, India, 2001
CAUSE OF LIQUEFACTION

- Ground vibration tends to compact sand and decrease its volume
- If drainage does not occur pore pressure builds up
- When pore pressure is equal to overburden pressure effective stress becomes zero

\[ \sigma' = \sigma - u \]

- Sand loses strength and gets into liquefied state
Field observation of liquefaction
Liquefaction potential in soil
Liquefaction potential as a function of depth and standard penetration resistance for different percentage of fines
### TABLE – 4

**Depth of liquefaction**

<table>
<thead>
<tr>
<th>Location &amp; Year</th>
<th>Magnitude of Earthquake</th>
<th>Grain size $D_{10}$ (mm)</th>
<th>Depth 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>8.3</td>
<td>0.01-0.01</td>
<td>8</td>
</tr>
</tbody>
</table>
A simplified procedure for evaluation of liquefaction potential is to determine the average cyclic shear stress imparted by the earthquake by the equation.

\[
\left( \frac{\tau}{\sigma_0} \right)_d = 0.65 \cdot \frac{\alpha}{g} \cdot \frac{\sigma_o}{\sigma_o} \cdot r_d
\]

Where

\[
\left( \frac{\tau}{\sigma_0} \right)_d = \text{average cyclic shear stress developed during earthquake}
\]

\[
\alpha = \text{maximum ground acceleration}
\]

\[
g = \text{acceleration due to gravity}
\]

\[
\sigma_o = \text{total stress at depth of interest}
\]

\[
\sigma_o/ = \text{effective stress at depth of interest}
\]

\[
r_d = \text{reduction factor with depth}
\]
Earthquake are responsible for some of the greatest landslides in recorded history. These slides have occurred in all kinds of ground situation:

a) Slides caused by liquefaction in cohesion less soil involving sand, silty sand and gravelly sand with sand seams.

b) Slides may occur in relatively thin layers of silt and fine sand at some depth in otherwise firm ground. Failure is attributed to liquefaction in the sand seams within the clay deposit or formation of water films along the vicinity of the slide surface.

c) Collapse of fills due to liquefaction or failure of loose saturated sand and silt. Such failure resembles flow of heavy liquid due to loss in shear shear strength of the soil. The magnitude of deformation is governed by the initial stresses and the residual strength of the soil, which is a function of the void ratio of the soil.
Liquefaction potential of granular soil
(Oshaki 1970)
MEASURES TO PREVENT LIQUEFACTION

1. Compaction of loose sand
   - Compaction with vibratory rollers
   - Compaction piles
   - Blasting

2. Grouting and chemical stabilization

3. Application of surcharge

4. Drainage by coarse blanket and drains
LANDSLIDE HAZARDS ZONATION

Contribution Features

Natural : Unstable Geology

  Heavy rainfall / cloudburst

  Rain – induced

  Earth – quake induced

Man - made : Indiscriminate construction

  Interference with natural drainage
# MACRO – ZONATION OF LANDSLIDE (RAO 1997)

<table>
<thead>
<tr>
<th>Hill Range</th>
<th>Landslide Incidence Potential</th>
<th>General Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Himalayas</td>
<td>Very high to high</td>
<td>Predominantly natural Increasing due to human intervention</td>
</tr>
<tr>
<td>North Eastern Hill Ranges</td>
<td>High</td>
<td>Predominantly natural</td>
</tr>
<tr>
<td>Western Ghats and Nilgiris</td>
<td>High to moderate</td>
<td>Human interventions dominate Natural causes secondary</td>
</tr>
<tr>
<td>Eastern Ghats</td>
<td>Low</td>
<td>Predominantly due to human intervention</td>
</tr>
<tr>
<td>Vindhyas</td>
<td>Low</td>
<td>Predominantly due to human intervention</td>
</tr>
</tbody>
</table>
# Weightage of Causative Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weightage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope angle</td>
<td>10</td>
</tr>
<tr>
<td>Land – use pattern</td>
<td>9</td>
</tr>
<tr>
<td>Geology</td>
<td>8</td>
</tr>
<tr>
<td>Geomorphology</td>
<td>6</td>
</tr>
<tr>
<td>Tectonics</td>
<td>5</td>
</tr>
<tr>
<td>Rainfall</td>
<td>3</td>
</tr>
</tbody>
</table>
In recent years, Building Materials Technology Promotion Council (BMTPC) and the centre for Disaster Mitigation and Management, Anna University (CDMM) have undertaken the task of preparing an Atlas on Landslide Hazard Zonation for the country. Two volumes of atlas pertaining to Uttaranchal and Himachal Pradesh have already been prepared.
LANDSLIDE
CONTROL MEASURES
Flattening of the slope

75 m

115 m

45°

Slide

25°
Excavation in upper hills
Provision of Drainage
Stitching of the debris cover to the rock
Retaining Walls
Drum – debris retaining walls
Grouting

Grouting can be an effective method of improving the shear strength and decreasing the permeability of coarse-grained soil. The method is particularly suitable for filling voids in the rock mass. Cement grouts are injected under pressure to close the voids in the rock.
Geotextiles

Geotextile have in recent years been used to stabilize hill slopes. Geotextile – wrapped filter drains are inserted into the slope extending beyond the estimated slip surface. They are connected to crib wall at the base which is made of crushed rock to provide drainage of water from the transverse drains.
THANK YOU