Landslide and Mitigation Measures and Approach

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A general view of the presence of IIT Mandi in Mid-Himalayan Region
A Geo-technical engineer’s view

Introduction

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- The various types of landslides can be differentiated by the kinds of material involved and the mode of movement.
The most common types of landslides. Source: USGS
Causative factors

- **Internal Causes**
  - Influence of slope-
  - Ground water or associated water
  - Rain water percolates through some fractures
  - Decomposition of minerals
  - Lithology-
  - Geological structures-
  - Human Influence

- **External Causes**
  - Earthquake
  - Blasting
  - Volcanic eruption

LANDSLIDE MITIGATION MEASURES
Monsoon disaster is a significant concern that spans the 22 states and 2 union territory of the country, affecting landslides and related disasters. These landslides vary in scale and severity. Mitigation strategies cannot be initiated without understanding the factors that trigger slope instability. The investigation of these factors includes both natural and anthropogenic elements.

**Natural Factors: Inherent Factors**
- Lithology (Type of Rock)
- Structure
- Slope
- Hydro-geological condition
- Geotechnical parameters

**External Factors**
- Seismicity
- Precipitation (Rainfall)
- Melting of snow
- Volcanic eruption

**Anthropogenic Factors**
- Improper land use
- Deforestation
Flowchart of methodology followed for investigation of landslides
1. Avoid or eliminate the problem itself
   - Facility relocation
   - Complete removal of slides
   - Bridging
   - Tunneling
   - Buttressing
   - Retaining structures
   - Reinforced soil slope and walls

2. Increase the resisting forces
   - Reinforcement
   - Surface slope protection
   - Unloading

3. Reduce the driving forces
   - Drainage systems
     - Surface drainage
     - Sub surface drainage

Drainage measures alone may not sufficient to improve slope stability, so drainage measures are adopted in conjunction with other methods based on the site specific requirement.

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THE SIZE OF THE INTERVENTION IS CHOSEN TAKING INTO ACCOUNT:
- Type of Infrastructure to be Protected
- Extent of the most probable Landslide/ Rock fall
- Correct evaluation of the technical feasibility of the solution
- Extent of Risk involved

A RISK ANALYSIS IS REQUIRED
### HAZARD RISK ASSESSMENT MATRIX

<table>
<thead>
<tr>
<th>Frequency of Occurrence</th>
<th>Hazard Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>(A) Frequent</td>
<td>1A</td>
</tr>
<tr>
<td>(B) Probable</td>
<td>1B</td>
</tr>
<tr>
<td>(C) Occasional</td>
<td>1C</td>
</tr>
<tr>
<td>(D) Remote</td>
<td>1D</td>
</tr>
<tr>
<td>(E) Improbable</td>
<td>1E</td>
</tr>
</tbody>
</table>

- **Unacceptable**
- **High**
- **Medium**
- **Low**

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### Risk Assessment Chart

- **Risk**
- **Cost**
- **Total Cost**

Minimun total cost at Plan 3.
Gabions

- Permeable
- Flexible
- Eco-friendly
- Simple to Construct

Stones from HILL CUTTING is used for filling GABIONS

Gabion Retaining walls along MUMBAI-PUNE EXPRESSWAY (2003)

Reinforced Soil System with Green Facia as facing element and secondary reinforcement

High Strength geogrid as main reinforcement
REINFORCED GABION

Reinforced Soil Systems – Sikkim Airport

CUT SLOPE STABILIZATION

Soil nailing with Gabion fascia

Soil nailing with Flexible fascia
SYSTEMS FOR ROCKFALL MITIGATION MEASURES

Prevention measures
- Act to control the detachment of rock/stabilize rock slope
- Rock anchors
- Drainage controlled blasting

Protection measures
- Controlling the direction, distance of fall and guide the falling rock.
- Berms
- Ditches
- Rock sheds

Retention measures
- Retains debris from falling down the slope.
- Secured Drapery (Mesh+anchors)
- Shotcrete

Warning measures
- Help in detection of rockfall or slope movement
- Using predictive warning alarms, remote monitoring systems and danger flashers
- Fences and warning signals triggered by falling rocks or detached rock masses

Active measures:
- Engineered cutting of slopes
- Retaining walls
- Nailing

Passive measures
- Nets
- Barriers
- Meshing/Shotcreting
- Early warning system

Remedial measures
- Drainage system
- Bio-engineering

References:
Chaturvedi et al., 2017
Crozier, 2010
Vertiver.org
- The retaining walls are subjected to dynamic earth pressure in seismic zones, the magnitude of which is more than the static earth pressure due to ground motion.

- For the analysis and design of retaining walls in earthquake-prone zones, accurate estimation of dynamic earth pressures is very important.

- Conventional methods either use pseudo-static approaches of analysis even for dynamic cases or a simple single-degree of freedom model for the retaining wall-soil system.

- As per **pseudo-static analysis**, the earthquake forces are considered as equivalent static forces which are obtained by multiplying the weight of the sliding wedge with seismic coefficients.

- In actual analysis, a lateral force acting through centroid of sliding mass is applied which acts in out of slope direction. This pseudo-static lateral force $F_h$ is calculated as follows:
  - $F_h = m \cdot a = W_s/g \cdot W_{hmax}/g = k_s W$
  - $W_s$ = horizontal pseudo-static force acting through centroid of sliding mass in out of slope direction. For two dimensional analysis, slope is usually assumed to have unit length.
  - $W_s$ = total mass of slide material.
  - $W$ = total weight of slide mass.
  - $a$ = acceleration,
    - maximum horizontal acceleration at ground surface due to earthquake, ($=a_{max}$)
  - $a_{max}$ = peak ground acceleration.
  - $a_{max}/g$ = seismic coefficient.
Certain guidelines regarding selection of seismic coefficient is as follows:

- Higher the value of peak ground acceleration, higher the value of $k_h$.
- $K_h$ is also determined as function of earthquake magnitude.
- When both items are considered, $k_h$ should never be greater than $a_{max}/g$.
- For small slide mass, $k_h = a_{max}/g$.
- For intermediate slide mass, $k_h = 0.65 \cdot a_{max}/g$.
- For large slide mass, $k_h = 0.1$ for sites near faults generating 6.5 magnitude earthquake and, $k_h = 0.15$ for sites near faults generating 8.5 magnitude earthquake.
- $K_h = 0.1$ for severe earthquake,
  $= 0.2$ for violent and destructive earthquake and
  $= 0.5$ for catastrophic earthquake.