Theme 5
Slope Instability Hazard and Risk Assessment
Theme 5.1
Definitions
Landslide Hazard

- A landslide hazard is a slope failure or slope movement that has the potential to cause damage.

It is defined by:
- Size and depth of failure
- Frequency and speed of movement

Landslide Risk

- Landslide risk is the actual or expected loss caused by a landslide hazard occurring.

It is defined by:
- Landslide hazard
- Location of the hazard in relation to the road (above, below or through)
- The vulnerability of the road structures to damage
- Their combined value
- Other related costs (maintenance costs, traffic delays & social costs)
An Assessment of Landslide Hazard and Risk is Required in Order to be Able to Prioritise Preventative or Remedial Works

- This is preferably carried out using an objective and formal risk assessment approach via a Landslide or Damage Inventory
Risk Computation in Landslide Inventory

\[ R \text{ (risk)} = \text{Magnitude} \ (M) \times \text{Probability} \ (P) \times \text{Value} \ (V_a) \times \text{Vulnerability} \ (V_u) \]

- Magnitude is the size of the landslide or slope failure
- Probability is the likelihood of a ground movement or slope failure occurring within a given time, such as a road design life
- Value is the value of elements judged to be at risk (e.g. a retaining wall or a side drain)
- Vulnerability is the degree of damage considered likely to occur to a given element at potential risk should the ground movement or slope failure occur.
Landslide Risk is therefore ultimately measured in terms of economic (and social) loss

- Repairs/losses caused by landslide impacts to engineering assets
- Landslide debris clearance and access provision in landslide areas
- Traffic delays
- Social and environmental costs*

*considered to be comparatively low in Lao PDR
### Emergency Maintenance Expenditure (US$M)

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Landslide removal and repair</th>
<th>Carriageway repairs and road grading</th>
<th>Total emergency maintenance expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004-05</td>
<td>5.15</td>
<td>1.19</td>
<td>6.34</td>
</tr>
<tr>
<td>2005-06</td>
<td>3.17</td>
<td>3.43</td>
<td>6.59</td>
</tr>
<tr>
<td>2006-07</td>
<td>3.14</td>
<td>2.08</td>
<td>5.21</td>
</tr>
</tbody>
</table>

Between 50-80% of emergency maintenance costs are due to landslides
Basis for Inventory Hazard and Risk Rating

- Failure in hill slope but not cut slope: Debris may slip on to side drain or road
- Failure in cut slope and hill slope: Debris will block drain and may block road
- Failure in cut slope only: Debris will block drain and may partially block road
- Erosion of cut slope surface: Debris will block drain and may block road
- Erosion of fill slope surface: Part of the road may eventually be lost
- Line of original ground
- Cut slope
- Side drain
- Road
- Fill slope
- Original valley slope
- River undercutting: Zone liable to damage from river bank erosion
- Deep failure in original ground below road: A whole section of road will eventually be lost, and will be difficult to replace
- Failure in fill slope only: Part of the road will be lost
- Failure in fill slope and original valley slope: Road is seriously endangered
- Failure in original valley slope only: Head-ward retreat will endanger road
zard ~ Low - Mod
ue ~ High
nerability ~ Low
k ~ Low - Mod
Hazard ~ Low - Mod
Value ~ High
Vulnerability ~ High
Risk ~ High
SEACAP 21/002 Landslide Hazard and Risk Inventory

- Notes, photographs and hazard/risk rating for >150 landslides
- Over 1,100 km of National Road included in Inventory
- Selected Roads:
  1E, 3, 4, 8, 12, 13N (as far as Chinese Border), 18

<table>
<thead>
<tr>
<th>Road</th>
<th>Km</th>
<th>Grid Ref (E/N)</th>
<th>Geology</th>
<th>Hazard Type</th>
<th>Risk (without mitigation)</th>
<th>Measures Taken</th>
<th>Degree of Success/ Residual Effects</th>
<th>Risk (without mitigation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>128+8 00</td>
<td>105°09'00&quot; 18°22'16&quot;</td>
<td>Granite WG II</td>
<td>Deep seated rockslide in cut slope. Approx 40m road length, extends approx 80m upslope</td>
<td>$M = 3$ $P = 2$ $Va = 3$ $Vu = 1$ $R = 18$</td>
<td>None, debris clearance only. Only other option would be large RW</td>
<td>OK, probable continued movement of debris into road</td>
<td>$M = 3$ $P = 2$ $Va = 3$ $Vu = 1$ $R = 18$</td>
</tr>
</tbody>
</table>
Summary of Inventory Findings

- Over 70% of recorded landslides had taken place above the road
- Approximately 60% of total recorded landslides were assigned low risk categories
- 3% of recorded landslides had resulted in movement of the entire carriageway, i.e. high risk
- 4% of recorded landslides were rock slope failures, i.e. almost all were in soil or weathered rock
# Computation of Risk

<table>
<thead>
<tr>
<th>Risk components</th>
<th>Assigned Relative Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude of hazard (M)</td>
<td>0: Small (shallow and extending over up to 500$m^2$) 1: Moderate 3: Large (deep and extending over area of 5000$m^2$ or more)</td>
</tr>
<tr>
<td>Probability of hazard occurring during 20 year period (P)</td>
<td>0: Not expected to happen 1: Possible 2: Expected to happen 3: Definite</td>
</tr>
<tr>
<td>Value of road elements at risk (Va)</td>
<td>0: Existing slope works and side drain 1: Existing slope works, side drain, and up to 50% of carriageway width (one lane) 3: Entire carriageway and adjacent structures</td>
</tr>
<tr>
<td>Vulnerability of elements to the hazard, should it occur (Vu)</td>
<td>0: No effect 1: Deformation or blockage 2: Partial loss 3: Total loss</td>
</tr>
</tbody>
</table>

Risk = M x P x Va x Vu
| Road 1E | 16+100 | 105°03'06" 17°47'24" | Sandstone mudstone WG II-III | Above Road: Rock slide in cut slope. 100m of road affected. Assume original failure blocked road. | Above Road: M = 2  P = 2  Va = 3  Vu = 1  R = 12 | Above Road: Cut slope angle reduced to being slightly greater than angle of dip of strata. No other mitigation undertaken, though rock bolting is under consideration by the contractor. | Tension cracks continue to develop. | Above Road: M = 2  P = 2  Va = 3  Vu = 1  R = 12 |
| Road 3 | 64+500 (approx) | 101°13'31" 20°46'38" | Not known WG IV? | Above Road: Failing rock mass forming cut slope. Original failure probably partially blocked road | Above Road: M = 2 P = 3 Va = 2 Vu = 3 R = 36 | Above Road: None, clearance only. | NA | Above Road: M = 2 P = 3 Va = 2 Vu = 3 R = 36 |
Route 8

Road 8

128+800

105°09'00"
18°22'16"

Granite
WG II

Above Road:
Deep seated
rockslide in cut slope.
Approx 40m road
length, extends
approx 80m upslope

Above Road:
M = 2
P = 2
Va = 3
Vu = 1
R = 12

Above Road:
None, debris
clearance only. Only
other option would be
large RW

OK, probable
continued
movement of
debris into road

Above Road:
M = 2
P = 2
Va = 3
Vu = 1
R = 12
## Practical Guidelines

### Assessing Hazard Based on Slope Angle & Height

<table>
<thead>
<tr>
<th>Hazard ranking</th>
<th>Soil/highly weathered rock or colluvial slope</th>
<th>Rock slope, fresh to moderately weathered</th>
<th>Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height (m)</td>
<td>Angle (deg)</td>
<td>Height (m)</td>
</tr>
<tr>
<td>High</td>
<td>&gt; 15</td>
<td>&gt; 35</td>
<td>&gt; 12</td>
</tr>
<tr>
<td>Moderate</td>
<td>5-15</td>
<td>25-35</td>
<td>7-12</td>
</tr>
<tr>
<td>Low</td>
<td>&lt; 5</td>
<td>&lt; 25</td>
<td>&lt; 7</td>
</tr>
</tbody>
</table>

**Notes:** For slopes, use height or angle to derive highest category

Table based on average conditions

Scott Wilson
# Practical Guidelines

## Prioritising Investigation

<table>
<thead>
<tr>
<th>Risk/hazard priority</th>
<th>Type of investigation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detailed site inspection only</td>
<td>Intermediate geotechnical investigation</td>
</tr>
<tr>
<td>Risk rating from Figure 3.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Hazard rating from Figure 3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Low</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>
## Practical Guidelines

### Prioritising Mitigation Based on Expected Outcome

<table>
<thead>
<tr>
<th>Actual or expected consequences</th>
<th>Risk ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Road completely lost (or road subsidence greater than 1m) or occupied buildings damaged or destroyed</td>
<td></td>
</tr>
<tr>
<td>Road partially lost</td>
<td>✓</td>
</tr>
<tr>
<td>Road completely blocked</td>
<td>✓</td>
</tr>
<tr>
<td>Road subsidence less than 1 metre</td>
<td>✓</td>
</tr>
<tr>
<td>Road partially blocked</td>
<td></td>
</tr>
<tr>
<td>Productive agricultural or forest land lost or destroyed</td>
<td></td>
</tr>
<tr>
<td>Walls damaged or slope drainage blocked or damaged</td>
<td></td>
</tr>
<tr>
<td>Roadside drainage damaged or blocked</td>
<td></td>
</tr>
<tr>
<td>Continued erosion without destroying vegetation cover</td>
<td></td>
</tr>
</tbody>
</table>

### Ranking and priority

1. Top priority, emergency measures required immediately; buildings may need to be evacuated.
2. High priority; realignment may be necessary.
3. Moderate priority, but some temporary remedial measures are required immediately, such as slip debris clearance, emergency road signing etc.
4. Low priority, but some actions are required quickly, such as slip debris clearance.
5. Least priority, but should be tackled as soon as possible under routine maintenance.