NATURAL SLOPE INSTABILITY MEASURES OF ROADS IN HILL COUNTRY, SRI LANKA

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Abstract:

Landslide movement is perceptible and may take the form of falls, topples, slides, or flows. It can consist of free-falling material from cliffs, broken or unbroken masses sliding down mountains or hillsides, or fluid flows. Materials can move up to 120mph or more, and slides can last a few seconds or a few minutes, or can be gradual, slower movements over several hours or days. In central Sri Lanka, there are many instability regions, landslides frequently happen and trunk roads are often closed temporally due to these problems. Landslide mudflows and rock falls usually strike without warning. The forces of rocks, soil or other debris moving down a slope can devastate anything in its path. These sections need to be taken countermeasures such as winding roads and protection of slopes or in case alternations of the route are necessary. However, all the effective countermeasures have not been reached steps to carry out, except for design of an alternative road and stabilizer work. Mitigation includes any activities that prevent an emergency, reduce the chance of an emergency happening or lessen the damaging effects of unavoidable emergencies. Investing in preventive mitigation steps now such as planting ground cover on slopes, or installation of structural & flexible schemes as a remedial measure, will help reduce the impact of landslides and rock falls in the future.

1. Introduction:

Landslides are fairly common natural hazard in Sri Lanka. They occur mostly in the hill country district areas such as Nuwara Eliya, Badulla, Kegalle, Matale, Kandy and Ratnapura. However, they some time occurs in the low country district areas mainly Kalutara, Galle and Matara District too. The landslide disrupts normal life style of the community and paralyses public and all essential services; transport, electricity, water services and some times development projects as well. It imposed a heavy financial burdened on the government, which has not only to provide relief assistance to victims, but also to reconstruct and restore all supplies and services as before, in minute time.

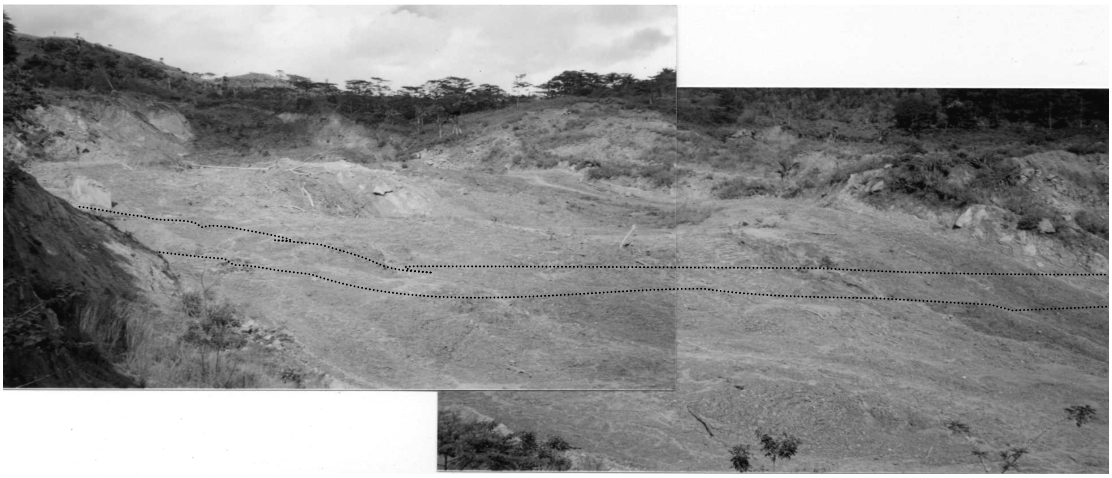


Fig 1: Longest slide (nearly 4km long) across the Colombo-Ratnapura-Wellawaya-Baticalloa; CRWB road between Balangoda and Wellawaya occurred in 1998 at Naketiya, Sri Lanka. Dotted line shows the existing road trace before failure.

Since, increased development in hillside areas has underlined the importance of understanding the factors promoting instability before beginning engineering analysis or design. All too often, sites prone to landsliding have been a scene of repeated implementation of temporary control measures over the period of time. Experience over the past half-century tends to suggest that many landslide repair attempts are made without benefit or full understanding of the mechanism of failure. In addition, the blind implementation of a conventional road construction scheme such as 'filling and re-compaction', may not serve to adequately mitigatory measure in the event of failure due to landsliding.

In recent memory in Sri Lanka, peaks of landslide activity had occurred in January, 1986 and then again in May – June 1989, October 1996(Fig.2) and most recently in November 1998 (Fig.1). All above situations, landslides affecting the national highway network of the hill country.

Fig .2: The most significant effect of landslides is the disruption of transportation and the destruction of private and public property. Some work has been done to prevent developments on top of or below slopes subject to sliding. However, the slide reactivate during last 15 year period, Kahagolla, Sri Lanka.

2. Vital Statistics on Natural Disasters in the Region

To survey occurrences of past natural disasters (floods, cyclones, earthquakes, landslides etc) in the region are sought out from the Emergency Disaster Events Database (EMDAT) of the Center for Research on the Epidemiology of Disasters, Catholic University of Louvain, Belgium (CRED). The extract of the eight year period of recorded disasters are tabulated in Fig 3.

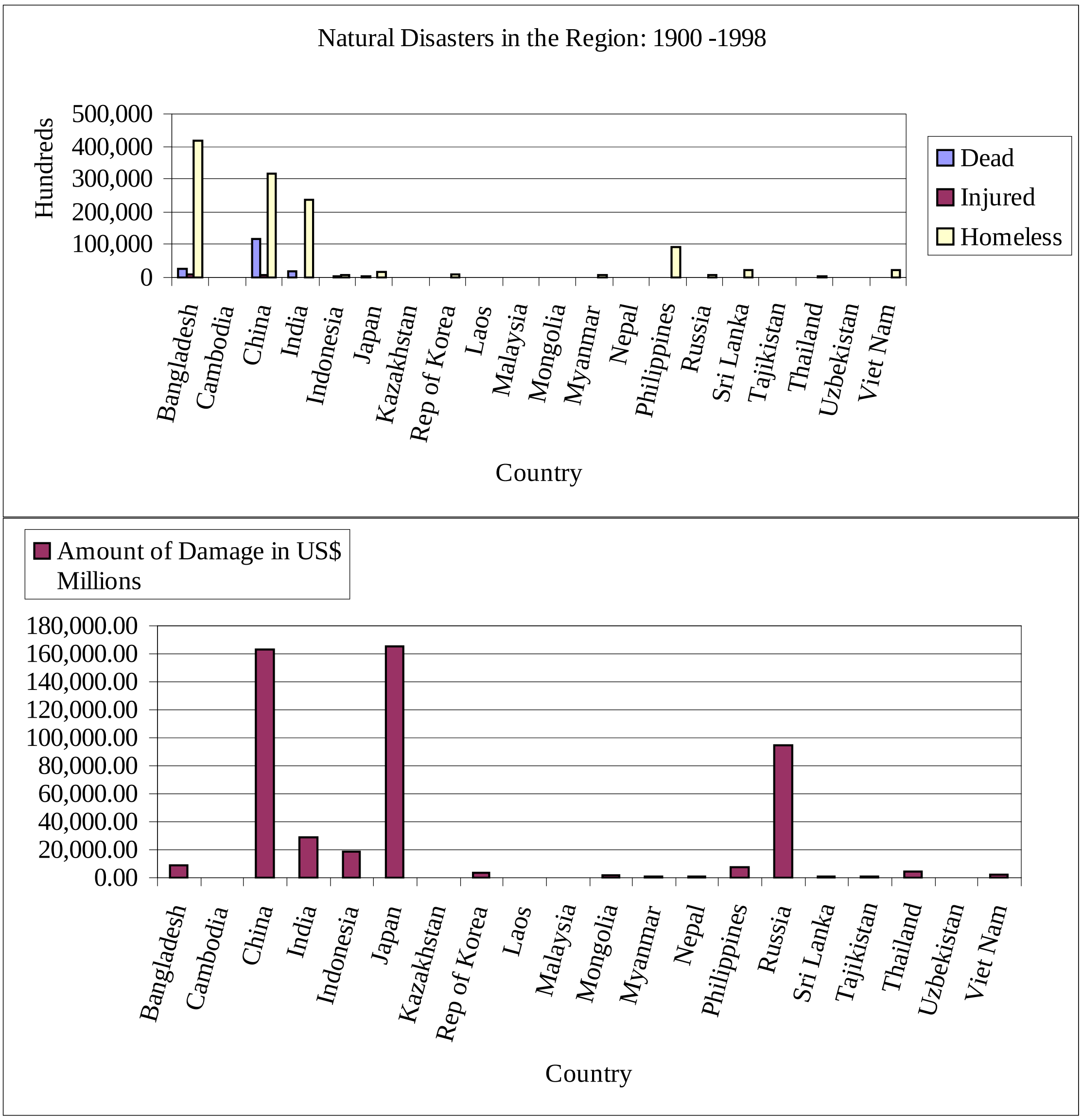


Fig. 3: Natural Disasters in the Region: 1900 – 1998

These data were made available from the EM-DAT Disaster Database, Center for Research into the Epidemiology. This information revealled that when disaster strikes, quantification of actual damage, loss of life and property does not show a simple rule of mitigation plan and a management mechanism.

3. Managing Road Network at Hill Country

Sri Lanka which comprises a land area of about 65,600 sq.km. has generally, a well distributed network of roads and the total length of roadway is about 100,000km (Traffic & Planning Division, Road Development Authority, 1993). Based on these statistics , the density of roads is about 1.5km/sq.km (Mallawarachchi, D P , 1994). Over 25,000km are classified roads belonging to classes A, B, C, D and E. The A and B roads constitute the National Highway Network amounting to about 11,000km and are presently managed by RDA. The other classified roads are maintained by the Provincial Councils.

i. The roads of class A are the trunk routes joining the provincial and district centers.
ii. The class B roads are termed the main roads, joining the other important towns with provincial and district centers and also between them.
iii.The C roads constitute secondary links and D and E roads could be considered to constitute tertiary links.

4. Climate

Sri Lanka is situated in the large belt of monsoon in South Asia. The climate in this region is mainly governed by the contrast of the large landmass of the Asian continent in the North and the Indian Ocean in the South. During the half of the year when the sun is above the northern hemisphere, the Asian landmass is heated, causing a low pressure belt to develop. This is the period of the humid SW monsoon (The direction of the monsoon wind deviates from the true South, on the account of the earth). During the other half of the year the Asian landmass cools and a zone of relatively high pressure is created over Asia. This is the period of the dry NE monsoon with somewhat lighter winds. The central highlands form a barrier for both monsoon, causing large climatic differences between the windward and the leeward regions, especially with respect to rainfall and consequently any specific area is alternately on the windward and the leeward side. In the lowlands the climate is more uniform.

5. Geology / Geomorphology

Three well marked erosion surfaces have been recognised in Sri Lanka. These vertically uplifted three regional erosion surfaces are the occurrence of off-shore and on-show up-lifts associated with ground lineaments(Vitanage,P W 1994). Landslides are usually associated with the boundary scarps along each morphological unit. The hill country area is generally plot in the break in slope range II and III below.

i. Break in slope 1; Coastal lowland with elevations from sea level to 270m above except for a few isolated inselbergs.

ii. Break in slope 11; ranging in elevation from 270m to 1060m. Upland with elevations from 270m to 1060m consisting of ridge and valley topography and highly dissected plateaus with narrow arenas and occupy nearly three tenths of the island. The average slope range varies from 10^o to 35^o along the upland ridges depending on the lithology and structures. The occurrences of local and large landslides is common in neglected and abandoned rubber and tea estates e.g. Ratnapura, Banlangoda area.

iii. Break in slope 111; ranging in elevation from 1060m to 2424m. :Highlands with a series of well defined high plains and plateaus. Influence of geological structures and tectonics are strikingly evident.

6. Strength Characteristics of Soil

The instability of residual soil overlaying completely weathered rocks can result in high velocity mass movements upon approaching saturation. This is mainly because of the primary loss of metric suction, intensive rate of penetration as well as percolation of rainwater and lack of slope protection ingredients in the event of heavy rains. One case study; Watawala Earthslide revealed that the residual soil formation consists of materials ranging from silty-sand and sandy silt to clayey sand. The liquid limits are between 47% +- 20% including the residual shear zones. The total density and dry density increase marginally with depth due to in-situ and completely weathered rock, with an average value of 1.5~1.6 and 1.89 Mg/m3, respectively. The specific gravity of the soil averages 2.6 to 2.9. Laboratory determination of shear strength characteristics was done using the UDS samples collected from and the discrete boundary shear locations. The multistage direct shear test were conducted and showed that the stable region soil formation have an average effective cohesion, C', of 4kPa to 8 kPa. The effective angle of internal friction, ϕ' is within the range of 29° to 35°. However, at the boundary, loss of strength is indicated by an average effective cohesion, C'= 0.0 kPa and effective angle of internal friction, ϕ'= 14°+-1° (Fig. 4). The shear strength contribution from the negative pore-water pressure, above the groundwater table are usually ignored by setting their magnitudes to zero in the conventional method of analysis.

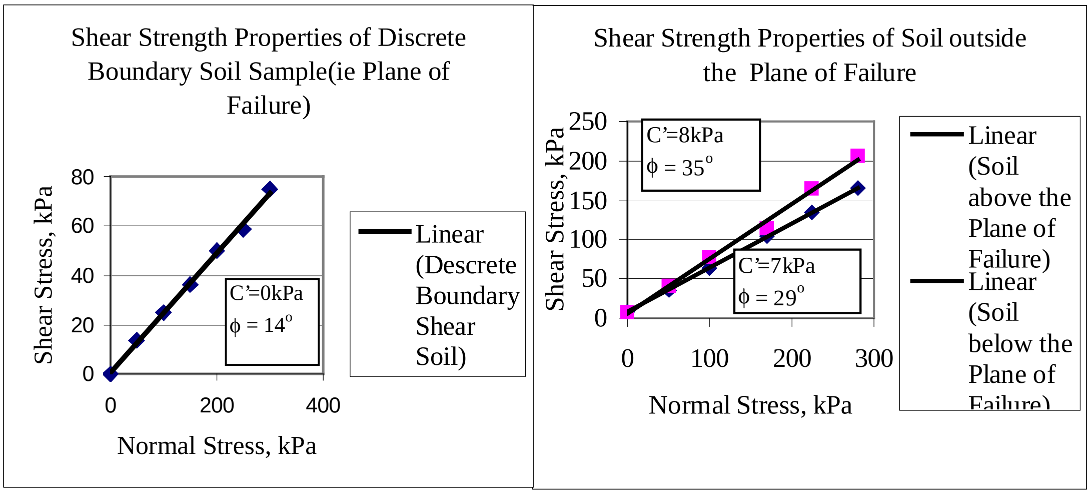


Fig 4: Average shear strength parameters on Discrete Boundary Shear samples

The existing slopes generally failed some time following a high level of precipitation over a prolonged period of time. This has been indicated that the Naketiya Earthslide that is recorded as the longest earthslide occurred in the nineteen century of the country. While the mechanism leading up to failure is well known few attempts have been made to model the problem. The main reason appears to be related to the difficulties in modeling of unsaturated or partially saturated boundary condition and the flow through the unsaturated soil.

7. Assessment of Potential Instability

The survey of slope instability areas along the road traces is fundamental and the most important activity of this study. And therefore, classifications of ground instabilities (Table 1) in the pervious standard documentary reports has been widely adopted. The activities were primarily focused on the development of scientific data base which of first hand geomohorphological units of the area through various field execution works and development of field maps including various ingredients of geomorphology such as bed rock geology, hydrogeology, overburdened deposits, slope, extent existing landslides/instability area and landform.

Fig.5 : Most common failure mechanisms associated with the hill country, Sri Lanka

Primary observations(Fig.5) are readily available through the number of earth cuts at the road trace at hilly area. The second and the major instability problem which encountered in the road trace is number of shallow to deep landslides. Thirdly, several observations on the ground confirm that the landslide material was in free fall during prolong period of rain and that may rocks bounced on impact.

Table 1 – Landslide Hazard Assessment for Emergency

Emergency Planning Stage	Hazard Identification Need
Preliminary Mission	Identify hazard issue
Phase I- Development Diagnosis	Degree of hazard from all types of landslides
Phase II - Action Plan and Project Formulation	Degree of hazard from all types of landslides supplemented by hazard from some specific types
Project Implementation	Site-specific hazard based on geotechnical models

Many impact areas and freshly and broken rocks on the surface of the older boulder deposits and up-slopes and lower slopes on the road. There are areas still consists of small and overhang boulders and highly rock fragments above the existing road trace. Rock fall may happen without triggering from any discernable external conditions such as prolonged rainfall, steeping of slopes or applying load to the top of a slope.

Earth debris flows are common with an event of a landslide or rock fall and only possible if the road trace is seating below the unstable region.

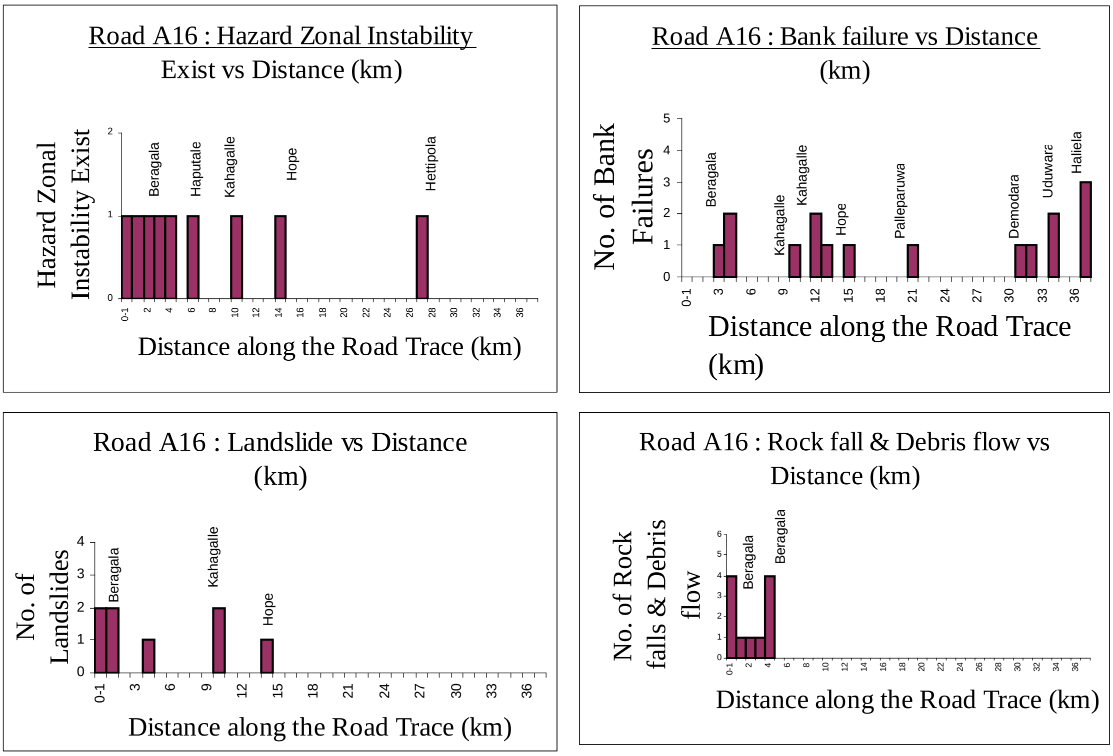


Fig. 6: Potential instability measures along the A16 road; Beragala – Haliela, Sri Lanka for an emergency planning against Landslides.

The A16 road at Beragala which is located 180km away from Colombo, are in landslide proven areas. In addition, A4 road; Colombo-Ratnapura-Wellawaya-Baticalloa;CRWB road between Balangoda and Wellawaya, and the A5 road between Gampola and Nuwara Eliya is located in landslides and rockslide proven areas respectively. These trunk roads are extremely significant routes, which connects Colombo with the Central Province, Eastern Province, Sabaragamuwa Province and Uva Province.

8. Integrated Hazard Map for Emergency Planning

Landslide hazard has been determined with a high degree of reliability for only a few locations. When a potential hazard is present in the study area, the first step is to undertake a brief survey to establish whether landslides have occurred in recent times as in Fig 6. Roads, railroads, and river banks are good sites for seeking signs of past landslide occurrence. Then landslide hazard map with the integrated of direct field evidences as above will contribute to some accuracy for emergency planning scheme of a road project. There are two situations when such intergraded landslide map may prove beneficial, both of which are related to mitigating the potential effects of landslides. In one case, it is conceivable that if areas identified with a moderate landslide hazard are targeted for development, greater detail of those areas is needed to ensure the project design compensates for this greater hazard potential. For example, moderate or higher hazard areas may not be entirely avoidable along any proposed road trace in hill country. In another case, existing infrastructure or communities may be located in previously unidentified high hazard zones. These areas should be given priority for introducing some measure of mitigation or early warning measures.

9. Knowledge Base System Model Approach

Today, various applications of knowledge base expert systems has been increasing significantly as a research on application tool for engineering analysis, design and management. Classification problems commonly encounter in hazard assessment and planning for emergency against natural disaster including selection, diagnostic, evaluation, interpretation, prediction, monitoring and control. All these problems choosing one or more " solutions" from a predicted and finite set of possible solution for the problem - even continuous evaluation involves choosing a part or interval on a defined scale for each dimension of interest. Therefore, this type of system model will help planner in diagnosing the type of problem. This will face with evaluation of hazard risk on hill slope area and predicting failures accurately to some extent with an appropriate site conditions. The author pin point in some basic development approaches what is useful in KBEs for the prediction and performance in Hazard Integration for Emergency Planning model (Fig.7).

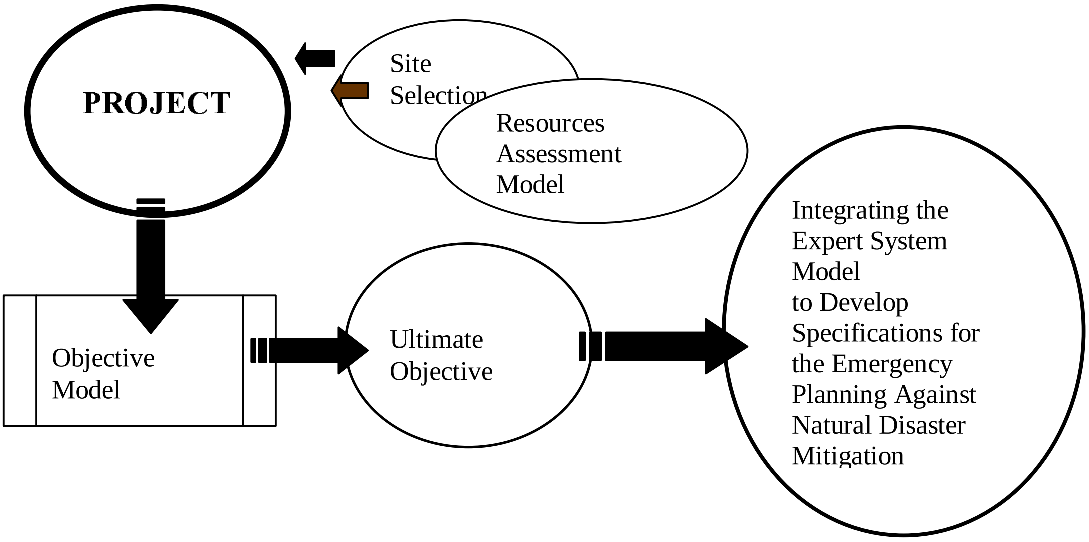
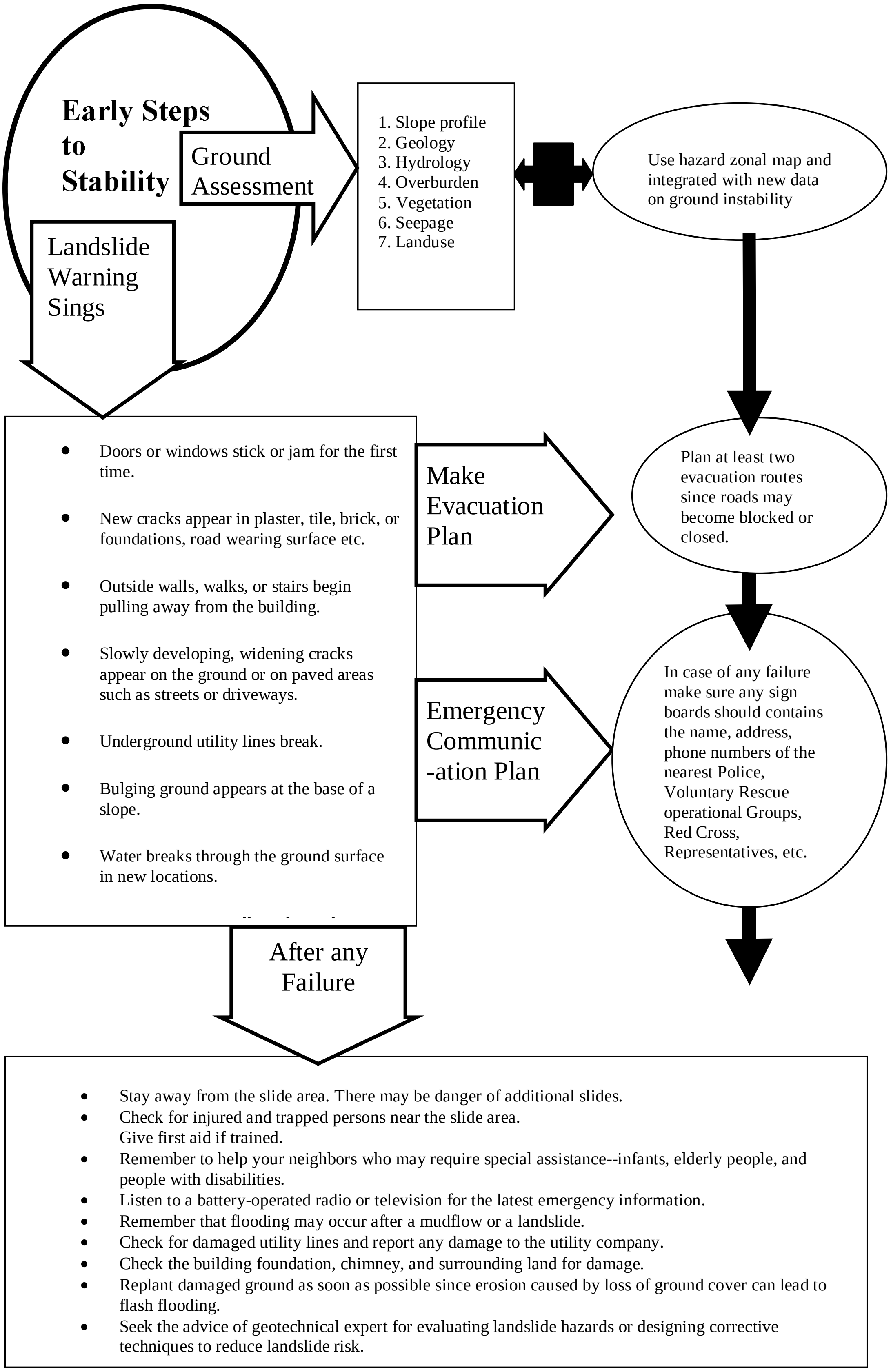


Fig. 7 : Basic model approach for Knowledge Base System Analysis

The knowledge base system model in slope stability analysis is being developed recent years. Systems widely explain the more realistic planning approach. The point is that knowledge is not static. When new knowledge is entered either as new rule or change in the forms of rules because of newly recognized dependencies, there will be old knowledge that must be (correctly or completely) updated or removed from the system. And as noted we must ensure that new rule do not impair the operation of the inference, either through the introduction of inconsistencies or contradictions or through the addition so many new rules that the system bogs down and runs inefficiently or not at all. Another aspect of system building that requires a major institutional commitment is the life of the system after its development, Therefore, KBES is –or at least should be a dynamic system that receives active maintenance and updating.

Author suggests a more appropriate knowledge acquisition system model (Fig.8) which can be well suited for hazard mitigation, planning and execution. This may be a single approach for mitigation planning including activities that prevent an emergency.



1. Slope profile
2. Geology
3. Hydrology
4. Overburden
5. Vegetation
6. Seepage
7. Landuse

Use hazard zonal map and integrated with new data on ground instability

- Doors or windows stick or jam for the first time.
- New cracks appear in plaster, tile, brick, or foundations, road wearing surface etc.
- Outside walls, walks, or stairs begin pulling away from the building.
- Slowly developing, widening cracks appear on the ground or on paved areas such as streets or driveways.
- Underground utility lines break.
- Bulging ground appears at the base of a slope.
- Water breaks through the ground surface in new locations.

Plan at least two evacuation routes since roads may become blocked or closed.

In case of any failure make sure any sign boards should contains the name, address, phone numbers of the nearest Police, Voluntary Rescue operational Groups, Red Cross, Representatives, etc.

- Stay away from the slide area. There may be danger of additional slides.
- Check for injured and trapped persons near the slide area.
  Give first aid if trained.
- Remember to help your neighbors who may require special assistance--infants, elderly people, and people with disabilities.
- Listen to a battery-operated radio or television for the latest emergency information.
- Remember that flooding may occur after a mudflow or a landslide.
- Check for damaged utility lines and report any damage to the utility company.
- Check the building foundation, chimney, and surrounding land for damage.
- Replant damaged ground as soon as possible since erosion caused by loss of ground cover can lead to flash flooding.
- Seek the advice of geotechnical expert for evaluating landslide hazards or designing corrective techniques to reduce landslide risk.

Fig 8 : Suggested Knowledge Base Data Acquisition Model for the natural disaster mitigation and emergency planning against Landslides

10. Conclusion

Landslides are often a secondary hazard related to other natural disasters. Consequently, the investigations of slope instabilities has been increasingly integrated with broader aspects of hazard assessments, road designs and stabilisation works. Various observations revealed that transportation facilities are stressed due to such slope instabilities and appropriate requirements translate into the specific needs of a more detailed evaluation, systematic investigation and design of mitigatory measures of landslides in hill country developments.

11. Acknowledgment

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