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Different Sets of Remediations for Mitigation of Landslides in Hilly Terrain of India

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Abstract. The great Himalayan Mountain is a majestic cluster of several numbers of more or less parallel hill ranges intervened by numerous valleys and extended plateaus. The Himalayan landscape, as said by expert geologists, is especially susceptible to landslides. The northward movement of the Indian plates caused continuous stresses on the hill slopes making it weak and prone to landslides. The Himalayan topography, as well as high seismic vulnerability and rainfall in the region, are enlarging the liability to landslides. Landslides or landslip involve a large ground movement due to the gravity forces which results in total mass wasting of the slope. The landslides are experienced in almost all the National and State highways adjacent to the hill slopes of the Himalayas and hill ranges of India North East, Western Ghats and Nilgiris, Eastern Ghats, Himachal, J&K, Garhwal & Kumaon hill ranges and Vindhyas. The remedial measures for landslides may be divided into four subcategories; restraint, removal, drainage, and relocation. The retaining structures are designed to retain rock/soil slope that it would not naturally be stable at its position. The reinforcement measures include soil nailing & earth reinforcement measures which involve the insertion of steel rods, metallic strips, geosynthetics, and steel angles to improve the stability of the slope. The reinforcement measures also include the improvement of the mechanical characteristics of the ground through chemical, thermal, or mechanical treatment. The third major remedial measures are drainage measures which are most effective in a geologic condition that allows interference with the natural water regime. Also, Bioengineering techniques in which vegetation is a fundamental part are useful approaches to prevent landslides as they improve slope stability and maintain ecological balance. They are most suitable to be deployed in developing countries because of their cost effectiveness and environmentally friendly nature. The chosen remedial measures depend upon several factors such as type movement (slide, flow, etc), type of material (debris, rock, soil, etc), location of the failure, the process of failures, etc. The several factors that are to be considered before designing and implementing landslides remedial measures will be discussed in the paper. The paper shall be dealt with a different sets of remediations such as soil nailing technique, earth reinforced structures, retaining structures, drainage measures and bioengineering technique for mitigation of landslides adjacent to roads in Himalayan terrain considering the economic as well as social feasibility, steadiness, and efficiency. Moreover, several advantages and disadvantages of remediation techniques shall be incorporated in the paper.

Keywords: Landslides, Reinforcement, Thermal, Feasibility, Efficiency

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1 Introduction

Landslides refer to the movement of mass of rock, debris or earth down the slope, when the shear stress exceeds the shear strength of the material. It occurs when the consequence of a complex field of forces (stress is a force per unit area) active on a mass of rock or soil on the slope. It happens due to geological causes, morphological causes, physical causes and human causes. There are two parameters that determine the landslides are as follows:

a. Increase of shear stress: It happen due to the removal of lateral and underlying support; increase of lateral forces as well as load; transitory stresses like blasting, earthquakes etc.; and geological movement.
b. Decrease of material strength: It happens due to the weathering, pore water pressure and changes in structure.
The incidents of landslides increasing day by day due to the over urbanisation, massive deforestation, construction and development work in landslide prone areas.

1.1 Falls: It happen due to the abrupt movements of masses of geologic materials, such as rocks and boulders that become detached from steep slopes or cliffs.

1.2 Topples: It happens due to the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks

1.3 Slides: In this types, rocks, debris or soil slide through slope forming material.

1.4 Spread: It usually occur on very gentle slopes or flat terrain.

a. By restricting or even removing population from landslides prone areas.
b. By restricting certain types of land use where slopes are vulnerable.
c. By installing early warning systems based on the monitoring of ground conditions such as strain in rocks and soils, slope displacement, and groundwater levels.

2 Reinforced Earth Structure for Stabilisation of Landslide

Reinforced earth is a composite medium. It consists of earth that is reinforced by layers of strips made of material able to withstand large tensile stresses. Basic concept involves behind the earth reinforced structure is combining two materials of different strength characteristics to form a composite material of greater strength likewise reinforced soil structures combines the high tensile strength of steel with the high compressive, but relatively low tensile strength of concrete. In earth reinforced structures the inclusion of materials (metallic strips, grids or meshes and polymeric strips sheets) with high tensile strength in the soil results in improving the tensile strength of soil. This mobilization of tensile strength is obtained by surface interaction between the soil and the reinforcement through friction and adhesion. Bang et.al (1980)

2.1 Components of earth reinforced structure

(a)Soil or Fill Matrix-Backfill, (b) Reinforcement, (c) Strips, (d) Grids, (e) Sheet Reinforcement and (f) Facing Elements.

The construction of a reinforced soil wall is carried out as given the following steps-

1. A reinforced soil structure is built in series of successive steps, in each layer of facing elements, and the placing of corresponding earth fill, followed by a new layer of reinforcing strips/grids/sheets.
2. Temporary supports are installed to ensure stability while concrete or metal facing elements are positioned and installed on the facing side of the wall. This is done to in order to obtain a perfectly vertical wall facing.
3. The reinforcing strips/grids/sheets are placed perpendicular to the wall face, with the broad side of the strip resting on the previously placed layer of the compacted earth fill. The metal strips are attached to the facing elements by means of high strength bolts which are of same material as of reinforcing strips.
4. The fill should be spread by the moving machinery parallel to the face of the wall in order to encounter the stresses that could be caused by earth moving equipment

5. It is also advisable that the trucks and other earth moving machinery do not go closer than 2m to the face of the wall. The area closer to the facing should be compacted with light compacting equipment.

The Reinforced earth structures for stabilization of hill slopes are a very useful technique. This technique results in many sided advantages such as long term durability, aesthetic value, ease of construction, suitability to various soil and hill slopes, large walls, ability to accept differential settlements etc. Also, these walls are capable of supporting large live and dead loads of the structure and vehicles etc.Cornoforth(2005). If proper specifications laid by BS 8006:1995 for out of water condition is followed up then the longetivity and productivity of the structure can be increased. The cost of the Earth reinforced walls depends upon many variables such need for cut and fill native soils, construction technique involves, selection and use of material etc. Length of reinforcement layers increases as height of wall increases. Design strength of reinforcement and vertical spacing between two reinforcements are also main factors. If basic principles of the design of Earth reinforced structures are considered with due care they can meet the mitigation and improvements of landslides and hill slopes in hilly terrains of India.

3 Soil Nailing Technique for Stabilization of Landslide

Soil nailing is one of the most efficient & widely used techniques for landslides prevention and mitigation. Soil nailing is the technique used in slope stabilization and excavation with the use of passive inclusions, usually steel bars, termed as soil nail. It consists of passive reinforcement which is encased in grout to provide corrosion protection and improved load transfer to ground. Soil nailing mainly includes excavation which is done with conventional earthwork equipments which is started at the ground surface and progressed downwards. It is done to accommodate the facing panels of soil nailing. Facing is done is to ensure local stability of the soil between the nails and to limit the decompression of the soil. Nailing involves insertion of nails into the holes to develop a strong bond between the nail and the soil.

Soil nailing is one of the most effective methods of earth reinforcement for landslides prevention and mitigation which involves reinforcing the soil with steel bars or other materials. The main purpose of soil nailing is to increase the tensile and shear strength of soil and restrain its displacement. The technique permits stabilization of both natural slope and vertical or inclined excavations. Soil nails provide adequate tensile strength to the slope that helps in effective stabilization of landslides. The design parameters involve calculations of various components including Calculation of Total Earth pressure and moments, External Stability, Overturning, Tilting/ Bearing Failure, Global Slope Failure, Internal Stability, Seismic Stability, etc. The limitations of soil nailing technique are not inevitable but the magnitude of limitations may be reduced to a certain extent by proper analysis and design. Sabahit et.al(1(96)

3.1 Soil nailing technique

Soil nailing is a reinforcement technique in which closely spaced parallel steel bars are installed into the face of a slope or vertical cut to improve stability. The basic concept behind soil nailing consists of placing in the ground passive inclusions, closely spaced, to restrain displacements and limit decompression during and after excavation. The function of soil nailing is to strengthen or stabilize the existing steep slopes and excavations as construction proceeds from the top to bottom. Soil nails develops their reinforcing action through soil-nail interaction due to the ground deformation which results in development of tensile forces in soil nail. The significant part of resistances comes from development of axial force which is basically a tension force. Conventionally, shear and bending have been assumed to provide little contribution in providing resistance. The effect of soil nailing is to improve the stability of slope or excavation through

(a) Increasing the normal force on shear plane and hence increase the shear resistance along slip plane in friction soil.

(b) Reducing the driving force along slip plane both in friction and cohesive soil

In soil nailing, the reinforcement is installed horizontally or gently inclined parallel to the direction of tensile strain so that it develops maximum tensile force develops. For a vertical cut slope with horizontal back slope, the length of soil nails is usually 60-100% of wall height. Based on various soil types and ground conditions the soil nails are placed 6-foot centers vertically and 5 to 8-foot centers horizontally. The most common installation method is to insert the steel bars into a drill hole and grout the bottom up by gravity or low pressure. This procedure is described in some detail in this paper. Other construction methods include jet grouting or driving nails into the slope. The soil nailing is a top-down construction procedure and is suitable for temporary and permanent cut slopes and for shallow depth landslide remediation. Excavation to expose the steep cut face proceeds with a series of step 3 to 6 feet high. After each step has been opened up, soil nails are installed in a row and the face is shotcrete to prevent collapse or erosion of the exposed face. The end of the nail which is projecting out of the slope face is then attached to the shotcrete facing by a metal plate and bolt. After the full depth of excavation has been reached, the second layer of shotcrete is further added to strengthen the wall and to protect the nails. Soil nails installed for permanent slopes require corrosion resistant treatment for durability.

3.2 Design procedure

Soil nailing method is an in-situ soil reinforcement technique that is used at present to stabilize natural slopes, cuts or excavation, walls in stiff cliffs, granular soils and also soft rocks. The procedure involves insertion of steel rods (usually 20-30mm in diameter) by simple driving or by grouting into the predrilled boreholes. The basic steps involved for construction are illustrated as below:
There are usually steel rods 20-30 mm in diameter which are inserted into the soil either by simple driving or by grouting in the predrilled borehole. Standard construction steps for typical soil nailing method can be broadly divided into four steps and these steps are repeated in the cycle as outlined below:

The installation of soil reinforcement depends upon the construction method adopted either top down or bottom up. It is always desirable to place the soil nails simultaneously after the excavation to avoid the complication and cost of pretreatment. There is also a requirement of dewatering if water is present in the slope in order to ease the construction and durability of soil nailing. Otherwise, if water percolates through the face, the unreinforced soil will slump locally on the initial excavation. The nail length plays a vital role in the design of soil-nailed structures as both the economy and stability of the structure depends on it. The commonly used L/H ratio is in the range of 0.5 to 0.8. However, higher values of L/H ratio indicate mainly the repairing of existing structures. L= Nail Length H= Overall structure height. Most commonly used nail inclination is between 10 to 20, with 15 is being the most used inclination. This inclination is because of the ease of construction. Nail diameter is varied from 14mm to 40mm but the range of 20mm to 30mm is very common. Grouted hole diameter varied from 56 to 200mm but the range 100mm to 120mm were more common. The basic behavior and mechanism of soil nailing have been explained with due regard to various failure modes of the nailed structure. The pullout strength of the nails has been explained with respect its strength envelopEffects of various parameters namely analysis and design, Potential Failure modes of a Soil Nail wall, Nail Strength Failure Envelope and nail inclination on the nail behavior have been discussed.

4 Landslides Remedial Measures-Retaining Structures

4.1 Retaining structures

Retaining walls can be constructed by either top down or base up methods. In top down method of construction the wall is built starting from ground surface of the landslide. The disturbed ground down slope of the wall is excavated after the wall support is in place. Top down walls can provide some assurance that the landslide will remain stable during remediation work, which is beneficial to safety and adjoining property owners.

Base up retaining walls are conventional walls founded on firm ground and provide resistance due to gravity or cantilever action. In landslide situations, there is usually a need to excavate some of the landslide debris at the bottom of the slide before the retaining wall can be constructed. As this undermines the landslide, it may require dry weather conditions or dewatering to lower groundwater level within the landslide before construction of the retaining wall can begin. Arya et.al (1983)

4.2 Retaining wall system

a. Masonry walls

Masonry is the building of structures from individual units laid in and bound together by mortar. The common materials of masonry construction are brick, stone such as marble, granite, travertine, limestone; concrete block, glass block, and tile. Masonry is generally a highly durable form of construction.

b. Sausage walls

Apart from masonry or concrete retaining walls, crib walls and sausage walls are also used as restraining structures. Crib wall is formed in a wooden crib/mesh, in which dry stone masonry is built. Sausage walls are made by forming sausage of steel wire netting of square or hexagonal holes and filling the sausages with hard local boulder/stones. The sausage walls have the advantages of being able to withstand large deformations without cracking. Further because of the open structure, sausage walls allow free drainage of water. One drawback that has been observed occasionally is that falling boulders may cut or break SWG mesh, thereby leading to the possibility of stones falling out of the sausage crates. Due to high humidity and other adverse climatic conditions, rusting of SWG may occur damaging the sausage casing. However, with adequate attention, such damages can be rectified and the integrity sausage walls maintained.

c. Concrete gravity retaining walls

The concrete gravity walls are very expansive and advantageous for important structures and both urban and rural areas. Such walls require foundation in bed rock or good soil below the slip surface. The design of the stem of the wall and the stability of the whole body of the wall, are both considered in the design. The body of the wall is taken top include the mass of soil directly above the heel of the cantilevered wall and earth pressure. The formula for the safety factor may be used to estimate resistance required to lateral thrust. The standard practice is to include weep holes in designing the wall. Concrete walls sometimes fail due to inadequate ability to resist groundwater pressures. In these cases analyzed routing of weep holes is recommended. These walls are fails due to sliding along the base in such cases a thin layer of crushed sand or sand gravel should be placed between the native soil and wall base.

d. Anchored walls

The stability of retaining wall can also be enhanced through ground anchors. Stabilization by deep, pre stresses anchors is being applied to soil slope. Walls with pre-stresses anchors have a major advantage by actively opposing the movement of the soil mass, rather than behaving passively as in the case of unstressed anchors and gravity structures. These are employed either in conjunction with retaining structures or alone to reduce the driving forces of a landslide and to increase normal effective stress on its slip surface. Tie back walls are used to transfer the imposed load to an area behind the slide mass where satisfactory resistance can be established. A tie back sheet pile wall can be used to ensure adequate anchorage in the stiff clays. Stabilization by deep, pre stressed anchors is being generally applied to soil slope. Walls with pre stressed anchors have a major advantage by actively opposing the movement of the soil mass, rather than behaving passively as to unstressed anchors.

e. Diaphragm wall

Diaphragm wall is a structural element that transmits lateral loads to the vertical resisting elements of a structure. Diaphragms are typically horizontal, but can be sloped. A diaphragm wall is constructed using a narrow trench excavated in ground and supported by an engineered fluid (typically a bentonite mud) until the mud is replaced by the permanent material. Generally diaphragm walls are made from reinforced concrete, though un-reinforced walls can also be used. Diaphragm walls are often used in congested areas or where the excavation depth is very deep which would otherwise require excavation of much greater soil volumes to provide stable battered slopes. They are well suited for deep basements, underground rail stations, rail car un-loaders, tunnel approaches, pumping stations and such like. Diaphragm Walls can be installed close to existing structures and in restricted headroom. They are often used in “top down” construction methods.

Despite of having several advantages diaphragm walls have limitations such as high cost of construction, special requirements of manpower and equipments which are not easily available in every part of the country Arya et al (1983)

5 Micro-Piles or Root Piles for Slope Stabilization

Micro piles (Shown in Fig.1.8) are essentially an outgrowth of the technology the construction of ground anchors. They are small diameter bored piles in which steel reinforcement is grouted into a borehole to form the pile. The loads are carried by skin friction between the soil and grout, but load-bearing is provided by the steel; they can carry loads in either compression or tension. End bearing capabilities are ignored.
The piles can be designed for two broad uses

- As a conventional pile of small diameter
- As a composite soil/pile mass in which the piles reinforce the soil mass three-dimensionally into a gravity-type structure.

Micro piles are typically 4 to 10 inches in diameter, 70 to 100 feet long, and carry loads of 35 to more than 100

tons in tension or compression. Their main attribute is flexibility of use. The piles can be drilled into almost all ground conditions at any preselected direction. The construction equipment requires little headroom and can gain access to restricted spaces. They have been widely used for residential underpinning, seismic retrofit, and many other difficult circumstances Micro piles for landslide stabilization typically are installed at various angles to the vertical (Figure 1.8) to knit soils together into a composite mass of soil and piles. The individual piles are not directly loaded but provide a framework for achieving a coherent mass of soil. Such piles are frequently referred to as reticulated piles or root piles to provide an analogy to the roots of a tree.

5.1 Advantages of micro piles

The micro-piles have advantages that they can be constructed under the following conditions,

- Low headroom
- Restricted access
- Almost all soil conditions, including boulders and voids etc.

6 Landslide Remedial Measures-Drainage

6.1 Drainage remedial measures- Surface drainage-Surface drainage is the removal of water that collects on land . The control of surface water is most important in the stabilization of slopes. Drainage not only reduces the weight of the mass tending to slide out but also increases the strength of the slope forming materials. Surface water can also cause erosion. Infiltration results in the development of excess pore water pressure within the slopes. Due to the absence of proper drainage facility landslips occur. It is therefore natural that the improvement of the drainage facilities in the area be given high priority.

Control of surface water consists of two main parts:

1. The collection of run-off at the uphill boundary of any unstable area
2. Maximum run-off from the unstable area and controlling and collecting this run-off.

Usually, any system of surface drainage should include investigating the need for other existing practices of hill side road construction such as slope treatment of the hill sides for erosion control, regarding or reshaping of the slope for promoting quick run-off. On the other hand, sealing of tension cracks by means of rodding in loamy earth will mitigate the susceptibility of the slope to a potential slide. Catch water or interceptor drains, side drains and cross drains constitute some of the more important types of drains used in a system of surface drainage.

6.2 Catch water drains

Surface water flowing from the hill slope toward potential unstable area or the road way is one of the main problems in the drainage of hill slope during heavy rains. In order to intercept and divert the water from the hill slope, catch water drains should be located very carefully, after the topography of the ground is studied in detail. It has been observed in practice that poor location of surface drains results in their serving no purpose, since no water would be collected by them and on the other hand, the run-off bypasses the drains and continues to damage the slopes.

Catch water drains should be lined and properly maintained and should be given a gradient of 1in 50 to 1 in 33 to avoid high water velocity and possible wash out. A number of interconnecting lined catch water drains may need to be constructed on the slope to collect the surface run-off if the area of the slide is large. Water from the catch water drains should be diverted into a chute or a natural hillside drain or diverted by sloping drains and lead into culverts at a lower level finally to be led through chutes into the nearest natural water course.

6.3 Deep trench drains

Deep Trench drains can also be used for the purpose of subsurface drainage. These are generally limited, by practical consideration, to those locations where water can be intercepted at depth less than 5m to 8m. Trench drains can also be used for the purpose of subsurface drainage when horizontal drilling is not possible because of site condition or economic considerations. Deep subsurface trench drains, consisting of a number of interconnected dug into the slope, and backfilled with well drainage rubble, can be highly effective in quickly draining a saturated slope. Maintenance is needed for proper functioning of trench drains. Flow rate can be decreased during dry weather flow & erosion (if any) takes place should be repaired.

6.4 Scupper

It is an economical type of culvert or cross drain where dry masonry retaining wall is provided for the road. The water collected through side drains or nallah, is discharged to the valley side through a small cross drainage structures usually 0.85m to 1.2m wide made of random rubble dry masonry abutments. The top of the abutments are corbelled with a few layers of stones and a stone slab is laid on the top. Hand packed stones are placed on top about 0.35m to 0.60m thick and also all round the scupper, Retaining walls are provided on both ends of scupper. Scuppers are provided approximately at every 150m apart in full width of road surface. Frequent maintenance is required in scuppers as it get choked due to the falling of boulders and materials into it resulting in very less or no drainage.

6.5 Sub-surface drainage

Subsurface drainage is concerned with removing water that percolates through or is contained in the underlying soil sub grade. Deep seated landslides and slope failures are often caused by the presence of subsoil water in the slope area, and the resulting high water pressure on possible failure planes. Hence successful methods for both prevention and correction of landslides have perforce to rely heavily on ground water control by employing suitable deep drainage techniques. Sub-Surface drainage acts to modify the seepage pattern within the soil or rock mass and reduce the pore water pressures. The removal of water from within a slope by subsurface drainage is costlier than surface drainage. However, subsurface drainage is usually more effective because it leads to a decrease in pore water pressure directly at the failure plane.

Removal of subsurface water tends to produce a more stable condition in several ways such as:

(a) Seepage forces are reduced
(b) shear strength
(c) there is reduction in pore pressure
(d) driving forces are reduced

Seepage forces act to increase the driving force on a landslide surface and hence attempts are generally made to intercept subsurface flows above the sliding mass. Subsurface drainage is also useful in cut areas and under proposed embankments. Methods generally used to accomplish subsurface drainage are the installation of horizontal drains, vertical, drainage wells, deep trench drains and drainage tunnels.

6.6 Horizontal drains

Horizontal drains are defined as multiple holes drilled into a cut slope or embankment and cased with a perforated metal or slotted plastic liner. The purpose of using horizontal drains as part of landslide control work is to drain away groundwater, thus keeping the soil dry.

7 Bioengineering Measures for Stabilisation of Landslides

Bioengineering techniques are useful approaches to prevent landslides as they improve slope stability and maintain ecological balance. They are mostly suitable to be deployed in developing countries because of their cost effectiveness and environmentally friendly nature. Lammeranner et.al (2005).

The bioengineering techniques contribute to renewable energy sector will contribute to the sustainable development of the local community. Vegetation helps in sustaining biodiversity and giving a positive influence on the ground structure by creating a balance between the soil and water. It is very important to understand the root–soil relationship for a successful implementation of bioengineering techniques. R. Raut et al

8 Conclusions

It is often very difficult to design effective, economic feasible and long lasting remedial measures for landslides. Different types of remedial measures are discussed in this paper by representing advantages and limitations of the same. Based on investigation of landslide, failure mechanism of landslide and stability analysis of slope a set of appropriate remedial measures are evolved. This paper will be beneficial for all the researcher & implementing agencies to refer major landslides remedial measures from one document. All important remedial measures are illustrated in this precise paper which can further be used for designing of innovative, cost effective and less complex remedial measures in future. Critical reviews of remedial measures given in this paper can be referred by the executing agencies to provide effective solutions to encounter landslides problems.

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