Study and Analysis of Causative Factors of Slumping for Designing the Preventive Measures: A Case Study in South Konkan, India

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ABSTRACT
Case study of a major landslide that took place on Banda Branch Canal of Tilari Project in South – Western Maharashtra has been presented in this paper. Location for this landslide is in Sindhudurga District and just about 7 km at South-East of Sawantwadi, having Latitude— N 15° 48’ 11” and Longitude— E 73° 52’ 9”. Geologically this region has metamorphic gneissic rocks, which are weathered near the surface due to highly oxidizing and humid climatic conditions, developing lithomarge clays and lateritic soil regolith. Loose cohesive soil matrix becomes soft and loses strength due to surface and subsurface flows during heavy precipitation. Regolithic mass of overburden became heavy, lost support / interlocking and slumped along the hill slope. This region lies in zone III as per map of seismic zones for our country. Therefore minute seismic event may act as triggering factor leading to slope instability. Study and analysis of this Slumping, by field observation, along with the general remedial measure that may mitigate the problems due to interruption in Canal flow, has been discussed in present paper. Thus the aim of this study is to interpret the observations for sorting out probable factors, which caused the slumping movement. This paper also includes few suggestions about preventive / remedial measures from geotechnical and geological points of view.

Keywords
Slump, Slip Circle, Plastic outflows, Upwarpment, Back analysis etc.

1. INTRODUCTION
Landslides are natural hazard that affect at least 15% of the land area of our country, covering an area of more than 0.49 million sq. km. Landslides of different types occur frequently in geodynamically active areas in Konkan and Western Ghats. Landslides form a significant component of natural disaster in many hilly, lateritic areas of Konkan. The slopes along Konkan Railway and many other Ghat Sections along roads have been affected by severe slope instabilities. The hilly terrain of Banda area is south-western part of Sahyadri in the coastal strip. It is composed of the oldest rock formation of the world that is Archean systems. This rock formation after weathering, has converted to the relict hilly terrain with lateritic soil mass resting on the angle of repose of gneisses. This hilly terrain in coastal zone experiences very heavy rainfall during monsoon. It is seismically active and comes under zone III as per seismic zonation map. Therefore Landslide is frequently observed phenomenon in this area during monsoon. Just like sliding along Ghat road and Konkan railway track, it is also common along the excavations of canal. Considerably large landslide has been reported along the Banda Branch canal at km 9 and it was found to be a huge slumping that developed near vertical scarps (Fig. 4) and wide crevasses (Fig. 5) and upwarpment (Fig. 8 & 9) of canal bed in monsoon of June 2010 and now it has been aggravated several folds. In case of this landslide, the slumping is associated with flows and creeps in increasing manner. The slumping movement is still being continued and the scarps now developed upto about 2.5 M. Apart from the main slip circle, two more slip circles have also been developed in the slumping mass (Fig. 4 & 5) The major rock in this area is Archean gneiss of metamorphic origin and it is a product of dynamo thermal metamorphism of some quartzo-feldspathic rock that might have happened 3.5 b.y. before present. This region is seismically active and comes under zone III as per map showing the seismic zones. Landslides may be triggered by minute seismicity and therefore blocking of roads results in disrupted traffic or blocking of canal is also possible in this area. Sliding is frequently observed phenomenon in ghat-roads during monsoon in this region. Therefore to tackle the problem of slope instability and landslides the present case study of Banda landslide may be useful in some or other way.

2. OBSERVATIONS AT SITE
The slumping that had occurred at Banda Branch Canal, Km. 10, Ch. 9/735 M to 9/920 M, developing about, near vertical scarps and wide crevasses and upwarpment of canal bed, in last monsoon, have now been aggravated several folds even after putting the porous and permeable draining bed. The slumping movement is still being continued and the scarps now developed upto about 2.5 M. Apart from the main slip circle, two more slip circles have also been developed in the slumping mass (Fig.7) Geologically they are belongs to Archean gneissic complex and has subjected to intensive oxidizing and humid weathering conditions in chronological past. The in-situ thick Lateritic soil regolith is resting with the steeper slopes varying between 15° to 45°. The regolith is fine to coarse and contain large and highly weathered gneissic boulders are present in the regolith and now are being seen to be exposed after the canal excavation. At the present site, the canal flows South to North on the West-ward slopping. The slumping happened from East side of the canal.

3. CAUSES OF THE SLUMP
Slump is a variety of debris slide. Debris slide is the failure of unconsolidated material on a surface of rupture. Debris slides or slumps mostly represent readjustment of the slope of the ground. Slump is often accompanied by complementary bulges at the toe. In present scenario, the partially constructed preventative structure is uplifted by about 1.5 M due to the
upwarpment of the canal bed, as the toe of the slip circle lies in the canal bed. The present slumping have occurred on such a slope where internal resistance to shear is reduced below the safe limit due to the following reasons cumulatively related to slope, soil structure, rainwater and nature of present excavation. 

Slope- It has been observed, that the slope are providing the angle of repose that prone to land slips of the loose overburden due to greater gravity influence.

Soil Structure- The soil, present at the site is derived at intensive weathering of Archaean gneisses, which are already structurally disturbed. The soil, comprises of lateritic lithomarge clays and fine to coarse regolith that always loses the cohesion in presence of rain water during monsoon. This soil is composed of such a clay mineral that is easily leached out causing porosity and permeability. Their Argillaceous clay content has found to be contributed to the slippery effect. The sequence of soft weak porous and permeable clayey regolith has provided a congenial set up for the present slumping movement in the canal.

Water - The present event have occurred in very high rainfall during the monsoon season. The presence of water had greatly reduced the intergranular cohesion of particles in loose ground. The ground acted as weakened inherently and made it prone to slump. Water percolated through the overlying zone and that might have flowned down as a film or sheet of water on the surfaces of embedded boulders. This had act as lubricating medium and induced the downward movement of overlying material along its direction of flow.

Plastic outflow - In presence of water the clayey material have become very plastic and might have formed slippery base. Since the thickness of regolith is too high, beneath the heavy loads, the lithomarge soil layers which had become plastic (in heavy rains) might have squeezed outwards in to the canal allowing the surface settlement in the upper side, i.e. towards eastern hill slope of canal. Thus excavation for the canal, itself, is one of causes of slumping. Slump is often accompanied by complimentary bulges at the toe. In the present scenario, the toe of the slump lies in the canal bed.

Therefore the entire canal bed, along this particular stretch has found to be up wrapped due to bulging. (Fig. 1) The slopes on the western side of the canal, just below the slumping zone are observed to be stable. It means that the slumping occur due to plastic outflows into the canal from eastern slopes during heavy rains.

Huge slip circle has been developed along which, the mass is being failure. The monitoring of the slide by site authorities indicate, that the movement is being accelerated after the heavy rainfall, that increases pore pressures and looses the cohesiveness in the mass. The interpretation of the data is difficult, as parameter values and available data seem to be not sufficient to model the event. The slopes on the western side of the canal, just below the slumping zone, are still observed to be stable but likely to become unstable in coming monsoon season because current slip circle may increase and new larger slip-circle may develop in undisturbed mass having it’s toe towards western side of canal. The slumping movement is being accelerated due to heavy plastic outflows into the canal bed from Eastern slopes during heavy rains. (Fig.2 & 3)

4. PREVENTIVE MEASURES

The preventive measures to counter the effects of slopes, water and plastic outflows are essential at this particular site. The RCC Box Conduit Structure designed by authorities, was being constructed and unfortunately during its construction, there was very heavy precipitation that accelerated the process of slumping that had started in the last monsoon. It was earlier thought that, to counter the effect of plastic outflow in the canal (which is the main cause of the event), the RCC Box Conduit, may prevent any plastic outflow from Eastern side and its own weight may resist any future upwarpment due to slumping. But in the present scenario, the rate of slumping has been increased. The counteracting loads
The concept of limit equilibrium linear relationship \( c' - \tan \phi' \), may be used to evaluate the effect of any remedial measure (drainage, modification of slope geometry, restraining structures etc.). And the same relationship of \( c' \) and \( \tan \phi' \) thus may be used to design the preventive measure to be proposed. Considering the present scenario the down slopes on the West side of the slump are presently observed to be stable. But in future, there is a chance to develop more slip circles along the entire slope, right from the upper reaches of the hill (i.e. above the present scarps) upto the foot hill (i.e. towards slopes along Western Side of the Canal). To make the effective control on this situation, any further excavation on West side of the slump zone must be avoided and in this area forestation is advisable to improve the slope stability. The settlement, present in the Western Side of the slump movement, may need the rehabilitation in early future.

It is further being suggested, that the preventive measures must be decided by Structural engineering authorities with the cumulative and integrated approaches of Geological and Geotechnical experts’ reports. Every civil engineering preventive measure should be based on proper quantitative investigations by Geotechnical Engineer and related proper load calculations by Structural Engineering Expert. It should be taken into consideration, that any heavy construction for preventive measure may aggravate the plastic outflows or sliding movement on the Western side of canal in coming monsoon seasons. However that may be, also, taken in the domain of back analysis.

The following sketch throws the light on how the above back analysis is helpful for the preventive measures.

Schematic view of the commonly used retaining and slope reinforcement measures (upper) along with pictures illustrating two of these measures: Large Diameter Caissons (lower left) and Ground Anchors (lower right).
Fig. 4 Scarp i.e. exposed part of Slip Circle. Now increased up to about 2.5 M

Fig. 5 Slip Circle being developed in Slumping Mass.

Fig. 6 - Part of Slumping Mass and Plastic Outflows

Fig. 7 - Part of Slumping Mass

Fig. 8 - Part of Plastic Overflows at Toe of Slump that dislocated the construction work.
Fig. 9 - Progressing Upwarptment at Toe of Slump that uplifted the ongoing construction work.

6. CONCLUSION
Certainly, a type of paradox is observed in case of present landslide that is because of the requirement of heavy preventive structures and simultaneously the incremental slope instability due to the weight of regolith mass. In the present scenario, the rate of slumping has been increased. The counteracting loads of the sliding debris and box conduit may be recalculated by the method of back analysis. The design of required heavy preventive measure may be decided after the proper quantitative investigations by Geotechnical Engineer, Structural Engineering Expert and Experienced Geologist. The Back analysis suggested in this paper, thus, may be used for designing the preventive structures as some conceptually represented in the sketch. Since, the present landslide disaster has both short term and long term impact that accounts for irrigation needs and loss of property at the site, the landslide hazard zonation mapping and vulnerability assessment work along the entire stretch of the canal passing through hilly and unstable slopes, may be carried out. This may help in future mitigative decision making. The Remote Sensing data and other Geoinformatical tools may be useful for this purpose.

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8. REFERENCES