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Micropiles for mitigation of landslide in the residential area of North Sikkim region

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ABSTRACT

Vulnerability of large landslides takes place due to many anthropogenic and natural factors. Frequent collapse and triggeringof landslide take place in active foothills of Himalayan region. The main primary factors causing destabilization of slope includes rain water infiltration in the topmost weathered layer, earthquake forces and local inhabitant activities. Vulnerable landslide zone having residential area is envisaged in 'Mangan', North Sikkim, India. Interesting factor affecting the slope stability in the area under study hasbeen noticed that in addition to rainwater and earthquake forces; the other forces being sewer line carrying waste water outfall of households across sections. The long-term disposal and subsequent accumulation of sewer water caused increase in pore space and overalldensity of soil due to saturation, rainwater additionally reduces cohesion of overlying mass causing slip-off from the parent strata. Preliminary stability analysis has been carried out for critical sections using LEM slide software and effect of intermediate micropiles (Zinc-Chromium coated stainless steel) has been evaluated using FEM technique. It has been seen that top 100 m of slant length of slope is quite unstable. Accordingly, intermediate series of micropiles have been installed with profiled benches in the unstable slope. Superstructure loads from the residential zone lying on the slope profile and vehicular loads at the road level has been considered for severe condition. Furthermore, location and length of micropile has been optimized based on concentrated stresses and strength reductionfactor. It has been observed that there is 48.5% and 37.8% increase in safety factor under static condition and seismic condition respectively. Analysis shows that micropiles work effectively in controlling local displacements due to sliding and add global stability to the effected region.

Keywords— *Micropile, local displacement, static condition, seismic condition, concentrated stresses, Zinc-Chromium coated stainless steel, earth movement, mass movement*

1. INTRODUCTION

Introduction of micropiles is emerging technology used not only for underpinning works for building and historical structures, but landslide prevention also. Micropiles has advantage over piles in terms of carrying lateral forces effectively in addition to axial force. This technique is advantageous to piles due to its lighter machine accessories requirement and easy installation in low headroom, access restrictive area. It is reliable method to support existing structures in any difficult terrainwith minimal disturbance due to its lesser vibration during construction sequence. Recent development in landslide mitigation techniques use soil nails for addressing surficial protection, cable anchors for resisting global failures. Micropilesare getting in to technical trends and using significantly due to its lateral capacity, seismic retrofit viability (1).

Micropiles are usually small-diameter piles having dia. typically less than 300 mm that are drilled, grouted and typicallyreinforced with steel with As/Ac less than 20%. Individual micropile should be spaced at least 760 mm (30 in.) or 3 times diameter of micropile, whichever is more (FHWA, 2005). This case study enlightens the use of series of micropiles in intermediate benches, road levels for shear mobilization and arresting lateral movement of slope. Taking all these considerations and technical design aspects regarding geomorphology, ground water conditions, structural loads due to residential area and vehicular loads at road levels; series of micropiles was purposed. After series of brain storming discussions with geotechnical experts it was proposed to use Type C grouted micropiles (Pearlman and Wolosick, 1992) (with Zinc-Chromium coated stainless steel casing). (Pearlman and Wolosick, 1992) describe economic feasibility of using micropiles for two span bridge abutments than anchored caisson walls, ground anchors. Micropiles for arresting slope failurescan be arranged in various patterns like A type, H type, staggered type based on transfer of stress from surrounding sliding mass. Lateral resistance and stiffness of individual micropiles (without casing) are relatively less, since these act as slender elements insufficient to carry shear forces occurring at contraflexure points. Present site demand use of structural element having more lateral load carrying capacity to hold the sliding mass, which ultimately required micropile with casing to meetshear strength and lateral capacity requirements.

Primary performance in terms of slope stability was performed based on collected engineered parameter from bore holes of slope profile.

2. GEOMORPHOLOGY
Present study area is located between the Himalayan Kingdom of Nepal in the West and Bhutan in the East. Stratigraphical and geological rock units set up of the area is quite complex. Daling rocks encompass this zone (Gansser, 1964, Acharya, 1989, the mapped area is covered by quartz-biotite schist / phyllite with interbands of quartzite. Manganis located on the domain of MCT, and as per seismic map of India Mangan area lies in Zone- IV/V. Accordingly Seismicacceleration coefficients has been considered as per Seismic Coefficient (Zone-IV) with Importance-1. Denselypopulated residential structures has caused dilation of underlying loose and weathered rock.

2.1 Geotechnical Site Investigation
The terrain of the problematic area has a gentle slope varying from 25° to 35°, with marginally higher gradients towardsits eastern margins where some rock exposures are noted. Apart from this, three sets of tension cracks having varying lengthstraversing the slide from east to west has been observed. Talus and slope wash debris material of 2 to 15m (crushed fragmented bed rock, rock floor and silty clay) are prevalent slope forming material with limited rock exposures. Slide zonecomprises 7.5m overburden debris and slope wash material underlined by 6 to 25 m bedrock depth quartz biotite schist comprising varied degree of weathered layers.

Vulnerable landslide zone having residential area is envisaged in 'Mangan', North Sikkim, India. Factors affecting the slope stability in the area under study has been noticed that in addition to rainwater and earthquake forces; the other forces being sewer line carrying waste water outfall of households across slope sections. The long term disposal and subsequent accumulation of sewer water caused increase in pore space and overall density of soil due to saturation, rainwater additionallyreduces cohesion of overlying mass causing slip-off from the parent strata.
Two number of exploratory bore holes were commenced up to 30 m and 20 m respectively. 7.50m depth has been observed to overlie weathered mica schist at both locations. Low water loss indicates saturated mass and low core recovery reflect deep weathering. Soil matrix comprised of coarse sand containing mica flakes which itself acting like confined aquifer and not allowing water to drain out due to blockage of interstitial pore spaces.

Fig. 1: Existing slope profile at Mangan area.

2.2 Summary of Geotechnical Investigation
Geological and geotechnical survey summarized as under Table 1. Jointed bed rock is mainly comprises of quartz biotite schist having three principal joint sets.

Table 1: Summary of geotechnical material.

Materials	Unit Weight (kN/m^3)	GSI	Cohesion (kPa)	Friction angle (ϕ)	Young's Modulus(Mpa)
Overburden	19	-	28	32	50
Highly Weathered & Crusted Bed rock mass	24	21	64	31	320
Bed Rock Mass	27	47	160	37	750

2.3 Installation of Micropiles at Site

Following site images shows the construction and installation of micropiles to achieve stability.

Fig. 2: Installation of Zinc-Chromium coated stainless steel cased micropiles at Mangan site.

2.4 Finite Element Analysis

Multistage modelling has been done to represent the actual slope profile condition. Critical section has been taken for analysis using Phase2 v8. Three different layers as described in geotechnical material layer details has been undertaken withtheir material properties. Geological Strength Index (GSI) of slope is computed based on rock mass structure and surface discontinuities and conditions of joints from GSI chart published by Hoek and Brown (1997). Extent of weathering, joint roughness and infilling material between the discontinuities, joint apertures have been analyzed; based on which ratings wereassigned to get GSI value for rock layers (Pandit et al., 2019). All figures and tables should be numbered. Table headings should be centered above the tables. Figure captions should be centered below the figures. Refer to the figure below for a sample.

Elastic and plastic ranges have been defined and hence adopted for these two disintegrated rock layers and equivalent continuum modelling has been done for whole model. Rocscience roclab data software has been used and analyzed by defining the rock type, its GSI, mi, degree of disturbance (D), slope height, unit weight, and uniaxial unconfined strength to validate the derived shear strength parameter from lab testing. Slope profile of around 200 m slant length with average inclination 24^0 having varied layer thickness has been modelled. Slope has been modelled by defining its boundary conditionshaving slope face as free, vertical sides as roller support allowing vertical movement, while base has been kept restrained forany moment. Three-noded with uniform type mesh is adopted for this finite element model as recommended in Rocscience manual (2012).

Surcharge load and vehicular load has been taken considering the future 25 years development. Consequently, analysis has been done considering pore water pressure and dynamic effects. Following additional slide triggering factor has been undertaken as Surcharge load (double to multifloor buildings etc.) = 25-50 kPa, and, Pavement Loading (Live Vehicular Load+ Dead load) = 70 kPa. For this critical earthquake zone of IV the horizontal acceleration Coefficient (α_h) = 0.15 and vertical acceleration coefficient (α_v) =0.10.

Analysis has been done for unprotected slope profile with various loading conditions and other factors as discussed. After this, analysis has been done using series of micropiles (Zinc-Chromium coated stainless steel casing) at three benches.Location of these micropiles have been fixed based on the displacement vectors and stress concentrations.

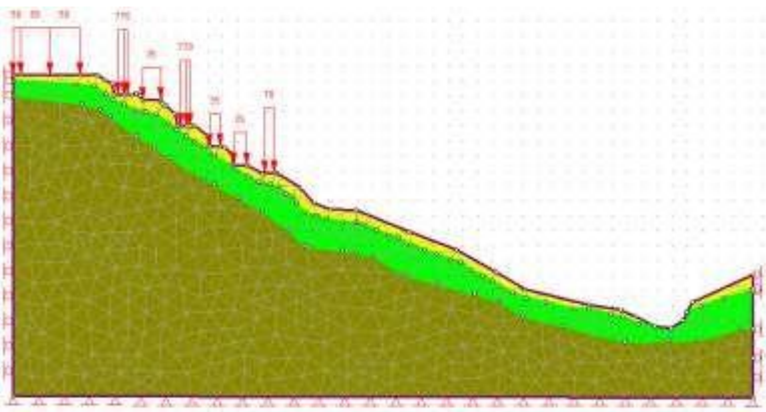

Fig. 3: Typical discretized mesh of slope profile with different loading conditions

3. RESULTS FROM FINITE ELEMENT ANALYSIS

It has been observed that the top portion of around 98m slant length of slope profile is more prone to failure. Pore water built up and loadings at intermediate levels adds more stress concentrations which requires use of some element to resist the displacement at intermediate levels. Accordingly, pore pressure (r_u) of value 0.25, 0.15 and 0.1 has been taken for top, intermediate and bottom bed rock layers respectively. For this series of micropiles at benches reduces the stress concentration effect and control the horizontal displacements.

It has been seen that factor of safety without any stability measures noted as 1.08 with 255 mm absolute horizontal displacement at static condition and 0.81 critical SRF with 439 mm absolute horizontal displacement at seismic condition. Allowable tensile and compression capacity of micropiles has been calculated as per FHWA NHI-05-039- clause 5.6. Four number of Fe 500 tor steel bars have been used in 273 mm diameter micropiles (8 mm casing thickness)with grout compressive strength as 30 N/mm^2. Lateral load capacity calculated as per FHWA as 1.83 ton. Effect of stability measures have been observed using micropiles at benches and reinforced erosion control mat at the face of slope. Following analysis results shows maximum shear strength with critical SRF and deformation vectors.

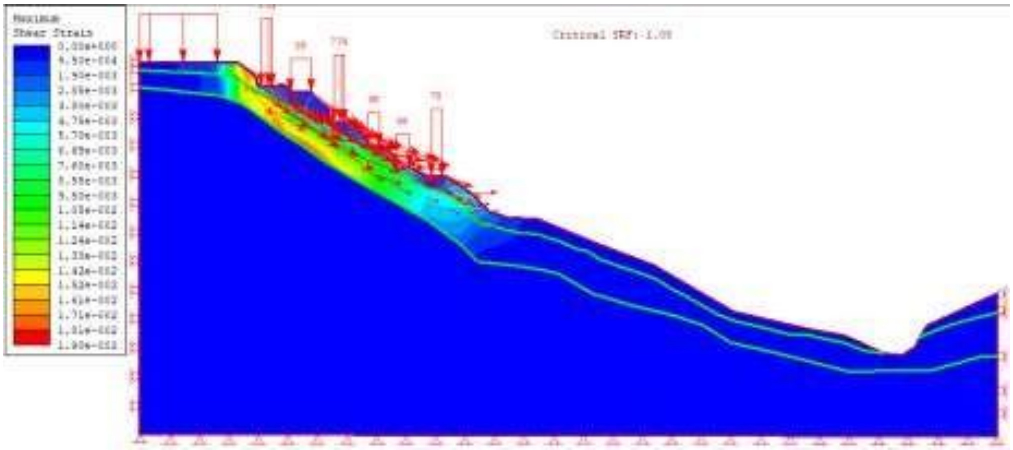

Fig. 4: Maximum shear strain with critical SRF at static condition

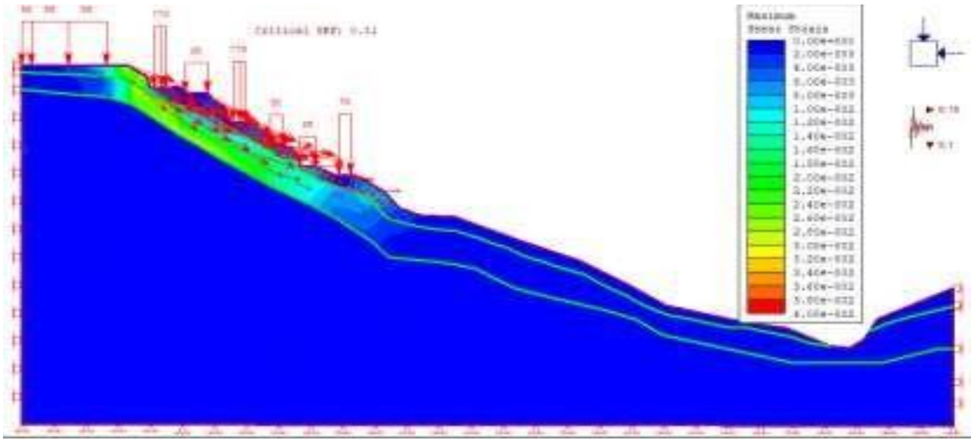

Fig. 5: Maximum shear strain with critical SRF at seismic condition

Intrusion of stability measures shows significant improvement in absolute horizontal displacement and safety factor results. Horizontal displacement of 84 mm has been noticed with 1.59 safety factor at static condition. Similar improvement has been observed at seismic condition with horizontal displacement as 69 mm and 1.12 safety factor.

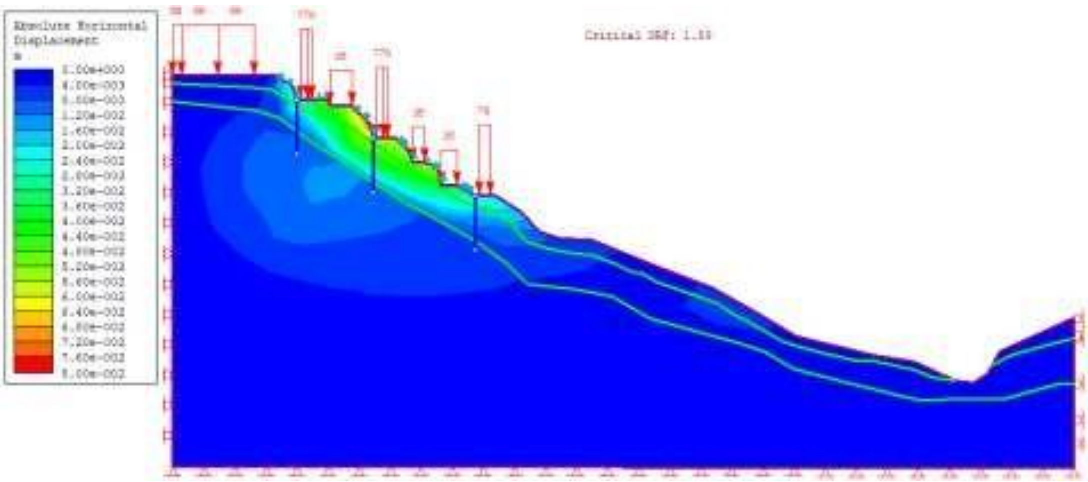

Fig. 6: Maximum shear strain with critical SRF at static condition after using stability measures

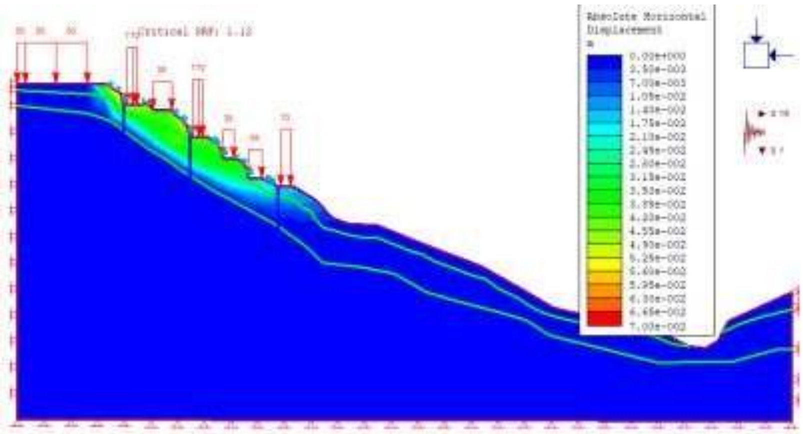

Fig. 7: Maximum shear strain with critical SRF at static condition after using stability measures

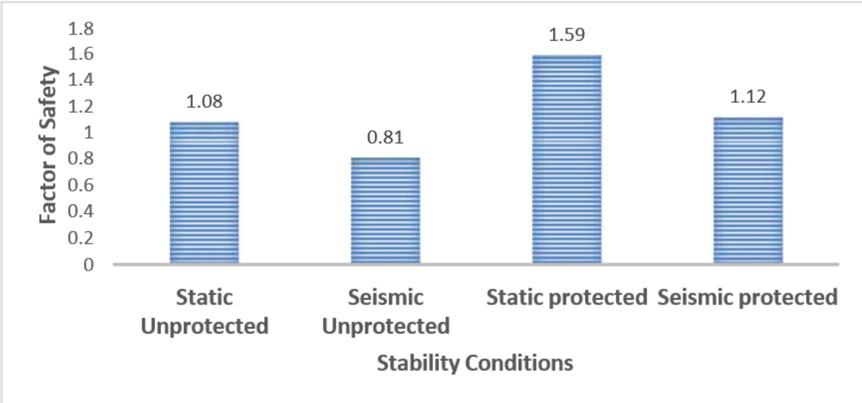

Fig. 8: Strength reduction factor variations under different stability conditions

4. METHODOLOGY

The methodology adopted in this paper is an intensive literature review on the various types of technologies for Landslide, FEM analysis of Earth movement in RAMSS software. Upon analysis of entire movement, the slope is stabilised with series of micropiles at designed spacing and simulation was carried out in Rockscienece Phase II.

5. CONCLUSION

It has been clear from the briefly discussed case study of slope stabilization project at Mangan area using series of micropiles (Zinc-Chromium coated stainless steel casing) and reinforced erosion control mat. Concluding factors whicheffect stability noticed are pore water pressure and overburden pressure due to increasing residential structures, heavy vehicular loads at road levels, improper water disposal seeping deep in to slope profile and creating horizontal displacements. Lateral displacement has been controlled by micropiles at three levels; thereby reducing the lateral thrust at next level. Introduction of micropiles significantly improve the lateral load carrying capacity with 48% and 38% at static and seismic condition respectively.

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