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Numerical modelling of sheet pile walls as landslide barrier

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Abstract. Landslides are one of the most challenging natural disasters occurring worldwide. Complete protection from a sliding soil mass may not be possible. Still, various techniques are being used to hold back the failing soil long enough to evacuate. Flexible retaining walls are one among them. This study aims to numerically analyze and evaluate use of sheet pile wall as a potential landslide barrier. An unconventional slope stabilization technique using parallelly oriented sheet pile walls, commonly known as Hardy Ribs is adopted for presented study. The effect of sheet piles on the slope displacement is studied in detail. Study is conducted using Finite Element Method (FEM). Soil profile from a real landslide site is used for analysis. Soil is modelled as a solid obeying Mohr-Coulomb yield criteria and sheet piles as linear elastic material with properties of steel. Using FEM, initial condition of slope as well as reinforced condition has been modelled and the difference in displacements are compared.

Keywords: *Landslide barriers, Slope stabilization, Sheet pile walls, Finite element analysis.*

1 Introduction

Landslides have become cause of major concern in India, especially in the last decades due to population increase and subsequent surge in land development operations in hilly regions. Two most vulnerable regions in India where landslides are becoming serious threat is the Himalayan ranges and Western ghats. These hilly areas are susceptible to various forms of landslides ranging from low slides to disastrous large scale debris flows. Landslides are thus becoming a major focus of various studies. From observing various cases of occurrences of landslides, it is evident that complete protection from a major slide is not possible. However, there are various studies focused on developing and evaluating effective landslide barrier systems.[1–4]. Most commonly used debris flow barrier is mesh type barrier, which has proven to be effective in holding rockfall mass and debris flow. Numerous studies are available regarding analytical and numerical modelling of mesh type flexible barriers [1,2,4-6].

The type of landslides occurring in Indian terrains are majorly because of excessive rainfall and rarely because of minor quakes. The slope failure occurring in such cases are mostly translational, i.e., the soil above strong impermeable bedrocks slide over hard stratum causing a massive flow of soil mass. In such cases mesh type barriers may not serve the purpose of obstructing the flow. Hence, there is a need for alternative methods of slope protection. Sheet pile walls are a commonly used structure for slope protection in large scale due to its ease of installation and cost effectiveness. Use of sheet pile walls for massive soil flow protection is hardly studied. An unconventional technique for landslide stabilization using parallelly installed sheet piles was implemented by Canadian National Railway Company to stabilize a river side slope for protection of railway line [7]. This sheet pile installations are locally known in Canada as 'Hardy Ribs' installations as it was first introduced by Dr. R.M. Hardy. The sheet piles are installed parallel to the direction of slope at a properly designed spacing. This arrangement would prevent the soil displacement to some degree, but at the same time it would also facilitate for drainage.

The primary intent of current study is to analyze the effectiveness of such an installation to arrest or decelerate the soil displacement and consequently providing some degree of protection to infrastructure downstream of a sliding soil mass.

Use of finite element analysis (FEA) has been most efficiently utilized for solving various geotechnical problems recently. FEA method is a powerful tool enabling engineers and researchers to model and analyze complex material behavior of soil. Due to its versatility and efficiency, FEA software is used for the present study.

2 Numerical Model

The finite element software MIDAS GTS NX was used to conduct numerical analysis in this study. The soil profile for study was adopted from [8] where a detailed cost benefit analysis of landslide prevention vs post event actions were presented. Fig.1 presents the soil profile adopted for study. The material properties as per literature is given in Table.1. For the ease of analysis soil under dry condition is considered in present study.

Table 1 Material properties used in study

	Layer A	Layer B	Bedrock	steel
Unit weight,γ(kN/m3)	19	19	27	78.5
Elastic Modulus (kN/m2)	5200	1300	$2.6*10^{10}$	$2.1*10^{8}$
Cohesion (kN/m2)	10	6	6000	-
Friction angle (°)	23	15	31	-

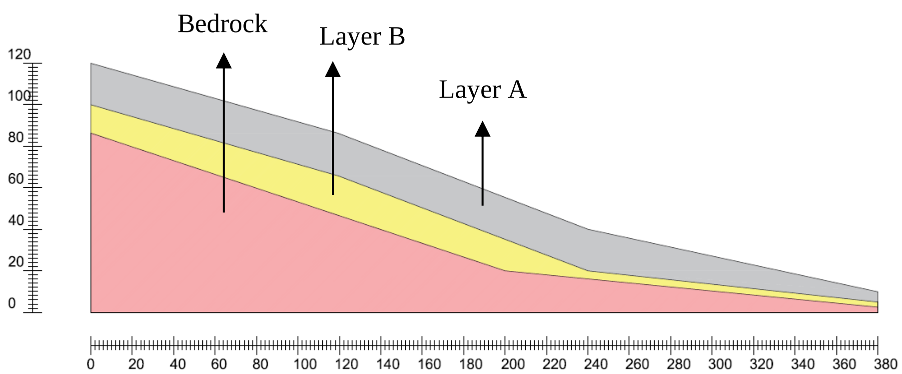

Fig 1 Soil profile adopted for study

Soil was modelled as a 3 dimensional solid with Mohr-Coulomb material while sheet pile walls were modelled as an elastic material with properties of steel. Sheet pile geometry was adopted as per literature on Hardy-Ribs [7] and given in Fig.2.

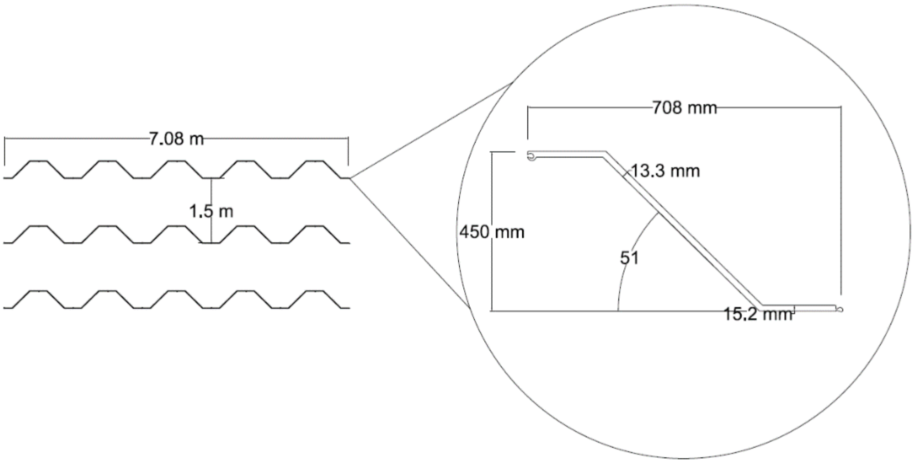

Fig 2 Geometry of sheet piles used

Model mesh has been generated using hybrid mesh generation function of MIDAS GTS NX, which creates a mesh set that use an optimal combination of hexahedral and tetrahedral elements. Hexahedral elements can provide more accurate stress results while tetrahedral elements have advantage of effectively modelling complex geometries. Hence combination of both gives a more efficient model without any significant loss in modelling or analysis speed. Fig.3 shows the model geometry with standard fixity conditions for the unreinforced slope. A width of 14m was taken for analyzing soil profile as 3D model. Sheet pile walls were placed parallel to the slope at a spacing of 1.5m. Total wall length of 30m was considered in order to ensure sufficient embedment in to the bedrock. Fig.4 shows the model geometry with sheet pile installation. The location of sheet pile installation was chosen based on maximum displacement shown in analysis results of unreinforced geometry.

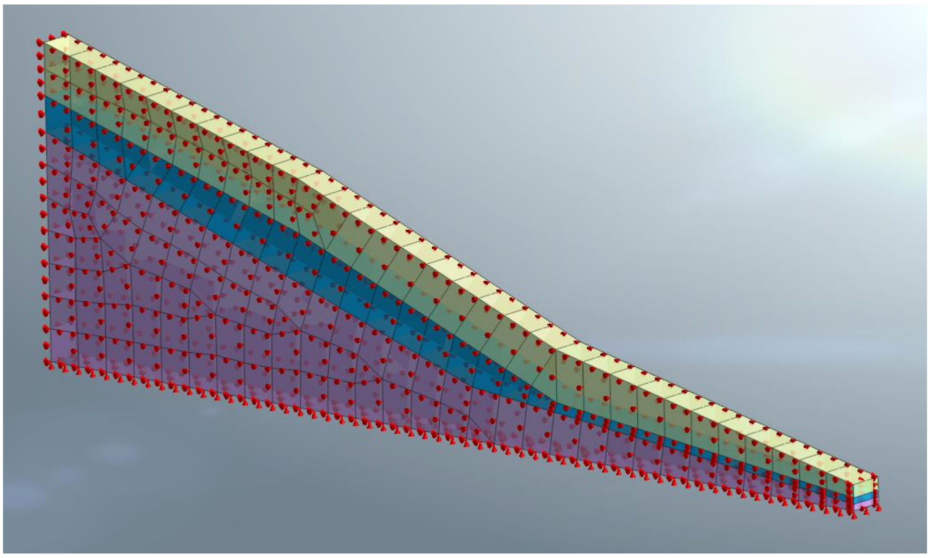

Fig 3 Finite Element Model of unreinforced soil slope

Soil slope without any barriers to sliding was analyzed initially under self-weight alone. The slope stability analysis was carried out using Strength Reduction Method, where no previous assumptions regarding failure is needed. The strength reduction method gradually decreases the shear strength and friction angle (c and ϕ) until the solution does not converge and this point is considered as the failure point of the slope. The maximum strength reduction ratio at that point is used to calculate minimum safety factor of the slope. In the present study both unreinforced and reinforced slope are analyzed using SRM to obtain failure pattern in both cases.

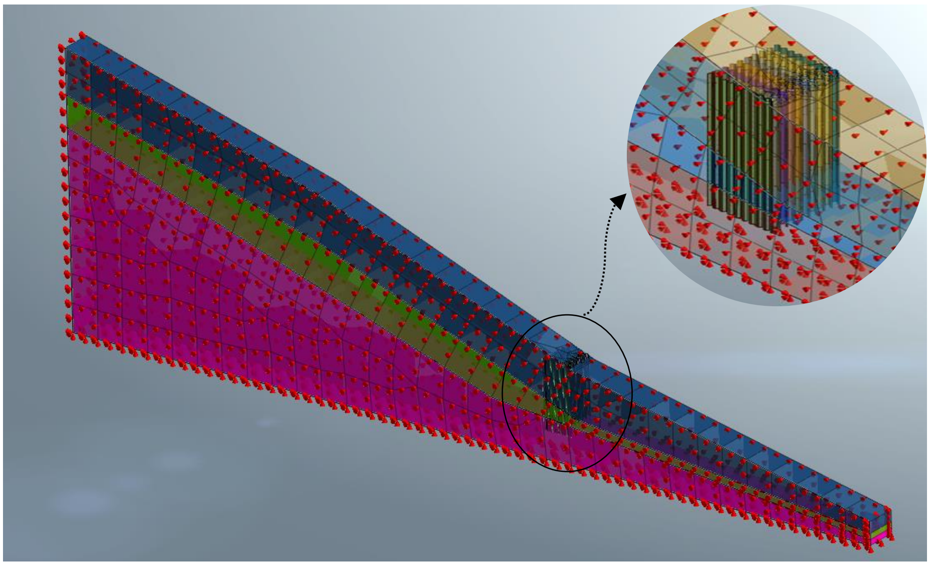

Fig 4 Model geometry with sheet pile installation

3 Results and discussions

Soil slope without any landslide barrier was analyzed initially using strength reduction method. A factor of safety of 1.00 was obtained for unreinforced slope. The displacement profile and the direction of failing soil mass is shown in Fig.5. It can be seen that the soil along the slope fails completely starting from head to toe of the slope, with a maximum displacement of 322m. This failure would evidently cause considerable damage and destruction to properties and infrastructure downstream of the slope. Fig.6 gives the plastic strain developed during failure and it can be seen that the failure surface extends all the way to the downstream end of slope. The maximum value of effective plastic strain developed was 51.6 located about the toe of slope.

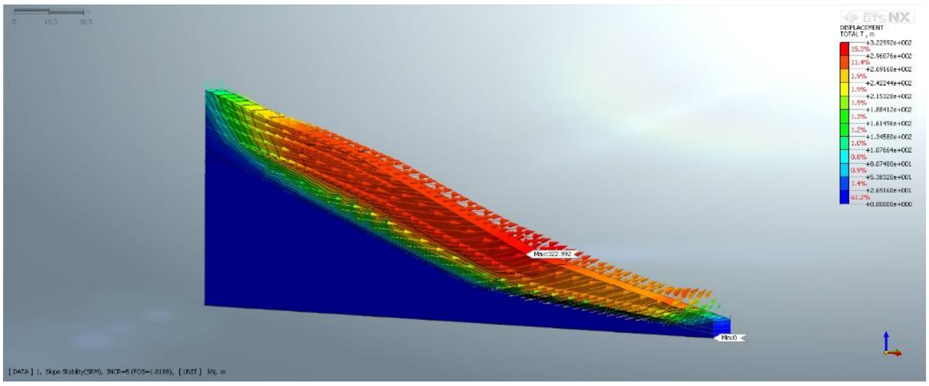

Fig 5 Failure of unreinforced slope

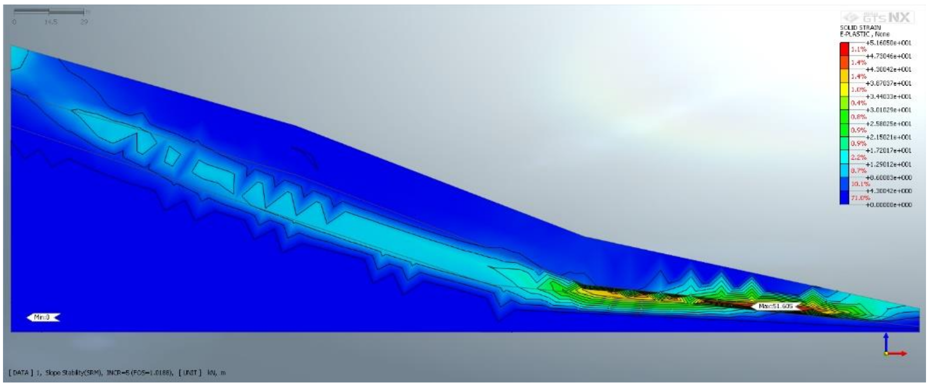

Fig 6 Effective plastic strain profile for unreinforced slope

As explained, the sheet piles were installed parallel to the direction of slope extending to the bedrock from the top layer (Fig.4). The effect of such a structural installation on the soil displacement is shown in Fig.7. The analysis results show that a factor of safety of 1.075, an improvement from unreinforced case, was obtained with the installation of Hardy Ribs. The maximum soil displacement has reduced to 75.9m, which amounts to 76.5% reduction from that of unreinforced case. Corresponding effective plastic strains along the slope is given in Fig.8. The maximum value reported was 19.08, developed just above the sheet pile installation. The failure pattern of soil slope after installation of Hardy Ribs clearly shows the degree of obstruction provided. Failing soil mass is confined to the point where sheet piles are installed ensuring minimal or zero destruction beyond the location of Hardy Ribs.

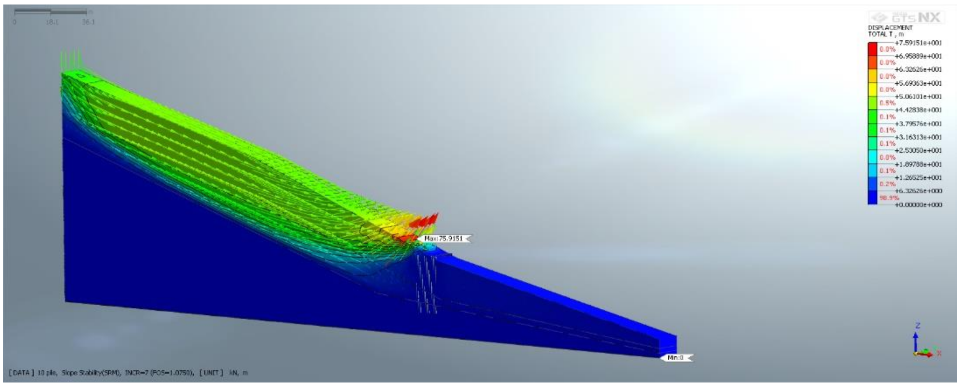

Fig 7 Total translational displacement of soil mass at failure after Hardy Ribs installation

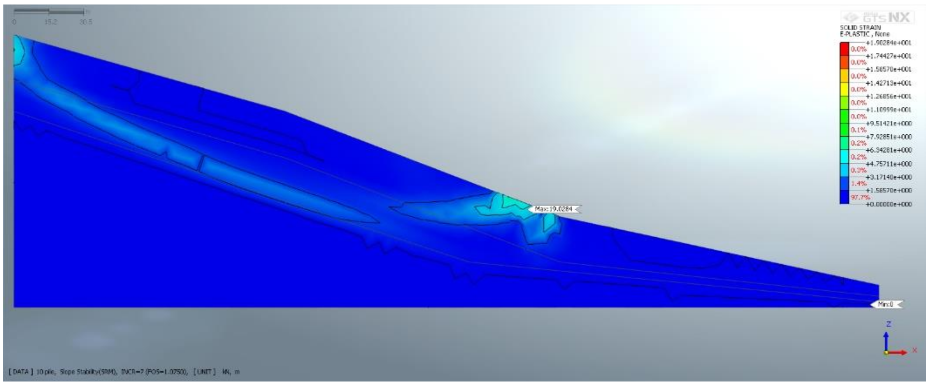

Fig 8 Effective plastic strain profile for reinforced slope

The reduction in total soil displacement and plastic strain value shows the effectiveness of Hardy Ribs installation. Even though improvement in factor of safety is not significant, present study clearly proves the efficiency of parallelly installed sheet pile walls as a barrier for landslides.

4 Conclusion

In this study, finite element analysis of a landslide susceptible slope was performed with and without sheet pile wall reinforcement. An unconventional sheet pile wall arrangement known as Hardy Ribs, where sheet piles are arranged parallel to direction of slope, is studied here. The change in total soil displacement at failure after sheet pile installation is compared with that of slope without any barriers. Considerable reduction in total displacement was observed as a result of Hardy Ribs installation. Variation in effective plastic strains in soil was also studied. The magnitude of plastic strains was also found to be reduced with implementation of Hardy Ribs.

It is evident that Hardy Ribs can be considered as an effective barrier method for landslides. Translational failure of top soil over a stable, hard strata can be effectively reduced by installing the sheet piles parallelly.

5 Reference

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