Comparative study of finite and distinct element methods for stability assessment of a jointed rock slope

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ABSTRACT: Every year the Himalayan regions of India experience several devastating landslides, which not only claim the lives of people, but also disrupt transportation facilities and the environment in general. The present study deals with assessing the instability conditions of a road-cut slope, under saturated conditions, using kinematic analysis with the help of Dips software, and two numerical simulation techniques, viz., the finite and the distinct element methods using the software packages RS2 and UDEC respectively. Probable mode of failure represented by the distinct element modeling agrees well with that predicted by the kinematic analysis of the slope. The results of the analyses suggest that the distinct element approach is a better suited technique for stability analysis of heavily jointed rock slopes compared to the finite element approach. The studied slope has been found to be unstable, hence few remedial measures have been suggested to improve its strength.

Keywords: Road-cut slope, Numerical simulation, Finite Element Method, Distinct Element Method, Stability analysis, Himalayas.

1 INTRODUCTION

1.1 Overview

Himachal Pradesh, situated in the western Himalayas, is a beautiful mountainous state with constantly changing climate and a rugged topography (Kundu et al. 2017). Almost every year, the hilly areas of this state suffer from the problem of landslides. Over the past few years, the relentless occurrence of landslides has been a matter of great concern. The constant increase in their frequency has been attributed to the alteration of the geo-environmental scenario of the area. There is an urgent need to analyze the stability of the vulnerable slopes in this region (Sarkar et al. 2016 and Singh et al. 2007).

In the present study, the stability of a jointed rock slope along the National Highway 05 between Jeori and Tranda in the Kinnaur district of Himachal Pradesh has been examined. Finite Element method (FEM) and Distinct Element Method (DEM) are the numerical simulation techniques employed for the stability analysis, after the application of kinematic analysis to determine the mode of failure.

1.2 Study area

The prime location under examination in our current work is located at latitude 31° 32' 8.29" N and longitude 77° 47' 0.4" E. Mica schist is the main type of rock found in this area, having well defined joint sets. The frail structural framework of the geological strata, the hydro-meteorological conditions, combined with several anthropogenic factors like removing vegetation covers, unplanned excavation activities (Sarkar et al. 2016 and Verma et al. 2018), have exacerbated the possibilities of slope failures. Mostly, failures in these rock slopes are aggravated during the monsoons. For this reason, the current analysis has been done taking into consideration the geotechnical parameters of the samples under saturated conditions.

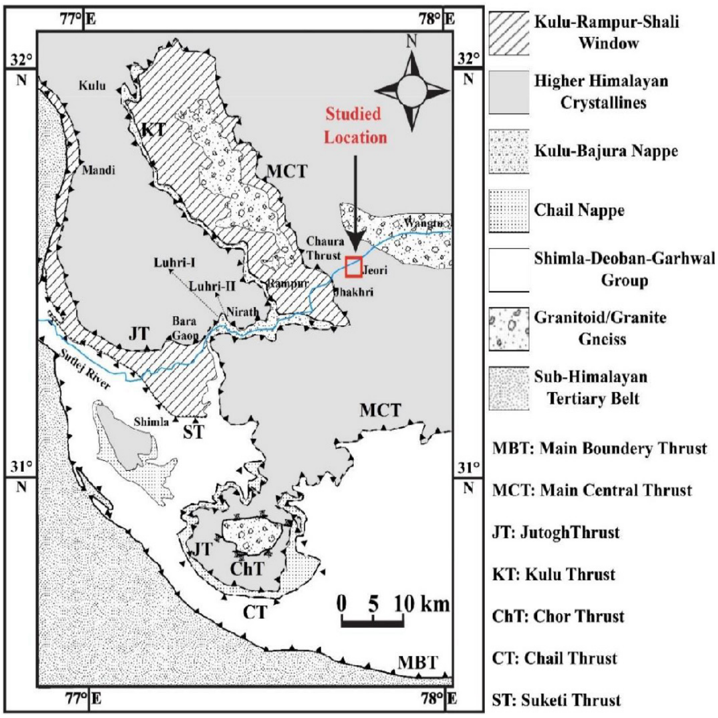

Figure 1. Regional geological map covering largely central and southern parts of Himachal Pradesh and northern parts of Uttarakhand in the Himalayas, India (after Singh et al. (2009)).

2 METHODOLOGY

2.1 Field and laboratory investigation

Detailed field investigation has been carried out in order to determine the geometry of the slope and its discontinuities, and to collect the representative rock samples from the face of the slope. The height of the slope is 25 m with an average slope angle of 80°. The slope material is composed of mica schist rocks which are highly jointed. The rock samples have been collected to determine the physico-mechanical properties in the laboratory under saturated conditions. The samples were tested in the laboratory following the accepted testing standards (ISRM 1978, ISRM 1981a, ISRM 1981b, ISRM 1981c and ISRM 1981d). Table 1 shows the structural orientation of the slope, and the two prominent joint sets observed during the field investigation. Table 2 gives the results of the laboratory tests performed on the rock samples, which have been utilized as input parameters for the numerical simulation of the slope.

Table 1. Structural orientation data.

Joint Set (J1)		Joint set (J2)		Slope	
Dip [°]	Dip Direction [°]	Dip [°]	Dip Direction [°]	Dip [°]	Dip Direction [°]
85	95	45	355	80	310

Table 2. Geotechnical parameters for numerical simulation (evaluated under saturated conditions).

Rock Parameters			Value
Unit Weight		[MN/m^3]	0.028
Peak cohesion		[MPa]	36.58
Peak friction angle		[°]	40.06
Residual cohesion		[MPa]	29.14
Residual friction angle		[°]	36.23
Young's modulus		[GPa]	37
Poisson's ratio			0.27
Joint Parameters			**Value**
Peak friction angle		[°]	33
Peak cohesion		[MPa]	11.62
Residual friction angle		[°]	27
Residual cohesion		[MPa]	6.73
Normal Stiffness	J1	[MPa/m]	48430
	J2	[MPa/m]	57730
Shear Stiffness	J1	[MPa/m]	4844
	J2	[MPa/m]	5769

2.2 Kinematic analysis

The kinematic analysis of the rock slope has been done with the help of the Dips software (version 6.017) provided by Rocscience Inc.

2.3 Finite element modeling

The finite element modeling has been done using the RS2 (Rock and Soil 2-dimensional analysis program) software package (version 11.016) provided by Rocscience Inc. The shear strength reduction approach is being employed here, using which, the magnitudes of the shear strength parameters of the slope material are systematically reduced until the solutions fail to converge (Acharya et al. 2017).

2.4 Distinct element modeling

The UDEC (Universal Distinct Element Code) software (version 7.00.80) provided by Itasca Consulting Group, Inc has been used for distinct element modeling of the rock slope. The FISH scripting language is applied to create data files for model creation and stability analysis.

3 RESULTS AND DISCUSSION

3.1 Result of kinematic analysis

In this location, slope (S_L) dips 80° due 310°. The angle of internal friction (Φ) is 36°, and the joint planes J_1 and J_2 dip 85° due 95° and 45° due 355° respectively. Figure 2 shows that there is a chance of planar failure along J_2 with failure direction 354°, and wedge failure between joint planes J_1 and J_2 sliding on both planes towards 10°.

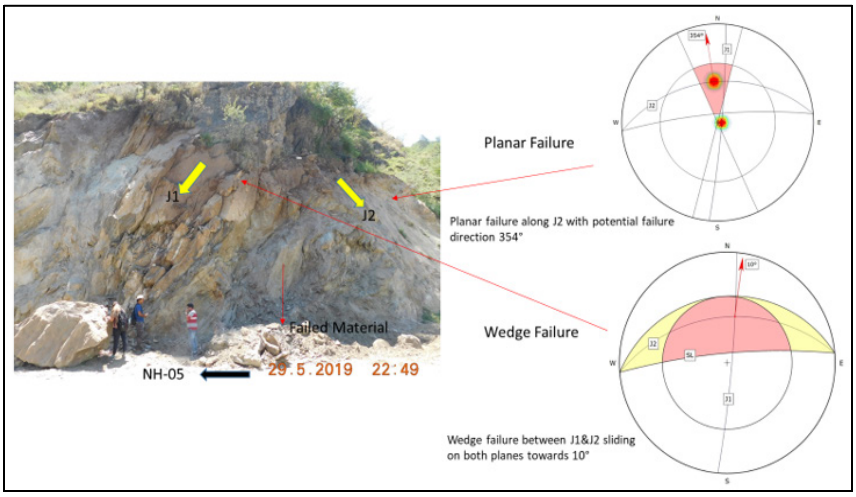

Figure 2. Planar failure along J_2 with potential failure direction 354°; wedge failure between J_1 and J_2 towards 10°.

3.2 Result of finite element analysis

With a critical SRF (SRF_c) of 0.54, the slope shows displacement at the face. The maximum value of the total displacement has been calculated to be 1.65 cm.

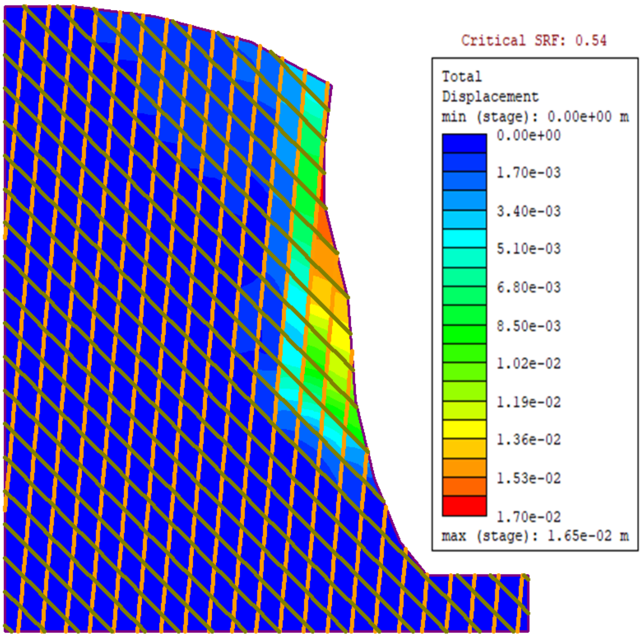

Figure 3. Model showing total displacement and the corresponding zone after the analysis.

3.3 Result of distinct element analysis

Unlike the finite element approach, the distinct element modeling focuses on the behavior of individual blocks in the model. The number of cycles for the computation was limited to 100000. The calculated Factor of Safety is 0.26, and the maximum value of block displacement is 6.89 cm.

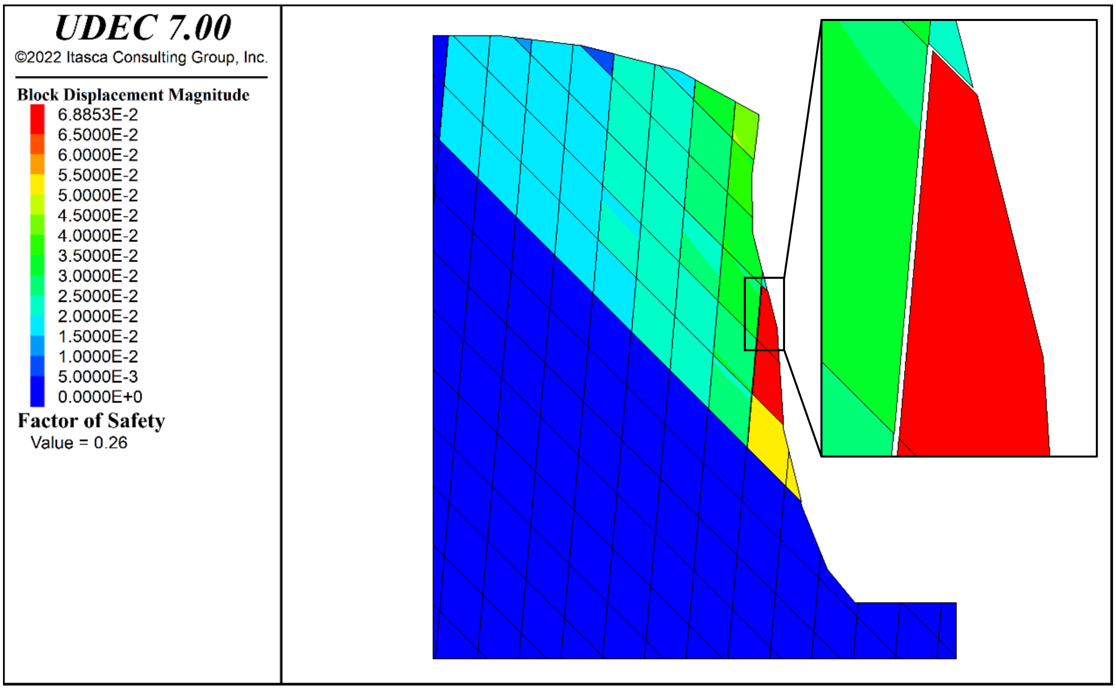

Figure 4. Model showing total displacement and the Factor of Safety after the analysis; magnified part showing the block dislodgement from the parent material (planar sliding along a joint plane of J_2).

4 CONCLUSIONS

The distinct element modeling represents the vulnerable zones of the slope more vividly than the finite element approach, which can be understood while comparing the zones of displacements, and the corresponding vectors obtained from the two approaches.

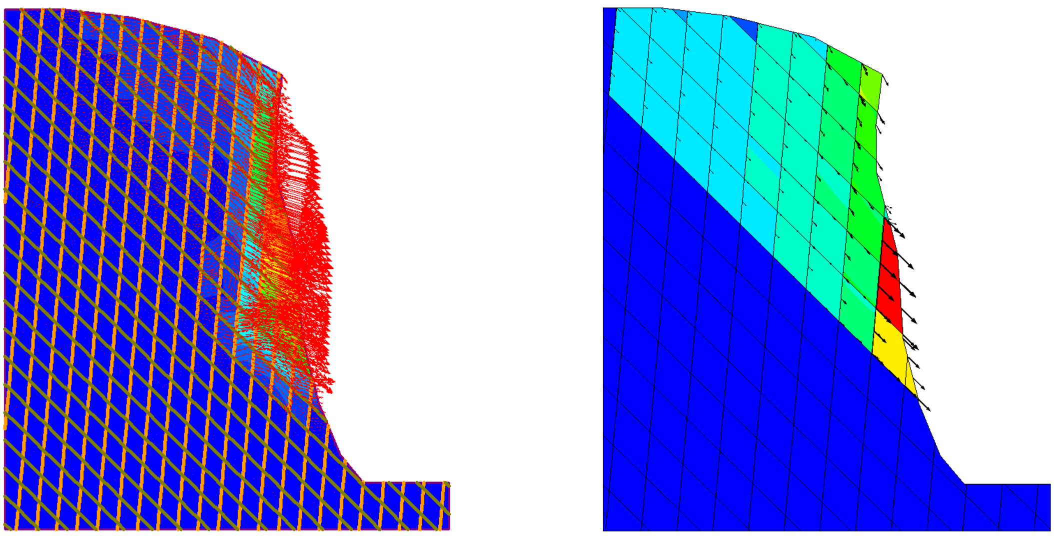

Figure 5. Displacement vectors of FEM model (left). Displacement vectors of DEM model (right).

The displacement vectors obtained from the distinct element analysis are predominantly concentrated in the region where block dislodgement occurs, unlike the finite element method where the deformation vectors are spread across the entire upper region of the slope face, showing a better contrast between the zones having different displacement magnitudes. The distinct element method is, therefore, a more appropriate approach in analyzing the stability of highly jointed rock slopes compared to the finite element method. From the critical strength reduction factor and the factor of safety obtained, the analyzed slope has been inferred to be highly unstable under saturated conditions.

Rock bolts can be installed across the zones showing high values of displacement. The bolts can help in increasing the shear strength of the rock mass by modifying the normal and shear stresses along the vulnerable surfaces. Re-sloping of the upper part of the slope can also be adopted to reduce the overall slope angle.

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