Geoscience Frontiers 6 (2015) 837–845

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Geoscience Frontiers

journal homepage: www.elsevier.com/locate/gsf

Research paper

Stability investigation of road cut slope in basaltic rockmass, Mahabaleshwar, India

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ARTICLE INFO

Article history:
Received 7 August 2013
Received in revised form
25 February 2014
Accepted 2 March 2014
Available online 17 March 2014

Keywords:
Slope stability
UDEC
Basalt
Mahabaleshwar
Road cut

ABSTRACT

Slope failures along hill cut road slopes are the major nuisance for commuters and highway planners as they put the human lives at huge risk, coupled with immense monetary losses. Analysis of these vulnerable cut slopes entails the assessment and estimation of the suitable material strength input parameters to be used in the numerical models to accomplish a holistic stability examination. For the present study a 60 m high, basaltic and lateritic road cut hill slope in Mahabaleshwar, India, has been considered. A number of samples of both basalt and laterite, in their natural state were tested in the laboratory and the evaluated maximum, minimum and mean strength parameters were employed for the three cases in a distinct element numerical model. The Mohr-Coulomb failure criterion has been incorporated in the numerical model for the material as well as the joints. The numerical investigation offered the factor of safety and insights into the probable deformational mechanism for the three cases. Beside, several critical parameters have also been judged from the study viz., mode of failure, factor of safety, shear strain rate, displacement magnitudes etc. The result of this analysis shows that the studied section is prone to recurrent failures due to the capping of a substantially thick layer of weaker lateritic material above the high strength basaltic rock mass. External triggering mechanisms like heavy precipitation and earthquake may also accelerate the slope failure in this area. The study also suggests employing instant preventive measures to avert the further risk of damage.

1. Introduction

In most of the developing nations, highways excavated along the hill slopes are the only means of conveyance. Both, major and minor slope failure activities along these hills cut slopes can be of dire consequences. The vehicular toppling as a result of the slight rock falls is quite prevalent in many parts of the world. The slope collapses, even though of limited extent can be grave; they place the human lives in jeopardy and put the local economy to a standstill. Hence, due to the immense liability associated with highway slope collapses, slope stability is a major concern for highway planners from both economic as well as risk point of view (Hoek et al., 2000). These slope failure activities chiefly depend on the slope geometry, slope material strength, prevailing geo-hydrological conditions and the discontinuity characteristics, orientation and distribution among the rock mass (Souley and Homand, 1996; Bhasin and Kaynia, 2004; Kainthola et al., 2012a,b, 2013). The hill slopes composed of weaker material, capping a jointed rock mass are more prone to failure. To mitigate a calamitous event, a comprehensive analysis is required to understand their failure mechanism. Estimation of slope deformation and instability using numerical technique entails knowledge of the slope-mass's response to stress induced changes which in turn are a function of the stresses in the rock mass, deformation characteristics, the intact material strength, mechanical behaviour of the intact rock, and any discontinuities (Fournier, 2008). Over the year various analysis tools and techniques like empirical, analytical, statistical, limit equilibrium, finite element, finite difference, distinct element methods, neural networks, GIS and fuzzy logic have been applied to the problems pertaining to landslides and slope stability (Pradhan and Saied, 2010; Pradhan, 2011; Alavi and Gandomi, 2012; Kainthola et al., 2012a, b; 2013; Ramakrishnan et al., 2013; Singh et al., 2013a,b,c;

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Peer-review under responsibility of China University of Geosciences (Beijing)

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http://dx.doi.org/10.1016/j.gsf.2014.03.002

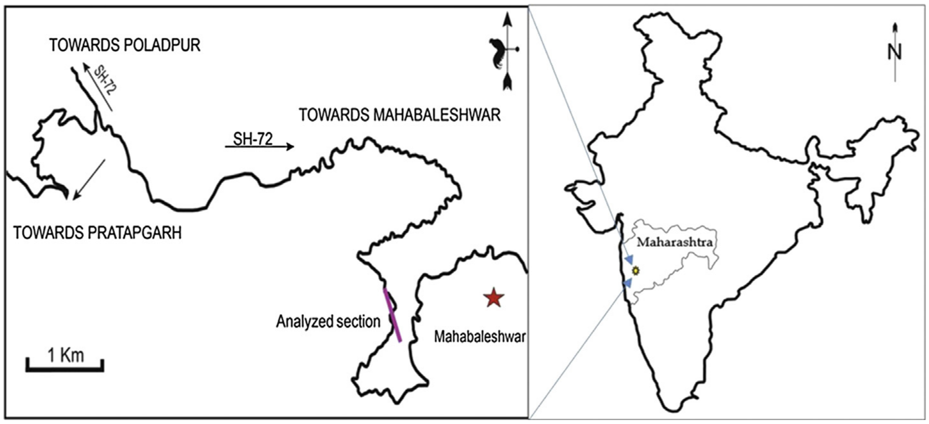

Figure 1. Location and the connectivity map of the study area.

Verma et al., 2013; Chang and Wan, 2015). The conventional continuum approaches like limit equilibrium methods, finite element methods and finite difference methods have certain disadvantages to model the behaviour of jointed rock masses, owing to the complex internal deformational mechanism (Kveldsvik et al., 2009; Lin et al., 2012). This has led to an increased usage of distinct element methods (DEM) and hybrid methods to simulate the behaviour of discontinuous rock masses (Stead et al., 2006). The Universal Distinct Element Code (UDEC), a DEM code was developed by Cundall to simulate the jointed blocky rock masses (Cundall, 1971). UDEC divides a rock mass into discrete blocks in which the block contacts represent a discontinuity. The relative displacements at block contacts are achieved by applying a force-displacement law at all contacts and Newton's force law at all the blocks (Cundall, 1980; Cundall and Hart, 1985; UDEC, 2011).

Previously, UDEC has been successfully used by various researchers to simulate a discontinuum media. DEM study has been carried out on the seismic response of a 120-m high rock slope of the Three Gorges Shiplock (Zhang et al., 1997). High natural hill slopes have also been simulated under static and dynamic conditions using UDEC, which provided valuable insights into deformational mechanism of hill slopes (Bhasin and Kaynia, 2004; Kveldsvik et al., 2009). Liu et al. (2004) used UDEC to investigate the response of blasting in jointed slope of an open cast mines. Previously, Kainthola et al. (2012b) carried out a finite element based slope stability assessment of the cut slopes of the same region. Singh et al. (2013a,b,c) estimated the velocity of block detachment in section of highly jointed basaltic cut slope, close to the present study area, for the rockfall analysis.

The present study deals with the distinct element simulation of a 51 m high blocky basalt cut slope topped with a 9 m thick lateritic layer. The cut slope is intersected with two major sets of discontinuities with a considerable variation in the dip angle. The section has seen sporadic events of failure activities. The investigation has been aimed relating the factor of safety of the slope (FOS) with the variable material strength. Twelve samples of both basalt and laterites were tested in the laboratory to assess the maximum, minimum and mean strength parameter, which have been utilized in the DEM numerical mode to gauge into the safety factor as well the deformational aspects of the slope.

2. Study area

The Mahabaleshwar area is an elevated Plateau surrounded on all sides by steep road climbs known as 'ghats'. Mesa and butte are the common geomorphic features in the study area. The present study focuses on a road cut section on state highway (SH-72), connecting Mahabaleshwar and Poladpur, Maharashtra, India (Fig. 1). The state highway is excavated on laterites and tholeiitic basalt which have been interlayered with red bole at some places.

Geologically, the formations belong to "Wai" subgroup, a part of the "Deccan Traps continental flood basalt" of Cretaceous–Tertiary age (Jay et al., 2009). The Wai subgroup consists of the lowermost Poladpur formation, followed by Ambenali formation and the upper most Mahabaleshwar formation (Beane et al., 1986). The basalt succession forming the Mahabaleshwar Plateau has been deformed into a gentle anticline–monocline plunging very gently towards the south (Mitchell and Widdowson, 1991). Typically, the basalts are composed of plagioclase phenocrysts together with clinopyroxene and olivine (Najafi et al., 1981). The region is capped with laterite layers (Fig. 2a). Bole beds are also observed in the study area as thin layers below the basaltic layers, representing the episodic flows of basaltic magma.

The laterites range from clayey to gravel size, composed mainly of montmorillonite, kaolinite and hematite. The rocks are fresh to moderately weathered, with high strength. The rock mass is intersected with two sets of discontinuities (J1 and J2) and another flow planes which gently dip inside the hill (Fig. 2b).

The prominent discontinuity sets, J1 dip towards the hill while J2 dips in the direction of the cut slope. The structural orientation of the discontinuities was assessed in the field (Table 1).

Structurally, the cut slope is undergoing a double plane sliding due to discontinuity sets J1 and J2 (Fig. 3a,b). The double plane sliding usually take place when the true dip of any of the discontinuity plane (T_{J1} and T_{J2}) lies in zone formed by the dip direction of the slope face (T_{sf}) and the intersection of the discontinuity planes (I_{J12}) (Yoon et al., 2002; Singh et al., 2013a,b,c).

The concerned cut slope section varies in height between 20 and 45 m. The analysed cut slope extends about 4 km in length. The erratic rock fall activity is quite visible along this patch particularly in the rainy season. The failed blocks range in size from 0.3 to 1 m^3 (Fig. 3a).

3. Model parameters

For proper and reliable estimation of input parameters for the numerical simulation, an extensive field work and laboratory experiments were carried out. The rockmass has been replicated as Mohr-Coulomb material in the numerical model, which follows a linear failure criterion. A number of samples of both basalt and laterite were tested in the laboratory to determine the bulk density, uniaxial compressive strength, Young's modulus, Poisson's