Back analysis and numerical modelling of Paglajhora landslide, Darjeeling, India

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Received April 2017/Accepted May 2017

Abstract

The Massive Paglajhora Landslide in Darjeeling-Sikkim Himalayan extends is one of the most disastrous Landslides in North-Indian Himalayas affecting a huge area. This landslide located on NH 55 near Pagalajhora in Kurseong block intersects the National Highway at two different elevations, thus causing a total disruption of three kilometres. The Paglajhora landslide has been active for around eighty years and more than twenty-one slope failure histories have been recorded till today causing unrecoverable damages to the lives and property. This paper describes various geological and geotechnical studies that are being done at and near Paglajhora landslide. This landslide lies in the close vicinity of MCT and is found to be composed of highly foliated schists and Phyllitic rocks. Laboratory testing of the collected samples has been performed using ISRM (2007-14) suggested methods of rock characterization to evaluate shear strength parameters. Back analysis using Slope/W and numerical modelling with Phase^2 program is performed for assessing the stability of this landslide. Numerical model is subjected to change in slope angle and slope height to obtain the effect of progressive and retrogressive nature of Paglajhora landslide. The corresponding variation in factor of safety is recorded and percentage increment and decrement is calculated.

Keywords: Slope Stability, Paglajhora Landslide, Numerical Modelling

1. Introduction:

There are many factors leading to the frequent instability and landslides in Paglajhora, Kurseong block region, but only a few site-specific studies have been conducted in the landslide area for the verification of rock mass conditions of slope failure, mainly due to the extremely difficult and far off reach terrain. For prevention of landslides different measures have been taken like construction of gabion walls and benches, surface chutes for draining the surface runoffs, building walls at the toe of the slopes for the prevention toe erosions, aqueducts for safely passing runoffs under the roadways, tying down of loose rocks and boulders with jute or wire geogrid to prevent toppling and sliding etc. However, none of these preventive measures have been survived for more than a few monsoon seasons [11].

In light of this, the following study is done to explore the causative factors and instability causing mechanisms associated with Paglajhora landslide. This research study includes geological and geotechnical investigations at Paglajhora landslide area both along and across the road. Field studies, laboratory testing and experimentation is done for rock characterization, Numerical modelling is done using Slope/W and Phase^2 software packages. Obtained results are than analysed comparatively and thoroughly and consequent discussion is done followed by a brief conclusion that can be derived from this study.

2. Site Description and Landslide Dimension:

Paglajhora landslide extends between *26º 52'N* to *26º57'N* latitude and *88º18'E* to *88º19'E* longitude, influencing a total area of about *1.67km^2*. Paglajhora lies in upper sub-part of the Shiva Khola basin near Tindharia town in the Kurseong sub division of Darjeeling district with a total basinal cover of *22.12km^2*. The crown of the landslide is at elevation of *1540m* and its toe extends down up to the elevation of *780m* (Shiva Khola basin) [11]. Figure 1 shows the satellite imagery, crown, lateral and toe view of this landslide. The total height of the landslide is *760m* and maximum width is of *1550m* near the middle. The Landslide intersects National Highway 55 (NH-55) at two different elevations, one between *1190m* to *1185m* and another between *1230m* to *1335m*, thus affecting the NH 55 for about *3000m*.

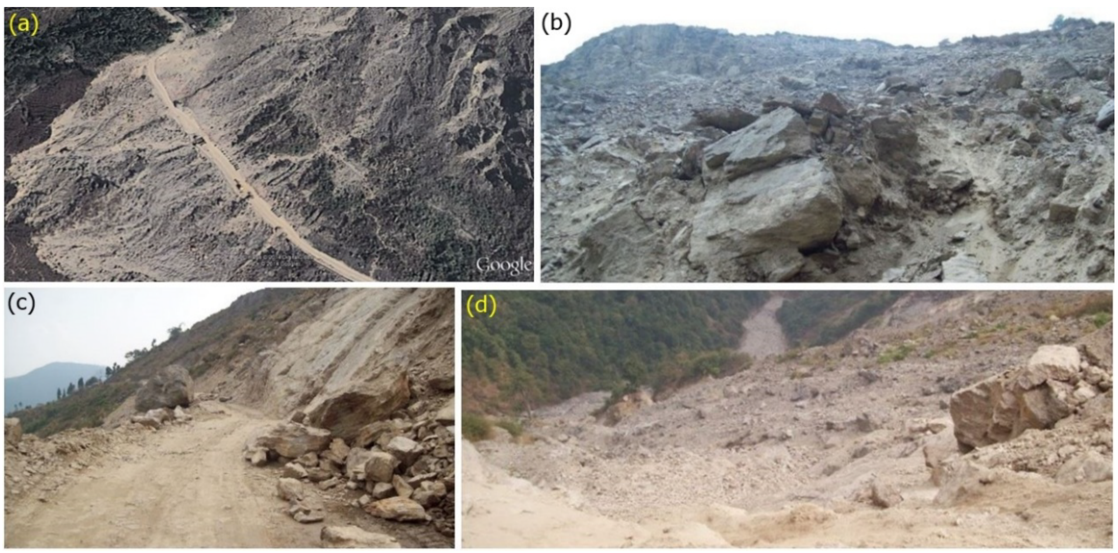

Figure 1 Photographs showing (a) Satellite imagery of the Paglajhora landslide, (b) Crown of Landslide, (c) Laterals Extension of Landslide and (d) Toe of Landslide

3. Local Geology:

The Paglajhora landslide is located in the Darjeeling hills area and the region is comprised of rock structures which are comparatively recent, causing a direct effect on slope failure. The study area is divided into two major litho-tectonic units, the Higher Himalayan Crystalline Sequence (HHCS) and the Lesser Himalayan Sequence (LHS), which are separated by a major ductile shear zone called as the Main Central Thrust (MCT) [5]. The HHCS consists of three different Quartzo-feldspathic gneisses of both igneous and sedimentary origin- i.e. the Amphibolite grade Paro and Lingtse gneisses, whose lower and upper contacts are the MCT2 and MCT1 zones respectively [1]. The granulite grade Kanchenjunga-Darjeeling gneiss are bounded by the MCT1 zone below and the South Tibetan Detachment system (STDS) above. The LHS is dominated by garnet-biotite-mica schists and chlorite schists in the upper part and slates and phyllites in the lower part. The local geological map [4] is shown in Figure 2.

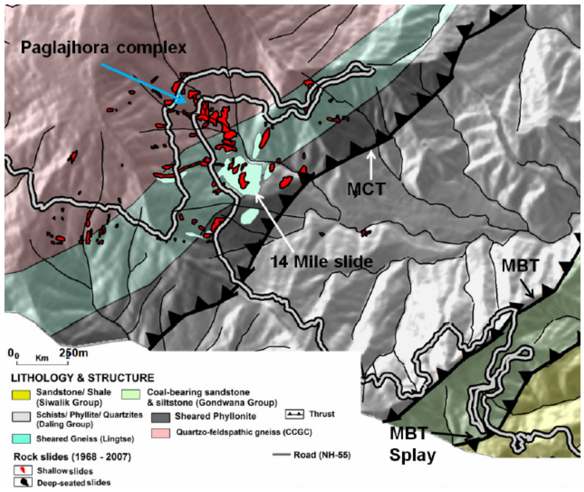

Figure 2 Geological map of area showing the Paglajhora complex [4].

4. Back Analysis and Numerical Modeling:

For Back analysis of any slope it is necessary to understand the process and causes resulting slope instability [12]. Intense field study in and around Paglajhora region revels the complex interaction of various slope failing parameters, leading to the gradual rise in the occurrence of landslides in this region. Slope instability due to high amplitude of relief angle of mica schists, results in large scale landslides even with the slightest equilibrium disruption. For the present study, Laboratory testing have been done on the collected rock samples from Paglajhora landslide. ISRM [6,13] and ASTM [2] standards are used to get the value of Point Load Index under dry (7.06 MPa) and saturated condition (*5.68MPa*), Water absorption (0.75%) Brazilian Tensile Strength (*8.28MPa*), Bulk Specific Gravity (*2.56*), Elastic Modulus (*46.32GPa*) and Poison's Ratio (*0.31*).
Paglajhora Landslide have undergone numerous progressive slope failures with multiple and complex interplay of parameters, controlling the initiation. This phenomenon with high level of complexity is hard to model; an attempt has been made here to understand and simplify the phenomenon. A detailed model is created using Slope/W and Phase^2 for simulating failure plane and performing back-analysis. Pre-and Post-Failure Coordinates for creating slope profile has been collected from the field and from the various agencies involved in the safety and disaster management. The Slope/W and Rocscience Phase^2 models are shown in Figure. 3 and Figure 4.

4.1 Laboratory testing

Laboratory testing is done on the collected rock samples from Paglajhora landslide. ASTM [8] and ISRM [9,10] standards are used to get the value of Point Load Index under dry and saturated condition, Brazilian Tensile Strength, Bulk Specific Gravity, Elastic Modulus and Poison's Ratio which serve as the inputs for the model. The results obtained are presented in Table 1.

Table 1
Mechanical properties of rock specimen

S. No.	Test Conducted	Average (MPa)
1.	Point Load Index (Dry)	7.06 MPa
2.	Point Load Index (Sat)	5.68 MPa
3.	Brazilian tensile strength	8.28 MPa
5.	Water absorption	0.75%
6.	Bulk specific gravity	2.56
7.	Elastic Modulus	46320 MPa
8.	Poison's Ratio	0.31

4.2. Slope/W Model

Rocscience RocLab 1.3 is used to obtain the rock mass mechanical properties using intact rock properties (mentioned above). A slope/W model is formulated. For Paglajhora landslide, the failure surface varies from (*98.55m, 382.34m*) to (*292.78m, 244.84m*). Several progressive checks have been performed for the verification of input data using slope/W optimize command. This errorless model is used for calculation of safety factor under different methods of slice. Critical slip surface has been generated and its corresponding FOS is recorded for the same model under different slice analysis [7] methods. The factor of Safety under all: Janbu Method of Slice (0.854), Ordinary Method of Slice (0.856), Bishops Method of Slice (0.914) and Morgenstern-Price Method of Slice (0.912) confirms it as an unstable slope.

4.3. Phase^2 Model

For Phase^2 Model, Mohr-Coulomb strength criteria is used and a parametric study has been performed. Slope angle and slope height has been varied from 26^0 to 40^0 and 300m to 410m respectively. Joints with dip of 45^0 are used with fixed persistence of *10m* and spacing of *1.5m*. The obtained results are represented in Figure 5 (a) and Figure 5 (b) respectively.

5. Conclusions:

This study makes an attempt to study the instability of Paglajhora landslide, in Kurseong block, Darjeeling. The landslide is investigated using two methods; back analysis using Slope/W and numerical modelling using Phase^2. The back analysis of slopes has resulted in factor of safety to be less than one by applying Janbu, Ordinary, Bishops and Morgenstern-Price methods of the slice. For the Phase^2 model, the analysis is performed under different slope angles, as Paglajhora landslide is a progressive landslide, and with every new failure, there is a continuous variation of slope angle. This analysis is performed for slope angle varying from 26^0 to 40^0 and revolves a continuous percentage increment in the factor of safety as the slope angle decreases [11]. The maximum increment is seen by reducing the slope angle from 32^0 to 30^0. For the same Phase[2] model, another analysis is

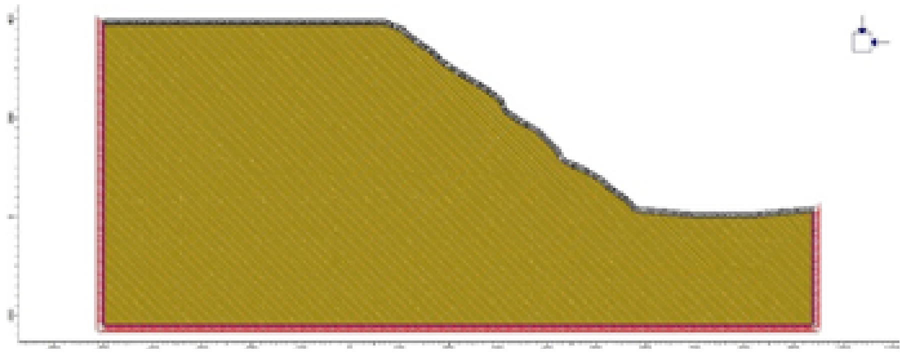

Figure 3 Phase[2] Model of Paglajhora Landslide with Joints (mesh and discretization)

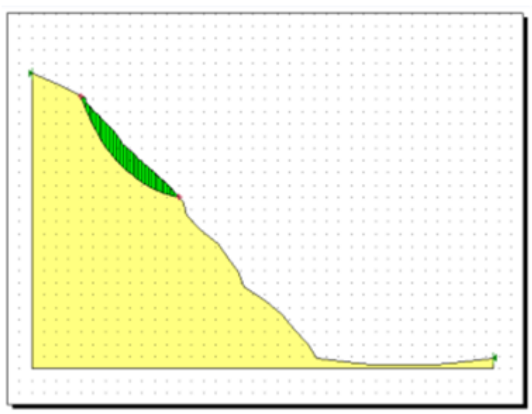

Figure 4 Slope/W model of Paglajhora Landslide showing slope surface before and after landslide.

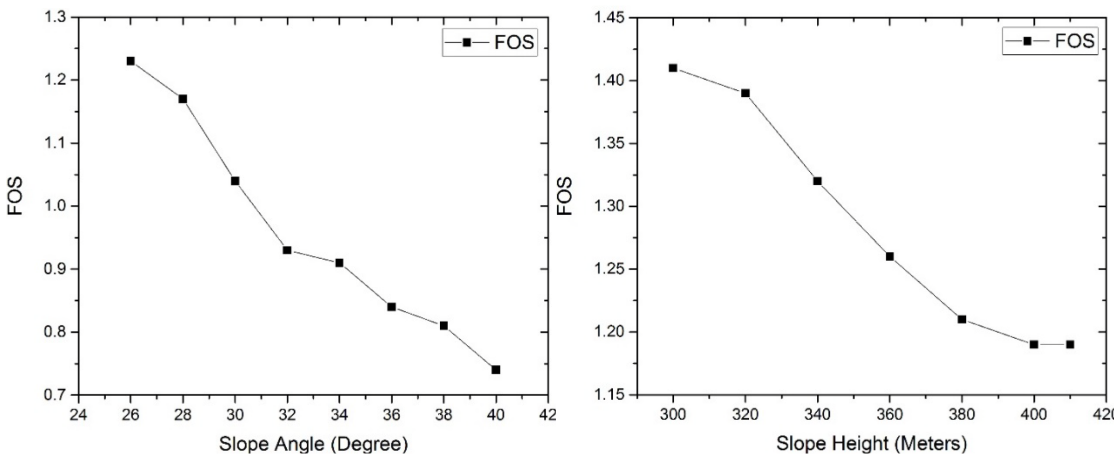

Figure 5 (a) Factor of Safety vs. Slope Angle and (b) Factor of Safety vs. Slope Height.

performed by varying the slope height. This variation in slope height is applied to model the retrogressive nature of the slope failure (base) surface. As the slope failure surface proceeds towards the crown at each new landslide event, the vertical height of the

Paglajhora landslide increases. This analysis revels a high percentage of reduction in the factor of safety with increment in height.
Local site geology is also described in detail along with the other causative factors, dominating for the initiation of Paglajhora landslide. The complex nature of this landslide cannot be modelled easily using the simple static analyses, and a further research is necessary.

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