Dynamic Analysis of Landslide in the North Bengal-Sikkim During 18th Sep 2011 Earthquake

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1 Introduction

Construction of road network and maintenance of transportation system, in the Himalayan regions is a major task for the engineers. Almost every year in monsoon season roads in this region get blocked due to landslides. Sikkim is one of the states in India and a part of Eastern Himalaya situated between 27°00'46" to 28°07'48" N latitude and 88°00'58" to 88°55'25"E longitude, covered an area of 7,096 km².

On September 18, 2011, a strong earthquake hit at Sikkim-Nepal border with a magnitude of 6.9. The epicentre location is at 27.7°N and 88.2°E, with a focal depth of 10.0 km in Sikkim. It was a shallow focus event, which was felt in Nepal, India, Bhutan, Bangladesh and China. Tremors which lasted for about 30–40 s were also north and north eastern states of the country. The strongest shaking occurred in west side of Sikkim, mostly in Gangtok and further in Siliguri at south Sikkim. Strong earthquakes frequently cause a huge number of landslides in large scale, in hilly and mountainous areas. Sikkim caused huge number of landslides during this earthquake as shown in Fig. 1. Nearly 120 people died, besides this several buildings/structures are collapsed causing sever economical loss. Several landslides have occurred from the Himalayan foot hill region up to the higher Himalayan range of Sikkim-Darjeeling Himalayas. Different road stretches of Darjeeling-Sikkim Himalayas revealed more than 210 landslides approximately in which, 114 are debris slides, 77 are rockslides and 8 are rock falls approximately. Due to very poor road network in this region and because of no alternate route, people face lot of troubles because of landslides. Around one lakh people are estimated as homeless after this event. Shallow translational type landslides are induced during earthquake are having failure planes of average depth ranging between 2 m and 5 m. Slope covered by thin unconsolidated screened deposits and debris slope which consist unconsolidated material are prone to slope failure during this earthquake.

In this paper, we studied the unsteadiness and mass movements of hill slopes along mountain roads in Sikkim region. Detailed evaluation of the slope failures has been studied under dynamic loading. The slope is modeled using Plaxis software and the configuration including geometry and properties of slope was considered for analysis.

2 Details of study area

The eastern India–Nepal Himalayan zone has been seismically active with major earthquakes occurring in the north of the MBT. The earthquake motions of this event were recorded at Gangtok and Siliguri by strong motion accelerographs operated by IIT Roorkee (http://pesmos.in/2011/). The PGA values recorded at these locations are 0.15 g and 0.20 g respectively. Sikkim lies in zone IV of the Indian seismic code (IS 1893–2002). Hills of Sikkim mostly consist of gneissose and half-schistose rocks, generally yields poor and shallow brown clay soils.
Jorethang is situated in the lap of north-east India. It is a major town in South Sikkim district located at an altitude of 300 m above sea level. It lies near Singtam town. Sikkim is divided into two seismic zones North Sikkim and South Sikkim. North Sikkim comes under zone 4 and south Sikkim, which includes areas of Gangtok and Singtam, falls under seismic zone 5 is highly responsive to moderate to major earthquakes. In the east districts of Sikkim, surrounding of Singtam road sections occurred 70 landslides are occurred in which 23 are rock flow and 37 are debris flow. Comparatively northern part of the state experienced severely compared to southern Sikkim during this earthquake. The slope considered is located at Jorethang area which is highly unstable with a horizontal length of 526m is considered for analysis. (Fig.2). Slope considered in this present study is at longitudes 27°07'53.36"N and Latitudes 88°17'27.53"E. The detailed cross section is located at an elevation of 591m above MSL.

Table 1: The material properties considered in the analysis

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of behavior</td>
<td>Undrained</td>
</tr>
<tr>
<td>$\gamma_{\text{unsat}}$ (kN/m$^3$)</td>
<td>17</td>
</tr>
<tr>
<td>$\gamma_{\text{sat}}$ (kN/m$^3$)</td>
<td>20</td>
</tr>
<tr>
<td>Young’s modulus $E_{\text{ref}}$ (kN/m$^2$)</td>
<td>1.90E+05</td>
</tr>
<tr>
<td>Poisson’s ratio $\nu$</td>
<td>0.3</td>
</tr>
<tr>
<td>Cohesion $c$ (kN/m$^2$)</td>
<td>75</td>
</tr>
<tr>
<td>Friction angle $\phi$ (°)</td>
<td>34</td>
</tr>
</tbody>
</table>

3 Numerical Modeling

The finite element program Plaxis 2D is used to evaluate the stability of the slope considered. 15-node triangular elements were used in the mesh modeling. When compared to regular ‘structured meshes these meshes are numerically efficient’. Accurate calculation of stresses and displacements are provides by 15-node element. Two cases are considered. First case, dynamic loading based on ground acceleration is applied for slope before 0-earthquake; secondly static loading is applied for slope considered after earthquake. Mohr–Coulomb model was used for the analysis. A simple finite element mesh is generated for both slopes. The study area consist of silty sand with fines (Prasad, 2003) Dynamic analysis is carried by pseudo-static analysis for first case and considered amplitude and frequency of 8.5 and 9 (Nath, S K, 2008). And c-ϕ reduction analysis for second case, the horizontal displacement contours and stresses contours are obtained. For both slopes material model assumed to be same, Geotechnical parameters are given in Table. 1.

4. Results and discussions

Numerical analysis was performed for the slope considered using Plaxis 2D. Dynamic and static analyses were carried out using detailed geotechnical properties to estimate displacements and stresses in the slope. From the analysis, it is clear that the horizontal displacements obtained in dynamic case before earthquake are approximately equal to static case and is shown below in Fig. 3(a) and 3(b).

References

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