Slope Stability Analysis Using Software GEO5 and C Programming

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Abstract— Analysis of slope stability is carried out to minimize the occurrence of slope failures and landslides. Slopes along the highway are highly susceptible to slope failure and thus landslides. Engineers must therefore give serious consideration before any construction or development is executed to ensure that the designed slopes remain stable. Slope failure can be determined through appropriate measurement of slope stability. In this study C- programming and GEO5 software have been used to determine the factor of safety of the selected slopes. Factors such as soil cohesion (c), angle of internal friction (φ), and unit weight of soil (γ) have been determined using lab experiments. Total station surveying has been used to prepare contour maps of the study area. Cross sectional profiles have been prepared at suitable intervals and these are used as input for the Geo5 software. The calculation of factor of safety (FOS) is based on finite slope stability analysis using Bishop’s method.

Keywords— Angle of internal friction, cohesion, factor of safety, slope stability.

I. INTRODUCTION

SLOPES may be natural or manmade or earth dam. Every slope has forces acting on it that tend to disturb its stability. The main force is the self-weight of soil mass forming the slope, but seepage, seismic activity and external loads are also disturbing forces. In a stable slope, resisting force due to shear strength are larger than disturbing force [1]. Slope failure is related to the following reasons: soil properties or soil type of slope, geometry of slope, weight, water content (one of the most aggressive factor reducing shearing strength of slope), tension cracks and vibrations due to earthquakes. Key factors in slope stability investigation include determining the boundaries of the slope instability, establishing a history of previous slope movement, assessing landslide causation [2]-[5], modeling landslide initiation as well as the travel paths taken by moving landslide debris [6], assessing the damage to affected buildings and structures [7], [8], and preparing the recommendations for stabilizing slopes. Conventional limit-equilibrium techniques i.e. they evaluate the slope as if it were about to fail and determine the resulting shear stresses along the failure surface, are the most commonly used analysis methods. Excellent commercial softwares like Geo5 [9], PLAXIS, Z-soil, have made a powerful viable alternative to the assistance of the geotechnical engineer. The aim is to obtain a comparison of solution to a man-made slope by conventional method and using Geo5 software.

II. SCOPE AND OBJECTIVES

Stability of slopes, natural and manmade, is particularly important for any hill road. Disturbance to slope can occur due to erosion caused by rain-fall and run-off and consequent slides. During monsoons the road network in hill roads experiences slips, erosions and major and minor landslides at many places. Hence, Slope stability and erosion control are therefore vital for control and prevention of landslides/slips. The present study will generate a section wise database regarding slope characteristics and factors of safety. This section wise data base can form a base for planning and designing mitigation measures and development activities.

III. STUDY AREA

Due to high seismicity, active tectonics, frequent catastrophic precipitation and wide variety of rock and sediments, slope failures are extreme in mid Himalayan region; so the sites were selected on NH 22 connecting Shimla to Dharamshala via Hamirpur. The 234 km stretch transcends the outer and lesser Himalayas (Mid Himalayan tract of H.P). The average rainfall that it receives monthly during monsoon experiences slips, erosions and major and minor landslides at many places. Hence, Slope stability and erosion control are therefore vital for control and prevention of landslides/slips. The present study will generate a section wise database regarding slope characteristics and factors of safety. This section wise data base can form a base for planning and designing mitigation measures and development activities.

Site 1- It is located at a distance of nearly 1.5 km from Hamirpur towards Kangra on NH 22. It has the following extent: length = 68m and height = 15m. This site has visible signs of partial failure from 30m to 68m. The first 30m stretch however does not show any sign of failure. The soil stratum is non-homogenous showing variation within stretches of 12-13 m along the length. The Vegetation consists of a dense cover of Pine trees and shrubs.

Site 2- It is located at a distance of 2 km from the township of Bhotha on NH 22. The extent of the site is as follows: length= 39m and height =10 m. The 39m stretch of this site shows complete slope failure. The soil stratum is non-homogenous showing variation within stretches of 8m along the length. It has comparatively lesser vegetation cover, mostly in the form...
of shrubs. It has experienced erosion and slips during heavy monsoons.

IV. SITE INVESTIGATIONS

A. Preparation of Contour Maps

Determination of basic geometrical characteristics of the slope was done using total station survey. Total station surveying was done for both the sites in order to generate contour maps of the slopes.

The reduced levels, horizontal distance, vertical and horizontal angle readings were recorded using total station. These are fed as input in the Software LISCAD. LISCAD was used to generate contour maps and sections of both the sites. Figure 1 and 2 show the contour maps of the sites generated using LISCAD.

Contour maps obtained were used for the following purposes:
1) Determination of the extent i.e. length and height of the slide.
2) Obtaining cross sections along the length at suitable intervals and the corresponding variations in elevations.
3) Determining x and y coordinates of points along the slope

B. Geotechnical Investigations

Keeping in mind the variation in strata, 4 to 5 soil samples were collected from both the sites using core cutters. For site 1, one soil sample was collected for every 13 m length interval. For site 2, one soil sample was collected per 8 m length interval. Disturbed samples were obtained using core cutter and were tested in the lab for determination of natural water content, bulk density.

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample</th>
<th>Water Content (%)</th>
<th>Bulk density (kN/m³)</th>
<th>Cohesion (kN/m²)</th>
<th>Angle of internal friction (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>14.29</td>
<td>19.414</td>
<td>2.6</td>
<td>8.2</td>
</tr>
<tr>
<td>2</td>
<td>8.60</td>
<td>17.740</td>
<td>4.5</td>
<td>26.8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6.80</td>
<td>17.088</td>
<td>5.1</td>
<td>24.9</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10.0</td>
<td>17.629</td>
<td>6.8</td>
<td>22.4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.71</td>
<td>16.363</td>
<td>4.8</td>
<td>25.4</td>
<td></td>
</tr>
</tbody>
</table>

Undisturbed samples were collected to determine the shear parameters cohesion, c and friction angle, φ using direct shear test. Table I shows the water content, bulk density, cohesion, angle of internal friction of various samples of soil collected from site 1 and site 2.
Fig. 3 Typical effective stress failure envelope of site 1 (sample 1)

Figure 3 shows a typical effective stress failure envelope of sample 1 of site 1 for calculation of shear parameters. Similarly, for all other samples of both sites, effective failure envelopes have been drawn to calculate shear parameters of respective samples.

V. ANALYSIS

A. Limit Equilibrium Methods

The various limit equilibrium methods are: 1. Swedish circle method, 2. Friction circle method and 3. Bishop’s method.

B. Bishop’s Method

The analysis has been performed using Bishop’s method of slices. In this method, the failure section is divided into a series of vertical slices. The slice width is sufficiently small that the actual shape can be replaced with a trapezoid. It is assumed that the slice weight W acts through the midpoint of the area.

\[
F = \frac{1}{\Sigma W \sin \alpha} \left( \sum c b \tan \alpha (W - U b) + \frac{secc}{\tan \alpha + \tan \phi} \right)
\]  

where, 
- \( F \) = Factor of safety
- \( w \) = weight of slice
- \( c \) = cohesion
- \( b \) = width of slice
- \( \Phi \) = angle of internal friction
- \( U \) = pore pressure at each slice

An iterative analysis is necessary to obtain the factor of safety. Since this is trial and error method, in this we enter assumed factor of safety with respect to which the new factor of safety is calculated and the iteration process is continue till the difference between the two factor of safety calculated is negligible. Both slopes were analyzed using C-programming and GEO5 to calculate the minimum factor of safety at sections at 6 m interval each.

C. C- Programming

Originally designed as a systems programming language, C has proved to be a powerful and flexible language that can be used for a variety of applications, from business programs to engineering. C is a particularly popular language for personal computer programmers because it is relatively small and requires less memory than other languages. In C-program input following parameters to find the minimum factor of safety:

1. Co-ordinates of points A, B, D
2. Assumed value of xo (x-coordinate of center of slip circle)
3. No. of slices, n
4. Bulk density of the soil
5. Value of cohesion of the soil, c
6. Angle of internal friction, \( \phi \)
7. Variation in pore pressure in slices, U
8. Assumed value of FOS, F
9. Maximum number of iterations

Since, in this study pore pressure variations were not included therefore variation was input as zero in programming analysis method.

D. GEO5

Geotechnical software with analytical and finite element analysis solutions consist of programs designed to solve large number of problems commonly encountered. It includes integrated modules such as stability of slopes, reinforced slopes, nailed slopes, rock stability, spread footing, plates, beams, piles, cantilever wall, abutment, gravity wall, gabions, earth pressure, sheeting design, sheeting check, settlement, etc.

A wide range of geotechnical problems such as beams on elastic foundations, excavation, etc. can be modeled which can be used to study the real behavior of the material in the structure. There are many software packages available in the market. Some that uses the Swedish method of slices and others that use more sophisticated methods. In addition to the grid of centers and increments of radii, other data required as input for these packages include:

2. Zoning: identification of zones of different soils within the slope and beneath it including depth to hard stratum
3. Properties: soil parameters for soil in each zone.
4. Pore water pressure: location of phreatic line or pattern in each zone (not included in study)
5. Water levels: levels of water adjacent to the slopes

Table II and table III show the height, base width, slope angle and factor of safety calculated using C-programming and GEO5 and percentage difference among both at various sections at 6 m interval of site 1 and site 2 respectively. Height, base width and slope angle were calculated from the total station data analyzed using LISCAD for both sites.
TABLE II
ANALYSIS OF STABILITY OF SLOPE FOR SITE 1 AT VARIOUS SECTIONS

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Height (m)</th>
<th>Base width (m)</th>
<th>Slope angle (°)</th>
<th>FOS C-Prog.</th>
<th>FOS GEO5</th>
<th>Difference in FOS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3.752</td>
<td>9.951</td>
<td>65</td>
<td>2.82</td>
<td>2.05</td>
<td>27.3</td>
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<tr>
<td>9</td>
<td>14.884</td>
<td>15.384</td>
<td>39</td>
<td>2.03</td>
<td>1.77</td>
<td>12.8</td>
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<tr>
<td>15</td>
<td>8.839</td>
<td>21.122</td>
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<td>2.09</td>
<td>1.86</td>
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<tr>
<td>21</td>
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<td>2.16</td>
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<td>10.6</td>
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<tr>
<td>27</td>
<td>9.864</td>
<td>24</td>
<td>40</td>
<td>1.90</td>
<td>1.94</td>
<td>2.1</td>
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<tr>
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<td>13.790</td>
<td>24</td>
<td>40</td>
<td>1.35</td>
<td>1.18</td>
<td>12.6</td>
</tr>
<tr>
<td>39</td>
<td>12.027</td>
<td>24</td>
<td>50</td>
<td>1.49</td>
<td>1.40</td>
<td>6.04</td>
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<tr>
<td>45</td>
<td>15.777</td>
<td>23.827</td>
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<td>1.17</td>
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<tr>
<td>57</td>
<td>13.762</td>
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<tr>
<td>63</td>
<td>12.363</td>
<td>13.474</td>
<td>63</td>
<td>0.34</td>
<td>0.31</td>
<td>8.82</td>
</tr>
</tbody>
</table>

TABLE III
ANALYSIS OF STABILITY OF SLOPE FOR SITE 2 AT VARIOUS SECTIONS

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Height (m)</th>
<th>Base width (m)</th>
<th>Slope angle (°)</th>
<th>FOS C-Prog.</th>
<th>FOS GEO5</th>
<th>Difference in FOS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>8.107</td>
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<td>21</td>
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</tr>
<tr>
<td>39</td>
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<td>13.00</td>
<td>67</td>
<td>0.29</td>
<td>0.23</td>
<td>20.69</td>
</tr>
</tbody>
</table>

Figure 4 shows a typical profile cross-section at a section 39 m from origin for site 1 from LISCAD and figure 5 shows the analysis of this cross-section in GEO5. Similarly, typical cross-sections are obtained using LISCAD and analyzed in GEO5 and C-programming.

Fig. 4 Typical profile of site 1 at section 39 m from origin

Fig. 5 Analysis of section of site 1 at section 39 m using GEO5

Fig. 6 Comparison of FOS using C programming & GEO5 for site 1
VI. CONCLUSIONS

1. Factor of safety obtained for all the sections of site 1 yielded values <1.5, which indicates that the slope is unsafe against failure, which is validated from the slips that have occurred during monsoons.

2. Factor of safety obtained for most of the sections of site 2 from 39 m to 68 m yielded values <1.5, which indicates that this portion of the slope is unsafe against failure, which is validated from the slips that have occurred during monsoons.

3. For site 2, from 0 to 39 m, FOS values obtained were >1.5 which indicates low susceptibility to slope failure.

4. Results of numerical analysis (using C programming) and software analysis are within 15-20% for most of the sections. Hence, both the methods can effectively be used to determine the factor of safety of the slope.

5. The 15-20% difference in FOS can be attributed to capability of GEO5 software to optimize the number of slices in Bishop’s method and selection of ideal trial slip circle.

6. Factor of safety values less than 1.5 indicate the susceptibility of slope to failure. At present the sites show signs of erosion and slips and if ignored they may develop into major landslides in the near future due to excessive rainfalls, earthquakes.

REFERENCES


Figure 6 and figure 7 show the variation in factor of safety at various sections calculated using C-programming and GEO5 for site 1 and site 2 respectively.