STATIC AND DYNAMIC ANALYSIS OF MANSA DEVI HILL LANDSLIDE USING FLAC$^{3D}$

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ABSTRACT

Slope movements are dynamic phenomenon which are complex in time and space. Slope failure generally occur in hilly regions like Himalayas. It is dangerous because of the sudden movement of the slope-forming material called as landslide.

The advancement in defining the characteristics of complex rock slope failure using numerical techniques have proved to be important tool for understanding the processes involved and the associated calamities. The present study mainly deals with the Static dynamic analysis of Mansa Devi hill landslide, Haridwar, Uttarakhand, India. The area experiences local as well as regional slides every year. The digital elevation model is made and Laboratory experiments were conducted to determine the various mechanical property of rock mass. The geotechnical parameters have been used as input for the numerical simulation of slope using FLAC3D. For dynamic analysis a sinusoidal wave of frequency 2 Hz and acceleration of amplitude 0.02 applied to model and observation was taken at 5, 10 and 15 second. The displacement along all the three direction and stresses along critical xx and zz direction have been calculated. Finally factor of safety of study area is calculated. The study indicates that slope at the higher height along the slope is unstable and it is stable at the lower height. The effects of instability have been thoroughly considered

Key words: Landslide; Deformation; Dynamic ; Flac3D.

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1. INTRODUCTION

Population growth and accompanying economic developments have meant that civil engineering projects are increasingly being carried out in mountainous region. During last
decade numerous landslides occurs resulting tragedies and loss of human life. In fact slopes are inherently unstable. Moreover erosion in the form of soil runoffs occurs daily as result of which slopes can collapse and result in destructive landslides. These landslides commonly occurs in mountainous regions especially along the hill-cut slope of the Lesser Himalaya. These landslide occur more frequently during the rainfall, but rock blasting method during road widening in dry season may also cause landslides. The present study aims at investigating the stability of slopes near Mansa Devi hill, which are vulnerable to the failure.

For many cases, the limit equilibrium methods have proven to give relatively reliable results despite its limitations. With the development of Finite Element Method (FEM), Boundary Element Method (BEM) and Finite Difference Method (FDM), these methods became popular for slope stability analysis in situations where the failure mechanism is not controlled completely by discrete geological structures. The use of numerical simulation is gaining importance due to many advantages over limit equilibrium method (Griffiths and Lane 1999, Duncan, 1996. Griffiths and Lane (1999) summarized the results of a slope stability analysis using FEM based on shear-strength reduction technique and gives advantage and disadvantage of FEM for use in a practical slope engineering problem. The development of discrete element method (DEM) by Cundall and Strack (1979) creates opportunity to explain the mechanical behavior of assemblies of discs and spheres. Wang et al. (2003) created Particle Flow Code (PFC) to carry out a general study on the stability of heavily jointed rock slope. Sung and Chung (2005) did stability analysis of jointed rock slopes by making use of Barton-Bandis (BB) constitutive model using UDEC.

The Numerical methods proved to be very important tool for slope stability method and Nowadays numerical method such as the finite element method (FEM), the finite difference method (FDM), the boundary element method (BEM), and the distinct element method (DEM) are gaining popularity for slope stability analysis where failure process is not controlled completely by discrete geological structures (Sarkar et al. 2010, Verma and Singh 2010a,b).

The dynamic characteristics of landslides and its failure mechanism with high potential energy is difficult (Guthrie et al. 2009; Xu et al. 2010; Burgh et al. 2012; Wu et al. 2013; Coe et al. 2016; Wang et al. 2017). The Numerical analysis of landslide occurrence is significantly important for risk evaluation before a landslide and during the rescue stage. Numerical modeling techniques including the discrete element method (Banton et al. 2009; Zhou et al. 2015; Shi et al. 2016), discontinuous deformation analysis (DDA) (Zhang et al. 2016; Beyabanaki et al. 2016) and depth integrated continuum mechanics method (Iverson et al. 2015; Ouyang et al. 2017), have been continuously shown to successfully reproduce the dynamic process of rockslides.

In the present research work, three-dimensional finite difference methods are applied. The stability analysis of potentially vulnerable slope are investigated and a quantitative measure for stability is provided in terms of factor of safety.

2. STUDY AREA

The study was carried out on the east facing slope of Mansa Devi hills in Hardwar, Uttarakhal. The area comes under toposheet number 53 k/1of the Survey of India. The soil sample is collected from the location 29°57’57.9” N, 78° 10’ 9.03” E, 395m elevation. The area is taken into consideration as it is regularly damaged and there is very high probability of landslide occurrence in future with possible loss of human lives and property.
3. NUMERICAL MODELING

3.1. FLAC 3D

Three dimensional nonlinear analyses were carried out using the finite difference code $FLAC^{3D}$ to study the effects of static and dynamic response of Mansa Devi hill model. $FLAC^{3D}$ contains an automatic 3D grid generator in which grids are created by manipulating and connecting pre-defined shapes such as brick, wedge, pyramid and cylinder. In the present study, the geometry of the soil domain is created using number of brick shape element Figure shows the element numbering for a brick shape used for creating the soil domain. In this figure, p0, p1,…p7 specify the reference (corner) points of the shapes, n1, n2 and n3 specify the number of zone in their respective directions and r1, r2 and r3 specify ratios that is used to space zones with increasing or decreasing geometric ratio. Similarly figure shows the wedge element which is used to create toe of the hill.

![Figure 1 Study Area](image)

![Figure 2 Model of study area](image)
3.1. Modeling Conditions

The size of the Mansa Devi model is considered as \( x = 227 \text{m} \), \( y = 10 \text{m} \), and \( z \) varies from 0 to 136m depending upon variation of slope. The whole grid is discretized into 7000 number of zones and 8481 number of grid points.

The distortion of the propagating wave can take place in dynamic analysis as a function of the modeling conditions. Both the frequency content of the input wave as well as the wave speed characteristics of the system will affect the numerical accuracy of wave transmission. The basic method of wave transmission which is an accurate representation of wave transmission through a model, the spatial element size, \( \Delta l \), must be lesser than approximately 1/10th to 1/8th of the wavelength associated with the highest frequency component of the input wave i.e.,

\[
\Delta l \leq \frac{\lambda}{10}
\]

Where \( \lambda \) is the wavelength related to highest frequency component that contains appreciable energy.

For the harmonic analysis case, the maximum frequency, \( f \), of the input wave is 2 Hz. Also \( V_s = \sqrt{\mu/\rho} \) Since \( \lambda = \frac{V_s}{f} \) and \( V_s = 170.58 \text{ m/s} \), we get \( \Delta l \leq 8.259 \text{ m} \). The maximum dimensions of the zones in \( X \) and \( Y \) and \( Z \) are coming out to be less than 8.259m. Thus the mesh size of the FLAC\(^{3D} \) model used ensures the accurate wave transmission.

3.2. Boundary Condition

At the bottom plane of the grid all movements are restrained. The lateral sides of the mesh were taken far enough from the pile to avoid any boundary effects. The planes at \( X = 0 \text{ m} \) are free to move in the \( Y \) and \( Z \) directions but not in the \( X \) direction. Similarly, the planes \( Y = 0 \) and \( Y = 10 \text{ m} \) are free to move in \( X \) and \( Z \) directions but not in the \( Y \) direction. The same boundary conditions were applied for dynamic case.

3.3. Material Properties

The parameters used for the soil modeling from Geotechnical test are summarized in the table.
Table 1 Input Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m$^3$) $\rho$</td>
<td>1890</td>
</tr>
<tr>
<td>Poissons ratio $\mu$</td>
<td>0.25</td>
</tr>
<tr>
<td>Young’s modulus (N/m$^2$) $E$</td>
<td>$137.5 \times 10^6$</td>
</tr>
<tr>
<td>Shear modulus (N/m$^2$) $G$</td>
<td>$55 \times 10^6$</td>
</tr>
<tr>
<td>Bulk modulus (N/m$^2$) $K$</td>
<td>$91.6 \times 10^6$</td>
</tr>
<tr>
<td>Cohesion N/m$^2$ $C$</td>
<td>$4 \times 10^4$</td>
</tr>
<tr>
<td>Internal friction angle $\phi$</td>
<td>31°</td>
</tr>
</tbody>
</table>

3.4. Constitutive Model

FLAC$^{3D}$ offers a wide range of capabilities to solve complex problems in geo-mechanics (Itasca, 2003). The program has certain basic built-in material models describing the constitutive behavior of the range of geologic materials.

In the present analysis, Mohr-Coulomb plasticity model has been used for the soil medium. The input parameters that are required by FLAC$^{3D}$ for Mohr-Coulomb model are bulk modulus, shear modulus, cohesion and friction angle.

The basic criterion for material failure in Mohr-Coulomb plasticity model is the famous Mohr-Coulomb relation,

$$f_s = \sigma_1 - \sigma_3 N_\theta + 2c\sqrt{N_\theta}$$

where $N_\theta = (1 + \sin \phi)/(1 - \sin \phi)$;

$\sigma_1$ = major principal stress;

$\sigma_3$ = minor principal stress

$\phi$ = friction angle; and

$c$ = cohesion.

3.5. Procedure for Dynamic Simulations using FLAC$^{3D}$

In this section the approach for dynamic analysis using a sinusoidal wave of frequency 2 Hz and acceleration of amplitude 0.02 m/s$^2$ is applied for 5, 10 and 15 second respectively. A static equilibrium calculation always precedes a dynamic analysis. Once the model is in equilibrium condition under the gravity loading, and then the subsequent changes in loading conditions are made in order to carry out dynamic analysis.

3.6. Static Equilibrium Calculations

The first step in the analysis approach is the generation of grid. Once the grid is generated for the soil medium, the model is assigned appropriate model (Mohr-Coulomb in this case) and brought to an equilibrium stress-state under gravitational loading. The model is in perfect equilibrium when the net nodal-force vector (the unbalanced force) at each grid point is zero. The maximum unbalanced force will never exactly reach zero for a numerical analysis, but the model is considered to be in equilibrium when the maximum unbalanced force is small compared to total applied forces in the problem. Figure so & so shows the plot of maximum unbalanced force history from where it can be seen that the maximum unbalanced force is approaching zero.
3.7. Dynamic Conditions and Simulations
Once the model is brought under static equilibrium condition, the dynamic simulation can now be performed by further making certain necessary changes in the model. Firstly, damping is specified for the model. Natural dynamic systems contain some degree of damping of the vibration energy within the system; otherwise the system would oscillate indefinitely when subjected to driving forces. Damping is due, in part, to energy loss as a result of internal friction in the intact material. Here in this case, the damping value of soil is assumed to be 5% of the critical damping.

3.8. Calculation of Factor of Safety
According to Zheng et al. (2005) the factor of safety is defined in two ways. The first is the strength reserving definition, which defines the factor of safety as the factor by which the shear strength $\sigma_m$ of the rock will be divided to bring the slope into the state of critical equilibrium and minimal safety factor (Fs) is obtained by shear reduction procedure

$$\sigma_m = \sigma/F_s$$

Factor of safety can also be defined as the ratio of total resisting forces to total driving forces along a certain slip line-

$$FoS = \tau/\tau_s$$

where, $\tau_s = \text{shear stress}$, $\tau = \text{shear strength given by-}$

$$\tau = c + \sigma_n\tan\phi$$

where $c = \text{cohesion}$, $\sigma_n = \text{total normal stress}$, and $\phi = \text{effective angle of internal friction}$.

4. RESULT AND DISCUSSIONS
The results obtained from Static dynamic (t=5sec) analyses are summarized from fig 5 to 14. The output obtained in all the analyses are in terms of displacement magnitude contours, x-displacement, y-displacement, z-displacement, stresses in xx and zz direction. Finally FOS is obtained which is shown by contours with respect to x-axis and z-axis (elevation) which is shown in fig 15. Also variation of FOS along the height of the Mansa Devi hill at different location from the toe of the hill has been plotted.

![Figure 4 Model of study area](http://www.iaeme.com/IJCIET/index.asp)
Static Condition

**Figure 5** Contour of x displacement

**Figure 6** Contour of y displacement

**Figure 7** Contour of z displacement
Static and Dynamic Analysis of Mansa Devi Hill Landslide Using FLAC3D

**Figure 8** Contour of XX stress

**Figure 9** Contour of ZZ Stress

**Dynamic condition t=5sec**

**Figure 10** Contour of X – Displacement

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Figur 11 Contour of Y- Displacement

Figure 12 Contour of Z - Displacement

Figure 13 Contour of XX – Stress
5. DISCUSSIONS

From the figure of displacement magnitude contour obtained from static analysis, it is evident that the maximum displacement of magnitude 94.57 cm occurs at the top of heel side of the study area. Also from the figure x-displacement contour it is clear that maximum X-displacement occurs at the downslope just adjacent to the road. The maximum value of X-displacement is observed to be 18.295 cm. Moreover Y-displacement is found to be of negligible value. Also figure shows displacement vector from which it can be conclude that the soil at downslope is sliding forward whereas settlement is observed at upstream slope. The maximum value of Z-displacement is found to be 94.675 cm.

From the figure of XX stress it is observed that the tensile stress occurs along the top of the slope. The maximum observed value of tensile stress is 26.019 kPa. Similarly it can be seen from the figure of ZZ stress contour that the tensile stress occurs along the top of the slope whose maximum value is 5.469 kPa.
From the figure of dynamic analysis for t=5 sec displacement magnitude contour obtained from dynamic analysis, it is evident that the maximum displacement of magnitude 1.6209 m take place at the top of heel side. The maximum value of X-displacement occurs at the downslope near to the road. The maximum value of X-displacement is observed to be 50.704 cm. Moreover Y-displacement is found to be of negligible value. Moreover from displacement vector figure it can be concluded that the soil at downslope is sliding forward whereas settlement is observed at upstream slope. The maximum value of Z-displacement is found to be 1.6209 m.

From the figure of XX stress it is observed that the tensile stress occurs along the top of the slope. The maximum observed value of tensile stress is 29.733 kPa. Similarly it can be seen from the figure of ZZ stress contour that the tensile stress occurs along the top of the slope whose maximum value is 6.47 kPa. Similarly all cases are described in table below-

<table>
<thead>
<tr>
<th>Type</th>
<th>X-Displacement in m</th>
<th>Y-Displacement in m</th>
<th>Z-Displacement in m</th>
<th>XX-Stress (KN/m²)</th>
<th>ZZ-Stress (KN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>0.18295</td>
<td>Small in power of 10⁻⁵</td>
<td>0.946</td>
<td>26.019</td>
<td>5.469</td>
</tr>
<tr>
<td>Dynamic T = 5sec</td>
<td>0.50704</td>
<td>Small in power of 10⁻⁵</td>
<td>1.6209</td>
<td>29.733</td>
<td>6.47</td>
</tr>
<tr>
<td>T= 10 sec</td>
<td>0.51245</td>
<td>Small in power of 10⁻⁵</td>
<td>1.6508</td>
<td>32.084</td>
<td>6.94</td>
</tr>
<tr>
<td>T = 15 sec</td>
<td>0.51432</td>
<td>Small in power of 10⁻⁵</td>
<td>1.6794</td>
<td>33.4</td>
<td>6.97</td>
</tr>
</tbody>
</table>

The contour of FOS wrt Elevation and Height is plotted which indicates it is unstable at higher height and is stable at lower height showing trends of circular failure. Also the plots of FOS vs Height at various position along X-axis from the toe of hill confirms the same results.

6. CONCLUSIONS

The research work analyses the instability of the most vulnerable slope of our study area along the road slopes in the Mansa Devi Hill, (Hardwar) Uttarakhand region. The slope was investigated for the stability using three dimensional finite difference codes. The specific maximum displacement computed in the slope in X – direction is 0.18295 m in static case and 0.51432m for dynamic case and the specific maximum displacement computed in the slope in Z – direction is 0.94675 m in static case and 1.6794 m for dynamic case. Thus we can definitely conceive that the slope is undergoing large deformations. The slope undergoes circular failure mechanism as obtained by the analysis. The factors of safety of the slope at some location are coming out to be less than one, which confirms its instability. The factor of safety along the slope is high at low heights and slope is quite stable. It then decreases due to positive shear strain rate and then again increases at higher heights due to negative shear strain rate. This trend of the factor of safety confirms the path of circular failure.

Hence what we can say on the wholistic point is that there are ongoing deformations at the Mansa hill and the analyzed slope is critically unsafe to the inhabitants of the area.
REFERENCES


