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Numerical Modeling of Rock Slopes in Siwalik Hills Near Manali Region: A Case Study

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ABSTRACT

Landslides are one of the frequently occurring natural hazards in seismically active regions of Northern part of Indian Himalayas. Landslides are the most destructive among all slope instability phenomena. Understanding the behaviour of landslides is very essential for planning and implementing landslide mitigation measures and microzonation studies. In this research paper, an endeavour has been made to model an active slope between Longitudes 32°07'N-32°13'N and Latitudes 77°08'E-77°11'E in the Manali area of Himachal Pradesh, India. This landslide is seismically active and it is joining national highway between Chandigarh to Manali (NH 21) which is junction with NH 22 and beas river to the down town. The site is located in the seismic zone V as per the Seismic Zonation Map of India (IS 1893:2002). The slope has been modelled using PLAXIS 2D a Finite Element Method considering both static and dynamic cases. In the present research work, detailed analysis has been carried out by considering different joint sets in three stages for predicting the behavior of the rock slopes for different joint sets considered in the present research work. First, an initial static loading is applied to the model considered; secondly interlocking conditions are modelled to simulate the prevailing rock mass conditions at the site by considering 5 joint sets in the rock slopes and finally seismic load, is applied using Chamoli 1999 recorded earthquake ground motion. This research paper provide very useful information in the deformation mechanism of the rock slopes in Siwalik hills. In first and second cases the slope is stable but in dynamic case the slope is critical since the displacements observed in the model will reflect the settlement. Excavation profiles of the slopes can be optimized and analyses can be carried out for those displacement profiles.

KEYWORDS: Landslides, Numerical modelling, Finite element method, Pseduo static analysis.

INTRODUCTION

Landslide is a general term used to denote a variety of mass movements in sloping terrains. Earthquake induced landslides, which have been documented from as early as 1789 B.C. have caused tremendous amount of damage in the past. During several earthquakes, landslides have been responsible for more damage than all other seismic hazards combined. In 1920 Haiyuan earthquake (M=8.5) in China produced hundreds of large landslides that caused more than 100,000 deaths (Steven L. Kramer, 1996). Often the reason of large scale mountain slope deformation is the toppling of rock masses. Landslide movements may also be considered as falls, slides, spreads or flows. Landslides are the most destructive among all slope instability phenomena.

The Rock slopes of Himachal Pradesh are seismically very vulnerable to landslides. In 1968, in Maling the landslide damages 1 Km of NH-22. In 1982, in Kinnaur this occurred at sholding nala collapsing 3 bridges and 1.5 Km of road vanished. In 1989, in Jhakri at Nathpa about 500 m of road was damaged due to this slide and in 1995, in Luggarbhati 39% of people were buried alive during the slide. These are some of the important landslides which caused huge damage in Himachal Pradesh. There are prominent slides in Beas valley are at Marhi, Bhang, Chhyal, and Mandu in upper catchment of the Beas river (Himachal SoER, 2010).

Seismicity of the Himalayan region has been examined in terms of its relationship with known geological faults and tectonic lineaments. The himalayan region is a zone of high seismicity suggests that stresses associated with underthrusting of the Indian plate at its collision boundaries with the Eurasian plate may cause fracture in the Indian shield resulting in the up flow of the asthenosphere material in the form of a ridge. In fact conductive zone is located in a belt which is bounded by a rupture of 1905 Kangra and 1934 Bihar earthquakes and further by 1991 Uttarkashi and 1999 Chamoli earthquakes.This is identified as a possible seat of a future major shock. Some investigations (N.Ambraseys and R.Bilham, 2000) suggest that the 1905 Kangra earthquake(M=8.5) occurred by an extended rupture in a major intracrustal low angle thrust fault dipping gently under the northwest Himalaya.

After these four great earthquakes, no such events have occurred in the Himalayan belt. This leads to a deduction of a potential spatio-temporal seismic gap associated with high probability of major earthquakes in this region in the near future (Basudeo Rai, 2004). As per seismic zoning map of India as incorporated in Indian Standard (IS 1893 : 2002) the study area lies in the seismic zone V. The zone V is broadly associated with a seismic intensity of IX or above on modified Mercalli scale (Himachal SoER, 2010).

Since the rockmass is not a continuum, its behaviour is due to presence of joint sets, bedding planes and faults etc. requires detailed investigations for assessment of seismic hazard due to landslides. In general, the presence or absence of discontinuities has profound influence on the stability of rock slopes the behaviour of these features playes a critical part in the stability evaluation (Shen B and Borton N, 1997). Stability of jointed rock mass slope depends on its geometry, rock mass characteristics and shear strength behavior of the joints (Souley and Homand, 1996). The stability of slopes can be analyzed either by using conventional approach or by using numerical models.

In this research paper, the numerical analysis of the discontinuum model has been considered. The slope considered for analysis has crown at an elevation of about 2,129m which is located near the famous hill station Manali. Fixed boundary conditions have been applied at the model considering no deformations to occur at the bottom (Singh T.N et al., 2007). Stability analysis of natural slopes of left and right sections under static and dynamic loading with different joint sets using Plaxis (Plaxis2D V8, 2006) is carried out along the central section for both left and right sections. This paper presents the results of detailed investigations on the stability on both the slopes using finite element methods under different loading conditions.

METHODOLOGY ADOPTED

The several methodologies have been developed to indentify the location of potential earthquake triggered rock slope instabilities up to several km^2 by many researchers. Failure is defined as the detachment of a rock mass from the slope face under given conditions. In this study, methodology for analysis involves the calculation of the maximum height of the hill, slopes of left and right side of the hill by using satellite maps from GOOGLE EARTH (Google, Inc., 2005). Discretization of the slope having homogenous aspect, slope angle, rock properties and joint set orientations has been carried out in detail. Estimation of joint properties including average dip angle (Ψ_p), cohesion (c) and friction angle (Φ) (O. Mavrouli et al., 2009).

The slope model without joints is considered as Mohr Coulomb model (Fig 1(a)). Mohr-Coulomb model is an elastic-perfectly plastic model. In general stress state, the model's stress-strain behaves linearly in the elastic range, with two defining parameters from Hooke's law (Young's modulus, E and Poisson's ratio, ν). The cohesion c and friction angle Φ parameters which defines the failure criteria. Mohr-Coulomb model is a simple and applicable to three dimensional stress space model with only two strength parameters to describe the plastic behaviour (Kok Sien Ti et al., 2009). The model is applicable to three-dimensional stress space model with only two strength parameters to describe the plastic behaviour Fig 1(b).

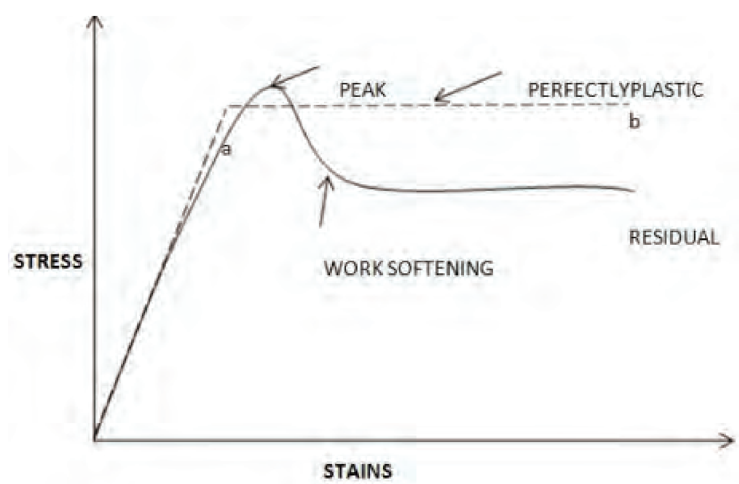


Figure 1(a): Elastic-perfectly plastic model (Kok Sien Ti et al., 2009)

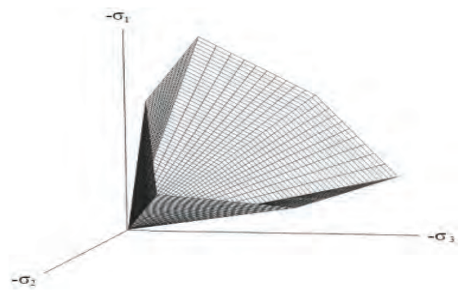


Figure 1(b): Mohr Columb yield surface in principal stress space (c= 0) (R.B.J.Brinkgreve, 2006)

The model consists of six yiel d functions and six plastic potential functions formulated in terms of principal stress es as given in Eq.(1) & Eq.(2). One of e ach function is given below for demonstration purposes (R.B.J.Brinkgreve ,2006):

$$f_1 = \frac{1}{2}(\sigma_2 - \sigma_3) + \frac{1}{2}(\sigma_2 + \sigma_3)\sin\Phi - c\cos\Phi \le 0 \quad (1)$$

$$g_1 = \frac{1}{2}(\sigma_2 - \sigma_3) + \frac{1}{2}(\sigma_2 + \sigma_3)\sin\Psi \quad (2)$$

where f_1= yield function , g_1= plastic potential function, σ_1, σ_2, σ_3= principal stresses.

Factor of safety (FoS) was computed by using the 'c-Φ reduction' procedure, which can be described as successively reducing the soil strength para meters c and tanΦ until failure occurs. The friction angle largely deter mines the shear strength as shown in Fig. 2. The strength parameters are automatically reduced until the final calculation in a full y developed failure mechanism. According to Nordal and Glaamen (2004), lowering the strength increm entally a soil body is identified to fail after a certain strength reduction. Factor of safety can be computed as the ratio of available shear strength to shear strength at failure as shown in Eq.(3).

$$\text{FoS} = \frac{\text{Available shear strength}}{\text{Shear strength at failure}} = \text{value of} \sum M_{sf} \text{ at failure} \quad (3)$$

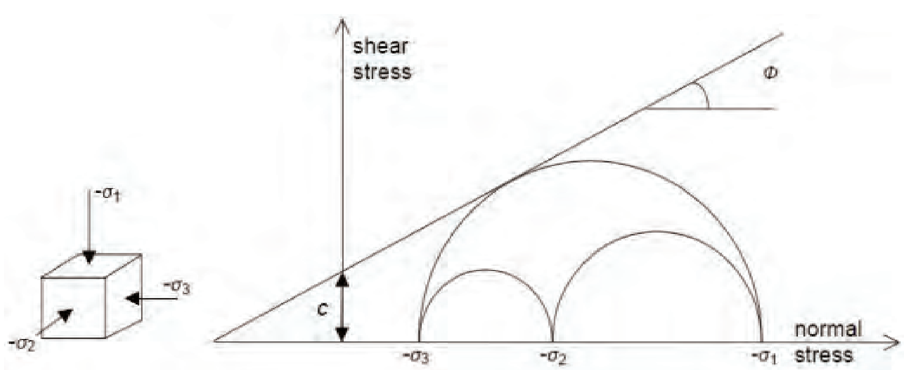


Figure 2: Stress circles at yield: one touches coulomb's envelope (R.B.J.Brinkgreve, 2006)

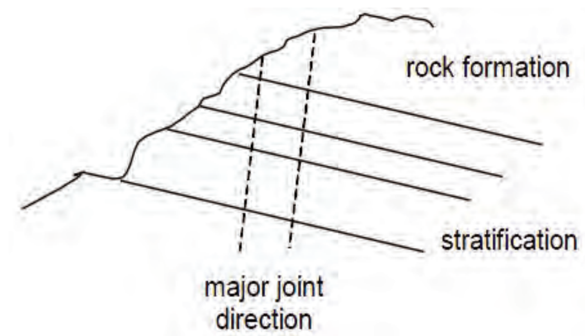


Figure 3: Jointed Rock model (R.B.J.Brinkgreve, 2006)

The slope model with joints is considered as Jointed Rock model as shown in Fig 3. Although the FEM is a continuum method, the joint (interface) elements have been developed to directly represent the discontinuous behaviour characteristic of joints and interfaces between adjacent blocks of material. They can assume linear elastic behaviour or plastic response when stresses exceed the strengths of discontinuities. The model is an anisotropic elastic perfectly -plastic model, especially to simulate the behaviour of the stratified and jointed rock layer.

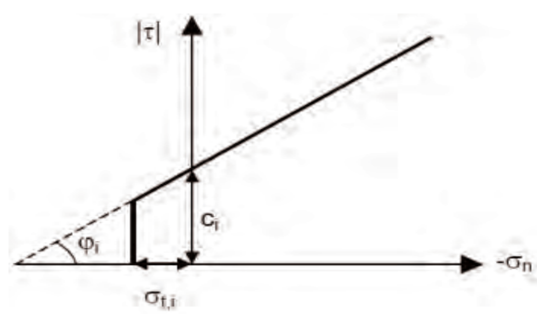


Figure 4: Yield criterion for individual plane (R.B.J.Brinkgreve, 2006)

The stratification plane will not be parallel to the global x-z plane and (*n,s,t*) are the local coordinate systems. The orientation of this plane is defined by the dip angle and dip direction as shown in Fig. 4. The local material stiffness matrix has to be transformed from local to global coordinate system as show in Eq. 4.

$$\underline{\underline{D}}^{*-1}_{xyz} = \underline{\underline{R}}^{T}_{\sigma} \; \underline{\underline{D}}^{*-1}_{nst} \, \underline{\underline{R}}_{\sigma} \qquad (4)$$

where $\underline{\underline{D}}^{*-1}_{xyz}$ = Global material stiffness matrix, $\underline{\underline{D}}^{*-1}_{nst}$ = Local material stiffness matrix

$\underline{\underline{R}}_{\sigma} = \frac{\underline{\sigma}_{nst}}{\underline{\sigma}_{xyz}}$

$\underline{\sigma}_{nst}$ = stress in local (n,s,t) coordinates

$\underline{\sigma}_{xyz}$ = stress in global (x,y,z) coordinates

Pseudo-Static Analysis has been carried out in the present study. The source of earthquake loading was created along the base of the model resulting to upwards propagating shear waves. Accordingly, the dynamic source was created in terms of the prescribed horizontal displacement at the base of the model to study the response generated by the soil mass. The basic equation for the time dependent movement under the influence of a dynamic load is shown below in Eq.(5) (Krishna Prasad Aryal, 2006).

$$F= M\ddot{u}+ C\mathring{u} +Ku \tag{5}$$

where F = dynamic load, M = inertia matrix (or mass of soil body), C = damping matrix (or damping coefficient) and K = stiffness matrix (or stiffness as spring constant). The displacement (u), the velocity (ů) and the acceleration (ü) are time dependent variables. The 1999 Chamoli earthquake data has been used for analysis of the slope considered and the factor of safety (FoS) has been calculated taking into account the water pressures, joint properties and peak ground acceleration on the slope face.

GEOLOGICAL AND SEISMOLOGICAL DETAILS OF THE STUDY

The state of Himachal Pradesh, is situated in the lap of north-western Himalayas. It is bounded by tibet to the east, Jammu and Kashmir to the north, uttaranchal in the southeast, Harayana in the south and the Punjab in the west. It harbours one of the most richly diverse mountain landscapes (Himachal SoER, 2010). In 1905, a great earthquake occurred with a magnitude of 8.0 on Richter Scale in which 20,000 people lost their lives. A maximum Intensity X on Rossiforel Scale was observed in the epicentral area which, when interpreted on the new current Modified Mercalli Scale, would be between X and XI. In 1906 an earthquake of magnitude 7.0 occurred in distict of Kullu which is near to Manali region.

The crown of the slope is at longitudes between 32°11'-56.51"N and Latitudes between 77°08'-35.92"E with an elevation of about 2,129m. These rocks are highly jointed and fractured. The rock joints are striking NE-SW, and dips with moderate to steep slope ranging from 20^o to 60^o. The area is described as highly unstable with about 2129m high and several km wide located near the famous hill station Manali. Location map of the area is shown in Fig 5(a) and the detailed cross-section of the slope considered for the dynamic stability analysis is shown in Fig 5(b).

Lithological and structural variations often lead to a difference in strength and permeability of rocks and soils (Pachauri and Pant 1992; Roering et al. 2005), which greatly infuences landslide occurrence. Many active faults of local and regional scale in the Siwaliks have been identified. Several straight to slightly curved linear topographic features have been traced that represent fractures, fault traces and topographic breaks. The slopes traversed by faults or lineaments are regarded as potentially unstable(Motilal Ghimire, 2011).

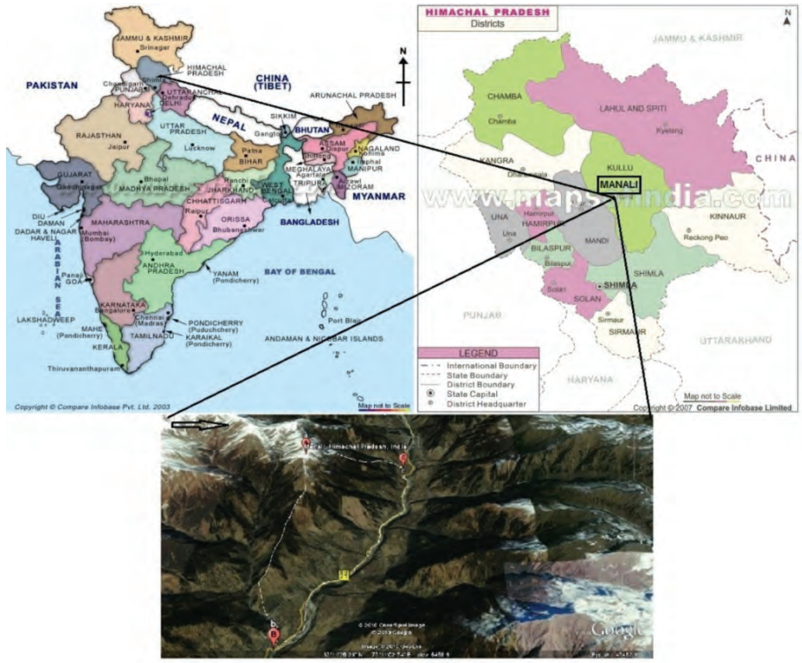


Figure 5(a): Location Details of the Study Area

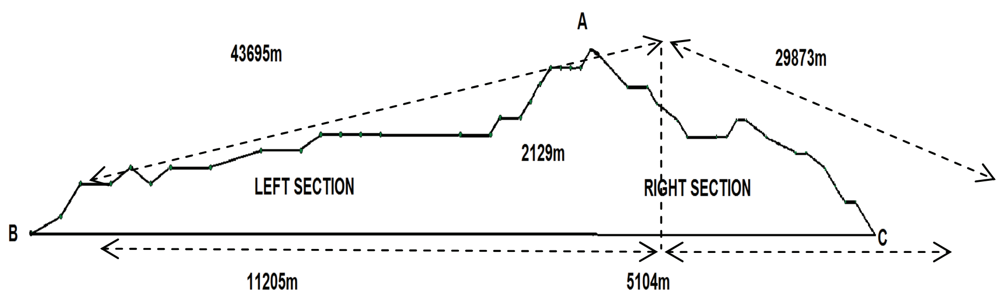


Figure 5(b): Details of rock slopes considered in the present study

The Himalayan Range which comprises in age from Proterozoic to Holocene have been subdivided into three NE-SW trending zones coinciding with three geomorphic divisions viz, the Higher and Tethys Himalays, the lesser Himalaya and Sub Himalaya, by two major tectonic planes, the Main Central Thrust (MCT) and the Main Boundary Fault (MBF). The Sub-Himalayan zone is occupied by the Siwalik belt. The Siwalik belt is divided into Lower, Middle and Upper regions. The Lower Siwalik is composed of hard brownish grey sandstone with clay intercalations. The massive medium to coarse grained sandstone is the dominant lithology of the Middle Siwalik. The Upper Siwalik includes silty clays, sands, pebble, and boulder beds. The Siwalik belt is separated from the Miri quartzite and Gondwanas by a system of steep faults, commonly known as Main Boundary Fault.

The frequency of landslides and rock falls in the Manali varies from area to area, depending on underlying rock structure and neotectonic activity along faults and thrusts. As a consequence, large landslides and rock falls do occur particularly in the zones of neo-tectonically active faults and boundary thrusts. The soils and different types of sandstones within the landslide zone are highly weathered and erosion continues on both sides of the landslide prone area. Siwalik comprising carbonaceous shale, clay and indurated pebbly sandstone with thin coal seams and partly in graniticporphyry, metabasics and quartzites of the Himalaya(Singh T.N et al., 2007).

The strata are characterized by prominent foliatiion joints, which has very pronouced strikes trending NS. Few random joint sets are also present occasionally in the slopes considered in the present study. The stratigraphy of rock and discontinuity pattern on either side of slope is more or less similar. Though, there is no unique value for a property and vart from location to location, the most appropriate values from the reported information and literature are chosen for the analysis. The geotechnical properties of the Rockmass considered in the present analysis for both left section (AB) and right sections (AC) are shown in Table 1.

Table 1: The material properties of the Rock Mass considered in the present study.

Property	Value
Type of behaviour	Undrained
Bulk unit weight γ_b (kN/m^3)	19.25
Saturated unit weight γ_{sat} (kN/m^3)	21
Horizontal permeability K_x (m/day)	1.00E-03
Vertical permeability K_y (m/day)	1.00E-03
Young's modulus E_{ref} (kN/m^2)	1.90E+05
Poisson's ratio ν	0.24
Cohesion c (kN/m^2)	2100
Friction angle φ (^{o})	29
Shear modulus G (kN/m^2)	7.60E+04

NUMERICAL MODELING

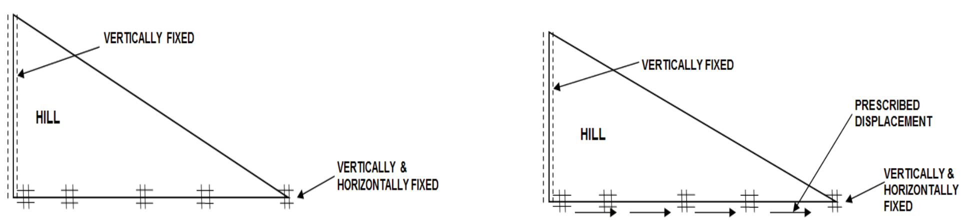
Geomaterials such as soils and rock masses display non-linear behavior. Rocks and soils may not be isotropic or homogeneous, and the loading may not be static, or the geometry of the problem may be complex. In these cases, solutions can only be obtained numerically. Numerical methods give only approximations to the correct or exact mathematical solution. This is so because some simplifications are made to solve the system of differential equations either inside the continuum or at the boundaries of the discretization. Numerical methods have been extensively used in the past several decades due to advances in computing power (AntonioBobet, 2010).

The two dimensional Finite Element numerical study considering the geometry and properties of the layers has been carried out in the present research work, first the static loading is applied to the slope model considered, secondly different joint sets are introduced with both static and dynamic load, by using chamoli (1999) earthquake ground acceleration data to induce actual earthquake conditions.

Case(i): UNDER STATIC LOADING WITHOUT JOINT SETS

The analysis of the rock slope under gr avity loading is carried out using Plaxi s 2D (Plaxis BV, Inc., 1989) a finite element program. Two dimensional plane strain modeling is carried out in which dimensions are given in meters giving the real geometry considered for the most critical section. The approxim ate dimensions of hilly slope considered is shown in Fig 5(b). Fi xed boundary conditions have been applied at the model considering no deformations to occur at the bottom as shown in Fig 6(a). The layers of the slope are modeled in undrained conditions as more critical for the stability of zones. For analysis the material model is considered as Mohr Coulomb. The 15 node triangular plane strain Finite elements are applied.

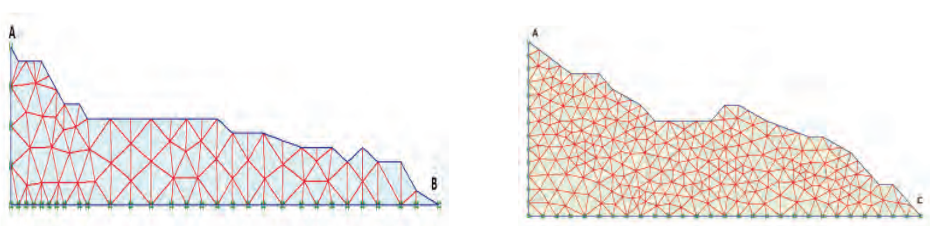
After inputing the material properties. The geometry of the model and entire slope geometry has been divided into number of elements by using mesh generation technique. A simple finite element mesh is generated for left section of th e slope (AB) an d for right section of the slope (AC) as shown in Fig. 7.



(a) For static loading **(b)** For dynamic loading

Figure 6: Boundary coundition

After analysis of Mohr-Coulomb model, the failure has occurred at the top of the left s ection of the slope considered. The maximum displacement is found at the top p art of the slope is shown in Fi g 8(a). Slop e failure has occurred near the toe part of the right section slope considered. The maxi mum displacement is found at the toe part of the slope as shown in Fig 8(b). The stresses contours in x-direction and str esses contours in y -direction of left se ction and right section are shown in Fig 9 and 10 respectively.



(a) Left section (AB) **(b)** Right section (AC)

Figure 7: Finite Element mesh generation for Case (i)

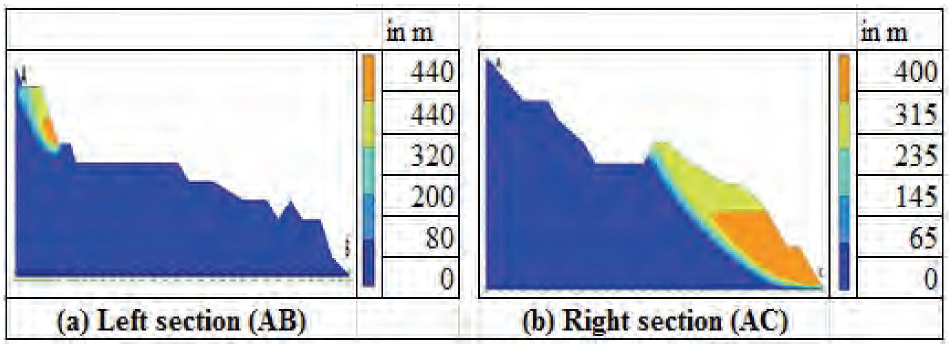


Figure 8: Horizontal displacement contours of the two considered slopes.

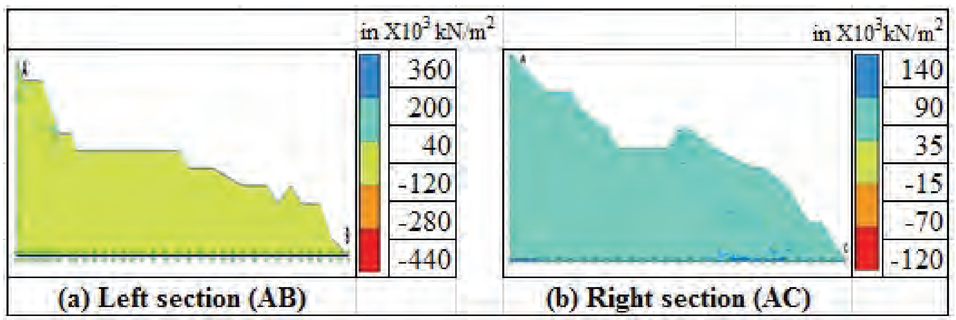


Figure 9: Stresses contours in x-direction of two slopes considered.

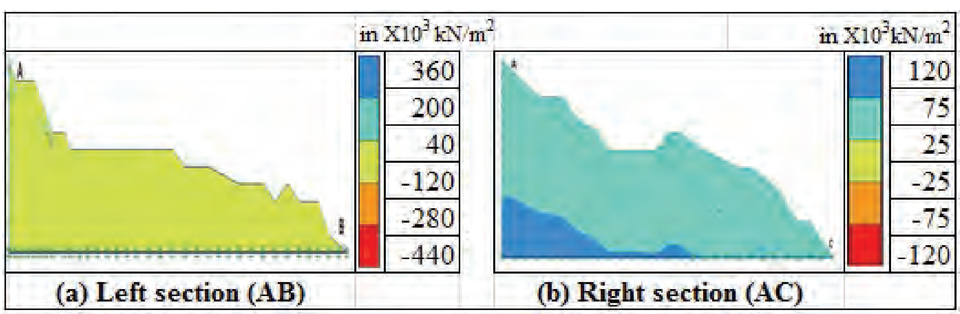


Figure 10: Stresses contours in y-direction of two slopes considered

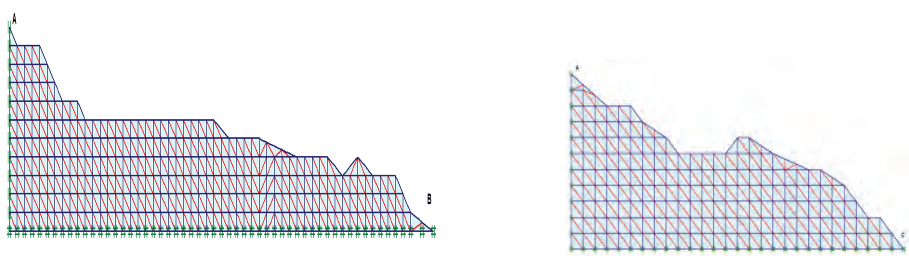
After c-Φ reduction analysis, the Factor of safety for left section (AB) and right section (AC) are 2.03 and 1.848 respectively.

Case(ii): UNDER STATIC LOADING WITH JOINT SETS

The analysis of slope is carried out with Plaxis 2D (Plaxis BV, Inc., 1989) by considering the Joint Rock Model. The anisotro py represents the trending joints in a Mohr -Coulomb failure criteria. Therefore the jointed rock mass i s treated as a continuum with equivalent material properties which reflect the effect of the joints . The material model used is named jointed rock model. Fixed boundary conditions have been applied at the model considering no deformations to occur at the bottom as shown in Fig 6(a).

The average joint shear strength characteristic of dolomite slopes in left and right sections considered are c=0.0 and $\varphi=36^0$. The joints sets available in the field are not continous throught the slope. Hence, the discontinous nature of joint is simulated in the modelling by introducing the space of 20m. To know the effect of joint sets(JS) a parametric study has been carried out with 5 joint sets i.e. JS1 (90o&180o), JS2 (75o&165o) , JS3 (60o&15 0o), JS4 (45o&135o) and JS5 (30o&120o). After inputi ng the m aterial parameters, geometry of the m odel discritized using mesh generation technique. A si mple finite element mesh is generated for left section (AB) and for left section of the hills (AC) (Fig 11).

After c-Φ reduction analysis, the horizontal displ acement contours, stresses contours in x-direction and stresses contours in y-direction of left section and right section is shown in Figs 12,13 and14 respectively.



(a) Left section (AB) **(b)** Right section (AC)

Figure 11: Finite Element mesh generation for Case (ii)

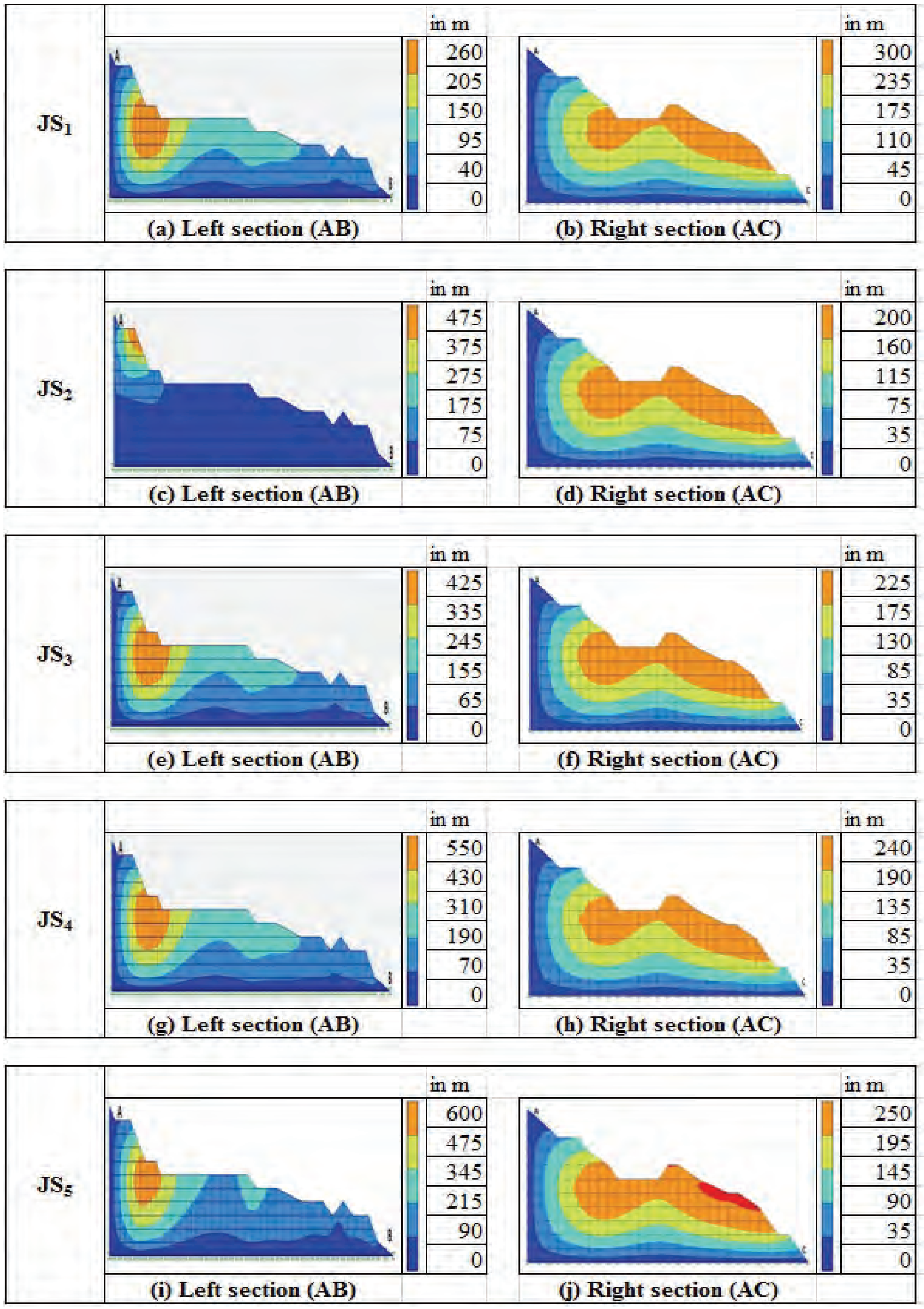


Figure 12: Horizontal displacement contours of both left and right slopes for all five joint sets considered

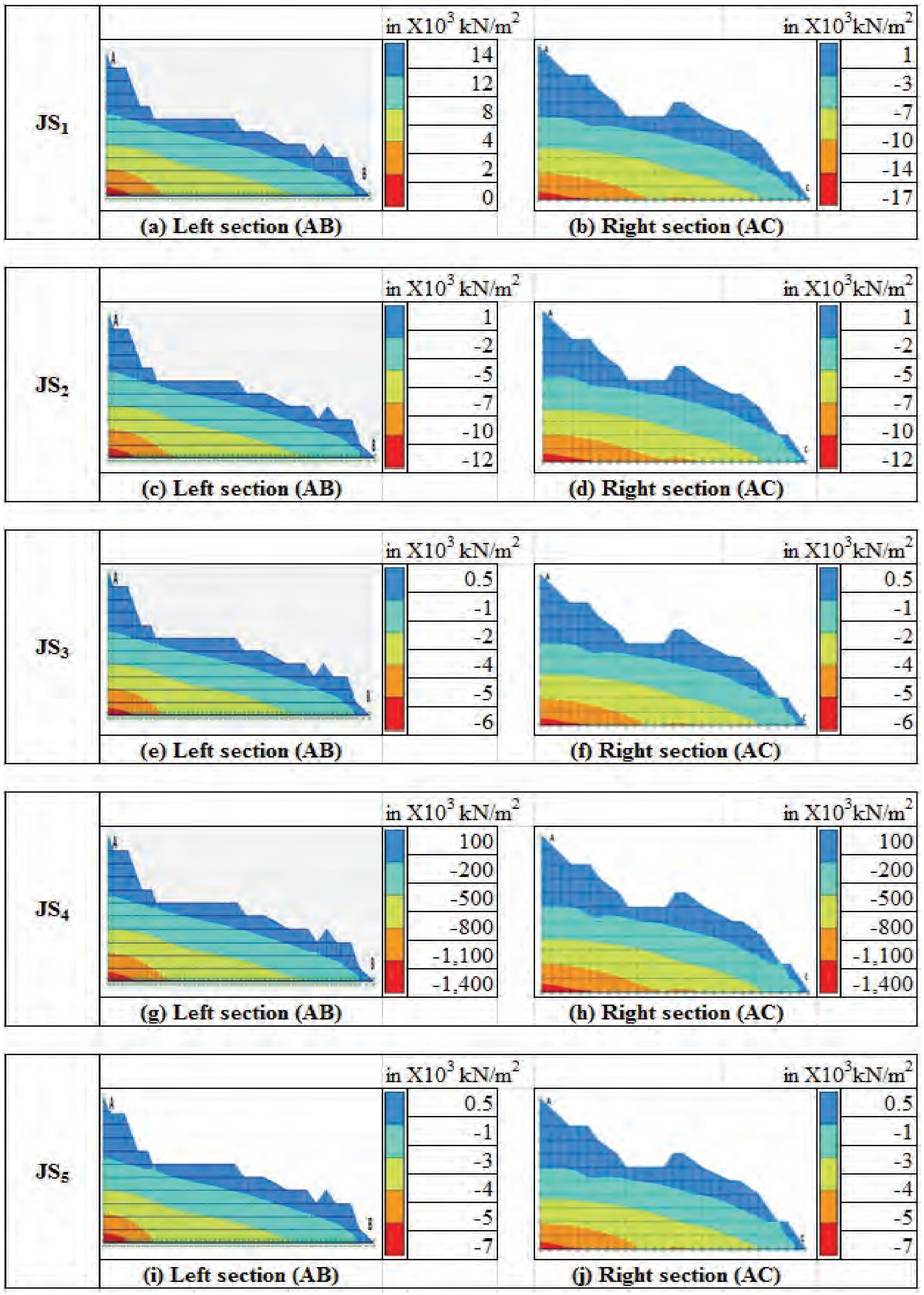


Figure 13: Stresses contours in x-direction for both left and right slopes for all 5 joint sets considered

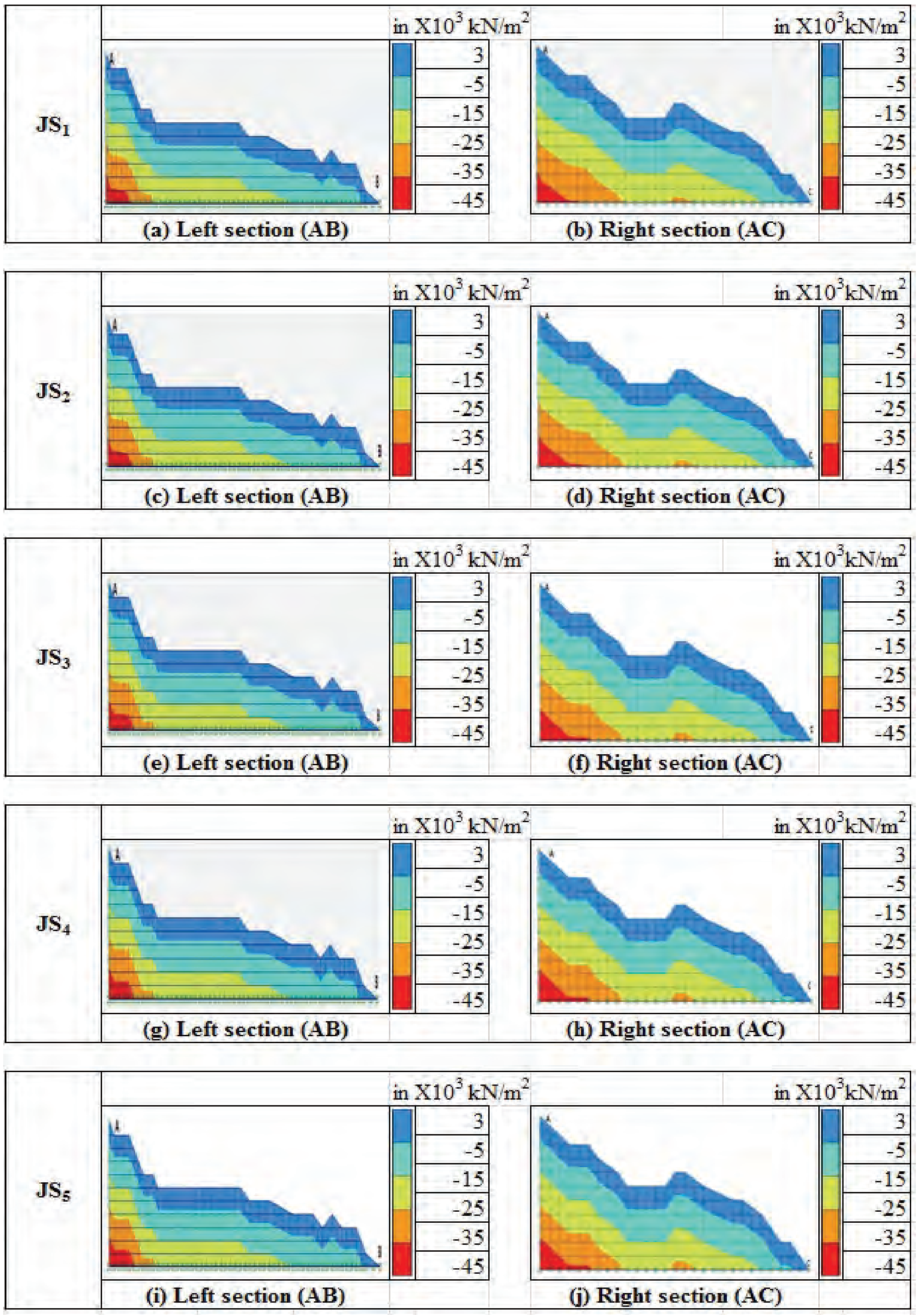


Figure 14: Stresses contours in y-direction for both left and right slopes for all 5 joint sets considered

Case(iii): UNDER DYNAMIC LOADING WITH JOINT SETS

In this case dynamic excitation is applied to the rock slope to simulate earthquake conditions. The analysis starts from end of static analysis.Then the boundary conditions in the model are modified accordingly to impose free-field earthquake motion as shown Fig 6(b). A simple finite element mesh is generated for left section (AB) and for rigth section (AC) (Fig. 11). Dynamic Analysis is carried out by Pseudo-Static Analysis.

The Chamoli earthquake on 29th March 1999 in northern India is yet another important event from the viewpoint of Himalayan seismotectonics and seismic resistance of non-engineered constructions. The earthquake occurred in a part of the Central Himalaya, which is highly prone to earthquakes and has been placed in the highest seismic zone (zone V) of India (K. Jain et al.,1999).The devastating earthquake (MSK=VIII) Chamoli, Garhwal Himalaya whichwas recorded on Delhi Strong Motion Accelerograph (Y Pandey et al, 2001). The Chamoli ground motion data is used in the present study for analysis. After analysis the deformed mesh of left (AB) and right (AC) section of the hill is shown in Fig. 15. The stresses contours in x-directions and in y-directions of left section and right section are shown in Fig 16 and 17 respectively.

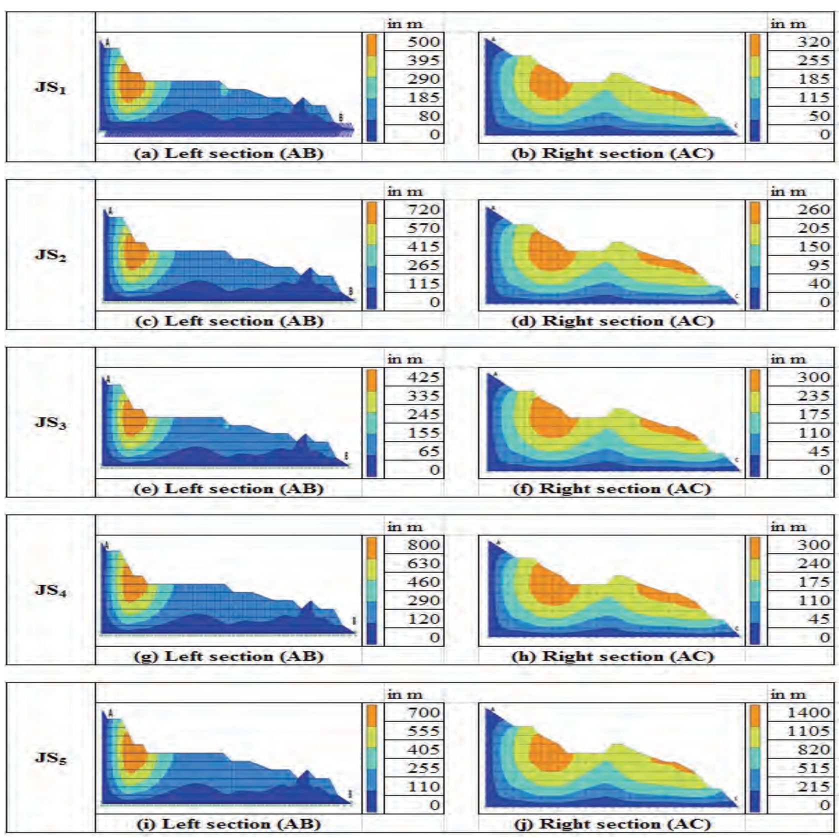


Figure 15: Horizontal displacement contours of both left and right slopes for all 5 joint sets considered

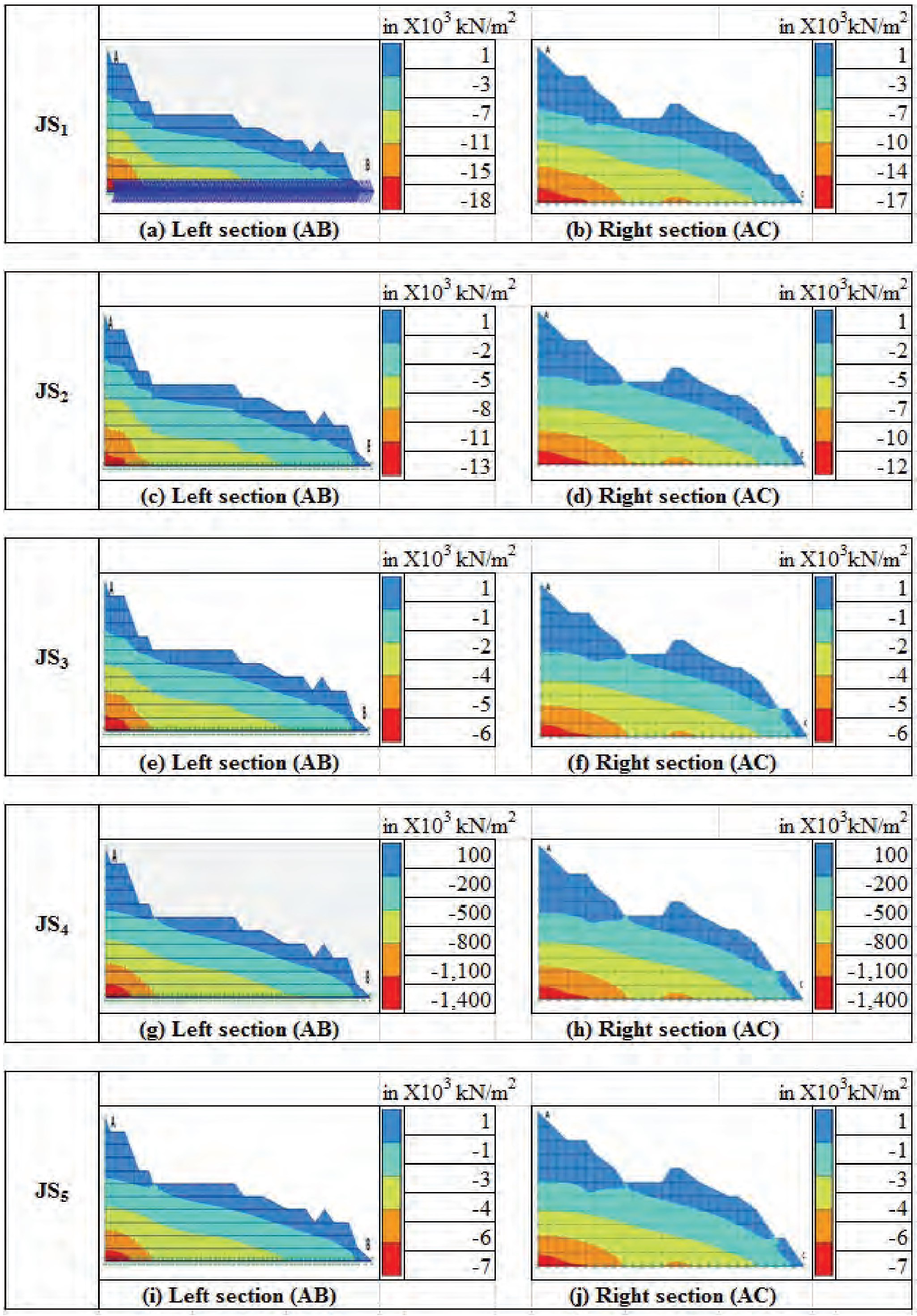


Figure 16: Stresses contours in x-direction for both left and right slopes for all 5 joint sets considered

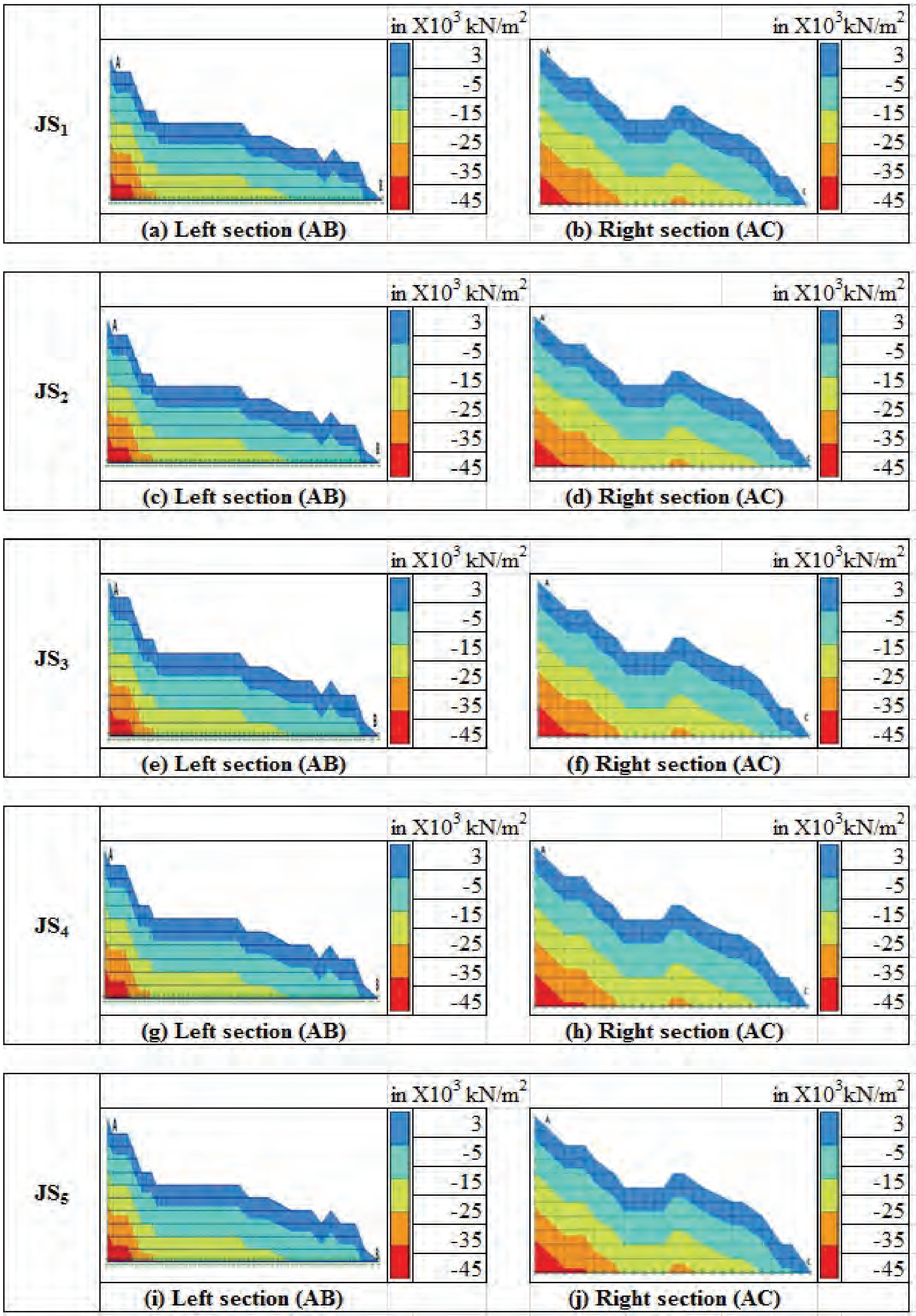


Figure 17: Stresses contours in y-direction for both left and right slopes for all 5 joint sets considered

RESULTS AND DISCUSSION

The numerical study carried out in two dimensional Finite Element considering the geometry and properties of the lay ers has be en carried out in the present research work, first the s tatic loading is applied to the slope model considered, secondly different joint sets are introduced with both static and dy namic load, by using cham oli (1999) earthquake ground acceleration data to induce actual earthquake conditions. The factor of safety values obtained are given in Table 2.

Table 2: Factor of Safety values obtained for different cases considered in the present study.

Sr. No.	SIDE	CASE	ROCK TYPE	JOINT SETS	SEISMIC LOAD	FACTOR OF SAFETY	STRESSES IN XX DIRECTION (x103) (kN/m2)	STRESSES IN YY DIRECTION (x103) (kN/m2)	MAXIMUM HORIZONTAL DISPLACEMENT (m)
1	LEFT	I	continouum rocl	-	-	2.026	-426	-427	558
2		II	Jointed Rock	JS1	-	1.1	-16.71	-40.77	258
3			Jointed Rock	JS2	-	1.045	-11.93	-41.23	336
4			Jointed Rock	JS3	-	1.175	-5.6	-41.83	420
5			Jointed Rock	JS4	-	1.26	-1.39	-42.22	535
6			Jointed Rock	JS5	-	1.04	-6.17	-42.35	538
7		III	Jointed Rock	JS1	YES	unsafe	-17.09	-41.34	498
8			Jointed Rock	JS2	YES	unsafe	-12.16	-41.66	683
9			Jointed Rock	JS3	YES	unsafe	-5.52	-41.93	408
10			Jointed Rock	JS4	YES	unsafe	-1.39	-42.19	760
11			Jointed Rock	JS5	YES	unsafe	-6.17	-42.35	682
12	RIGHT	I	continouum rock	-	-	1.848	122	119	795
13		II	Jointed Rock	JS1	-	1.08	-16.68	-40.44	284
14			Jointed Rock	JS2	-	1.13	-11.85	-40.99	197
15			Jointed Rock	JS3	-	1.09	-5.42	-41.73	228
16			Jointed Rock	JS4	-	1.25	-1.38	-42.19	228
17			Jointed Rock	JS5	-	1.03	-6.18	-42.35	254
18		III	Jointed Rock	JS1	YES	unsafe	-16.86	-40.61	302
19			Jointed Rock	JS2	YES	unsafe	-11.9	-40.91	253
20			Jointed Rock	JS3	YES	unsafe	-5.44	-41.67	292
21			Jointed Rock	JS4	YES	unsafe	-1.38	-42.18	298
22			Jointed Rock	JS5	YES	unsafe	-6.16	-42.35	332

The maximum displacement is found at the top pa rt of the slope for left section (AB) fro m Fig.12. The maximum displacement is found at th e bottom part of the sl ope for ri ght section (AC) from Fig.12. The factor of safety (FoS) values obtained for static case for both the slopes are greater than 1 which indicates that the slope is stable. In dy namic case the shear stress are approching zero at the end of t he analysis but the displacements are very high which indicates that there is noticeable movements of blocks and slope is unstable.

CONCLUSIONS

Landslide is one of the major natural hazards that are commonly experienced in hilly terrains all over the world. Landslides affects at least 15% of the land area of India an area which exceeds 0.49 million km^2. In India the incidence of landslides in Himalayas and other hill ranges is an annual and recurring phenomenon. There is a variation in the degree of landslide incidences in various hill ranges. The landslide hazard zonation atlas of India published by Building Materials and Technology Promotion Council (BMTPC), Government of India revals that the landslide incidences are high to very high in Himalayas (G.P.Ganapathy et al., 2010).

A numerical analysis is carried out for both sections of the slope in Manali area, Himachal pradesh using Plaxis 2D (Plaxis BV, Inc., 1989) considering joint sets, rock properties and stiffness characteristics. The joint sets available in the field are not continous throughout the slope and hence the discontinuity in joint sets is simulated in the analysis. Both static and dynamic analysis are carried out considering different loading conditions.

The height of the slope considered for the analysis in this present study is 2129m and the horizontal dimension of the left and right section are 11205m and 5104m. The anaysis revealed left and right slopes are stable with respective factor of safety (FoS) under static loading conditions. In the static case the left side hill section with joint set 5 is less stable compared to the other joint sets and in the right side section of the slope with joint set 5 is less stable compared to the other joint sets.The dynamic case for both the sections are considered to be the most critical. The displacements observed in the model will reflect the settlement. Since maximum diplacement values are very high which indicates that slope is highly unstable.

Since slope is unstable limit existinguse rights to rebuild, and limit the use of buildings. The most realistic approach is to avoid further development and use of buildings (building type) is consistent with the level of risk posed.The slope can be strengthening with some techniques for slope strengthening vertical sieve pipe drainage technique, shallow grouting technique, frame bolt reinforcement technique, changed section retaining pile technique, slanting overeat rigid retaining pile technique, pre-stress cable retaining pile in H section, and they all have been applied in situ engineering (LI-Kai et al., 2010**)**.

Excavation profiles of the slopes(left and right section) are to be optimized and analyses shall be conducted for those profiles. Also proper drainage system can be designed such that the slopes remain a free draining media.

REFERENCES

1. Antonio Bobet (2010) "Numerical Methods in Geomechanics," The Arabian Journal for Science and Engineering, Vol. 35, Number 1B, pp. 27.
2. Basudeo Rai (2004) "Himalayan Seismicity and Probability of Future Earthquake," IAGA WG 1.2 on Electromagnetic Induction in the Earth Proceedings of the 17th Workshop, S. 1-P.20.
3. Google (2005) "Google Earth User Guide Version 4".

4. G.P.Ganapathy, K.Mahendran and S.K Sekar (2010) "Need and Urgency of Landslide Risk Planning for Nilgiri District, Tamil Nadu State, India," International Journal of Geomatics and Geosciences,Vol. 1, No. 1.

5. Himacal SoER (2010) "State of Environment Report Himachal Pradesh," Department of Enviroment, science & Technology Government of Himachal Pradesh.

6. IS: 1893:2002 "Criteria for Earthquake Resistant Design of Structures, Part 1 General Provisions and Building," Bureau if Indian Standards, New Delhi.

7. Krishna Prasad Aryal (2006) "Slope Stability Evaluations by Limit Equilibrium and Finite Element Methods," Norwegian University of Science and Technology , Trondheim, Doctoral Thesis at NTNU.

8. Kok Sien Ti , Bujang B.K. Huat, Jamaloddin Noorzaei, Moh'd Saleh Jaafar (2009) " A Review of Basic Soil Constitutive Models for Geotechnical Application," Electronic Journal of Geotechnical Engineering, Bund. J, Vol. 14.

9. LI-Kai, FU Helin, TAN Hanhua and He Yuwu (2010) "New Strengthening technique for Slope in Guizhou Highway," EJGE, Vol. 15, pp.1948-1966.

10. Motilal Ghimire (2011) "Landslide occurrence and its relation with terrain factors in the Siwalik Hills, Nepal: case study of susceptibility assessment in three basins, " NaturalHazards 56:299–320.

11. N.Ambraseys and R.Bilham (2000) "A note on the Kangra Ms = 7.8 earthquake of 4 April 1905," Current Science, 79(1), pp. 45-48.

12. O. Mavrouli; J. Corominas and J. Wartman (2009) " Methodology to Evaluate Rock Slope Stability under Seismic conditions at Sola De Santa Coloma Andorra," Natural Hazards Earth System science- 9, pp. 1763–1773.

13. Pachauri AK, Pant M (1992) "Landslide hazard mapping based on geological attributes," Eng Geol 32:81–100.

14. Plaxis BV (1989) "Plaxis 2D " Plaxis AsiaPac Pte Ltd.

15. Roering JJ, Kirchner JW, Dietrich WE (2005) "Characterizing structural and lithologic controls on deepseated landsliding: Implications for topographic relief and landscape evolution in the Oregon Coast Range, USA," Geol Soc Am Bull 117:654–668.

16. Shen B and Borton N (1997) " The Disturbed Zone Around Tunnels in jointed Rock Masses," International journal of Rock Mechanics and Mining Sciences,Vol.34, pp. 117-125.

17. Singh T.N, Sharma P.K and Pandey.V (2007) " Numerical Approach for Evaluation of Instability of slopes," International conference on Regional Rock Mechanics Symp, Sri Lanlka,1-5.

18. Souley M and Homand F (1996) " Stability of jointed rock masses evaluated by UDEC with an extended Saeb-Amadel constitutive law," International journal of Rock Mechanics and Mining Sciences & geomechanics Abstracts, Vol.33, pp. 233-244.

19. Steven L.Krammer (1996) "Geotechnical Earthquake Engineering," pp. 423-461.

20. Sudhir K. Jain, C.V.R. Murty and Jaswant N. Arlekar (1999) “Chamoli (Himalaya, India) Earthquake of 29 March 1999,” EERI Special Earthquake Report, EERI Newsletter Vol.33, No.7.

21. Y.Pandey, R.Dharmaraju and P.K.S C hauhan (2001) “Estimation of source parameters of Chamoli Earthquake, India,” Earth planet science,110, No.2, PP.171-177.