AN INVESTIGATION ON SEISMIC STABILITY OF MINE OVERBURDEN DUMP SLOPE

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Abstract – *Mine overburden slopes are often deposited in loose forms and no ground improvement techniques are adopted to enhance its stability. Often, the mines are located in earthquake prone zones and in those areas, the stability of mine overburden dump slopes may be affected due to the occasional occurrence of earthquakes. In the present study, a seismic stability assessment of mine overburden dump slopes have been carried out. For this, the samples are collected from several different locations in Dhanbad and the basic characterizations tests are carried out. The obtained engineering parameters of the overburden dump slopes are then used for numerical analysis using finite element limit analysis technique. The earthquake stresses are induced using pseudo-static technique. Based on the results obtained through the study, a seismic slope stability assessment has been made.*

Key Words: Overburden dump, slope stability, seismic stability, FOS, OptumG2.

1.INTRODUCTION

Dhanbad is frequently referred to as India's coal capital. As of July 2021, 112 coal mines in Dhanbad were operational, with a total yearly production of 27.5 MT. In developing countries like India, coal is the primary source of energy, and as the population grows, so does the demand for coal. Coal is the chief source of energy globally with a total share of 29% as per 2015 (Bhatt et al. 2019, Anand and Sarkar 2021)

In the last few decades, the demand for coal for power generation has skyrocketed. Due to increase demand of power, coal mining companies are under tremendous pressure to produce huge amount of coal to fulfil the growing need of power. Consequently, a lot of open pit mines are being excavated to fill the gap between demand and supply of the coal for power generation.

To ensure maximum and efficient recovery of coals, a lot of open pit mines are functional in the district of Dhanbad. However, open cast mining operation also leads to generation of a bulk volume of overburden waste material, which needs to be deposited in a safe and in accordance with the environmentally friendly manner.

The first phase in a coal winning operation is to remove overburden in order to expose the underlying coal for excavation. Because the overburden material is a waste and non-marketable product, it is carefully removed and disposed of. The major goal of the overburden dump construction is to offer a stable operating surface for the dump deposit.

A dump slide occurs when a dump mass of earth positioned beneath a slope fails. It entails the full mass of soil involved in the dump slope failure moving lower and outward. Dump slide can happen in practically any way, slowly or quickly, and with or without apparent provocation. Slides are most commonly caused by excavation or undercutting the foot of an existing dump slope. However, in some cases, they are created by the overburden dump's structure gradually disintegrating. Dumping optimization saves space on the ground and eliminates the risk of sliding, which could lead to future mishaps. Low-rise, flat dumps may be ideal from a stability standpoint, but they would not only take up a lot of ground space, but they would also be quite expensive. As a result, a balance must be struck between the maximum slope and the smallest amount of ground space occupied while ensuring that dumps do not slide and create any unpleasant incidents or accidents. Internal dumps produced by in-pit dumping concurrent with voids produced by coal extraction can be external dumps produced at a location other than the coal bearing area, or internal dumps produced by in-pit dumping concurrent with voids produced by coal extraction can be external dumps produced at a location other than the coal bearing area. External dumps are used to dispose of overburden, which has a number of significant consequences. The most important of these is the need for extra land, which comes at a considerable expense in terms of transportation and re-handling. As a result, it significantly raises the cost of coal production, as well as the site's stability and reclamation. Even if we do in-pit dump practise, we cannot totally remove the possibility of external dump thoughts. The use of both exterior and internal dumps will significantly reduce the amount of land required. As an outcome, it will considerably reduce the surface land demand, which is a challenging undertaking to do in any area due to population increase, forest cover, and other issues.

At present, obtaining a single figure of critical displacement was challenging, resulting in an inability to assess the performance of the dumping slope during the earthquake. Field engineers have a better understanding of the critical, or tolerable, value of the permanent displacement to degree of the problem dimensions and slope mass material behaviour. As a result, ductile, flexible materials on the slope can withstand greater displacement than brittle, sensitive materials. Houston et al. (1987), in their explanation of Newmark's approaches, made the following comment, which may propose the optimal solution: "It should probably be regarded as a tool to aid the engineer in determining whether the likely slope displacement is:

(1) a fraction of an inch (2) a few inches, or (3) a few feet."

This amount of differentiation is usually sufficient to allow an engineering or managerial decision to be made."

Under this aspect, a study has been conducted to determine the stability of the OB dumps in reaction to earthquake vibration. The impacts of OB dumps parameter and OB strength features on OB dump stability in response to seismic excitation are the main subject of this work. To solve a dynamic equation of motion, numerical methods are used.

1.1 Geographical location of study area

Materials from mine OB dumps were collected from three separate locations in Dhanbad district. The locations are Chasnala, Katras and Lodna. The dump collection sites for the Overburden have been listed below. The geographic location of the three separate collection sites is also indicated in the diagram below.

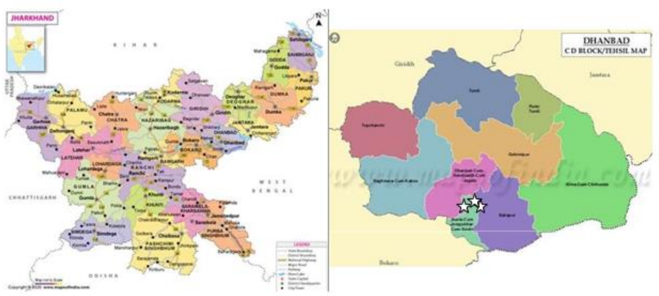

Fig -1: Location of Dhanbad and sites from which samples were collected. (https://www.mapsofindia.com)

2. LABORATORY INVESTIGATION

The basic characterizations and engineering properties of all of the soil samples were tested. All of the tests were carried out in accordance with relevant Indian Standard codes' recommendations. Specific gravity, particle size distribution, compaction tests, and other experiments were conducted on different samples collected from the sites. Undisturbed sampling was used for the Direct shear test.

2.1 Specific Gravity

The specific gravity of OB dump materials was determined in the laboratory according to IS 2720 recommendations (part III). In the soil mechanics laboratory of BIT Sindri, materials collected from three distinct places were tested.

Table -1: Specific gravity of different locations

S No.	Location	G_s
1	Chasnala	2.66
2	Katras	2.44
3	Lodna	2.63

The greater specific gravity values in the Chasnala and Lodna areas might be related to a higher iron content when compared to specific gravity observations of Katras.

2.2 Grain Size Distribution

Grain size distribution analysis of the samples were obtained based on a dry and wet sieve analysis, as recommended by IS 2720.

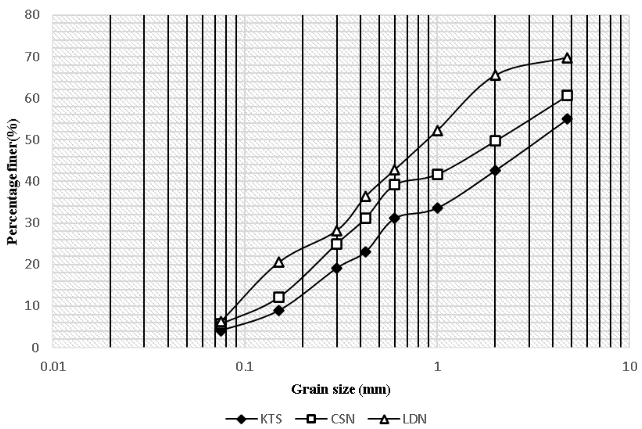

Fig -2: Grain size distribution curve of different locations.

2.3 Compaction characteristics

The light compaction test, as recommended by IS 2720(Part VII), was used to obtain the compaction curves for waste materials acquired for each site. The maximum dry density (MDD) and optimum moisture content (OMC) for each sample are shown below in Fig. 3, and the corresponding maximum dry density (MDD) and optimum moisture content (OMC) are reported in Table 2 below.

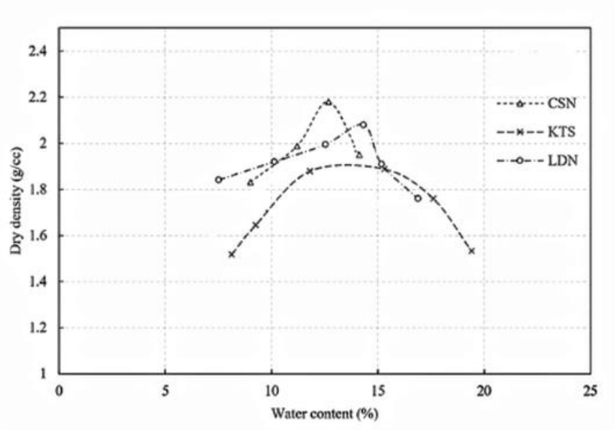

Fig -3: Compaction curve obtained for OB dump material from various locations

Table -2: MDD and OMC for different locations

Location	MDD (g/cc)	OMC (%)
Chasnala	2.18	12.67
Katras	1.92	13.81
Lodna	2.08	14.32

2.4 Direct shear test

Detailed laboratory experiments were carried out in the current work to estimate the shear strength characteristics of the dump materials. A total of ten samples were gathered from each location and analyzed for shear using a traditional direct shear test apparatus, as recommended by IS 2720. (Part 39). The mean and variation of the shear strength characteristics of the dump waste material were determined by a large number of tests. Table 3 shows the effective cohesion and effective angle of internal friction values obtained for all three sites.

Table -3: Shear strength parameters obtained for OB dump materials

Location	c' (kPa)	ϕ'
Chasnala	1.661	35.1°
Katras	3.133	32.1°
Lodna	3.343	35.9°

3. Numerical Analysis using OptumG2

Strength Reduction Finite Element Limit Analysis (SR-FELA) is used in OPTUM G2 to calculate safety factors. Aside from quick computation times, SR-FELA also allows for the calculation of strict upper and lower bounds on the genuine factor of safety. In reality, this means that the true factor of safety may be determined in a couple of seconds with a minuscule tolerance.

The numerical models in this paper includes a simplified total stress analysis that does not account for pore-water pressures. It's a straight forward study that depicts a uniform slope with specified soil parameters. The factor of safety and its critical circular failure surface are the prerequisites for this challenge with a horizontal seismically induced acceleration of 0.1g to 0.4g are included in the analysis. The factor of safety and its corresponding critical circular failure surface is also shown.

3.1 Pseudo-static Analysis

Pseudo-static analysis, which essentially extends the static analysis FOS of a slope subjected to a static horizontal acceleration is determined. The horizontal inertia force caused by an earthquake is represented in this study by a static horizontal force calculated from the seismic coefficient k and the weight of the prospective sliding mass.

The static and pseudo-static FOS of slope of different location described in Table were calculated using the limit equilibrium method. This was accomplished with the help of the Optum G2software, which applied a steady horizontal acceleration to the slopes until the FOS reached unity. This force is thought to be critical Acceleration Ac, of the incline. The key advantages of this strategy are that it uses the well-known limit equilibrium method and that it is simple to implement. The pseudo-static technique, on the other hand, cannot account for the transient nature of seismic motion.

4. Result and discussion

After conducting a thorough finite element limit analysis the factor of safety (FOS) derived for OB dump material is discussed in this section.

Table -4: Dynamic factor of safety due to lateral acceleration in positive direction

Acceleration	CSN	KTS	LDN
$K_h = 0$	1.311	1.224	1.401
$K_h = +0.1g$	1.224	1.137	1.306
$K_h = +0.2g$	1.142	1.063	1.221
$K_h = +0.3g$	1.072	0.990	1.144
$K_h = +0.4g$	1.006	0.924	1.072

Table -5: Dynamic factor of safety due to lateral acceleration in negative direction

Acceleration	CSN	KTS	LDN
$K_H = 0$	1.311	1.224	1.401
$K_H = -0.1g$	1.407	1.324	1.510
$K_H = -0.2g$	1.517	1.436	1.630
$K_H = -0.3g$	1.642	1.569	1.768
$K_H = -0.4g$	1.786	1.716	1.928

Table -6: Dynamic factor of safety due to vertical acceleration in positive direction

Acceleration	CSN	KTS	LDN
K_V = g	1.311	1.224	1.401
K_V = g + 0.1g	1.311	1.228	1.405
K_V = g + 0.2g	1.312	1.232	1.409
K_V = g + 0.3g	1.317	1.237	1.412
K_V = g + 0.4g	1.317	1.240	1.416

Table -7: Dynamic factor of safety due to vertical acceleration in negative direction

Acceleration	CSN	KTS	LDN
K_V = g	1.311	1.224	1.401
K_V = g - 0.1g	1.310	1.224	1.400
K_V = g - 0.2g	1.306	1.221	1.396
K_V = g - 0.3g	1.306	1.217	1.394
K_V = g - 0.4g	1.306	1.214	1.393

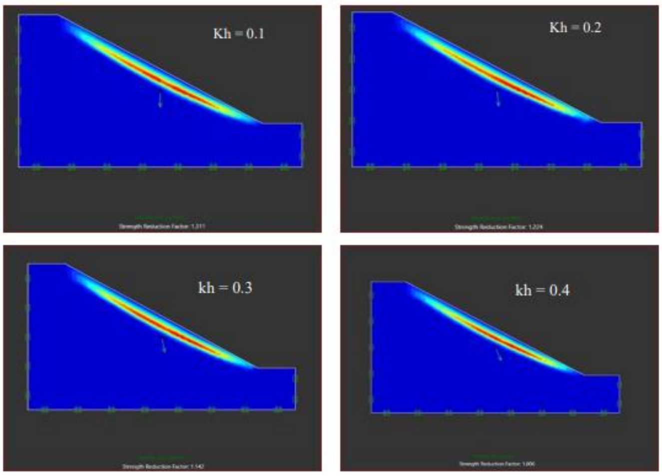

Fig -4: Failure pattern of slope under Positive Acceleration in Lateral direction at Chasnala

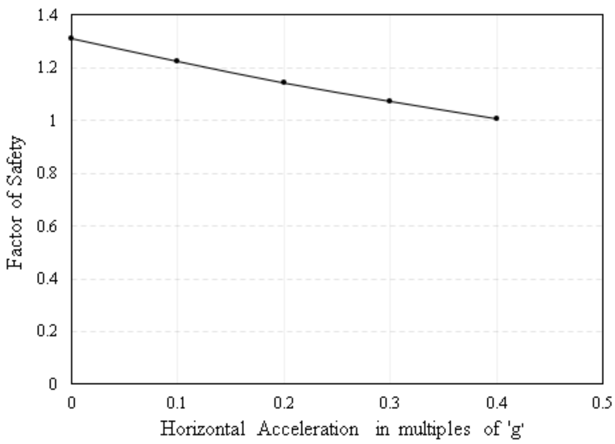

Fig -5: Variation of FOS with Positive Acceleration in Lateral direction

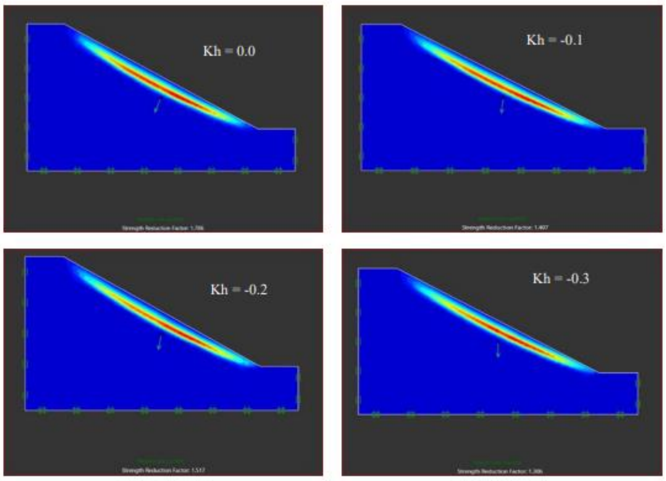

Fig -6: Failure pattern of slope under Negative Acceleration in lateral direction at Chasnala

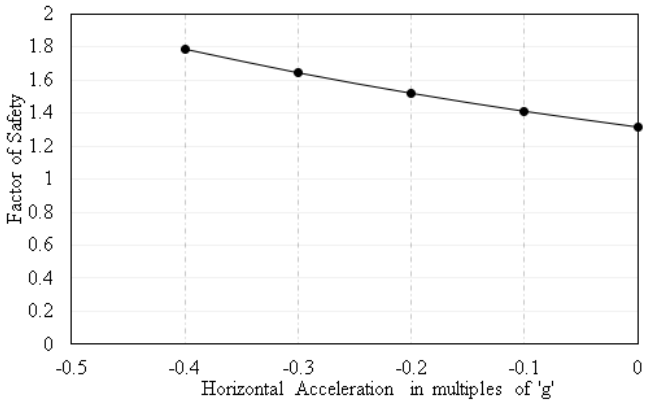

Fig -7: Variation of FOS with Negative Acceleration in Lateral direction

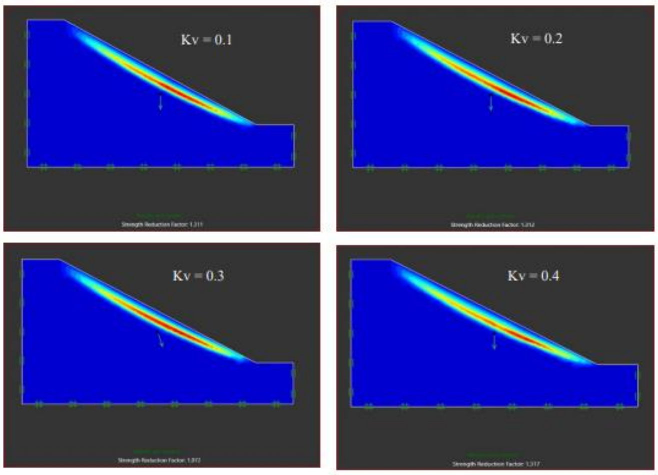

Fig -8: Failure pattern of slope under Positive Acceleration in Vertical direction at Chasnala

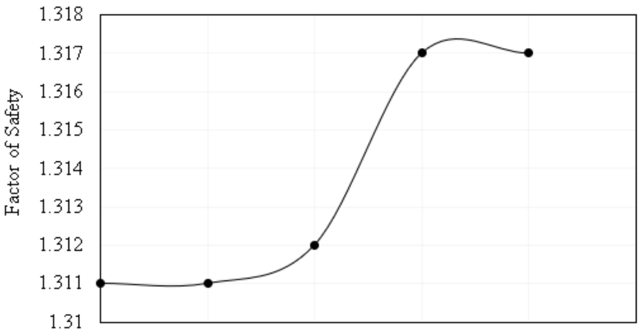

Fig -9: Variation of FOS with Positive Acceleration in Vertical direction

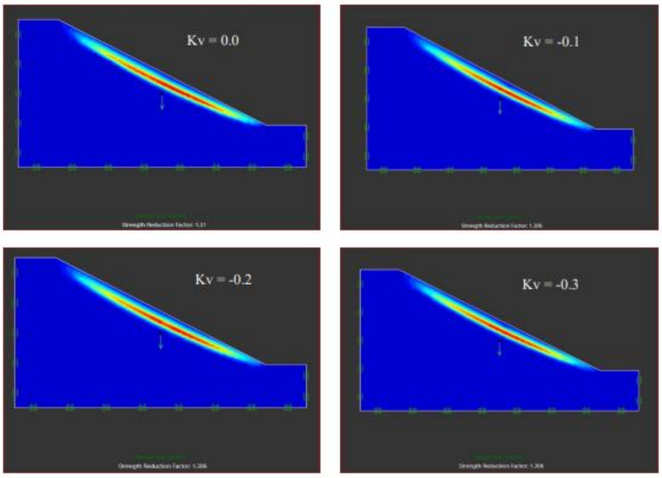

Fig -10: Failure pattern of slope under Negative Acceleration in Vertical direction at Chasnala

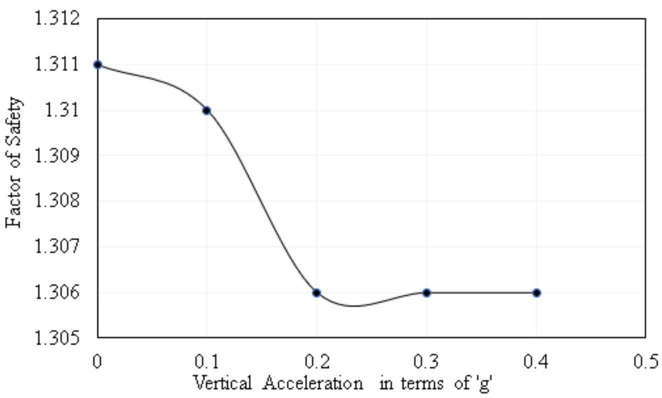

Fig -11: Variation of FOS with negative Acceleration in Vertical direction

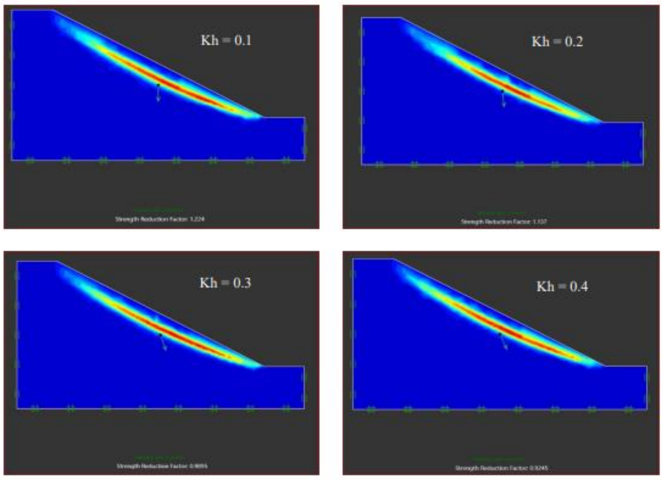

Fig -12: Failure pattern of slope under Positive Acceleration in Horizontal direction at Katras

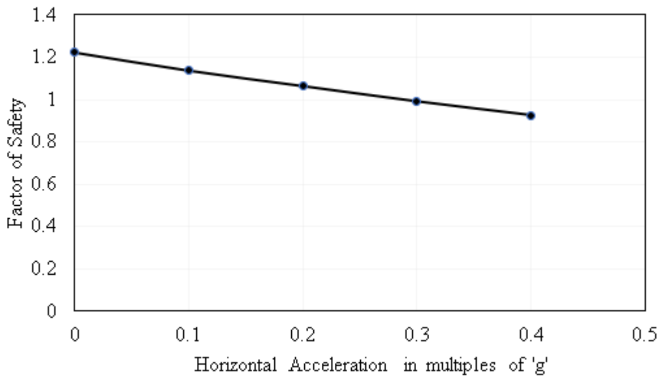

Fig -13: Variation of FOS with Positive Acceleration in Lateral direction

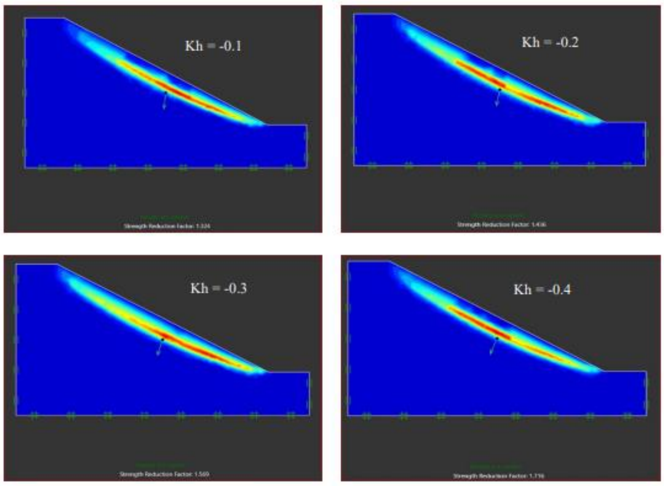

Fig -14: Failure pattern of slope under Negative Acceleration in Horizontal direction at Katras

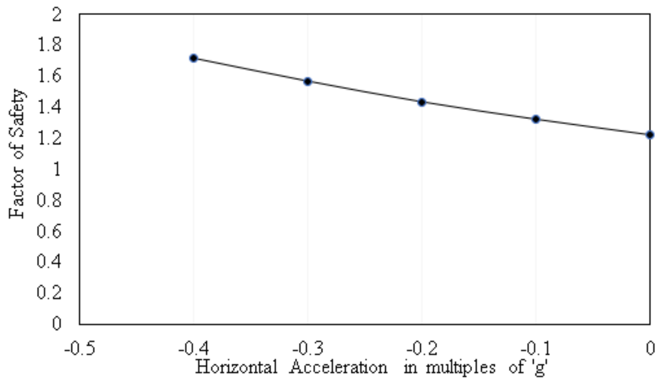

Fig -15: Variation of FOS with Negative Acceleration in Lateral direction

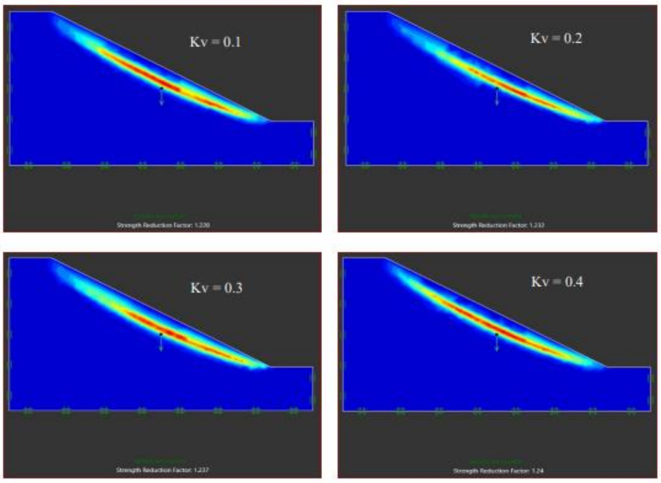

Fig -16: Failure pattern of slope under Positive Acceleration in Vertical direction at Katras

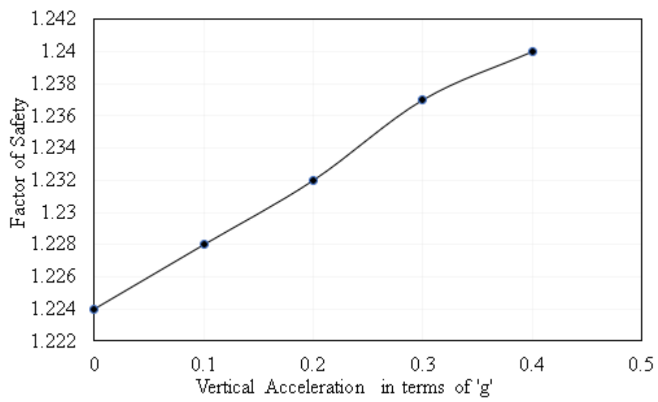

Fig -17: Variation of FOS with Positive Acceleration in Vertical direction

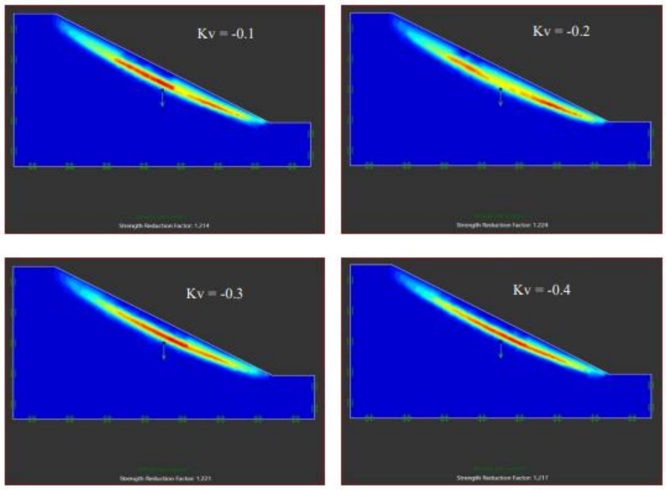

Fig -18: Failure pattern of slope under Negative Acceleration in Vertical direction at Katras

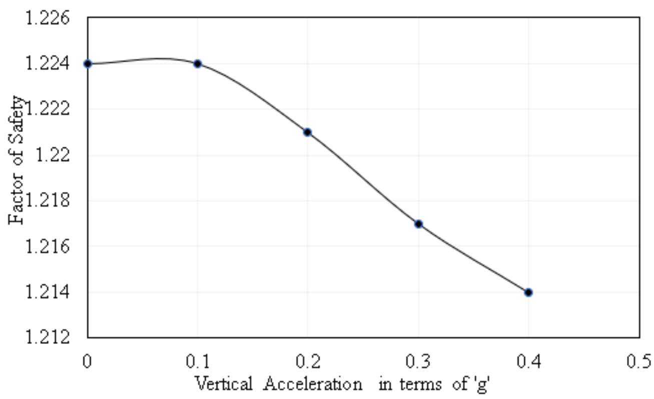

Fig -19: Variation of FOS with negative Acceleration in vertical direction

5. SUMMARY AND CONCLUSIONS

In this study, a complete investigation of the safety aspects of the OB dump slope for three mine samples are performed. The geotechnical parameters are determined by laboratory testing and are recorded. Cohesion of Chasnala mine is 1.661kN/m^2 and that of Katras and Lodna are 3.133 kN/m^2 and 3.343 kN/m^2 respectively. Frictional angle of Chasnala is 35.1^o and that of Katras and Lodna are 32.1^o and 35.9^o respectively.

It is well known fact that the slope and stability of the mine OB dump are critical. Considering India is an earthquake-prone country, mining OB dumps are constantly subjected to seismic forces. From the study it can be concluded that percentage reduction in FOS due to increase in K_h is 24.05 % and due to K_v is 0.82 %.

During earthquake direction of force changes drastically, it was discovered that the factor of safety achieved when lateral loading was present was significantly lower than when the lateral load was absent, implying that extreme caution should be taken while designing slopes of overburden dumps in earthquake-prone areas.

REFERENCES

[1] Koo, R.C.H., Kong, V., Tsang, H.H. & Pappin, J.W., (2008), "Seismic slope stability assessment in a moderate seismicity region, hongkong", wcee,vol. 14,p12-17.

[2] Khaburi, M.A. & Mortazavi, A., (2019), "Slope stability analysis of sarcheshmeh copper mine west wall under seismic loads", Geotech GeolEng vol. 37, p3141–3155. https://doi.org/10.1007/s10706-019-00830-3

[3] Azhari A & Ozbay, U. (2016)" Evaluating the effect of earthquakes on open pit mine slopes",US rock mechanics/geomechanics symposium,50

[4] Anand, A. and Sarkar, R. (2021). "A comprehensive study on bearing behavior of cement fly ash composites through experimental and probabilistic investigations", Innovative Infrastructure Solutions, 6(1), https://doi.org/10.1007/s41062-020-00404-w

[5] Hack, H. R., Alkema, D., Kruse, G., Leenders, N. (2007), "Influence of earthquakes on the stability of slopes", Engineering Geology 91(1):4-15, https://doi.org/10.1016/j.enggeo.2006.12.016

[6] Ishihara, K., (1986). "Stability of natural deposits during earthquakes", International conference on soil mechanics and foundation engineering, vol. 24. Dept. Civil Engg., Tokyo, pp. 1–56

[7] Koner, R. & Chakravarty, D, (2010), "Evaluation of Seismic Response of External Mine Overburden Dumps", International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, 17, pno.4.63b

[8] Rajak, T. K., Yadu, L., Chouksey., S.K.& Dewangan, P. K., (2018) "stability analysis of mine overburden dump stabilized by fly ash", International journal of geotechnical engg, vol.15, pp.587-597. https://doi.org/10.1080/19386362.2018.1503780

[9] Poulsen, B., Khanal, M., Rao,A.M. & Rao,B.(2014) "Mine overburden dump failure: case study", Geotechnical & geological engg.,vol.32,pp.297-309. https://doi.org/10.1007/s10706-013-9714-7

[10] Chakravarty,D.& Koner,R.(2010) "Discrete element approach for mine dump stability analysis",minig science and technology china, vol. 20,pp.809-813. https://doi.org/10.1016/S1674-5264(09)60286-6

[11] Rai, R., Kalita, S., Gupta, T. & Srivastava, B. K., (2012), "Sensitivity analysis of internal dragline dump stability: finite element analysis", Geotechnical & geological engg.,vol.30,pp.1397-1404. https://doi.org/10.1007/s10706-012-9541-2

[12] Damjanac, B., Varun & Lorig., (2013), "Seismic stability of large open pit slopes and pseudo-static analysis", Proceedings of the 2013 International Symposium on Slope Stability in Open Pit Mining and Civil Engineering, pp. 1203-1216. https://doi.org/10.36487/ACG_rep/1308_85_Damjanac

[13] Pan, Q.J., Xing, R.Q. & Wang, X., (2019), "Probabilistic seismic stability of three-dimensional slopes by pseudo-dynamic approach", journal of central south university, vol.26, pp.1687-1695. https://doi.org/10.1007/s11771-019-4125-4

[14] Behera, P. K., Sarkar, K., Singh, A. K.., Verma, A K., Singh, T N, (2016) "Dump Slope Stability Analysis – A Case Study", Journal of the Geological Society of India; Bangalore Vol. 88, Iss. 6, 725-735. https://doi.org/10.1007/s12594-016-0540-4

[15] Kainthola, A., Verma, D., Gupte, S. and Singh, T. N., (2011) "A Coal Mine Dump Stability Analysis—A Case Study," Geomaterials, Vol. 1, issue. 1, pp. 1-13. DOI: 10.4236/gm.2011.11001

[16] Richards, B., Coulthard, M. & Toh, C.T.,(1981) "Analysis of slope stability at goonyella mine", Canadian Geotechnical Journal,vol.18. https://doi.org/10.1139/t81-023

[17] Bhatt, A., Priyadarshini, S., Mohankrishnan, A.A., Abri, A., Sattler, M., Techapaphawit, S. (2020), "Physical, chemical, and geotechnical properties of coal fly ash: A global review", Case Studies in Construction Materials, 11, https://doi.org/10.1016/j.cscm.2019.e00263

[18] Houston, S. L., Houston, W.J., Padilla, M. (1987) "Microcomputer-Aided Evaluation of Earthquake-Induced Permanent Slope Displacements", Computer-Aided Civil and Infrastructure Engineering, vol. 2, issue 3, pp 207-222.