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ESTIMATION OF LIQUEFACTION POTENTIAL OF MINING DUMP AREA IN NAGPUR REGION BASED ON FIELD ASSESSMENT BY SPT DATA

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Abstract

In geotechnical engineering, liquefaction is a difficult, contentious, but crucial issue, particularly in earthquake-prone areas. Regarding the design of the mining waste disposal system, the expanding mining sector in Nagpur may pose a significant difficulty due to the seismic activity. One of the main reasons for this form of structure failure, which is primarily ascribed to liquefaction, is earthquakes.

Infrastructure suffers significant damage as a result of this earthquake's secondary effect. The third-largest and most rapidly developing city in Maharashtra is Nagpur. The major goal of this study is to map the mining dump area of Nagpur region in light of the possibility of liquefaction occurring and to make data easily accessible for use in further studies. For liquefaction assessment of soil found during investigation in the mining region, an SPT-N based approach is adopted. The possibility for liquefaction is evaluated in relation to the factor of safety (FS) component along the depth of various soil strata encountered throughout the study. By conducting Standard penetration tests (SPT) and recording the results in bore holes, this liquefaction potential is assessed at 11 sample sites throughout the mine dumped area. The current work on liquefaction potential computation demonstrates the sensitivity of liquefaction computation to the SPT blow count and peak ground acceleration. The SPT-N value is corrected for the Cyclic Resistance Ratio (CRR), which shows that the soil in the area is not uniform at all locations, the water table is variable, and N values vary according to the soil properties but are typically on the higher sides, indicating that liquefaction potential is significantly lower.

***Keywords*: Liquefaction Potential, Standard Penetration Test SPT-N value, Cyclic Resistance Ratio (CRR), Factor of Safety (FS).

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1. Introduction

Numerous studies have demonstrated that a significant portion of soil mass loses its shear resistance when subjected to cyclic loading or shaking, primarily caused by earthquakes, and tends to flow like a liquid [1]; this phenomenon is referred to as liquefaction. The quick loading that occurs during seismic events prevents the natural drainage of excess pore water pressure, which causes liquefaction of the soil. This increase in pore water pressure causes fine-grained material to soften cyclically, changing the substance's state from solid to liquid. Increased pore water pressure causes a decrease in the shear strength and stiffness of soil deposits. The likelihood of liquefaction depends on a wide range of variables, including the strength and duration of the earthquake, the duration and intensity of the ground motion, the type and thickness of the soil deposits, the grain size distribution, density, fine content, and plasticity of the soil, the degree of saturation, confining pressure, changes in the ground water table, the characteristics of the soil's permeability, the reduction of effective stress, and many others.

After the devastating quakes in Alaska (1964) and Niigata (1964), many researchers began to focus on the liquefaction phenomenon. There are countless instances of enormous amounts of damage being reported globally during previous earthquakes. During the earthquakes in Dhubri, Assam (1930), Bihar-Nepal (1934), Niigata (1964), San Fernando (1971), Tangshan (1979), Loma Prieta (1989), Kobe (1995), Koyna (1995), Turkey (1998), Chi-Chi, Taiwan (1999), Bhuj (2001), and the Great East Japan earthquake (2011)., failures of buildings, bridges, dams, foundations, slopes, and many other were observed.

Large earthquakes have recently struck India and its surrounding region, including Muzaffarabad (2005), Sumatra (2004), Bhuj (2001), and Nepal (2015). This type of earthquake has caused significant damage and devastation to low and high-rise structures, as well as the loss of numerous lives. Geotechnical investigations related to estimating an area's liquefaction potential must be considered for systematic urbanisation planning. As a result, understanding the influence of natural hazards such as earthquakes, landslides, and subsidence on the built environment is essential for human progress and safety. This needs systematic development with the least amount of danger. Nagpur, Maharashtra, is located in the eastern region of the state and in the central part of India. Nagpur city is experiencing a larger impetus in constructional, mining activities and rising human settlements as a result of population growth, urbanisation, and industrialization. Given the foregoing facts, it is necessary to analyse the liquefaction threats that may result from an earthquake event.

Tailings dams or mining dump are earthen retention structures used to store mining waste generated during the mineral beneficiation process in the mining industry. Large constructions, such as mining dumps, have seen a variety of collapses throughout history due to many variables (such as operation, natural occurrences, and building). One of the main reasons for these constructions failing is due to earthquakes, which are primarily caused by liquefaction, with disastrous results as shown in case studies[2, 14]. This study uses geotechnical investigation to assess the liquefaction risk of mining dump locations in the Nagpur region based on SPT-N values [3, 16]. For evaluating the risk and potential of the area linked with the liquefaction, the findings and recommendations drawn from this research will be very helpful.

Since liquefaction-related phenomena were often thought to only occur in sands, it has long been recognised that coarse-grained sediments and sandy soils are more vulnerable to liquefaction potential.

However, silty and clayey soils also provide important challenges in liquefaction evaluation. It was noted that fine-grained soils that meet Chinese criteria may be considerably susceptible to significant losses in strength [4], so all types of soils encountered during investigation were examined for liquefaction potential in this study. In the 1999 Kocaeli (Turkey) earthquake and Chi-Chi (Taiwan) earthquake, liquefaction actuated in cohesive soil led to partial settlement and bearing capacity failures of shallow foundation of structures [5, 17].

2. Background of study

The reason for this study's development is that, despite the fact that Nagpur, the second capital of Maharashtra, is situated in Seismic Zone II [6] and has experienced a few minor earthquakes of 4 to 6 magnitude on the Richter scale, which is a sign of danger for the majority of new to mining dump arriving in the area and may be harmful to the same, it has not yet experienced any major **earthquakes. The** National Centre for Seismology has stated that on October 27, 2020, at 4:15 a.m., a minor earthquake measuring 5.3 on the Richter scale occurred in Nagpur's North Eastern region. However, no significant property damage or casualties have been recorded as of yet. The earthquake's epicentre was 96 kilometres northeast of Nagpur. Additionally, on March 15, 2020, Nagpur had three separate mild earthquake shocks. According to reports, residents of Beltarodi in Nagpur felt the earthquakes. At 1:39 PM (1.4 magnitude), 2:38 PM (1.5 magnitude), and 2:41 PM, the earthquakes were felt (1.2 magnitude). The earthquake had a fairly low magnitude. It was established that residents of Beltarodi felt the earthquakes. Mild earthquakes were felt on April 23, 2020, in 14 villages in the Hinganghat, Deoli, and Wardha tehsils, 79 kilometres from Nagpur. This study will be helpful for assuring the safety of the intended engineering, advancements, and constructions in order to reduce the risks associated with shocks and earthquakes.

3. Geology of Mining Dump area under study

The area under study is in Nagpur district and a municipality. It is 290 metres above sea level and situated at 20° 51' 14N and 17° 19' 29E. Three sizable open-cast mines owned by Western Coalfields Limited are located near to the town. It is the taluka's biggest employer. In the following five years, the production of coal will increase from 2.2 million to 10 million tonnes annually. The coalfields of Umred Makardhokra, Kamptee, and Bokhara are divided apart from the mining area. Basalt generally moves in a N-S direction with a little slope in the SE and NW directions. The moderate slope of basalt beds makes them nearly flat. The mining lease area is a representation of the landscape of the Deccan Basalt. In the mining licence area, outcrops of rocks that indicate the existence of basalt lava flows were discovered during field surveys. Within the mining lease area, there are no significant structural deformations, shear zones, or fault zones. The basalt rock outcrop had irregular cracks, columnar joints, and flow beds ranging in thickness from a few centimetres to a few metres a flat piece of land with a north-south sloping mining lease The Basalt rock has a fine-grained Aphanitic texture and is exposed 1.0 metres below the surface at a quarry next to Sy. No. 81. Plagioclase feldspar, Muscovite, Biotite, Amphibole, Pyroxene, and Quartz are the primary mineral components of basalt rock. Spheroidal weathering is visible on the rock cover that occupies up to 3 metres on the flow rock since it is a surface formation. Rock has an earthy to siliceous sheen and a grey to black tint. On dirt with black cotton and murrom. Geologically, the region under examination is bordered by the volcanic Deccan Trap Basalt, the metamorphic Tirodi Gneissic Complexes, the limestone- and shale-rich Cretaceous-Lameta Group of Upper Gondwanan Sedimentary Rocks.

4. Soil parameters and geotechnical Investigation

At mining dumped area under study, geotechnical studies are conducted to assess the underlying lithology and stratified profile of the area. A total of 11 boreholes of various depths were drilled at various locations noted on the map in Figure 1. During the drilling process, disturbed and undisturbed soil samples were taken. According to IS 2131:1981[7], the routine penetration tests were carried out at specific intervals and with each change in stratum. In addition to the lithology of the strata encountered, normalised SPT-N values were recorded throughout the field work, and sampling was also done. After 24 hours, the water table depth in the drilled borehole was also measured in accordance with the applicable code. Seasonal variations in the water table's depth have been noted. Due to the rise in density with depth, the SPT-N value at shallow depths was found to be lower than that at deeper depths. The observed field SPT-N values rely on a variety of variables, including the kind of hammer used, the drilling rods utilised, the size of the bore hole, the type of sampler used, the test process, etc. In certified laboratories, split spoon samples and undisturbed samplers were examined for the engineering and index properties of soil needed for characterising and assessing the area under study's potential for liquefaction. The measured SPT-N values are further changed according to the applicable regulation and site-specific requirements.

5. Subsurface lithological correlation

The locations of the investigation's focus points are shown in figure no 1. Geological portions of the area under study were used to correlate the subsurface strata, as illustrated in Figure no 2.a & b.

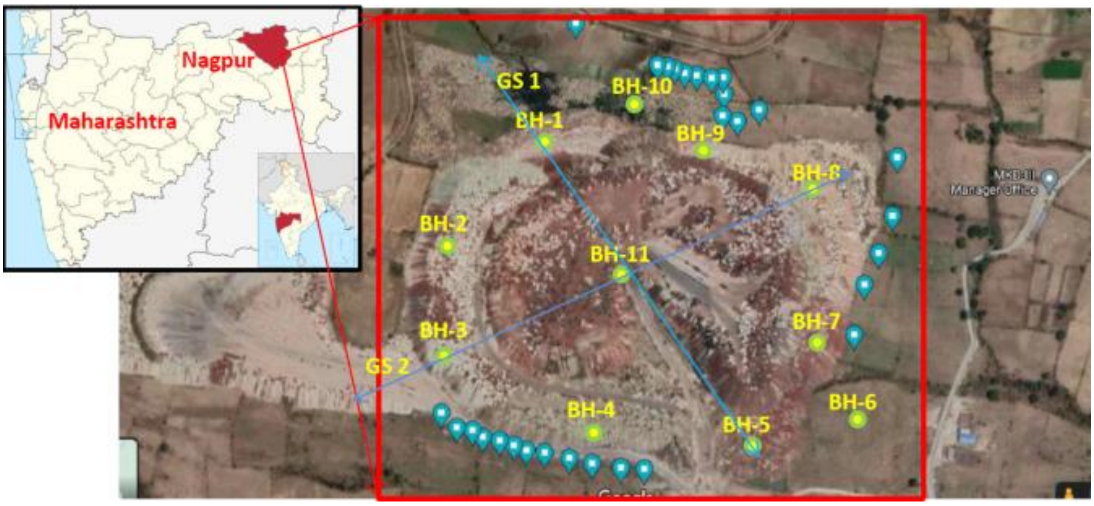

Figure. 1: Locations of boreholes and chosen hosen geological section are shown on the map.

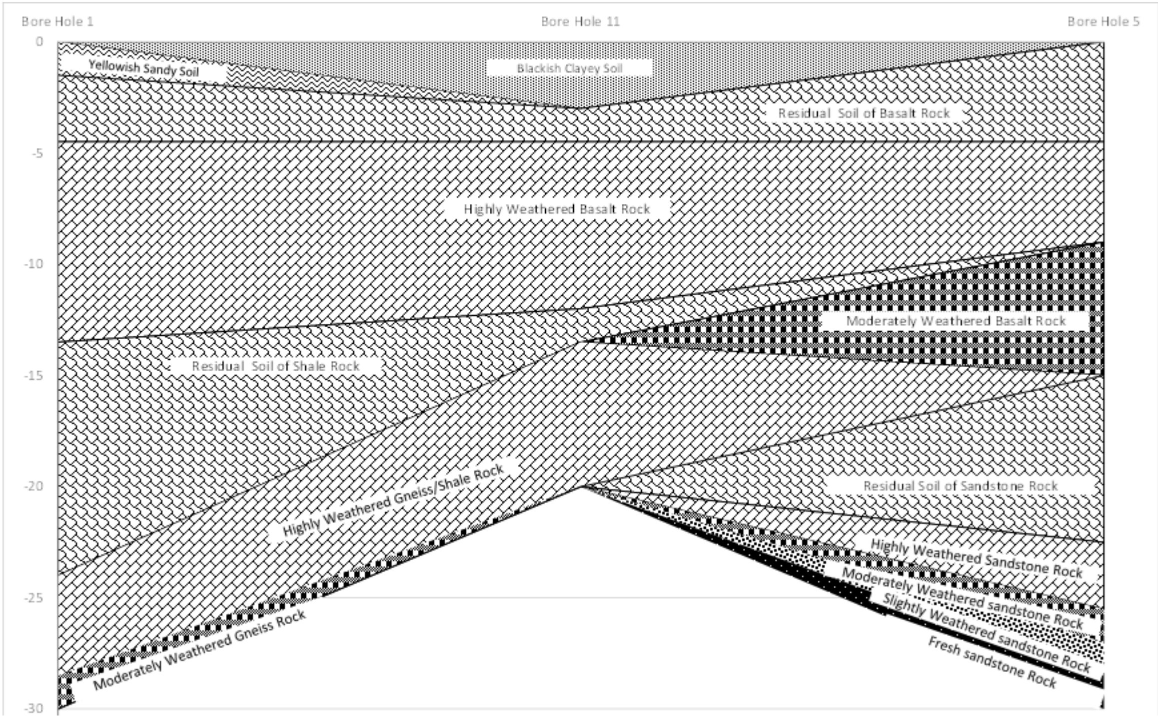

Figure. 2 (a): Geological section (GS-1) along BH. 1, 11 and 5

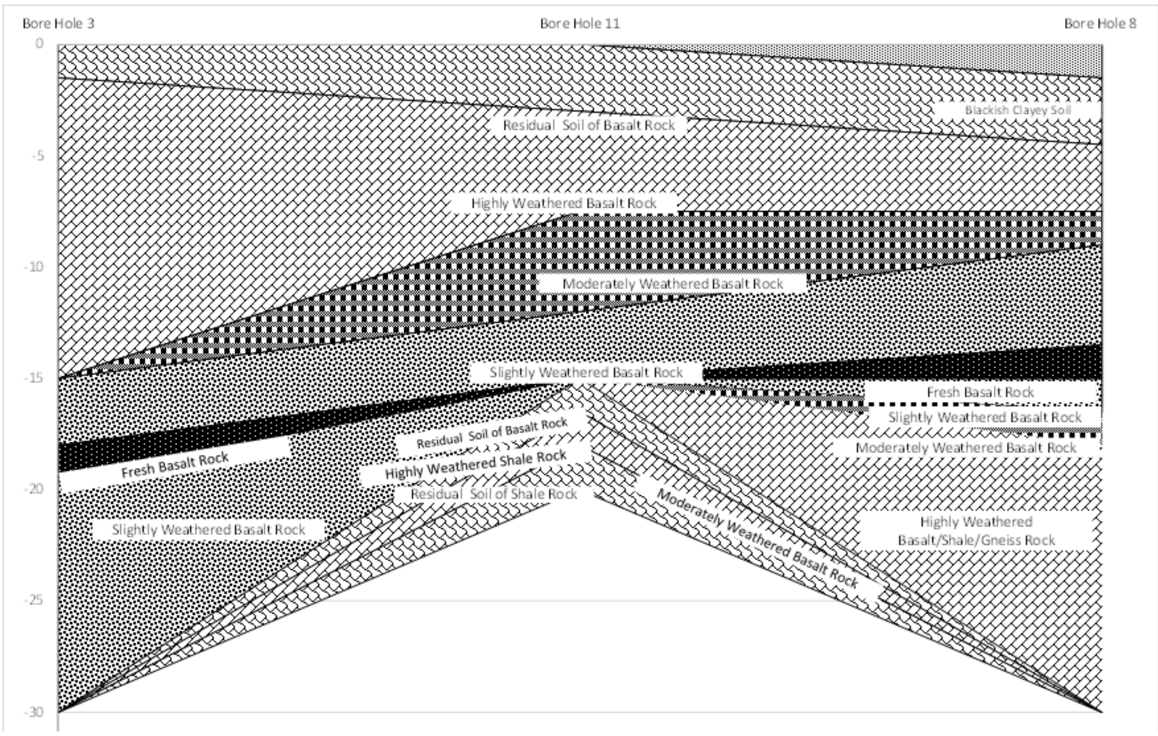

Figure. 2 (b): Geological section (GS-1) along BH. 3, 11 and 8

According to the geological section GS-1, the clayey stratum is initially existent and becomes thicker towards the middle portion

and gain reduces towards end point of the study region, reaching a depth of maximum 3.0 m. Clayey sand may be found in the

starting section, and a hard strata of leftover soil or rock layer follows till the final studied depth of 30.0 m. At an average depth of 10 m, SPT N-value was determined to be larger than 50. Clayey soil is only present in GS-2 to a maximum depth of 2.0 m, after which a sufficient layer of clayey silty sand with an SPT N-value of greater than 50 is encountered up to a depth of 15.0 m, after which a hard layer of residual soil or rock is found up to a depth of 30.0 m. It has been noted that some quality of rock encountered is of very week quality which while testing in laboratory disintegrates in water absorption test. Varying quality and type of rock is encountered during investigation. It is also observed that, at some location clayey strata is encountered after rock stratum as it may be residual part of shale rock, which after laboratory testing's comes under clayey classification.

6. Assessment of the potential for liquefaction

This study uses the SPT N value to calculate the study area's potential for liquefaction [3]. In situ testing is preferred for evaluating liquefaction in accordance with IS 1893 (Part 1): 2016 [6] and numerous modifications are made in some parameters based on literatures resurrected for this field-based experimental investigation because getting representative undisturbed soil samples from is problematic. The position of the water table, the SPT blow count, and the fines content of the soil encountered at a specific depth are among the data needed to determine the susceptibility to liquefaction. Calculations must be made for the vertical overburden stress (σ_{vo}) and effective vertical overburden stress (σ'_{vo}) at various depths. According to the depth of the exploratory bore hole, the stress reduction factor (r_d) is calculated as follows:

r_d = 1-0.00765z when $0 < z \leq 9.15$ m, r_d = 1.174-0.0.2367z when 99.15 m $< z \leq$ 23.0 m, and r_d = 0.744-0.008z when 23 m $< z \leq 30$ m [8]. IS 1893 (Part 1) only makes provision for reduction factors up to a depth of 23 m; however, in this study, analysis is performed up to a depth of 30 m in some locations [18]. The depth of the water table is measured at ground level because to the poorer conditions associated to it.

Peak ground acceleration, which is dependent on site-specific ground motion and can be calculated using the expression given below, can be used to derive the earthquake-induced Cyclic Stress Ratio (CSR), which characterises the earthquake-induced seismic demand

$$CSR=0.65(a_{max}/g)\ (\sigma_{vo}/\sigma'_{vo})\ r_d$$

a_{max} is the preferred peak ground acceleration (PGA) in terms of *g*, which is the acceleration due to gravity. In the absence of a PGA value, (a_{max} /g) can be taken to be equal to seismic zone factor Z. 0.65 is the weighing factor required to calculate uniform stress cycles necessary to generate the same pore water pressure at the time of an earthquake. Using this information from IS 1893 (Part 1) [6] and the fact that Nagpur City is in zone II according to India's seismic zoning map, (a_{max} /g) is set as 0.10 for the estimation of liquefaction potential.

Using the equation below, we can determine the Cyclic Resistance Ratio (CRR), which depends on the soil variables under study, such as the fine content (FC) and final corrected SPT N value. The calculated value of CRR must be adjusted for earthquake magnitude, high overburden stress levels, and high beginning static shear stresses in order to reflect the equivalent uniform shear stress caused by an earthquake of magnitude Mw=7.5.

$$CRR = CRR_{7.5}\,(MSF)\,K_{\sigma}\,K_{\alpha}$$

When an earthquake's magnitude deviates from 7.5, a magnitude scaling factor, or $CRR_{7.5}$, which is generated from SPT data and may be computed as MSF= (102.24/MW2.56), is needed. K is considered to be unity since it is only necessary in sites with sloping land because K = $(\sigma_{vo}/P_a)^{(f-1)}$ is necessary for high overburden stress typically when depth is greater than 15 cm. P_a denotes atmospheric pressure, and f denotes an exponent whose range varies on relative density Dr. as shown in Table 1.

Table 1. Relative density and atmospheric pressure.	
D_r (%)	f
40-60	0.8-0.7
60-80	0.7-06

As a result of reviewing the SPT number and relative density correlations, based on field N number [9, 15,], the values for Dr are tabulated as follows in table 2. It is not possible to obtain relative density in the laboratory from the SPT samples as it required sufficient soil samples.

Table 2. Relative density and *N* values.

Relative Density	N-Value	D_r (%)
Very loose	0 to 4	0
Loose	5 to 10	15
Medium	11 to 30	35
Dense	31 to 50	65
Very Dense	Above 50	85

For hammer efficiency of 60%, $N_{60}=NC_{60}$ value if standard penetration test is conducted by non-standard type equipment, otherwise $C_{60}=1$ as SPT is conducted in accordance with IS 2131 [7], as is the case in this study, $C_{60}=1$ is taken into consideration when calculating CRR value

based on field SPT N value. The computed value of N_{60} is normalised with respect to effective overburden pressure using the formula $(N1)_{60}=C_N N_{60}$, where C_N is the effective overburden correction factor.

$$C_N = \sqrt{(P_a/\sigma'_{vo})} \leq 1.7$$

As in this study, M_W = 7.0 is taken into account and fine contents are also different as given in code, further calculations are carried out for more accuracy and reliability of results and study. $CRR_{7.5}$ can be evaluated by the graph given in IS 1893 [6] based on $(N_1)_{60}$ value for given percentage of FC, for M_W = 7.5.

Correcting $(N_1)_{60}$ to $(N_1)_{60CS}$ allows for the calculation of FC's reliable accountability, as,

$$(N_1)_{60CS} = \alpha + \beta\,(N_1)_{60}$$

The values and requirements for α & β are provided in IS code. With the SPT clean sand based curve, the value for $CRR_{7.5}$ can once more be estimated by using curves, but each time the clean sand encountering is not required, hence $CRR_{7.5}$ is estimated

Figure.3. Factor of safety against liquefaction with respect to depth.

by applying the equation shown below.

$$CRR_{7.5}=\frac{1}{34-((N1)60CS}+\frac{(N1)60CS}{135}+\frac{50}{[10X(N1)60CS+45]^2}+\frac{1}{200}$$

The results of the examination of liquefaction susceptibility are given in terms of a safety factor (FS)

According to Seed and Idriss [10], soil is thought to be liquefiable if FS is less than 1; if FS is greater than 2, ground deformation caused by earthquakes will typically be smaller. When the soil's FS is between 1 and 1.2, it will liquefy just slightly; soil that is above 1.2 will not liquefy [11]. The formula for FS is FS=CRR/CSR.

Figure 3 compares the findings of the liquefaction analysis using the FS vs. Depth and Figure 4 shows $(N_1)_{60}$ vs. CSR

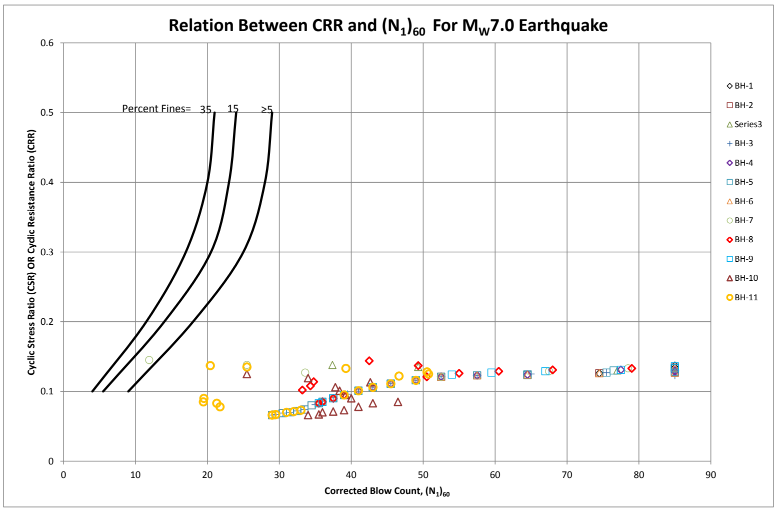

Figure. 4. Factor of safety against liquefaction with respect to depth.

metrics. According to Youd et al [12],

7. Liquefaction computation

A typical location from the entire study region has been chosen to elaborate the liquefaction calculations, and this location is circled in Figure 1.

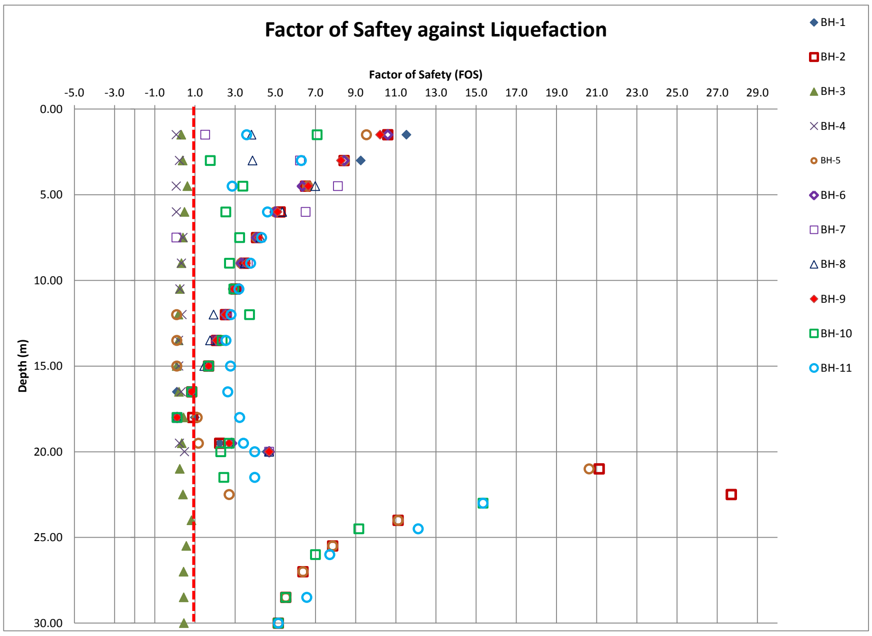

Figure 5 depicts the stratification of this location, the fine content and the final estimated FOS with respect to depth. Moreover, liquefaction severity is depicted according to depth magnitudes. Figure 6 does a good job of illustrating the specifics of the site's soil stratification, including SPT number. At this specific location, the lithological layers consist of clayey soil, residual soil followed by distinctly weathered Rock stratum. At the designated bore hole, the FOS calculation for the M_W = 7.5 earthquake is done in relation to the possibility for liquefaction. The approach used for calculating follows the guidelines provided in the section above on evaluating liquefaction potential. A spreadsheet is created to make calculations easier, and an example is provided in table 3 below.

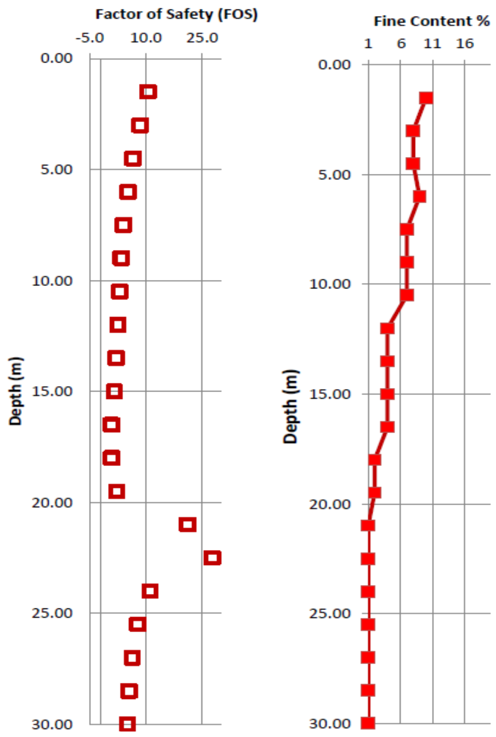

Figure. 5. Fine contents, FOS vs Depth for the liquefaction at a typical site

Table. 3. Liquefaction potential Calculation.

Depth (m)	Fine Content (%)	(r_d)	(σ'_{vo}) (t/m^2)	CSR	C_N	N_{60}	$(N_1)_{60}$	[illegible]	$(N_1)_{60CS}$	$CRR_{7.5}$	CRR	FOS
1.50	10	0.989	1.38	0.134	1.7	50	85	1	87.57	0.63	1.42	10.6
3.00	8	0.977	3	0.127	1.7	50	85	1	86.15	0.61	1.07	8.4
4.5	8	0.966	4.5	0.126	1.49	50	74.5	1	75.54	0.53	0.82	6.5
6.0	9	0.954	6	0.124	1.29	50	64.5	1	66.35	0.46	0.65	5.2
7.5	7	0.943	7.5	0.123	1.15	50	57.5	1	58.2	0.38	0.5	4.1
9	7	0.931	9	0.121	1.05	50	52.5	1	53.15	0.34	0.42	3.5
10.5	7	0.894	10.5	0.116	0.98	50	49	1	49.61	0.3	0.35	3.0
12	4	0.854	12	0.111	0.91	50	45.5	1	45.5	0.25	0.28	2.5
13.5	4	0.814	13.5	0.106	0.86	50	43	1	43	0.2	0.22	2.1
15	4	0.774	15	0.101	0.82	50	41	1	41	0.16	0.17	1.7
16.50	4	0.733	16.5	0.095	0.78	50	39	1	39	0.08	0.08	0.8
18.00	2	0.693	18	0.09	0.75	50	37.5	1	37.5	0.08	0.08	0.9
19.5	2	0.653	19.5	0.085	0.72	50	36	1	36	0.2	0.19	2.2
21.0	1	0.613	21	0.08	0.69	50	34.5	1	34.5	1.8	1.69	21.1
22.5	1	0.573	22.5	0.074	0.67	50	33.5	1	33.5	2.24	2.05	27.7
24	1	0.552	24	0.072	0.65	50	32.5	1	32.5	0.9	0.8	11.1
25.5	1	0.54	25.5	0.07	0.63	50	31.5	1	31.5	0.63	0.55	7.9
27	1	0.528	27	0.069	0.61	50	30.5	1	30.5	0.51	0.44	6.4
28.5	1	0.516	28.5	0.067	0.59	50	29.5	1	29.5	0.44	0.37	5.5
30.0	1	0.504	30	0.066	0.58	50	29	1	29	0.41	0.34	5.2

8. Discussion

Given the significance of the mining dump area of Nagpur region, this study attempts to map the mining dump area at risk of liquefaction and to make data available for technocrats developing methodology in order to shield them from any dangers brought on by liquefaction, as indicated in Table 4. The 11 boreholes lithological variances show that the study mining dump region is made up of a variety of soil types and gradations of gravels, sand, silt, and clay. The thickness and shape of the stratification that was discovered in the boreholes varied from location to location at site.

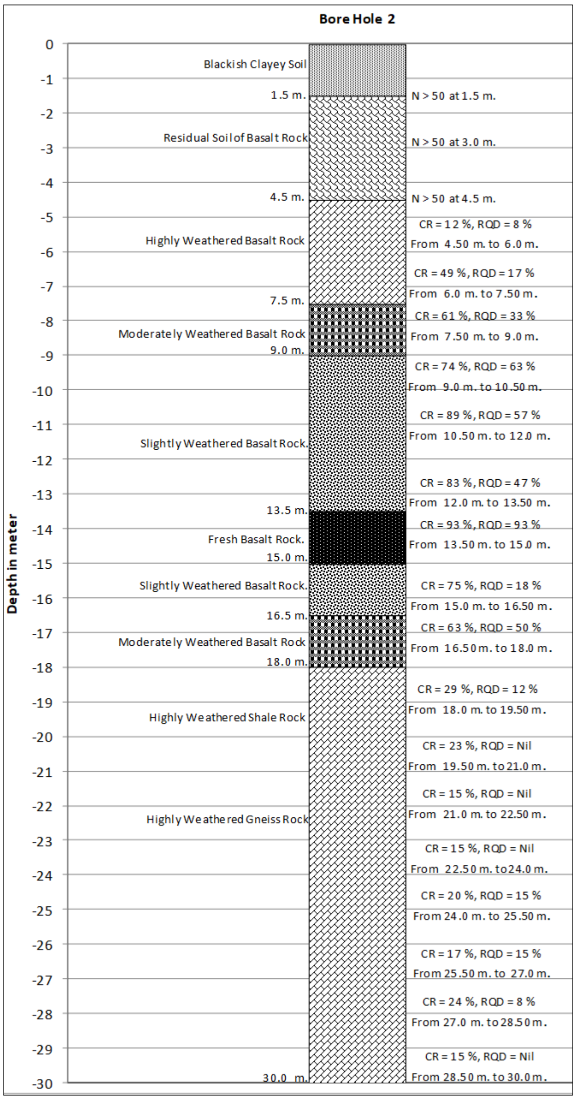

Figure. 6. Soil stratification of location BH-2

Certain layers of the bore hole in same research areas of mining dump were discovered to be liquefiable; two of them, BH-3 & BH-4 showed signs of liquefaction potential throughout the depth, while BH-11 showed no effect of liquefaction. Just marginal liquefaction activity is shown at BH-1 and BH-5 at middle depth. The depths of liquefaction layers vary depending on stratification, and this may happen because that layer contains a significant amount of sand. Nevertheless, this is not the only reason; some clay-containing layers also exhibit liquefaction capabilities, as indicated in Table 4. Because of the density caused by compaction and the low proportion of fines found in many areas of the study area, liquefaction cannot be seen at shallow depths.

Table 4. Estimated FOS and Potential to Liquefaction.

Bore Hole Number	Depth of liquefiable layer in meter	F.O.S	Description
1	16.5	0.1	Liquefiable
2	18.0	1.0	Marginally Liquefiable
	16.5	0.8	Liquefiable
	18.0	0.9	Liquefiable
3	1.50 to 30	0.2-0.6	Liquefiable
4	1.50 to 30	0.1-0.6	Liquefiable
5	12 to 16.5	0.1-0.8	Liquefiable
	18.0 to 19.5	1.1-1.2	Marginally Liquefiable
6	16.5 to 18.0	0.1 -0.8	Liquefiable
7	7.5	0.1	Liquefiable
	16.5 to 18.0	0.1 -0.8	Liquefiable
8	16.5 to 18.0	0.1 -0.8	Liquefiable
9	16.5 to 18.0	0.1 -0.8	Liquefiable
10	16.5 to 18.0	0.1 -0.8	Liquefiable
11	Non liquefiable layer		

Two of the eleven locations—BH-3 and BH-4—are considered to be liquefaction-vulnerable places.

In this study, a variety of parameters were examined in order to eliminate tiresome calculations and evaluate the liquefaction potential directly. For estimating $CRR_{7.5}$, a figure is given in IS 1893 (Part 1):2016 [6], but it is limited to clean sand, which is not a condition in every location that clean sand will be encountered. To get around this, a curve is developed in this study as shown in Figure 4, and by using it; $CRR_{7.5}$ can be directly estimated for the area around this research work. In this study, work on the stress reduction factor up to 30.0 m of depth, which is limited to 23 m as per IS standards of practice, has been done. Several scholars have explored the relationship between the stress reduction factor and depth, but the findings have been largely inconsistent.

Actual calculations up to 30 meters in depth were made for this study. Figure 7 depicts the relationship between stress reduction factor r_d and depth up to 30 m.

It demonstrates that as depth increases, the stress reduction factor falls, ultimately leading to a drop in CSR and an increase in the likelihood of liquefaction. The rate of decline increases after 20 meters of depth, but it decreases up to that point.

Overburden stress K_σ, a correction factor for initial shear stress and effective overburden pressure that varies on atmospheric pressure and relative density, has also been highlighted. This value varies for various soil types and ought to be assessed whenever possible on a site-specific basis [13]. However, in order to calculate overburden stress K_σ for each location under investigation, detailed site and laboratory generated data were used.

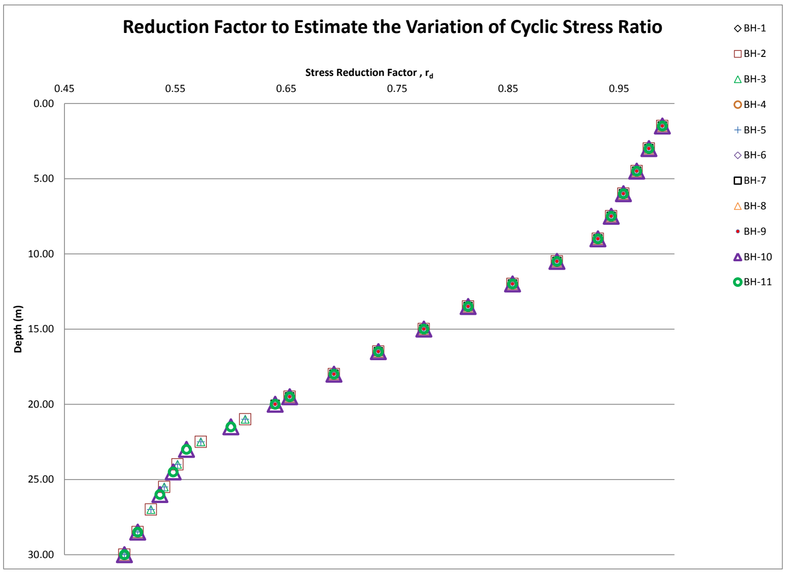

Figure. 7. Relationship between Reduction Factor to Estimate Cyclic Stress Ratio Variation with Respect to Depth

A relationship between effective overburden stress and K_σ was established, as shown in Figure 8, and it shows that as effective overburden stress increases with depth, the K_σ value decreases. This figure can be used to determine the of Nagpur's mining dump region liquefaction potential.

depth of 15 meters due to the presence of dense strata followed by compacted layers of sand and rock strata, after this depth liquefiable layers are present up to shallow depth and some part of this site is thoroughly liquefiable from starting depth, according to thorough site investigations,

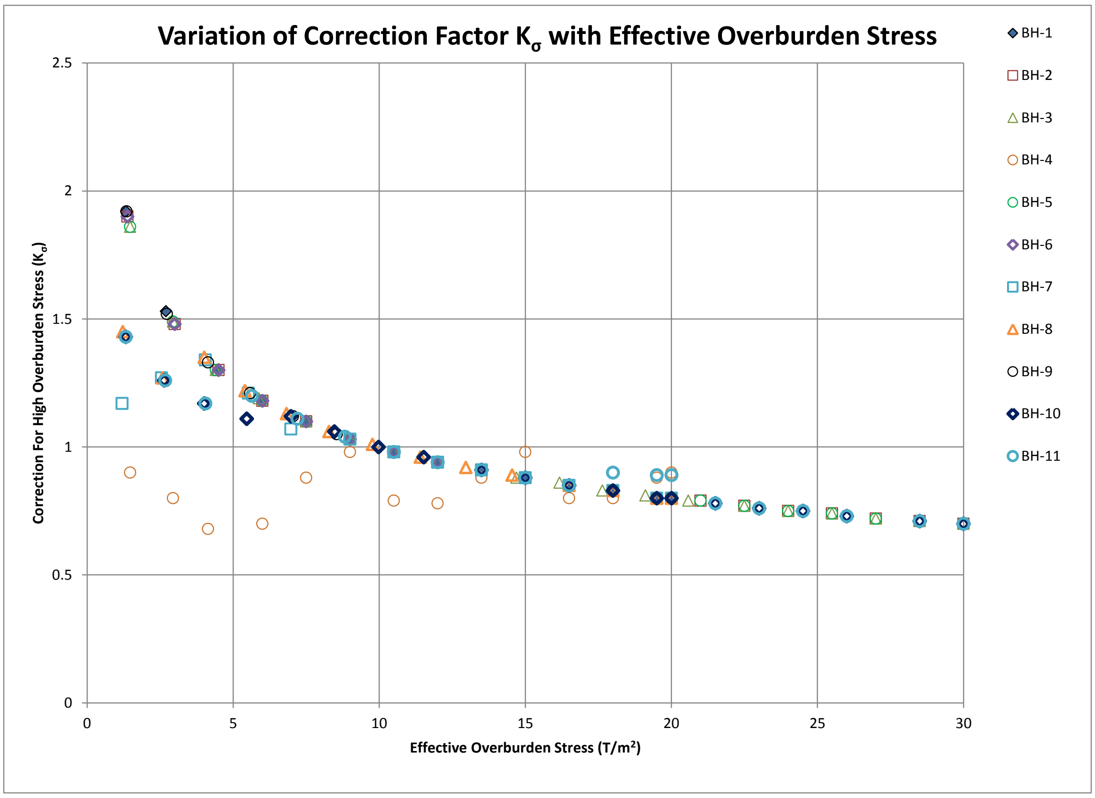

Figure. 8. Adjusting the effective overburden pressure with respect to the correction factor K_σ

According to Figure 9, the findings of laboratory tests on soil samples for grain size analysis have demonstrated that the fine content significantly decreases with depth. Non-plastic soils have been reported to liquefy, which suggests that grain size analysis influences but does not entirely determine a region's vulnerability to liquefaction. This means that, in the mining dump area, liquefaction is not confined to just sands, whether they are coarse or fine-grained; clayey soil may also liquefy under specific conditions.

The likelihood of liquefaction is lower in the majority of the study area up to certain

laboratory tests on samples obtained from various location of mining dump area of Nagpur, and data analysis for various parameters. So, it can be said that the mining dump area of Nagpur region is not fully safe from the risk of liquefaction. However, in order to assess the potential for liquefaction, a thorough and site-specific examination is needed.

It can also be said that by using the information from this study, the waste computations needed by using codes can be avoided, and the site-specific liquefaction potential may be quickly assessed with the use of graphs created by thorough inquiry and laboratory testing.

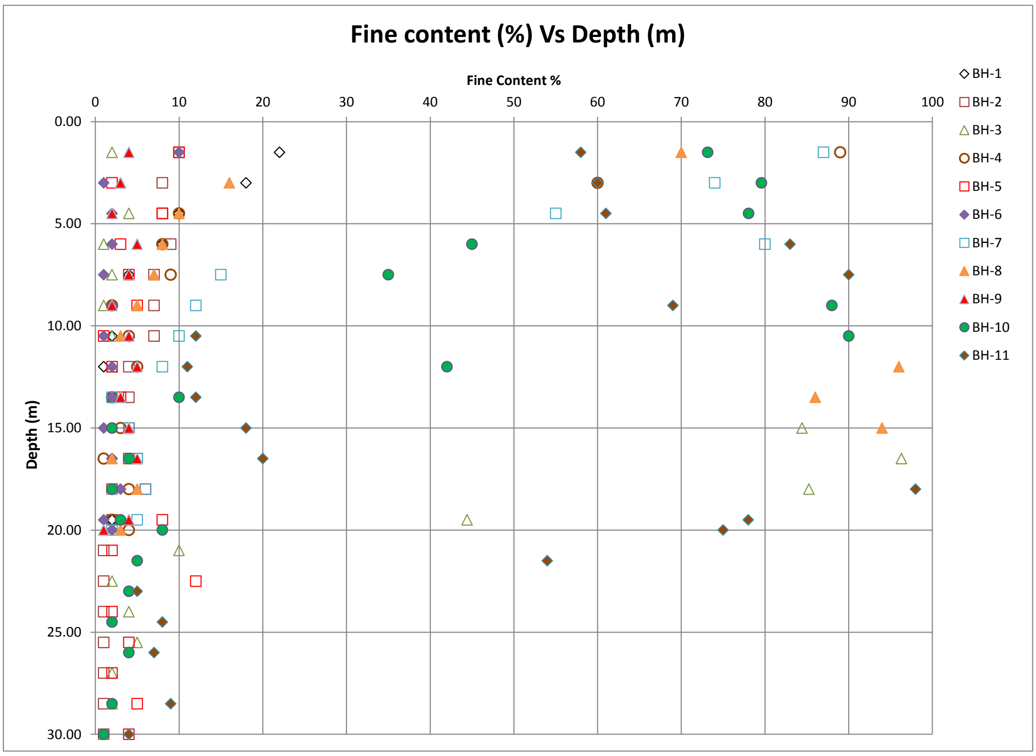

Figure. 9. Depth and fine content relation

9. Conclusion

Considering the aforementioned studies and findings, it can be inferred that studied mining dump area of Nagpur region is not fully safe for the event of liquefaction, even though some regions are vulnerable. Using the graphs and tables provided in this paper, site-specific evaluation of liquefaction potential for all types of soil found at a specific place in area should be possible.

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