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Analysis and Statistical Assessment of Liquefaction Potential Using SPT-N Approach in Bhandara Region Maharashtra: Implications for Infrastructure Development

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Abstract:

The Bhandara area in Maharashtra, India, has a lot of earthquakes, so its liquefaction potential needs to be studied in detail to help with building infrastructure. This research uses the Standard Penetration Test (SPT-N) method to check how easily the dirt in the area can become liquefied. When SPT-N numbers are added to soil qualities and seismic factors, they are used to figure out how likely it is that the ground will liquefy when it is loaded with earthquake energy. Different types of dirt and different levels are more or less likely to liquefy, according to the results. The makeup of the soil, the level of the groundwater table, and the history of earthquakes are some of the most important things that affect the liquefaction potential. The study finds places where there is a high risk of liquefaction that are also expected to have big building projects. These results make it clear how important it is to include liquefaction mitigating measures when designing and building roads, houses, and other important infrastructure to make sure it is safe and strong. The study also gives a plan for future earthquake risk ratings in the area, showing how important it is to keep an eye on and update records of soil data and earthquakes. Using the SPT-N method along with current geotechnical and earthquake analysis methods, this study gives a full picture of the area's liquefaction risk. The results have big effects on the growth of infrastructure because they help engineers and managers make smart choices about how to lower risks, improve design, and make infrastructure in the Bhandara region last longer and be safer. In the larger field of geotechnical engineering and crisis preparation, this study adds to it by showing how important specific studies are for building strong infrastructure in areas that are prone to earthquakes.

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

1. Introduction

Soil liquefaction caused by earthquakes can do a lot of damage to civil engineering buildings. A lot of big earthquakes have caused damage to the ground by liquefying it. Some examples are off the coast of Ecuador in 1906, Assam-Tibet in 1950, Alaska in 1964, Niigata in 1964, Loma Prieta in 1989, Kobe in 1995, Sumatra in 2005, Chile in 2010, and Sendai in 2011. Since then, many people around the world have worked hard to learn more about soils and figure out how easily they can turn into liquid using a variety of experimental and analytical methods. These efforts show how important it is to know how the qualities of the soil and the way earthquakes happen affect how badly the soil liquefies in areas that are prone to earthquakes.

A lot of people have died and a lot of damage has been done to both low-rise and high-rise buildings by these disasters. For organized urban planning to work, geotechnical studies of an area's earthquake possibilities are needed. To make sure people are safe and progress is made, it is important to know how natural disasters like earthquakes, floods, and subsidence affect the built environment. People are moving to cities and factories, which is causing Bhandara, which is in the eastern part of Maharashtra State and close to the middle of India, to grow. Because of movement, the city is getting a lot of new facilities and more places for people to live. In this situation, it is important to look at the liquefaction risks that might come up after an earthquake. Using SPT-N values and geotechnical studies, this paper looks at the liquefaction potential of empty places in the Bhandara region. The results and conclusions of these studies will be very important for figuring out how dangerous things are and where liquefaction could happen. It is a well-known fact that sandy and coarse-grained sands are more likely to melt. In the past, it was thought that liquefaction only happened in sands. However, silty and clayey soils also make evaluating liquefaction very difficult. The Kocaeli (Turkey) and Chi-Chi (Taiwan) earthquakes in 1999 liquefied compact soils, which caused some buildings to drop and weak supports to stop holding weight. Also, fine-grained sands that meet Chinese standards may be very likely to lose a lot of strength. Because of this, all the types of dirt that were found during the investigation were tested for their ability to liquefy in this study. To look at the underlying rock and find the liquefaction factor of safety, different types of soil were tested. The study's main goal is to give useful information about the liquefaction risk in the Bhandara area. This is important for making sure that built buildings are safe and for long-term urban growth.

2. Background

The Bhandara region in Maharashtra, India, is very interesting because it is prone to earthquakes, which could damage buildings and other structures. Geology and soil conditions in the area make it important to know a lot about liquefaction potential to make sure that buildings, roads, and other important structures are safe and last a long time. Liquefaction is when wet soil loses a lot of its strength and stiffness in response to stress, like an earthquake. It can cause the ground to break apart badly and damage buildings. The Standard Penetration Test (SPT-N) is a well-known way to check the qualities of dirt and see how likely it is to liquefy. The SPT-N figure tells us a lot about the density and power of the soil because it shows how many hits are needed to break through a standard-sized piece of soil. These numbers, along with other structural factors, are very important for figuring out how resistant the soil is to liquefaction. Studies in the past have shown how important it is to know about the local soil conditions and how earthquakes can change the liquefaction potential. Some studies have been done on specific sites in the Bhandara area, though, to get more accurate risk estimates and more thorough information. This study tries to fill in that gap by using a lot of site and lab data to look at the liquefaction possibilities in different parts of the area.

The goal of this study is to give a full picture of the region's ground stability by combining the SPT-N method with current analysis methods. The results are meant to help with building infrastructure and putting in place safety steps that will make buildings stronger in this earthquake-prone area. Not only does this method help make local infrastructure safer and last longer, it can also be used as a model for similar tests to be done in other places with similar earthquake and ground conditions.

3. Area of Study

The location for infrastructure development in bhandara region of Maharashtra. It lies around 21.061218 latitude, 79.575455 longitude. The study area is shown in Fig. 1 below.

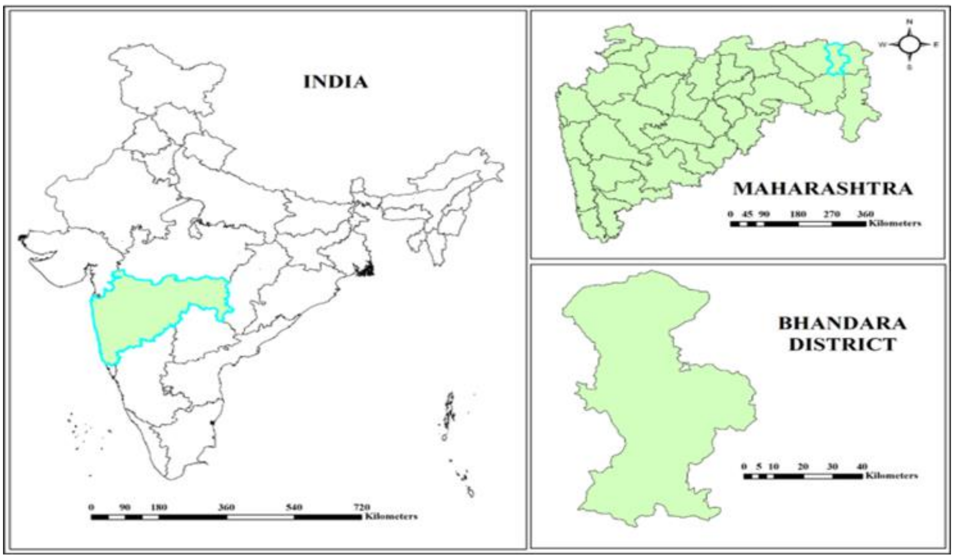

Fig 1:- Representation Research study area

4. Geographic Location of Study Area

Bhandara is located in the north-east part of Maharashtra, between 20°38' and 21°36' north latitude and 79°27' to 80°06' east longitude. The district covers a total area of 4087 square kilometres and is part of Survey of India degree sheets 55O, 55P, 64C, and 64D.

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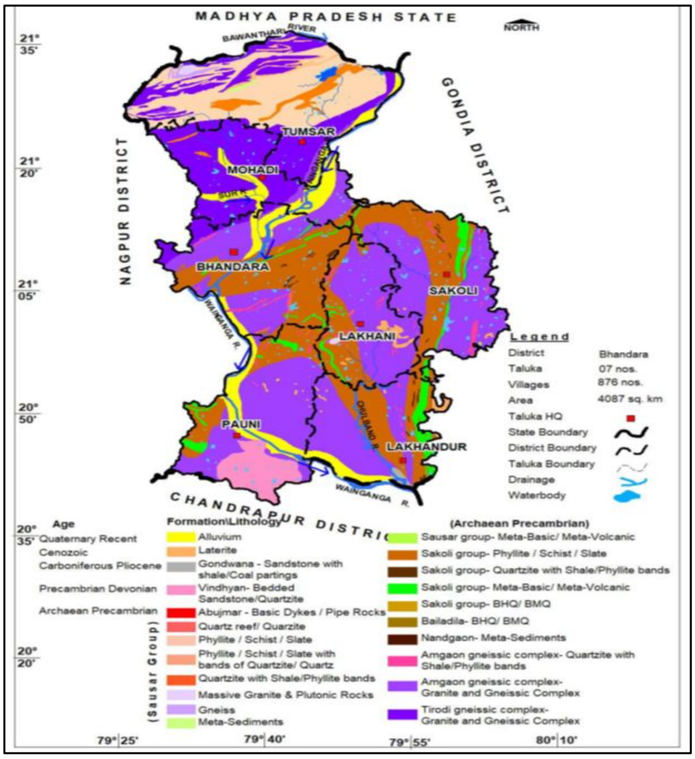


Fig. 2:- Geology of Bhandara District

Bhandara district is unique in Maharashtra since it is entirely made up of metamorphic and igneous rocks, shown in fig 2.

5. Ground water table

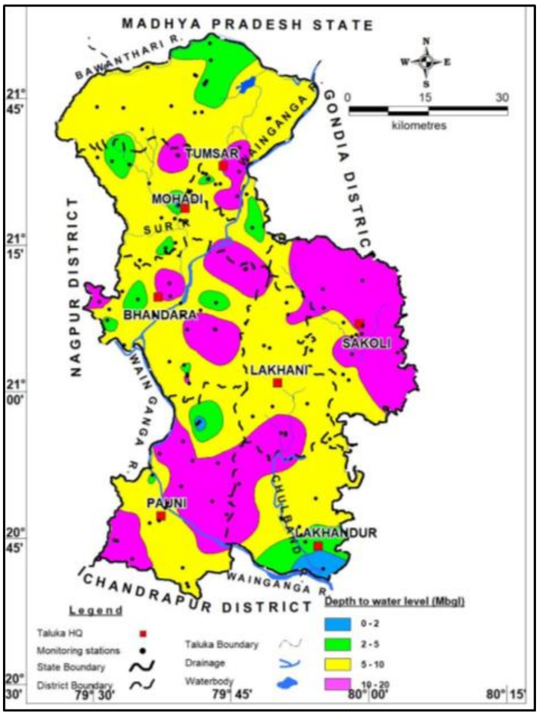


Fig. 3:- Depths of Ground water table of Bhandara District

Ground water table is fluctuating as the seasonal variations, bust as shown in fig.3. GWT ranges from ground level to maximum up to 20 m. This study's liquefaction analysis relied on observed groundwater tables for inland areas, but for river and bridge sites, the worst-case scenario with GWT reaching the surface was considered.

6. Geotechnical investigation and Data collection

This study gathered data on SPT, laboratory tests, and groundwater table levels from actual field geotechnical investigation work. We obtained 10 borehole data from 10 places from study area. Most geotechnical investigations have been limited to depths between 35.0. Fig. 4 shows the borehole sites. Geotechnical investigations are conducted in areas around bhandara to evaluate the region's subsurface lithology and stratified profile. A total of 10 boreholes of 35.0 m. depths were drilled in different places as indicated on the map in Fig. 4.

Fig. 4:- Borehole locations for the research in Bhandara District.

7. Characterization of soil

Laboratory test parameters were analyzed to assess the soil characteristics of the soils. The soil type of 10 boreholes was determined using the Indian Standard Classification System.

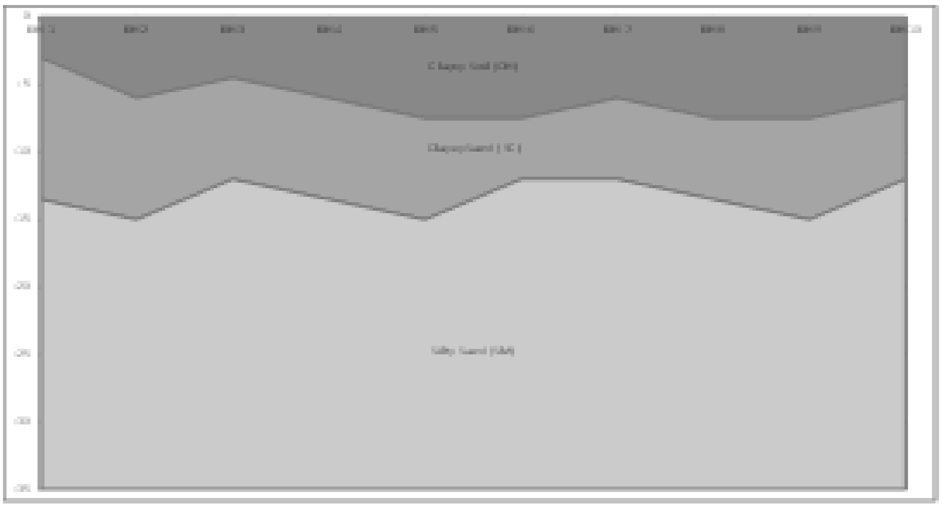


Fig. 5:- Geological profile for the study area

Testing was done on clayey sand up to 14.00 m then hard silty sandy strata is present till final depth of 35.0 m and is represented in the geological profile below in Fig 5.

8. Assessment of liquefaction potential

In this section methodology adopted for evaluation of liquefaction potential is explained. The water table's location, the SPT blow count, and the fines content of the soil met at a definite depth are among the data needed to define the vulnerability to liquefaction.

- **Analysis and Assessment of Liquefaction Potential Using SPT-N Approach**

$Step$ 1: $Correct\ SPT - N\ Values$

1. $Overburden\ Stress\ Correction\ (N_{160})$:

$$(N^1)^{60} = N \times C_N \times C_E \times C_S \times C_B \times C_R$$

$where$:

$- N = observed\ SPT\ blow\ count$

$- C\_N = correction\ factor\ for\ overburden\ stress$

$- C\_E = correction\ factor\ for\ energy\ ratio$

$- C\_S = correction\ factor\ for\ borehole\ diameter$

$- C\_B = correction\ factor\ for\ rod\ length$

$- C\_R = correction\ factor\ for\ sampler\ type$

$Step$ 2: $Overburden\ Stress\ Correction\ Factor\ (C\_N)$

2. $Correction\ Factor\ (C\_N)$:

$$C_N = \left(\frac{P_a}{\sigma'_{\{vo\}}}\right)^{\{0.5\}}$$

$where$:

$- P\_a = atmospheric\ pressure\ (typically\ 100\ kPa)$

$- \sigma'\_\{vo\} = effective\ overburden\ stress$

$Step$ 3: $Cyclic\ Stress\ Ratio\ (CSR)$

3. $Cyclic\ Stress\ Ratio\ (CSR)$:

$$CSR = 0.65 \times \left(\frac{\tau_{\{max\}}}{\sigma'_{\{vo\}}}\right)$$

$where$:

$$- \tau_{\{max\}} = 0.65 \times a_{\{max\}} \times \frac{\sigma_{\{vo\}}}{ga}\_$$

$-\{max\} = peak\ ground\ acceleration$

$- \sigma\_\{vo\} = total\ vertical\ overburden\ stress$

$- g = acceleration\ due\ to\ gravity$

$Step$ 4: $Cyclic\ Resistance\ Ratio\ (CRR)$

4. $Baseline\ CRR\ Equation$:

$$CRR_{\{7.5\}} = \frac{1}{(34 - (N^1)^{60})}$$

$Step$ 5: $Magnitude\ Scaling\ Factor\ (MSF)$

5. $Magnitude\ Scaling\ Factor\ (MSF)$:

$MSF = 10^{\{(\frac{-2.24}{M_w - 2.56})\}}$
$where:$
$- M\_w = moment\ magnitude\ of\ the\ earthquake$
$Step\ 6: Adjusted\ CRR$
$6. Adjusted\ CRR\ for\ Magnitude\ (CRR):$
$CRR = CRR_{\{7.5\}} \times MSF$
$Step\ 7: Factor\ of\ Safety\ (FS)$
$7. Factor\ of\ Safety\ against\ Liquefaction:$
$$FS = \frac{CRR}{CSR}$$
$Step\ 8: Integration\ for\ Overburden\ Stress$
$8. Effective\ Overburden\ Stress\ (\sigma'\_\{vo\}):$
$$\sigma'_{\{vo\}} = \int_0^z (\gamma - \gamma_w) dz$$
$where:$
$- \gamma = unit\ weight\ of\ the\ soil$
$- \gamma\_w = unit\ weight\ of\ water$
$- z = depth$
$Step\ 9: Calculation\ of\ Peak\ Ground\ Acceleration\ (PGA)$
$9. Peak\ Ground\ Acceleration\ (PGA):$
$a\_\{max\} = F \times S \times Z \times T$
$where:$
$- F, S, Z, T$
$= factors\ depending\ on\ site\ characteristics, soil\ type, and\ seismic\ zone$
$Step\ 10: Correction\ for\ Fines\ Content\ (FC)$
$10. Correction\ for\ Fines\ Content:$
$$(N^1)^{60} cs = (N^1)^{60} \times \left(1 + \frac{FC}{100}\right)$$
$where:$
$- FC = fines\ content\ in\ percentage$
$Step\ 11: Derivative\ for\ Overburden\ Stress\ Correction$
$11. Derivative\ of\ Overburden\ Stress\ Correction\ (for\ sensitivity\ analysis):$
$$\frac{d(C_N)}{d(\sigma'_{\{vo\}})} = -0.5 \times \frac{P_a^{\{0.5\}}}{\sigma'^{\{1.5\}}_{\{vo\}}}$$
$Step\ 12: Simplified\ Integration\ for\ CSR\ over\ Depth$
$12. Integrated\ CSR\ over\ Depth:$
$$CSR_{\{avg\}} = \int_0^D \left(0.65 \times \frac{\tau_{\{max\}(z)}}{\sigma'_{\{vo\}(z)}}\right) dz$$
$where:$
$- D = depth\ of\ interest$

When the PGA value is unavailable, (a_{max}/g) might be assumed to be equivalent to the seismic zone factor Z. Considering that this is stated in IS 1893 (Part 1):2016 and that Nagpur is located in zone II on the seismic zoning map of India, this liquefaction potential assessment uses (a_{max}/g) = 0.10.

The final corrected SPT-N value and other parameters of the soil under research, such as fine content (FC), are used to calculate the Cyclic Resistance Ratio (CRR) using the following expressions. For an earthquake of magnitude of M_w=7.5, a high overburden stress level, and a high initial static shear stress, CRR must be adjusted to the comparable uniform shear stress.

$$CRR = CRR\,7.5\,(MSF)\,K\sigma\,K\alpha$$

Where,

CRR $_{7.5}$ = CRR for an earthquake of magnitude 7.5 calculated using SPT data

MSF = magnitude scaling factor and can be calculated as follows

$$MSF = \left(\frac{102.24}{MW2.56}\right)$$

K_σ = Correction for high overburden stress , when depth of assessment is greater than 15 m, then correction for high overburden stresses is required and can be calculated as below;

$$K\sigma = \left(\sigma'\frac{vo}{Pa}\right)(f-1)$$

Where, P_a = atmospheric pressure and f = exponent that is depending on the relative density Dr and when D_r is in between 40% to 60% then f will be 0.8 to 0.7 and when D_r is in between 60% to 0% then f will be 0.7 to 0.6

Examining the SPT-N number and relative density correlations, the values for Dr are tabulated as follows in Table 1 based on field N number. In a laboratory, relative density cannot be determined from the SPT samples because it requires sufficient samples.

Table 1. Relative density and SPT-N values.

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

K_α = is only necessary for sloping terrain and is not essential for standard engineering practice; as a result, this value is taken to be 1 for the purposes of this work.

Numerous adjustments and corrections are needed for filed N_{60} for hammer efficiency of 60% in order to calculate the CRR value based on the field SPT-N value as N_{60}=NC_{60}. As per IS 1893 (Part 1) : 2013 if Non-standard method is used for conducting SPT then corrections will be require as given in clause F-1, Step:6(a) and Table 12 of IS 1893 (Part 1) : 2013. But in this research work standard method is adopted for conducting SPT hence no corrections is required and C_{60} = 1 is considered. Further it required normalizing this computed N_{60} value with effective overburden pressure, as$(N1)60 = CNN60$. Here C_N is effective overburden correction factor and can be found as,

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

The graph in Fig.8 of IS 1893 (Part 1): 2013, which is based on the $(N_1)_{60}$ value for a specific percentage of FC, can be used to calculate $CRR_{7.5}$ for M_W = 7.5. Since M_W=7.0 is taken into account in this study and the fine contents differ from what is specified in the code, further calculations are made in order to increase the correctness and dependability of the findings and research. By discovering $(N_1)_{60CS}$ and correlating $(N_1)_{60}$, it is reasonable to explain the effect of FC in percent in the following way.

$$(N1)60CS = \alpha + \beta\,(N1)60$$

Where, values and conditions for α & β is given in IS IS 1893 (Part 1): 2013

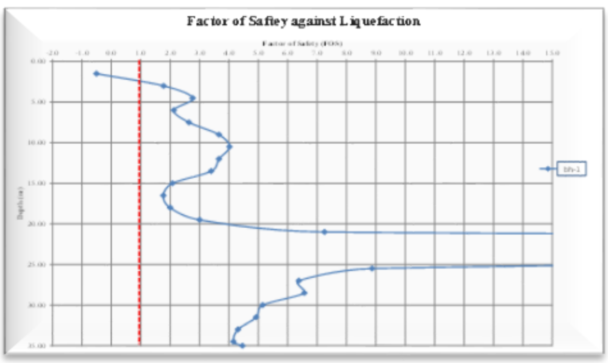
Figure.8 of IS 1893 (Part 1): 2013 can be utilised in estimation of $CRR_{7.5}$, with $(N_1)_{60CS}$ being used in place of $(N_1)_{60}$ and just the SPT clean sand based curve being utilised, regardless of the amount of particles. However, it is not required to meet clean sand every time; hence, the $CRR_{7.5}$ is determined using the equation below.

$$CRR7.5 = \frac{1}{34-((N1)60CS} + \frac{(N1)60CS}{135} + \frac{50}{[10X(N1)60CS+45]^2} + \frac{1}{200}$$

The examination of liquefaction susceptibility results is presented as a factor of safety (FS) concern and is calculated as

$$FS = \frac{CRR}{CSR.}$$

It is considered that soil is liquefiable if FS<1. The soil is assumed to be marginally liquefiable when the FS is between 1.1 and 1.2, and not liquefiable when the FS is more than 1.2. The findings of the liquefaction study utilizing the aforesaid methodology are assessed for FS vs Depth in Figure 6, and $(N_1)_{60}$ vs CSR in Fig. 8, which specifies the liquefiable condition. Additionally, r_d vs Depth in Fig. 9 and σ'_{vo} vs K_σ is analyzed in Fig.10



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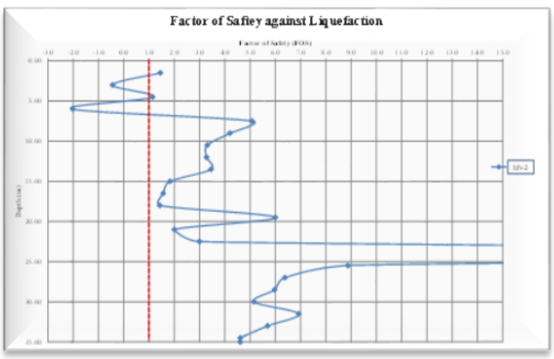

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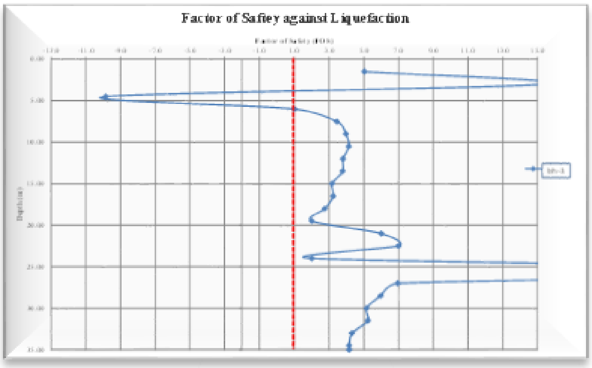

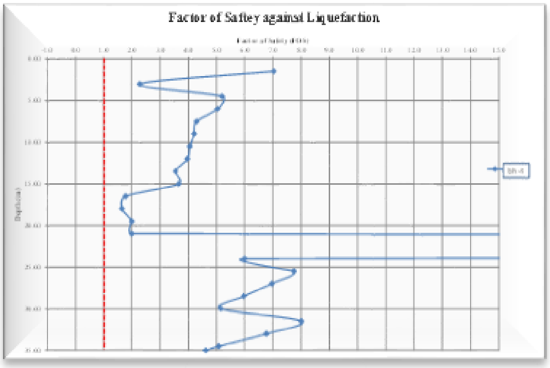

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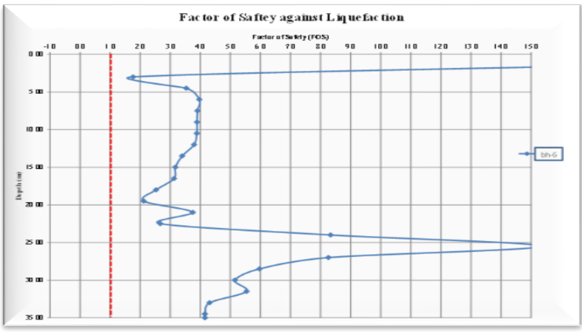

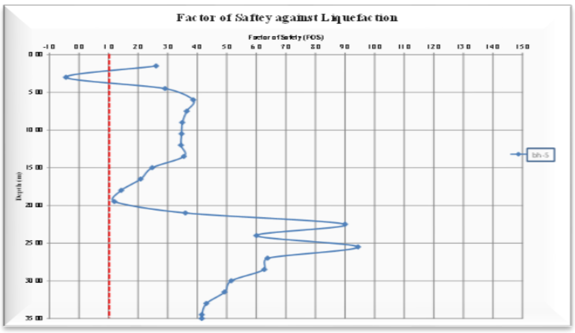

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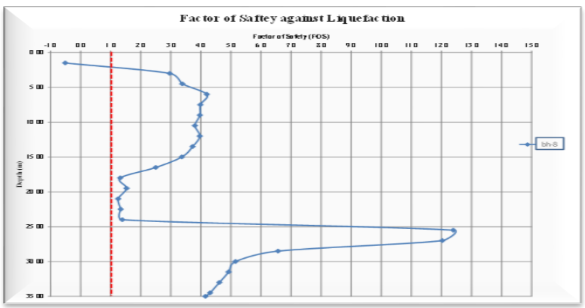

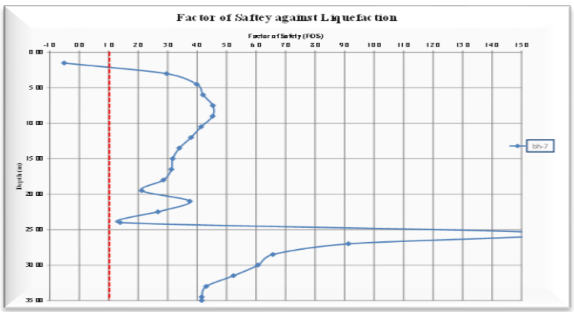

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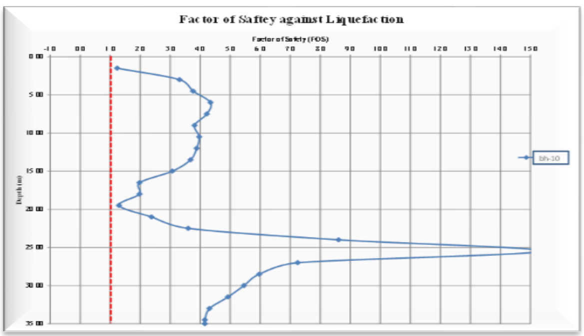

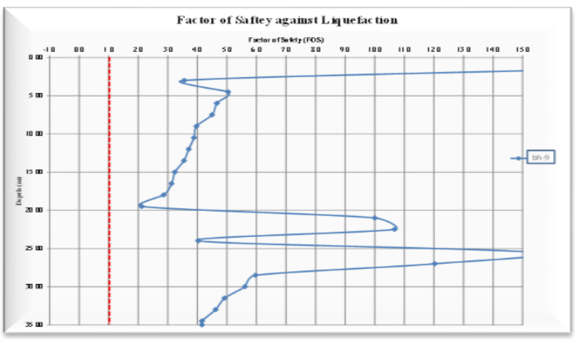

(9) (10)

Fig. 6 Different study factor in depth

9. Calculation of liquefaction potential

An example location from the entire study region was chosen to elaborate on the computation of liquefaction calculations, as shown in Fig. 4. This detailed analysis is crucial for understanding the specific conditions and risks associated with this site. The borehole (BH-1) data provides a comprehensive profile of the soil stratification, including SPT-N values, which are fundamental to assessing liquefaction potential.

- Soil Stratification and SPT-N Values

The soil stratification at this location, as illustrated in Fig. 7, includes three distinct layers:

Clayey Soil: The uppermost layer, characterized by lower SPT-N values, indicating a relatively loose and potentially less stable soil structure.

Sandy Silty Soil: This intermediate layer exhibits varying SPT-N values, reflecting changes in density and composition. Sandy silty soils are particularly susceptible to liquefaction due to their granular nature and the presence of fine particles.

Rock Strata: The deepest layer consists of rock, which provides a stable foundation and typically has high SPT-N values, indicating high resistance to penetration and low liquefaction susceptibility.

- Liquefaction Potential Assessment

The Factor of Safety (FOS) with respect to liquefaction potential is a critical metric used in this assessment. For an earthquake magnitude of MW=7.0, the calculation at BH-1 involves several steps:

Determine Cyclic Stress Ratio (CSR): CSR is calculated using the earthquake magnitude, site-specific seismicity, and overburden pressure. It represents the shear stress induced by the earthquake.

Calculate Cyclic Resistance Ratio (CRR): CRR is derived from the SPT-N values, considering soil type and depth. It indicates the soil's capacity to resist liquefaction.

Compute Factor of Safety (FOS): The FOS is the ratio of CRR to CSR. A FOS greater than 1.0 implies that the soil can resist liquefaction, while a FOS less than 1.0 indicates potential liquefaction.

- Detailed Results at BH-1

Clayey Soil Layer: The SPT-N values in this layer are relatively low, leading to a lower CRR. Given the CSR induced by an MW=7.0 earthquake, the FOS may be close to or less than 1.0, suggesting a potential risk of liquefaction.

Sandy Silty Soil Layer: This layer shows variability in SPT-N values. Zones with lower SPT-N values have a higher risk of liquefaction, especially if the CRR is insufficient to counteract the CSR. The FOS in these zones can be less than 1.0, highlighting areas of concern.

Rock Strata: With high SPT-N values, the CRR is significantly higher than the CSR, resulting in a FOS much greater than 1.0. This indicates no risk of liquefaction in this layer.

$Calculation\ of\ Liquefaction\ Potential$

$Step\ 1: Calculation\ of\ Cyclic\ Stress\ Ratio\ (CSR)$

$1. Cyclic\ Stress\ Ratio\ (CSR):$

$CSR\ =\ 0.65\ \times\ (\tau\_\{max\}\ /\ \sigma'\_\{vo\})$

$where:$

$-\ \tau\_\{max\}\ =\ 0.65\ \times\ a\_\{max\}\ \times\ \sigma\_\{vo\}\ /\ g$

$-\ a\_\{max\}\ =\ peak\ ground\ acceleration$

$- \sigma\_\{vo\} = total\ vertical\ overburden\ stress$
$- \sigma'\_\{vo\} = effective\ overburden\ stress$
$- g = acceleration\ due\ to\ gravity$
$Step\ 2: Calculation\ of\ Cyclic\ Resistance\ Ratio\ (CRR)$
$2. Baseline\ CRR\ Equation:$
$CRR\_\{7.5\} = 1 / (34 - (N_1)_{60})$
$where:$
$- (N_1)_{60} = corrected\ SPT\ blow\ count$
$Step\ 3: Magnitude\ Scaling\ Factor\ (MSF)$
$3. Magnitude\ Scaling\ Factor\ (MSF):$
$MSF = 10\text{^}(-2.24 / M\_w - 2.56)$
$where:$
$- M\_w = moment\ magnitude\ of\ the\ earthquake$
$Step\ 4: Adjusted\ Cyclic\ Resistance\ Ratio\ (CRR)$
$4. Adjusted\ CRR\ for\ Magnitude\ (CRR):$
$CRR = CRR\_\{7.5\} \times MSF$
$Step\ 5: Factor\ of\ Safety\ (FS)\ against\ Liquefaction$
$5. Factor\ of\ Safety\ against\ Liquefaction:$
$FS = CRR / CSR$

Example Calculation:
Given:
- Observed SPT blow count N = 20
- Overburden correction factor C_N = 1.2
- Peak ground acceleration a_{max} = 0.3g
- Total vertical overburden stress σ_{vo} = 100 kPa
- Effective overburden stress σ'_{vo} = 80 kPa
- Moment magnitude of the earthquake M_w = 7.5

Step-by-Step Calculation:
1. Corrected SPT-N Value:
$(N^1)^{60} = N \times C_N = 20 \times 1.2 = 24$
2. Cyclic Stress Ratio (CSR):
$\tau_{\{max\}} = 0.65 \times a_{\{max\}} \times \sigma_{\{vo\}} = 0.65 \times 0.3 \times 100$
$= 19.5\ kPa$R = 0.65 × (19.5 / 80) = 0.158

3. Cyclic Resistance Ratio (CRR):
CRR_{7.5} = 1 / (34 - 24) = 1 / 10 = 0.1
4. Magnitude Scaling Factor (MSF):
MSF = 10^(-2.24 / 7.5 - 2.56) ≈ 1 (for M_w = 7.5, MSF is often considered as 1)
5. Adjusted CRR:
CRR = CRR_{7.5} × MSF = 0.1 × 1 = 0.1
6. Factor of Safety (FS):

FS = CRR / CSR = 0.1 / 0.158 ≈ 0.63

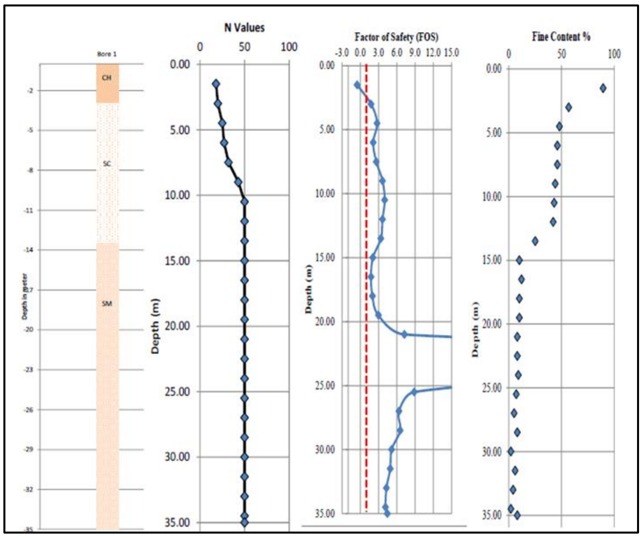

Fig. 7 Representation of soil layers, Standard Penetration Test (SPT) N-values, Factor of Safety (FOS) against liquefaction

10. Result and Discussions:-

10.1 Soil Characterization

In study locations, 10 boreholes were bored to a depth of 35.0 m. A typical penetration test was performed each 1.5 m up to this depth. SPT-N results varying from 11 to above 50 (refusal). Bhandara soils are predominantly Clayey soils followed by coarse-grained (sand and gravel) with tiny amounts of silt and fine clay, forming alluvial deposits. The thickness of these layers varies significantly. Non-plastic inorganic silts were discovered in an every location after clayey soils. The majority of the coarse-grained component is classified as SM. Fine-grained soils have plasticity indexes ranging from 7.81 to 21.48%, with most falling within the 20% to 22% range. The 10 drilling logs revealed that the majority of the water table was within 0-5 m of the ground surface. The presence of granular soil and a near-surface water table can lead to liquefaction during earthquakes. Fig 5 shows typical soil profiles from four locations in the Bhandara region where the study is conducted. The image shows varied soil layers with a significant concentration of sand and gravel

Depth Below EGL, m	Type of Strata	Observed SPT value	Fine Content (%)	Stress reduction factor (r_d)	Saturated density (gm/cc)	Vertical Overburden Stress (σ_{vo}) (t/m^2)	Effective Vertical Overburden Stress (σ'_{vo}) (t/m^2)	Cyclic Stress Ratio CSR	C_N	N_{60}	Corrected SPT $(N_1)_{60}$	$(N_1)_{60CS}$	$CRR_{7.5}$	Relative density, Dr%	f	K_σ	Magnitude scaling factor MSF	Cyclic Resistance Ratio CRR	FOS	Discription
1.5	CH	18	89	0.989	1.87	2.805	1.305	0.138	1.7	18	30.6	37.22	-0.04	35	0.83	1.43	1.19	-0.07	-0.5	Liquefiable
3.0	CH	20	56	0.977	1.89	5.67	2.67	0.135	1.7	20	34	41.3	0.16	35	0.83	1.26	1.19	0.24	1.8	Non Liquefiable
4.5	S	25	48	0.9	1.9	8.73	4.23	0.1	1.5	25	38.	46.	0.2	35	0.8	1.1	1.1	0.3	2.8	Non

Depth Below EGL, m	Type of Strata	Observed SPT value	Fine Content (%)	Stress reduction factor (r_d)	Saturated density (gm/cc)	Vertical Overburden Stress (σ_{vo}) (t/m^2)	Effective Vertical Overburden Stress (σ'_{vo}) (t/m^2)	Cyclic Stress Ratio CSR	C_N	N_{60}	Corrected SPT $(N_1)_{60}$	$(N_1)_{60CS}$	$CRR_{7.5}$	Relative density, Dr%	f	K_σ	Magnitude scaling factor MSF	Cyclic Resistance Ratio CRR	FOS	Discription
	C			66	4			3	4		5	7	6		3	6	9	6		Liquefiable
6.0	SC	27	46	0.954	1.95	11.7	5.7	0.127	1.32	27	35.64	43.27	0.21	35	0.83	1.1	1.19	0.27	2.1	Non Liquefiable
7.5	SC	32	46	0.943	1.96	14.7	7.2	0.125	1.18	32	37.76	45.81	0.25	65	0.68	1.11	1.19	0.33	2.6	Non Liquefiable
9.0	SC	43	44	0.931	1.97	17.73	8.73	0.123	1.07	43	46.01	55.71	0.36	65	0.68	1.05	1.19	0.45	3.7	Non Liquefiable
10.5	SC	50	43	0.894	1.98	20.79	10.29	0.117	0.99	50	49.5	59.9	0.4	65	0.68	0.99	1.19	0.47	4.0	Non Liquefiable
12.0	SC	50	42	0.854	1.99	23.88	11.88	0.112	0.92	50	46	55.7	0.36	65	0.68	0.95	1.19	0.41	3.7	Non Liquefiable
13.5	SC	50	25	0.814	1.99	26.865	13.365	0.106	0.86	50	43	52.45	0.33	65	0.68	0.91	1.19	0.36	3.4	Non Liquefiable
15.0	SM	50	10	0.774	1.99	29.85	14.85	0.101	0.82	50	41	42.69	0.2	65	0.68	0.88	1.19	0.21	2.1	Non Liquefiable
16.5	SM	50	12	0.733	1.99	32.835	16.335	0.096	0.78	50	39	41.72	0.17	65	0.68	0.85	1.19	0.17	1.8	Non Liquefiable
18.0	SM	50	10	0.693	1.99	35.82	17.82	0.091	0.75	50	37.5	39.12	0.09	65	0.68	0.83	1.19	0.09	2.0	Non Liquefiable
19.5	SM	50	10	0.653	1.99	38.805	19.305	0.085	0.72	50	36	37.59	0.09	65	0.68	0.81	1.19	0.09	3.0	Non Liquefiable
21.0	SM	50	8	0.613	1.99	41.79	20.79	0.08	0.69	50	34.5	35.14	0.62	65	0.68	0.79	1.19	0.58	7.3	Non Liquefiable
22.5	SM	50	8	0.573	1.99	44.775	22.275	0.075	0.67	50	33.5	34.13	7.44	65	0.68	0.77	1.19	6.82	90.9	Non Liquefiable
24.0	SM	50	9	0.552	1.99	47.76	23.76	0.072	0.65	50	32.5	33.71	3.69	65	0.68	0.75	1.19	3.29	45.7	Non Liquefiable
25.5	SM	50	7	0.54	1.99	50.745	25.245	0.071	0.63	50	31.5	31.94	0.72	65	0.68	0.74	1.19	0.63	8.9	Non Liquefiable
27.0	SM	50	5	0.528	1.99	53.73	26.73	0.069	0.61	50	30.5	30.5	0.51	65	0.68	0.73	1.19	0.44	6.4	Non Liquefiable
28.5	SM	50	8	0.516	1.99	56.715	28.215	0.067	0.6	50	30	30.6	0.52	65	0.68	0.71	1.19	0.44	6.6	Non Liquefiable
30.0	SM	50	2	0.504	1.99	59.7	29.7	0.066	0.58	50	29	29	0.41	65	0.68	0.7	1.19	0.34	5.2	Non Liquefiable

Table 2. Sample calculation for liquefaction potential evaluation.

10.2 Liquefaction potential of the area:-

Given the importance of Bhandara, this study aims to map the study region in terms of liquefaction risk and provide data for technocrats to use in constructing structures and preventing liquefaction-related risks, as indicated in Table 3. The lithological differences acquired from 10 boreholes demonstrate that the study region contains distinct layers of soil types and gradations of gravels, sand, silt, and clay. The stratification seen in boreholes varies in thickness and shape depending on location.

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Table 3. Estimated FOS and Potential to Liquefaction.

BH No	Depth of liquefiable layer in meter	F.O.S	Description
BH-1	1.50	-0.5	Liquefiable
BH-2	3.00	0.4	Liquefiable
	4.50	1.1	Marginally Liquefiable
	6.00	-2.0	Liquefiable
BH-3	4.50	0.90	Liquefiable
	6.00	1.00	Marginally Liquefiable
BH-5	3.00	0.40	Liquefiable
BH-7	1.50	0.50	Liquefiable
BH-8	1.50	0.50	Liquefiable

Some layers of the bore hole in various sections of Bhandara under study were found to be sensitive to liquefaction; two of them showed marginal liquefaction activity, while six showed evidence of liquefaction potential. The depths of liquefaction layers vary depending on the stratification and this might be due to the existence of a significant amount of sand in that layer, but it is not limited to that; certain layers contain clay and exhibit liquefaction capabilities, as shown in Table 4. Many parameters were evaluated in this study to directly evaluate the liquefaction potential if an investigation is conducted and to reduce the time-consuming calculations. IS 1893 (Part 1):2016 provides a curve for estimating $CRR_{7.5}$, but this curve is limited to clean sand, which is not a condition in every location where clean sand is encountered. To overcome this, in this study, a curve is evolved as shown in Fig. 8, based on actual field and laboratory testing, and $CRR_{7.5}$ can be estimated directly for the bhandara region.

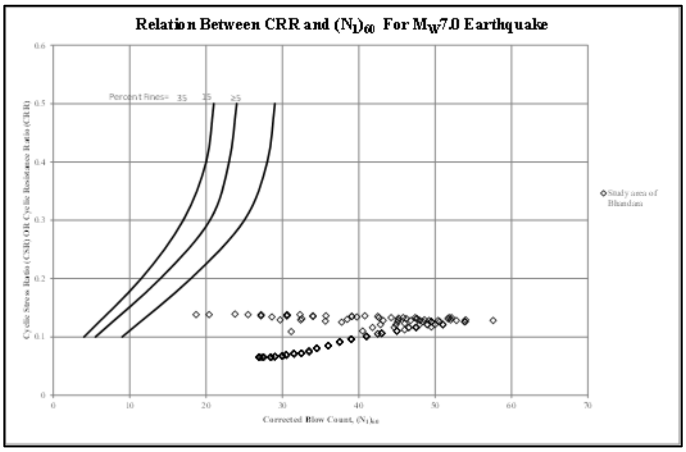

Fig. 8 Representation of Correlation for Earthquake

It was looked at up to a depth of 35 meters in this study, which is deeper than the 23-meter limit set by IS standards. Scholars have found different results when they try to connect rd and depth, which has led to different readings. The calculations here tried to make things clearer by increasing the depth range to 35 meters, as shown in Fig. 9. Figure 9 shows that as depth goes up, the stress reduction factor goes down. It is this drop in rd that causes the Cyclic Stress Ratio (CSR) to go down and the Factor of Safety (FOS) against liquefaction to rise. There is a clear trend in the graph. The rate of drop in rd is slower up to 20 meters, but then it speeds up. The research shows that the stress reduction factor decreases slowly up to 20 meters, but it becomes more noticeable after that. Inferring from this that deeper layers of dirt have much lower CSR makes them more resistant to liquefaction. This connection is very important for building infrastructure because it shows how important it is to do more in-depth soil studies to correctly figure out and lower the risks of liquefaction in areas that are prone to earthquakes.

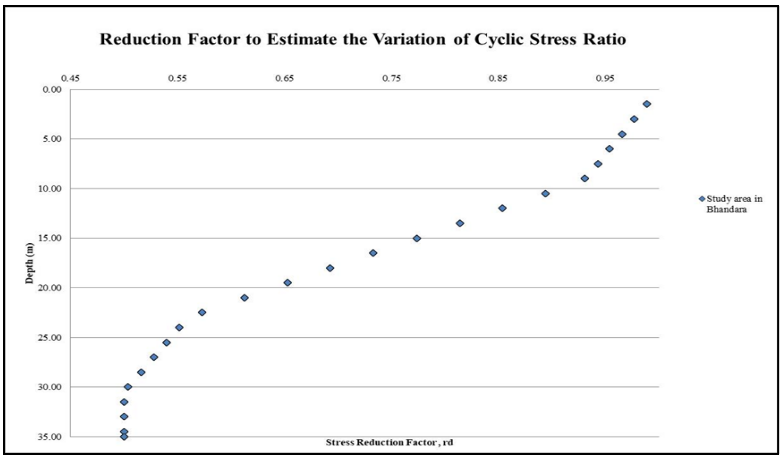

Fig. 9 Representation of depth rate factor

Stress too much Kπ is an adjustment factor for initial shear stress and effective top pressure. It changes depending on the type of soil and how dense and pressurized the air is. In this study, detailed data from both the site and the lab were used to figure out Kπ for each place. Figure 10 shows the connection between Kπ and effective overburden stress. It shows that as effective overburden stress rises, so does Kπ. This image makes it easier to figure out the liquefaction potential for the study area. This saves time and cuts down on the amount of data that needs to be collected to figure out Kπ, which makes risk estimates more accurate.

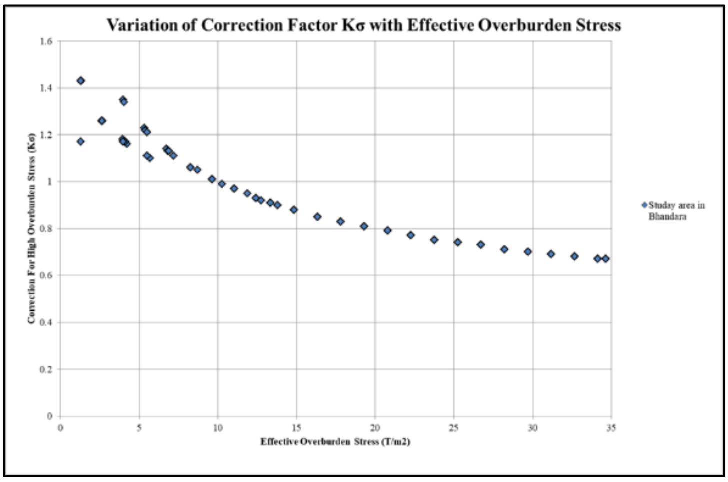

Fig. 10 Overview representation variation correlation factor

Laboratory test results on soil samples for grain size measurement demonstrate that as depth increases, fine content drops significantly, as illustrated in Fig. 11.

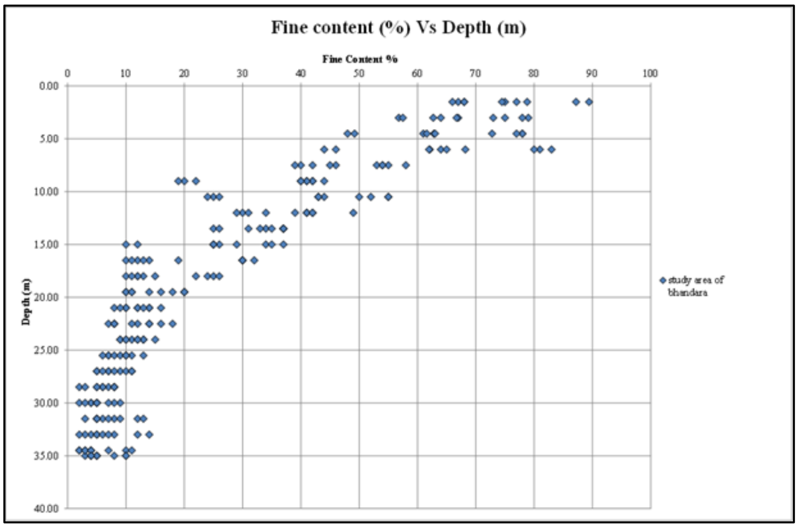

Fig. 11 Representation of Fine consent Vs depth

11. Conclusion

According to the Standard Penetration Test (SPT-N) method, this study gives a full look at the liquefaction potential in the Bhandara area of Maharashtra. The results show that liquefaction susceptibility varies a lot depending on the type of soil and how deep it is. The depth of the research was increased from the usual 35 meters set by IS standards. This study gives a better picture of the physical qualities of the area. The stress reduction factor (rd) study shows that rd drops slowly up to a depth of 20 meters, but drops more quickly after that. This means that in deeper layers, the Cyclic Stress Ratios (CSR) are lower and the Factors of Safety (FOS) against liquefaction are higher. This information is very important for correctly figuring out the risk of liquefaction and using it to build and create strong infrastructure. The study also stresses how important it is to look at overload stress Kπ in each place individually. We found the link between effective overload stress and Kπ by using thorough data from both the site and the lab. This gives us a useful way to quickly check the liquefaction potential. The connection graph speeds up math, cutting down on the need to collect large amounts of data and shortening the time it takes to evaluate danger. What this means for building up facilities is very important. Finding high-risk areas lets you take specific steps to protect buildings, like stabilizing the dirt, building deep foundations, and improving drains. This makes sure that buildings last and are safe. This localized assessment approach not only makes infrastructure in the Bhandara region more resistant to earthquakes, but it can also be used as a model for similar assessments of seismic risk in other places.

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