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LIQUEFACTION HAZARD MAPPING

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ABSTRACT

The study of Mapping of Liquefaction Potential Zonation involves many Geological, Geo-Hydrological, Geo-Morphological, Strength Parameters and Seismic Parameters. The detailed analysis for mapping covers all the above conditions and parameters as deciding factors. An effort has been made to produce realistic and detailed mapping based on all the parameters and details available. This is been very prelim study and mapping still requires finer analysis by adding more data. The work is been extended to smaller area and shall be extended to cover larger area of the study area.

The **Macro** level of investigation is an overlook to the Liquefaction **Susceptibility**. While, the **Micro** level of investigation provides the preliminary Liquefaction **Potentiality**. Further, the liquefaction potentiality thus identified shall be analyzed with respect to the area specific strength characteristic and seismic activity.

Keywords: Liquefaction, Zonation, Mapping, Susceptibility, Potential

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INTRODUCTION

Looking to the recent development and industrial growth of the Gujarat especially the coastal belts of Mundra, Dholera, Dahej, Hazira etc, it is a prime requirement of evaluating Seismic hazard possibilities. We have witnessed worst earthquake in Kachchh in the year 2001. Also, in present times we have observed increase in Seismic activities all over the world. So to face the challenges of nature we must be ready well in advance to protect our creations.

LIQUEFACTION HAZARD MAPPING

One of the major effects caused by earthquake is liquefaction phenomenon. Liquefaction leads to large failures of structures and devastating collapses in the form of sudden settlements, landslides/sudden drawdown of slopes, lateral spreading etc. Before preparing and studying mitigation ways for such failures it is required to understand ways and causes of failures. Liquefaction Zonation mapping avails us as a ready recknor to design the structures for its useful life.

Micro Zonation relates to the distribution of an area into smaller parts with respect to liquefaction potentiality. The study parameters are derived based on site specific strength parameters of the sub soil, its response to seismic forces. For this purpose study was carried out based on Borehole data, Geological, Geomorphological, Geohydrological and Seismological features. In this article maps are presented based on above features for liquefaction potential of soils.

LIQUEFACTION PHENOMENON:

"The phenomenon of pore pressure build-up following with the loss of soil strength is known as liquefaction (Committee on Earthquake Engineering, 1985)".

Study of Liquefaction potential zone has been broadly divided into three parts:

(A) **Macro geo engineering** features of the study area – This should be the base for the selection of area for **Liquefaction Susceptibility**.

a. Geology of the area,
b. Age and type of deposits,
c. Geomorphology of the area,
d. Water table in the study area,
e. Seismicity of the area.

(B) **Micro geo engineering** features of the study area - This should be base for the categorization of the area for their **Liquefaction Potential.**

a. Soil type,
b. Physical properties of soil and
c. SPT value at various depths.

(C) **Liquefaction Potential Severity Index:** To map the spatial variability of Liquefaction Hazard at a particular location. This is based on the strength parameters, tested and analyzed for the determination of its resistance during seismic, cyclic forces.

Area Selection for Mapping of Liquefaction Potential Zonation:

Dahej is a well developed port and growing business hub. There are many giant industrial infrastructures present in the Dahej area. The study area selected based on the Macro geo engineering features of the area which are discussed in detail below. The study area is located between the latitude 21^0 39' 8.28" and 21^0 44' 12.51" and longitude 72^0 32' 40.88" and 72^0 39' 36.9". The study area covers approximately 400 square kilometer and situated in Bharuch district of Gujarat.

LIQUEFACTION HAZARD MAPPING

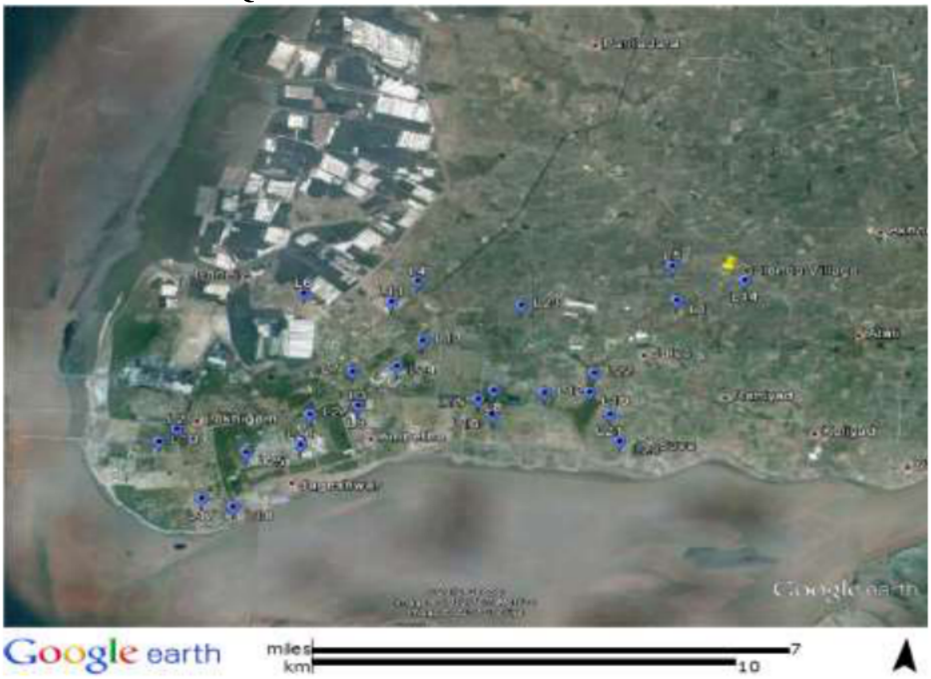


FIGURE 1: MAP SHOWS LOCATIONS OF BOREHOLES AND VILLAGES

MACRO LEVEL STUDY ASPECTS

WATER TABLE: - Water table is the most important factor for liquefaction as only saturated sediments can liquefy. Figure 2 shows the water table depth contour of the study area. The water table in the study area varies between 3.4m to 15m from the existing ground level. Moreover, it is also apparent from the map that the liquefaction susceptibility and water table depth increase from East to West. This is because of the presence of relatively younger formation in the West and nearness of Gulf of Cambay or presence of local streams.

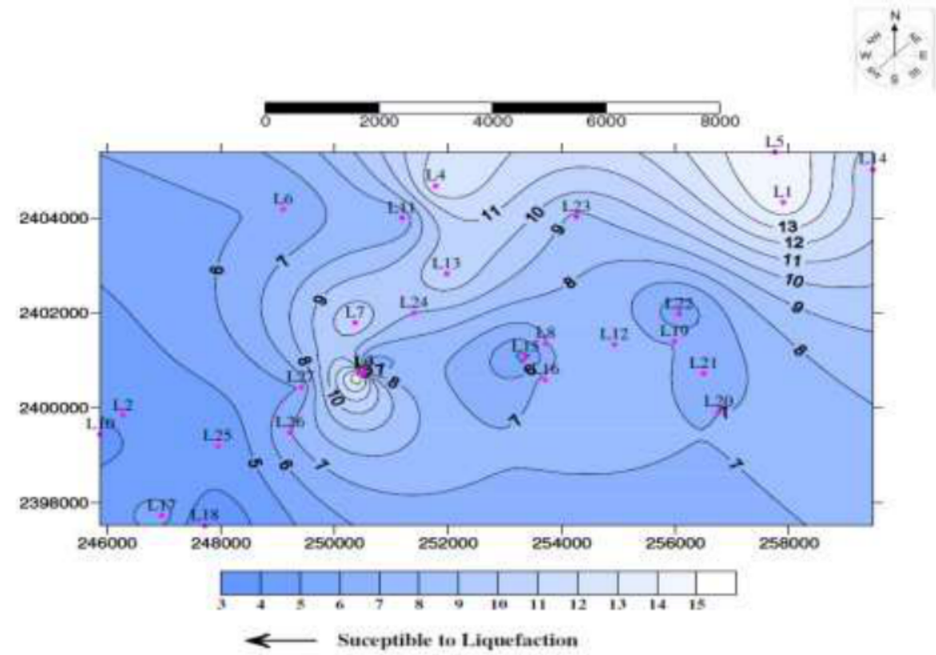


FIGURE 2: LIQUEFACTION SUSCEPTIBILITY BASED ON WATER TABLE DEPTH

LIQUEFACTION HAZARD MAPPING

GEOLOGY

The type of geological process that created a soil deposit has strong influence on its liquefaction susceptibility. Deposits formed by rivers, lakes & wind and man-made deposits, particularly those created by the process of hydraulic filling, are highly susceptible to liquefaction. Figure 3 shows the geology map of the study area. The geology of the study area comprises of Tidal flat and older tidal flat. The tidal flat deposition usually comprises of clay, silt and fine sand. Table 2 shows the liquefaction potential based on the geological criteria.

Table 1: GEOLOGY OF DAHEJ

Age	Formation	Lithology
Holocene	Rann Clay Formation	Older tidal flat deposit and tidal marsh deposit
	Katpur Formation	Flood Plain deposit
	Akhaj Formation	Coastal dune and sand dune deposit
	Mahuva Formation	Split bar/ tidal flat/ shoal deposit

(Source: District Resource Map, Geological Survey of India, 2002)

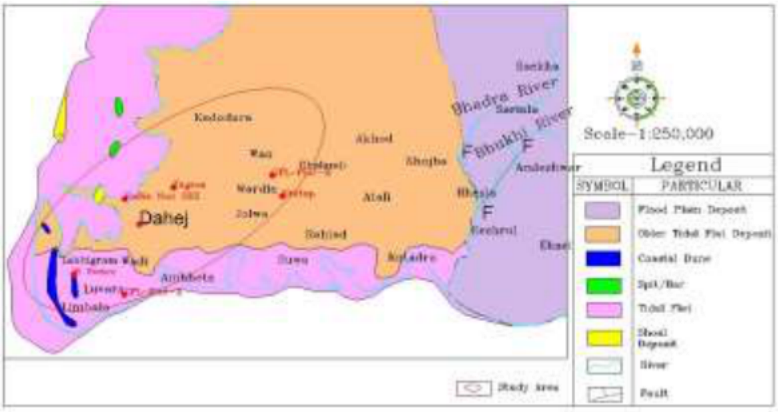


FIGURE 3: GEOLOGICAL MAP OF STUDY AREA

(Source: Geological Survey of India, 2002)

Table 2: Liquefaction Susceptibility using Geologic Criteria (YOUD & PERKINS, 1978)

Sr.No.	Geological Description	Susceptibility
1	Deltaic deposits: Delta coastal zone	High – Very High
2	Fluvio marine deposits: Estuarine, marine terraces and beaches	Moderate - High
3	Fluvio lacustrine deposits: Lagoonal deposits with an age less than 10,000 yrs	Moderate - High
4	Alluvium: Flood plain, River channels	Low - Moderate
5	Quaternary strato volcano: tuff, tephra, with an age betn 500 to 3000000 yrs	Low – Moderate
6	Residual soils: Residual soil with an age more than 500 yrs	Low - Moderate

(Source: Chapter 6 Zonation of Liquefaction potential using Geological Criteria)

AGE OF THE DEPOSITS

Age of the sedimentary geological deposits is an important factor as older sediments are compacted and less susceptible to liquefy. Table 3 shows the relation between age of the deposits and their susceptibility for liquefaction.

Table 3: Relationship between Age of Deposit & Potential for Liquefaction (YOUD & PERKINS, 1978)

Type of deposit	Distribution of cohesionless sediments in deposits	Likelihood that Cohesionless Sediments When Saturated, Would Be Susceptible to Liquefaction (by age of deposit)			
		<500 yr	Holocene	Pleistocene	Pre Pleistocene
Delta	Widespread	Very high	High	Low	Very Low
Estuarine	Locally variable	High	Moderate	Low	Very Low
Beach					
High wave energy	Widespread	Moderate	Low	Very Low	Very Low
Low wave energy	Widespread	High	Moderate	Low	Very Low
Lagoon	Locally variable	High	Moderate	Low	Very Low
Fore shore	Locally variable	High	Moderate	Low	Very Low

Source: Surficial Geologic & Lique. Suscep. Mapping in Shelby County, Tennessee by Roy Van Arsdale & Randel Cox

GEOMORPHOLOGY

Geomorphic features of the study area are also important to select the area for further study of their potential to liquefy. Iwasaki et al (1982) made an attempt to categorize the various geomorphic features based on their potential to liquefy. The geomorphic features of the study area fall in the category where the liquefaction is either likely or possible. Figure 4 shows the geomorphic features of the study area.

TABLE 4: LIQUEFACTION POTENTIAL BASED ON GEOMORPHOLOGY

Rank	Geomorphologic Units	Liquefaction Potential
A	Present riverbed, Old River bed, Swamp, Reclaimed land, inters dune lowland.	Liquefaction Likely
B	Fan natural levee, Sand dune, Flood plain, Beach other plains.	Liquefaction Possible
C	Terrace Hill mountain	Liquefaction Un-Likely

(Source: Collection of surface data for the prediction of liquefaction potential by Ishihara and Yasuda (1991))

FIGURE 4: GEOMORPHIC MAP OF STUDY AREA

(Source: Geological Survey of India, 2002)

SEISMICITY OF THE AREA

Seismicity of the area is another essential parameter need to be considered for identification of zone for potential liquefaction. The study area falls in the **Zone 3** as per the zonation map 2002. Based on above discussed macro geo engineering features, the study area can be given rank for its susceptibility to liquefy. Table 5 apparently indicates that the study area posse's macro geo engineering features which are potential to liquefy. However, it is essential to study the micro geo engineering parameters to map the potential zone of liquefaction present in the study area.

TABLE 5: CATEGORIZATION OF STUDY AREA BASED ON MACRO GEO ENGINEERING PARAMETERS

Sr. No.	Macro geo engineering Parameter	Liquefaction Potential	Category
1	Geology	Yes	Moderate – High
2	Sediments' geological age	Yes	Moderate – High
3	Water table depth	Yes	Nil – High
4	Geomorphology	Yes	Moderate – High
5	Seismicity	Yes	Moderate – Low

MICRO LEVEL STUDY ASPECTS

VARIOUS LIQUEFACTION POTENTIAL CRITERIA

Resistance of a soil to liquefaction is determined by a combination of multiple soil properties. All of these properties and factors should be taken into account in an ideal evaluation of the liquefaction resistance of a soil. Because a comprehensive evaluation of soil properties and environment is neither feasible nor practical, there are various soil properties suggested by researchers for categorization of liquefaction potential zone mapping.

The majority of liquefaction studies to date have concentrated on relatively clean sands. Comparatively little liquefaction research has been undertaken on soils within the grain size range of very silty sand to silt with or without some clay content.

LIQUEFACTION HAZARD MAPPING

These silty soils are frequently encountered in engineering practice, and there is an abundance of evidence to show that they can be susceptible to liquefaction. Some of the physical properties of the soil used as the criteria by various researchers are discussed below:

TABLE 6: LIQUEFACTION POTENTIAL CRITERIA

Sr. No.	Assessment Method	Potentially Liquefiable	Test for decision	Non Liquefiable
1	Chinese criteria – Wang (1979)	FC <= 15%	--	Otherwise
		LL<=35%	--	
2	Seed et al (2003)	PI < 12%	12 < PI < 20	Otherwise
		LL < 37%	37 < LL < 47	
3	Boulanger & Idriss (2006)	PI < 3%	3 <= PI <= 6	PI >=7

LITHOLOGS AND SOIL CLASSIFICATION

Total 335 nos. of borehole data are investigated and put which 27nos. of bore data are selected as representative data.

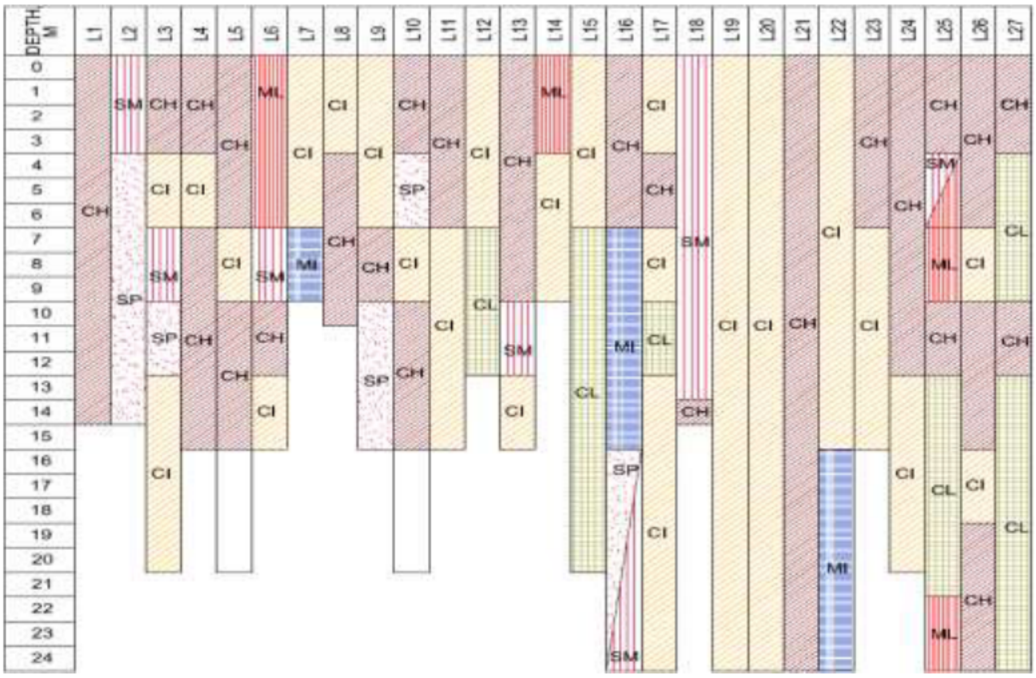


FIGURE 5: STRATIFICATION LITHOLOGS

SEISMICITY OF THE AREA

Table 2 describes the past history earthquake with their respective location of epicenter and magnitude around the study area. The study area falls in the **Zone 3** as per the zonation map 2002.

TABLE 7: EARTHQUAKE EPICENTER LOCATION WITH THEIR RESPECTIVE MAGNITUDE

Latitude	Longitude	Magnitude	Year	Location
21.60	72.96	5.4	1970	Bharuch
21.70	73.00	3.5	1970	Bharuch
21.70	73.00	4.1	1970	Bharuch
21.60	72.70	3.4	1970	Bharuch
21.70	73.00	3.4	1971	Bharuch
21.84	72.90	3.0	1978	Amod
21.97	72.91	2.8	1978	Amod
21.90	72.90	3.2	1972	Amod
21.81	73.03	2.9	1980	Nabipur
21.68	73.21	2.6	1980	Netrang
21.68	73.21	3.1	1980	Netrang
21.96	72.95	2.6	1980	Kevadia
22.00	72.88	3.6	1982	Amod
21.70	71.44	4.8	1993	Gulf of Cambay

(Source: Catalogue of earthquakes in Gujarat from 1668 to 2010)

TABLE 8: PROBABILITY OF EARTHQUAKE OCCURRENCE

Magnitudes	Occurrences	Earthquake Occurrence Probability, %		
		Probability for Yrs.		
		10	25	50
M < 3.0	4	94.3	99.9	100.0
3.0 ≤ M < 4.0	7	99.3	100.0	100.0
4.0 ≤ M < 5.0	2	76.0	97.2	99.9
5.0 ≤ M < 6.0	1	51.0	83.2	97.2
Total Numbers	14			

$$(1-e^{(-(10yrs.*(Nos.\ of\ Occ/Total\ Occ)))})*100$$

LIQUEFACTION POTENTIAL CRITERIA

Cyclic Stress Ratio (CSR) Caused by Earthquake

CSR can be obtained from the following formula:

LIQUEFACTION HAZARD MAPPING

$$CSR = \left\{\frac{\tau_{cyc}}{\sigma_{vo}'}\right\} = 0.65\, r_d \left\{\frac{\sigma_{vo}}{\sigma_{vo}'}\right\}\left\{\frac{a_{max}}{g}\right\}$$

Where,

a_{max} = Maximum Horizontal Acceleration at ground surface induced by earthquake
σ_{vo} = Total vertical stress at bottom of soil column = $\gamma_t z$
$\tau_{cyc(max)}$ = Maximum Shear Stress
σ'_{vo} = Vertical Effective Stress
g = acceleration due to gravity (32.2 ft/s^2 or 9.81 m/s^2)
r_d = depth reduction factor

Depth reduction factor assumes a linear relationship of r_d versus depth and use the following equation (Kayen et al. 1992):

$$r_d = 1 - 0.012z$$

Where, z = depth in meters below the ground surface where the liquefaction analysis is being performed (i.e., the same depth used to calculate σ_{vo} and σ'_{vo}).

Cyclic Resistance Ratio (CRR) from standard penetration test:

MEASURED SPT VALUES IN THE FIELD

The N–value are the blow counts for the last 30 cm of penetration and 50 times is the maximum value. However, for harder soil penetration cases, there often happens that penetration depth does not reach 30 cm or counts need more than 50 times for 30 cm penetration. For practical use of N-values for earthquake engineering purpose, the corrected N-value of "N_{SPT}" was defined as following:

CORRECTIONS TO SPT N-VALUES

The measured SPT blow count (N_{SPT}) is first normalized for the overburden stress at the depth of the test and corrected to a standardized value of $(N_1)_{60}$. Using the recommended correction factors given by Robertson and Fear (1996), the corrected SPT blow count is calculated with:

(Source: Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils)

$$(N_1)_{60} = N_{SPT} \times (C_N \times C_E \times C_B \times C_R \times C_S) \text{ ------------ } 4$$

(A) Clean Sand adjustment Factor

α = 0 for FC $\leq$ 5%

= $e^{\left(1.76 - \frac{190}{FC^2}\right)}$ for 5% < FC < 35%

= 5 for FC $\geq$ 35%

β = 1.0 for FC $\leq$ 5%

= $0.99 + \frac{FC^{1.5}}{1000}$ for 5% < FC < 35%

= 1.2 for FC $\geq$ 35%

CALCULATION OF CRR VALUES

$$CRR_{7.5} = \frac{1}{34-(N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{(10(N_1)_{60} + 45)^2} - \frac{1}{200}$$

The above equation for CRR is valid for $(N_1)_{60} < 30$. For $(N_1)_{60} < 30$, Clean granular soils are too dense to liquefy and are classed as non-liquefiable. The CRR value thus obtained is further corrected for its Magnitude Scaling Factor (MSF), therefore, corrected $CRR_M = CRR_{7.5}$ X MSF.

$$\mathbf{CRR_6 = CRR_{7.5} \times MSF}$$

The value of MSF is given as under.

$$\mathbf{MSF = 87.2 \times (Mw)^{-2.215}}$$

Where, Mw is the anticipated earthquake magnitude

LIQUEFACTION POTENTIAL INDEX (LPI

LPI as originally defined by Iwasaki et al. (1978) weighs factors of safety and thickness of potentially liquefiable layers according to depth. It assumes that the severity of liquefaction is proportional to:

1. Cumulative thickness of the liquefied layers;
2. Proximity of liquefied layers to the surface; and
3. Amount by which the factor safety (*FS*) is less than 1.0, where *FS* is the ratio of soil capacity to resist liquefaction to seismic demand imposed by the earthquake.

Iwasaki et al. (1978) defined LPI as:

$$P_L = \int_0^{20} (1 - F_L)(10 - 0.5x)dx$$

Where,

P_L= Liquefaction potential index

F_L = Liquefaction resistance factor (= CRR / CSR)

X = depth (in m)

TABLE 9: LIQUEFACTION POTENTIAL INDEX CATEGORISATION

P_L value	Liquefaction Potential	Explanation
$15 < P_L$	Very High	Ground improvement is indispensable.
$5 < P_L <= 15$	Relatively High	Ground improvement is required. Investigation for important facilities is indispensable.
$0 < P_L <= 5$	Relatively Low	Investigation for important facilities is required.
$P_L = 0$	Very Low	No remedial method is required.

(Source: Toshio Iwaski, Tadashi arakawa & Ken Ichi Tokida, "Simplified procedures for assessing soil liquefaction during earthquakes Earthquake Disaster Prevention Department, Public Works Research Institute, Ministry of Construction, Tsukuba Science City, lbaraka-Prof 305 Japan)

LIQUEFACTION HAZARD MAPPING

SAMPLE CALCULATION SHEET:

BH Location: 9 **Co-ordinates: E 250504; N 2400724** Groundwater Level: GL, m - 15

z	Soil type	FC	I_P	D_{50}	D_{10}	N-value	γ_t	σ_{vo}	σ'_{vo}	Liquefiable ?	SPT Correction Factors					$(N_1)_{60}$	α	β
(GL - m)		(%)		(mm)	(mm)	N_{SPT}	(kN/m^3)	kN/m^2	kN/m^2		C_N	C_E	C_B	C_R	C_S			
3.0	CI	77.0	14.4	0.0260	0.0	17	18.27	54.81	54.81	No	1.36	0.7	1.0	0.80	1.2	16	5.0	1.2
6.0	SP	14.0	0.0	0.0750	0.0	18	18.64	110.73	110.73	No	0.96	0.7	1.0	0.95	1.2	14	2.2	1.0
9.0	SP	13.0	0.0	0.0038	0.0	14	18.87	167.34	167.34	No	0.78	0.7	1.0	0.95	1.2	9	1.9	1.0
12.0	SP	15.0	0.0	0.0550	0.0	13	19.05	224.49	224.49	No	0.67	0.7	1.0	1.00	1.2	7	2.5	1.0
15.0	SP	14.0	0.0	0.1200	0.0	10	18.91	281.22	281.22	Yes	0.60	0.7	1.0	1.00	1.2	5	2.2	1.0

$(N_1)_{60cs}$	$CRR_{7.5}$	CRR_6	Seismic Shear Stress Ratio			F_L for 0.24 PGA		P_L for 0.24 PGA		Pi for 0.24 PGA		F_L for 0.4 PGA		P_L for 0.4 PGA		Pi for 0.4 PGA	
			r_d	$CSR_{0.24}$	$CSR_{0.4}$	$M_{7.5}$	M_6	$M_{7.5}$	M_6	$M_{7.5}$	M_6	$M_{7.5}$	M_6	$M_{7.5}$	M_6	$M_{7.5}$	M_6
24	0.267	0.440	0.955	0.15	0.25	1.782	2.936	0.00	0.00	5.8	0.6	1.069	1.762	0.00	0.00	38.1	6.1
17	0.176	0.290	0.910	0.14	0.24	1.256	2.069	0.00	0.00	23.0	3.1	0.732	1.207	1.90	0.00	77.2	26.3
11	0.121	0.200	0.865	0.13	0.22	0.932	1.536	0.40	0.00	53.3	10.8	0.551	0.908	2.50	0.50	92.4	56.3
10	0.115	0.189	0.820	0.13	0.21	0.883	1.455	0.50	0.00	59.3	13.3	0.547	0.901	1.80	0.40	92.7	57.1
7	0.091	0.151	0.775	0.12	0.20	0.762	1.256	0.60	0.00	73.9	23.0	0.457	0.753	1.40	0.60	96.6	74.9
								1.50	0.00					7.60	1.50		
Liquefaction Potential Index, P_L								**RL**	**VL**					**RH**	**RL**		

LIQUEFACTION HAZARD MAPPING

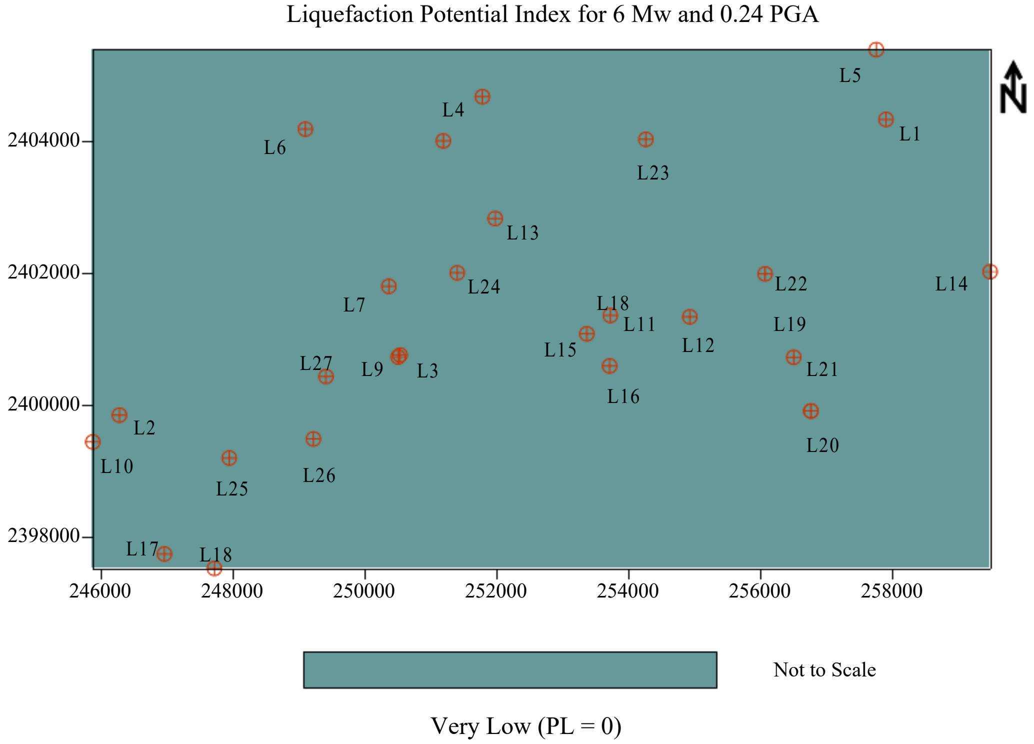


FIGURE 6: LPI FOR 6 Mw EARTHQUAKE & 0.24 PEAK GROUND ACCELERATION

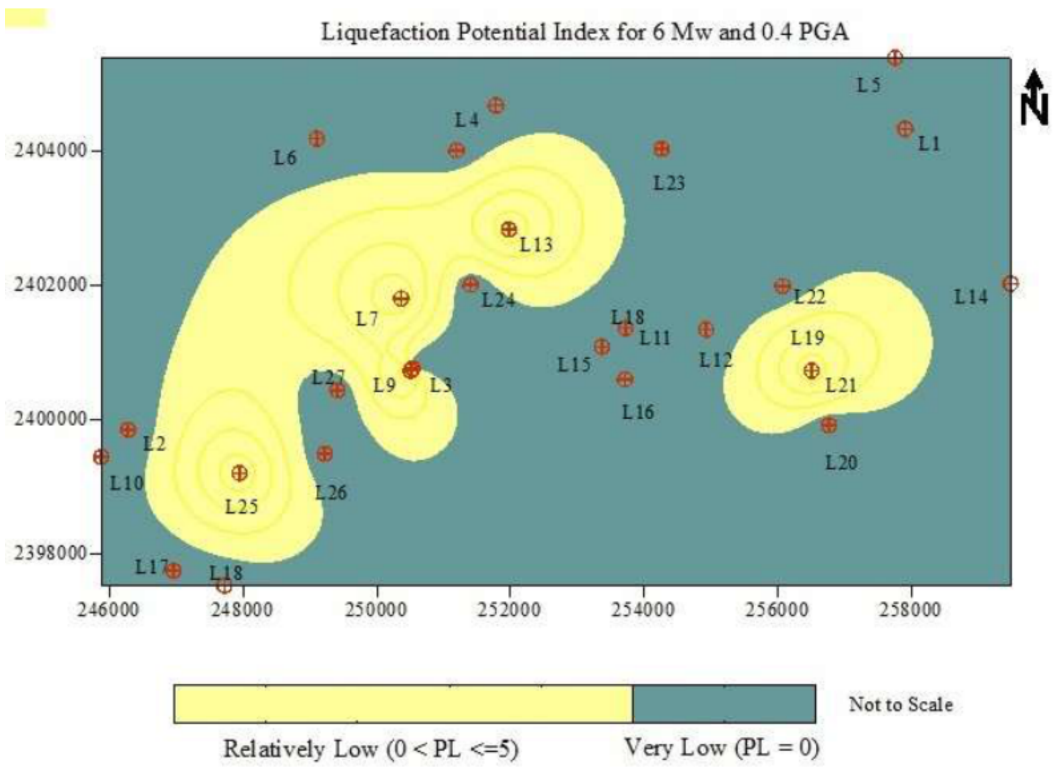


FIGURE 7: LPI FOR 6 Mw EARTHQUAKE & 0.4 PEAK GROUND ACCELERATION

LIQUEFACTION HAZARD MAPPING

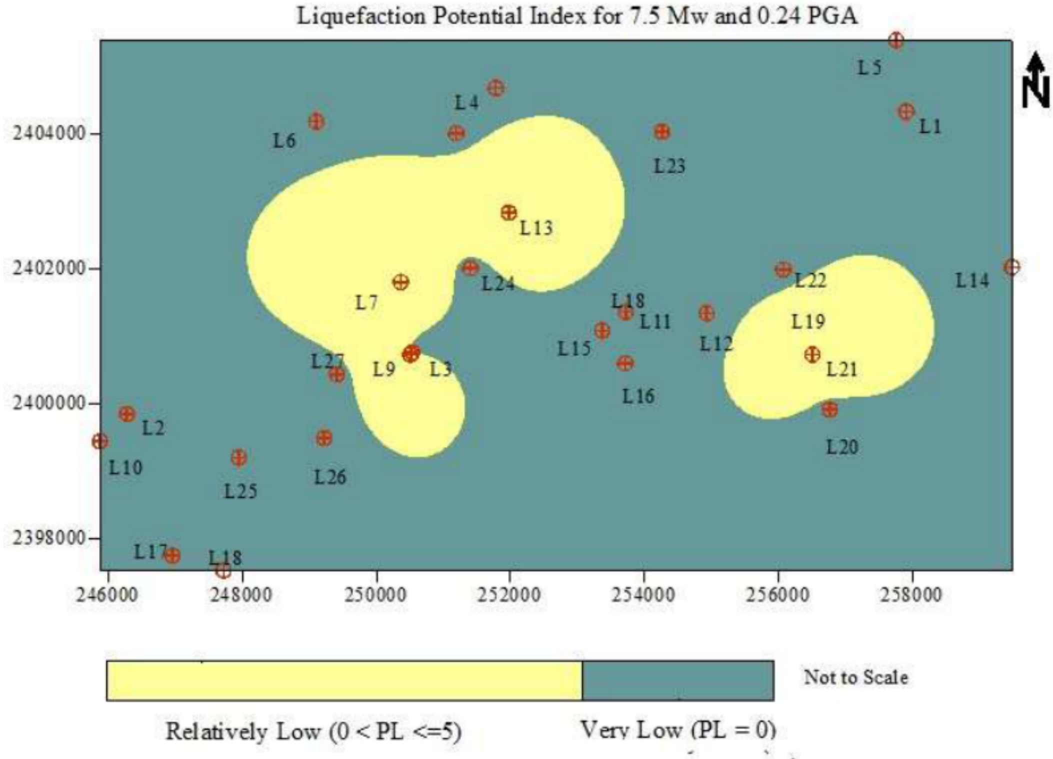


FIGURE 8: LPI FOR 7.5 Mw EARTHQUAKE & 0.24 PEAK GROUND ACCELERATION

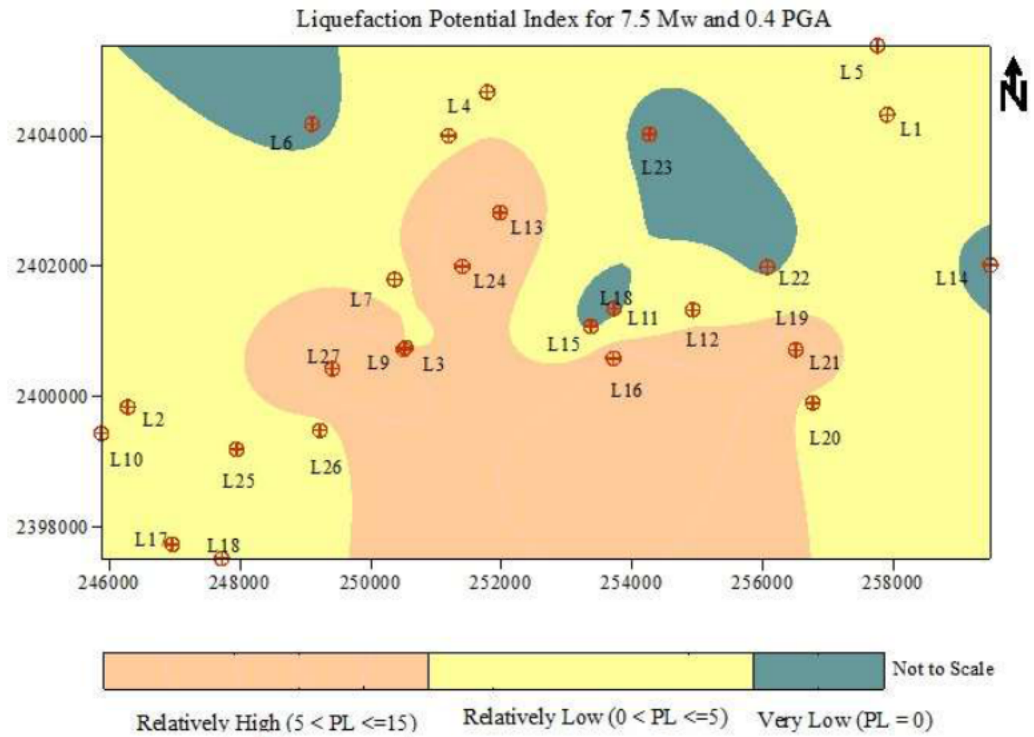


FIGURE 9: LPI FOR 7.5 Mw EARTHQUAKE & 0.4 PEAK GROUND ACCELERATION

LIQUEFACTION HAZARD MAPPING
DISTRIBUTION OF FACTOR OF SAFETY IN TERMS OF PROBABIITY INDEX

The variability of Factor of Safety (F_L) is converted in terms of the probability function. **Liquefaction Probability Index (Pi)** as a function of factor of safety (F_L) is calculated as mentioned below:

$$Pi = \frac{1}{1 + \left(\frac{F_L}{0.96}\right)^{4.5}}$$

NORMALISED HISTOGRAMS OF LIQUEFACTION PROBABILITY INDICES

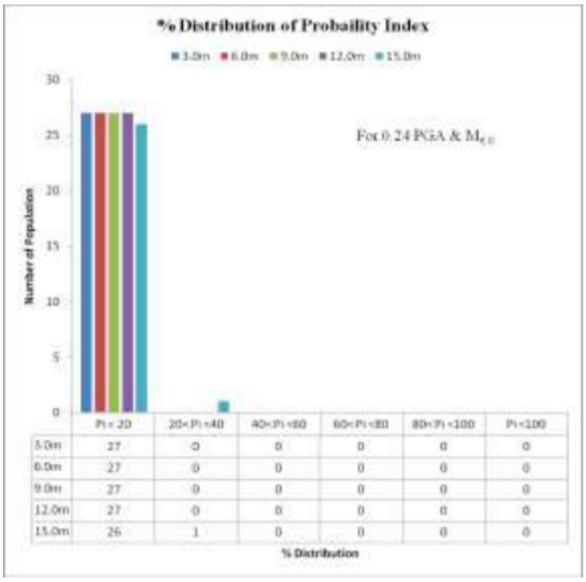


FIGURE 10: Histogram for 6 Mw and 0.24 PGA

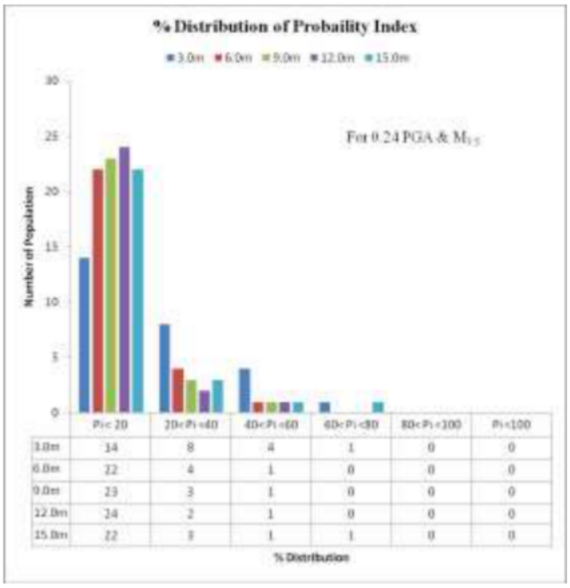
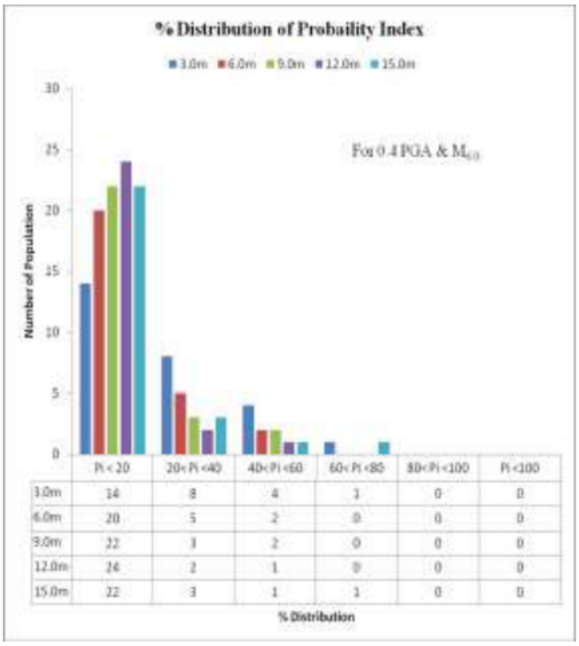


FIGURE 11: Histogram for 7.5 Mw and 0.24 PGA



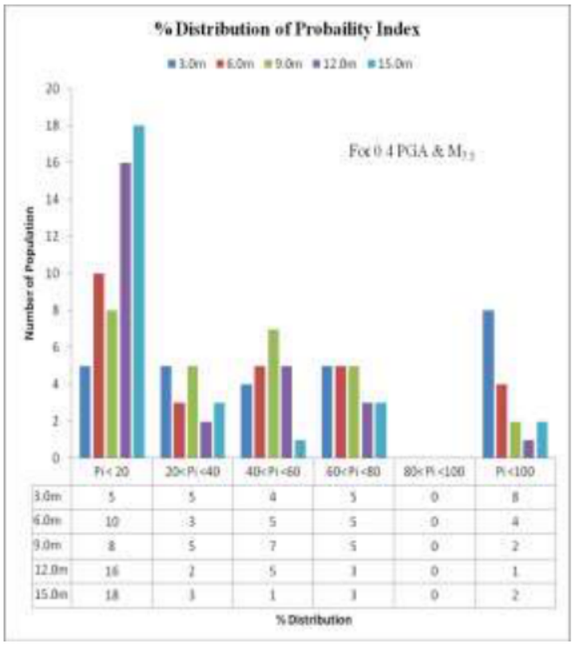


FIGURE 12: Histogram for 6 Mw and 0.4 PGA

FIGURE 13: Histogram for 7.5 Mw and 0.4 PGA

LIQUEFACTION HAZARD MAPPING

Variance of Factor of Safety w.r.t. Earthquake Intensity and Peak Ground Acceleration

The variability of Factor of Safety (F_L) for particular depth is presented for the group of data of various bores. The factor safety value is analyzed statistically to obtain an extrapolated range as 1st & 3rd Quartile which determines the range of factor of safety. The range is obtained of the Median values of factor of safety.

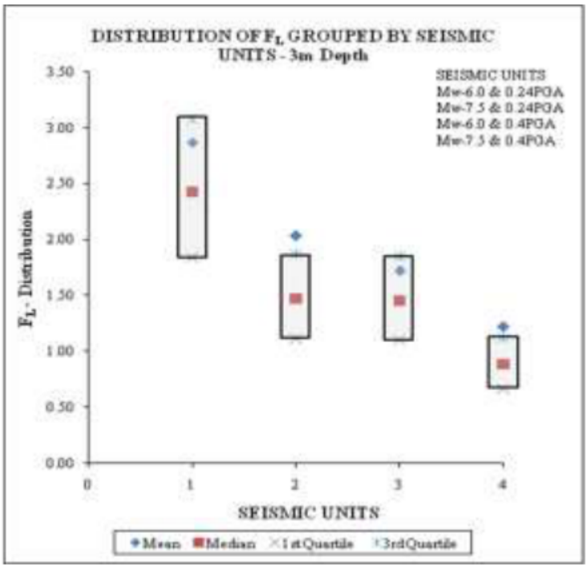


FIGURE 14: FOR 3.0m DEPTH

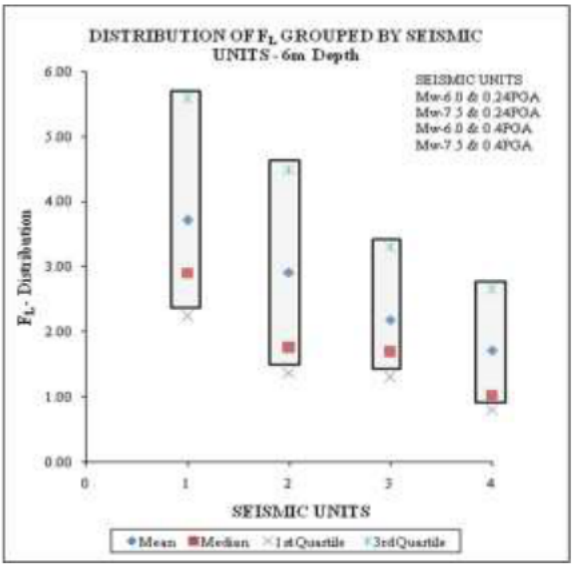


FIGURE 15: FOR 6.0m DEPTH

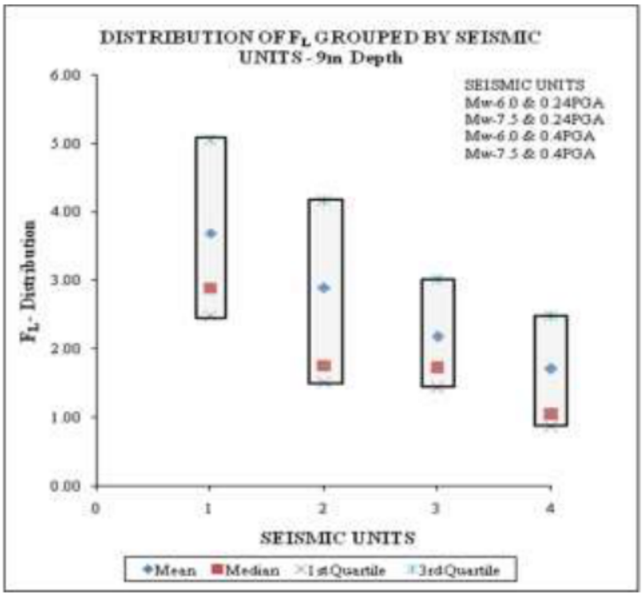


FIGURE 16: FOR 9.0m DEPTH

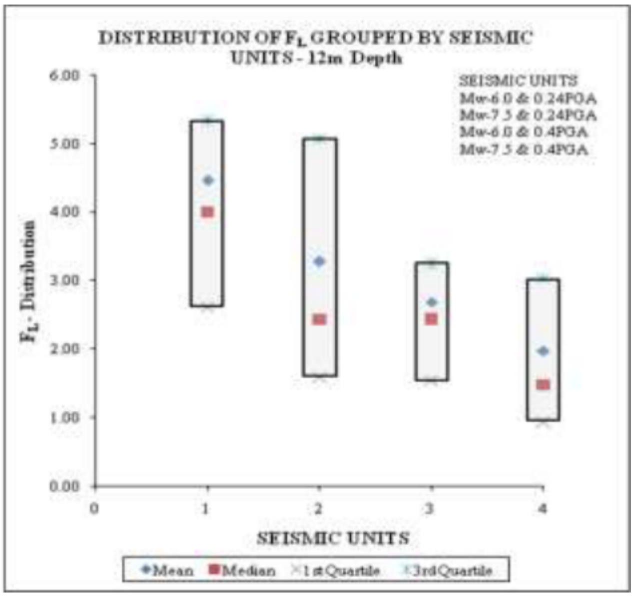


FIGURE 17: FOR 12.0m DEPTH

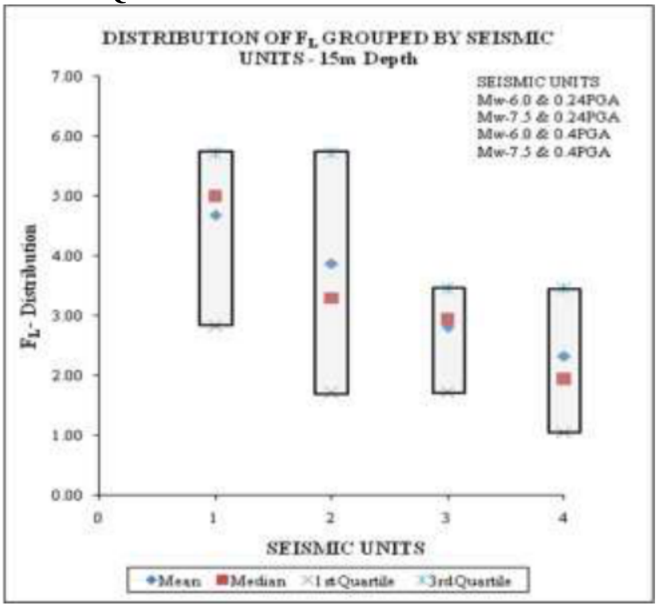


FIGURE 18: FOR 15.0m DEPTH

CONCLUDING REMARKS

Liquefaction Potential Mapping is done based on the susceptibility and Potentiality criteria's with the use of simplified methods. The use of characterization maps are first look at the area "Potentially Hazardous to Liquefaction". The Liquefaction Potential Index is area specific level of Liquefaction Potential. The designer requires the factor of safety variation in the area due to the effect of Liquefaction. The variation of Factor of safety is analyzed statistically. The variability and distribution of Factor of Safety with respect to the depth, Peak ground Acceleration and Earthquake Intensity magnitude can be presented in the form of Histogram Distribution and Variability with range of probable values.

The procedure thus involves the steps to evaluate probable Susceptibility and Potentiality with statistical approach for an area and provides range of factor of safety for design consideration.

	ABBREVIATIONS		NOTATIONS
G –	Gravel	Z =	Depth below Ground
S –	Sand	D_{50} =	Mean Particle Size having 50% material finer
M –	Silt	D_{10} =	Particle size at 10 % passes
C –	Clay	γt =	Unit weight of soil above the groundwater level
PI / IP –	Plasticity Index	$\gamma' t$ =	Submerged Unit weight of soil
LL –	Liquid Limit	τ_{cyc} =	Cyclic Shear Stress
PL –	Plastic Limit	r_d =	Depth Reduction Factor
NP –	Non-Plastic	σv =	Total overburden pressure
CH –	Clay of High Plasticity	$\sigma' v$ =	Total overburden pressure
CI –	Clay of Intermediate Plasticity	a_{max} =	Maximum Horizontal Acceleration at ground surface

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CL –	Clay of Low Plasticity
MH –	Silt of High Plasticity
MI -	Silt of Intermediate Plasticity
ML -	Silt of Low Plasticity
SW -	Well Graded Sand
SP -	Poorly Graded Sand
SM -	Silty Sand
SC -	Clayey Sand
GW -	Well Graded Gravel
GP -	Poorly Graded Gravel
GM -	Silty Gravel
GC -	Clayey Gravel
OH -	Organic Silt with High Plasticity
OI -	Organic Silt with Intermediate Plasticity
OL -	Organic Silt with Low Plasticity
GL -	Ground Level
WL -	Water Level
FC -	Fines content
N-value	Results of standard penetration test (SPT)
LP -	Liquefaction Potential
CSR -	Cyclic Stress Ratio
CRR -	Cyclic Resistance Ratio
F_L -	Factor of Safety
P_L –	Liquefaction Potential Index
Pi -	Liquefaction Probability Index
ER =	Energy Ratio
Mw =	anticipated earthquake magnitude
MSF	Magnitude Scaling Factor

$\tau_{cyc(max)}$ =	Maximum Shear Stress
g =	acceleration due to gravity (32.2 ft/s^2 or 9.81 m/s^2)
C_N =	Correction for Overburden Pressure
C_E =	Correction for Hammer Energy
C_B =	Correction for Bore Diameter
C_S =	Correction for SPT Sampler
C_R =	Correction for Rod Length
α, β =	Clean Sand adjustment factor

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