LIQUEFACTION SUSCEPTIBILITY CRITERIAS FOR ZONATION

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Abstract— **"The phenomenon of pore pressure build-up following with the loss of soil strength is known as liquefaction (Committee on Earthquake Engineering, 1985)". Liquefaction Potential Zones can be identified based on Superficial features (i.e. Preliminary Investigation), Sub surface features (i.e. Secondary Investigation) and Detailed Strength Parameters. The study of Mapping of Liquefaction Potential Zonation involves many Superficial Features like Geological, Geo-Hydrological, Geo-Morphological, Drainage, Age of Deposit etc. These studies give qualitative idea and indication of Liquefaction Susceptibility. The Sub surface investigation provides quantitative assessment of the Liquefaction Potentiality. Detailed analysis for mapping includes the strength parameters with all the above conditions and parameters as deciding factors and can be classified as:**

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.

Here, the methods deciding the Liquefaction Susceptibility is discussed.

***Index Terms*— Liquefaction, Zonation, Mapping, Susceptibility**

I. 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.

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 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 features for liquefaction susceptibility of soils.

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

Manuscript received September 18, 2013.

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(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 is located between the Latitude (21^0 44' 0.41", 21^0 44' 43.86", 21^0 39' 29.16" and 21^0 40' 9.05") AND Longitude (72^0 31' 44.59", 72^0 40' 43.62", 72^0 32' 2.26" and 72^0 40' 45.89"). The study area covers approximately 130 square kilometer and situated in Bharuch district of Gujarat.

FIGURE 1: MAP SHOWS LOCATIONS OF BOREHOLES AND VILLAGES

II. MACRO LEVEL STUDY ASPECTS

In each geological setting, the inherent physical characteristics that affect the liquefaction susceptibility. The most important factors are found to be:

1. **T**ype of deposit (Geology)
2. **A**ge of deposit
3. **De**pth to water level
4. **G**eomorphology
5. **S**eismicity

This is the "TADGS" method used for mapping the liquefaction susceptibility in the study area. The acronym "TADGS" is formed from the highlighted. A numerical ranking system to assess liquefaction susceptibility in geological settings has been devised using TADGS factors. Each factor divided into various indicators and has given rank for their importance. Higher the value, more susceptible to liquefy.

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 2 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)

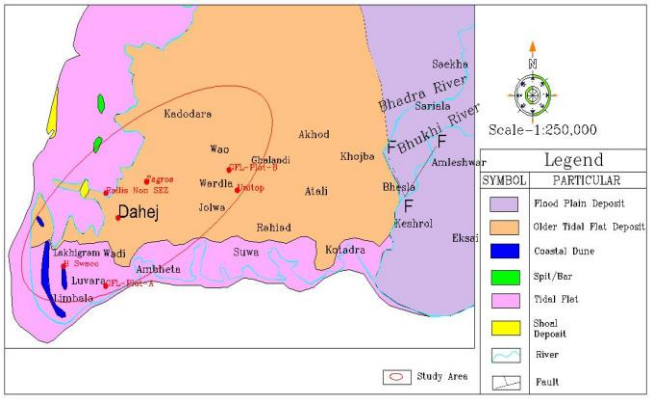

FIGURE 2: GEOLOGICAL MAP OF STUDY AREA

(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 < 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 > 500 yrs	Low - Moderate

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

It is known the deposit type is the most important indicator for the liquefaction susceptibility. The factor is sub divided into following indicators and ranking assigned.

Sr. No.	Indicators	Rank
1	Consolidated deposit	1
2	Semi consolidated deposit	2
3	Unconsolidated deposit	3

The study area comprises of unconsolidated alluvium deposit, hence the rank assigned for this factor of susceptibility is "3". The deposits are tidal flat deposits, coastal dune deposits and older tidal flat deposits. The depositional environment may be of marine to continental type.

AGE OF THE DEPOSITS: - Age of the sedimentary geological deposits is an important factor as older sediments are compacted and less susceptible to liquefy where as the younger unconsolidated deposits are more 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 cohesion less sediments in deposits	Likelihood that Cohesion less 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

According to Wiliam M. Phillips "Liquefaction Susceptibility Map of Teton County, Idaho (2011)" Holocene deposits are ranked as "5" the most susceptible unit. The study area is of Recent to Holocene age i.e. less than 10,000 years age. The deposits are ranked as an average "2.5" as mentioned below:

Sr. No.	Geological unit	Age	Rank
1	Tidal flat	Recent	3
2	Coastal dune	Sub Recent	2
3	Older tidal flat	Holocene	1

WATER TABLE: - Water table is the most important factor for liquefaction as only saturated sediments can liquefy. Figure 3 shows the water table depth contour of the study area. 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 4).

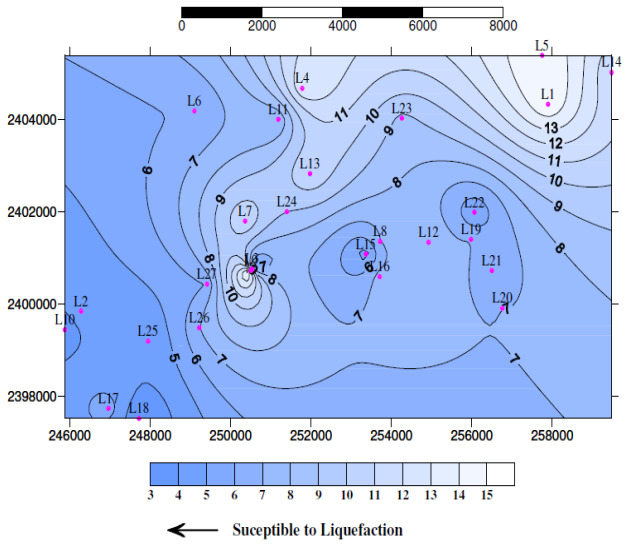

FIGURE 3: LIQUEFACTION SUSCEPTIBILITY BASED ON WATER TABLE DEPTH

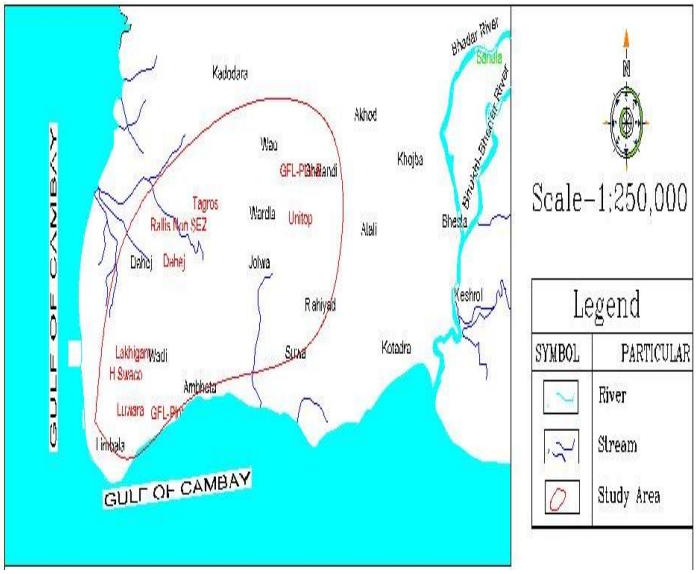

FIGURE 4: DRAINAGE MAP OF STUDY AREA
(Source: Survey of India Toposheet)

TABLE 4: Influence of Age Deposit & Depth of Water Table on Liquefaction Susceptibiltiy by Oberemier, 1996

Age of Deposit	Depth of Water Table		
	0-3m	3-10m	10m
Latest Holocene	High	Low	Nil
Earlier Holocene	Moderate	Low	Nil
Late Pleistocene	Low	Nil	Nil

*(**Source**: Generation of Geological database for liquefaction hazard assessment in Kathmandu valley pp.46 by Birendra Kumar Piya 2004)*

In the study area, the depth to water table varies between 2.5m to 15.0m. Accordingly, for depth of water table the aea is ranked as "2" as mentioned in table below:

Sr. No.	Depth to water table (in m)	Liquefaction Susceptibility	Rank
1	0 – 3	High	3
2	3 – 10	Moderate	2
3	10 – 15	Low	1

GEOMORPHOLOGY: - Geomorphic features of the study area are also important to select the area for 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 (Table 5). Figure 5 shows the geomorphic features of the study area.

TABLE 5: Liquefaction Potential based on GeoMorphology

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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)

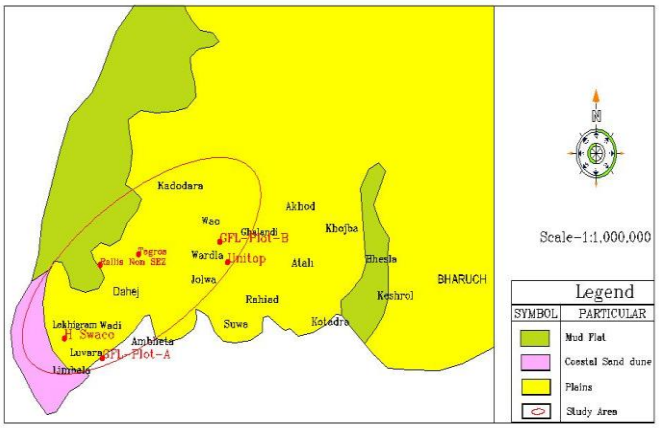

FIGURE 5: GEOMORPHIC MAP OF STUDY AREA

(Source: Geological Survey of India, 2002)

Geomorphologically, the study area comprises of Younger alluvium and older alluvium of marine continental type of deposit. The rank for the geomorphological indicator is tabulated below for the study area. . The geomorphic setting of the study area apparently depicts that the area is susceptible to liquefy with an average rank to "2.5".

Sr. No.	Geomorphic unit	Liquefaction Susceptibility	Rank
1	Younger alluvium	High	3
2	Older Alluvium	Moderate	2
3	Other	Low	1

SEISMICITY OF THE AREA: - Seismicity of the area is another essential parameter need to be considered for identification of zone for potential liquefaction. Table 6 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. The Figure 6 shows the zonation of earthquake based on their intensity. According to this classification, study area can feel the earthquake of MMI VII and potential for liquefaction will be moderate (Table 7).

TABLE 6: 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

TABLE 7: Liquefaction Hazard based on combination of Modified Mercalli Intensity & Liquefaction Susceptibility

MMI Value	Description of Shaking Severity	Summary Damage Description	Liquefaction Susceptibility Category				
			Very Low	Low	Moderate	High	Very High
I – IV	--	--	--	--	-- --	--	--

V	Light	Pictures Move	--	--	--	--	--
VI	Moderate	Objects Fall	--	--	--	--	--
VII	Strong	Non-Structural Damage	--	--	Moderately Low	Moderately Low	Moderate
VIII	Very Strong	Moderate Damage	--	--	Moderate	Moderate	Moderate
IX	Violent	Heavy Damage	--	--	High	High	High
X	Very Violent	Extreme Damage	--	--	High	High	High

(Source: Generation of Geological database for liquefaction hazard assessment in Kathmandu valley pp.97 by Birendra Kumar Piya 2004)

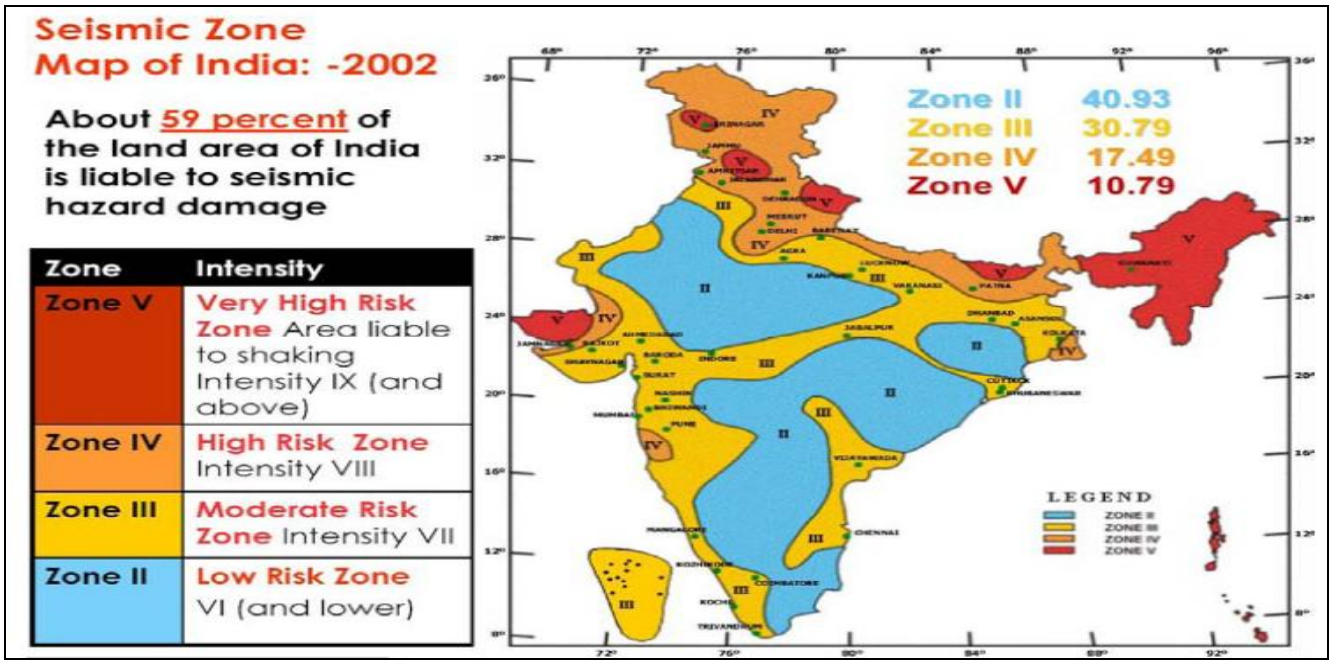

FIGURE 6: SEISMIC ZONE MAP OF INDIA
(*Source: IS: 1893-2002)*

The study area has given ranked as tabulated below:

Sr. No.	Seismic Hazard	Rank
1	High	3
2	Moderate	2
3	Low	1

The study area falls in the category of Moderate type of seismic hazard and hence rank "2"is given.

III CONCLUDING REMARKS:

Based on above discussed macro features, the study area can be given rank for its susceptibility to liquefy. Table 8 apparently indicates that the study area possesses macro 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 8: Categorization of study based on Macro 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

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The area is categorized to Susceptibility based on the below table:

The most of the area categorized under Moderate to High susceptibility of the liquefaction. The rank is summarized to make total of all the indicators covered and the categorized as Low, Moderate and High category of liquefaction susceptibility.

Sr. No.	Category	Rank Total
1	Low	0 - 5
2	Moderate	5 - 10
3	High	10 - 15

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