13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 82

Liquefaction Assessment For Microzonation Of Kolkata City

Pradipta CHAKRABORTTY[1], A.D.PANDEY[2], S. MUKERJEE[2], Ashish BHARGAVA[2]

SUMMARY

Results of an extensive analysis for determination of liquefaction hazard of Kolkata city at different locations are addressed here. The simplified procedure suggested by Seed- Idriss and the method (on the basis of field performance data) suggested by Seed, Idriss and Arango is used for determination of liquefaction potential at different locations of Kolkata for different acceleration levels (0.05g, 0.1g, 0.12g, 0.15g, 0.2g and 0.25g). From the analysis it is observed that the areas with river channel deposit are the most hazardous area for liquefaction. From the study it is also concluded that if acceleration level is increased then more area will be affected due to liquefaction. The plotted contour maps would assist the designers in taking suitable decision regarding necessary sub-soil treatment at different locality based on the design Peak Ground Accelerations.

INTRODUCTION

Liquefaction in soil is one of the major problems in Geotechnical Earthquake Engineering. This phenomenon has been observed after each and every earthquake, but was brought to the attention of engineers only after Niigata (1964) and Alaska (1964) Earthquake. Mapping of liquefaction hazards started from the early 1970s, with much of the early work done in USA. Since then, using different methodologies and scales liquefaction hazard maps have been produced for other areas in various other countries (Todorovska [1], Ansary [2]). Some Microzonation work has been done for Delhi (Rao [3]), but no study has so far been undertaken to establish liquefaction possibilities at local levels in Kolkata. It has been, therefore, felt necessary to undertake a study to develop a liquefaction potential hazard map of Kolkata city.

Greater Kolkata city (Shown in Fig. 2) is located on the left bank of the river Hooghly (Ganga). The city also comes under the seismic zone III as per the seismic zoning map of India (IS: 1893 [4]). Objective of the present study was to determine the hazardous areas in the city and divide it into different liquefaction potential zones by using different equipotent (liquefaction potential) lines, for different acceleration levels. For this work, analysis has been done using borehole data collected from different soil investigating agencies (private and governmental) in Kolkata. Since each agency has not conducted tests or processed data in the same manner, so some required data were found to be missing. Back Propagation Neural Network Algorithm was used to predict these missing values. Two different methods were used for determination of liquefaction potential.

- Simplified Procedure for Evaluating Soil Liquefaction Potential (Seed et. al. [5])

[1] Memorial University of Newfoundland, Canada
[2] Department of Earthquake Engineering, IIT Roorkee, Roorkee, India

- Evaluation of Liquefaction Potential using field performance data (Seed et. al. [6])

Subsequent to determination of liquefaction potential values at the borehole locations at different depth, the liquefaction potential values at different predetermined grid points on the city map were evaluated by using a different Neural Network model. These liquefaction potential values were then used for plotting liquefaction potential contours for different acceleration levels at different depths.

GENERAL SUBSOIL CONDITION OF KOLKATA CITY

Extensive soil exploration was carried out in the early seventies for the metro construction in Kolkata. The top layers of the soil sediments are of recent deposit and have been deposited by the Ganga (Hooghly) river system (Dostidar et. al. [7]). The soil layers in Kolkata are generally three types.

1. Normal Kolkata deposit: Soil consists mostly of silty clay / clayey silt strata with laminations and occasional lenses of silt and fine sand
2. River channel deposit: Soil consists of fine sand in the top layer
3. Reclaimed land: Consists of fine sand in top layer and after few metre soil layer consist of silty soil

DETERMINATION OF PEAK GROUND ACCELERATION FOR KOLKATA CITY

The empirical attenuation relations based on the data collected from different parts of the world are seen to have huge regional variations. Hence it is very difficult to choose an attenuation relationship for a region lacking in recorded Strong motion data. The Kolkata region, lacks recorded strong motion data hence it is very difficult to prescribe a Peak Ground Acceleration (PGA) value. However a popular attenuation relationship (suggested by Abrahamson et. al. [8]) can be used in such circumstances. The recommended relation (shown in equation (1)) based on 585 records from 76 worldwide earthquakes is as follows:

$$\log(a) = -0.62 + 0.177M - 0.982\log(r + e^{0.284M}) + 0.132F - 0.0008Er \;\ldots\ldots\; (1)$$

Where, a= Peak Ground Acceleration

r = Distance in Km to the closest approach of the zone of energy release

M= Magnitude of the earthquake

F= A Dummy variable - 1 for reverse or reverse oblique fault, 0 otherwise

E= A dummy variable - 1 for inter plate, 0 for intra plate events

Seismic source the Eocene hinge zone is the most prominent and closest to the Kolkata site. Expected magnitude of earthquake to be caused by this feature is taken as 6. Because, earthquake of magnitude 5.9 in 1935 having 80 Km focal depth and 5.2 in 1964 having 36 Km focal depth, toward north and south of Kolkata in this Eocene hinge zone, has been already taken place in last 100 years. The Design PGA value obtained from this relationship for Kolkata site for this 6-magnitude earthquake is 0.12g. The PGA values for other magnitudes of Earthquake are also tabulated in Table 1.

ARTIFICIAL NEURAL NETWORKS FOR EVALUATION OF LIQUEFACTION POTENTIAL

Artificial neural network takes their name from the networks of nerve cells. In a neural network model generally a large number of processors operates in parallel, each with its own small sphere of knowledge and access to data in its local memory. Typically a neural network is initially trained or fed large amounts of data and rules about data relationship. A program can then instruct the network how to behave in response to an external stimulus (e.g. input from a computer user who is interacting with the network) or can initiate activity on its own (within the limit of its access to the external world). The main characteristics of neural networks are there ability to learn non-linear functional relationships from examples and to discover patterns or regularities in data through self-organization (Goh [9]). Back propagation type neural network process information in interconnecting processing elements known as neurons or nodes. These nodes are organised in different groups known as layer. A network model consists of one input layer, one out put layer and one or more than one hidden layer (as shown in Figure 1). Information enters in a network through the nodes of input layer. The hidden and output layer nodes process all incoming signals by applying factors to them, known as weights. All inputs to a node are weighted, combined and then processed through the node's output connections. Network processing continued until the networks response is obtained at the output layer. After satisfactory completion of training phase, verification of the performance is done by testing. This is done by known data, which are not included during training. No additional learning occurs during this phase. There is a lot of works for successful prediction of soil property (Pandey et. al. [10]; Cal [11]) or soil liquefaction (Goh [12]; Pandey et. al. [13]; Rahman et. al. [14]; Rahman et. al. [15]). After successful completion of training the model may be used for prediction of missing data.

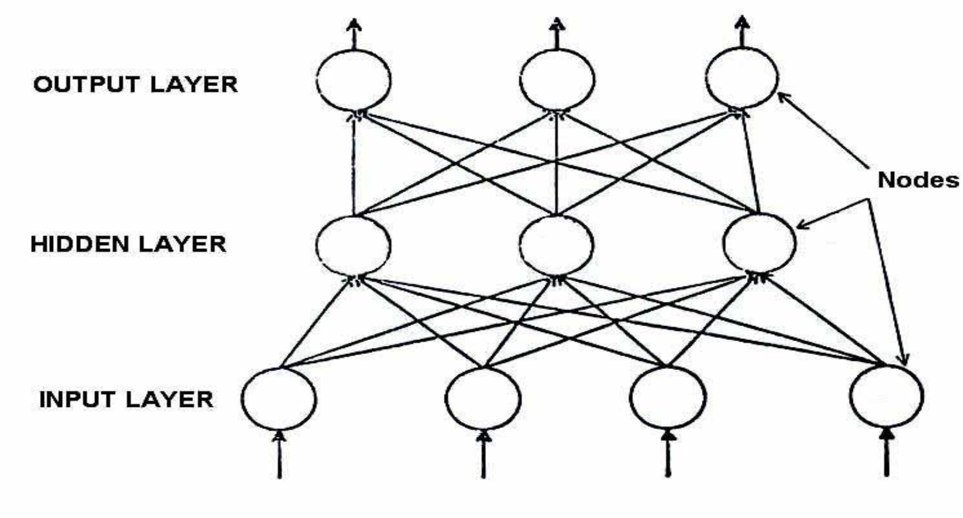

Figure 1: Three-Layer model of ANN (Goh [12])

DATA BASE FOR EVALUATION OF LIQUEFACTION POTENTIAL

More than 100 bore log data have been collected from different sources (Government and private agencies) in Kolkata (Borehole locations are as shown in Figure 2). Those borehole locations are from different areas (Salt lake, Kasba, Tolleygaunge, Sealdah etc.) and are spread all over the city.

The data available for the different boreholes is primarily deficient because the data has been collected from different agency and each agency has conducted different tests or processed data in different manner. To complete the database in a cohesive manner, the missing data was generated from neural nets developed specifically for interpolation / extrapolation of parameters essential for evaluation of liquefaction potential. Some of the data was withheld while training the neural network but was later used to test and validate the developed neural network. Some typical value of soil properties obtained from Bore log data, used for training the neural network models, are as shown in Table 2. A typical set of known and predicted values of mean grain size D_{50} is shown in Table 3.

Subsequently the liquefaction potential, using both the Simplified Procedure suggested by Seed-Idriss [5] and Method suggested by Seed, Idriss and Arango [6], were determined at different depths at each borehole and the mare conservative values were adopted for further calculation.

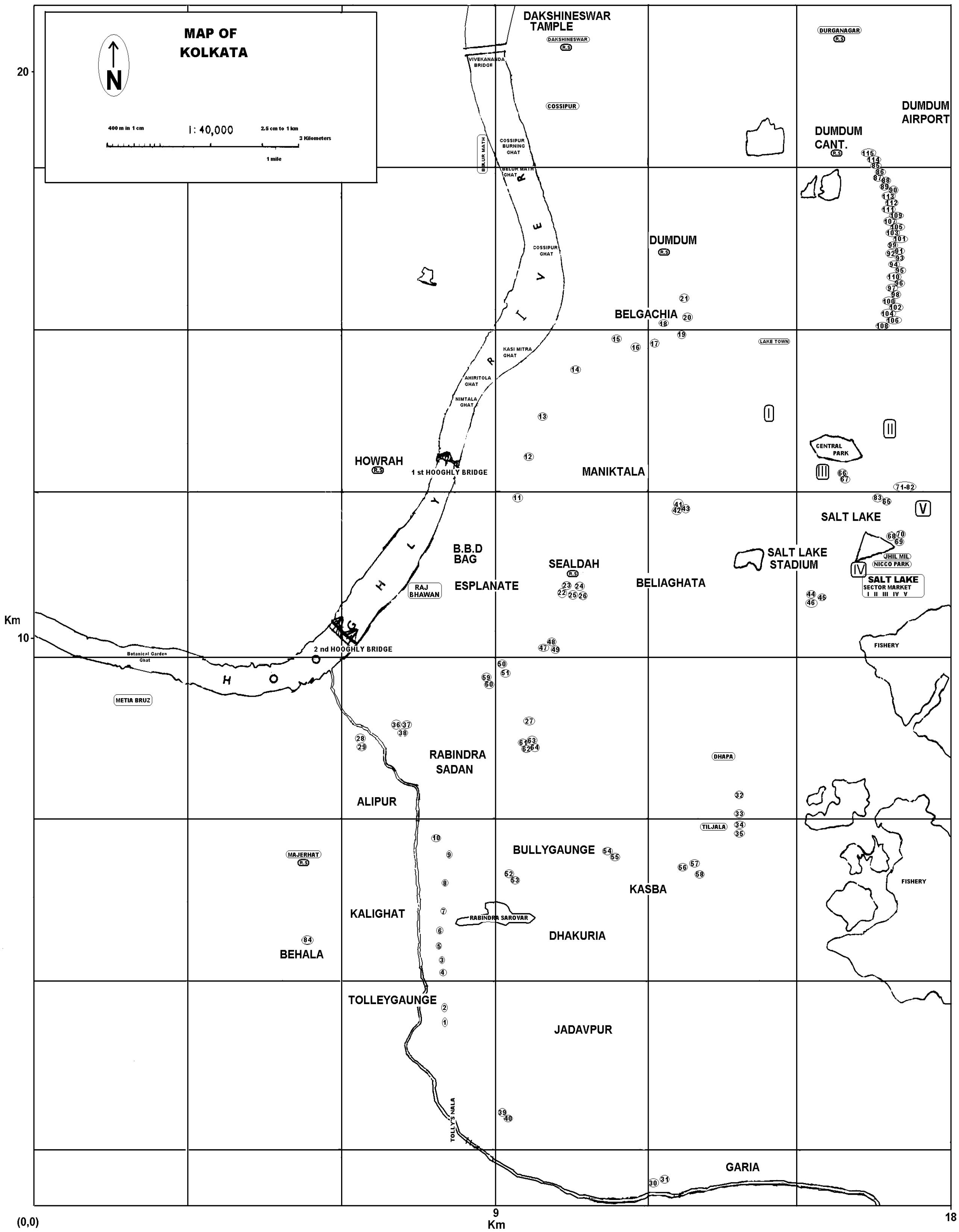

Figure 2: Map of Kolkata city showing different areas and borehole points

Neural Network for Determination of Liquefaction Potential at Grid Points:

Subsequent to the determination of liquefaction potential it was observed that at some locations in silty clay layer (with more than 30% clay content) liquefaction potential value obtained was more than 1. Such improbable values were replaced by zero appropriating to ensure liquefaction potential consistent with site conditions. The liquefaction potential was generated for predetermined grid points at different depths using a neural network. In this neural network four nodes are used as input nodes (x, y, Depth, Water Table Depth) and seven hidden nodes are used in a single layer and one output node (Liquefaction Potential) is used. Liquefaction Potential values having been obtained at grid points contours were plotted for an acceleration level 0.05g. Similarly liquefaction potential contours were also plotted for other acceleration levels i.e. 0.1g, 0.15g, 0.2g, 0.25g at different depths.

DISCUSSION OF CONTOUR MAP

Contour maps of equipotential line are plotted for different depths i.e. 2.5, 5, 7.5, 10 metre with the values of liquefaction potential obtained from Neural Network model. The areas with liquefaction potential value more than 1 (where full liquefaction can possible) are shown with dark red colour in the figure. From the result it is clear that, at 2.5 metre (Figure 3 to 7) depth, liquefaction is possible in the area adjacent to the Hooghly River, some portions of north Kolkata like Salt Lake, and some portion of south Kolkata like Kasba area for acceleration levels greater than 0.1g. Much area adjacent to Hooghly river has a higher liquefaction susceptibility for PGA value greater than 0.2g. Those vulnerable areas have soils, which are predominantly silty sand, and so liquefaction is a distinct possibility. A 5.5-magnitude or greater earthquake can cause extensive damage due to soil liquefaction at this depth.

At a depth of 5-metre (Figure 8), some area of southern Kolkata like Rabindra Sadan has a more liquefaction susceptibility for acceleration level 0.15g. Liquefaction potential value has also been calculated for other acceleration level at this depth. From the result it is observed that, some areas of northern Kolkata like Dumdum Cantonment have a liquefaction probability for acceleration level greater than or equal to 0.15g, primarily because in those regions of Kolkata city, sand layer is present at 5-metre depth. The increase in acceleration levels also increases the liquefiable area.

At 7.5-metre depth (Figure 9), it is observed that some areas of northern Kolkata like Belgachia, Dumdum and some area of south Kolkata like Racecourse has higher liquefaction susceptibility for 0.15g PGA value. Liquefaction potential values are also calculated for other acceleration levels at this depth. Salt Lake area has less liquefaction potential at this depth due to the presence of a silty clay layer, which reduces the possibility of liquefaction at this depth.

At 10-metre depth (Figure 10), some locations of northern Kolkata like Belgachia, some area in south Kolkata like Behala, Tolleygaunge have liquefaction potential value more than 1 for acceleration level more than 0.15g. At this depth some portions of south Kolkata like Kalighat, Tolleygaunge, Behala and some area of north Kolkata like Belgachia, Dumdum cantonment have higher liquefaction probability for PGA value more than or equal to 0.2g. All other regions have relatively lower liquefaction potential value at this depth.

Table 1: Different Peak Ground Acceleration For Different Magnitude Of Earthquake For Kolkata Site

Sl. No.	Magnitude of Earthquake	Peak Ground Acceleration
1	8.5	0.283
2	8	0.240
3	7.5	0.202
4	7	0.170
5	6.5	0.143
6	6	0.119
7	5.5	0.099
8	5	0.083
9	4	0.057

Table 2: Some Typical Input Value Obtained from a Bore log Data.

Borehole no.	X (M)	Y (M)	DEPTH (M)	N-VALUE	Sand (%)	Silt (%)	Clay (%)	Bulk density (Kn/M^3)	Dry density (Kn/M^3)	Water content	Specific gravity	D_{50}
108	16478	15501	2	7	10	63	27	19.23	14.98	0.28	2.68	0.022
			4	7	10	63	26	18.02	13.3	0.36	2.67	0.013
			5	13	44	48	8	18.2	14.1	0.29	-	-
			7	22	96	4	0	-	-	-	-	0.19
			9	20	85	15	0	18.2	14.1	0.29	-	-
			11	24	1	48	51	17.7	12.2	0.45	2.59	0.0055
			13	22	94	6	0	18.2	14.1	0.29	-	-
			15	36	0	39	61	19.5	15.4	0.27	-	0.0006
			17	23	9	32	59	18.8	14.5	0.3	2.67	0.0008
			19	39	1	48	51	18.8	14.5	0.3	2.67	0.0008
			21	72	95	5	0	18.2	14.1	0.29	-	-
			22.1	18	17	63	19	17.75	13.5	0.32	2.67	0.026
			24	31	2	42	56	-	-	-	-	-
			26	36	92	8	0	-	-	-	-	0.18
			28	40	1	45	54	-	-	-	-	-
			34	47	92	8	0	-	-	-	-	0.2

Table 3: Some Typical Results From A Neural Network Model

Borehole no.	X	Y	Depth	D_{50} (Actual)	D_{50} (Predicted)
108	16478	5817	4	0.355	0.289
97	16651	5142	11	0.0015	0.002
97	16651	5142	37.1	0.059	0.059
97	16651	5142	27	0.16	0.166
28	6330	13136	6	0.0125	0.013
72	16826	8647	18.5	0.0028	0.074
68	16644	9556	6	0.002	0.002
97	16651	5142	5.1	0.016	0.015

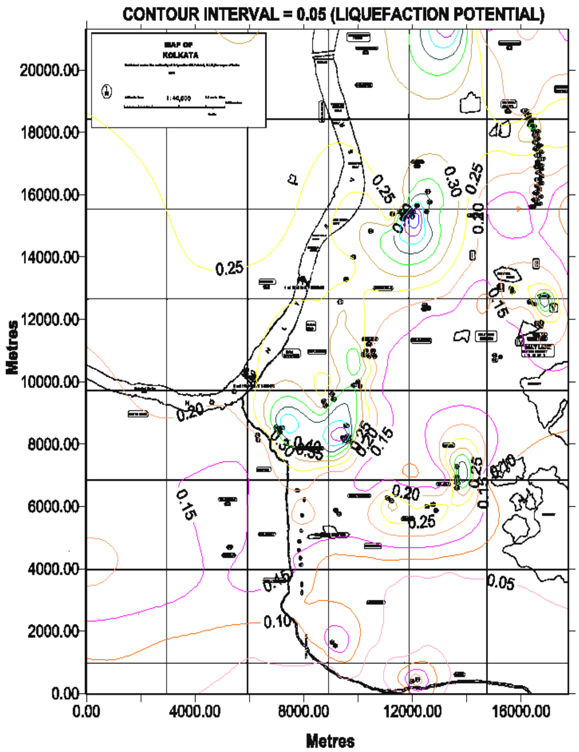

Figure: 3 Liquefaction Potential Map of Kolkata City at 2.5 Metres Depth for Peak Ground Acceleration of 0.05g

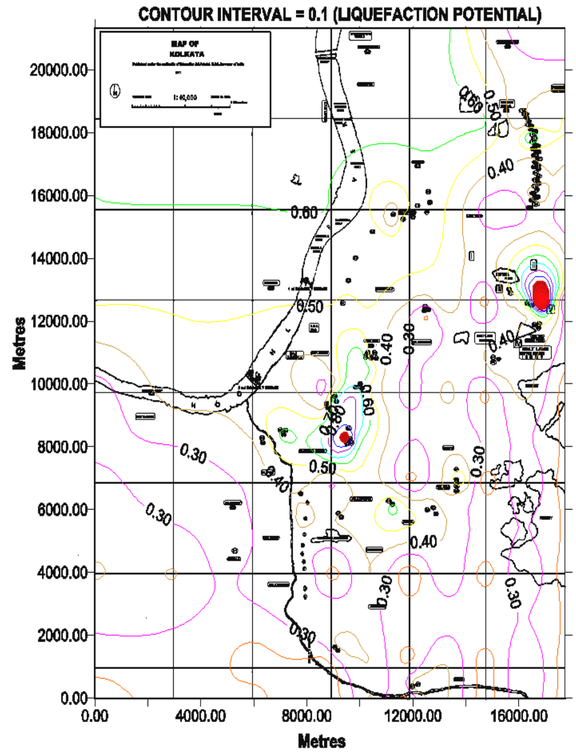

Figure: 4 Liquefaction Potential Map of Kolkata City at 2.5 Metres Depth for Peak Ground Acceleration of 0.1g

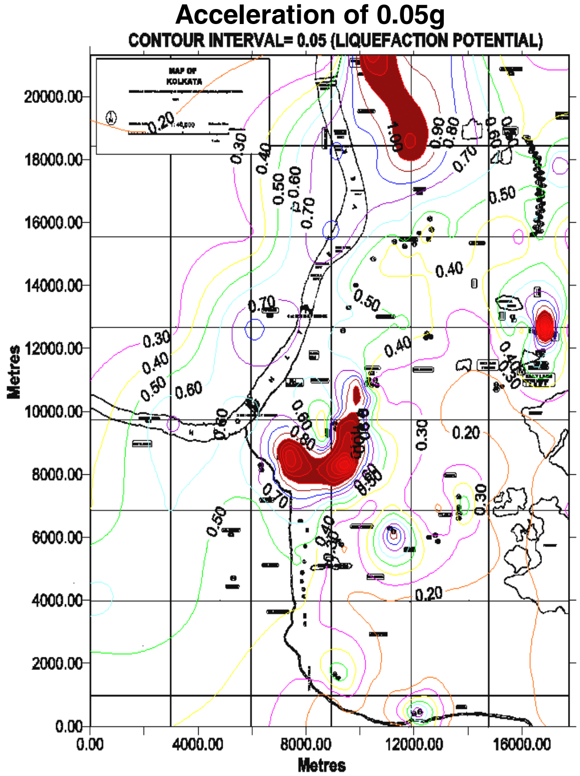

Figure: 5 Liquefaction Potential Map of Kolkata City at 2.5 Metres Depth for Peak Ground Acceleration of 0.15g

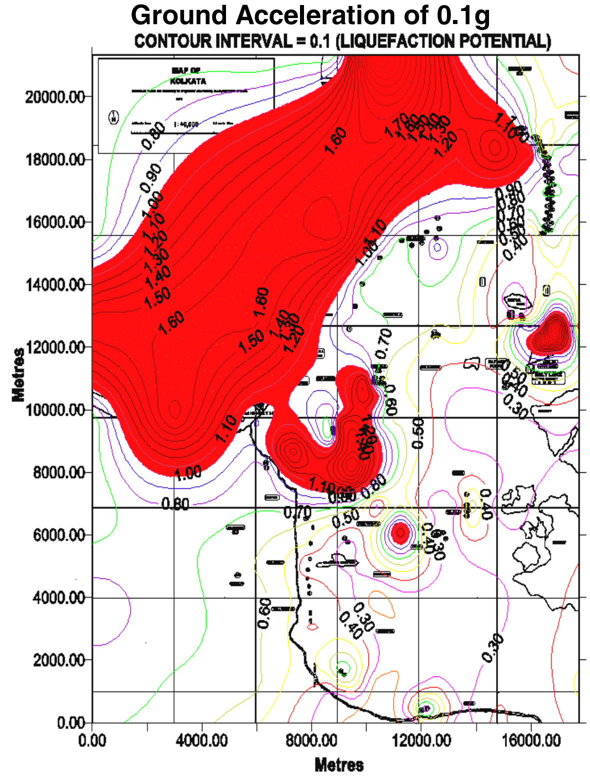

Figure: 6 Liquefaction Potential Map of Kolkata City at 2.5 Metres Depth for Peak Ground Acceleration of 0.2g

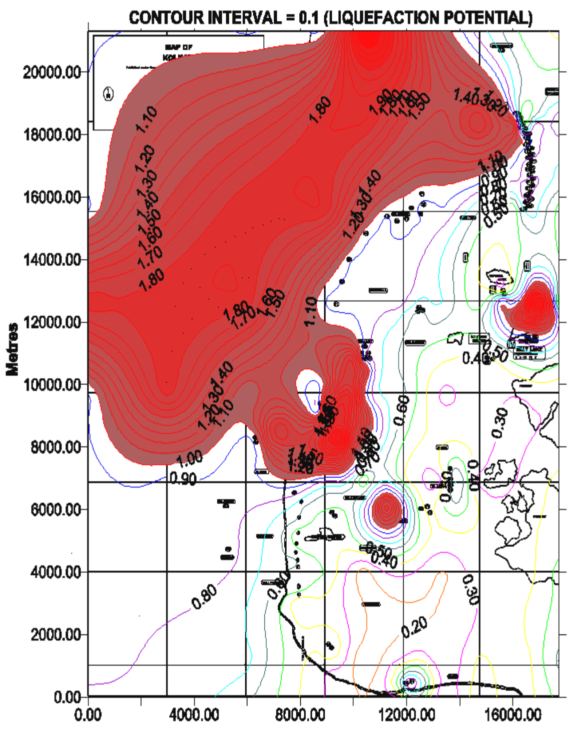

Figure: 7 Liquefaction Potential Map of Kolkata City at 2.5 Metres Depth for Peak Ground Acceleration of 0.25g

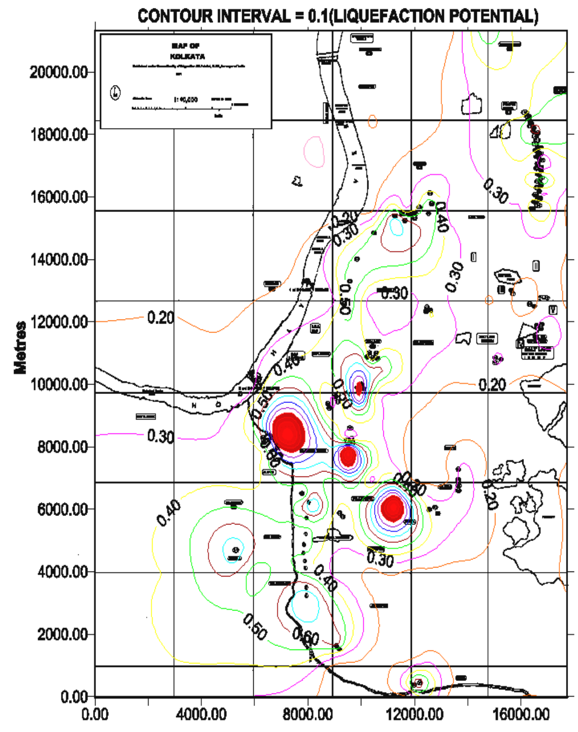

Figure: 8 Liquefaction Potential Map of Kolkata City at 5.0 Metres Depth for Peak Ground Acceleration of 0.15g

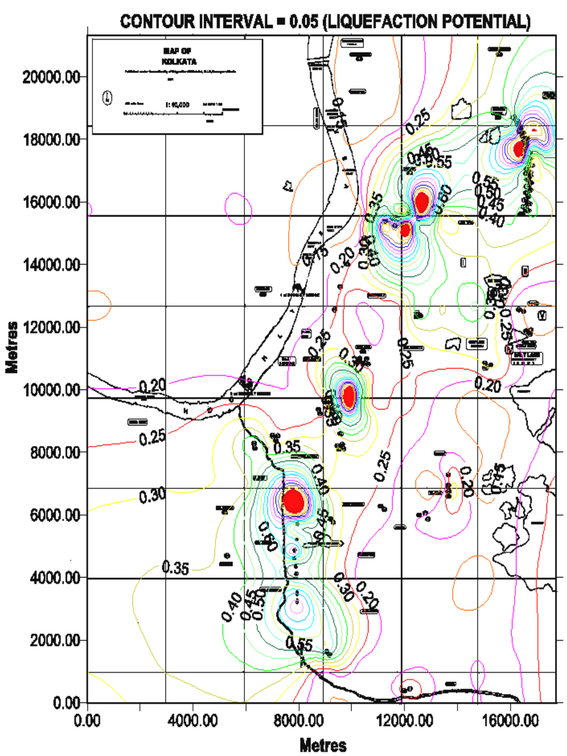

Figure: 9 Liquefaction Potential Map of Kolkata City at 7.5 Metres Depth for Peak Ground Acceleration of 0.15g

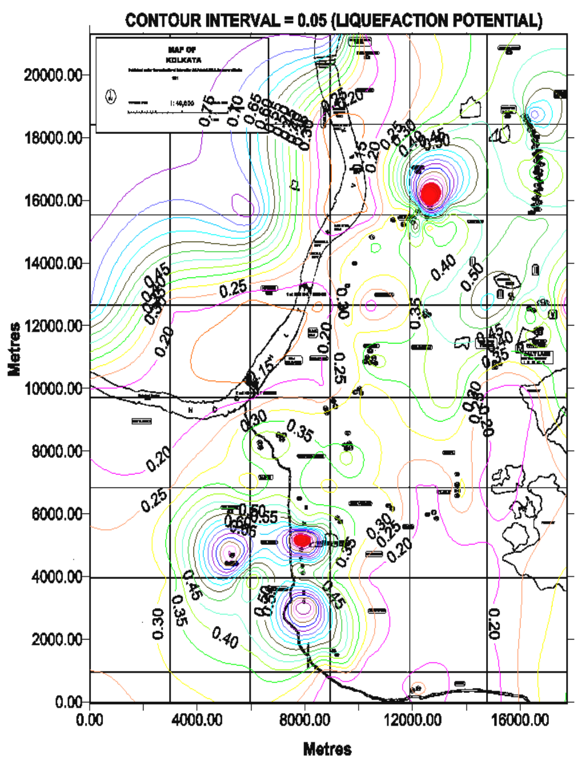

Figure: 10 Liquefaction Potential Map of Kolkata City at 10 Metres Depth for Peak Ground Acceleration of 0.15g

CONCLUSIONS

Based on the study for assessment of liquefaction potential for Kolkata City, it is concluded that:

- River Channel deposit in South Kolkata area like Tolleygaunge, Kasba are found to be most susceptible to liquefaction. Extra care should be taken against liquefaction during construction of a structure upon this type of deposit.
- The Salt Lake region being a reclaimed area has a top layer of very loose fine sand followed by soft to medium stiff / loose sandy silt or clayey silt mixed with decayed vegetations and this soil is also susceptible to liquefaction.
- The Normal Kolkata deposit in central Kolkata areas like Beliaghata, Sealdah generally are less susceptible to liquefaction.
- From the study it is also concluded that if an earthquake of magnitude more than or equal to 7 on Richter Scale occurs in Kolkata or adjacent region then most of the areas will be extensively damaged due to liquefaction while only some part of Central Kolkata will be marginally damaged due to liquefaction at that magnitude.

REFERENCES

1. Todorovska, M.I., "Quick Reference Liquefaction Opportunity Maps For A Metropolitan Area", Proc. Third ASCE Special Conf. on Geotechnical Earthquake Engineering and Soil Dynamics, 1998, 2-6 Aug, Seattle Washington, ASCE, Geotechnical Special Publication No. 75, Vol. 1, pp. 116-127.
2. Ansary, M.A., Rashid, M.A., "Generation Of Liquefaction Potential Map For Dhaka, Bangladesh", 8th ASCE Specialty Conference on Probabilistic Mechanics and Structural Reliability, 24-26 July 2000, Notre Dame, Indiana, PMC2000-061.
3. Rao, K.S., "Liquefaction Studies for Microzonation of Delhi Region", IGC 2001- "The New Millennium Conference" 14-16 December, Indore (M.P.) India.
4. BIS, "IS 1893: Criteria for Earthquake Resistance Design of Structure (Part 1) - General Provision and Buildings", 2002, Bureau of Indian Standards, Manak Bhawan, New Delhi.
5. Seed, H.B., Idriss, I.M., "A simplified Procedure for Evaluating Soil Liquefaction Potential", Earthquake Engineering Research Centre, 1970, report no. EERC 70-9, November.
6. Seed, H.B., Idriss, I.M., Arango, I., "Evaluation of Liquefaction Potential Using Field Performance Data", Journal of Geotechnical Engineering Division, 1983, ASCE, vol.-109, No.-3, March.
7. Dostidar, A. G., Ghosh, P. K., "Subsoil condition of Calcutta", Symposium on 'The Study of Soil Properties in Calcutta Region', 1964, Calcutta, September 19-20.
8. Abrahamson, N.A., and Litehiser, J.J., "Attenuation of vertical peak acceleration", Bull. Seismological Society of America, 1989, 79(3), pp. 549-580.
9. Goh, A.T.C., "Probabilistic neural network for evaluating seismic liquefaction potential", Canadian Geotechnical Journal, 2002, vol.39, pp.219-232.
10. Pandey, A.D., Venkatesh K., Mukerjee, S., "Application of Artificial Neural Networks in Estimating SPT N-Value", Indian Geotechnical Conference, 2002, Allahabad, pp. 505-508.
11. Cal, Y., "Soil classification by neural network", Advances in Engineering Software, 1995, 22, pp. 95-97.
12. Goh, A.T.C., "Seismic Liquefaction Potential Assessed by Neural Networks", Journal of Geotechnical Engineering, 1994, ASCE, vol.120, No. 9, September.
13. Pandey, A.D., Mukerjee, S., Gupta, D.K., Varma, G.S., "Neural-Nets for Evaluation of Liquefaction Potential", South-Asian Countries Conference on Challenges to Architects and Civil Engineers During Twenty-First Century, 1999, Kathmandu, Nepal, April 7-9.
14. Rahman, M.S., Zahaby, K.M.El., "Probabilistic liquefaction risk analysis including fuzzy variables", Soil dynamics and Earthquake Engineering, 1997, 16, pp. 63-79.
15. Rahman, M.S., Wang, J., "Fuzzy neurl network models for liquefaction prediction", Soil Dynamics and Earthquake Engineering, 2002, 22, pp. 685-694.