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SOIL LIQUEFACTION AND ITS EVALUATION BASED ON SPT BY SOFT-COMPUTING TECHNIQUES

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Abstract

Damages due to earthquakes in the 21st century have attracted many researchers and engineers on the seismic safety of densely populated cities. One of the fastest growing city Allahabad in Uttar Pradesh (India) is situated on the bank of river Ganga and Yamuna. Most part of river Ganga carries alluvial soil which is an important parameter that influences liquefaction potential of soil. Several factors that also can affect liquefaction behavior of soil that are local site condition, water table location etc. Present research work motivates on liquefaction potential of soil calculated by semi-empirical methods (like Modified Seed's method, Idriss and Boulanger (I&B) method & Tokimatsu and Yoshimi (T&Y) method). The calculated liquefaction value had been used as output/target value for developing the soft computing models. Artificial Neural Network (ANN) & Adaptive Neuro Fuzzy Inference System (ANFIS) techniques have been adapted to the development of soft computing models. I&B method gives more conservative results than other one semi empirical methods.

Keywords

Earthquakes, Liquefaction, Artificial Neural Network (ANN), Adaptive Neuro Fuzzy Inference System (ANFIS)

1. Introduction

Liquefaction is destructive threats due to an earthquake. This can be as a tendency of loose sand to compress once a load is applied on the other hand dense sands tends to expand in volume or 'dilate' when exposed to high water content. If the water saturates the soil then, water fills the gaps between soil grains. Due to that, the pressure of this pore water will increase and makes an attempt to flow out of the soil from the zones of low pressure (generally rising near the ground surface) (Kumar, 2009).

Strong earthquakes in other part of the world like Niigata & Alaska (1964), San Fernando (1971), Loma Prieta (1989), Northridge (1994), California and Japan (1995), Turkey (1999), Taiwan (1999) and Canterbury (2010) earthquake have provided additional evidence of the damaging due to liquefaction. The most recent earthquake like Kathmandu Earthquake struck in 2015 was felt several major cities in India; Sikkim earthquake occurred in 2011, of magnitude 6.9 was felt up to Allahabad, Delhi, Jaipur and North Central Region (NCR) in India. To assess the liquefaction for a zone or region is always an important duty for engineers and researchers to protect the structures from this phenomenon.

India has experienced some strong earthquakes, like Assam-1897 (M = 8.7), Kangara-1905 (M = 8.6), Bihar-Nepal-1934 (M = 8.4), Latur-1993 (M= 6.4), Chamoli-1999 (M = 6.8), Muzaffarabad-Kashmir-2005 (M = 7.6). In recent past some frequent earthquakes jolted the India viz Delhi NCR 2011 (M = 4.2), Sikkim India 2011 (M = 6.9), New Delhi 2012 (M = 4.9) and Koyna Nagar 2012 (M = 4.9).

Figure 1: *Soil liquefaction and lateral spreading after the 2001 Nisqually earthquake*

Figure 2: *East Coast of Honshu, Japan, March 11, 2011 Magnitude 9.0*

Figure 3: *Pile foundation after liquefaction (Source: http://www.ktoo.org)*

The seismicity status of Allahabad city is low and it is placed in the zone-II as per beauro of Indian standard code BIS-1893 (2002). It has been seen in past liquefaction had been occurred in area of low seismicity viz. Latur (Magnitude-6.2), Jabalpur (Magnitude-6.0) etc. Before the Latur earthquake, it was in zone-I but, now it is zone-III (Mahapatra et al., 2010). Allahabad city is also situated on the bank of river Ganga and Yamuna and these river beds are situated near the fault plane. This study will lead to assess and analyze of liquefaction potential to densify the liquefaction prone zone in Allahabad city.

The average standard penetration resistance ($\bar{N}$) at any boreholes is computed by the following expression (Pallav et al., 2012).

$$\bar{N} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \left({d_i}/{N_i} \right)} \tag{1}$$

Where, d_i and N_i are the thickness and the SPT-N value of i^{th} layer, n is the total number of soil layers. Out of 70 boreholes in the present study 28 & 42 boreholes are classified as E-type ($\bar{N} < 15$) and D-type ($15 < \bar{N} < 50$) respectively. As per IBC E-type sites are susceptible to liquefaction of soil and failure. Therefore it can be said that as most parts of Allahabad city are vulnerable to liquefaction induced failure.

Depth of water table is also one of the most pertinent parameters that influence liquefaction potential of soil. Depth to water from ground level in pre monsoon ranges between 3.0 to 15.0 meter below and average water level is 6.0 to 7.0 meter below in Trans Ganga area. Post monsoon water table varies in between 1.5 to 13.0 meter below ground level in Trans Ganga area. Water level varies 5.0 to 6.0 meter below ground level in Trans Yamuna area (Singh et al., 2014).

After Japan earthquake, Seed and Idriss (1971) proposed frameworks for SPT-N-based assessments of liquefaction potential in simplified way. This procedure is time to time modified and improved by the researchers like Seed, 1979; Seed and Idriss, 1982; Seed et al., 1985; Youd et al., 2001; Cetin et al., 2004; Idriss and Boulanger, 2006). In 1997, a report published by National Centre for Earthquake Engineering Research (NCEER) but review continued till Youd et al. 2001 published final recommendation on behalf of the committee which then became standard for liquefaction assessment. Numerous additional researchers have made subsequent improvement, and these types of SPT-based methods continue to evolve today.

2. Techniques Adopted

For estimation of liquefaction potential by empirical methods following protocol has been followed:

2.1 Geotechnical Data: Conventional methods govern the data requirements. Therefore, geotechnical data required for liquefaction potential assessment are: Depth; SPT-N value; Soil type; Grain size; Density; Depth of water table etc. Geotechnical data are required for the assessment of liquefaction potential was collected from different agencies like MNNIT Allahabad; Uttar Pradesh Public Works Division (UPPWD) Allahabad; Uttar Pradesh Jal Nigam Limited (UPJNL) etc. Total 70 borehole datasets (214 datasets) were collected to assess the liquefaction potential. These datasets are summarized in Table 1.

2.2 Seismic Data: Conventional method has the relationship between geotechnical data and seismic data therefore seismic data required for liquefaction potential assessment are Earthquake Magnitude; maximum horizontal acceleration.

Variation of maximum horizontal acceleration (a_{max}) taken from the analysis from Bhuj earthquake (2001) felt 0.35g. To carry out the parametric study, earthquake magnitude (M) 8.0 and depth of water table at ground level were also assumed.

On the variation of these data, liquefaction potential of soils by conventional methods have been determined which is extensively discussed in next section.

3. Appraisal of Liquefaction Potential

Collected datasets and variations of seismic parameters as well as depth of water table from ground level were used for the evaluation of liquefaction potential by conventional as well as computational methods.

3.1 Evaluation of Liquefaction Potential by Conventional Approaches

There are three semi empirical approaches have been used to evaluate liquefaction potential these are modified Seed's method, I&B method and T&Y method. These methods follow certain protocols:

- Estimation of the CSR.
- Estimation of the CRR.
- Evaluation of factor of safety against liquefaction potential of soils.

FOS estimated by semi-empirical methods for all 70-borehole data i.e. 214 datasets with the aforesaid depth of water table, earthquake magnitude and horizontal acceleration. The estimated FOS was used for development of model by computational models. FOS obtained by conventional methods is also arranged in Table 1.

Table 1: *Detail of Datasets of Bore Hole*

S. No.	Bore Hole No.	Depth (m)	SPT Value	Particle Size Distribution: Percentage finer than in mm			moisture content	Unit Weight	Specific Gravity	Angle of Internal Friction (ϕ)	*LP Value*		
				2.00	0.075	0.002	%	gm/cc			*Modified Seed's Method*	I&B	T&Y
1.	BH-1	1.5	18	100	45	4	4.8	1.84	2.65	25	0.824	0.469	0.502
2.		3	13	100	45	4	4.8	1.84	2.65	25	0.625	0.334	0.347
3.		4.5	22	100	45	4	4.8	1.84	2.65	25	0.793	0.448	0.372
4.	BH-2	1.5	15	99	26	3	5.9	1.82	2.65	23	0.736	0.41	0.393
5.		3	19	99	26	3	5.9	1.82	2.65	23	0.772	0.44	0.356
6.		4.5	32	99	26	3	5.9	1.82	2.65	23	1.056	0.704	0.390
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
210.	BH-69	1.5	17	92.51	88.62	5.3	18.6	1.82	2.66	16	0.795	0.439	0.759
211.		3	14	92.51	88.62	5.3	18.6	1.82	2.66	16	0.650	0.330	0.420
212.		4.5	15	99.91	90.66	4.35	28.3	2.16	2.66	20	0.624	0.350	0.410
213.	BH-70	4.5	17	98.59	97.64	4.68	26.7	2.28	2.66	18	0.659	0.382	0.446
214.		6	17	98.59	97.64	4.68	26.7	2.28	2.66	18	0.633	0.366	0.432

3.2 Development of Liquefaction Potential models by Computational Methods

To develop the ANN & ANFIS total 214 datasets were collected in terms of input and output values of the models for Allahabad city. Out of these 214 datasets, 36 datasets were reserved for examine the developed model. Hence, there are 178 datasets were used to develop the model.

3.2.1 Development of ANN model

In this literature, eight input variables were used. SPT-N value (N), depth (d), bulk unit weight (γ_t), particle size finer than 0.075 mm ($D_{0.075}$), natural/field moisture content (w_f), particle size finer than 2.00 mm ($D_{2.0}$), particle size finer than 0.002 mm ($D_{0.002}$) and angle of internal friction (φ) are the eight input variables whose range are shown in Table 2.

Table 2: *Ranges of Input Parameters.*

Input Parameters	Ranges
SPT-N value (N)	0-50
depth (m)	0-12
Bulk unit weight (γ_t)	1.31-2.39
Particle finer than 0.075 mm (%) ($D_{0.075}$)	18.34-99.69
Natural water content (w_n)	1.16-43.9
Particle finer than 2.0 mm (%) ($D_{2.0}$)	69.92-100
Particle finer than 0.002 mm (%) ($D_{0.002}$)	0-15
Angle of internal friction (φ)	14-42.6

Normalization of input parameters (Vijay et al., 2014) is based on activation (tan-sigmoid) transfer function, which has been used in this research.

To identify combination, a coding was used, as $M_8A_{0.35}W_0$ where, M_8 denotes earthquake at 8.0 magnitudes, W_0 denotes depth of water table is at ground level and $A_{0.35}$ denotes maximum horizontal acceleration is 0.35g. The predicted values of liquefaction potential as FOS by developed models are discussed in subsequent heading.

MATLAB (7.4) software was used for all operations in which ANN were trained having varying hidden layers (single or double) with varying numbers of neurons from 2 to 20. Liquefaction potential evaluated from parametric study was used as output variable whereas input variable taken from borehole data. Considering every condition and case of parameters and network architecture ANN models were developed.

3.2.2 Development of ANFIS model

To, ANFIS tool in MATLAB (7.4) was also used for the development of ANFIS networks. Networks were trained with three membership functions (triangular) and up to 75 numbers of epochs for each of the eight input vectors. Grid partitioning methods were used to generate the FIS, whereas linear membership function was used for the target variable. Hybrid optimization technique was used for training the FIS.

4. Results and Discussion

On the basis of LP values obtained by various semis empirical approached like modified Seed's method, I&B method and T&Y method, computational models (ANN & ANFIS) has been developed. These developed models have been examined with the reserved datasets. On the basis of results obtained, further discussion has been carried out.

4.1 LP by Computational Models

Results predicted by ANN and ANFIS were studied but in this literature only one model has been discussed whose combination is $M_8A_{0.35}W_0$. It can be observed that prediction in accordance with ANN results by actual liquefaction potential. ANN showed good prediction accuracy. Comparative study between results estimated through semi empirical methods and results obtained by various soft computing i.e. by ANN and ANFIS are shown in Table 3 & 4 respectively.

Table 3: *Comparative study of L.P. for Combination $M_8A_{0.35}W_0$ between Empirical method and ANN*

S. No.	Depth (m)	SPT-N value	Liquefaction Potential Value by											
			Modified Seed's method		ANN		I&B method		ANN		T&Y method		ANN	
			Ratio	Status	Ratio	Status	Ratio	Status	Ratio	Status	Ratio	Status	Ratio	Status
1.	1.5	16	0.648	Yes	0.636	Yes	0.181	Yes	0.195	Yes	0.181	Yes	0.176	Yes
2.	3.0	21	0.730	Yes	0.738	Yes	0.253	Yes	0.277	Yes	0.253	Yes	0.213	Yes
3.	1.5	14	0.582	Yes	0.620	Yes	0.11	Yes	0.079	Yes	0.11	Yes	0.094	Yes
4.	3.0	14	0.514	Yes	0.588	Yes	0.091	Yes	0.068	Yes	0.091	Yes	0.089	Yes
5.	4.5	26	0.809	Yes	0.786	Yes	0.329	Yes	0.232	Yes	0.329	Yes	0.367	Yes
6.	1.5	7	0.197	Yes	0.194	Yes	0.015	Yes	0.016	Yes	0.015	Yes	0.014	Yes
7.	3.0	39	1.500	No	1.171	No	1.500	No	1.494	No	1.500	No	1.496	No
8.	4.5	40	1.288	No	1.093	No	1.279	No	1.444	No	1.279	No	1.343	No
9.	6.0	45	1.362	No	1.256	No	1.500	No	1.327	No	1.500	No	1.494	No
10.	7.5	24	0.604	Yes	0.631	Yes	0.217	Yes	0.211	Yes	0.217	Yes	0.204	Yes
11.	9.0	32	0.745	Yes	0.723	Yes	0.384	Yes	0.323	Yes	0.384	Yes	0.369	Yes
12.	1.5	4	0.007	Yes	0.010	Yes	0.03	Yes	0.030	Yes	0.03	Yes	0.030	Yes
13.	3.0	7	0.101	Yes	0.114	Yes	0.03	Yes	0.030	Yes	0.03	Yes	0.029	Yes
14.	6.0	21	0.522	Yes	0.514	Yes	0.238	Yes	0.166	Yes	0.238	Yes	0.234	Yes
15.	9.0	9	0.107	Yes	0.055	Yes	0.002	Yes	0.0018	Yes	0.03	Yes	0.028	Yes
16.	7.5	11	0.200	Yes	0.113	Yes	0.008	Yes	0.007	Yes	0.008	Yes	0.011	Yes
17.	9.0	12	0.212	Yes	0.109	Yes	0.036	Yes	0.047	Yes	0.036	Yes	0.031	Yes
18.	4.5	17	0.491	Yes	0.470	Yes	0.158	Yes	0.163	Yes	0.158	Yes	0.156	Yes
19.	6.0	17	0.460	Yes	0.394	Yes	0.139	Yes	0.149	Yes	0.139	Yes	0.135	Yes
20.	1.5	15	0.585	Yes	0.586	Yes	0.192	Yes	0.192	Yes	0.172	Yes	0.198	Yes
21.	3.0	19	0.627	Yes	0.654	Yes	0.228	Yes	0.213	Yes	0.127	Yes	0.137	Yes
22.	4.5	32	0.969	Yes	0.950	Yes	0.545	Yes	0.579	Yes	0.168	Yes	0.182	Yes
23.	3.0	19	0.629	Yes	0.603	Yes	0.222	Yes	0.210	Yes	0.103	Yes	0.115	Yes
24.	4.5	26	0.771	Yes	0.816	Yes	0.347	Yes	0.314	Yes	0.108	Yes	0.106	Yes
25.	1.5	50	1.500	No	1.498	No	1.500	No	1.493	No	1.500	No	1.495	No
26.	3.0	10	0.293	Yes	0.364	Yes	0.05	Yes	0.051	Yes	0.052	Yes	0.055	Yes

27.	4.5	8	0.134	Yes	0.128	Yes	0.03	Yes	0.030	Yes	0.009	Yes	0.009	Yes
28.	6.0	26	0.765	Yes	0.880	Yes	0.256	Yes	0.261	Yes	0.18	Yes	0.103	Yes
29.	3.0	10	0.294	Yes	0.344	Yes	0.056	Yes	0.051	Yes	0.079	Yes	0.079	Yes
30.	4.5	17	0.519	Yes	0.547	Yes	0.157	Yes	0.165	Yes	0.082	Yes	0.095	Yes
31.	6.0	29	0.786	Yes	0.789	Yes	0.374	Yes	0.368	Yes	0.121	Yes	0.134	Yes
32.	3.0	50	1.500	No	1.497	No	1.500	No	1.490	No	1.500	No	1.496	No
33.	4.5	14	0.447	Yes	0.424	Yes	0.092	Yes	0.093	Yes	0.091	Yes	0.089	Yes
34.	6.0	11	0.243	Yes	0.184	Yes	0.037	Yes	0.040	Yes	0.07	Yes	0.08	Yes
35.	1.5	13	0.525	Yes	0.585	Yes	0.114	Yes	0.113	Yes	0.387	Yes	0.426	Yes
36.	3.0	16	0.549	Yes	0.539	Yes	0.112	Yes	0.083	Yes	0.24	Yes	0.256	Yes

Table 4: *Comparative study of L.P. for Combination $M_8A_{0.35}W_0$, between Empirical method and ANFIS model*

S. No.	Depth (m)	SPT-N value	Liquefaction Potential Value by											
			Modified Seed's method		ANFIS		I&B method		ANFIS		T&Y method		ANFIS	
			ratio	status	ratio	status	ratio	status	ratio	status	ratio	status	ratio	status
1.	1.5	16	0.648	Yes	0.753	Yes	0.181	Yes	0.168	Yes	0.181	Yes	0.224	Yes
2.	3.0	21	0.730	Yes	0.725	Yes	0.253	Yes	0.158	Yes	0.253	Yes	0.170	Yes
3.	1.5	14	0.582	Yes	0.545	Yes	0.110	Yes	0.102	Yes	0.110	Yes	0.099	Yes
4.	3.0	14	0.514	Yes	0.548	Yes	0.091	Yes	0.096	Yes	0.091	Yes	0.080	Yes
5.	4.5	26	0.809	Yes	0.599	Yes	0.329	Yes	0.365	Yes	0.329	Yes	0.339	Yes
6.	1.5	7	0.197	Yes	0.128	Yes	0.015	Yes	0.014	Yes	0.015	Yes	0.017	Yes
7.	3.0	39	1.500	No	1.214	No	1.500	No	1.425	No	**1.500**	**No**	**0.980**	**Yes**
8.	4.5	40	1.288	No	1.329	No	1.279	No	1.479	No	**1.279**	**No**	**0.850**	**Yes**
9.	6.0	45	1.362	No	1.467	No	1.500	No	1.493	No	**1.500**	**No**	**0.908**	**Yes**
10.	7.5	24	0.604	Yes	0.600	Yes	0.217	Yes	0.216	Yes	0.217	Yes	0.216	Yes
11.	9.0	32	0.745	Yes	0.671	Yes	0.384	Yes	0.326	Yes	0.384	Yes	0.316	Yes
12.	1.5	4	0.007	Yes	0.009	Yes	0.030	Yes	0.033	Yes	0.030	Yes	0.025	Yes
13.	3.0	7	0.101	Yes	0.193	Yes	0.030	Yes	0.037	Yes	0.030	Yes	0.028	Yes
14.	6.0	21	0.522	Yes	0.579	Yes	0.238	Yes	0.180	Yes	0.238	Yes	0.278	Yes
15.	9.0	9	0.107	Yes	0.213	Yes	0.002	Yes	0.002	Yes	0.030	Yes	0.030	Yes
16.	7.5	11	0.200	Yes	0.204	Yes	0.008	Yes	0.009	Yes	0.008	Yes	0.006	Yes
17.	9.0	12	0.212	Yes	0.264	Yes	0.036	Yes	0.030	Yes	0.036	Yes	0.032	Yes
18.	4.5	17	0.491	Yes	0.486	Yes	0.158	Yes	0.194	Yes	0.158	Yes	0.209	Yes
19.	6.0	17	0.460	Yes	0.443	Yes	0.139	Yes	0.161	Yes	0.139	Yes	0.109	Yes
20.	1.5	15	0.585	Yes	0.600	Yes	0.192	Yes	0.215	Yes	0.172	Yes	0.122	Yes
21.	3.0	19	0.627	Yes	0.618	Yes	0.228	Yes	0.231	Yes	0.127	Yes	0.134	Yes
22.	4.5	32	0.969	Yes	0.917	Yes	0.545	Yes	0.393	Yes	0.268	Yes	0.268	Yes
23.	3.0	19	0.629	Yes	0.602	Yes	0.222	Yes	0.213	Yes	0.103	Yes	0.117	Yes
24.	4.5	26	0.771	Yes	0.759	Yes	0.347	Yes	0.401	Yes	0.108	Yes	0.111	Yes
25.	1.5	50	1.500	No	1.496	No	1.500	No	1.500	No	1.500	No	1.500	No
26.	3.0	10	0.293	Yes	0.390	Yes	0.05	Yes	0.046	Yes	0.052	Yes	0.053	Yes
27.	4.5	8	0.134	Yes	0.119	Yes	0.030	Yes	0.030	Yes	0.009	Yes	0.008	Yes
28.	6.0	26	0.765	Yes	0.713	Yes	0.256	Yes	0.224	Yes	0.180	Yes	0.210	Yes
29.	3.0	10	0.294	Yes	0.392	Yes	0.056	Yes	0.063	Yes	0.079	Yes	0.065	Yes
30.	4.5	17	0.519	Yes	0.516	Yes	0.157	Yes	0.188	Yes	0.082	Yes	0.083	Yes
31.	6.0	29	0.786	Yes	0.788	Yes	0.374	Yes	0.365	Yes	0.121	Yes	0.119	Yes
32.	3.0	50	1.500	No	1.494	No	1.500	No	1.500	No	1.500	No	1.499	No
33.	4.5	14	0.447	Yes	0.428	Yes	0.092	Yes	0.113	Yes	0.091	Yes	0.086	Yes
34.	6.0	11	0.243	Yes	0.408	Yes	0.037	Yes	0.037	Yes	0.070	Yes	0.080	Yes
35.	1.5	13	0.525	Yes	0.701	Yes	0.114	Yes	0.186	Yes	0.387	Yes	0.317	Yes
36.	3.0	16	0.549	Yes	0.525	Yes	0.112	Yes	0.029	Yes	0.24	Yes	0.241	Yes

The AAE, RMSE and Coefficient of correlation for the combination $M_8A_{0.35}W_0$ are shown in table 5.

Table 5: *Statistical parameters between LP value obtained from examined models and semi empirical methods*

Empirical Methods	Values obtained by ANN			Values obtained by ANFIS		
	AAE (%)	RMSE (%)	R^2	AAE (%)	RMSE (%)	R^2
Modified Seed's Method	11.496	17.629	0.9636	16.484	29.011	0.9535
I&B Method	9.160	13.220	0.9898	14.124	21.433	0.9868
T&Y Method	8.060	12.340	0.9991	13.570	17.790	0.9924

AAE: Average Absolute Error; RMSE: Root Mean Square Error; R^2 = Coefficient of Correlation

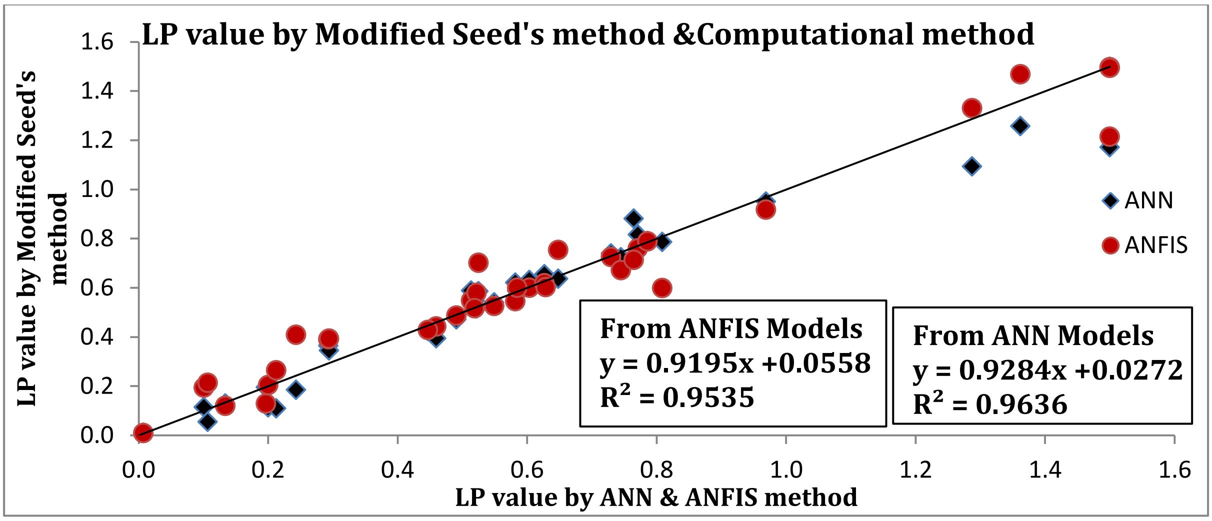

Figure 4: *Comparative Study of L.P. between Modified Seed's Method and Computational Methods*

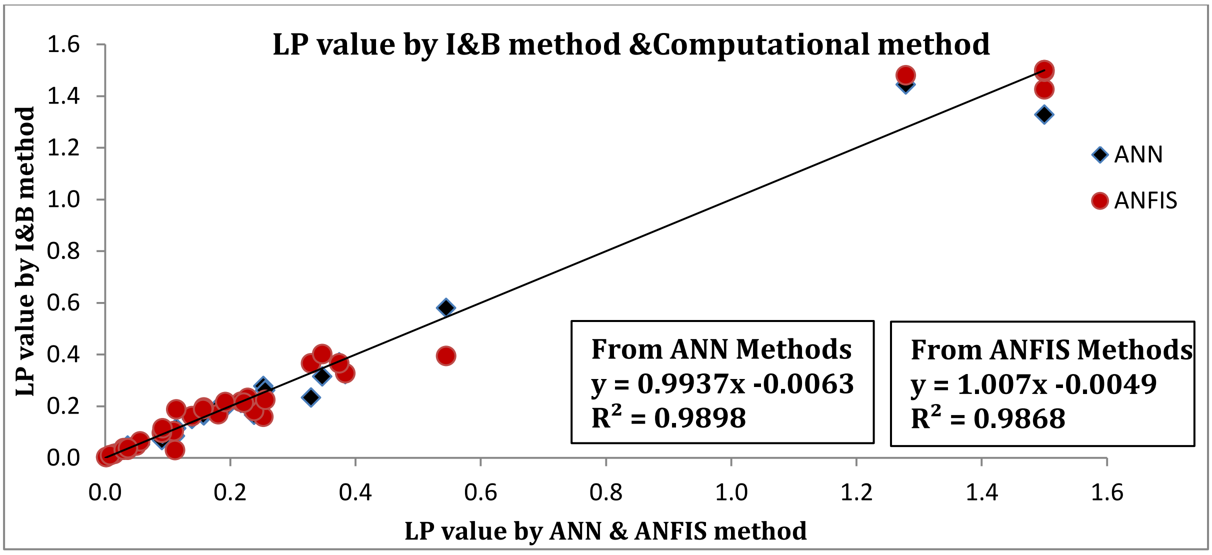

Figure 5: *Comparative Study of L.P. between I&B Method and Computational Models i.e. ANN & ANFIS*

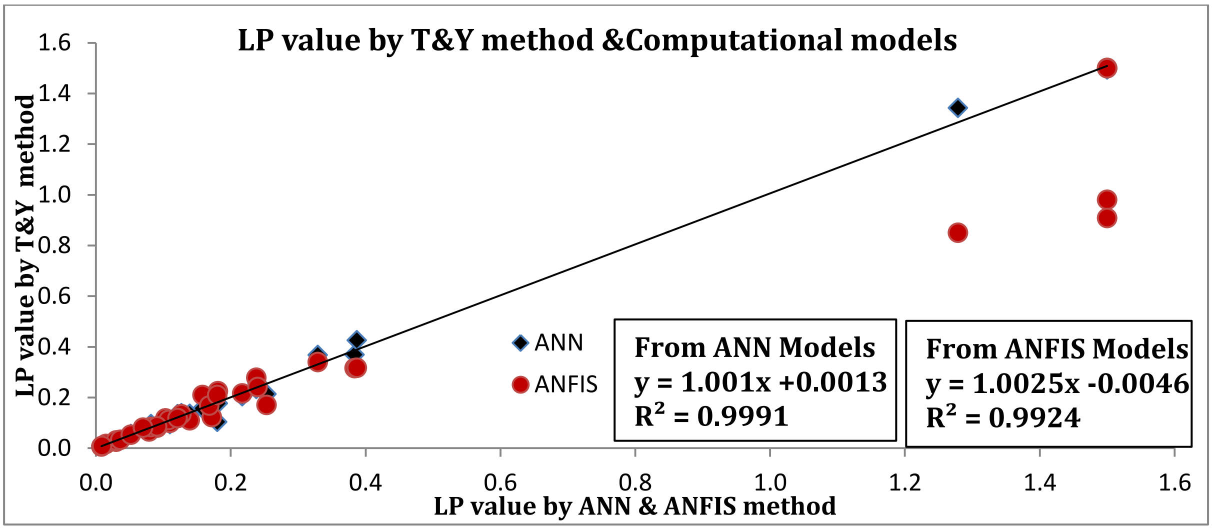

Figure 6: *Comparative Study of L.P. between T&Y Method and Computational Models i.e. ANN & ANFIS*

Fig. 4, 5 and 6 shows that the Comparative Study of L.P. between Modified Seed's method, I&B method and T&Y Method versus Various Computational Models i.e. ANN & ANFIS for $M_8A_{0.35}W_0$. There are three incorrect predictions found by ANFIS models of serial no. 7, 8 & 9. Rather than these three sets all predictions are correct.

5. Conclusions

In this paper, liquefaction potential was evaluated for above-mentioned combinations. Semi empirical methods like modified Seed's method, Idriss and Boulanger (I&B) method and Tokimatsu and Yoshimi (T&Y) method were applied to evaluate L.P. value is based on geotechnical datasets. The obtained FOS values were used to develop the ANN and ANFIS models. On the basis of present study following points may be concluded:

- Factors that affect the liquefaction potential of soils such as SPT-N value (N), depth (d), bulk density (ρ_f), particle size finer than 2.00 mm, 0.002 mm and 0.075 mm, natural/field moisture content (w_f), and angle of internal friction were selected as the evaluating indices during development of ANN model.
- It has been observed that predictions of L.P. by ANN & ANFIS models based on T&Y approach are having better predictive results.
- Liquefaction Potential study on Soils will also help the local government, organisations, builders and researchers in urban planning and its development.

Although the work presented in this work give the impression of an extensive and comprehensive study on the "Soil Liquefaction and its Evaluation Based on SPT by Soft-

Computing Techniques" But presence of more datasets for training testing and validation can improve the confidence level and reliability of the present results. To improve the analysis, a detailed soil investigation obtaining SASW data and CPT data are required for actual estimation of L.P.

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