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Estimation of liquefaction potential of soil using Neuro-Fuzzy Techniques

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Abstract- Liquefaction of loose, saturated granular soils during earthquake poses a major hazard in many region of the world. The determination of liquefaction potential of soil induce by earthquake is a major concern and an essential criterion in the design process of the civil engineering structure. This study refers to the estimation of liquefaction potential of soils by Neuro-Fuzzy models evaluated using Modified Seed's method. The potential of genetic expression programming (GEP) and Adaptive Neuro-Fuzzy (ANFIS) computing paradigm to forecast the safety factor for liquefaction for soils. Modified Seed's method used for evaluation of liquefaction potential of soils for its better estimation capability compared to other conventional methods. To estimate the liquefaction potential bore log data were obtained from SPT tests conducted at sites. Three hundred twenty five datasets from hundred eleven boreholes up to a depth of twelve meters were collected for training Neuro-Fuzzy models whereas seventy two datasets were reserved for validating the models. The predicted results of Neuro-Fuzzy models compared with Modified Seed's method advocate that trained Neuro-Fuzzy models are capable of predicting liquefaction potential adequately.

Keywords *- Liquefaction Potential, Neuro-Fuzzy Models, Standard Penetration Test, ANFIS, Modified Seed's*

I. INTRODUCTION

During an earthquake, when the ground is subjected to strong shaking, certain types of soils liquefy, often leading to ground failures. Ground failure associated with liquefaction of soils are potentially very damaging as forcefully demonstrated by many disastrous earthquakes of the past.

Modified Seed's method, Tokimatsu and Yoshimi method, Idriss and Boulanger method etc used for estimation of liquefaction potential of soil require in situ and laboratory test. Site exploration techniques like SPT are one of the suitable and familiar methods for soil specimen collection. However in-situ testing is tedious method involving skilled labour, high cost and extra time. Now a day's a new technique known as Neuro-Fuzzy in the field of artificial intelligence is in progress. Neuro-Fuzzy refers to the combination of artificial neural network and fuzzy logic. Neuro-Fuzzy which was first proposed by J.S.R. Jang [1] in fuzzy modeling environment is divided into two areas: linguistic fuzzy modeling which is focused on interpretability is mainly the Mamdani model; and precise fuzzy modeling that is focused on accuracy is mainly the Takagi-Sugeno-Kang (TSK) model.

Though computational methods have been applied in various field of civil engineering however limited applications are available in the area of liquefaction assessment Goh, 1995, 2002; Wang et al., 2010; Moradi et al, 2011; Wang and Rahman, 1999; Hanna et al., 2007a, 2007b; Hsu et al. 2006; kayabah, 1996; Sitharam, et al., 2004; Rao et al., 2007; Juang et al. 2000, 2001; Hsu et al. 2006; Ramakrishnan et al., 2008; Gracia et al., 2008; kayadelen et al., 2009 etc.[2-10].

Current research is the effort of assessing liquefaction potential at Allahabad city near the banks of river Ganga, Yamuna and central portion of Allahabad since alluvial soil is abundantly present in said areas. Soil strata on the bank of river Ganga and Yamuna mainly consists sandy and clayey soil at various depths. The upper part of strata contains major portion of silty soil and sandy silt enhancing probability. So there is a major chance of liquefaction occurrence in the upper soil zone at greater earthquake magnitude. Two different methods namely Modified Seed's and

ANFIS modeling approach are used to find out liquefaction potential of soil.

MODIFIED SEED'S METHOD

Modified Seed's had studied various places data and shown a very first generalized equation for suggestion liquefaction potential. This method has empirical approach finding out cyclic stress ratio. Cyclic stress ratio developed in the field due to earthquake shaking is readily computed from this method. This method is frequently used for liquefaction potential due to its simplicity. The various steps involved in this method are following:

1. Estimation of the cyclic stress ratio (CSR) induced at various depths within the soil by the earthquake.
2. Estimation of the cyclic resistance ratio (CRR) of the soil, i.e. the cyclic shear stress ratio which is required to cause initial liquefaction of the soil.
3. Evaluation of factor of safety against liquefaction potential of in situ soils

CALCULATION OF CSR

The average cyclic shear stress [11,16] imparted by the earthquake in the top 12 m of a soil deposit can be estimated by equation 1.

CSR= "avg / Ã,v = 0.65(Amax/g) ($Ã_v$ / $Ã'_v$) r_d ……….(1)

Value of CSR is adjusted for the moment magnitude M=7.5

Where, r_d = 1-0.00765z; z d 9.15m………….(2a)
= 1.174-0.0267z; 9.15m < z d 23m….(2b)
= 0.744- 0.008z; 23m < z d 30m…....(2c)

r_d = Stress reduction factor
A_{max} = Peak horizontal acceleration at the ground surface
g = acceleration due to gravity (9.81 m/s^2)
$Ã_v$ = total vertical stress in kN/m^2
$Ã'_v$ = total effective vertical stress in kN/m^2

CALCULATION OF CRR

Estimation of the cyclic resistance ratio (CRR) of the soil [11], for magnitude of 7.5, is given in equation 3.

$CRR_{7.5}$= $(a+cx+ ex^2+ gx^3)/(1+bx+ dx^2+ fx^3+ hx^4)$…….(3)

Where, $X=N_{60}$

a = 0.048 b = - 0.1248

c = - $4.721E^{-3}$ d = $9.578E^{-3}$

e = $6.136E^{-4}$ f = - $3.285E^{-4}$

g = - $1.673E^{-5}$ h = $3.714E^{-6}$

CRR FOR ANOTHER VALUE OF MAGNITUDE

The general equation of CRR for another value of magnitude is shown in equation 4 and Multiplication Scaling Factor (MSF) is given by equation 5.

CRR=MSF * $CRR_{7.5}$ ……............ (4)

MSF= $10^{2.24}/M^{2.56}$………………. (5)

MSF = multiplication scaling factor

CALCULATION OF FACTOR OF SAFETY

If the cyclic stress ratio caused by an earthquake is greater than the cyclic resistance ratio of the in situ soil, then liquefaction could occur during the earthquake, and vice versa. The factor of safety (FOS) against liquefaction is defined as:

FS=CRR/CSR ………… (6)

Liquefaction is predicted to occur when FSd 1.0, and liquefaction predicted not to occur when FS > 1. The higher the factor of safety, the more resistant against liquefaction however, soil that has a factor of safety slightly higher than 1.0 may still liquefy during the earthquake. (9)

ANFIS METHOD

Adaptive Neuro-Fuzzy Inference System (ANFIS) is one of the most successful schemes which combine the benefits of ANN and FIS into a single capsule [1]. The attractive features of an ANFIS include: easy to implement, fast and accurate learning, strong generalization abilities, excellent explanation facilities through fuzzy rules, and easy to incorporate both linguistic and numeric knowledge for problem solving [15]. According to the Neuro-Fuzzy approach, a neural network is proposed to implement the fuzzy system. A typical

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architecture of an ANFIS, in which a circle indicates a fixed node, whereas a square indicates an adaptive node, is shown in Figure 1.1. In this structure, there are input and output nodes, and in the hidden layers, there are nodes functioning as membership functions (MFs) and rules. For simplicity, we assume that the examined FIS has two inputs and one output. For a first-order Sugeno fuzzy model, a classic rule set with two fuzzy "if then" rules is as following:

Rule 1: if x is A_1 and y is B_1, then $f_1 = p_1x+q_1y+r_1$.......... (7a)
Rule 2: if x is A_2 and y is B_2, then $f_1 = p_2x+q_2y+r_2$........... (7b)

Where x and y are the two crisp inputs, and A_i and B_i are the linguistic labels associated with the node function.

As indicated in Fig. 1.1, the system has a total of five layers. The functioning of each layer is described as follows.

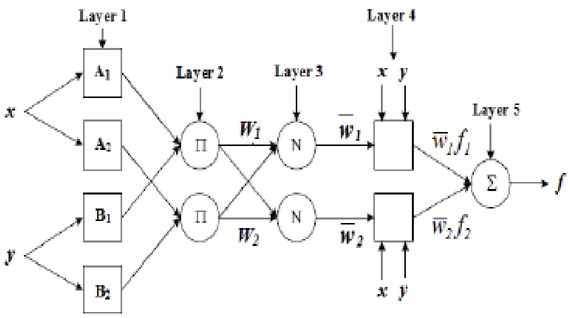

Fig.1.1 First order Sugeno ANFIS architecture

Input node (Layer 1): Nodes in this layer contains membership functions. Parameters in this layer are referred to as premise parameters. Every node i in this layer is a square and adaptive node with a node function:

$O_i^1 = \mu_{Ai}(x)$ for i =1,2………(8)

Where x is the input to node i, and A_i is the linguistic label (small, large, etc.) associated with this node function. In other words, O_i^1 the membership function of Ai and it specifies the degree to which the given x satisfies the quantifier A_i

Rule nodes (Layer 2): Every node in this layer is fixed node labeled , whose output is product of all incoming signals.

$O_i^2 = W_i = \mu_{Ai}(x) \times \mu_{Bi}(y)$ for i =1,2....................(9)

Average nodes (Layer 3): Every node in this layer is fixed node labeled N. The i^{th} node calculates the ratio between the i^{th} rule's firing strength to the sum of all rules' firing strengths. Every node of these layers calculates the weight, which is normalized. For convenience, outputs of this layer are called normalized firing strengths.

$$O_i^3 = \overline{w_i} = \frac{w_i}{w_1+w_2} \quad \text{for } i=1,2 \quad .....(10)$$

Consequent nodes (Layer 4): Every node **i** in this layer is an adaptive node with a node function

$$O_i^4 = \overline{w_i} \times f_1 = \overline{w_i} \times (p_i x + q_i y + r_i) \quad .... (11)$$

Where is a normalized firing strength from layer 3 and is the parameters set of this node. Parameters in this layer are referred to as consequent parameters.

Output node (Layer 5): The single node in this layer is a fixed node labeled ©, which computes the overall output as the summation of all incoming signals:

$$O_i^5 = \sum_i \overline{w_i} \times f_1 = \frac{\sum_i w_i \times f_i}{\sum_i w_i} \quad ....(12)$$

II. METHODOLOGY

To estimate liquefaction potential of sandy soil SPT tests on different stations were conducted as it is the most suitable site exploration test for sandy soil. Data collected from SPT tests were utilized to find out liquefaction potential through Modified Seed's method, further these data were used to develop ANFIS models. Output parameter that is occurrence of liquefaction in the ANFIS model is designed to answer in yes/no format based on Modified Seed's & Idriss method. The soil properties found through SPT and other laboratory test used as input vectors in ANFIS method is shown in Table 2.1.

INPUT PARAMETER	RANGE
Depth (m)	1.5-12
SPT-N value	2-50
Particle finer than 0.075 mm(%)	2.33-97.92
Natural water content (%)	0.55-43.98
Bulk unit weight (gm/cc)	1.18-3.99

Table 2.1 Range of Input Parameters

The detailed methodology adopted is discussed under following sub-headings.

Experimental method

Standard penetration test were conducted in order to collect bore-hole datasets. Disturbed and undisturbed soil specimen was collected from these bore-holes up to depth of 12 meters as well as SPT N-values were also determined at a regular interval of depth 1.5 m. Disturbed soil samples were used to determine liquid limit; plastic limit; angle of internal friction; particle size finer than 2 mm, 0.075 mm and 0.002mm and undisturbed samples were used to find out natural water content, bulk unit weight. All experiments were conducted according to bureau of Indian standard's guidelines for soil testing.

Data modification

Corrected SPT-N values were required to apply modified Seed method to calculate liquefaction potential hence standard method for SPT-N value correction was adopted as given by IS: 2131-1981. A brief discussion on corrected SPT-N value is discussed here under:

Correction for overburden pressure

N- value obtained from SPT test is corrected first which is either calculated by the equation:

$$N_1 = C_N \times N \quad \ldots\ldots (13)$$

C_N is correction factor. It can calculate from the formulae:

$$C_N = 0.77 \log10 (2000/p) \quad \ldots\ldots (14)$$

Where, p is effective overburden pressure in kN/m^2.

Dilatancy correction

The values obtained in overburden pressure (N_1) shall be corrected for dilatancy if the stratum consist of fine sand and silt below water table for values of N_1 greater than 15

$$N'' = 15 + 0.5(N_1\text{-}1) \quad \ldots\ldots (15)$$

Calculation of CSR value through Modified Seed's method is calculated for specific depth of water table, peak horizontal acceleration and earthquake magnitude. Therefore CSR values were interpreted for different combination of depth, peak horizontal acceleration and earthquake magnitude as shown below in table no. II.

Depth of water table (m)			Earthquake magnitude (rector scale)			Peak horizontal ground acceleration	
0	4	8	6	7	8	0.15g	0.35g

Table 2.2 – Assumed Water Table and Earthquake Magnitude

III. NETWORK ARCHITECTURE

A total combination of 5 input variables comprising depth (z), SPT-N value (N), natural / field moisture content (w), bulk unit weight and particle size finer tha n 0.075 mm were used for ANFIS model development. A total of 325 datasets were used for training in which 72 datasets were reserved for validating the network. Datasets were normalized using the following equation:

Normalized value = $\pm_{actual}$ - $\pm_{min}$./$\pm_{max}$.-$\pm_{min.}$

Where, ± is the input and output parameter's value.

ANFIS tool built in MATLAB (R2011a) software was used for all operations in which networks were trained for 60 numbers of epochs and three membership functions was allotted for each five input. Grid partitioning method and triangular membership function for input variables were used to generate fuzzy inference system, whereas linear membership function was used for target variable. Hybrid optimization technique was used for training FIS. Initially liquefaction potential model were developed using two fundamental input variables i.e. depth (z) and SPT-N value (N) subsequently further inputs were selected randomly from remaining set of inputs to study the effect of individual parameter on liquefaction.

To identify different network architecture with its fundamental attributes a coding method was used for different networks, as such $A_XM_XW_X$ denotes A_X: peak horizontal acceleration at 0.15g M_X: earthquake magnitude value at 6 and W_X: depth of water table at 0m, $A_YM_YW_Y$ denotes A_Y: peak horizontal acceleration at 0.35g M_Y: earthquake magnitude value at 7 and W_Y: depth of water table at 4m, $A_XM_ZW_Z$ denotes A_X: peak horizontal acceleration at 0.15g M_Z: earthquake magnitude value at 8 and W_X: depth of water table at 8m Some of the liquefaction values obtained through selected networks are discussed in subsequent literature.

IV. RESULTS AND DISCUSSION

Two peak ground acceleration, three water table depth and three earthquake magnitude values were considered for assessing liquefaction potential through Modified Seed's and ANFIS method as shown in Table II. This resulted in total of eighteen set of liquefaction values for each zone through eighteen combinations of peak ground acceleration, water table and earthquake magnitude values. Table no. [III-V] shows liquefaction potential values for these eighteen combinations. Networks were trained taking these liquefaction values as target parameters.

Using the liquefaction values through modified seed's method and ANFIS (by validating the networks) method, graphs (fig.)were prepared for comparative analysis for these eighteen set of combinations of peak ground acceleration, water table and earthquake magnitude values however input vectors retained common in all ANFIS models (i.e. 5 number of inputs). Result through less than 5 input vectors is avoided since close liquefaction values were obtained on 5 combinations of input vectors only. Average error calculated through eighteen models for each zone is summarized in table no. [VI-VIII].

Fig. 4.2 - 4.7 present comparison of liquefaction values for water table depth of 4m Peak horizontal ground acceleration of 0.15 and 0.35 and earthquake magnitude value of 6, 7 and 8 respectively. They gave close coefficient of correlation i.e. 0.929, 0.971, 0.975, 0.959, 0.948, 1.00 and respectively, more ever coefficient of correlation in other models were also found more than 0.8.

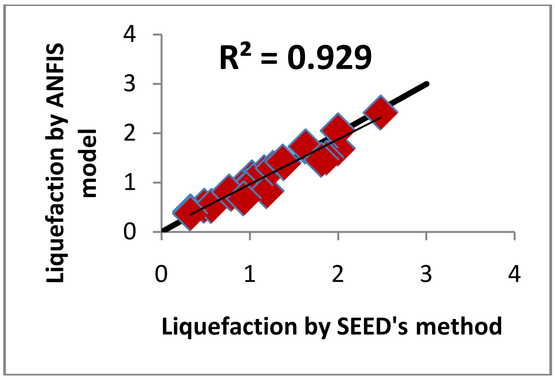

Fig. 4.1 ANFIS Model for $A_YM_Y W_Y$

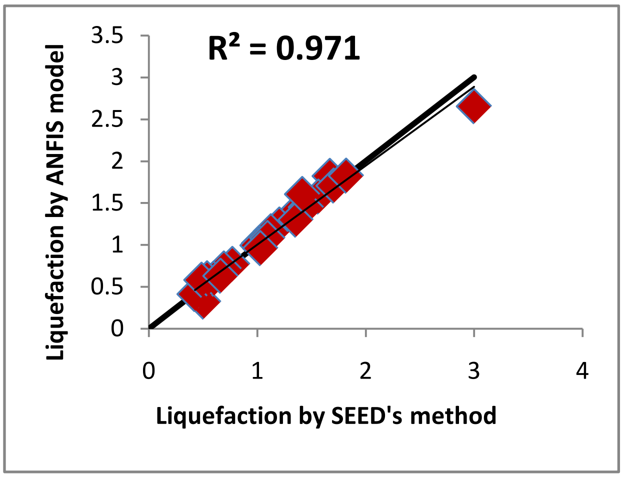

Fig. 4.2 ANFIS Model for A_YMxW_Y

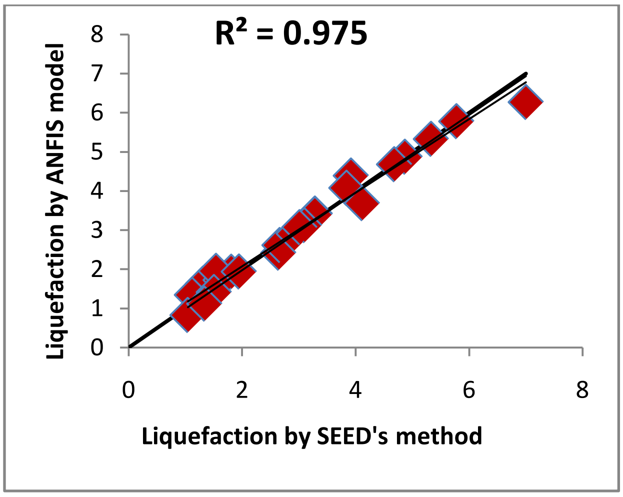

Fig. 4.3 ANFIS Model for AxMxWx

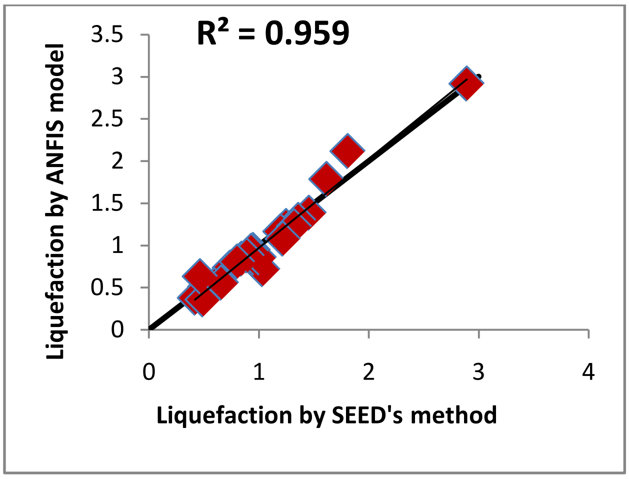

Fig. 4.4 ANFIS Model for $AxMzW_Y$

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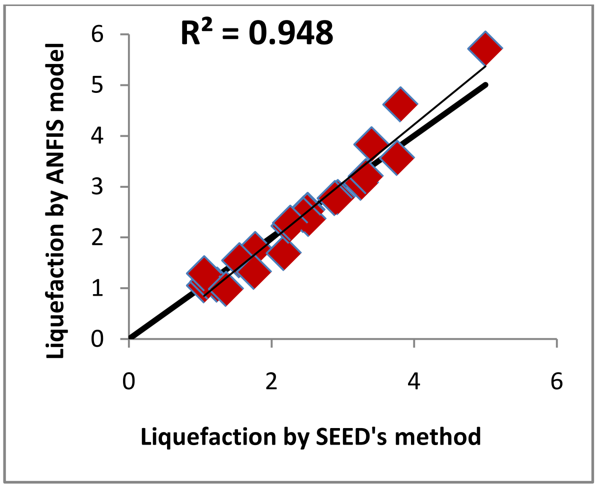

Fig. 4.5 ANFIS Model for AxMxWx

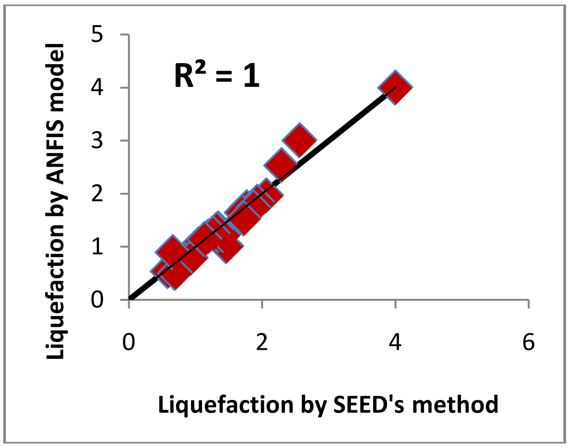

Fig. 4.6 ANFIS Model for AxMxWx

V. CONCLUSION

Coefficient of correlation values in all models greater than 0.8 indicate satisfactory prediction capability of ANFIS models. Moreover results obtained in occurrence / non-occurrence form of liquefaction for particular combination of peak ground acceleration, depth of water table and earthquake magnitude values are as shown in table no. [III-V] for ANFIS method indicates closeness of predicted value to Modified Seed's method.

Liquefaction value at Yamuna bank for the combination of peak ground acceleration 0.15, magnitude of earthquake value 8.0 depth of water table 8 m through Modified Seed's method and ANFIS were 1.032 and 0.801 respectively. It shows different liquefaction occurrence and may be attributed to the higher SPT-N value at relatively lower depth of 1.5 m. likewise network AxMyWx depth 4.5m at central, AxMyWy depth 3m at Yamuna and AyMxWz depth 1.5m at ganga etc. showed a difference in liquefaction potential occurrence and may again be attributed to higher SPT-N value or otherwise due to over-fitting. However, other liquefaction values through ANFIS method remained close to Modified Seed's method.

Average absolute error varied in between 0.044 to 5.319. This indicates that ANFIS models may satisfactorily be used in place of theoretical method, which will reduce the tedious calculations requirements of theoretical methods.

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Table 5.1- Liquefaction Potential Using Modified SEED'S at Ganga Bank for $A_YM_YW_Y$

Depth	N-value	N"	CSR	CRR	Liq. Pot. By Modified Seed's	Liq. Pot. By ANFIS	Liq. Pot. By Modified Seed's	Liq. Pot. By ANFIS
3	20	19.52322	0.095262	0.373208	3.917682	4.390472	NO	NO
4.5	50	34.49437	0.094144	0.950093	7	6.266792	NO	NO
6	23	18.70335	0.093025	0.357179	3.83961	4.078714	NO	NO
3	7	8.897394	0.095262	0.172224	1.807887	1.936822	NO	NO
4.5	5	5.67733	0.094144	0.123373	1.31048	1.633147	NO	NO
6	18	15.96741	0.093025	0.305321	3.282147	3.420558	NO	NO
3	7	7.860888	0.095262	0.154698	1.62391	1.729561	NO	NO
4.5	4	3.949575	0.094144	0.105269	1.118178	1.350255	NO	NO
6	8	7.129527	0.093025	0.143259	1.540015	1.959915	NO	NO
3	11	13.12639	0.095262	0.251517	2.640252	2.421779	NO	NO
4.5	3	3.015462	0.094144	0.098034	1.041324	0.833546	NO	YES
6	14	12.92087	0.093025	0.247586	2.661509	2.618071	NO	NO
7.5	8	6.786387	0.091906	0.138203	1.503742	1.419535	NO	NO
9	7	5.511302	0.090787	0.121364	1.336796	1.122788	NO	NO
10.5	18	13.24404	0.087131	0.253765	2.912455	2.912509	NO	NO
12	12	8.293513	0.083226	0.161844	1.944633	1.942595	NO	NO
7.5	32	22.97031	0.091906	0.447345	4.867421	4.869655	NO	NO
9	32	21.9948	0.090787	0.424851	4.67964	4.679136	NO	NO
10.5	40	23.66063	0.087131	0.464286	5.328609	5.325745	NO	NO
12	44	24.29431	0.083226	0.480743	5.776352	5.776062	NO	NO
4.5	17	16.16254	0.094144	0.308989	3.282102	3.409012	NO	NO
6	15	15.047	0.093025	0.287994	3.095881	3.12612	NO	NO
7.5	16	14.45279	0.091906	0.276762	3.011356	3.074161	NO	NO
9	31	19.53443	0.090787	0.37343	4.113244	3.68613	NO	NO

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Table 5.2 Liquifaction Potential Using Modified SEED'S at Yamuna Bank for AxMxWx

	N-value	N"	CSR	CRR	Liq. Pot. By Modified Seed's	Liq. Pot. By ANFIS	Liq. Pot. By Modified Seed's	Liq. Pot. By ANFIS
3	17	17.73532	0.222279	0.227678	1.02429	1.100062	NO	NO
4.5	8	8.685035	0.233781	0.113302	0.484648	0.524862	YES	YES
6	6	5.937157	0.258906	0.085136	0.328829	0.409995	YES	YES
1.5	13	16.96917	0.224889	0.21794	0.969098	0.925602	YES	YES
3	20	20.07854	0.222279	0.258377	1.162402	1.201974	NO	NO
4.5	50	33.75617	0.232364	0.591127	2	2.05182	NO	NO
1.5	7	9.854394	0.224889	0.127365	0.566345	0.521407	YES	YES
3	14	15.79171	0.222279	0.203051	0.913498	0.908329	YES	YES
1.5	14	18.23365	0.224889	0.234064	1.040794	1.030969	NO	NO
3	14	16.61109	0.222279	0.213408	0.960091	0.863418	YES	YES
4.5	26	21.52524	0.233499	0.278693	1.193555	0.820235	NO	YES
1.5	19	21.88551	0.224889	0.284001	1.262847	1.291796	NO	NO
3	25	23.44469	0.222279	0.308515	1.387965	1.388526	NO	NO
4.5	50	33.50549	0.231989	0.576125	2.483414	2.414559	NO	NO
1.5	22	23.46078	0.224889	0.308784	1.373047	1.421345	NO	NO
3	50	37.97967	0.222279	1.003851	2	1.682172	NO	NO
4.5	40	28.77006	0.232878	0.435773	1.871253	1.499075	NO	NO
6	50	32.95926	0.262676	0.544891	2	2.05182	NO	NO
7.5	50	31.49036	0.28061	0.458088	1.632473	1.72881	NO	NO
9	50	29.90282	0.289056	0.524046	1.81296	1.457619	NO	NO
4.5	13	14.48459	0.23504	0.186476	0.793381	0.766688	YES	YES
6	16	15.34976	0.257879	0.19746	0.765707	0.813326	YES	YES
7.5	7	6.745617	0.281415	0.092522	0.328773	0.370093	YES	YES
9	30	21.58411	0.299606	0.279553	0.933068	0.675139	YES	YES

Depth	N value	N"	CSR	CRR	Liq. Pot. By Modified Seed's	Liq. Pot. By ANFIS	Liq. Pot. By Modified Seed's	Liq. Pot. By ANFIS
1.5	6	8.8124411	0.096381	0.170738	1.771483	1.770617	NO	NO
3	6	7.4216826	0.095262	0.147725	1.550719	1.549805	NO	NO
4.5	4	3.2242813	0.094144	0.099502	1.056921	1.056922	NO	NO
6	7	4.9690725	0.093025	0.115199	1.238367	1.070563	NO	NO
7.5	4	3.491835	0.091906	0.101508	1.104472	1.132627	NO	NO
1.5	8	10.932095	0.096381	0.209591	2.174607	1.691756	NO	NO

4.5	16	16.033857	0.094144	0.30657	3.25641	3.071834	NO	NO
7.5	19	15.9766	0.091906	0.305494	3.323982	3.201956	NO	NO
9	25	17.891302	0.090787	0.341612	3.762781	3.560776	NO	NO
1.5	14	17.17249	0.096381	0.327997	3.403118	3.828905	NO	NO
3	20	18.999911	0.095262	0.362934	3.809835	4.613578	NO	NO
6	50	31.062494	0.093025	0.618765	5	5.709754	NO	NO
6	8	8.3869062	0.093025	0.16342	1.756738	1.321895	NO	NO
7.5	6	5.8424554	0.091906	0.125427	1.364737	0.987522	NO	YES
1.5	2	2.3795389	0.096381	0.094065	1.05692	1.293899	NO	NO
3	12	12.53906	0.095262	0.240277	2.522261	2.362079	NO	NO
4.5	14	14.402766	0.094144	0.275814	2.929716	2.791875	NO	NO
6	16	14.033261	0.093025	0.268803	2.889583	2.77216	NO	NO
7.5	13	10.7486	0.091906	0.206122	2.242747	2.228015	NO	NO
9	15	11.881764	0.090787	0.227689	2.507942	2.539518	NO	NO
7.5	13	11.791735	0.091906	0.225967	2.458672	2.476429	NO	NO
9	14	11.845217	0.090787	0.22699	2.50024	2.527689	NO	NO
10.5	14	11.123531	0.087131	0.213223	2.447154	2.440941	NO	NO
12	13	9.7978951	0.083226	0.188404	2.263766	2.287161	NO	NO

Table 5.3 - Liquifaction Potential Using Modified SEED'S at Central Bank for AxMxWx

Table 5.4 - For Calculation Errors: Central zone

Network Name	Avg. Abs. Error	Regression
AxMxWx	0.472	0.975
AyMxWy	0.304	0.971
AxMzWz	0.352	0.973
AxMyWy	0.607	0.964
AxMxWz	1.06	0.968
AyMzWz	0.044	0.966
AxMyWz	0.456	0.966
AyMxWz	0.174	0.967
AyMzWy	4.41	0.938
AxMzWy	0.957	0.958
AyMzWx	0.879	0.963

Table 5.5 - For Calculation Errors: Yamuna Bank

Network Name	Avg. Abs. Error %	Regression
AxMxWx	0.179	0.948
AyMxWy	2.567	0.957
AxMzWx	4.57	0.948
AxMyWy	2.524	1
AxMxWz	3.574	0.92
AyMzWz	4.763	0.929
AxMyWz	4.426	0.93
AyMxWz	5.319	0.926
AyMzWy	2.337	0.956
AxMzWy	2.383	0.959
AyMzWx	4.602	0.948

Table 5.6 – For Calculation Errors: Ganga Bank

Network Name	Avg. Abs. Error %	Regression
AxMxWx	0.914	0.887
AxMyWx	0.923	0.849
AxMyWy	2.596	0.905
AyMyWy	4.673	0.929
AyMxWz	1.001	0.808

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