

Estimating Maximum moment and shear exerted on Contiguous Piles for seismic loads using ANN

Mateen Ibrahim A. Barwari¹ and Najdat S. Akrawi²

¹ Department of Civil Engineering, Nawroz University, Duhok, KRG-Iraq.

² Department of Civil engineering, Collage of Engineering, University of Dohuk, Duhok, KRG-Iraq.

ABSTRACT: Recently the usage of Contiguous piles in many different aspects of construction projects are become more common. Determination of the shear force and moment values exerted on the contiguous piles require extensive analysis and calculations especially when earthquake is to be encountered. Finite element technique was utilized for the analysis using linear material model for the concrete properties of the contiguous piles. The analysis F.E.M for calculating the moment and shear forces was conducted utilizing 144 input sets that represent height of excavated (H), ratio of H to the depth of embedment (D), unit weight of retained soil (γ) and angle of internal friction (ϕ) is presented in this paper. The mathematical models obtained show more than 0.99 correlation coefficient and less than 0.0013 variance. It was found that both shear and moment values subjected on the piles are decreases with the decrease of (γ) and increases with the increase of (ϕ). The height of excavation (H) was found as the most important input parameter that affects the output values of the models.

KEYWORDS: Earth pressure, Seismic, Finite element F.E, Artificial neural network ANN, Contiguous piles, Earthquake, Shear, Moment.

1. INTRODUCTION

During the last decades, the usage of contiguous piles as a retaining structure becomes successful alternative instead of conventional retaining walls. Contiguous piles are sequentially creation of straight or curve aligned bored or driven piles with gap between each other used in dense traffic urban area as there is deep excavation on either side that may encountered in projects like new developed underpasses and road interchanges. Recently, the method of retaining soil was applied on several underpasses in Dohuk and Mosul governorates when constructing conventional retaining wall becomes useless and disturbing. The method is widely adopted in the aspects of road engineering for the effectiveness and applicability in many developed intersections that cut and cover girder bridges is the main construction components (Chavda et al., 2019). Because of that the recent records of earthquake in the region are become in order of (3) instead of (2B) according to UBC-1997, earthquake design should be importantly included.

Two main types of piles are usually used, the contiguous piles and secant pile. The latter is necessary when the soil is cohesion-less and the potential of shallow water content will encounter the excavation for the projects, the former is in permanent absence of water table. The secant piles in some texts are called curtain piles. For either method the rough appearance side after the required excavation is usually cladded by spraying cement mortar and appropriate aesthetic panels (Clayton et al., 2014). (Mononobe, 1929)-(Okabe, 1924) formula for calculating the active and passive earth quake thrust is used theoretically and experimentally in many researches. The formula, originally, derived from the theory of lateral earth pressure of (Coulomb, 1776) with additional parameter related to the vertical and horizontal of ground acceleration (μ).

The developed active or passive lateral earth pressure coefficients formula of Mononobe-Okabe is not separate the seismic effect from the static effect in the thrust exerted on the structure. Separation should be applied by using Coulomb's or Rankin's static lateral earth pressure coefficients.

Finite element formulation via excel sheet and VBA (Visual Basic Application) is used to calculate the stresses exerted on the contiguous pile by considering two strain parameters (u and v) for one dimensional beam element discretization. The soil stresses subjected on each node is calculated by Mononobe-Okabe formulation.

Artificial cohesion-less soil parameter ranges of unit weight, angle of internal friction is selected to introduce the input of the retained soil properties, while the input should include also the depth of pile embedment and the height of the soil retained for the pile-soil interaction geometry parameters.

2. OBJECTIVE

The results of moment and shear exerted on the pile are calculated for all elements from the top down to the toe of the pile, the structural properties of the concrete for the pile are fixed during the work.

A feed forward back propagation artificial neural network (FFBP-ANN) mathematical model expressing the values of the maximum moment and shear over the pile is obtained as the main design structural parameters of the piles for such projects.

3. METHOD OF STRESS CALCULATION

In order to simulate the stresses on the contiguous piles subjected to seismic loads, (Mononobe, 1929, Okabe, 1924) formula has been proposed to be used, this formula calculates the lateral earth pressure as a combination sum of the static and seismic thrust that exerted on the pile. While the static thrust is hydrostatically act on one third of the height (H) from the tip of the pile and that the seismic thrust action is on two third of (H). Many researches recommend to use the combination thrust effect to be exerted on the middle of the height. The formulation of the equations is as follows: -

$$P_{AE} = \frac{1}{2} \gamma H^2 (1 - k_v) K_{AE} \quad (1)$$

Where: -

$$K_{AE} = \frac{\cos^2(\varphi - \mu - \theta)}{\cos \mu \cos^2 \theta \cos(\delta + \theta + \mu) \left[1 + \sqrt{\frac{\sin(\delta + \varphi) \sin(\varphi - \mu - \beta)}{\cos(\delta + \mu + \theta) \cos(\beta - \theta)}} \right]^2} \quad (2)$$

Where:

- $\mu = \tan^{-1} \left(\frac{k_h}{1 - k_v} \right)$
- γ = unit weight of soil.
- H = height of wall.
- φ = angle of friction of soil.
- δ = angle of wall friction.
- β = slope of ground surface behind the wall.
- θ = slope of back wall to the vertical.
- k_h = horizontal ground acceleration / g.
- k_v = vertical ground acceleration / g.

For vertical piles and horizontal ground surface considering smooth interaction between the soil and the piles, parameters like θ , β and δ could be disregarded for the case considered herein. The coefficient of the lateral earth pressure becomes as follows: -

$$K_{AE} = \frac{\cos^2(\varphi - \mu)}{\cos^2(\mu) \left[1 + \sqrt{\frac{\sin(\varphi) \sin(\varphi - \mu)}{\cos(\mu)}} \right]^2} \quad (3)$$

Where :-

- $\theta = 0$ for vertical walls,
- $\beta = 0$ for horizontal backfill,
- $\delta = 0$ for friction-less interaction between the piles and backfill

Usually, k_v , for such calculations, take the value of (0) value and k_h is (0.3) proposed by (UBC, 1997) for zone (III), . (AASHTO 2nd, 1998) recommends for tolerable wall lateral displacement is to be allowed and for economical design

to reduce the value of k_h to half. So that k_h is taken as 0.15 throughout the calculation of the lateral earth thrust.

The calculation of the passive earth pressure is kept using Rankin’s coefficient of earth pressure formula, which is:

$$K_p = \frac{1 + \sin(\phi)}{1 - \sin(\phi)} \tag{4}$$

The thrust calculated in equation (1) above is the combination of the static and seismic force together, separation of these forces is conducted as follows:

$$P_{AE} = \overline{P_{AE}} + P_A \tag{5}$$

Where:

$\overline{P_{AE}}$ is the seismic part and P_A is the static part, because of that the later point of application is at $1/3 H$ from bottom of the pile and that the point of application of the former is at $0.6 H$ from bottom of the pile. For practical calculations, (Murthy, 2002) suggests to assign the point at the middle of the retained structure, or the pile. In such case, the pressure can approximately become uniform on the pile active side.

4. FINITE ELEMENT FORMULATION

As stated before, the uniform distribution stress is assumed on the active side of pile and the linear distribution is kept for the stress in the passive side as in Figure1 (Murthy, 2002) below: -

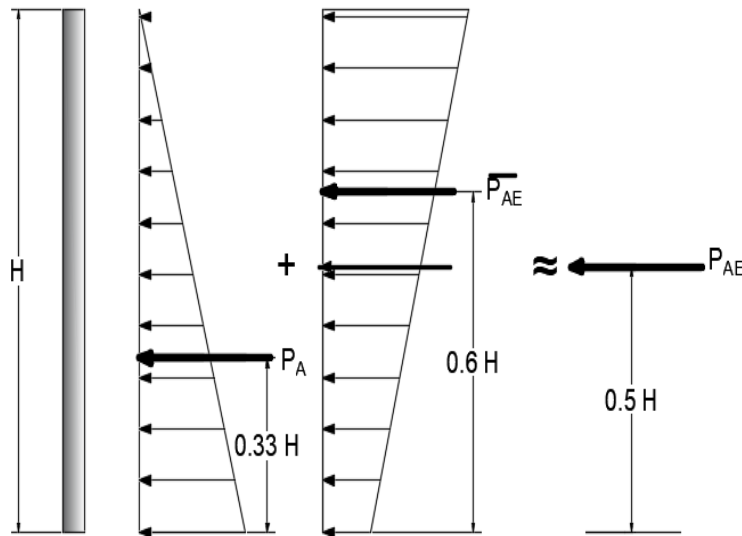


Figure1: The scheme of stress distribution over the contiguous pile. (Murthy, 2002)

For one dimensional Finite element analysis, the number of elements and nodes are selected in the excel program is 16 and 17 respectively. (Desai and Kuppasamy, 1980) The general three-dimensional beam displacement matrix formulation is as follows:

$$\begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = \begin{bmatrix} [N_b] & 0 & 0 \\ 0 & [N_b] & 0 \\ 0 & 0 & [N_a] \end{bmatrix} \begin{Bmatrix} \{q_{b1}\} \\ \{q_{b2}\} \\ \{q_{ba}\} \end{Bmatrix} \tag{6}$$

$$[N_b] = [(1 - 3s^2 + 2s^3) \quad ls(1 - 2s + s^2) \quad s^2(3 - 2s) \quad ls^2(s - 1)] \tag{7}$$

that is $s = \frac{x}{L}$ with range of x from 0 to L

$$\{q_{b1}\}^T = [u_1 \quad \theta_{x1} \quad u_2 \quad \theta_{x2}] \tag{8}$$

$$B = [N_b'']$$

$$[K] = \int_0^L B^T EI B ds \tag{9}$$

$$[k]\{q\} = \{Q\}$$

$\{q\}$ is the vector of nodal unknowns, and $\{Q\}$ is the vector of nodal forces:

$$[k] = \begin{bmatrix} a_x[k_x] & 0 & 0 \\ 0 & a_y[k_y] & 0 \\ 0 & 0 & [k_w] \end{bmatrix} \tag{10}$$

$$a_x = \frac{EI_x}{l^3}$$

$$a_y = \frac{EI_y}{l^3}$$

(Desai and Kuppusamy, 1980) Taking in considerations that the above matrix formulation is for the three-dimensional displacement occurs in the beam element. However, the case for the contiguous pile can be considered as a plain strain problem, so that only the x -direction toward the excavation remains in the analysis, and that the element stiffness matrix for the problem analysis becomes as: -

$$[k_x] = a_x \begin{bmatrix} 12 & -6l & -12 & -6l \\ \text{symm.} & 4l^2 & 6l & 2l^2 \\ & & 12 & -6l \\ & & & 4l^2 \end{bmatrix} \tag{11}$$

The assembly of the equations for each of the elements with applying the appropriate boundary conditions for the displacements and their derivatives for the assemblage will be introduced to find the global stiffness matrix. The solution of this global $[K]$ for nodal displacements are then used to find moments, M_y , and shear forces, V_x , as: -

$$\{M_z\} = \left\{ EI_x \frac{d^2u}{dz^2} \right\} = EI_x [N_b''] \{q_{b1}\} \tag{12}$$

$$\{V_x\} = \left\{ EI_x \frac{d^3u}{dz^3} \right\} = EI_x [N_b'''] \{q_{b1}\} \tag{13}$$

5. ANN GENERAL ARCHITECTURE

The Artificial Neural Network (ANN) is applicable as an alternative for some statistical analysis techniques such as multivariable regression, autocorrelation, linear regression, and so on. Many geotechnical problem analysis and design with the aid of ANN are gathered using field data, experimental data, and numerical analysis data collections.

ANN architecture consists of three fundamental layers arranged consequently input, hidden and output layers each of these layers consists of several neurons.

In addition, the network, is processed throughout transfer functions between the layers and learning or training laws (Samarasinghe, 2016) .

Several algorithms have been designed to train the neural networks, among which the back-propagation (BP) algorithm is known as the most powerful technique (Vanluchene and Sun, 1990). In addition, (BP) can solve predictive complex engineering problems that makes BP popular among all algorithms for training ANN (Alkroosh and Nikraz, 2012). Generally, the feed-forward BP neural network process uses Levenberg–Marquardt technique optimization as mathematical operations for updating weights and bias.

Different activation functions (i.e., radial, linear, hyperbolic tangent sigmoid, and logarithmic sigmoid) are available and can be used to transfer the input to output data within the hidden layer and the output layer. In the current research, the hyperbolic tangent sigmoid function (TANSIG) was found to be suited between the input and the hidden layer, while the logarithmic sigmoid was found to be rational better than other functions to transfer data between the hidden layer and output layer, as follows:

$$TANSIG(f) = \frac{2}{1+e^{-2lf}} - 1 \tag{14}$$

$$LOGSIG(f) = \frac{1}{1+e^{-lf}} \tag{15}$$

Before subjecting the input and output data to the network process, it should be normalized to scale-up the inputs and output so that they fall in the range of the selected activation function corresponding to the highest and lowest values, respectively. The obtained normalized output is then need to be de-normalized to the real values, the normalization and de-normalization formula is

$$Y_{norm} = \frac{(Y_{max}-Y_{min}) * (X_{actual}-Y_{min})}{X_{max}-X_{min}} \tag{16}$$

Where, Y_{norm} is the normalized value of X actual. The values of Y_{max} and Y_{min} are (-1 and +1) for the input data and (0 and +1) for the output data, respectively, this normalization scheme was found appropriate for such data. X_{actual} , X_{min} , and X_{max} are the actual, minimum, and maximum values of the independent parameters of interest. The de-normalization process is the calculation of the Shear force and Moment subjected on the contiguous piles.

6. MATHEMATICAL MODEL USING ANN

Figure2 shows the network adopted for the problem in this paper, the input comprises of the Depth of embedment (D), the ratio related to the height of excavation (D/H), the angle of internal friction (ϕ), and the unit weight of the soil (γ). The hidden layer consists of 3 neurons so selected to be less than the input neurons and to simplify the mathematical model expression as possible taking in consideration acceptable performance of the network applied.

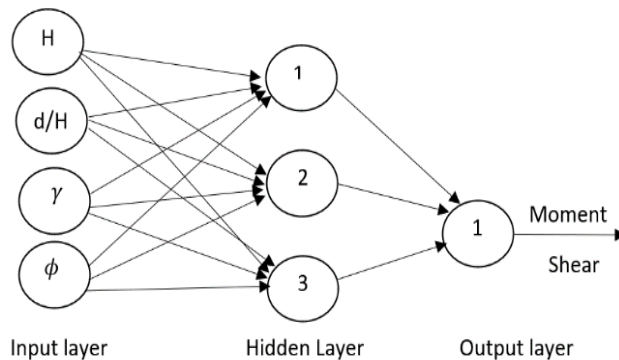


Figure 2: Architecture of the NN model

Table (1) and Table (2), demonstrate the range of data input and output results respectively, those results have been used to generate the network for both the shear and moment results each of 144 sets of 70% of data was used for the training process and 15% for each of the validation and checking.

Table 1: Range of the input dataset for the Four controlling parameters

Input Parameter	H (m)	D/H	γ (kN/m ³)	ϕ
Minimum	3	0.6	16.5	30
Maximum	9	1.4	21	40
No. of Data	3	3	4	4
Total			144	

Table 2: Range of the output shear and moment dataset

Output Parameter	Moment (kN.m)	Shear (kN)
Minimum	250.1155	187.3738
Maximum	5835.319	1178.852

Table (3) and Table (4) show the weights and bias (threshold) obtained as a result of the training the networks between the input-hidden and hidden-output respectively.

Table 3: Wights and ias (threshold) for input-hidden layers

	Nodes	w_{ji}				Hidden thresh-old (b_j)
		$i = 1$	$i = 2$	$i = 3$	$i = 4$	
Shear	1 j=1	0.561	0.581	0.160	-0.245	-1.372
	j=2	-0.847	0.345	-0.254	0.295	1.277
	j=3	-1.262	-0.108	-0.178	0.219	-1.621
Moment	j=1	1.068	0.317	0.193	-0.255	-2.298
	j=2	-0.709	-0.084	-0.068	0.082	-1.050
	j=3	-0.680	-1.427	-0.293	0.330	-0.879

Table 4: Weights and bias (threshold) for hidden-output layers.

		Shear and Moment Weighted and Bais between hidden and outputs			
	Nodes	w_{kj}			Output threshold (b_k)
		$j = 5$	$j = 6$	$j = 7$	
Shear	k=4	2.007	-1.473	-2.464	-0.009
Moment		5.427	-4.858	-0.130	0.354

The process between the input layer and the hidden layer is

$$h_j^H = b_j + \sum_{i=1}^{N_i} w_{ji} x_i \tag{17}$$

$$h_j^H = b_j + w_{1j}H + w_{2j}H/d + w_{3j}\gamma + w_{4j}\varphi \tag{18}$$

$$i = 1 \text{ to } N_i$$

$$j = 1 \text{ to } N_h$$

Where, N_h is the number of the hidden neurons.

Each neuron of the hidden layer gets its input h_j^H , which should be used as the argument for hyperbolic tangent activation function f , to produce an output y_j^H and expressed as:

$$y_j^H = f(h_j^H) \tag{19}$$

$$y_j^H = \frac{2}{1+e^{-2h_j^H}} - 1 \tag{20}$$

The input for the neurons of the output layer h_k^O is calculated as:

$$h_k^O = b_k + \sum_{i=1}^{N_h} w_{kj} y_j^H \tag{21}$$

Consequently, b_k is the output threshold or bias, and w_{kj} is the synaptic weight that interrelates hidden neuron j to output neuron k .

And the final network output y_k is calculated by a sigmoidal activation function f

$$y_k = f(h_k^O) \tag{22}$$

$$y_k = \frac{1}{1+e^{-h_k^O}} \tag{23}$$

The general expression representing the mathematical model output for the shear and/or moment exerted on contiguous piles using 6 parameter input and one hidden of 3 neurons becomes as:

$$y_k = \frac{1}{1+e^{-\left(b_4+w_{45}\left(\frac{2}{1+e^{-2h_1}}-1\right)+w_{46}\left(\frac{2}{1+e^{-2h_2}}-1\right)+w_{47}\left(\frac{2}{1+e^{-2h_3}}-1\right)\right)}} \tag{24}$$

Finally, using the data resulted from training the network in Tables from 1 to 4 with the formulation obtained above the mathematical model for the shear (Y_s) and moment (Y_m) can be obtained as follows:

$$Y_s = 187.374 + \frac{991.5}{1 + e^{\left(3.009 + \frac{4.014}{1+e^{-2h_1}} - \frac{2.946}{1+e^{-2h_2}} - \frac{4.928}{1+e^{-2h_3}}\right)}}$$

$$Y_m = 250.116 + \frac{5585.2}{1 + e^{\left(2.646 + \frac{10.854}{1+e^{-2h_1}} - \frac{9.716}{1+e^{-2h_2}} - \frac{0.26}{1+e^{-2h_3}}\right)}}$$

Figure 3 and Figure 4 shows that the mathematical models obtained above have a well correlation coefficient between the predicted values by the network and numerically calculated data shear and moment respectively.

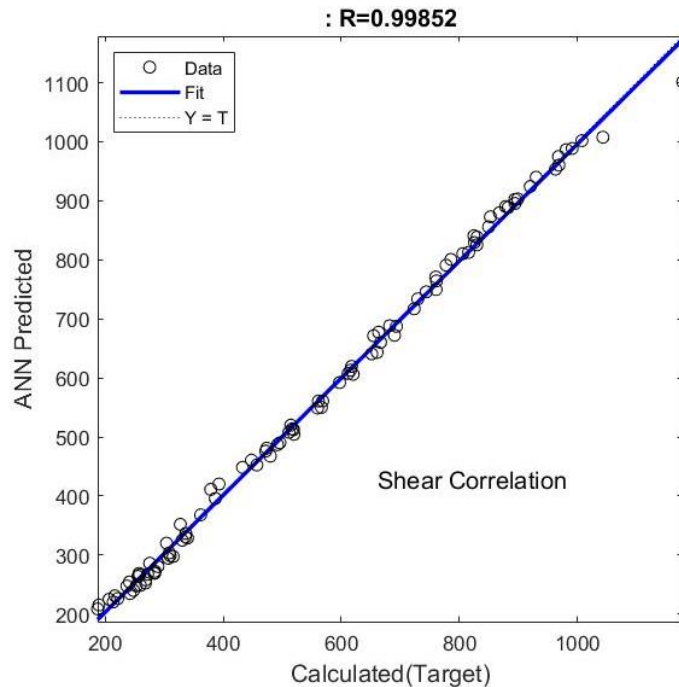


Figure3: The predicted shear stress on the piles with the corresponding calculated values.

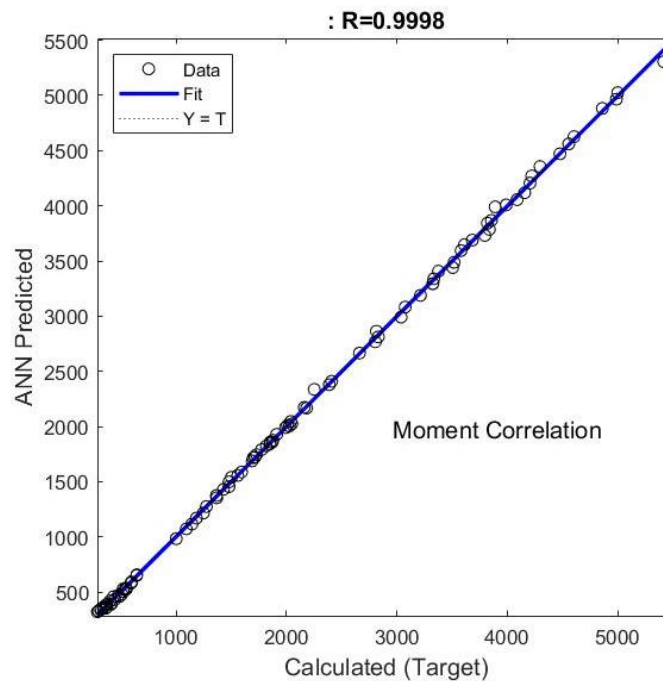


Figure4: The predicted Moment on the piles with the corresponding calculated values.

In order to assess the suitability of the model for the structural design of contiguous piles Gaussian distribution frequency magnitude is obtained using all 144 numerically calculated versus ANN predicted ratios of the shear and moment values as shown in Figure5 and Figure6 respectively, the magnitude of the frequency becomes smaller when the value moves away from the mean central value. The probability of obtaining the value of shear and moment ratios between 0.95 and 1.05 is 89% and 88%, such acceptable probability results give additional confidence to the models obtained. The figures also show that the standard deviation and the variance obtains rather acceptable values.

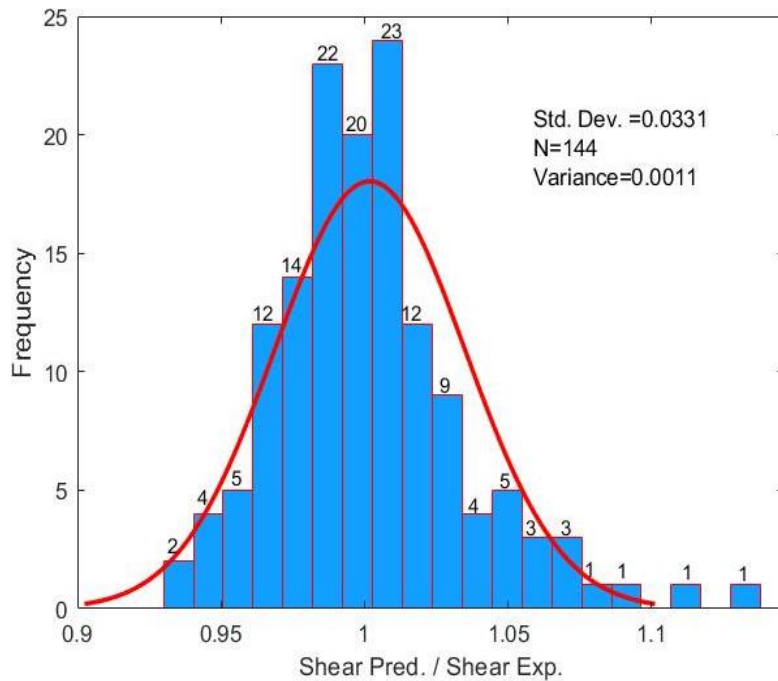


Figure5: Histogram and Gaussian distribution of the Numerical and ANN obtained shear value ratios.

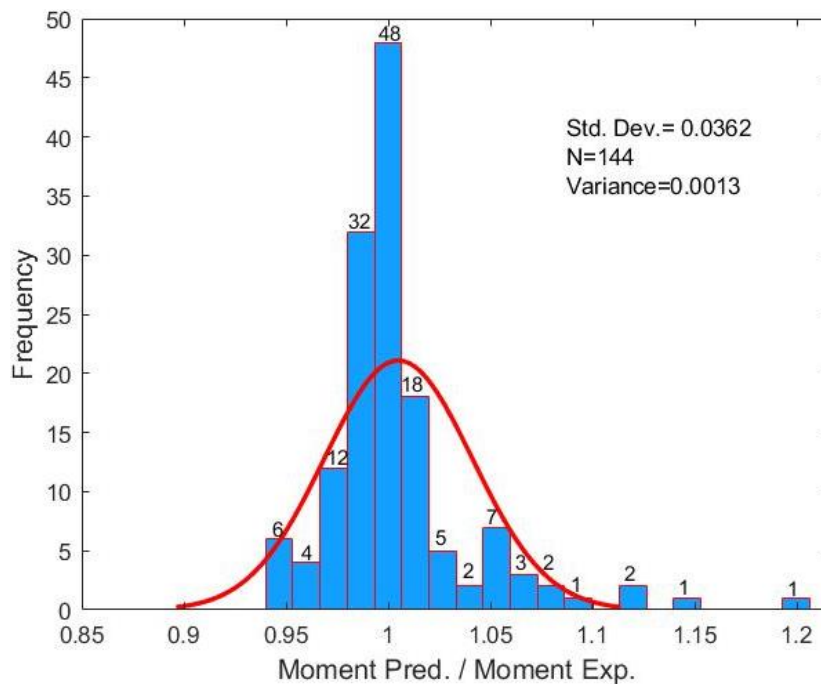


Figure6: Histogram and Gaussian distribution of the Numerical and ANN obtained moment value ratios.

7. IMPORTANCE OF THE INPUT PARAMETERS

The principle of partitioning weight suggested by (Garson, 1991) and adopted by (Goh, 1995) is used for obtaining the relative effectiveness and importance of the input parameters on the ANN predicted values of the moment and shear for the design of contiguous piles. Figure7 and Figure8, shows same trend of importance values regarding the input parameters on both shear and moment. Strong effect on the ANN calculated values is held by the height of the

excavated soil behind the contiguous piles (H), while moderate effects are obtained for the D/h, γ and φ . Such trend is attributed to that the square power of the height (H) that contributed on the lateral thrust values and the normal contribution of the other input values.

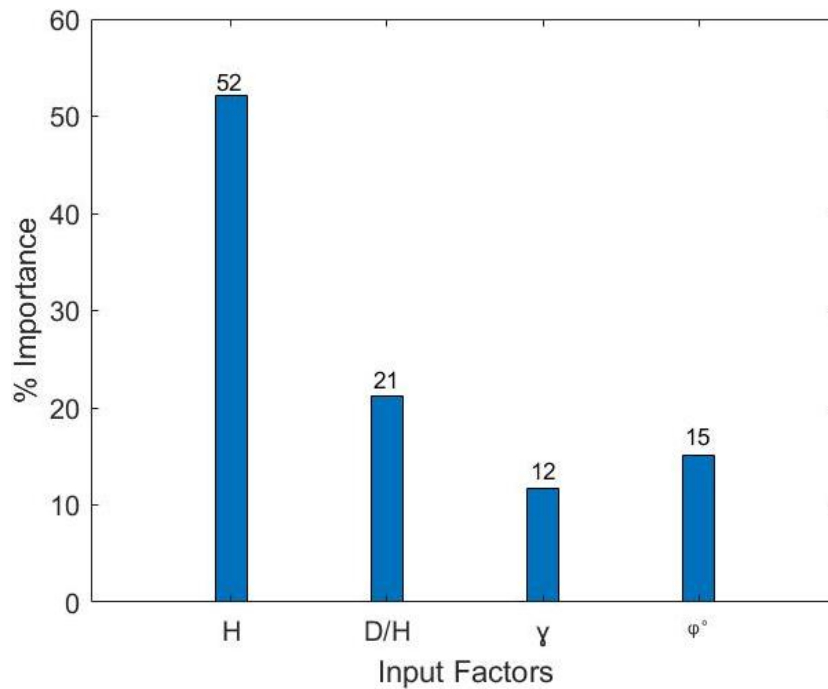


Figure7: The importance values of the input parameters on the shear values obtained by ANN model.

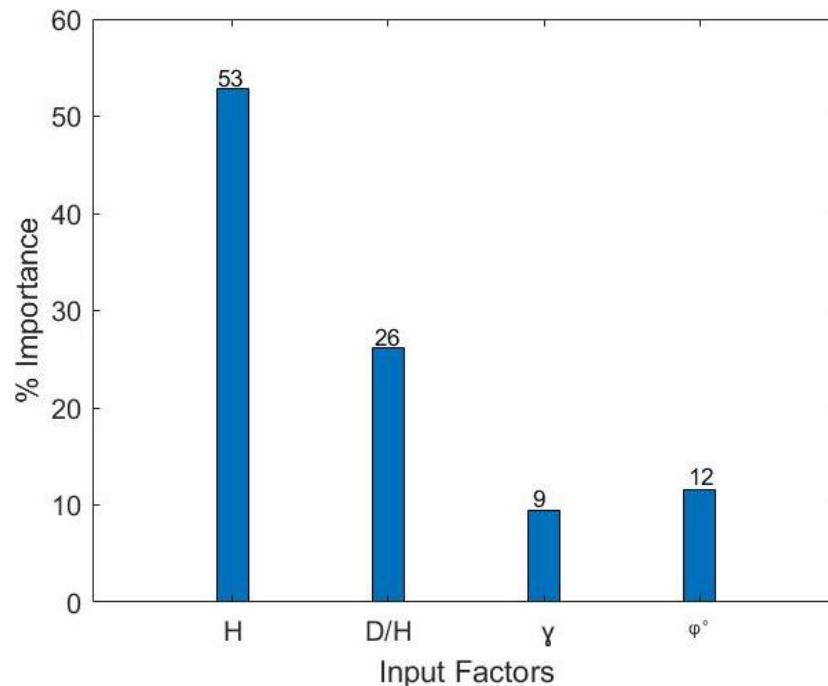


Figure8: The importance values of the input parameters on the Moment values obtained by ANN model.

8. PARAMETRIC STUDY

The physical behavior and reliability of the mathematical models for obtaining the shear force and moment

subjected on the contiguous pile can be well demonstrated by conducting parametric study, this has been clarified in Figure9

It is clear from the figures that, for any specific height of excavation, that both the shear force and moment values are decreases as the unit weight of the soil retained decreases in contrario of the angle of internal friction of the retained soil.

The decrease of the values of the shear and moment shown in the figures with the decreasing the unit weight can be attributed to the accompanied decreases occurs in the overburden pressure which inturn decreases the lateral forces. However, the angle of internal friction has inverse effect on the active lateral earth pressure and the decrease of the both values is attained.

The same attribution can be derived for increase of the shear and moment values exerted on the contiguous piles for the incese in the height of excavation of the retained soils, this also is clarified in the figures below.

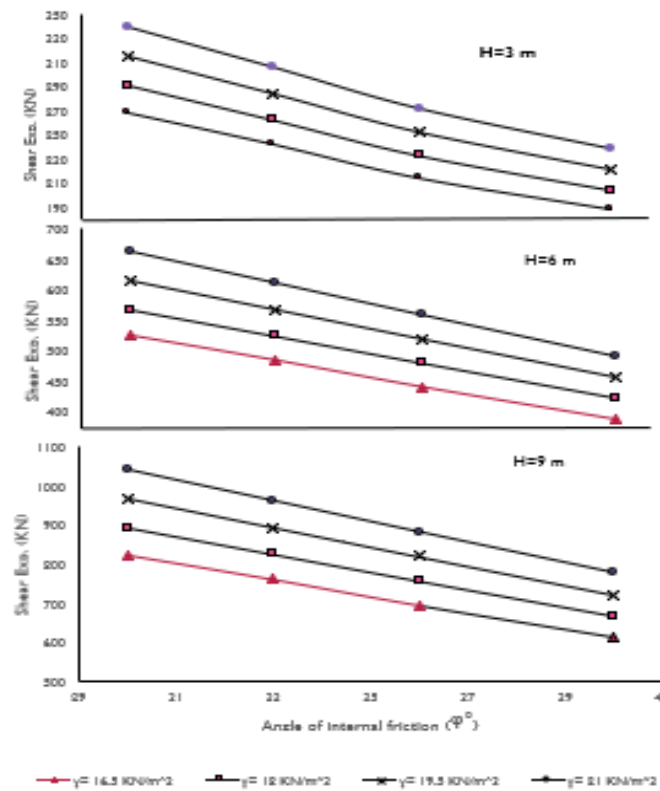


Figure9: Effect of varying (γ) values on the Shear force of the studied contiguous piles

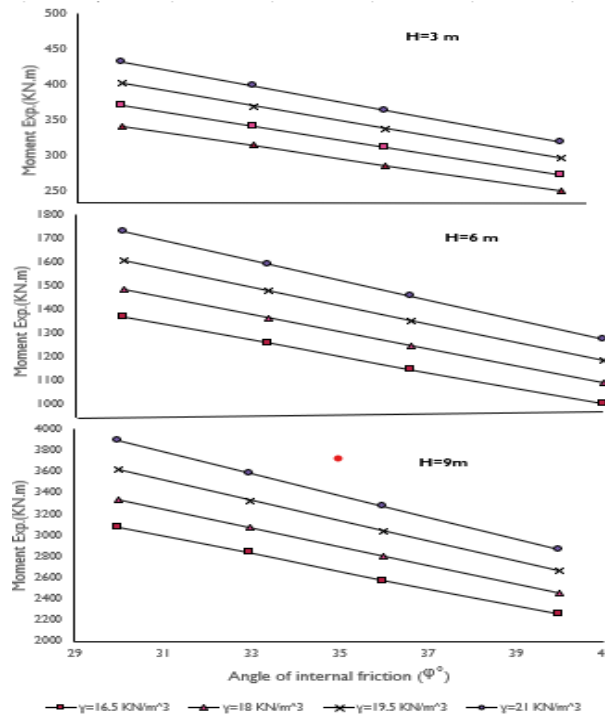


Figure10: Effect of varying (γ) values on the Moment of the studied contiguous piles.

9. CONCLUSIONS

Calculating the maximum shear force and moment values subjected on contiguous pile is essential process for the structural design of such piles. The mathematical model representing these values using ANN contributing the parameters controlling the calculation was found to be highly accurate. The regression values for the data calculated by finite element and the model gives more than 0.95 for shear and moment and variance values less than 0.0013. The attained function can be used to generalize prediction of the value moment and shear for values of the input parameters within the range considered in this study.

10. REFERENCES

1. AASHTO 2ND, L. 1998. Bridge design specifications. *American Association of State Highway and Transportation Officials, Washington, DC.*
2. ALKROOSH, I. & NIKRAZ, H. 2012. Predicting axial capacity of driven piles in cohesive soils using intelligent computing. *Engineering Applications of Artificial Intelligence*, 25, 618-627.
3. CHAVDA, J. T., SOLANKI, C. H. & DESAI, A. K. 2019. Lateral Response of Contiguous Pile Wall Subjected to Staged Excavation: Physical and Numerical Investigations. *Indian Geotechnical Journal*, 49, 90-99.
4. CLAYTON, C. R., WOODS, R. I. & MILITITSKY, J. 2014. *Earth pressure and earth-retaining structures*, CRC press.
5. COULOMB, C. 1776. Essai Sur Une Application Des Maximis et Minimis a Queques problems Des Statique Relatifsa1" Architecture. *Nem. Div. Sav. Acad. Sci*, 7.
6. DESAI, C. & KUPPUSAMY, T. 1980. Application of a numerical procedure for laterally loaded structures. *Numerical methods in offshore piling*. Thomas Telford Publishing.
7. GARSON, D. G. 1991. Interpreting neural network connection weights.
8. GOH, A. 1995. Empirical design in geotechnics using neural networks. *Geotechnique*, 45, 709-714.
9. MONONOBE, N. On determination of earth pressure during earthquake. Proc. World Engineering Congress, 1929. 177-185.
10. MURTHY, V. 2002. *Geotechnical engineering: principles and practices of soil mechanics and foundation engineering*, CRC press.
11. OKABE, S. 1924. General theory on earth pressure and seismic stability of retaining wall and dam. *Proc. Civil Engrg. Soc., Japan*, 10, 1277-1323.
12. SAMARASINGHE, S. 2016. *Neural networks for applied sciences and engineering: from fundamentals to complex pattern recognition*, Auerbach publications.
13. UBC, U. B. 1997. UBC 97, Code for Seismic Design of Buildings (1997 Edition). *Structural engineering design provisions*, 2.
14. VANLUCHENE, R. & SUN, R. 1990. Neural networks in structural engineering. *Computer-Aided Civil and Infrastructure Engineering*, 5, 207-215.