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Prediction of Concrete and Steel Materials Contained by Cantilever Retaining Wall by Modeling the Artificial Neural Networks

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ABSTRACT

In this study, the Artificial Neural Network (ANN) application is implemented for predicting the required concrete volume and amount of the steel reinforcement within the inversed-T-shaped and stem-stepped reinforced concrete (RC) walls. For this aim, seven-different RC wall designs were approached differentiated within the wall heights and various internal friction angles of backfill materials. Each RC wall is proportionally designed and subjected to active lateral earth pressure defined with the Mononobe-Okabe approach foreseen by Turkish Specification for Building to be Built in Seismic Zones (TSC-2007). Following the stability analysis of the RC retaining walls, the structural and reinforced concrete analyses are performed according to the Turkish Standard on Requirements for Design and Construction in Reinforced Concrete Structures (TS500-2000). Input parameters such as concrete volumes, weights of the steel bars, soil and wall material properties are subjected to the ANN modeling. The prediction of the concrete volume and amount of the steel bars are achieved with the implementation of the ANN model trained with the Artificial Bee Colony (ABC) algorithm. As a result of this study, it is revealed that ANN models are useful for verifying the existing RC retaining wall designs or performing preliminary designs for the L-shaped and stem-stepped cantilever retaining walls.

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1. Introduction

Implementation of the retaining walls are frequently ascertained for numerous engineering applications such as in hydraulic engineering especially including coastal and river protection structures, transportation engineering in land slide protection structures of deep excavations and embankments and in marine transportation covering infrastructures of sea ports, and structural engineering in concrete and steel-based structural analysis. Especially implementing a proper retaining wall design is not solely based on the soil-base characteristics but the intensity of the earthquake risk, the preliminary design of the retaining wall and dimensioning. This study is extensively based on the structural analysis of the retaining walls and the stability analysis of the wall body under the influence of the passive and active soil pressure behind the wall statue. Structural systems of the earth-retaining walls are generally categorized into; T-shaped cantilever walls, stem-stepped cantilever walls, counter-fort walls, caisson-type wall and retaining wall with pile system. While designing a typical retaining wall, the loading types such as soil pressures, hydrostatic pressure, surcharge and earthquake must be assigned. In general, retaining walls are designed by lateral earth pressures based on Rankine or Coulomb's theories. Mononobe and Matsuo, and Okabe (M-O) proposed a method to determine the lateral earth pressure of the granular cohesion-less soils during earthquake. The method was a modified version of Coulomb theory in which earthquake forces are applied to the failure mass by pseudo-static method. In stabilization of a wall, the general procedures are; check for overturning about its toe, check for sliding along the base, check for bearing capacity failure, settlement, and overall stability.

2. Literature survey

It is known that the ANN analysis is progressively used in optimization processes of counter-fort and cantilever walls, geo-synthetic reinforced retaining wall design and extensively other fields of geotechnical engineering. In 2003, *Lee* developed the I-PreConS (Intelligent PREdiction system of CONcrete Strength) that provide in-place strength information of the concrete to facilitate concrete form removal and scheduling for construction. For this aim, two major techniques were applied to increase the accuracy and to more precisely predict concrete strength development. One was to use parameter condensation technique in the determination of input neurons. The other was to apply the weighting technique of input neurons for more prediction accuracy. Consequently, this study indicated that I-PreConS using ANNs was very efficient for predicting the compressive strength development of concrete [1]. Mansour et al. (2004) investigated the application of the ANNs to predict the ultimate shear strengths of reinforced concrete (RC) beams with transverse reinforcements. They developed the ANN model trained the available test data of 176 RC beams collected from the technical literature. As a result of this study, model based on the ANNs had strong potential as a feasible tool for predicting the ultimate shear strength of the RC beams with the transverse reinforcement within the range of considered input parameters [2].

On the other side, to optimize the area of steel bar in tension (A_{st}) and area of concrete ($A_{c.}$) of the specified-sized cantilever retaining wall, Manjunath et al. (2012) studied changing just only the total number of 15 input parameters and applied the ANNs for the different outputs (A_{st} and

A_c) [3]. Similarly, Chethan et al. (2012) studied for the ANNs training of parameters composed of the steel weights and concrete volumes required for specific-sized counter-fort retaining wall and certain soil parameters [4].

Shehata (2016) also worked for the structural assessments of two shelves of inversed T-shaped retaining wall with certain wall size and soil parameters [5]. Chougule et al. (2017) analyzed three different cantilever wall model with/without shelves at stem and they revealed that RC walls with two shelves were economical as compared to RC wall with single shelf without applying the ANNs [6].

Alias et al. (2015) examined the performances of the ANNs for predicting the external stability of cantilever RC retaining walls. Two types of this model were used as follows: Model I (for 1 output) and Model II (for 3 outputs). The results of their study indicated that, when compared in terms of R^2 value, first model had better performance than second considering the prediction performance the of external stability [7]. Patil et al. (2015) performed a study on Analysis and Design of Stepped Cantilever Retaining Wall with using the aid of soft computing methods [8]. Buhuniyan et al. (2017), studied the retaining walls with relief shelves. The finite element analysis of 2-D models of retaining walls by using STAAD-Pro was performed in this study and his findings indicated the advantage of using the relief shelves over the cantilever and counter-fort retaining walls. Gokkus et al. (2018) presented a study on the comparison of the relevant footing widths of the proportionally-sized reinforced concrete retaining walls under extreme loading conditions according to the Turkish Standard-2000 (TS500) Specification as in Fig. 1. [9].

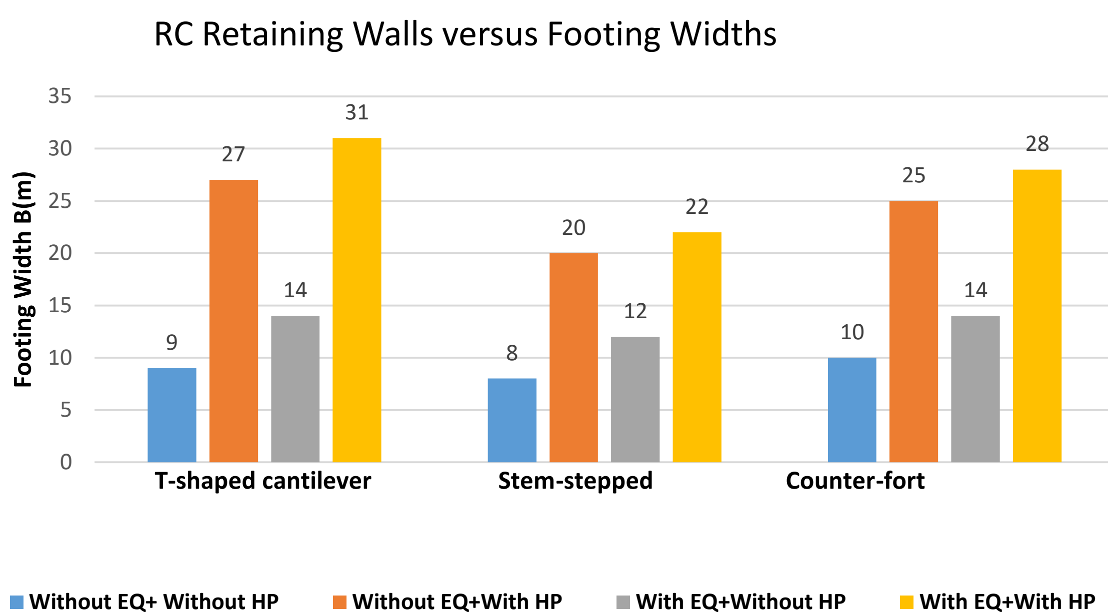

Fig. 1. RC retaining walls versus footing widths (EQ=Earthquake Motion HP=Hydraulic Pressure).

As indicated in Fig.1, it can be said that stem-stepped cantilever walls provided the most suitable wall dimensions satisfying conditions regarding the stability analysis and reinforcement amounts. This process was followed by the counter-type cantilever wall as second one and finally by T-shaped cantilever wall. It is obvious that this study aimed to carry out the ANNs application of inversed T-shaped and double stem-stepped RC retaining wall.

3. Aim of the study

In recent years, it is known that structural assessments and the ANN applications related to the different-shaped RC retaining walls with specific design parameters has been carried out. Apart from the above-mentioned studies, as warm based ANN application (Artificial Bee Colony) for the inversed-T-shaped and double stem-stepped RC walls dimensioned for7 different input parameters with 7 different wall heights were implemented for this study for prediction of concrete volume and steel rebar weight required for the variable heights of the RC retaining walls. Additionally, both of the structural stabilities and resistances of the RC retaining walls with proportionally-varied sizes were verified against extreme loading conditions. Even if there have been changes in heights and loading conditions, the backfill material height corresponding to each RC retaining wall height was taken equal to each other in all cases. By this approach, this study demonstrates the implementation of the ANN models for a quick preliminary design of special types of RC retaining walls under the design considerations such as variable H (wall height) and internal soil-friction coefficient.

4. Methodology

For this study, a typical inversed T-shaped retaining wall with two relief shelves was designed and differentiated models were generated with varying wall heights and soil-friction coefficient values. The structural analysis of the model was performed and the output of the structural analysis phase was the required concrete volume in cubic meters and the steel reinforcement amount in kilogram. With the implementation of the ANNs model trained with the swarm based ABC training algorithm, it was concluded that, such models can be implemented for verifying or performing preliminary design of the inversed T-shaped and double stem-stepped cantilever beam-like retaining walls for many projects. In the following subsections, the loading conditions, stability analysis and reinforcement detailing of the RC retaining walls are briefly mentioned.

4.1. Total earth pressures due to extreme loads

Total active, K_{at}, and passive, K_{pt}, pressure coefficients based on the Mononobe-Okabe (M-O) model including earthquake motion foreseen by Turkish Specification for Building to be Built in Seismic Zones [10] is considered as in Eq.1a and Eq.1b.

$$K_{at} = \frac{(1 \mp C_V) cos^2(\varphi - \lambda - \alpha)}{cos\lambda cos^2\alpha \cos(\delta + \alpha + \lambda)} \left[1 + \sqrt{\frac{\sin(\varphi + \delta)\sin(\varphi - \lambda - i)}{cos(\delta + \alpha + \lambda)\cos(i - \alpha)}} \right]^{-2} \tag{1-a}$$

$$K_{pt} = \frac{(1 \mp C_V) cos^2(\varphi - \lambda + \alpha)}{cos\lambda cos^2\alpha \cos(\delta - \alpha + \lambda)} \left[1 + \sqrt{\frac{\sin(\varphi + \delta)\sin(\varphi - \lambda + i)}{cos(\delta - \alpha + \lambda)\cos(i - \alpha)}} \right]^{-2} \tag{1-b}$$

whereφ is the soil friction angle, δ is the wall friction angle, α is the wall inclination with respect to the vertical axis, i is the ground inclination with respect to horizontal on both sides of the wall and the angle λ for dry and submerged soil.The resultant $P_{ad}$and P_{pd}(dynamic active and passive soil pressures) are obtained respectively as seen in Eq.2a and Eq.2b:

$$P_{ad} = 0.5\gamma K_{ad} H^2 \quad \{z_{cd} = H/2\} \tag{2-a}$$

$$P_{pd} = 0.5\gamma K_{pd} H^2 \tag{2-b}$$

where γ is the unit weight of soil (γ_{sub} for submerged soil, γ_{sat} for) and H is the vertical height of thewall. The resultant of the active and passive soil pressures are also included into to the analysis in addition to the static soil pressures by contribution of the earthquakes seen in Eq.3a and Eq.3b:

$$Q_{ad} = q_0 \left(K_{at} - K_{as}\right) H \frac{cos\alpha}{\cos(\alpha - i)} \quad \{z_{cd} = H/3\} \tag{3-a}$$

$$Q_{pd} = q_0 \left(K_{pt} - K_{ps}\right) H \frac{cos\alpha}{\cos(\alpha - i)} \tag{3-b}$$

where Q_{ad} and Q_{pd} are respectively the resultant of active and passive soil pressures, K_{as} and K_{ps} are respectively static active and passive pressure coefficient, and surcharge load q_0.

4.2. Stability analysis

The stability analysis of the wall is performed by consecutive analyses regarding the overturning about its toe, sliding along its base, bearing capacity failure of the base, settlement, and overall stability as in Eq.4.

$$FS_O = \frac{\sum M_R}{\sum M_O} \qquad FS_S = \frac{\sum F_{R'}}{\sum F_S} \qquad FS_{BC} = \frac{q_u}{q_{max}} \tag{4}$$

where FS_O is safety against overturning (total resisting and overturning moments, respectively, $\sum M_R$ and $\sum M_O$), FS_S is safety factor against sliding (total resisting forces and sliding forces, respectively, $\sum F_{R'}$ and $\sum F_S$), FS_{BC} is safety factor against bearing capacity failure (q_u is the ultimate soil-bearing capacity, q_{max} is maximum pressure at toe, q_{min} is minimum pressure at the heel).

4.3. Reinforcement

Before designing a reinforced concrete retaining wall, earth and water pressures were calculated according to Eurocode-8 (1994) [11]. Also with including the earthquake force, the loading conditions required for the M-O earth pressure equations are provided as foreseen in the TSC (2007) [10]. Each of the proportionally-sized element RC retaining wall with varying height was analyzed from aspect of overturning and sliding stability conditions, and bearing capacity of the subjected soil. As the following phase of the study, the appropriately dimensioned RC retaining wall was subjected to the reinforced concrete design. Afterwards, the structural system of the RC retaining wall exposed to the design loads was analyzed by Structural Analysis Program (SAP2000). The results such as bending moments, shear forces and axial compression forces of the structural sections at the upper and lower steps, stem and footing were obtained. This analysis is performed along whole wall members and all structural nodes of the models. Later on, the reinforced concrete design was achieved for the mentioned sections according to TS500 Turkish Standard on Requirements for Design and Construction in Reinforced Concrete Structures (TS500) (2000) [12].

Total areas of the steel bars required for footing section (at toe and heel), stem and two shelves exposed to the combined axial and shear forces, and bending moments are determined at the reinforcement concrete design stage of the study which are composed of longitudinal steel bars and shear reinforcement elements (stirrups). For reinforced concrete design of the steps and footings, the combined flexural and shear design methods were used similar to the designing of a beam section. On the contrary, the reinforcement design of the stem is analyzed with the combination of the axial compression load, shear force and bending moment similar to the sole design phase of a reinforced concrete column. Outputs of the reinforced design phase of the study are the concrete volume (m^3) and total area of steel members (kg^f) for each wall with unit length and different height. The outputs of the structural analysis and design phases are subjected to the ANN modeling for the prediction phase of the study.

4.4. Artificial neural networks

In this study, the ANN regression approach is implemented considering the outputs of the structural analysis and reinforced concrete design phases and various inputs representing the dimensioning of the RC retaining walls and soil conditions. A typical ANN model acts as a human brain with the inter-connected neurons to each other and it has the capability of pattern detection and fitting a suitable model to a nonlinear data for applying a regression model. The basic structure of a ANN model is well known in literature and shown in the Fig. 2.

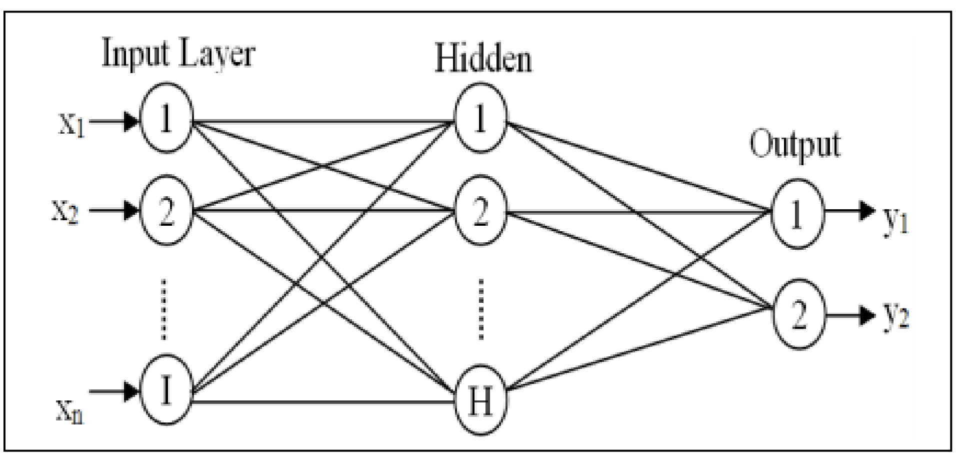

Fig. 2. A typical diagram of the ANN model.

After the training of the ANN model, the best performing model is selected by evaluating the performance statistics such as the R-Square of the model output and the Mean Square Error (MSE) defined with Eq.5.

$$\mathrm{MSE} = \frac{\left(\mathrm{O_e} - \mathrm{O_m}\right)^2}{\mathrm{n}-1} \tag{5}$$

where n is the number of sample, O_e is the vector denoting values of n number of estimations and O_ma vector representing n number of measured values.

4.5. Implementing the ANNs model

In the prediction model, the concrete volume and the reinforcement amount in kilograms are the outputs of the ANN model to be predicted. The independent variables for the ANN model were the height of the L-shaped wall (H), the soil-friction coefficient (angle). In Table 1, the input variables are shown with the output variables of the generated ANN model.

Table 1
Input and output variables for the ANN model.

Variables	Symbol	Variable Type
Height of Wall	Meters	Independent
Soil friction coef.	-	Independent
Concrete Volume	m^3	Dependent
Reinforcement Amount	kg^f	Dependent

A single hidden layer, feed forward neural network model was used for this study with a swarm based Artificial Bee Colony (ABC) training algorithm as it is was considered sufficient for approximating complex nonlinear functions.All variables were normalized between 0.1 and 0.9 for a better ANN generalization performance by using Eq.6.

$$\mathrm{Y_n} = 0.9\frac{\mathrm{Y_r} - \mathrm{Y_{rmin}}}{\mathrm{Y_{rmax}} - \mathrm{Y_{rmin}}} + 0.1 \tag{6}$$

In the Eq, Y_n is the normalized data-point, Y_n is the raw data-point Y_{rmax} and Y_{rmin} are maximum and minimum data-points observed in the data.

5. Case study: specified-sized and stem-stepped RC retaining walls

5.1. Retaining wall and soil characteristics

Eurocode-8 (1994) and TSC (2007) are used to apply loading conditions [3,13]. In this case, the wall height to determine proportionally the dimensions of wall elements is taken as variable parameters to model the ANNs. RC retaining wall and soil characteristic parameters are presented in Table 2.

In addition to the physical parameters induced by soil, concrete and steel materials, the proportionality ratios on wall elements are also applied to the stability and reinforced-concrete design calculations. The proportionality ratios considered in RC wall members in Fig.3a and illustrative retaining wall type in Fig.3b are presented.

Table 2
RC retaining wall and soil characteristic parameters.

Wall Height	H	SafetyFactors(Sliding/Overturning/BearCap)	1.5/2.0/1.5
Footing Width	0.4H-0.7H	Allow. Bearing Capacity of Ground	350 kN/m^2
Footing Thickness	H/12-H/10	Unit Weight of Concrete	23 kN/m^3
Top Thick. of Stem	Min20-30cm	Bulk Unit Weight of Soil	18 kN/m^3
Bottom Thick.of Stem	H/12-H/10	Submerged Unit Weight of Soil	20 kN/m^3
Wall Inclination Angle	90^0	Backside Slope of Stem	0
Wall Friction Angle	0^0	Depth/Thickness of Upper Step	(H/3)/0.50m
Passive Earth Height	H_p=t_{BASE}	Depth/Thickness of Lower Step	(2H/3)/0.50m
Passive Water Height	H_w=t_{BASE}	Building Importance Factor	I=1.0
Active Earth Height	H_a=H	Seismic Zone in TURKEY	2^0(High Risk)
Active Water Height	H_w=2/3H	Concrete Comp.Strength	30Mpa
Eff.Eq.Acc.Coff. k_h	0.35g	Yield Strength of Longitudinal Bar	220 Mpa
Surcharge Load	Qt=20 kN/m^2	Yield Strength of Transversal Bar	220 Mpa
Eff.LenghtofSurcharge	6m	Concrete/Steel Class	C30/ST37

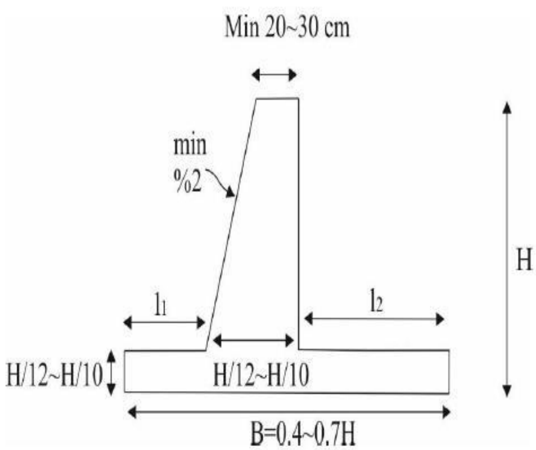

Fig. 3a. Proportionally-sized stem-stepped wall.

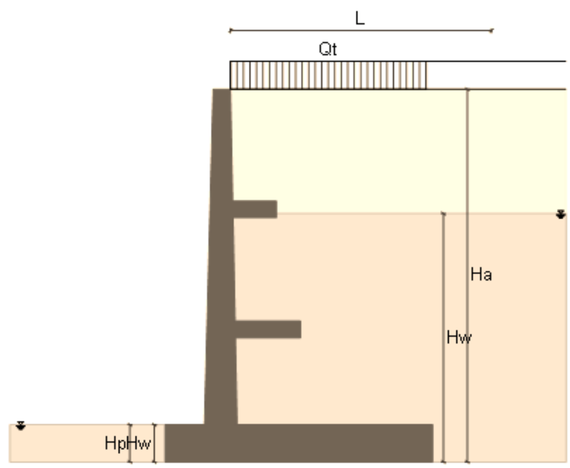

Fig. 3b. The relevant dimensions and loading.

The general proportions of components regarding inversed T-shaped and stem-stepped RC retaining wall were experienced from the projects commonly used.

5.2. Model implementation for typical inversed T-shaped and double stem-stepped wall

In order to apply the ANN modeling on the inversed T-shaped and double stem-stepped walls, the volumes of concrete and weights of steel bars with stirrups are obtained from the analytical and numerical studies based on loading, stability, structural and reinforced concrete design.

The input parameters are arranged to be described by figures: Fig.4a and Fig.4b indicate respectively the variation of volumes of concrete of wall elements (V_{CON} in m^3) and total weights of steel bars (longitudinal bars and stirrups) (W_{ST+STR} in kg^f) corresponding to internal fiction angles (ϕ^0) varying from 15^0 to 45^0 and wall heights (H) varying from 3m to 15m.

Similarly, Fig. 5a, Fig. 5b, Fig. 5c, and Fig.5d represent the variations of widths (thicknesses) at the top (b_{TOP}) and bottom of wall (b_{BOTTOM}) and the variations of thicknesses of wall bases

(t_{BASE}) and widths of footing of wall ($B_{FOOTING}$) corresponding to the above-mentioned internal friction angle intervals and various wall heights.

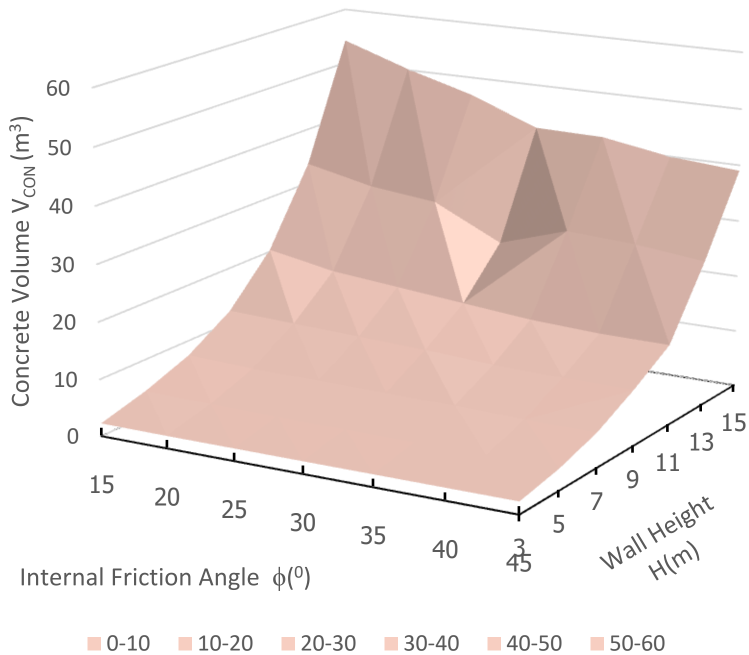

Fig. 4a. Variation of the concrete volume with respect to internal friction angle and height.

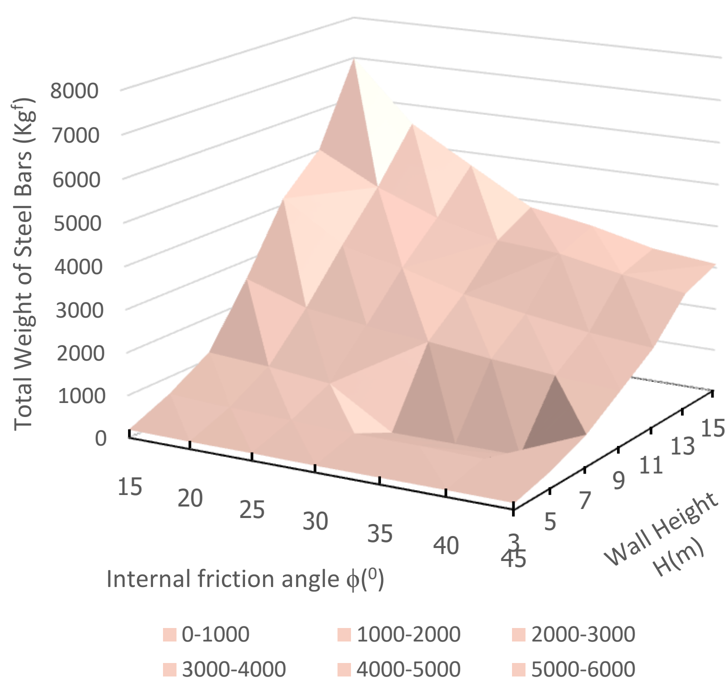

Fig. 4b. Variation of the total weight of steel bars with respect to internal friction angle and height.

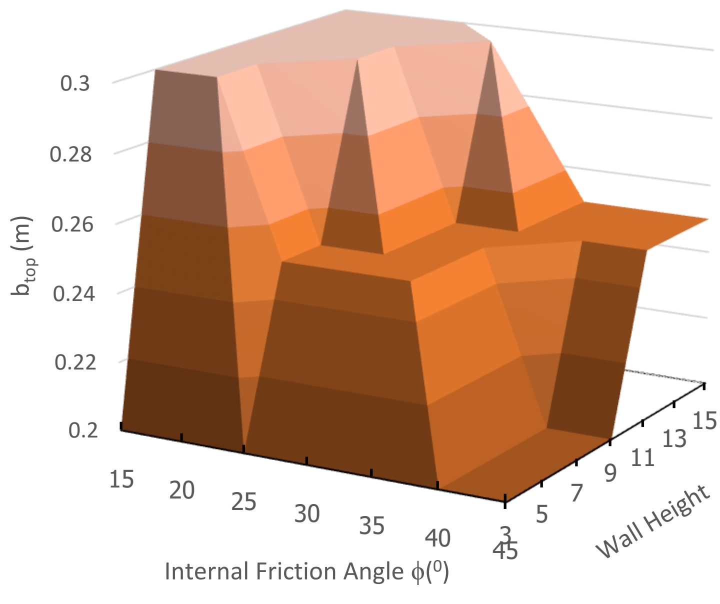

Fig. 5a. Variation of the b_{top} with respect to internal friction angle and height.

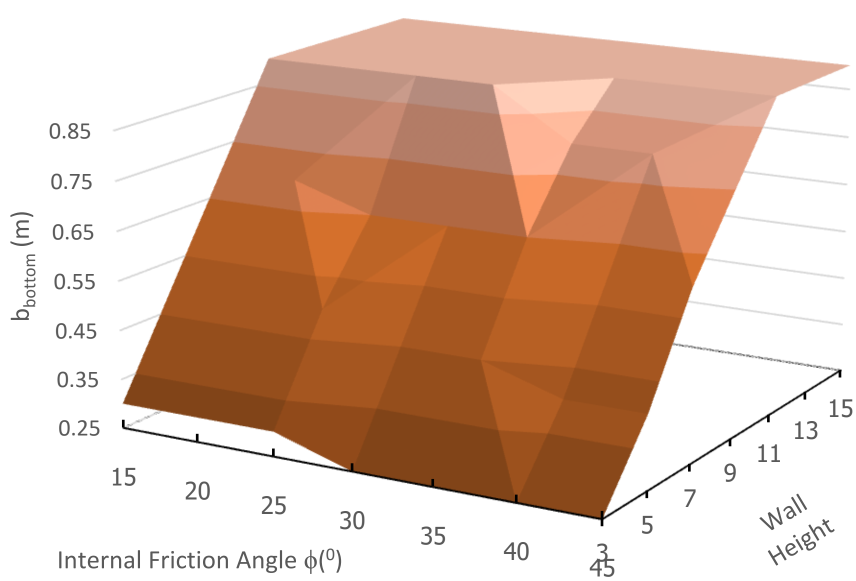

Fig. 5b. Variation of the b_{bottom} with respect to internal friction angle and wall height.

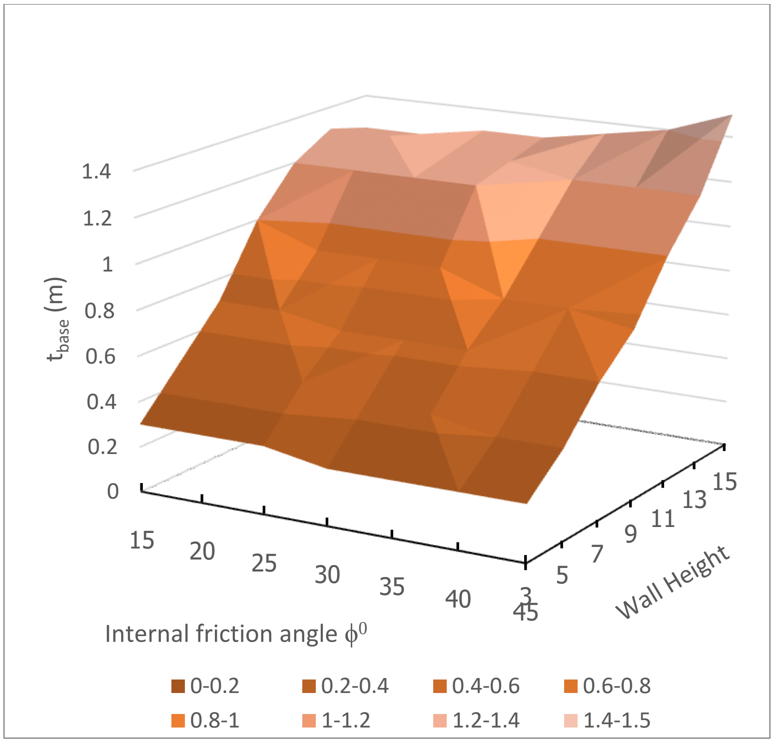

Fig. 5c. Variation of the thicknesses of wall bases with respect to internal friction angle and height.

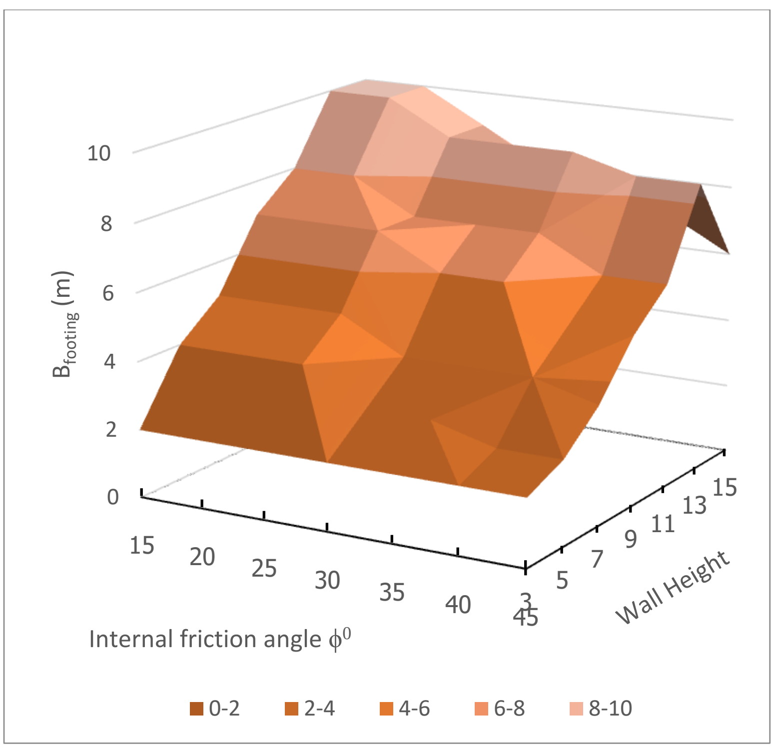

Fig. 5d. Variation of the widths of wall footings with respect to internal friction angle and height.

5. Conclusion

Up to now, it is determined that structural analyses of cantilever (with/without shelf) and counter-fort walls based on the specific wall sizes and specific design parameters were performed. They do not consider the ANNs application to evaluate the outputs of such wall analyses. After this, it is seen that there is the ANNs application thereafter, but specific parameters are applied only to a certain size of the wall.

Table 3
The dependent and independent variables for building the ANNs model.

Sample	Wall Height	Int.Fric. Angle	Concrete Volume	Steel Reinforcement	Sample	Wall Height	Int.Fric. Angle	Concrete Volume	Steel Reinforcement
N	H(m)	$\emptyset^0$	m^3	kg^f	25	9	30	10.84	1731
1	3	15	2.25	191.8	26	9	35	10.16	1561
2	3	20	2.19	173.5	27	9	40	9.93	1421
3	3	25	2.19	172.8	28	9	45	9.80	1312
4	3	30	2.18	158.6	29	11	15	20.34	4154
5	3	35	2.15	155.2	30	11	20	18.14	3221
6	3	40	2.12	149.2	31	11	25	17.04	2884
7	3	45	2.01	147.6	32	11	30	15.94	2469
8	5	15	4.42	602.6	33	11	35	14.84	2224
9	5	20	4.17	531.7	34	11	40	14.21	2014
10	5	25	4.02	487.5	35	11	45	14.10	1886
11	5	30	3.89	437.5	36	13	15	33.56	5030
12	5	35	3.79	427.8	37	13	20	30.95	4291
13	5	40	3.61	392.3	38	13	25	29.66	3735
14	5	45	3.52	380.1	39	13	30	28.36	3385
15	7	15	7.37	1168.0	40	13	35	27.71	3286
16	7	20	6.95	1067.0	41	13	40	27.01	3004
17	7	25	6.81	912.0	42	13	45	25.76	2772
18	7	30	6.67	902.0	43	15	15	54.18	7002
19	7	35	6.53	821.0	44	15	20	50.18	5532
20	7	40	6.21	751.0	45	15	25	46.10	4686
21	7	45	6.01	740.0	46	15	30	42.18	3844
22	9	15	12.19	2562.0	47	15	35	41.80	3598
23	9	20	11.74	2071.0	48	15	40	39.96	3249
24	9	25	11.29	1883.0	49	15	45	39.00	3088

This study aimed to evaluate the ANNs application of analytical and numerical findings of inversed T-shaped and double stem-stepped walls with seven different dimensions and seven different physical parameters. Therefore, concrete volume and amount of concrete were calculated according to each design based on two separate models. The ***first ANNs model*** depicted as ***ANN1*** is constructed for the concrete volume prediction. Its results are presented in Fig.6a and Fig.6b.

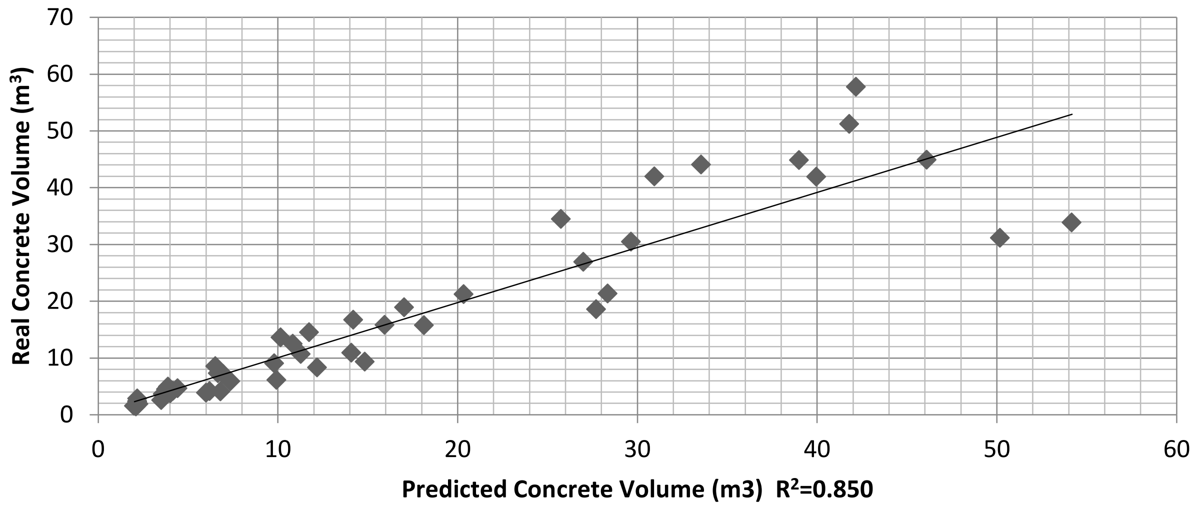

Fig. 6a. The ANN1 model for predicting the concrete volume) R^2=0.850.

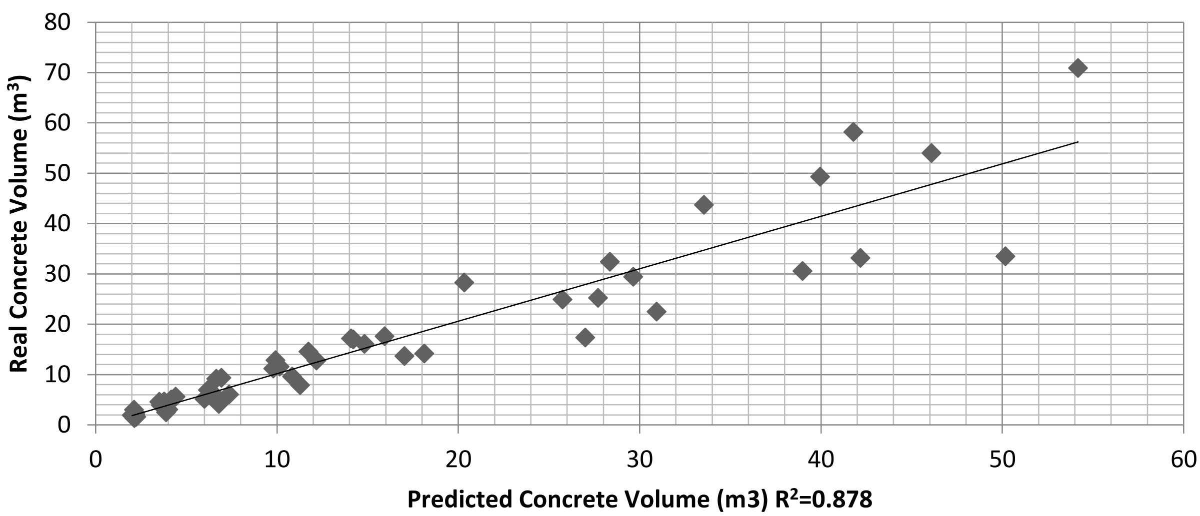

Fig. 6b. The ANN1 model for predicting the concrete volume R^2=0.878.

The result for the ***ANN1 model*** demonstrated that, the real and predicted concrete volumes for the training and testing periods are close to each other. Especially high deviations were observed for the values larger than V>20 M3. The mean square error values for the traiaing and testing periods of the ANN1 models were 17.853 M3 and 32.517 M3 for the training and testing period.

The ***second ANN model*** depicted as ***ANN2 model*** was also configured for predicting the reinforcement amount for the retaining walls as in Fig.7a and 7b.

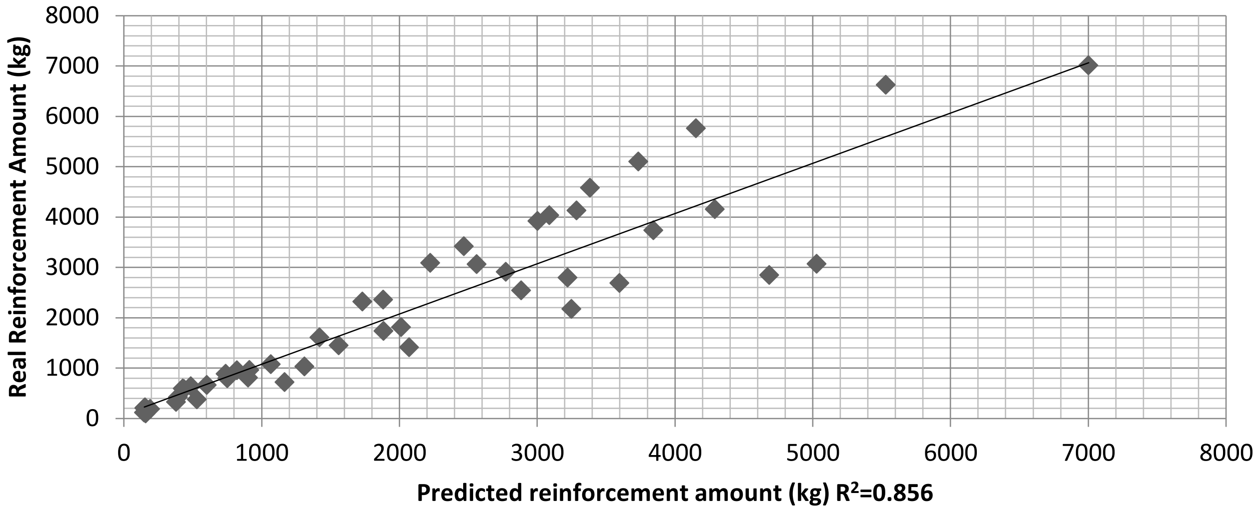

Fig. 7a. The ANN model for predicting the reinforcement amount R^2=0.856.

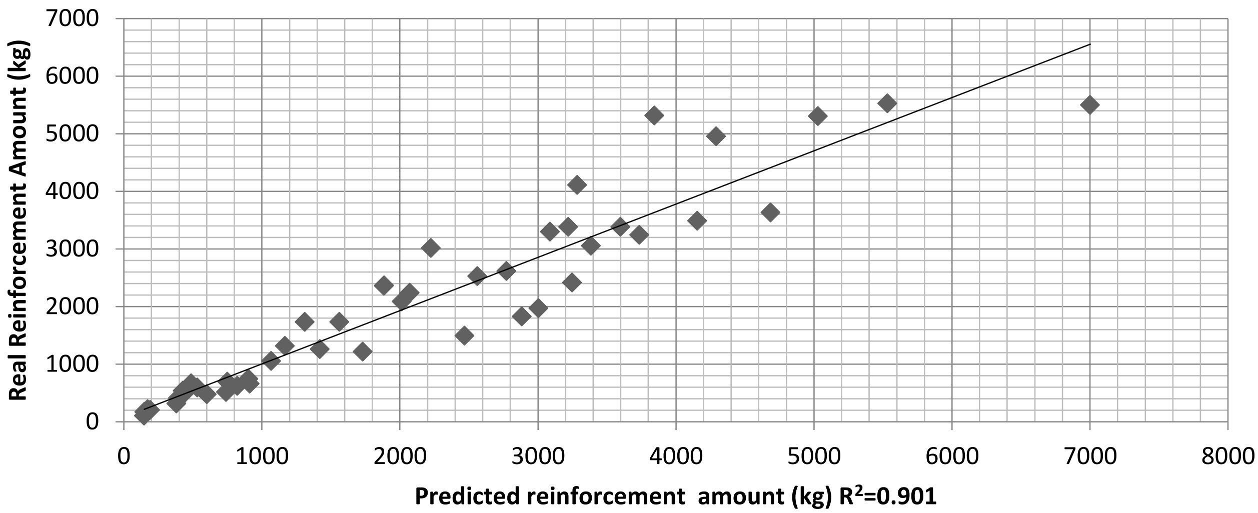

Fig. 7b. The ANN model for predicting the reinforcement amount R^2=0.901.

For the ANN2 model the input variables were same as the ANN1 model but the output variable was configured as the reinforcement amount in kilograms.

Two different ANN models depicted as ANN1 for predicting the concrete volume and ANN2 for predicting the reinforcement amount were implemented for a inversed T-shaped retaining wall. The structural and stability designs for the L shaped retaining walls were performed with regard to the recent design methodology referenced from the block stability design and TS500 structural design codes.

Both the ANNs models were trained with the design output data and by using the back propagation training algorithm as generally used for ANNs training. The result demonstrated that both models were successful in predicting the reinforcement amounts and concrete volumes for different design configuration such as variable soil friction factors and wall heights.

This study concludes that conventional ANN implementation can be beneficial for preliminary design of the L shaped retaining walls and propose important clues for the designer during the final design of these structures.

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