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ANN COMPUTATIONAL APPROACH FOR PREDICTION OF SHEAR STRENGTH OF SOIL

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Abstract: *Over the last few years or so, the use of artificial neural networks (ANNs) has increased in many areas of engineering. In particular, ANNs have been applied to many geotechnical engineering problems such as to predict pile capacity, settlement, liquefaction etc. Uncertianty is associated with determination of shear strength of the soil by using the correlations between shear strength parameters and other soil properties individually are common among Geotechnical engineers. ANN could be well adopted for prediction by creating model using set of data and validating it. The assessing strength parameters could be Grain Size Distribution, Plasticity Index and Dry Density.*

Keywords: *ANN, Shear Strength*

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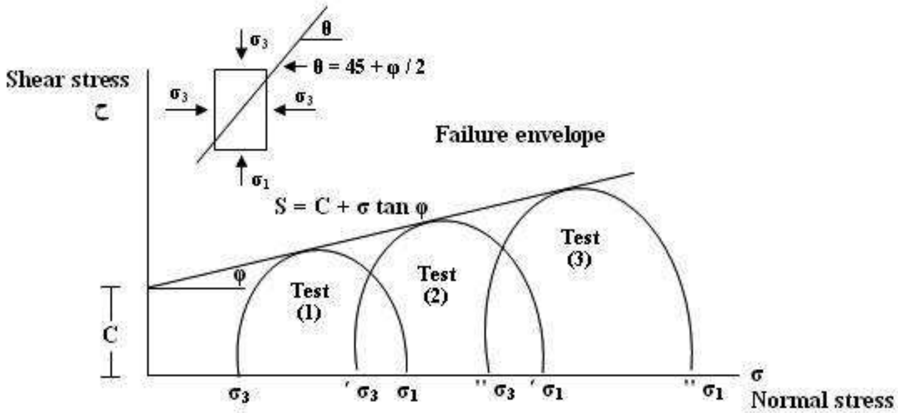
INTRODUCTION

Shear strength is ability of soil mass to resist induced shear stresses and is considered to be most important engineering property of soil mass as it governs stability of slopes, load bearing capacity of foundations, lateral pressure exerted by retained soil mass etc. Shear strength is determined experimentally in terms of shear strength parameters cohesion 'c'' & angle of internal friction'ϕ''.

1.1 Shear Strength:

Applied normal stresses on a soil element induce shear & normal stresses on other inclined plans of the soil element. When the applied normal stresses at failurewhich are in mutually perpendicular directions are represented graphically, the circle obtained is known as Mohr's circle. Each point on Mohr's circle represents a unique combination of shear & normal stress and angle of the corresponding plan on which these stresses occurs. According to Mohr-Coulomb theory there exists a unique relationship between these induced shear& normal stresses acting on weakest plan when the soil fails. When plot is made between these induced normal & shear stress, the curve obtained is unique failure envelop for that soil and is known as Mohr Envelope. The intercept of Mohr's envelope on vertical shear axis represents cohesion and inclination of envelope represents angle of internal friction. c and ϕ are considered as mathematical parameters for the equation of a straight line which best fits the experimental data , describes the failure envelope and relate shear strength to normal effective stress on the failure plane at failure [1].

In saturated soil, which is considered as an three phase system , namely solids , water & air the total normal stress at a point is the sum of the effective stress (σ') and pore water pressure (u), or $\sigma = \sigma' + u_w$[1]. The effective stress σ' is carried by the soil solids. The Mohr-Coulomb failure criterion, expressed in terms of effective stress, will be of the form $\tau_f = c' + \sigma' \tan\phi'$, where c': cohesion and ϕ': angle of internal friction, based on effective stress and u_w is pore water pressure, Fig[1].



Fig[1]: Mohr-Coulomb failure criterion of Shear Strength

1.2 Experimental Determination of Shear Strength:

Direct Shear Test: The shear strength parameters, hence shear strength can be calculated by direct shear test or triaxial shear test. In direct shear test the testing procedure essentially comprised of placing the soil in a horizontally split box , applying normal stress to the soil from top, applying shearing stress till failure of soil sample by holding the bottom of the box fixed and imparting horizontal movement to the top of the box. Number of identical specimens are tested under different normal stresses and the shear stress required for the failure is determined for each normal stresses. The failure envelope could be obtained by dotting the points for respective normal & shear stress and joining them with straight line. The inclination of failure envelope to horizontal gives the angle of friction ϕ and its intercept on the vertical axis is equal to the cohesion c. However, fixed horizontal orientation of the failure plan, lack of drainage controlling arrangements and non-availability of pore pressure measurement arrangements are considered to be less representative of actual field situation[1].

Triaxial Shear Test: Triaxial Shear Test is considered as most versatile and useful test to measure shear strength of soil wherein the actual loading conditions on the soil element of field is well simulated[14]. The test is carried out in two stages, wherein first stage the sample is subjected to normal stress by placing it in triaxial cell and applying confining pressure only. Second stage comprise of inducing shear stresses in soil element under specified drainage condition by applying additional normal stress till the sample fails on the weakest plan. Numbers of identical specimens are tested at specified drainage condition under different confining pressure and subjecting them to additional normal stress till failure. Mohr's circles are drawn for different sets of confining pressure as minor normal stress &vertically applied additional normal stress at failure as major normal stress. Failure envelope is obtained by drawing common tangent to these circles, inclination of which with horizontal gives the angle of friction ϕ' and its intercept on vertical axis is equal to the cohesion c'. The instrument is well equipped to control & simulate different drainage conditions, measurement of pore pressure and above all the failure plan represents the weakest plan on which the mobilised shear strength is not sufficient to resist induced shear stresses[1].

Triaxial test can be performed under different drainage conditions[14] depicting the field soil element situation and replicating soil response for different engineering applications such as for assessing soil stability in the short-term (e.g. during or directly following a construction project) , particularly for soils having very low permeability. The analysis carried out in terms of total stress from undrained test can be used to investigate the initial stability of the foundation of a structure, embankment on saturated clay, of open cut or sheet piled excavation made in clay and the stability against bottom heave of a deep excavation in clay. Besides, the analysis on the stability of the clay foundation of an embankment or dam where the rate of construction permits partial consolidation can also be determined in terms of effective stress by using the values of c and ϕ obtained from drained test or consolidated-undrainedtest[14].

1.3 Practical concerns over Triaxial Shear test and ANNs as alternative approach:

Even with its versatile ability of predicting shear strength of soil as an engineering material under varied situation there are some concerns pertaining to requirement of high end equipment, high execution skill, time for testing and cost of the equipment. In academic scenario wherein the goal is to provide good knowledge of experimental apparatus, testprocedure, interpretation, and errors associated with the measurement techniques is hardly achievable on account of the limited time availability. Technical compatibility of the test executor is questionable unless he has been trained and has ample experience of conduction. Even with good teaching skill its felt too optimistic to make students understand the apparatus and test procedure and perform the test without error[8]. In construction industry the cost involved in testing has been proving discouraging factor firstly on account of non availability of local equipment manufacturer, even when imported, procedures for assembly of specimens in the triaxial cell take more time and demands attention to detail than would be required in other testing processes. Thus, the technicians are required to handle & interact with instrumentation effectively and are supposed to have high skill level with high level of literacy.

More often an situation arise in construction project where sophisticated analysis is sought owing to change in the design or/ and expansion of the project and the required input parameter such as shear strength parameters may not have been determined at the geotechnical investigation stage. Such situations demands empirical determination of parameters accuracy of which may be questionable and always have an approximation associated with it, which often gets reflected in terms of uneconomical and highly conservative designed structures. Availability of an tool to predict shear parameters with fair degree of accuracy will be of great help under such situations.Over the last decade, artificial neural networks (ANNs) have been applied to many geotechnical problemssuch as prediction of soil behaviour, earth retaining structures, slope stability, pile capacity, swelling behaviour,estimation of shear strength etc[9]. On referring various work carried out and documented in the referred technical paper, it is felt that the same could be employed to arrive at an tool for prediction of shear strength parameter of the saturated soil. The main objective of the work is to develop model using Artificial Neural Network approach to predict shear strength parameters for saturated soils using data obtained from laboratory tests such as Atterbergs limit, compaction test, unconfined compression test, direct shear test and triaxial shear test.

2.0 Literature Review

The growing interest in neural networks among researchers is due to theirexcellent performance in modelling nonlinear multivariate relationships. A neural network is a computationalmechanism able to acquire, represent, and compute a mapping from one multivariate space of information toanother, given a set of data representing that mapping.

Mohamed A. Shahin, Mark B. Jaksa and Holger R. Maier, 2001[2], reviewed the literature over application of ANNs in pile capacity prediction,modelling soil behaviour, site characterisation, earth retaining structures, settlement of structures, slope stability, designof tunnels and underground openings, liquefaction, soil permeability and hydraulic conductivity, soil compaction, soilswelling and classification of soils. Capacity prediction of driven piles, liquefaction and theprediction of soil properties and behaviour are found to be most success full applications. Other application (e.g. settlement of structures) has been advised to be treated with caution and has been identified for further refinements.

Ch. Sudha Rani, Phani Kumar Vaddi,N.V.Vamsi Krishna Togati, 2013[3], developed an model for Engineering properties of soil i.e. Shear Strength parameters, permeability and compression index in terms of Fine Fraction (FF), Liquid Limit (WL), Plasticity Index (IP), Maximum Dry density(MDD), and Optimum Moisture content(OMC). A multi-layer perceptron network with feed forward back propagation with varying the number of hidden layers was used. Amongst the tested 68 soils data,47 soils data was used for training and remaining 27 soils for testing using 60-40 distribution with different inputs-hidden layers-outputsarchitectures. It is concluded that the proposed neural network model satisfactorily predictshear strength and is put forward as a foremost model for predicting the engineering properties i.e., Strength parameters, Permeability and Compressibility of soils using Artificial Neural Network.

Rajeev Jain, Dr.Pradeep Kumar Jain, Dr.Sudhir Singh Bhadauria, 2010[4], used artificial neural network technique to predict shear strength parameters of mediumcompressible soil. Commercial softwareMATLAB-7 was used for this study. Triaxial shear tests were conducted to obtainparameters at different water contents and densities, the results were used to predict strengthparametersCohesion & Angle ofinternal friction. Back propagationMLPN (multilayer perceptron) method is found to be most suitable than RBFN (radial basis function) for prediction of shearstrength parameters of medium compressible soil under UU conditions for the input variables of degree ofsaturation, dry density, and compaction effort.

Hernán Eduardo Martínez-Carvajal, Márcio Muniz de Farias, (2004)[5] adopted void ratio range (e_{max}-e_{min}) as main physical input variable for training amultilayered ANN to investigateand simulate stress path response for given strain pathsimposed during 3D triaxial tests on clean sand. Data from true triaxial tests on Cambria, Toyouraand Monterrey sand were used. Two different types of training were explored, static and recurrent, as well as two different simulation techniques: “point-to-point” and “autonomous”. “Point-to-point” simulations presented optimal responses, however they are not found to be useful in numerical applications such the finite element method.

B. Amel, A. Nechnech, PrVerbrugg (2008)[6]*,*attempted evaluation of static capacity of piles in cohesionless soils with ANNs Back Propagation Feed ForwardNeural Network. Established experimental data of 130 examples was incorporatedwith appropriate architectures and theprocess of training. After execution of the two models its concluded that with geometry and constructionmaterials of the piles andgeotechnical properties of soilas influencing factors total bearing capacity can be predicted. The influence of each factor is studied by generalization of the MNNFNCOHSmodel.

Yie-Ruey Chen, Shun-Chieh Hsieh, Chin-Hung Liu, (2010)[7],applied artificial neural networks (ANN) to simulate the soil stress-strainrelationship of saturated sand in triaxialshear testing. It is concluded that theadaptive neural network (GANN) can effectively model undrainedmonotonic and cyclic triaxial behaviour of saturated sand under isotropic or anisotropicconsolidation. The relation of cyclic stress ratio versus the number of cycles to cause 3% axial strain was found to beconsistent for predicted data and experimental data.

DayakarPenumadu, AmitPrashant, and David J. Frost, (2004)[8],developed a multimedia software (Geo-Sim) for performing virtual triaxial experiments to complement and extend the existing laboratory course component related to soil behaviour. Well-trained neural network based sand models are used to simulate the triaxial compression response for varying drainage, and under a range of testconditions. The knowledge of learning and teaching styles in engineering education are considered in this research. Ability to perform tests more rapidly than with conventional equipment is emphasised which enables the students to perform supplemental 'simulated' tests with different initial conditions, thereby enhancing their understanding of soil behaviour.

M. B. Jaksa, H. R. Maier, M. A. Shahin, (2008)[9]critically analysed ANNbasedmodels and appreciated the successfull application of ANN to virtually every problem in geotechnical engineering. The author has overviewed the operation of ANN models, highlighted and discusses four important issues which requirefurther attention in the future. These model arerobustness, transparency and knowledge extraction,extrapolation, and uncertainty.

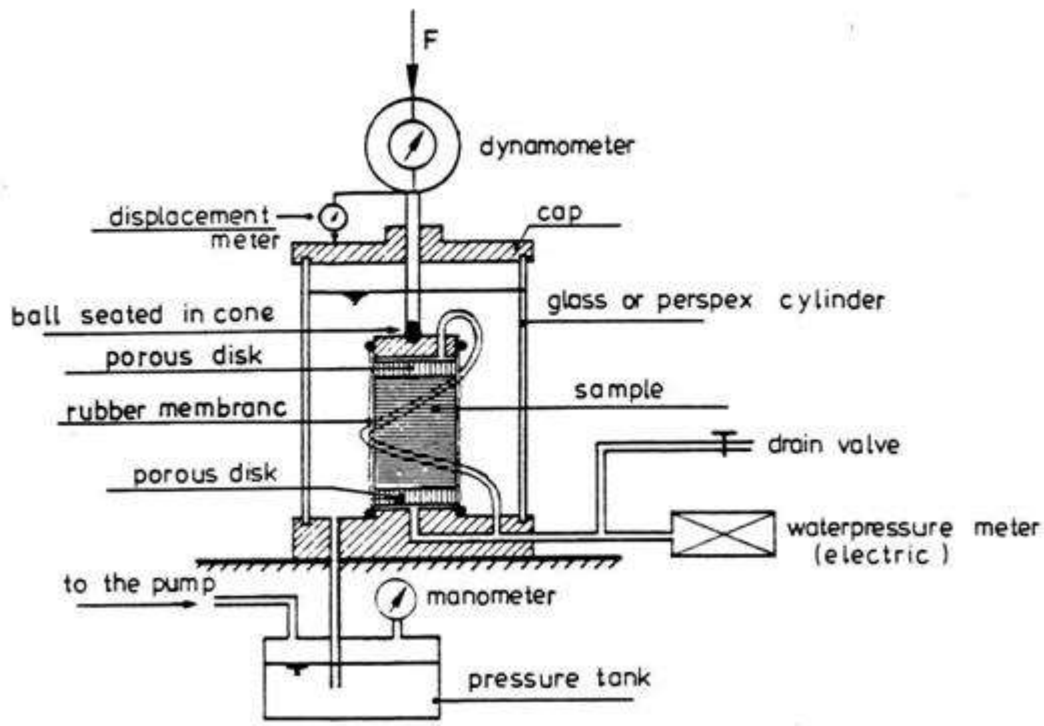
Based on the study of the above literature by the researchers in the field of geotechnical Engineering it could be concluded that the ANNs approach could be successfully used for prediction of many geotechnical characteristics of soil, pile capacity, settlementcalculation etc. Actual study for “Predicting shear strength parameters of the saturated soil by using ANNs” shall be carried out based on literature review of good number of published papers cover most of the aspects essential for the Study.

3.0PROPOSED METHDOLOGY

The methodology essentially comprise of experimental determination of basic engineering properties and shear strength parameters, deciding Artificial Neural Network architecture, Training ANNs model, validation of ANNs model. Artificial Neural Network approach is proposed to be used to effectively develop an model based on a large database of Shear strength parameters for saturated soils obtained by performing triaxial tests, namely: consolidated drained test (CD),constant water content test (CW), consolidated undrained test with pore pressures measurement (CU) and unconfined compression test (UC)[14].

3.1 Triaxial Test:

Triaxial apparatus proposed to be used for determine the shear strength parameters shall beequipped with an externallinear variable differential transformer(LVDT) for deformation measurement, external load cell for applied load measurement and transducer for pore-waterpressure measurement, Fig[2] .



Fig[2]: Triaxial Shear Test Apparatus

3.1.1 **Procedure:**

i) Placing the cylindrical soil sample to be tested on the pedestal of a triaxial cell after placing on the pedestal a saturated porous stone

ii) Isolating the soil sample from the water with a rubber membrane and sealing it at the bottom with the pedestal and at top with the top cap by rubber “O” ring.

iii) Filling the triaxial cell with water and applying pressure to the water , the normal stress so applied shall be denoted by σc and is called as cell pressure or confining pressure.

iv) In the second stage of the test, keeping the cell pressure constant and applying additional axial stress, $\Delta\sigma a$, on the sample through the piston which produces shearing stresses on all planes through the sample except the horizontal and the vertical planes.

v) Continuously increasing the additional axial stress applied to the sample through the piston until the sample fails. At failure the existing axial stress is denoted by $\sigma 1f = \sigma c + \Delta\sigma af$ and the existing radial stress is denoted by $\sigma 3f = \sigma c$

3.1.2 Observations:

i) The increase in pore water pressure at the instant of application of cell pressure can be measured by pore water pressure transducers.

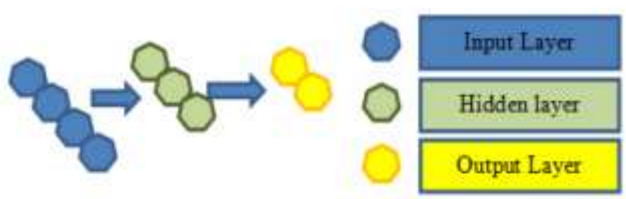
ii) The change in the volume of sample due drainage equals the observed amount of water drained and could be measured by collecting the water in burretegetting drained off during test.

iii) The axial deformation of the soil element due to pistons downward movement can be measured by LVDT and from that observation the axial strain can be determined.

3.1.3 Results: For each confining pressure σc , the axial stress$\sigma 1f$ at failure is determined from the plot of deviator stress vs axial strain. Mohr's circle shall be then plotted for each set of confining pressure σc as minor stress and axial stress $\sigma 1f$ at failure as major stress for each set. An commen tangent then shall be plotted to all these Mohr's circle, which gives the c-intercept at y-axis and ϕ- inclination of this line with horizontal[4]. These determined shear strength parameters along with the basic engineering properties of the soil such as Fine Fraction (FF), Liquid Limit (WL), Plasticity Index (IP), Maximum Dry Density (MDD), and Optimum Moisture Content (OMC), Water contents, Volume changes shall be subjected to further analysis by ANNs approach.

3.2 Artificial Neural Networks:

In artificial neural networks problem is identified in terms of set of nodes, and connections between nodes. The nodes are computational units, which receive inputs and process them to obtain an output, the processing might be very simple (such as summing the inputs), or quite complex (a node might contain another network). The connections determine the information flow between nodes. They can be unidirectional, when the information flows only in one sense, and bidirectional, when the information flows in either sense.The interactions of nodes through the connections lead to a global behaviour of the network, which is said to be emergent. This means that the abilities of the network supercede the ones of its elements, making networks a very powerful tool. Artificial Neural Network is one such type of network which represents nodes as 'artificial neurons'. An artificial neuron is a computational model inspired by the natural neurons. Natural neurons receive signals through synapses located on the dendrites or membrane of the neuron. When the signals received are strong enough (surpass a certain threshold), the neuron is activated and emits a signal though the axon. This signal might be sent to another synapse, and might activate other neurons[15].

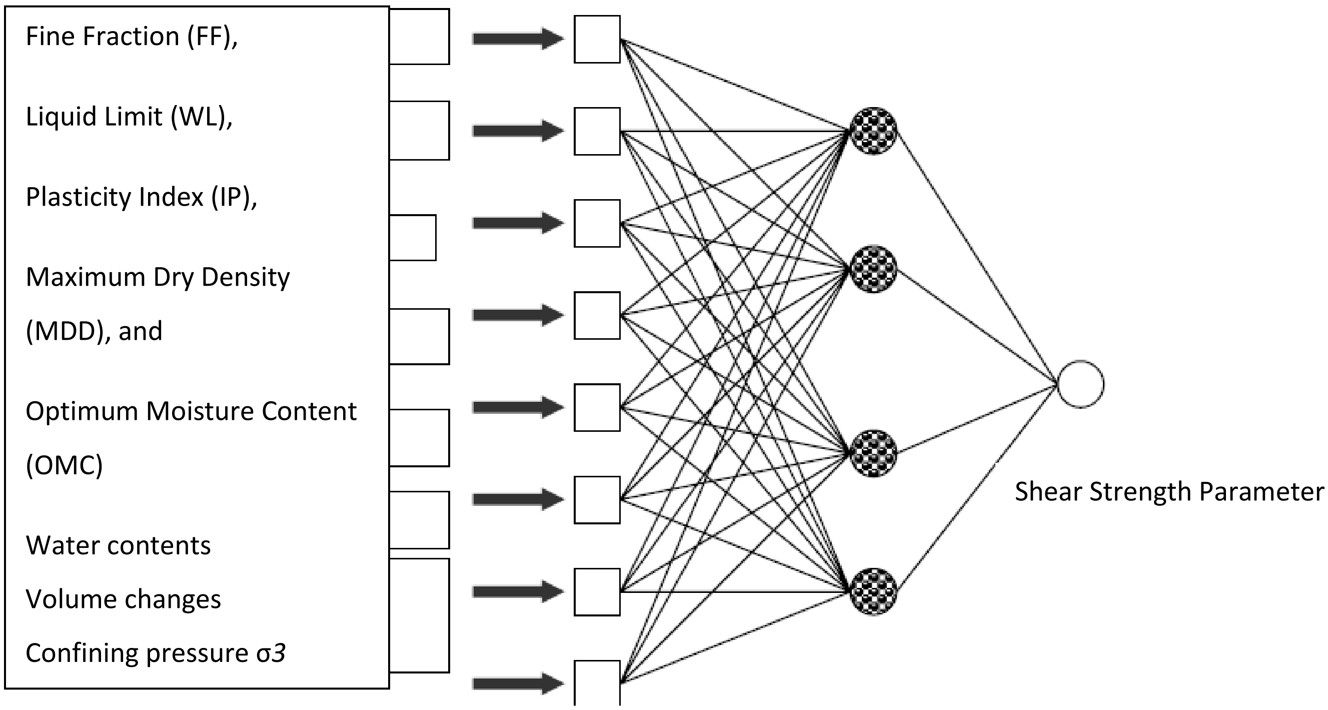


Fig[3]: A Simple Three-Layer Artificial Neural Network

The neurons are tightly interconnected and organized into different layers. The input layer receives the input; the output layer produces the final output. Usually one or more hidden layers are sandwiched in between the twoFig[3]. This structure makes it impossible to predict or know the exact flow of data.The economic uses of ANNs may be the most exciting reason of engineers for ANN's applications.

3.2.1 Artificial Neural Networks Architecture:

The proposed ANNs model is presented in the following Fig[4]:



Fig[4]: Architecture of model of ANNs

3.2.2 Network Training and validation:

The network shall be first trained with the sizable portion of experimental data which essentially comprise of the basic engineering properties and its corresponding shear strength parameters. The network shall be trained till the mean square value converges to a prespecified tolerance value or upto the predefined number of epochs[4]. Once the model has been trained till required mean square value or required number of epochs the validation and testing of the model shall be carried out, which could be also termed as predictive ability of the ANNs. The predictive ability of ANNs model shall be arrived at by predicting the shear parameters by giving basic engineering properties of remaining portion of the experimental data as input. The predicted shear strength parameters then shall be compared with the experimentally determined shear strength parameter for corresponding set of basic engineering properties. These could be repeated for number of times and the predicted & actual experimentally determined shear strength parameter are compared graphically. If good agreement or match is found then the model shall be adopted for prediction of shear strength parameters.

4.0 RESULTS:

In many of the literature studied good predicting ability has been reported for ANNs in case of shear strength parameters[3],[4]. it can be stated that the trained neural network is capable in modelling of soil shear strength paramaters with an acceptable level of confidence and it should be added that the ANN is useful to model complex relationships between input and outputs.

SUMMARY AND CONCLUSION:

The complex soil behaviour may be well simulated by Artificial Neural Networks by suitably training the network. In this case, the source of knowledge for the ANN will be the comprehensive set of experimental data obtained by conducting triaxial shear test on disturbed or undisturbed soil sample under varying confining pressure. Number of different training and transfer functions, in combination with wide variety of model sizes could be tested to approximate an optimal architecture. The work will be concentrated efforts on theconception of stronger neural models, looking forward to find a universal neural constitutive model, or a set of models, able to predict the Shear strength parameter for saturated soil by using artificial Neural Network approach.

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