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Estimation of Free Swell and Swelling Pressure using Genetic Programming

Vishweshwaran M, Anandha Kumar S

Abstract: ***Regression models by genetic programming are useful in establishing relationships among various parameters using Darwin's theory of evolution. Geotechnical parameters have been used in this model for the dataset obtained from literature. Genetic Programming is the automatic creation of computer programs to perform a selected task using Darwinian natural selection. The datasets for the expansive soil contain all the 3 expansive clay minerals – montmorillonite, illite and kaolinite. The origin for this problematic soil in Tabuk region, Saudi Arabia is due to the presence of Hanadir shale. Consolidometer was used in determining free swell for the undisturbed soil.***

Keywords: Swelling Pressure, Genetic Programming, Symbolic Regression, Free Swell

I. INTRODUCTION

Expansive soils pose problems due to the presence of clay minerals, montmorillonite being primarily responsible. Volcanic rocks subjected to atmospheric changes, over-consolidated shales are also responsible for expansion in certain parts of the world. The commonly observed difficulty in building a structure on an expansive soil is due to swelling and shrinkage of the soil. A huge loss in economy occurs every year due to this class of soil. In India, most black cotton soils possess high plasticity index. Swelling properties of the soil are very dependent on plasticity properties of the soil. [1]. These soils range from shallow depths to up to 6 m in general. Cracking and progressive damage are usually observed due to swell – shrink nature of the soil during rainy and summer seasons.

II. FACTORS INFLUENCING EXPANSIVE SOIL

Geotechnical factors influencing the expansive soil are the dry density, amount of water in the soil, limits of consistency, etc. [2]. Depth of water table is an important parameter for soil swelling because it influences the moisture content of the soil present above the water table. Soils below the water table are hardly affected by expansion. Swelling pressure is due to the constraints offered by the foundation to swell freely. If the proposed bearing pressure is more than the swelling pressure, it is preferable to build structures on an expansive soil during summer seasons rather than rainy seasons and the maximum swelling pressure may reach up to 2 MN/m^2. Clays fall under three categories depending on the smectite or kaolinite or illite. Kaolinite and illite do not swell as high as montmorillonite. Use of software models in expansive soil framework sometimes result in overestimating the swell percentages. A robust solution is required to establish the various factors responsible for the free swell and swelling pressure. Free swell corresponds to the difference in final and initial volume of the soil to the initial volume of the soil, indicated in percentage. Bentonite clays may exhibit free swell of 1200%. Free swell of 100% may damage light structures built on an expansive soil. Swelling of the soil depends on various factors in addition to clay minerals. Some of the environmental and geological factors are the stresses due to constriction, extent of atmospheric variation and classification of rock, age of the rock respectively. Specifically, the compressibility of a soil depends on the structural arrangement of the soil particles, and in fine-grained soils, the degree to which adjacent particles are bonded together. Water held between the flaky particles by certain forces gets squeezed out under compression. When the stress is removed, these forces cause the water to be sucked in again, resulting in the phenomenon of swelling. When water is added to a clayey soil, there will not be tension in the soil water. Owing to the reduction in compressive stresses, elastic expansion of clay takes place. Quantity of water held by the soil is directly related to activity of the soil. Entrapped air, adsorption, repulsion within the clay particles are also responsible for swelling of soil. Illustration of the mechanism for expansion is more complex than shrinkage.

III. GEOTECHNICAL PROPERTIES

The dataset for free swell percentage and swelling pressure is obtained from Abdullah A. Sabtan [3] and is presented in Table 1. Depth, initial moisture content (w), percentage of clay, plastic limit (w_P), liquid limit (w_L), plasticity index (I_p), activity of clay minerals (A) have been used as inputs for the model. Water content of the soil used in the datasets is found to be lesser than the plastic limit. Low, medium and high swelling percentages were observed for the soil. The category of clay with respect to swelling could be determined by the values of liquid limit and plasticity index. Limits of consistency are very helpful in clayey soils by offering a provisional indication on the behavior of the field soils. Plasticity index of the clays possess a close relationship with the fineness of the particles of the soil.

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***** Correspondence Author
Vishweshwaran M*, School of civil Engineering, SASTRA Deemed University, Thanjavur, India.
Anandha Kumar S, School of civil Engineering, SASTRA Deemed University, Thanjavur, India.

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IV. GENETIC PROGRAMMING MODEL

From the availability of multiple programs, symbolic regression uses probability in picking up each program to perform a series of functions. The functions involve algorithmic utilization of its two fundamental operators. Outcome of the model is dependent on the range of operators we choose and the difficulties involved with each operator. Genetic programming is used in various fields in an efficient manner to improve productivity, to save time and cost.

Sample number	Depth (m)	Water Content, w (%)	% of clay	Plastic Limit (w_P)	Liuid Limit (w_L)	Plasticity Index (I_p)	Activity (A)	Free swell (%)	Swelling Pressure, SP (kPa)
1	3.5	27	32	52	20	0.74	2.4	215	27
2	3.2	26	34	58	24	0.92	2.5	144	26
3	2.6	61	21	46	25	0.41	5.6	283	61
4	3.0	32	37	67	30	0.94	4.8	204	32
5	1.8	73	23	58	35	0.48	6.5	302	73
6	3.0	34	12	36	24	0.71	3.8	237	34
7	1.6	71	32	72	40	0.56	7.8	341	71
8	2.4	61	42	87	45	0.74	6.6	247	61
9	2.5	51	34	54	20	0.39	6.3	360	51
10	3.0	37	31	45	14	0.38	4.1	276	37
11	3.5	21	24	32	8	0.38	1.7	123	21
12	0.8	93	24	94	70	0.75	10.2	480	93
13	0.5	91	26	105	79	0.87	10.8	521	91
14	2.4	41	39	72	33	0.80	4.3	223	41
15	3.0	33	18	39	21	0.64	3.1	223	33
16	1.7	84	17	80	63	0.75	9.2	425	84
17	2.3	56	66	110	44	0.79	7.1	460	56
18	2.0	77	35	85	50	0.65	7.8	263	77
19	2.4	55	37	63	26	0.47	5.1	368	55
20	1.7	53	27	82	55	1.04	7.2	257	53
21	1.8	58	15	67	52	0.90	8.4	377	58
22	1.3	84	26	79	53	0.63	9.7	383	84
23	2.0	66	40	76	36	0.55	7.3	406	66
24	1.8	71	16	62	46	0.65	8.5	421	71
25	2.2	44	16	57	41	0.93	5.4	249	44
26	0.7	79	37	93	56	0.71	10.5	430	79
27	3.0	48	30	58	28	0.58	4.1	182	48
28	3.0	36	16	35	19	0.53	5.1	324	36
29	2.6	49	31	62	31	0.63	5.7	244	49
30	1.5	91	31	89	58	0.64	8.2	453	91

The above 2 equations for free swell and swelling pressure illustrate that the percentage of clay content and liquid limit are responsible for free swell whereas the increase of depth does not contribute to swell. Expansive soils do not go beyond 6 m deep in typical circumstances and the equation has rightly suggested it. Activity of the clay was not a major contributing factor to the swelling of soil. Initial water content did not contribute to free swell percentage as well. Figures represent the scatter plot, residual error plot and complexity plot for swell percentage as well as swelling pressure.

Free swell percent = 6.02 + 0.037 * (% of clay) + 0.038 * Liquid Limit * Activity - 0.79 * Depth - 0.49 * Initial water content * Activity. (1)

Swelling pressure = 435 + 0.02 * Initial water content * Plastic limit^2 + 0.00025 * Liquid limit * % of clay^2 - 3.54 * Plastic limit - 1.70 * Depth * Plastic limit - 24.61 * Initial water content * Activity (2)

Table- I: Dataset for Free swell percentage and

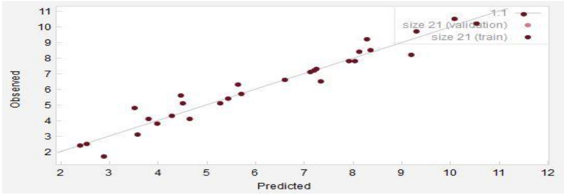

Fig.1. Scatter plot for free swell percentage swelling pressure [3]

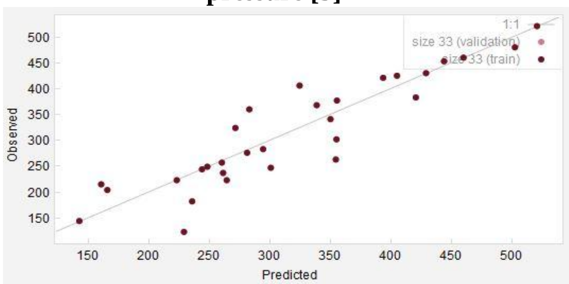

Fig.2. Scatter plot for swelling pressure

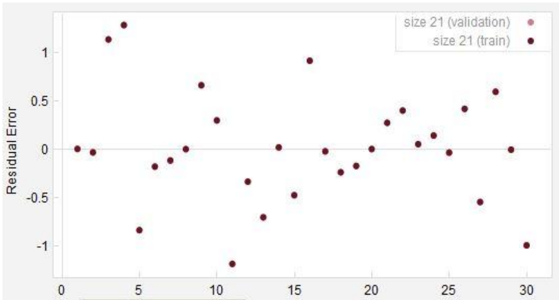

Fig.3. Residual error plot for free swell percentage

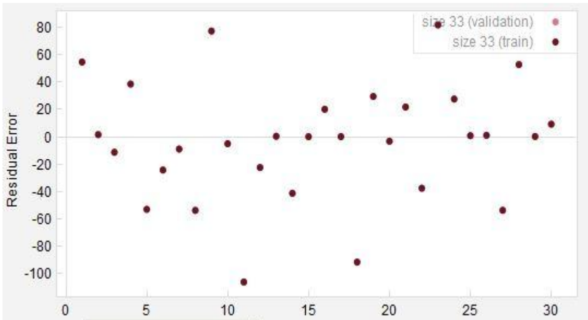

Fig.4. Residual error plot for swelling pressure

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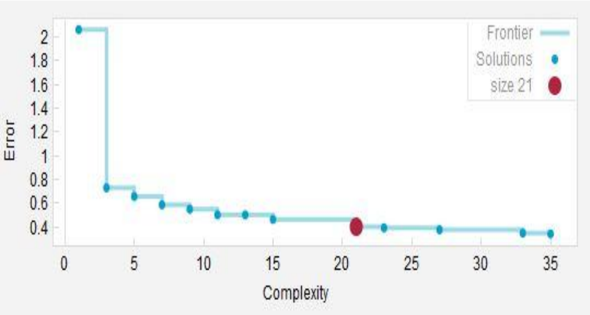

Fig.5. Complexity plot for free swell percentage

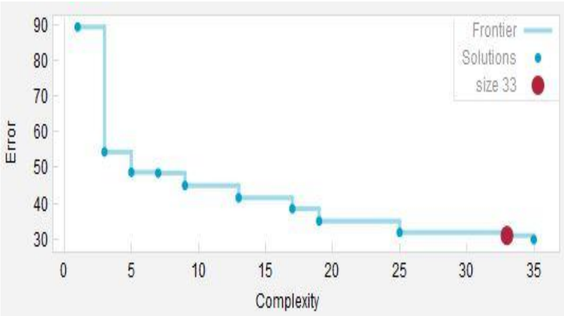

Fig.6. Complexity plot for swelling pressure

Coefficient of determination R^2 was found to be 0.948 and 0.828 for free swell percentage and swelling pressure respectively. Mean absolute error was found to be 0.4 and 30.9 respectively for free swell percentage and swelling pressure. The behavior of swell varies from lab results to actual field observations. Exchange of cations influence the swelling depending on the charge of ions. Compared to divalent ions, monovalent ions induced higher expansion for clays in Saudi Arabia. [2] Scatter plot, residual plot and complexity plot represent the accuracy of the 2 models for free swell percentage and swelling pressure and it is observed that the model for free swell percentage provides more reliable results when compared to the swelling pressure. The time taken for training and validation was quick. The degree of complexity varies depending on the number of operators chosen for the model. The operators chosen here are multiplication, addition, subtraction, integer and constant. Iteration was performed for various generations until 100% convergence followed by termination. The total complexity of each solution is the sum of the complexity values of the operators used in that solution. As less complex models with low errors of measurement are desirable, sometimes the researcher has to make a trade-off between complexity and fit by choosing less complex models over more complex models with slightly better fit statistics [5]. Symbolic regression can achieve much higher precision if influential variables in a predictive model are reliably identified, operationalized, and measured [6].

V. CONCLUSION

Symbolic regression offers very good results for free swell percentage and satisfactory output with respect to swelling pressure. Darwinian natural selection achieves the objectives of automatic programming by biologically inspired operators. They have high potential applications in various Geotechnical engineering linear and non linear analyses. In this analysis, 2 models were developed using symbolic regression, one for swelling pressure and other for free swell index. Predicted values were found to be close to the measured values. Equations were developed for free swell percentage and swelling pressure. These equations are highly suited for free swell index and swelling pressure of clay shales of Tabuk region. More datasets are required for different types of clays to understand the soil behavior with respect to swelling of clays. Similar to symbolic regression, various other models in genetic programming and genetic algorithm may provide solutions for complicated problems in Geotechnical engineering.

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AUTHORS PROFILE

Vishweshwaran M works as an Assistant Professor in SASTRA Deemed University, Tamil Nadu, India. He has pursued M.E. in Geotechnical Engineering. His areas of interest include soil stabilization, biopolymers in ground improvement, geosynthetics. He is a life member of Indian Geotechnical Society – Coimbatore and Thanjavur chapters. He has an academic experience of 3 years. He believes that environmental friendly practices in geotechnical engineering are very important in the future. He also believes that an inter-disciplinary approach is required in efficient and environmental friendly waste management issues. Geo-Environmental Engineering deals with engineering solutions relating to environmental impacts of contaminants within soils, and includes such aspects as understanding the migration, interactions and fate of contaminants, the protection of uncontaminated regions, the remediation or clean-up of contaminated sites.

Anandha Kumar S is a full time Research scholar in SASTRA Deemed University, Tamil Nadu, India. He completed his M.E., in Soil Mechanics and Foundation Engineering under Anna University. His area of specialization is Soil Stabilization, Ground Improvement Techniques and Geo-environmental Engineering. He has an academic experience of 2 years and 1 year of research Experience. The author is curious in understanding the relevant principles of chemistry, biology and physics, types of contaminants, geosynthetic and other barriers and containment systems, regulatory requirements and site remediation technologies in the area of geo-environmental engineering. Also interested in site investigation, sampling approaches and methods, modeling, assessments, treatment and control strategies. The author believes that an understanding of soil behaviour, waste characteristics and contaminant-soil interaction is a basic building block for more specialized.