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Application of Symbolic Regression in Modeling Soil Deformation Modulus

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Abstract: ***It is not simple to determine in-situ horizontal stresses even though vertical stresses could be determined directly. Pressuremeter is not given high importance even though it is useful in illustrating various geotechnical parameters effectively. It is important to characterize geomaterials which in turn helps us to understand the properties and behavior of the materials. Symbolic Regression model has been prepared to relate pressuremeter test results with geotechnical engineering properties. Understandingthese properties help geotechnical engineers in design and analyses of foundations, earth pressures, etc.***

Keywords : Symbolic regression, Genetic programming, Pressuremeter, Geotechnical properties, Geotechnical model.

I. INTRODUCTION

Pressuremeter test helps in determining angle of dilation for cohesionless soils, angle of internal friction for cohesionless soils, compressibility of a soil, undrained strength of cohesive soils, horizontal. It is imperative that the installation of pressuremeter contributes to the correctness of the results to be obtained. In order to install it to the very best quality, standardization of the installation methodology is required. Calibration of the instrument and measurements are to be done accurately. Pressuremeters represent cylindrical devices which apply unvarying, undifferentiated stresses to the surrounding walls of a borehole. Measurement of applied stresses and the deformation is the chief requirement for pressuremeter tests. In order to establish pressuremeter as a commonly used device, its accuracy and reliability in determination of its parameters from the in situ tests are preferable.

II. IMPORTANCE OF PRESSUREMETER TEST

Laboratory tests could be prone to more errors due to the disturbances of soil from its in situ state and the determination of engineering properties by cutting edge facilities may not be economical and may even delay the schedule of a project. Due to the factors such as flexible membrane features, differences in heights, compressibility, corrections are to be applied to the values of stress, lateral deformation and volume.

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Pressuremeter was initially used as an empirical measurement device but due to the requirements of good field data, the importance of pressuremeter is inevitable. Moreover, the in situ soils' boundary conditions are difficult to replicate in the laboratory in terms of load and deformation. In situ tests are equally important when compared to laboratory tests to analyze the properties of soils comprehensively. In situ pressuremeter tests have in recent years come into wide use in the determination of the parameters to be used for foundation design [1]. Model factor for evaluation of bearing capacity of piles in ultimate limit state is possible by Menard's pressuremeter test results [2]. It is possible to design laterally loaded piles with the help of P-y curve which could be obtained from pressuremeter curve. [3]. Response of the model with respect to predictor variable shall be analysed by parametric analysis. The robustness of a design equation is determined by examining how well the predicted target values agree with the underlying physical behavior of the investigated system [4]. The typical manner in which a pressuremeter is installed is installing vertically at various depths in the ground, and connected by tubing or cables to a control unit at the ground surface. There are various types of pressuremeters and all methods of interpretation of pressuremeter test results assume that the expanding cavity is sufficiently long for the deformation to be considered as cylindrical. A major difference between categories of pressuremeter tests lies in the method of installation of the pressuremeter device in the ground [5].

III. SYMBOLIC REGRESSION MODEL

Datasets for the model were selected from a literature of Jafar Bolouri Bazaz [6] and is presented in Table 1. Information on different particle sizes, soil classification parameters, moisture content, unit weights of the soil have been used in the datasets against secant modulus of the soil. The model aims in predicting equation for secant modulus based on the available geotechnical data. One of the principal benefits of using pressuremeter is the simultaneous measurement of deformation and strength. FC (%), D_{10} (mm), D_{30} (mm), D_{60} (mm), C_u, C_c, LL (%), w (%), ρ_d (%) and E_p (kg/cm^2) represent percentage of fines, particles sizes finer than 10%, 30%, 60%, coefficient of uniformity, coefficient of curvature, liquid limit, water content, dry density and secant modulus respectively. To utilize the search space in an efficient manner, evolutionary algorithm requires diversity because of which better performing models shall be created [1]. Response of the model with respect to predictor variable shall be analyzed by parametric analysis.

The robustness of a design equation is determined by examining how well the predicted target values agree with the underlying physical behavior of the investigated system [5].

Table- I: Dataset of geotechnical parameters and pressuremeter results [6]

S.No	FC (%)	D_{10}	D_{30}	D_{60}	C_u	C_c	w_L	w	ρ_d
1	93.6	0.0007	0.0043	0.027	38.571	0.978	42	16	15.5
2	71	0.0001	0.016	0.051	510.000	50.196	18	21	15.5
3	97.0	0.0001	0.0003	0.007	70.000	0.129	40	22	15.5
4	76.9	0.0008	0.0065	0.03	37.500	1.760	30	27	16.0
5	94.0	0.0004	0.0011	0.024	60.000	0.126	28	20	15.5
6	96.0	0.0001	0.007	0.014	140.000	35.000	35	22	15.5
7	90.5	0.0001	0.0017	0.017	170.000	1.700	28	18	16.0
8	98.0	0.0001	0.00017	0.012	120.000	0.024	17	18	16.0
9	47.8	0.0001	0.025	0.28	2800.000	22.321	17	26	16.0
10	17.6	0.013	0.48	1.5	115.385	11.815	17	26	16.0
11	86.0	0.0001	0.003	0.02	200.000	4.500	17	26	16.0
12	99.4	0.0001	0.011	0.031	310.000	39.032	27	18	16.5
13	93.2	0.002	0.0084	0.025	12.500	1.411	34	17	17.8
14	61.0	0.0017	0.024	0.07	41.176	4.840	33	22	15.3
15	96.9	0.0007	0.007	0.022	31.429	3.182	34	10	17.5
16	94.9	0.006	0.02	0.034	5.667	1.961	24	19	17.0
17	86.6	0.0013	0.0073	0.035	26.923	1.171	31	15	17.0
18	63.4	0.0029	0.021	0.064	22.069	2.376	23	12	19.8
19	87.8	0.0012	0.017	0.03	25.000	8.028	25	17	16.9
20	66.7	0.0029	0.0165	0.06	20.690	1.565	22	23	16.7
21	87.8	0.0028	0.0115	0.035	12.500	1.349	26	17	17.8
22	86.75	0.0018	0.0081	0.031	17.222	1.176	27	13	17.0
23	92.75	0.0015	0.0085	0.025	16.667	1.927	34	13	17.0
24	66.06	0.003	0.041	0.063	21.000	8.894	23	13	17.0
25	93.66	0.0032	0.022	0.045	14.063	3.361	29	16	17.2
26	83.85	0.0061	0.042	0.064	10.492	4.518	22	16	17.2
27	80.44	0.0044	0.023	0.059	13.409	2.038	26	16	17.2
28	91.39	0.0044	0.031	0.06	13.636	3.640	26	16	17.2
29	97.0	0.0001	0.003	0.015	150.000	6.000	26	17	16.1
30	52.0	0.0004	0.005	0.84	2100.000	0.074	21	20	16.8
31	96.8	0.0011	0.004	0.021	19.091	0.693	20	19	16.1
32	90.0	0.0006	0.001	0.017	28.333	0.098	32	19	16.3
33	97.5	0.0007	0.0067	0.033	47.143	1.943	29	20	16.5
34	71.7	0.0006	0.004	0.03	50.000	0.889	32	26	16.8
35	86.5	0.0044	0.02	0.033	7.500	2.755	23	16	16.4
36	80.0	0.0007	0.009	0.029	41.429	3.990	17	9	18.0
37	81.4	0.0002	0.008	0.034	170.000	9.412	17	26	15.0
38	59.0	0.0022	0.013	0.074	33.636	1.038	17	10	19.0
39	32.5	0.0069	0.05	1.4	202.899	0.259	23	19	18.0
40	47.8	0.0001	0.018	0.6	6000.000	5.400	23	14	16.2
41	47.5	0.0003	0.018	0.95	3166.667	1.137	26	14	16.5
42	94.6	0.0001	0.006	0.025	250.000	31.000	22	18	17.5
43	12.3	0.007	0.9	6	857.143	19.286	16	6	14.6
44	47.8	0.0001	0.013	0.7	7000.000	2.414	28	15	15.5
45	56.7	0.0003	0.008	0.15	500.000	1.422	28	15	15.5
46	92.0	0.0009	0.0071	0.02	22.222	2.801	27	15	15.5
47	87.5	0.0005	0.0035	0.025	50.000	0.980	30	16	17.0

48	52.0	0.0005	0.014	0.17	340.000	2.306	23	16	17.0
49	84.5	0.0006	0.0015	0.018	30.000	0.208	36	14	14.5
50	73.4	0.0014	0.0114	0.04	28.571	2.321	31	18	14.3
51	40.0	0.0007	0.02	2.1	3000.000	0.272	28	14	17.5
52	89.6	0.0007	0.003	0.018	25.714	0.714	29	18	14.5
53	91.8	0.0006	0.0027	0.021	35.000	0.579	29	18	14.5
54	90.8	0.0012	0.009	0.024	20.000	2.813	35	18	14.5
55	86.0	0.0023	0.01	0.03	13.043	1.449	38	4	19.0
56	87.5	0.0004	0.0014	0.014	35.000	0.350	31	17	17.0
57	92.0	0.0004	0.0027	0.028	70.000	0.651	34	17	17.0
58	91.0	0.0002	0.005	0.028	140.000	4.464	17	18	17.5
59	97.0	0.0001	0.0012	0.02	200.000	0.720	31	18	17.5
60	60.0	0.0032	0.0215	0.073	22.813	1.979	18	15	17.5
61	89.6	0.0055	0.019	0.039	7.091	1.683	24	11	17.0
62	99.0	0.0012	0.011	0.029	24.167	3.477	28	17	17.0
63	71.0	0.001	0.013	0.063	63.000	2.683	30	17	17.0
64	88.4	0.00155	0.014	0.044	28.387	2.874	30	10	18.9
65	97.7	0.0015	0.0084	0.021	14.000	2.240	29	17	17.5
66	64.8	0.0021	0.014	0.06	28.571	1.556	23	16	17.5
67	56.0	0.0012	0.015	0.1	83.333	1.875	18	16	18.3
68	78.8	0.001	0.011	0.045	45.000	2.689	28	15	18.1
69	81.0	0.0006	0.0013	0.025	41.667	0.113	29	16	18.3
70	94.5	0.0005	0.004	0.021	42.000	1.524	28	17	18.5
71	33.0	0.0005	0.04	1.1	2200.000	2.909	17	17	18.5
72	49.2	0.013	0.051	0.11	8.462	1.819	20	14	18.9
73	48.0	0.004	0.02	0.25	62.500	0.400	17	12	18.0
74	20.0	0.02	0.21	0.595	29.750	3.706	17	12	18.0
75	62.5	0.0006	0.012	0.05	83.333	4.800	28	17	16.8
76	28.0	0.008	0.1	1.2	150.000	1.042	21	17	16.8
77	26.5	0.0056	0.15	1.3	232.143	3.091	21	17	18.0
78	37.5	0.0053	0.031	0.71	133.962	0.255	21	10	19.0
79	26.7	0.009	0.15	1.44	160.000	1.736	20	10	19.0
80	22.0	0.011	0.595	6	545.455	5.364	19	12	17.5
81	35.5	0.0009	0.04	1	1111.111	1.778	24	11	19.5
82	44.0	0.001	0.023	1.1	1100.000	0.481	17	7	19.0
83	74.4	0.0003	0.0095	0.03	100.000	10.028	24	15.94	19.5
84	30.0	0.002	0.083	2.2	1100.000	1.566	23	11	19.5
85	36.0	0.0011	0.04	2.1	1909.091	0.693	23	11	19.5
86	93.0	0.0003	0.0042	0.012	40.000	4.900	39	4	19.0
87	45.0	0.0033	0.013	0.8	242.424	0.064	23	4	19.0
88	38.0	0.0041	0.022	2	487.805	0.059	17	4	19.0
89	41.0	0.0041	0.019	1.3	317.073	0.068	17	4	19.0
90	87.0	0.00065	0.00477	0.0165	25.385	2.121	30	4	18.7
91	34.0	0.0044	0.05	9.7	2204.545	0.059	17	4	19.0
92	34.0	0.0045	0.05	9.6	2133.333	0.058	17	1.42	19.7
93	94.0	0.0007	0.0084	0.0215	30.714	4.688	35	3	19.0
94	70.0	0.00065	0.007	0.035	53.846	2.154	33	3	19.6
95	51.0	0.0006	0.011	0.6	1000.000	0.336	38	4	19.0
96	96.7	0.00006	0.0005	0.018	300.000	0.231	30	22	16.0
97	90.0	0.00005	0.0007	0.0138	276.000	0.710	32	22	16.0
98	99.9	0.0001	0.0008	0.014	140.000	0.457	32	22	16.0

99	100.0	0.00008	0.00143	0.021	262.500	1.217	28	22	16.0
100	97.5	0.00007	0.0005	0.015	214.286	0.238	29	20	16.5
101	97.6	0.00007	0.00005	0.0115	164.286	0.003	34	20	16.5
102	88.8	0.0001	0.0022	0.023	230.000	2.104	27	20	16.5
103	86.8	0.0003	0.0035	0.022	73.333	1.856	29	20.85	16.0
104	56.5	0.00065	0.0021	2	3076.923	0.003	31	24	16.0
105	98.7	0.0007	0.0053	0.014	20.000	2.866	29	18	15.5
106	98.0	0.0004	0.014	0.03	75.000	16.333	23	17	16.5

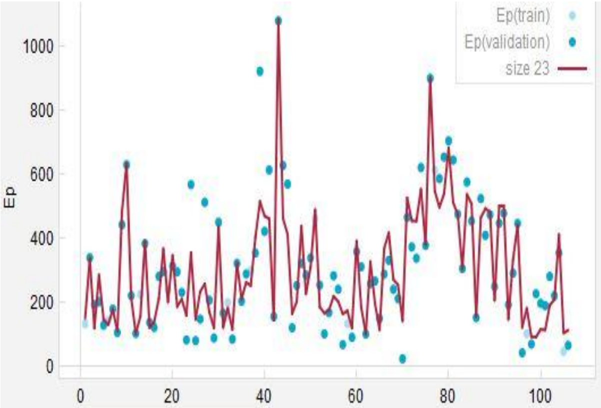

Fig. 1.Solution plot

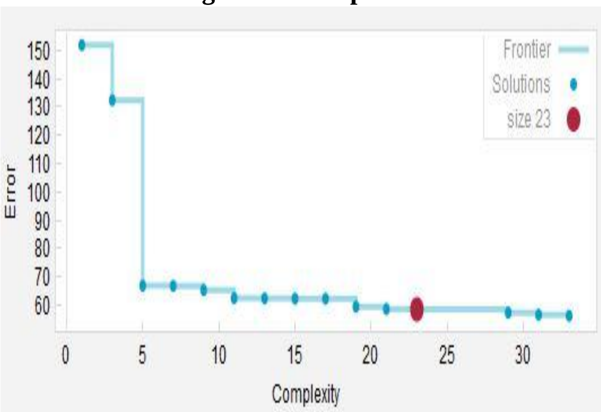

Fig. 2.Accuracy vs Complexity plot

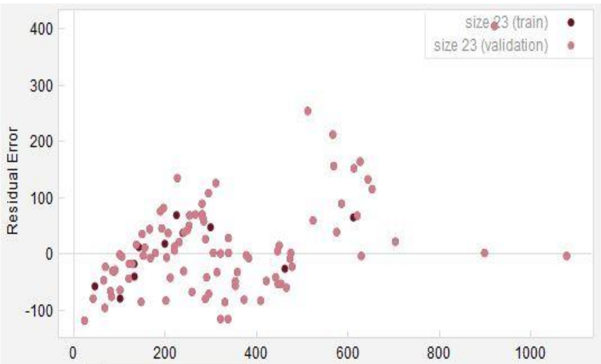

Fig. 3. Residual error plot

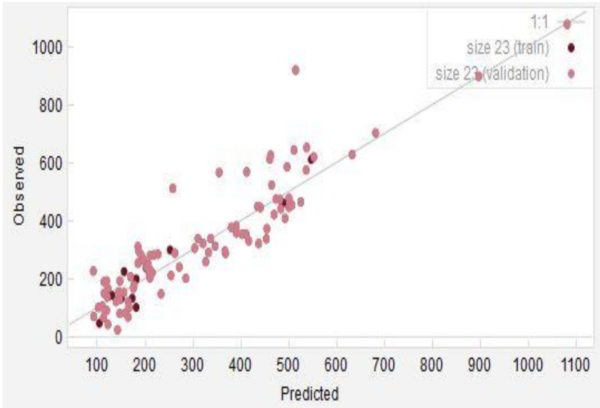

Fig. 4. Observed vs predicted plot

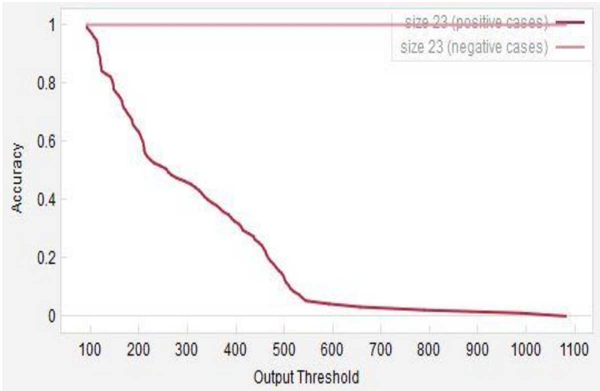

Fig. 5. Classification Threshold plot

IV. RESULTS AND DISCUSSION

$$E_p = 562.81 + 4.58 * D_{60} * C_c + \tan(588.71 * D_{10}) - D_{60} - 0.047 * FC^2$$

The above equation indicates that effective size of the soil (D_{10}), D_{60} and coefficient of curvature (C_c) result in positive values for secant modulus. Amount of fines, liquid limit, water content, coefficient of uniformity parameters do not contribute to the effectiveness of the secant modulus of pressuremeter test. Coefficient of determination (R^2) of the model indicating the goodness of fit is 0.829 with a mean average error of 58.48. Plots for solution, complexity, residual error, accuracy, classification threshold are shown in the figures.

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V. CONCLUSION

The result shows that symbolic regression is a satisfactory tool for modeling complex geotechnical data. More number of datasets and more input parameters for different soils may increase the effectiveness of the model. Sensitivity analysis, parametric analysis may be further conducted to check and enhance the robustness of the obtained model. Deformation modulus of the soil is a very important field parameter and the reliability of the result may be useful in future analyses, design purposes, etc. The model shall also be used for cross verification for problematic soils.

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AUTHORS PROFILE

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