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Empirical Modeling on Swell Pressure of Clay using Index Properties

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Abstract. Expansive soils undergo volume expansion, when it gains moisture content. Light structures constructed on this type of soil will be lifted by the upward swell pressure. Swelling characteristics decides the degree of safety of structures resting on expansive soil strata. Predicting the swell pressure of the soil consumes nearly 5 days of time (variable with respect to soil potential) in the laboratory as well as needs expensive testing setup. In our study, a correlation is proposed to develop for swell pressure using the index properties of soils namely liquid limit and plastic limit, which shall be assessed at the laboratory relatively short period of time. Swelling Pressure tests by Free Swell Method are performed on dynamically compacted 20 remolded soil samples collected within Coimbatore Corporation limit. The study area is between the four coordinates of $11^0$08'49.25" N $76^0$53'36.28" E, $11^0$12’05.58’’ N$76^0$55'57.84" E, $10^0$59'16.52" N $76^0$52'17.47" E, $10^0$57'00.59" N $76^0$57'43.71" E. Laboratory experimental data given as input in MATLAB gives satisfactory results and correlation is extracted from curve fitting method.

Introduction

Building foundations bears the entire super structure load. The soils beneath the foundations hold play a crucial part in holding the foundation. But Expansive soils, such as montmorillonite deforms more provides lesser resistance against the foundation load. One-fifth of the Indian land is covered by these expansive soils, produces difficulty to building & Road construction activities.

Black cotton soil, which is rich in montmorillonite clayey mineral and exhibits higher degree of shrinkage, swelling and compressibility nature under loading due to its chemical composition. Higher the montmorillonite presence, it becomes black or blackish grey in colour. Montmorillonite has the structural composition of 1 octahedral alumina sheet and 2 tetrahedral silica sheets in the structural term defined as 2:1 composition. Due to the Isomorphous substitution they are highly adsorbs the water and forms diffusible double layer around the surface. It becomes more expansive in nature with increase in moisture content. This water imbibing phenomena is occurring in higher degree, comparatively with kaolinite and bentonite clay mineral.

Coimbatore, Tamilnadu, India is highly covered by the clay deposits, especially montmorillonite mineral. As observed, many of the light structures in Coimbatore lost its stability due to this swelling nature. Hence it is taken as study area.

Sample Collection

The sample used for the conducting various experiments in our project were collected at a depth more than 1.5 meter from the Existing ground level.

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The representative soil samples were collected from 20 locations within the Coimbatore city. The study area is between the four coordinates of A (11^{0}08'49.25" N 76^{0}53'36.28" E), B(11^{0}12'05.58" N 76^{0}55'57.84" E), C(10^{0}59'16.52" N 76^{0}52'17.47" E), D(10^{0}57'00.59" N 76^{0}57'43.71" E). The locations of twenty soil samples are shown in Figure1

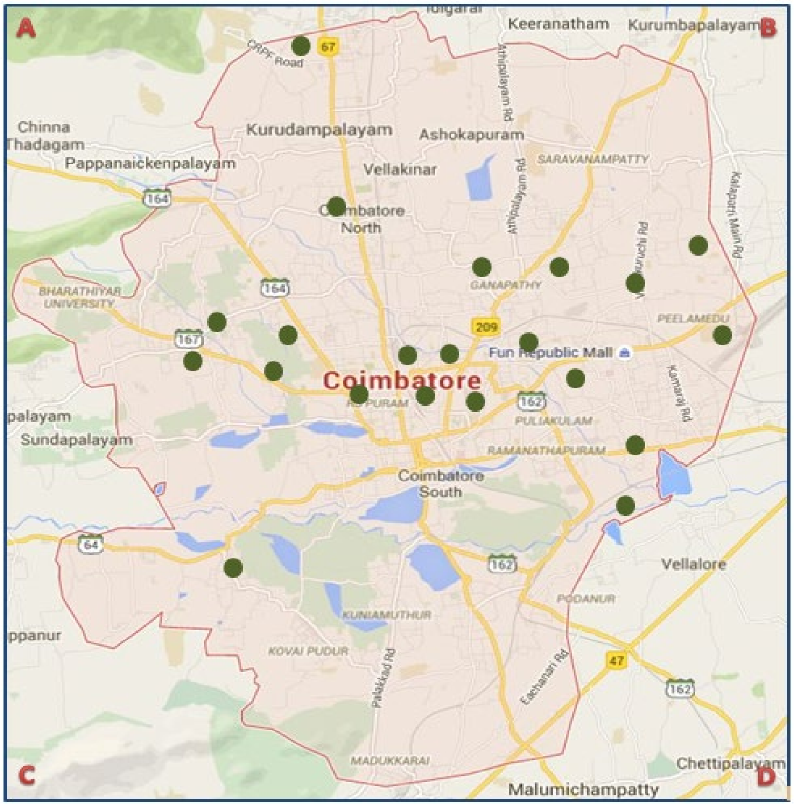

Fig.1 Locations of sample collection within Coimbatore

The locations of twenty soil samples are collected within the Coimbatore limit are shown in Table 1.

Table 1- Locations of sample collection

Sample Identification	Location	Latitude	Longitude
S1	GCT campus	11^{0}01'20.20" N	76^{0}56'09.87" E
S2	SOWRIPALAYAM	11^{0}00'42.42" N	77^{0}00'32.27" E
S3	SINGANALLUR	11^{0}00'06.55" N	77^{0}01'30.03" E
S4	KARUPPARAYAN KOIL	11^{0}01'26.19" N	76^{0}54'56.60" E
S5	CHERAN MANAGAR	11^{0}03'07.34" N	77^{0}01'10.53" E
S6	KALAPATTI ROAD	11^{0}02'29.74" N	77^{0}02'13.25" E
S7	AGRI UNIVERSITY	11^{0}01'04.82" N	76^{0}56'17.04" E

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S8	VADA KOVAI	$11^0$01'05.64" N	$76^0$57'15.24" E
S9	RATHINAPURI	$11^0$01'37.78" N	$76^0$58'05.49" E
S10	MULLAI NAGAR	$11^0$01'39.28" N	$76^0$55'03.59" E
S11	GANDHI PARK	$10^0$59’59.21" N	$76^0$56’55.98" E
S12	NARASIMANAICKENPALAYAM	$11^0$07’55.34" N	$76^0$56'05.91" E
S13	KRISHNARAYAPURAM	$11^0$01’55.26" N	$76^0$59’31.55" E
S14	SAIBABA COLONY	$11^0$01’19.84" N	$76^0$56’36.41" E
S15	THUDIYALUR	$11^0$04’57.54" N	$76^0$56’27.75" E
S16	NEELAMBUR	$11^0$04’26.59" N	$77^0$05’05.44" E
S17	SIVANANTHA COLONY	$11^0$01’38.54" N	$76^0$57’18.09" E
S18	PEELAMEDU	$11^0$01’59.00" N	$77^0$01’38.31" E
S19	VELLALORE	$10^0$56’36.09" N	$76^0$55’59.51" E
S20	PERUR	$10^0$56’00.62" N	$76^0$58’52.58" E

Literature review

Various statistical/empirical methods have been attempted to predict the swell pressure based on index properties of soil [1-9]. A review of previous investigations is presented is paramount to appraise the state of art and to get idea of the areas that are already covered by investigators. It also helps to understand various correlations between index properties and engineering properties. The literature review is presented author wise and summary of the review given below as a Table.

Table 2- List of Correlations

AUTHOR	EQUATIONS
Seed et al	$P_s = 21.6 \times 10^{-5} (I_P)^{2.44}$ $P_s = 3.6 \times 10^{-5} (A_c)^{2.44} \times (C)^{3.44.}$
Ranganatham and Satyanarayana	$P_s = 21.6 \times 10^{-5} (I_P)^{2.67}$
Komornik and David	For marl, $P_s = 6.7+2.4(I_P)$ For clay, $P_s = 0.9+2.1(I_P)$
Nayak and Christensen	$P_s = 3.6 \times 10^{-2} (I_P)^{1.12} [\frac{C}{Wn}]^2+3.8$
Vijayvergiya and Ghazzaly	$\log P_s = 0.033 (W_L) - 0.083 (W_n) + 0.458$
Guiras-Skandaji	$P_s = -117.59 + 3.0501(W_i)$

Where,

P_s – Swell Pressure
I_P – Plasticity index
A_c – Activity of Clay

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C – Clay Fraction
W_L – Liquid Limit
W_n and W_i – Natural water content

Laboratory Investigation
Preliminary tests are conducted as per the IS 2720 code covering various parts on the representative clay soil in order to determine the properties of the soil. The experimental laboratory tests results mainly includes Atterberg's limits and Swell pressure test, which are going to be the Base data for this study. In addition to that, Sieve analysis is conducted to know about the proportion. Standard Proctor test is conducted to get the optimum moisture content to prepare the sample for soaking.

Swell pressure test
Swell pressure, defined as the pressure which is required to return a swelled specimen back to its original state prior to swelling. Swell pressure test is obtained by conducting Free Swell method as per IS 2720 (Part41) – 1997.

The remolded representative soil samples for swell pressure test were prepared under optimum moisture content to achieve maximum dry density. The sample preparation for swell pressure test and swell pressure apparatus is shown in figures 2 and 3. The results obtained from swell pressure test for 20 samples with minimum test time of 4 days each are shown in table 3.

Fig.2 Sample preparation

Fig.3 Loading Setup

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Table 3- Consolidated results

Sample No.	Soil Type	Liquid Limit, W_L (%)	Plastic Limit, W_P (%)	Plasticity Index, I_P (%)	OMC (%)	MDD (g/cc)	Swell Pressure, P_S (kPa)
S1	CH	57.5	16.67	40.83	20.1	1.67	137
S2	CH	55.2	22.22	32.98	23.4	1.526	94.7
S3	CH	63	22.5	40.5	25.1	1.727	131.2
S4	CH	58.4	11.22	47.18	17.45	1.725	145.7
S5	CI	49	18	31	23.5	1.634	99.5
S6	CH	60.3	15	45.3	23.8	1.52	143.6
S7	CH	65.75	22.48	43.27	21.8	1.59	139.3
S8	CI	54.08	21.05	33.03	25.1	1.47	91.5
S9	CL	34	11.3	22.7	15.8	1.36	71.7
S10	CI	48	14.7	33.3	22.5	1.6	96.7
S11	CH	65.3	12.9	52.4	28	1.487	175.3
S12	CH	68.7	15.3	53.4	23.2	1.49	167
S13	CH	60.12	23.09	37.03	27.1	1.43	115.6
S14	CH	70.1	20	50.1	22.2	1.49	162
S15	CH	63.3	24.1	39.2	30	1.58	97.65
S16	CH	61.2	22.5	38.7	24	1.45	101.45
S17	CH	58.2	19.4	38.8	16.2	1.7	125.4
S18	CH	64.4	22.6	41.8	23	1.542	137.4
S19	CH	66.4	24.3	42.1	25.1	1.595	138.5
S20	CH	68.6	19	49.6	23.5	1.62	162.7

Where,

CL – Low Compressible Clay
CI – Intermediate Compressible Clay
CH – Highly Compressible Clay
OMC – Optimum Moisture Content
MDD – Maximum Dry Density

Plasticity Index (I_P) = Liquid Limit – Plastic Limit

MATLAB - Curve Fitting Tool

Experimental results are need to be given as input parameters and plotted against X and Y axis as per the requirement. Plot will show the special distribution of data given. Under the curve fitting tool, Polynomial order shall be selected to connect the points distributed in the plot. On selecting the different orders, Goodness of fit will be analyzed and displayed in terms of R-Square, Adjusted R-Square and RMSE. The R Square is a measure that is used to determine the relative correlation and the goodness of fit.

R Square >0.8	Strong correlation exists between two sets of variables;
0.2 < *R Square* < 0.8	Correlation exists between the two sets of variables; and
R Square <0.2	Weak correlation exists between the two sets of variables.

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Figure 4 shows the input data given in the command window for curve fitting method, where Plasticity index is loaded as X data and Swell pressure is loaded as Y data.

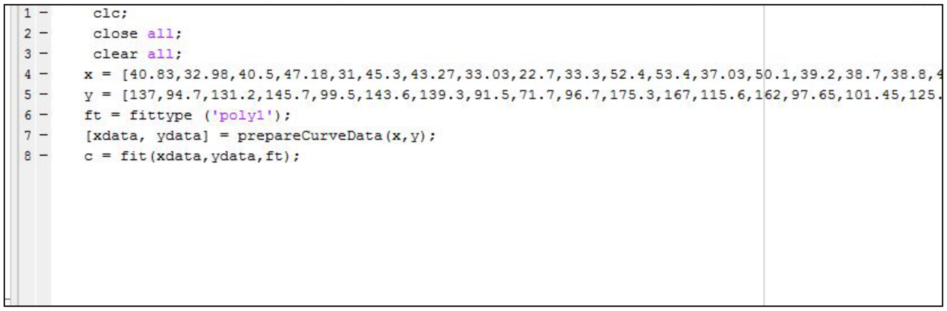

Fig. 4 Data Input (Command Window of MATLAB)

Figure 5 shows the data plotted under curve fitting tool, where polynomial order is given as one.

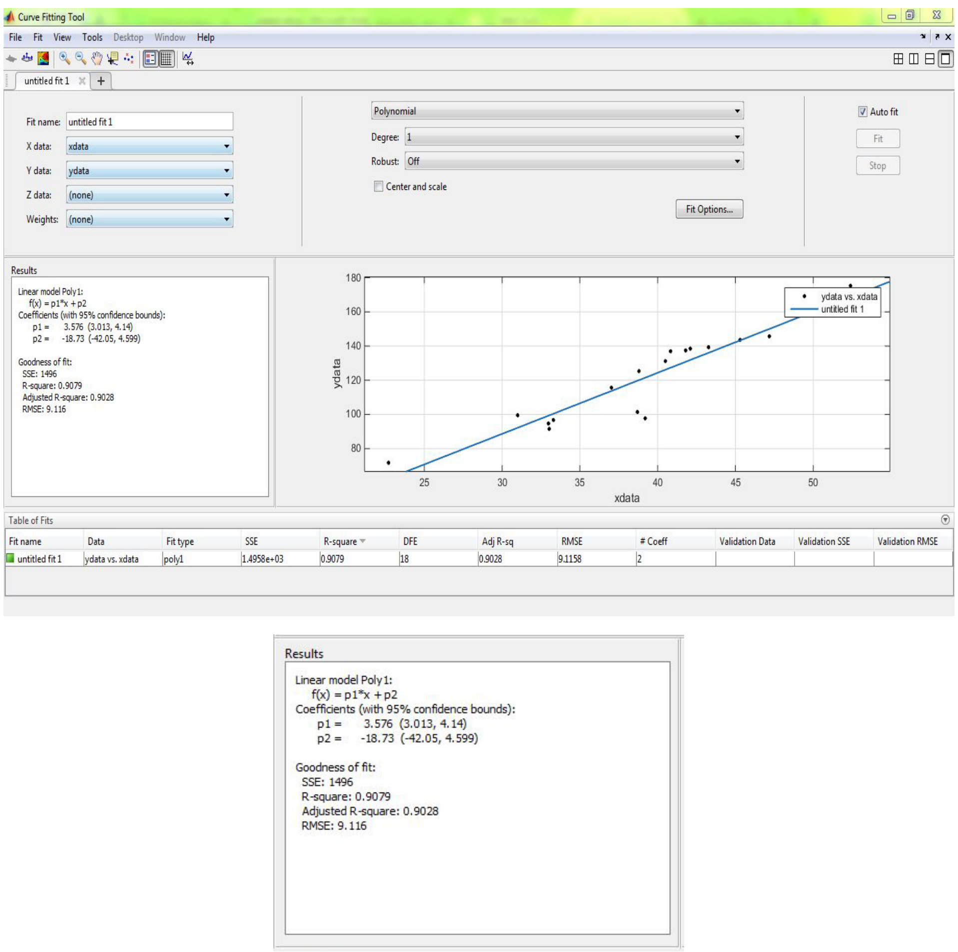

Fig.5 Curve Fitting Window

Results shows that strong relation existing between the plasticity index and Swell Pressure Analysis gives the R Square value of 0.90. Coefficients are with 95 % confidence bounds for this linear curve developed. The correlation given by the Matlab as linear line is shown below.

$$\mathbf{P_S = 3.576\ I_P - 18.73}$$

Where,

P_S -Swell pressure in kN/m^2

I_P -Plasticity Index in %

Conclusion

Plasticity Index can be calculated from quick results of Liquid limit and Plastic limit. As plasticity index is highly influencing the swell pressure, it is selected as the variable for the Matlab modeling. Despite, Amount of Clay, Activity number of clay and type of clay mineral will also influence the Swell pressure, but they are not given as input parameter for this study, since hydrometer analysis involves tedious testing procedures and calculations.

Under the Matlab Modeling, Polynomial order 1 is selected for this analysis.

When the polynomial order is increased, R Square value becomes stronger as observed. The correlation given by the Matlab is shown below.

$$\mathbf{P_S = 3.576\ I_P - 18.73}$$

Where,

P_S Swell pressure in kN/m^2

I_P Plasticity Index (%)

References

[1] Yusuf Erzin , Orhan Erol (Turkey), Correlations for quick prediction of swell pressures, Electronic journal of geotechnical engineering, 14 (2004) 78-87.

[2] Iman Ashayeri - shahabodin Yasrebi, Free swell and swell pressure of unsaturated compacted clays; experiments and neural network modeling, Journal of Geotech Geol Eng. 27 (2009) 137-153 https://doi.org/10.1007/s10706-008-9219-y

[3] Dr. Ch. Sudha Rani, Prediction of swell pressure of expansive soils using compositional and environmental factor, Int. Journal of Civil Engineering and Technology , 4 (2013) 134-142.

[4] V. NAYAK and R. W. CHRISTENSEN, Swelling characteristics of compacted, expansive soils, Journal of Clays and Clay Minerals, 19 (1971) 251-261 https://doi.org/10.1346/CCMN.1971.0190406

[5] Abdel kader Djedid, Naouel Ouadah, Indirect estimation of swelling clay soils parameters, Electronic journal of geotechnical engineering, 18 (2013).

[6] Yusuf Erzin and Nazmi Güneş, The prediction of swell percent and swell pressure by using neural networks, Journal of Mathematical and Computational Applications, 16 (2011) 425-436. https://doi.org/10.3390/mca16020425

[7] Nihat SinanI ýk, Estimation of swell index of fine grained soils using regression equations and artificial neural networks, Scientific Research and Essay 4 (2009) 1047-1056.

[8] Berawala, K. S. Solanki, C. H, Empirical Correlations of Expansive Soils Parameters for the Surat Region, Electronic journal of geotechnical engineering 17 (2012).

[9] Vikas K. S. Thakur and Devendra N. Singh, Rapid Determination of Swell pressure of Clay Minerals, Journal of Testing and Evaluation, 33 (2005). https://doi.org/10.1520/JTE11866

[10] Indian standard code of practice IS 2720 (Part1 to Part41) & IS 1498-1970