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PREDICTING SWELLING PRESSURE IN EXPANSIVE SOILS: INFLUENCE OF SOIL STATE AND SOIL TYPE

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Abstract

Expansive soils undergo significant changes in volume as their moisture content varies. Structures built on such soils often suffer damage from swelling. It's crucial to determine swelling characteristics like Swelling Pressure, Swell Potential, and Swell Index for safe and cost-effective design of foundations on expansive soils. However, directly measuring these characteristics can be time-consuming and expensive, requiring expert services and skilled technicians. Therefore, geotechnical engineers aim to develop simpler methods to predict soil behavior based on factors like soil state and soil type. This study explores how both soil state and soil type affect the prediction of swelling pressure. Soil state is represented by initial Moisture Content, in-situ Dry Density, and Initial Surcharge Pressure, while soil type is represented by compositional parameters such as Liquid Limit and Plasticity Index.

Keywords: Soils, Soil state, Soil type, Swelling Pressure, Swell Potential, Swell Index

1. Introduction

Expansive clayey soil deposits demonstrate a high sensitivity to moisture levels, significantly affecting stress, deformation, and strength. Their behavior, including heaving, settlement, and shrinkage, varies greatly as moisture content changes. Numerous studies have aimed to identify and analyze factors influencing the swelling of clayey soils, relying on both laboratory and field test results. Swelling Pressure, Swell Potential, and Swelling Index are critical characteristics needed to assess heave and design foundations safely and economically on expansive soils. Various methods have been proposed for directly measuring swelling characteristics in the laboratory, utilizing one-dimensional Consolidometer tests. Previous research has attempted to establish correlations between swelling characteristics and index properties, often using factors such as Liquid Limit, Plasticity Index, Colloid Content, Suction Pressure, Surcharge Pressure, In-situ Dry Density, and In-situ Moisture Content. While some factors are soil composition-dependent, others are influenced by environmental factors. The inclusion of Atterberg limits and indices derived from them is motivated by their dependence on soil composition, which in turn affects engineering properties. Swelling Pressure, a key characteristic, is essential for estimating heave and designing canal linings safely and economically. Various researchers have developed correlations for predicting swelling characteristics based on compositional, environmental, or combined factors. However, the general applicability of these models is subject to whether all influencing factors are accounted for. Therefore, understanding the influence of each compositional and environmental factor on swelling characteristics is essential for developing meaningful correlations with broader applicability. This investigation aims to evaluate the relationship between Swelling Pressure

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and influencing parameters, including Liquid Limit, Plasticity Index, Initial Dry Density, Initial Surcharge Pressure, and Initial Moisture Content.

2. Experimental Investigation

Disturbed samples of expansive soil are collected from four distinct regions of India, obtained from open trial pits at depths ranging between 2.5m to 3.0m. Table 1 presents the index properties of the soils utilized, along with the placement conditions and Compression Index for all tested soils. Analysis of Table 1 reveals that the Liquid Limit of the soil samples ranges from 50% to 120%, while the Plasticity Index varies from 24% to 88%. The broad range of each parameter covers a wide spectrum of soils typically encountered in practical applications. For convenience, the four soils investigated are labeled as SS1, SS2, SS3, and SS4. A total of 46 free swell oedometer tests are conducted across the four soils, with three series of tests performed on each soil. These tests vary the three placement conditions (Initial Moisture Content, Initial Dry Density, Initial Surcharge Pressure) individually over a practical range while maintaining the other two factors at a constant level. Swelling Pressure (PS) is derived from the e-log p plots obtained from all 46 free swell oedometer tests.

Table 1 Properties of Tested Soils

Properties	SS1	SS2	SS3	SS4
Gravel (%)	0%	0.6 %	0.4 %	1 %
Sand (%)	5%	5.2%	4.4%	4.8%
Silt + Clay (%)	95%	94.2%	95.2%	94.2%
Liquid Limit (W_L)	120%	69%	56%	48%
Plastic Limit (W_P)	32%	36.9%	30.81%	21.47%
Plasticity Index (I_P)	88%	32.1%	25.19%	23.61%
Free Swell Index (FSI)	275%	120%	90%	75%
Shrinkage Limit (W_S)	8.5	9%	11%	13.5%
I.S Classification	CH	CH	CH	CI
Specific Gravity (G_s)	2.75	2.78	2.81	2.87
Degree of Expansion	VH	H	M	M

3. Results and Discussions

Figure 1 depicts the typical e-log p plots derived from the free swell oedometer tests. Swelling Pressure (PS) is determined from these plots following the relevant I.S. codes of Practice. A summary of all test results is provided in Table 2.

4. Applicability of the Proposed Correlation

The effectiveness of the proposed correlation for Swelling Pressure is evaluated by comparing the predicted values of Swelling Pressure with the results obtained from this investigation, as well as with data from previous studies in the literature.

The predicted Swelling Pressure is plotted against the observed Swelling Pressure for both sets of data, as illustrated in Figures 7 and 8. In these plots, the solid lines represent the line of equality. It is observed that for the results obtained from this investigation, the points closely align with the line of equality, indicating accurate prediction. This alignment is expected since the data used in developing the proposed regression model is from this investigation.

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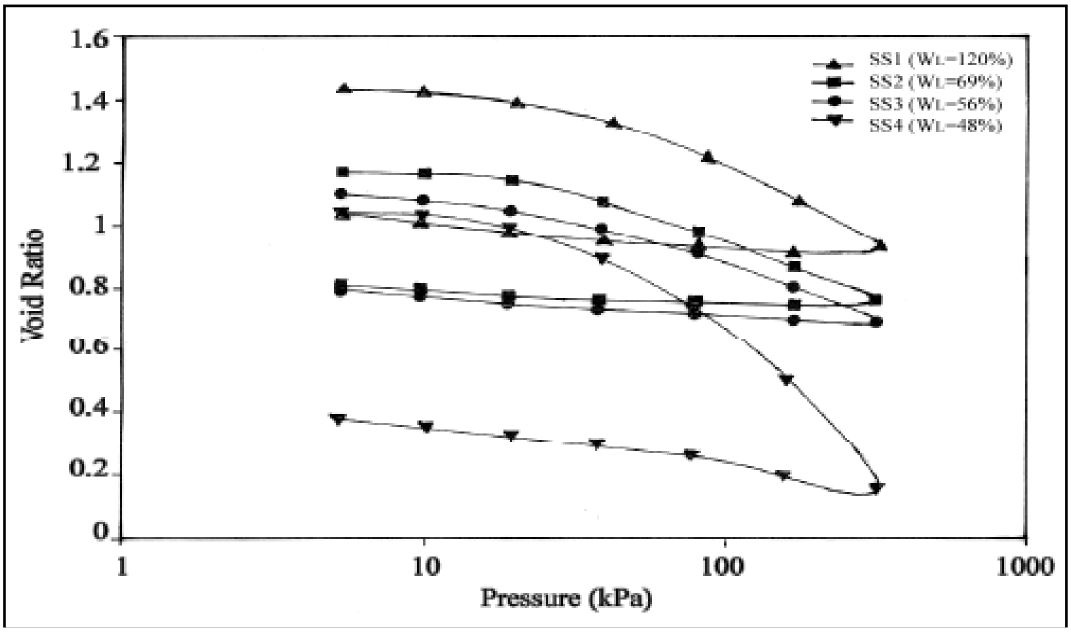

Figure 1 Typical e-log p Curves from Free Swell Odometer Tests

However, for data from other sources, although many points align closely with the line of equality, some points are dispersed away from it. This suggests that while the prediction is accurate for many soils, it may not be for all soils. This discrepancy could be due to the omission of the coarse fraction, which can influence swelling characteristics, in the proposed regression model. In the case of the four soils studied (SS1, SS2, SS3, and SS4), the coarse fraction is less than 5%. Therefore, the proposed regression models are valid only when the coarse fraction is less than 5%. Consequently, there is a necessity to adjust the regression model to incorporate the coarse fraction. In examining the performance of regression models on data from various sources, it's observed that while many data points adhere closely to the line of equality—indicating accurate predictions—there are notable deviations where the predictions are not as precise. This variation in prediction accuracy suggests that the current model might not be universally applicable across different soil types. One significant factor contributing to these discrepancies is likely the exclusion of the coarse fraction from the regression model. The coarse fraction of soil can significantly impact its swelling properties, which are critical in predicting soil behavior under various conditions. For the soils analyzed in this study, labeled SS1, SS2, SS3, and SS4, the coarse fraction is notably minimal, under 5%. As such, the regression models have demonstrated validity primarily for soils where the coarse fraction remains within this limited range. Given these findings, there is a clear need to refine the regression models to account for the coarse fraction. This adjustment would likely improve the model's applicability and accuracy across a broader range of soil types, enhancing its utility in practical scenarios. Such an enhancement would ensure that the predictive models can reliably accommodate the diverse characteristics presented by different soils, particularly those with higher coarse fractions, thereby broadening the scope of their effectiveness in real-world applications.

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Table 2 Details and Results of Tests conducted

S.No	Soil Designation	Atterberg Limits			Placement Conditions			Swelling Pressure (Ps) Kpa
		Plastic Limit (W_P) (%)	Liquid Limit (W_L) (%)	Plasticity Index (I_P) (%)	Initial Dry Density γ_d (kN/m^3)	Initial Moisture Content (m_c) (%)	Initial Surcharge (S_i) (kPa)	
1	SS1	32.00	120.00	88.00	13.50	0.00	5.00	330.00
2	SS1	32.00	120.00	88.00	14.50	0.00	5.00	470.00
3	SS1	32.00	120.00	88.00	15.50	0.00	5.00	680.00
4	SS1	32.00	120.00	88.00	16.50	0.00	5.00	950.00
5	SS1	32.00	120.00	88.00	16.00	0.00	5.00	810.00
6	SS1	32.00	120.00	88.00	17.00	0.00	5.00	1120.00
7	SS2	36.90	69.00	32.10	14.00	0.00	5.00	170.00
8	SS2	36.90	69.00	32.10	16.00	0.00	5.00	300.00
9	SS2	36.90	69.00	32.10	17.50	0.00	5.00	640.00
10	SS2	36.90	69.00	32.10	18.50	0.00	5.00	700.00
11	SS3	30.81	56.00	25.19	14.00	0.00	5.00	160.00
12	SS3	30.81	56.00	25.19	16.00	0.00	5.00	260.00
13	SS3	30.81	56.00	25.19	17.50	0.00	5.00	410.00
14	SS4	21.47	48.00	26.53	14.00	0.00	5.00	99.00
15	SS4	21.47	48.00	26.53	16.00	0.00	5.00	240.00
16	SS4	21.47	48.00	26.53	17.50	0.00	5.00	380.00
17	SS1	32.00	120.00	88.00	16.00	16.00	5.00	410.00
18	SS1	32.00	120.00	88.00	16.00	20.00	5.00	350.00
19	SS1	32.00	120.00	88.00	16.00	24.00	5.00	300.00
20	SS1	32.00	120.00	88.00	16.00	28.00	5.00	250.00
21	SS2	36.90	69.00	32.10	16.00	7.00	5.00	290.00
22	SS2	36.90	69.00	32.10	16.00	15.00	5.00	210.00
23	SS2	36.90	69.00	32.10	16.00	20.00	5.00	190.00
24	SS2	36.90	69.00	32.10	16.00	25.00	5.00	100.00

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S.No	Soil Designation	Atterberg Limits			Placement Conditions			Swelling Pressure (Ps) kPa
		Plastic Limit (W_P) (%)	Liquid Limit (W_L) (%)	Plasticity Index (I_P) (%)	Initial Dry Density γ_d (kN/m^3)	Initial Moisture Content (m_c) (%)	Initial Surcharge (S_i) (kPa)	
25	SS2	36.90	69.00	32.10	16.00	35.00	5.00	60.00
26	SS3	30.81	56.00	25.19	16.00	15.00	5.00	135.00
27	SS3	30.81	56.00	25.19	16.00	22.00	5.00	120.00
28	SS3	30.81	56.00	25.19	16.00	30.00	5.00	65.00
29	SS4	21.47	48.00	26.53	16.00	6.00	5.00	180.00
30	SS4	21.47	48.00	26.53	16.00	15.00	5.00	120.00
31	SS4	21.47	48.00	26.53	16.00	20.00	5.00	100.00
32	SS4	21.47	48.00	26.53	16.00	25.00	5.00	72.00
33	SS1	32.00	120.00	88.00	16.00	0.00	20.00	710.00
34	SS1	32.00	120.00	88.00	16.00	0.00	40.00	600.00
35	SS1	32.00	120.00	88.00	16.00	0.00	60.00	510.00
36	SS1	32.00	120.00	88.00	16.00	0.00	80.00	430.00
37	SS2	36.90	69.00	32.10	16.00	0.00	15.00	200.00
38	SS2	36.90	69.00	32.10	16.00	0.00	30.00	190.00
39	SS2	36.90	69.00	32.10	16.00	0.00	60.00	160.00
40	SS2	36.90	69.00	32.10	16.00	0.00	100.00	140.00
41	SS2	36.90	69.00	32.10	16.00	0.00	150.00	100.00
42	SS3	30.81	56.00	25.19	16.00	0.00	20.00	210.00
43	SS3	30.81	56.00	25.19	16.00	0.00	55.00	140.00
44	SS3	30.81	56.00	25.19	16.00	0.00	110.00	110.00
45	SS4	21.47	48.00	26.53	16.00	0.00	40.00	185.00
46	SS4	21.47	48.00	26.53	16.00	0.00	80.00	150.00

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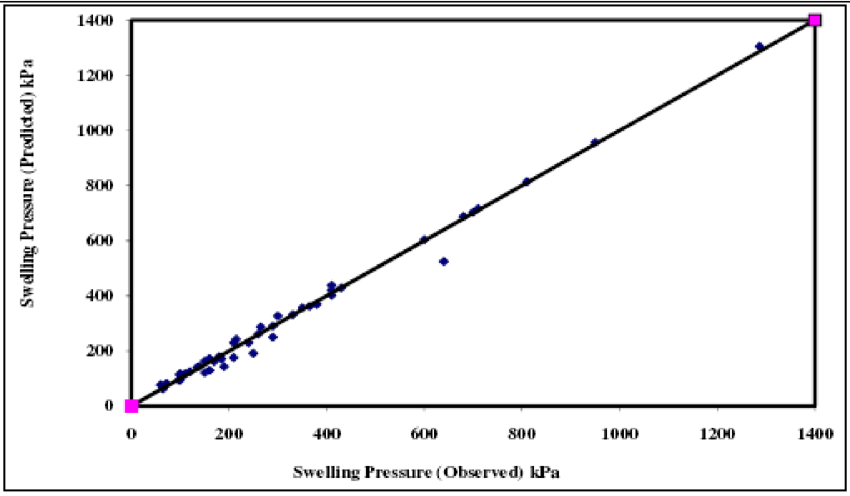

Fig. 2 Observed Vs Predicted Swelling Pressure (Results of Present Investigation)

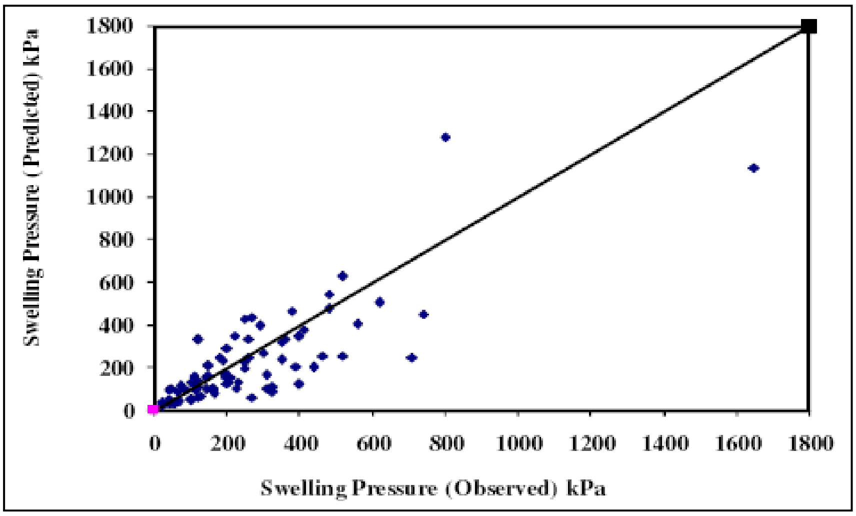

Fig. 3 Observed Vs Predicted Swelling Pressure (Literature data)

5. Conclusion

The study underscores the significance of understanding the behavior of expansive soils, which experience notable volume changes with fluctuations in moisture content. Given the detrimental effects of soil swelling on structures, it is imperative to ascertain swelling characteristics such as Swelling Pressure, Swell Potential, and Swell Index to ensure the safe and economical design of foundations on expansive soil. However, the direct measurement of these characteristics is resource-intensive and requires specialized expertise. Therefore, there is a pressing need for simpler methods to predict soil behavior, considering factors like soil state and soil type. This investigation sheds light on the influence of both soil state and soil type on the prediction of swelling pressure. By considering parameters such as initial Moisture Content, in-situ Dry Density, Initial Surcharge Pressure, Liquid Limit, and Plasticity Index, the study provides valuable insights into the factors affecting soil behavior. Ultimately, this knowledge can inform more effective and reliable strategies for mitigating the adverse effects of soil swelling on civil engineering structures.

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