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Preliminary Analysis of the Identification of Key Parameters in Expansive Clay Soil

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Abstract **-** This study assessed the key factors influencing the applicability of prediction methods and the development of regional models for expansive clayey soils in Marcavelica and Paita Baja, Piura. Through sample characterization tests and correlation analysis, the study focused on understanding how soil properties relate to expansion parameters. Both areas are dominated by montmorillonite clays, which exhibit medium to high expansion potential. In Marcavelica, the plasticity index, liquid limit, and dry unit weight were identified as the most influential factors affecting the expansion percentage and expansion pressure. In Paita Baja, the shrinkage limit, fines content, and activity significantly influenced the expansion percentage, while expansion pressure was correlated with unit weight and void ratio. The findings emphasize the importance of a preliminary evaluation of local factors before applying prediction models, as the influence of parameters can vary even with the same mineralogical composition of clay, which are otherwise expected to show similar behavior.

Keywords**:** Expansive soils, clay characterization, expansion prediction.

1. Introduction

Expansive clays are highly problematic soils due to their ability to undergo significant volume changes when absorbing or losing water, leading to adverse effects on structures built on them. These clays cause damage to buildings, pavements, and civil works due to their unpredictable behavior, particularly in climates with marked seasonal fluctuations. According to [1], the differential movements caused by the expansion and contraction of these soils can result in structural cracks, foundation failures, and deformations, posing a significant challenge to geotechnical engineering.

In northern Peru, expansive clays have caused critical problems, particularly in coastal regions and inter-Andean valleys, where soils with high plasticity and expansive minerals such as montmorillonite are prevalent. Research by [2] has documented recurrent structural damage to adobe and concrete buildings in areas such as Piura and Lambayeque, exacerbated by extreme climatic events like El Niño. Intense rainfall saturates the soils, increasing their expansion potential and affecting both urban and rural structures. Figure 1a illustrates a vertical and diagonal crack in a wall, characteristic of structural failures associated with differential settlement caused by expansive clays. Meanwhile, Figure 1b shows a rough, elongated vertical crack inclined at approximately 45°, with a separation of 2 mm, located between a door and a window. This crack originates from vertical movement of the frame due to soil expansion or settlement.

To address the challenges posed by expansive clays, it is essential to first evaluate the key factors influencing their behavior, laying the groundwork for the development of effective prediction models. Focusing on the analysis of geotechnical variables in the preliminary stages enables a deeper understanding of the conditions that contribute to expansivity. According to [3], predictive tools based on local data are crucial for optimizing resources and minimizing future damage, particularly in vulnerable regions like northern Peru. This research aims to identify and analyse the critical variables affecting clay expansivity in northern Peru, providing a foundation for more accurate predictions and effective management methodologies. Ultimately, this approach seeks to enhance safety and sustainability in engineering projects by prioritizing thorough preliminary assessments.

2. Review of prediction models

Prediction models for assessing the degree of expansion in clays are essential tools in geotechnical engineering, as they simplify the analysis process, reduce costs associated with field or laboratory tests, and provide results close to actual values. According to [4], these models efficiently predict the expansive behavior of soils, facilitating decision-making in construction projects and preventing future issues. They also represent an economical and practical alternative, especially in regions where resources for detailed studies are limited.

From a chronological perspective, prediction models have undergone significant evolution in recent decades. In the 1970s, early models primarily relied on empirical correlations between plasticity indices and expansive behavior [5]. By the 1990s, advances in mineralogical characterization led to the inclusion of X-ray diffraction analysis and montmorillonite content as key variables [3]. More recently, models have adopted more complex approaches, such as artificial intelligence and machine learning algorithms, to improve prediction accuracy [1].

The analysis of these models reveals that while the early approaches were useful as initial approximations, they had limitations in their predictive capacity due to the omission of local geological and climatic factors. In contrast, modern models have improved accuracy by incorporating a broader range of variables and advanced data processing techniques. However, their implementation may require technological infrastructure and specialized knowledge, which could limit their use in developing regions [4].

Among the most common variables used in these models are liquid limit (LL), plasticity index (PI), and clay content, which indicate the soil's expansion potential. On the other hand, more recent models have integrated innovative variables such as swell pressure, undrained strength, and climatic factors such as aridity indices and precipitation patterns [1]. These advancements allow for a more comprehensive soil characterization and more reliable predictions tailored to the specific conditions of the environment.

3. Field sampling and laboratory testing

3.1 Study Area and Field Sampling

The study encompassed two main areas, selected based on their geological and climatic characteristics favorable to the presence of expansive soils. The first area is located in Paita Baja, Paita district, Paita province, Piura department, Peru. Previous research and geological maps identified formations of expansive clays rich in sodium montmorillonite with a high degree of expansion, situated on the steep slopes surrounding the city. Among the most affected sectors are San Rafael and settlements such as Alan García and Nueva Esperanza. These soils are associated with recent Quaternary deposits composed of fine materials (silts and clays) with medium to high plasticity, corresponding to the Chira geological unit. For this study, 10 test pits were strategically excavated: four in the lower part of Paita (C3, C4, C9, and C10) and six on the hillsides (C1, C2, C5, C6, C7, and C8). This design allowed coverage of the most representative areas while avoiding zones altered by human activities.

Fig. 1: Structures damaged by expansive clays in Sullana, Piura.

The second study area is located in the Marcavelica district, Sullana province, Piura department, Peru. This district features a tropical arid climate with marked seasonal variations that affect soil moisture, characterized by rainfall from January to April and droughts during the rest of the year. Geological studies revealed that the area is underlain by deposits from the Cenozoic era, specifically the Neogene and the Miramar Formation, with a notable presence of clay in the soil (16.5%) and subsoil (18.9%). The selection of sampling areas in this zone was based on an expansive soil zoning map developed by [2]. To obtain representative results, 10 sampling points were delineated (M1, M2, M3, M3, M4, M5, M6, M7, M8, M9, and M10), avoiding altered areas. The distribution of boreholes in the first and second study area is shown in Figure 2. Similarly, Table 1 provides the UTM (Universal Transverse Mercator) coordinates of the 20 boreholes performed. Figure 4 illustrates the sample extraction process following NTP 339.15 [6].

3.2 Laboratory Tests

Laboratory tests were conducted on the samples collected in the field to determine the basic physical properties of the clays, such as particle size distribution, plasticity limits, specific gravity, and moisture content. According to the AASHTO classification, all samples were identified as clayey (groups A-6 and A-7), while the SUCS system categorized them mainly as clays (CL and CH) and silts (ML and MH). Figure 4 presents the liquid limit and expansivity tests performed in the laboratory.

Expansion tests revealed that the expansion percentage of the samples ranged from medium to high, while the expansion pressure varied between 0.38 and 3.14 kg/cm², classified as medium to high. This behavior confirmed the expansive potential of the soils. Additionally, it was observed that the initial moisture content significantly influences the expansion percentage, with higher expansion observed in dry soils. However, expansion pressure was found to be less sensitive to these variations and was considered a more reliable parameter for assessing soil expansivity.

The study further investigated the mineralogical composition of the soils to enhance the understanding of their behavior and provide detailed insights into their geotechnical properties. Established indirect methods (see Table II), as proposed by Sridharan and Prakash [7], Skempton [8], Das [9], and Holtz and Kovacs [10], were employed to ensure robust and reliable characterization. The findings revealed that montmorillonite is the predominant mineral, identified in all samples following the criteria outlined by [7], and in the majority of samples according to [9]. Illite and kaolinite indicate diverse soil composition.

Table 1: UTM Coordinates of the boreholes

Zone	Code	Easting (m)	Northing (m)
17S	C1	487206	9437987
17S	C2	487210	9437015
17S	C3	487809	9437614
17S	C4	487783	9437631
17S	C5	487160	9437801
17S	C6	487085	9437447
17S	C7	487604	9436991
17S	C8	487417	9436933
17S	C9	488259	9437827
17S	C10	488329	9437874
17S	M1	533510	9461650
17S	M2	533526	9461568
17S	M3	533523	9461589
17S	M4	533546	9461566
17S	M5	533529	9461562
17S	M6	533518	9461579
17S	M7	533455	9461663
17S	M8	533434	9461662
17S	M9	533427	9461543
17S	M10	533456	9461567

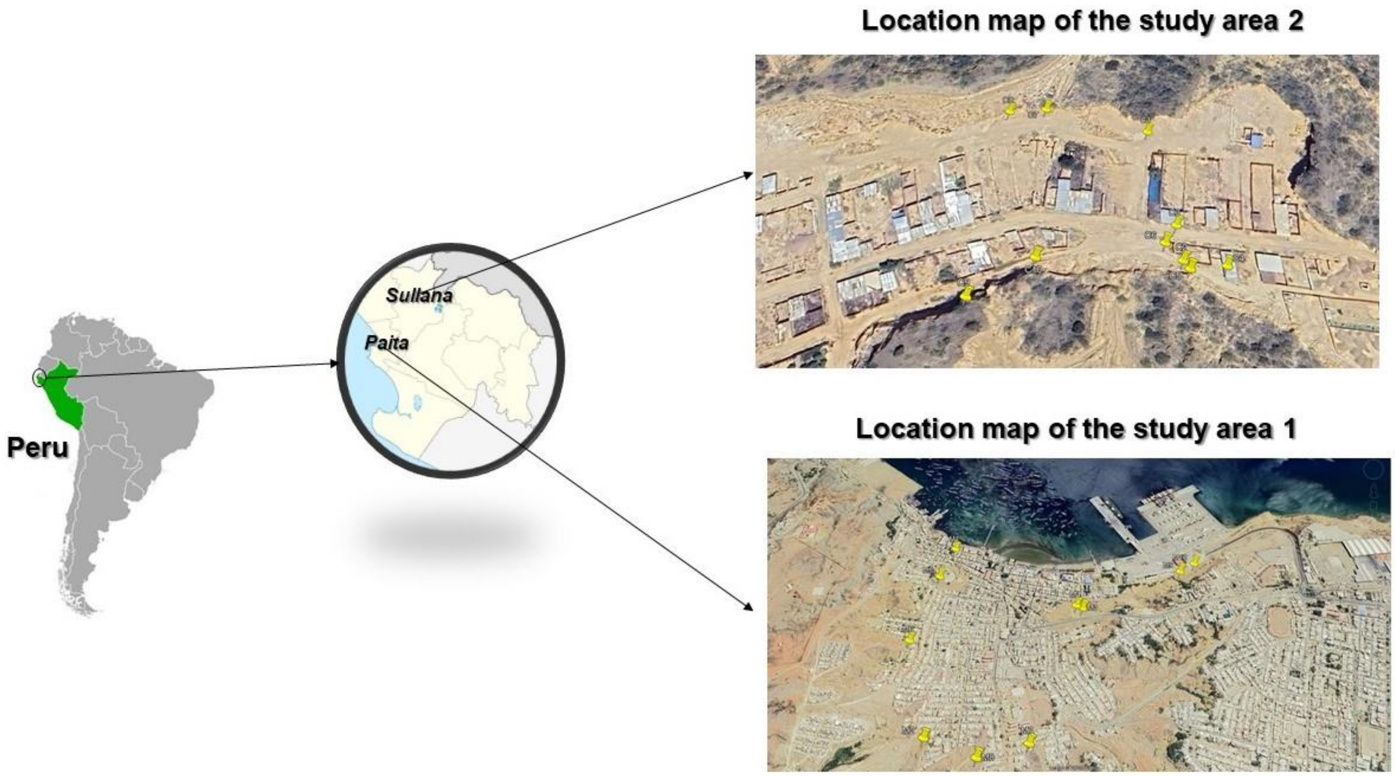

Fig. 2: Location map of study area 1 and 2: Paita and Sullana

Table 2: Prediction methods for expansive clays

Author	Parameter	Low expansion	Medium expansion	High expansion	Very high expansion
Skempton (1953)	A	< 0.75	0.75 – 1.25	> 1.25	
Hotz and Kovacs (1956)	IP	< 18	15 – 28	25 – 41	> 35
	LC	> 15	10 – 16	7 – 12	< 11
	c	< 15	13 – 23	20 – 33	> 28
Raman (1967)	IP	< 12	12 – 23	23 – 32	> 32
	IC	< 15	15 – 30	30 – 40	> 40
Sridharan and Prakash (1973)	IP	< 18	15 – 25	25 – 41	> 35
	LL	20 – 35	35 – 50	50 – 70	> 70
	LC	> 15	10 – 15	7 – 12	< 11
Chen (1988)	IP	0 – 15	10 – 35	20 – 55	> 35
Pitts (1984) and Kalantari (1991)	IP	< 25	25 – 35	> 35	
	LL	< 50	50 – 60	> 60	
Gonzales de Vallejo (2002)	IP	< 30	30 – 60	60 – 95	> 95
	LL	< 35	35 – 60	60 – 65	> 65
Norma Técnica E.050 Suelos y cimentaciones (2018)	IP	< 20	12 – 34	23 – 45	> 32
	c	< 17	12 – 27	18 – 37	> 37

4. Selection of Predictor Variables

4.1 Expansion percentage

Figure 5 presents the analysis of the expansion percentage (E) as a function of various soil parameters, showing how geotechnical properties influence expansive behavior. In general, soils with higher plasticity, such as those classified as CH and MH, exhibit higher expansion levels, while soils with lower plasticity, like CL and ML, show reduced expansions, highlighting the direct influence of plasticity on expansiveness.

The shrinkage limit (LC) initially shows a weak relationship with the expansion percentage; however, when considering only CL samples, a moderate negative trend is observed, suggesting a complex behavior that could be modeled by a parabolic curve. On the other hand, the shrinkage index (IC) demonstrates a more significant positive correlation with E, especially in CH soils, emphasizing the relevance of this parameter in their expansive behavior.

Regarding specific gravity (Gs), the correlation is weak but improves when the data is fitted to a parabolic model, becoming more evident in samples with Gs values higher than 2.65. The fines percentage (F) reveals a moderate positive correlation, with CH soils, containing more than 80% fines, tending to have higher expansions, aligning with previous studies linking fines content to expansiveness.

Clay content (C) initially shows a positive linear relationship with E; however, when adjusted to a parabolic model, a more robust determination coefficient is obtained. In the case of activity (A), the relationship with E is weak and, in some cases, contradictory to what is reported in the literature; however, a third-degree polynomial fit improves interpretation.

Finally, moisture content (W) exhibits a parabolic behavior, with higher expansions observed in dry clays with moisture contents below 10%, which is consistent with previous research. Regarding dry unit weight (γd), a strong parabolic relationship is identified, indicating that more compacted soils, with densities greater than 1.75 g/cm³, tend to exhibit greater expansiveness.

4.2 Expansion pressure

Figure 6 shows the relationship between the expansion pressure (PE) and various soil parameters, highlighting significant trends in some cases, although several correlations remain weak. The results indicate that plasticity continues to be a key factor in expansion, as reflected in the Atterberg limits. For example, the correlation between the liquid limit (LL) and PE is moderate (R^2=0.198), confirming its influence on this behavior. Regarding the plastic limit (LP), the correlation is similar (R^2=0.200), while the plasticity index (PI) improves slightly, with an R^2 of 0.232, emphasizing the relevance of plasticity in expansion pressure.

The shrinkage limit (LC) shows a more pronounced relationship with PE in this figure (R^2=0.227), suggesting that this parameter could have a moderate impact on expansive clayey soils. On the other hand, the shrinkage index (SI) presents a somewhat higher correlation than in previous analyses (R^2=0.289), indicating a more significant relationship with expansion pressure.

Fig. 3 Sample extraction process following NTP 339.15

The fines percentage (F) shows a low correlation with PE (R^2=0.188), but when analyzing CH soils, the fines content appears to align with higher expansion pressure. Clay content (C), on the other hand, presents the highest correlation in this figure (R^2=0.331), reinforcing its importance as a determining factor for expansion pressure in soils dominated by clay minerals.

In terms of specific gravity (Gs), the relationship remains weak (R^2=0.127), while clay activity (A) continues to show a marginal correlation with PE (R^2=0.165). On the other hand, moisture content (W) stands out for its parabolic behavior and moderate correlation (R^2=0.092), highlighting the influence of initial moisture conditions on expansion levels. Finally, dry unit weight (γd) shows a minimal correlation (R^2=0.005), contrasting with other analyzed parameters. Tables III and IV show the correlations between the parameters of the expansive clay soils studied, with expansion pressure and expansion percentage, respectively.

Fig. 4 Liquid limit and expansivity tests

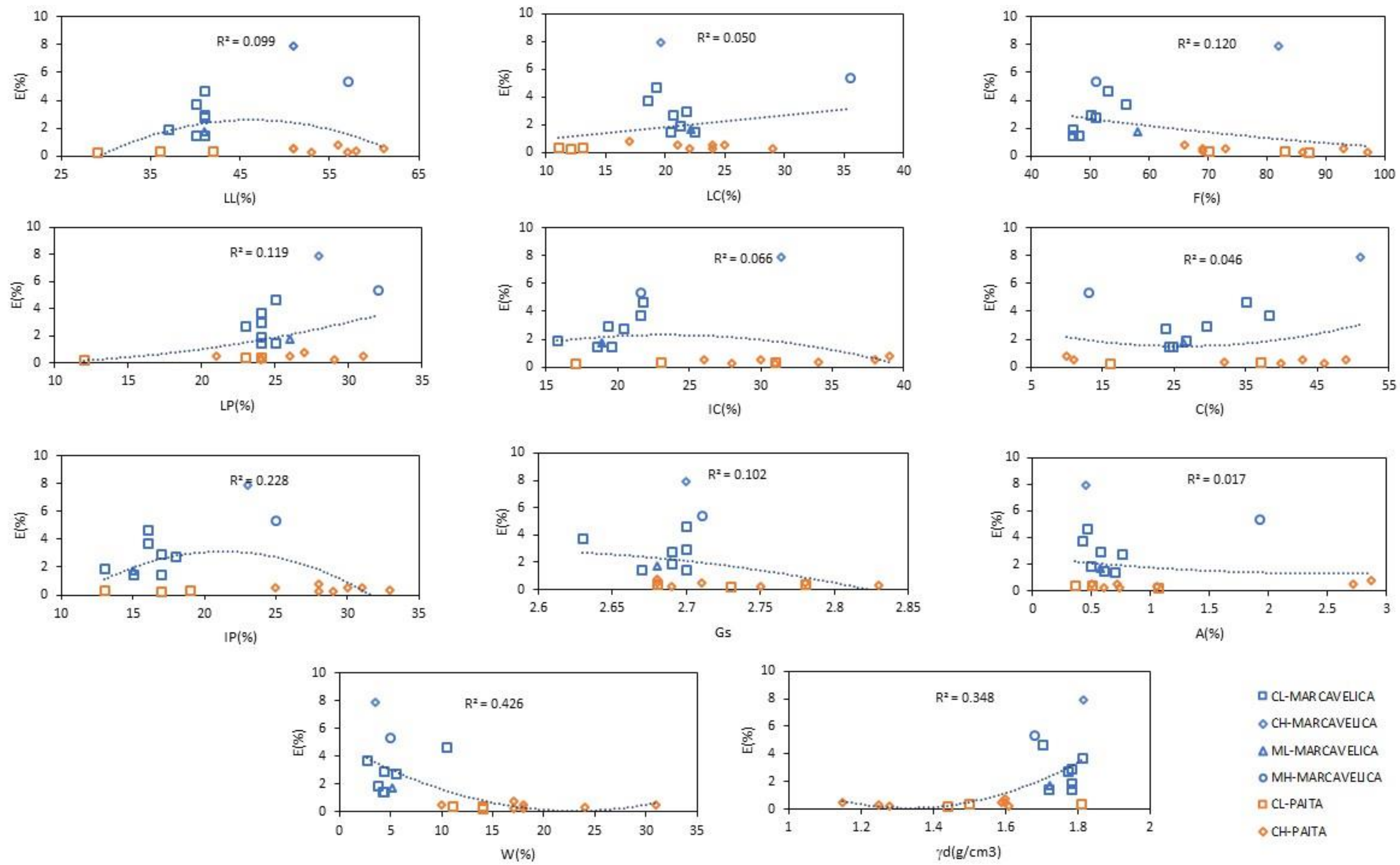

Fig. 5: Correlation between the expansion percentage with various soil parameters

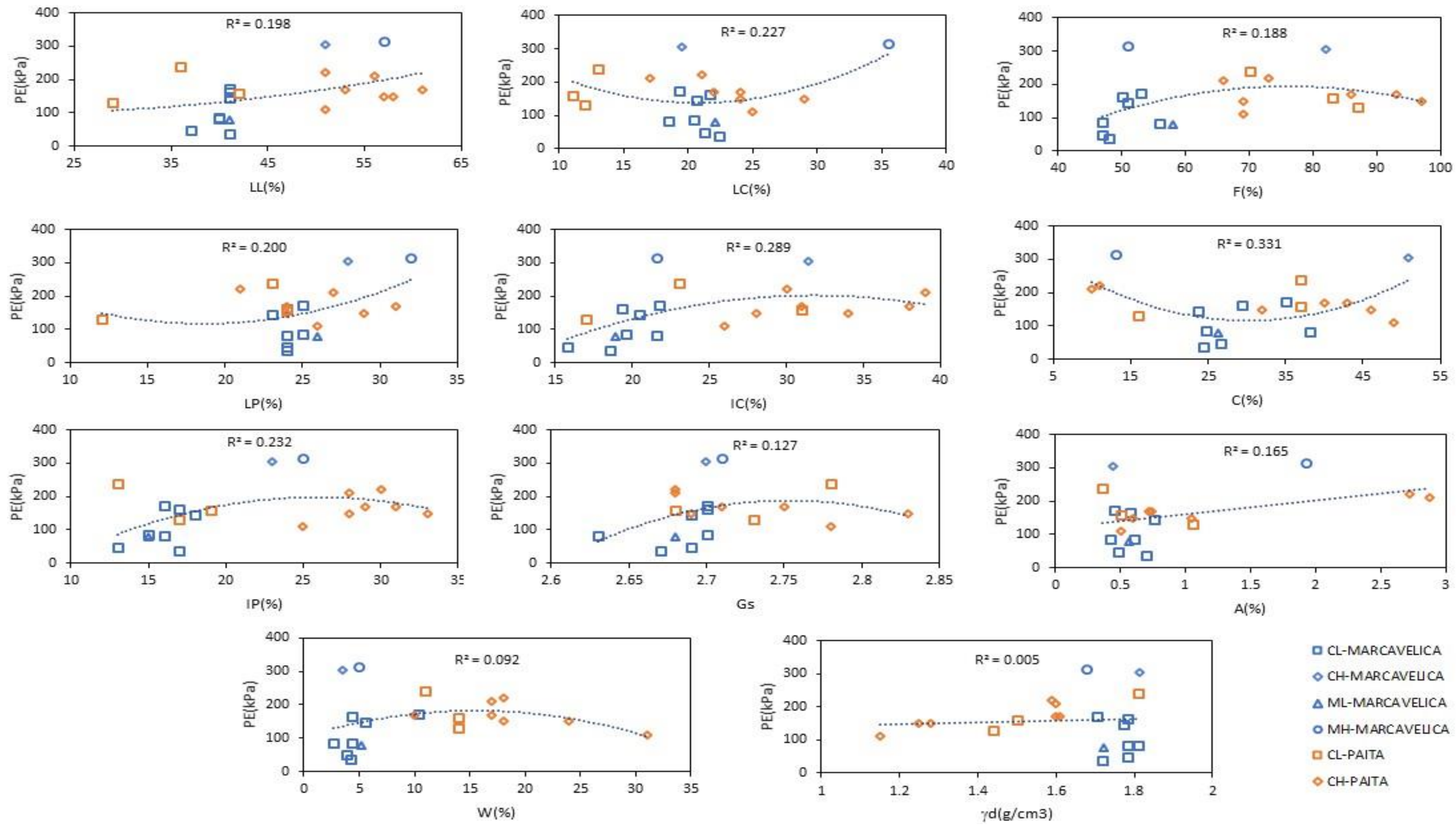

Fig. 6 Correlation between the pressure expansion with various soil parameters

5. Conclusion

This analysis constitutes a preliminary study aimed at identifying the key parameters influencing the expansive behavior of clayey soils, serving as the foundation for the future development of a predictive model that improves the prediction capability in areas affected by expansive soils. In this study, two representative zones, Marcavelica and Paita Baja, with distinct geotechnical and expansive characteristics, were evaluated, allowing for a more accurate approach to local conditions.

It has been identified that the plasticity index, liquid limit, shrinkage limit, and dry unit weight are key parameters that significantly influence the expansive behavior of clayey soils. These parameters are essential for evaluating both expansion potential and expansion pressure, particularly in soils containing montmorillonite. In Marcavelica, an expansive behavior with medium to high potential was observed, primarily influenced by plasticity and dry unit weight. In contrast, in Paita Baja, the shrinkage limit, fine content, and clay activity played a more prominent role in determining the expansiveness of the soil.

This study emphasizes the importance of considering regional variations and local geological and climatic conditions when developing predictive models. The implementation of such models will enable more precise identification of high-risk areas and facilitate decision-making regarding mitigation strategies in infrastructure projects.

Laboratory tests confirmed that montmorillonite-rich soils exhibit considerable expansion when dry, and field observations validated the spatial variability in expansion potential across different sampling sites, highlighting the need for region-specific solutions.

In conclusion, precise soil characterization and the development of predictive models are fundamental to ensuring the structural safety of buildings and infrastructure in areas affected by expansive soils. This preliminary analysis is only the first step toward the creation of predictive tools that will help minimize the economic and social impacts of problematic soils in the future.

References

[1] G. A. Al-Rawas and M. F. A. Goosen, Expansive Soils: Recent Advances in Characterization and Treatment. CRC Press, 2005.

[2] J. J. Rojas Foinquinos and J. E. Alva Hurtado, “Arcillas y lutitas expansivas en el norte y nororiente peruano,” Laboratorio de Geotecnia, Pontificia Universidad Católica del Perú, 1987.

[3] J. D. Nelson and D. J. Miller, Expansive Soils: Problems and Practice in Foundation and Pavement Engineering. John Wiley & Sons, 1992.

[4] F. H. Chen, Foundations on Expansive Soils. Elsevier, 1988.

[5] W. G. Holtz and H. J. Gibbs, “Engineering properties of expansive clays,” Trans. Am. Soc. Civil Eng., vol. 121, no. 1, pp. 641-677, 1956.

[6] NTP 339.15: Preservación y transporte de muestras de suelos. Lima, Perú; 2001.

[7] Sridharan A, Prakash K. Classification procedures for expansive soils. Proc Inst Civ Eng Geotech Eng. 2000;143(4):235-240.

[8] Skempton AW. The colloidal activity of clays. Proc 3rd Int Conf Soil Mech Found Eng. 1953

[9] Das BM. Principles of Foundation Engineering. 8th ed. Cengage Learning; 2015.

Holtz RD, Kovacs WD. An Introduction to Geotechnical Engineering. Prentice Hall; 1981.