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Effect of Chemical Agents and Hydrogen Potential (pH) of Sandy Soils on Continuous Foundations in Housing Modules

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Abstract*– The influence of chemical agents in soft soils on the durability of continuous foundations in social housing modules is a topic of growing importance. This study experimentally analyzed the chemical composition of soil samples, evidencing acidity levels such as the hydrogen potential (pH), chlorides, and sulfates. Furthermore, the compressive strength of the extracted cores from the continuous foundation was evaluated, showing adequate results despite a slight decrease compared to optimal standards. Additionally, carbonation tests revealed a pH above 9.5, demonstrating good resistance to corrosion by carbon dioxide (CO2). These findings underscore the necessity of conducting preliminary soil evaluations prior to construction, highlighting the importance of appropriately selecting materials to ensure structural durability. Overall, the results indicate that under the studied conditions, sandy soils with negligible moisture have minimal influence on the deterioration of concrete foundations, thereby ensuring the stability of buildings in such areas. This research paves the way for future investigations into the interaction between concrete and different soil types in contexts with aggressive chemical agents.

Keywords-- pH, foundations, sulfates, chlorides, total salts, test pits.

I. Introduction (Heading 1)

In Peru, there is a high prevalence of soft soils, which necessitates studies to determine their chemical properties, particularly in the field of foundations. These foundations, whether made of cyclopean, simple, or reinforced concrete, are in direct contact with the soil. Therefore, it is essential to identify the chemical phenomena that can compromise the durability of the concrete. Among the aggressive chemical agents that affect the foundations are sulfates, acids, and other harmful compounds present in the environment, which can cause concrete corrosion. Structures that are in direct contact with the soil often face durability issues, as the deterioration of materials, both concrete and steel, is caused by environmental influences.

In accordance with the detection of compaction issues in the soil, which was carried out through a visual inspection based on the technician's expertise, construction and design defects are considered the primary causes of building problems [1]. Proper project planning can prevent unforeseen events that may affect the quality and durability of a building. It is important to perform the work correctly to avoid issues, and the lack of thorough soil testing is a common cause of foundation problems. In the analyzed case, it was assumed that soil compaction would stabilize over time, so interventions to address soil compaction were limited to the most critical areas, covering only the seventh perimeter of building Ta. However, soil analyses have not been conducted to confirm this assumption. The repair cost is approximately R$ 7,150.00, and the estimated cost for the total expansion of the works is R$ 103,900.00, not considering subsequent demolitions and sidewalk reconstruction.

According to research, massive concrete foundations are essential to ensure adequate stability in high-rise buildings, which necessitates the application of more extensive foundations. This article presents a practical case focused on the foundation of a skyscraper located in Fortaleza, Brazil [2]. A specific design of the casting is suggested to mitigate problems associated with temperature increase, such as delayed ettringite formation (DEF) and cracks caused by shrinkage. Additionally, the study evaluates the reliability of a method that predicts the thermal behavior of the structure, based on temperature measurements taken on-site, which report the deterioration of concrete in the foundations of residences in Japan. In particular, in contact with sulfate content, the structures suffer infiltration of sodium sulfate solutions, resulting in the formation of white crystalline deposits of thenardite or mirabilite on the concrete surface [3]. This degradation phenomenon is commonly referred to as "physical sulfate attack," "physical salt attack," or "saline erosion." Incidents of deterioration have been frequently documented in areas where marine soils rich in sulfides predominate, a characteristic condition in much of the Japanese territory. The study demonstrates the degradation mechanism of concrete through the review of field research and the analysis of soil and concrete samples. Additionally, an expedited testing method is presented to simulate the effects of physical sulfate attack, leading to an exhaustive examination of a particular case of foundation failure in a residential building. This analysis encompasses the initial diagnostic evaluation up to the rehabilitation phases [4]. To carry out this process, a phased intervention plan was established, which allowed for the strengthening of the structure and ensured an adequate level of safety for the building. A study addressing the emerging issues in the field of foundations, arising from the boom in the construction of high-rise structures, has generated the need to develop more robust and efficient foundation solutions for both urban buildings and various infrastructures. The study focuses on the creation and validation of an advanced thermal simulation model for large-scale foundations [5]. This model, based on experimental data, was designed with multiple objectives: to assess risks associated with pathological problems, implement a structural thermal monitoring system, and analyze the impact of alternative components in concrete mixes. The methodology employed included the incorporation of fly ash (FA) as a partial replacement for Portland cement and the use of multifunctional additives (PF). These variables, along with other simulated conditions, allowed for a comprehensive analysis of the thermal behavior of the foundations under different scenarios. The results obtained from the simulations yielded significant findings for foundation engineering. It was observed that the integration of fly ash into the concrete mix contributed to a notable reduction in the maximum temperatures reached by the structure. On the other hand, the incorporation of multifunctional additives proved effective in delaying the onset of the heating process, although it did not affect the recorded peak temperatures.

Chemical effects can occur internally or externally; therefore, it is crucial to be aware of the mixture of materials used and their interactions, as well as the environment in which the structure will be placed. When evaluating the durability of foundations in contact with sulfate soils, tests were conducted on both the soil and the concrete in a coal mining area. The concrete was analyzed with a prediction of its degradation, and the methodology applied to predict this degradation only considers the diffusion of the aggressive solution [6].

In recent decades, alkali-silica reaction (ASR) has become one of the main concerns regarding concrete durability. The chemical and physical mechanisms of ASR remain poorly understood. This manuscript aims to review the most recent and relevant achievements and existing knowledge on the reaction mechanisms of ASR. Additionally, this manuscript focuses on the conditioning factors, diagnostic and prognostic methodologies, preventive measures, and testing methods (including their limitations) of ASR conducted at an academic level. Future research challenges and perspectives are also identified and discussed [7].

The development of an analytical model aimed at examining the variations in the seismic behavior of pile foundations that have suffered deterioration due to chloride-induced corrosion over time investigates the combined effects of chloride-induced erosion and seismic activity on the foundations. By evaluating seismic vulnerability, displacement and damage levels in deteriorated piles over various service intervals are established. The findings reveal that chloride-induced erosion significantly affects the seismic vulnerability of these foundations, with a notable decrease in the threshold of the final state as the service life of the structure extends [8].

On another note, the presence of sulfates can significantly affect the compressive strength and durability of concrete. Consequently, it is essential to conduct a detailed evaluation of the different types and concentrations of sulfate ions in the environment, as well as the characteristics of the aggregates and other materials used in the manufacture of concrete [9].

The effects of different molar ratios of NaCl-MgSO4 on the macroscopic properties of concrete (appearance, weight change, compressive strength, and dynamic elastic modulus), ion content, microstructure, and porosity of concrete were studied. The effects of different molar ratios on the macroscopic characteristics and erosion depth of concrete were revealed through the concrete's appearance, weight, mechanical properties, and $SO4^{2-}$ and Cl^{-} content. The microstructural evolution process and the complex mineral composition of concrete were analyzed using various microscopic testing methods. The results showed that with the increase in salt concentration and erosion time, the weight change rate, compressive strength change rate, and relative dynamic elastic modulus of the concrete samples tended to first increase and then decrease. The evolutionary process involved the transition from large to medium and small pores, and then back to large pores. In the initial stage of erosion, with the increase in MgSO4, the corrosion products were deposited in pores and cracks, refining the pore structure of the concrete and reducing the diffusion rates of Cl^{-}, $SO4^{2-}$, and Mg^{2+} ions. In the later stage of erosion, the corrosion products caused damage to the matrix and produced interlaced cracks, promoting ion diffusion rates and inducing the deterioration of the macroscopic properties of the concrete [10].

In concrete structures, the medium's pores can absorb minerals through heavy precipitation during a chemical reaction, resulting in the growth of geomaterial. The occurrence and variation of these reactions gave rise to chemomechanical models, leading to a generic chemoporo-mechanical model that anticipates material degradation caused by different concrete pathologies and the multifactorial environmental impact on macroscopic expansion. Key applications focus on external sulfate attack and formation. The findings also indicate the accuracy of the chemoporo-mechanical model in simulating various internal deformations [11]. The macroscopic characteristics of crack trajectories caused by differential deformation, material impact, and swelling align with experimental data. In the field of foundation engineering, a unique methodological approach is introduced for the identification and categorization of critical deteriorations affecting foundation structures throughout their life cycle. The uniqueness of this study lies in its source of information: final judicial resolutions issued in response to litigation initiated by property owners due to defects in their buildings. This unprecedented database allowed researchers to trace the origin of each deterioration, resulting in the identification of eleven distinct categories of damage [12]. The analysis revealed that three main causes, referred to as C-01, C-02, and C-03, were responsible for over 60% of the cases, being considered "fundamental" in the context of foundation pathology. Notably, more than two-thirds of the reported deteriorations were classified under the category of "structural-origin cracks," highlighting the prevalence of this type of damage in foundations. The research also introduced the concept of the 'damage-causal origin binomial pair,' identifying the most frequent combinations as D2-C-03 and D3-C-04. This approach allows for a deeper understanding of the relationship between types of damage and their underlying causes. Additionally, the authors established three causal affinity groups based on the similarities between the origins of the damage. The predominant group, representing 58.3% of the cases, was related to terrain factors (CO/G), while the group associated with watertightness issues (CO/W) was the least frequent, constituting only 15.7% of the cases.

II. MATERIALS AND METHODS

A. Materials

Concrete exposed to aggressive chemical agents such as chlorides and sulfates must meet specific requirements to ensure durability. Crucial factors include compressive strength, the type of cement used, and the water-cement ratio [13]. Research suggests that incorporating supplementary cementitious materials (SCM) can enhance durability by increasing resistance to chloride ion penetration and sulfate attack. Chemical agents present in the soil can trigger aggressive reactions that tend to propagate. When these agents come into direct contact with concrete, they can cause harmful anomalies or alterations. This article describes simulations of the chemical degradation of cement for different types of rainwater and soil at an ambient temperature of 10°C. The types of rainwater and soil were derived using generic equations and measurements of representative atmospheric conditions in northern Belgium [14]. An updated and consistent thermodynamic model was used to calculate geochemical changes during the chemical degradation of concrete. A foundation is defined as the part of a building that is in direct contact with the soil and has the fundamental function of transferring structural loads to the underlying soil or rock [15]. This function is essential for maintaining the stability and integrity of the structure throughout its service life. Research indicates that foundation designs generally adhere to serviceability and strength criteria, ensuring that the foundation can adequately support the loads imposed by the superstructure while minimizing the risks of settlement and failure. It is also indicated that continuous foundations are predominantly constructed of cyclopean concrete, and their purpose is to transfer the forces generated by the structure, such as those from load-bearing walls, to the underlying ground [16].

B. Methods

2.2.1. Materials acquisition

This process identified essential base materials such as cement and aggregates, which were sourced from the nearest quarry to produce cyclopean concrete for the continuous foundation. Additionally, after digging the pit, soil samples were collected and transported to a suitable laboratory for analysis.

The procedure was conducted in the specified order, first with the soil sample and then with the cyclopean concrete sample.

2.2.2. Laboratory tests, analysis and data processing

In the context of geotechnical research, a subsurface exploration program was implemented by excavating strategically located test pits in the study area. This methodological approach aims to obtain representative soil samples for subsequent thorough chemical analysis. The chemical characterization of the soil is fundamental to identifying and quantifying potentially aggressive agents present in the foundation environment.

The chemical properties of the soil on which a structure is built can play a significant role in foundation degradation processes. The interaction between certain chemical compounds present in the soil and construction materials, particularly reinforced concrete, can trigger adverse reactions that compromise long-term structural integrity. Among the most pernicious chemical agents for foundations, sulfates and chlorides stand out for their ability to initiate and accelerate deterioration processes. Sulfates can cause expansions in concrete, while chlorides are known for their role in the corrosion of steel reinforcements. These phenomena can manifest as cracks, spalling, and, in severe cases, loss of load-bearing capacity of the structure.

Early identification of these aggressive agents through chemical analysis allows foundation engineers to implement preventive measures and design solutions tailored to the specific site conditions. These may include the selection of sulfate-resistant cements, the use of corrosion-inhibiting additives, or the implementation of physical barriers to protect the foundation against chemical attack.

Through the tests conducted, it was possible to determine the aggressiveness of sulfates towards concrete, as well as the potential aggressiveness of chlorides on steel, if present. Additionally, the risk of acid attack on concrete was assessed when the soil pH is below 4. On the other hand, proper compaction of the concrete mix increases its resistance to loads, wear, impact, and vibrations. It also improves its resistance to the adverse effects of chlorides and sulfates, as a well-compacted mix minimizes pores, thus reducing the pathways for the penetration of external agents.

The diamond testing was planned according to ASTM C42 with the purpose of taking concrete samples from strip foundations [17]. These samples are evaluated after at least 48 hours of curing. At this stage, data on core compressive strength and carbonation are collected and analyzed to determine how these properties affect the durability of concrete in strip foundations.

II. RESULTS

Chemical analyses were conducted on the five soil samples collected via test pits. The obtained results are presented in the sample, including the chemical analysis parameters and the soil pH level of 7.1. The results of the test pit samples are detailed in Table 1, which shows the total salt, chloride, and sulfate content in each collected sample.

Table 1: Results of the pit samples

Sample	Total Salts (Ppm)	Chlorides (Ppm CI)	Sulfates (Ppm SO4)
C-01	1 251	149.37	203.493
C-02	1 198	141.24	192.354
C-03	1 376	175.24	251.96
C-04	1 308	155.98	201.857
C-05	1 427	182.46	259.18

The compressive strength of the diamond cores extracted from the strip foundations reveals significant variations in the results. Samples Diamantina 01, 02, and 03 show adequate compressive strength values, ranging from 91 to 97 kg/cm², indicating good concrete performance. However, sample Diamantina 04 shows the lowest compressive strength (83 kg/cm²), suggesting potential issues with material quality or curing. The height-to-diameter ratios are appropriate for most samples, supporting the validity of the tests conducted.

Table 2: Compressive strength of extracted diamond cores

Sample	Diameter (cm)	Height (cm)	Load reading (Kgf)	F´c (Kg/cm2)
D01	7.40	14.73	4 280	95
D02	7.44	14.03	4 070	91
D03	7.39	14.84	4 220	97
D04	7.51	11.71	3 890	83
D05	7.45	14.96	3 910	88

The carbonation test analysis reveals that all diamond core samples extracted from the foundations show a carbonation depth of 0.00 mm, indicating that there has been no CO_2 penetration into the concrete. All samples exhibit a pink-purple coloration, suggesting a pH higher than 9.5, which is a good indicator of the concrete's alkalinity and its resistance to corrosion. The absence of regular, irregular, or singular penetration in all samples reflects excellent material quality in terms of carbonation protection.

IV. DISCUSSION AND CONCLUSIONS

This study focuses on the characterization of the chemical components of the soil to assess their impact on the durability of structures, specifically strip foundations. Through a thorough on-site analysis, the levels of total salts, chlorides, and sulfates in the five collected soil samples were identified. To complement this analysis, five concrete samples were extracted from the foundations and evaluated through compression tests.

The chemical composition analysis of the soil reveals that the levels of total salts are below 15,000 ppm. This figure suggests the absence of a significant risk to concrete structures, as detailed in the attached Table 2. According to the literature, it has been established that high concentrations of sulfates and chlorides in the soil can be detrimental to foundations [18]. Sulfates, upon contact with concrete, can generate adverse chemical reactions, causing damage manifested in various ways depending on the environment and conditions to which the concrete is exposed. This process can lead to the formation of ettringite [19], which can compromise the integrity of the concrete paste by filling internal spaces and causing cracks. Regarding the chloride content, values ranging from 0 to 1000 ppm were recorded. These levels suggest a mild degree of alterations in the concrete and minimal risk related to chemical attacks on the foundations. This finding contrasts with previous studies that report significantly higher levels of chlorides and sulfates in specific locations, which adversely affect concrete properties. Therefore, our measurements indicate that the use and exposure of concrete in the studied area have not been subject to extreme conditions, justifying the absence of deterioration [20].

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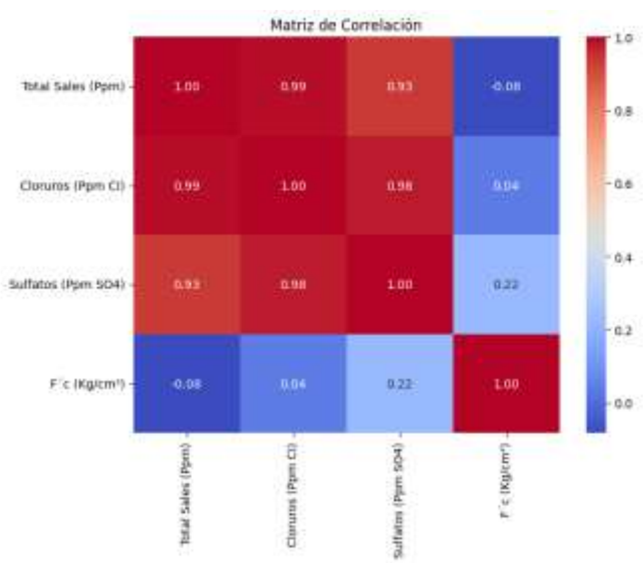

Fig. 1 Representation of the Correlation between Total Salts, Chlorides, Sulfates, and Concrete Compressive Strength.

The analysis of the correlation matrix reveals a significant positive correlation between 'Total Sales (Ppm)', 'Chlorides (Ppm Cl)', and 'Sulfates (Ppm SO4)', suggesting that an increase in total salt content is related to higher levels of chlorides and sulfates. On the other hand, the relationship between compressive strength (F´c) and these variables shows a negative correlation, indicating that an increase in salts, chlorides, and sulfates can reduce the structural strength of the material. This analysis is crucial, as it implies that soil quality directly impacts the compressive strength of the cores extracted for the compression testing of concrete specimens obtained through diamond drilling, guiding decisions to improve the durability of foundations [21].

Another aspect of the study was the carbonation analysis of cores extracted using diamond drilling for the compression testing of concrete specimens. Given the importance of evaluating the condition of concrete under the influence of chemical agents present in the environment, a phenolphthalein test was conducted. This compound produces a color change indicating the pH of the concrete. In all specimens analyzed, the resulting coloration was pink-purple, indicating a pH above 9.5. This result is a positive indicator, suggesting optimal conditions and the absence of significant carbonation penetration. This information is vital, as the CO_2 present in the air can trigger reactions that affect the neutrality of concrete, thus compromising its capacity to protect the internal steel, if present. Concrete mixes analyzed in past studies managed to maintain their stability under adverse conditions, while our research reaffirms that the concrete studied also remains in optimal condition despite the presence of chemical contaminants in the soil [18].

The implications of these findings are significant from a practical standpoint. In terms of building design and construction, it is crucial to consider the chemical properties of the soil on which the foundations are built. The evidence suggests that, in our study area, the low levels of salts, chlorides, and sulfates not only ensure the durability of structures but also underscore the importance of conducting pre-construction evaluations. Informing architects and engineers about the results of chemical studies can help make more effective decisions regarding materials and construction techniques.

From a theoretical perspective, our results reinforce the understanding of the relationship between soil chemical elements and concrete durability. They indicate that factors such as pH and the chemical composition of the environment play a crucial role in structural integrity. According to the findings, a new line of research could be encouraged to explore alternative construction materials that offer greater resistance to corrosion and deterioration in more aggressive environments. Additionally, there is a need for continued long-term monitoring of existing structures to validate the capability of these materials against potential changes in soil chemical composition in the future.

It is important to acknowledge that this study presents certain limitations. First, the methodology used was based on a limited number of samples, both soil and concrete. Although significant results were obtained, a larger sample size could offer a more precise and generalizable picture of concrete behavior in relation to the variables analyzed. Moreover, it is crucial to note that climatic and environmental conditions can change over time, which could influence long-term results. A longer-term approach, including periodic monitoring, would be ideal for obtaining a more accurate assessment of potential structural deterioration.

The present analysis does not consider other factors that may also influence concrete durability, such as the quality of materials used in the mix and the construction methods implemented. Opting for construction practices that incorporate additional preventive measures could be beneficial in extending the service life of buildings [22].

Future research should delve deeper into the findings and evaluate the behavior of concrete under changing soil or climatic conditions, which could provide invaluable information. This would include experimental studies on the resistance of concrete with different added compounds that could improve its reaction to chemical agents. Additionally, research into the incorporation of additives that mitigate the impact of sulfates and chlorides could expand the horizon of solutions to construction challenges in critical areas. It is also important to evaluate the impact of moisture and drought cycles on durability, considering the effect of climate change on these cycles.

In conclusion, the study demonstrates that the chemical agents present in sandy soil with no moisture or high-water table have minimal influence on the durability and deterioration of strip concrete foundations. Soil chemical analyses indicate that the total levels of chlorides and sulfates are within acceptable limits, without posing a significant risk to the structural integrity of the concrete. In particular, it was confirmed that the total salt content does not exceed 15,000 ppm, and the chlorides and sulfates present do not trigger relevant adverse effects.

The evaluation of the compressive strength of the cores obtained by diamond drilling suggests that, although there was a slight decrease compared to optimal standards, the strength remains at acceptable levels, confirming the functionality and safety of the concrete for its application. Additionally, the carbonation tests indicated that the concrete's pH is above 9.5, demonstrating that there has been no significant penetration of carbon dioxide (CO_2), a factor that could compromise its integrity.

These findings highlight the importance of thoroughly analyzing soil conditions before undertaking any construction and reinforce the need to adopt good practices in material selection and construction techniques that protect foundations. Furthermore, the results open opportunities for future research to investigate the interaction between concrete and different types of soils, especially in contexts with high concentrations of aggressive chemical agents and high water tables. By adopting a proactive approach, the durability and structural integrity of buildings can be ensured in the long term, contributing to the safety and well-being of the most vulnerable communities that use them.

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