ZANCO Journal of Pure and Applied Sciences

TYPE Original article
DOI http://dx.doi.org/10.21271/ZJPAS.38.1.16

OPEN ACCESS

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RECEIVED : 02 /01 /2025
ACCEPTED :04/09/ 2025
PUBLISHED :28/ 02/ 2026

KEYWORDS:
Construction waste materials, Landfill, Collapse compression, Permeable fills, Plate load test, Soil saturation

Transforming construction waste into eco-friendly foundations for lightweight housing: case study

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ABSTRACT

Construction activities generate large quantities of waste materials, creating significant challenges for waste management and environmental sustainability. This study investigates the feasibility of reusing coarse-grained construction waste deposited in a landfill as a foundation for lightweight residential buildings. To assess its long-term engineering performance, in-situ plate load tests were carried out on landfill material that had been in place for approximately ten years, as well as on the underlying natural coarse- and fine-grained soils after removal of the landfill. The tests were performed under three ground conditions: natural moisture content, submerged conditions after three days of inundation, and full landfill flooding achieved by filling a surrounding trench with water once the applied stress reached 200 kPa and maintaining saturation for 24 hours. The results indicated that although the landfill exhibited a collapse at 200 kPa following saturation, the settlements recorded under both dry and submerged conditions remained within acceptable limits for lightweight structures.

1.Introduction

Large volumes of waste, associated with the construction process, pose a serious problem to waste management and environmental sustainability (Wahi et al., 2016). The conventional mode of disposal through landfills has limited capacity; moreover, it gives way to resource depletion and causes pollution. Experts and professionals are engaged in finding innovative solutions to address this problem, and one among them is utilizing landfill construction waste materials as foundations for lightweight buildings (Mohajerani et al., 2020). This approach can reduce waste and resource conservation potential and make residential lightweight structures very cost-effective and sustainable (Elgizawy et al., 2016).

The use of landfill construction waste materials for foundations of lightweight buildings includes refashioning existing landfills and turning their waste materials into structural elements. Therefore, it will turn the landfill area into a very useful and productive area while at the same time cutting down the environmental impact associated with throwing away refuse (Thormark, 2001). This method is therefore explained and proposed in light of a circular economy, where materials are encouraged to be reused and recycled, in order to give them an extended lifespan and reduce virgin resource demand (Minunno et al., 2020). Moreover, the raft footing can also be used as a foundation system where lightweight buildings are built over construction waste materials (Dalal et al., 2011). Raft foundation is a large concrete slab that spreads out the load of the building over a large area. It is normally used in cases of weak soils or variable conditions of soil, such as over landfills or areas with fill material (Yanev and Books, 1975). The design of the raft foundation will depend on the building weight, construction waste materials in landfills, and properties of soils. Materials considered for use in raft foundations are normally those that depict good strength and durability under various probable types of loads, with reinforced concrete.

Different studies have focused on the recycling, to minimize waste, conserve resources disposal, as well as to promote sustainability in the construction industry (Begum et al., 2006, Batayneh et al., 2007, Bolden et al., 2013, Abdulhamid et al., 2021, Mostert et al., 2022, Robayo-Salazar et al., 2022, Guo and Chen, 2022, Schützenhofer et al., 2022, Rojas-Valencia et al., 2022, Ahmed et al., 2023, Shamsaei et al., 2023). Andersen et al. (2004) conducted a settlement-monitoring program on a roadway embankment constructed over a closed landfill. The program utilized a field instrumentation system, including settlement plates, vertical extensometers, and vibrating wire piezometers, to monitor embankment settlement and evaluate the effectiveness of preload treatment over a period of approximately 18 months. The study discusses the collected settlement and piezometric data, presents time-settlement relationships for the different compressible layers, compares back-calculated compressibility parameters for landfill refuse with previous research, and evaluates the reliability of hyperbolic methods for settlement predictions in similar preload procedures. Dalal et al. (2011) investigated the ground improvement alternatives for old landfill sites in urban areas, aiming to achieve permissible bearing capacity and limited settlement. Plate load tests were conducted using a geotextile mat and stone-filled wire mesh mattress, with geotextile and sand cushion showing promising results for improving landfill properties and resisting differential settlement. The findings suggest that these techniques can be applied for low-rise housing construction on old landfill sites within urban centers, providing a feasible solution for land utilization and urban development. Erbil is estimated to produce 1500 tons of solid waste every day and produce 547500 tons of solid waste every year. For example, in some Middle Eastern countries, construction waste constitutes 20–30% of total waste generated. Applying this to Erbil, where solid waste generation is estimated at around 547.5 million tons annually, construction waste could be in the range of 164.25 million tons per year (Bekr, 2014, Sadeq Ali and Mahdi, 2019, Aziz et al., 2019). In terms of the materials of the demolition waste in Erbil City, Wali (2020) stated that most the of them includes cement, sand, gravel, concrete, blocks, bricks, steel bars, plastics, ceramic, marble and mosaic tiles. However, limited research has been conducted on utilizing construction waste in landfills as foundation materials for lightweight residential buildings. Therefore, this case study aims to bridge this research gap, provide valuable insights into the potential benefits, and explore the possibility of utilizing construction waste materials in landfills as foundations for lightweight residential buildings.

2. Materials and Methods

This study investigated the potential use of the Red Zone area in Ganjan City, located in Erbil City (described in section 3), as an appropriate site for lightweight residential buildings. The characteristics of the Red Zone area are dominated by large backfilling processes, primarily consisting of building demolition wastes and Municipal Solid Waste (MSW). It is important to indicate that the landfill site involved materials that were over ten years old, a period considered sufficient for the decomposition and settlement processes. Additionally, the choice of the Red Zone area was based on its direct relevance to the set-out objective of the research in establishing cost-effective and sustainable means of utilizing construction waste materials landfill in foundation systems. The study contributed to the understanding of the mechanism and strength characteristics of such ground, in particular, with respect to investigating the behavior and load-carrying capacity of this sort of ground.

With the MSW present in the landfill, it was essential to focus on evaluating its impact on overall site suitability and potential foundation performance. Incorporation of MSW in backfill materials increases complexity in analysis, as the de-composition process and settlement behavior resulting from it may be different than what is solely associated with construction waste materials. The present study was conducted to provide a comprehensive evaluation of the feasibility of the Red Zone area for lightweight residential buildings. Besides, the landfill materials chosen for this study, aged ten years, presented a representative base for evaluating settlement behavior in the long term and the probable load-carrying capacity of the ground. It is expected that these aged materials could have undergone extensive decomposition and consolidation processes. Consequently, they markedly affect the engineering properties of such ground and their subsequent behavior.

In this investigation, the plate load test is the prime method being referred to or taken into consideration, because it is internationally accepted in an evaluation that deals with the settlement and bearing capacity of soils. The plate load test determines the behavior of a soil under loads and has been applied in commonplace geotechnical engineering studies. Settlement Bearing capacity of the site were evaluated by carrying out nine plate load tests at different locations within the study area. Four tests were conducted directly on the landfill area where the construction waste materials were deposited. Whereas, the other five tests performed on the original soil after removal of the construction waste materials.

The plate load tests followed the standard procedure outlined by the American Society for Testing and Materials (ASTM, 1994), with Designation ASTM D1194. The ASTM standard provides guidelines for conducting field load tests and ensures consistency and reliability in the testing process. In addition, circular steel bearing plates were utilized during the plate load tests, consisting of two different sizes. The first plate had a diameter of 300 mm, while the second plate had a larger diameter of 450 mm. Both plates had a uniform thickness of 25 mm. The first plate with the smaller diameter is placed on top of the larger one to avoid deflection of the larger plate. After each load increment, a suitable interval was given for the settlement of the soil. Necessary instrumentation for measurements was provided, and the settlement process was closely monitored and measured up to the time such that the bearing plate settlement was already becoming insignificant, indicating stabilized condition of the soil.

Stress-settlement curves for each test were plotted from the load-cell and three dial-gauge measurements. Stress applied to the soil was calculated by dividing the load applied to the bearing plate by its area. Settlement measurements were taken regularly to see how the soil responded under increasing loads applied using a heavy-weight excavator. This study aimed to precisely establish the settlement and bearing capacity of the site with and without the presence of construction waste landfill materials. These tests will eventually give results that will help in understanding the geotechnical characteristics of the site and hence the feasibility of using the landfill as a foundation for light-weight residential buildings.

3. Site Description

The Red Zone is a villa residential area near the central area of Ganjan city in Erbil governorate in the Kurdistan Region of Iraq (see, Figure 1). A large area in Ganjan city is occupied by the Red Zone, which is characterized by vast landfill sites for construction wastes, as illustrated in Figure 2a and 2b. These landfills have been established over time due to the disposal of various types of construction debris and waste generated from development activities within and around the city. Furthermore, most of the land use within the Red Zone primarily revolves around construction waste materials. The landfill occupies a substantial portion of the area, with construction waste being backfilled and deposited over time. The landfill is a repository for various materials such as concrete, bricks, wood, and other construction-related debris, see Figure 2a and 2b. Beside the landfill, the Red Zone is also surrounded by residential, commercial, or industrial structures. These structures may interact with the landfill and potentially be influenced by the geotechnical properties of the underlying soil and waste materials. The area provides a representative case study for assessing the geotechnical characteristics of the soil and understanding the behavior of the landfill under applied loads. Table 1 shows the physical and geotechnical properties of the original soil under the landfill at a depth of about 1.5m under the original soil surface at P_5.

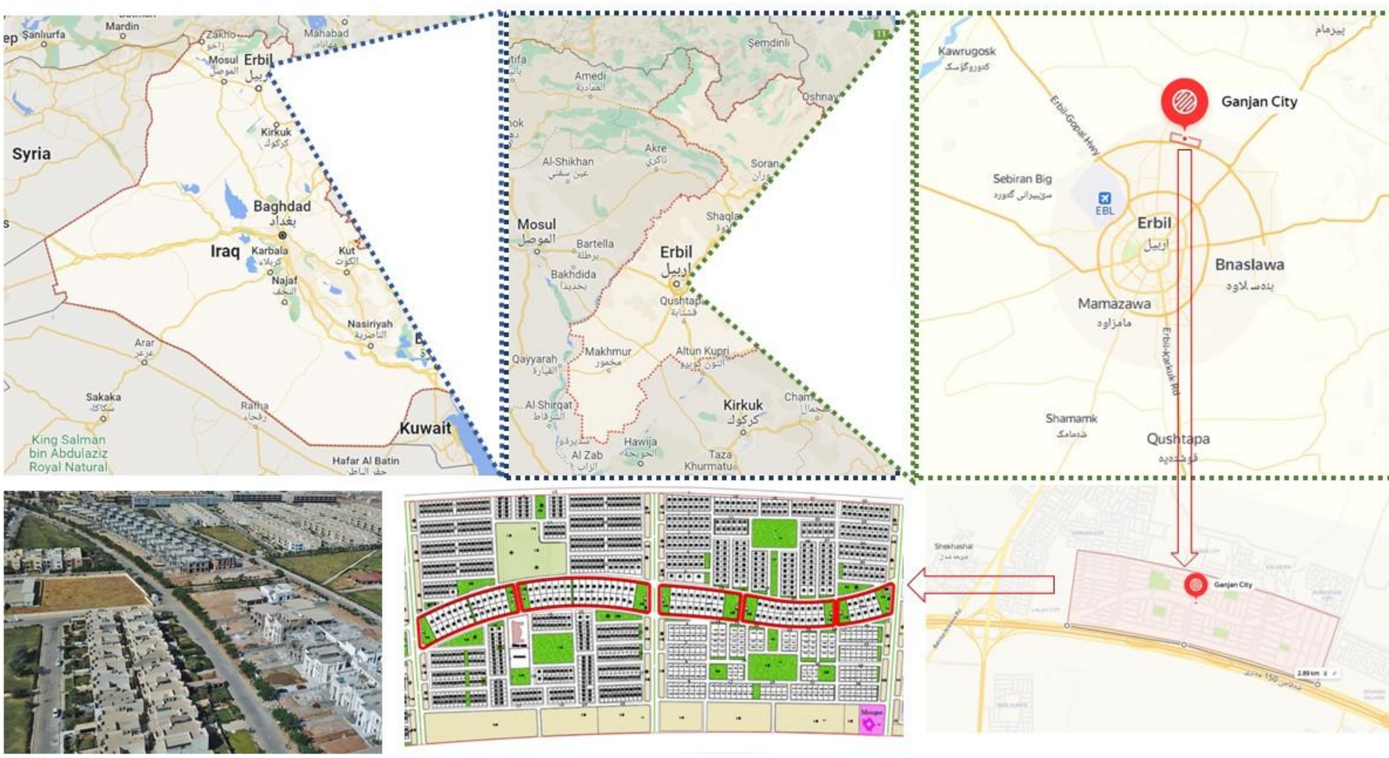


Figure 1: the location of the Red Zone in Ganjan city, Erbil City-Kurdistan Region of Iraq

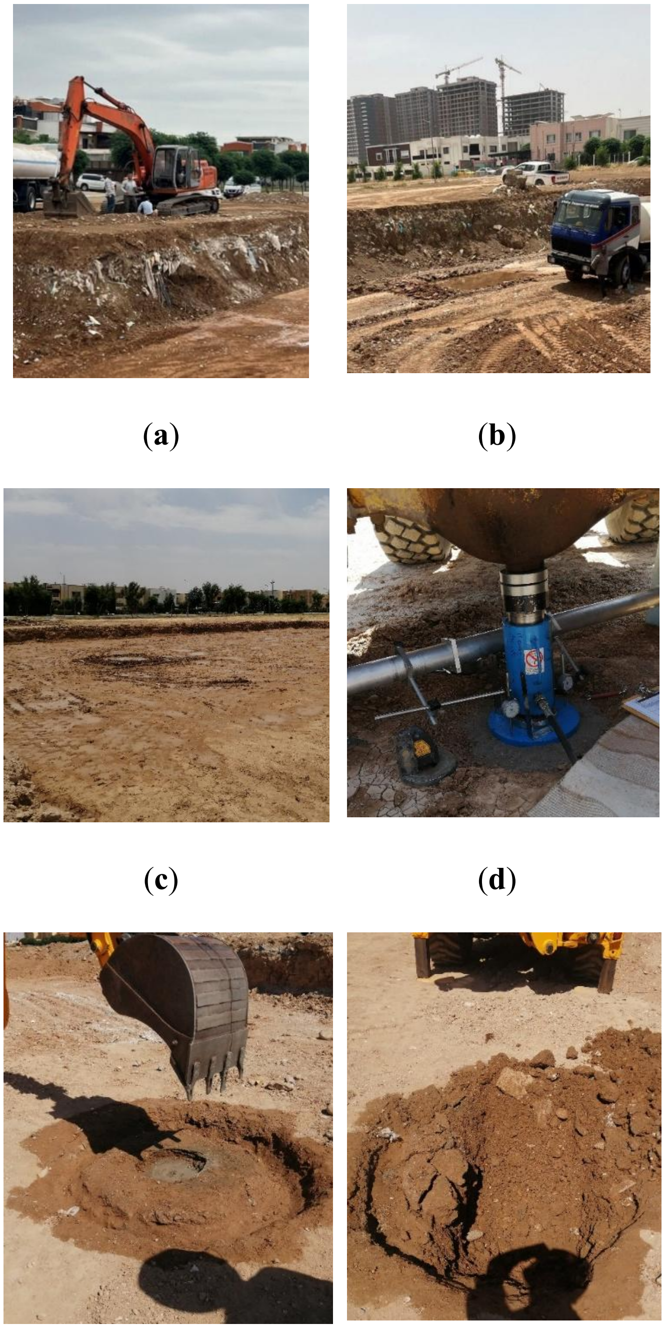


Figure 2: Photos before and after in-situ plate load tests: (a) actual profile of the landfill (b) saturation process at P_2 for coarse-grained original soil (c) saturation process at P_3 for fine-grained original soil (d) plate load test on the fine-grained original soil at P_2 (e) Fully saturated landfill soil at P_9 at the end of the plate load test (f) Visual soil inspection at the end of the plate load test at location P_9 to ensure avoiding unrealistic of results due to existing bulk materials or cavity

Table 1: Physical and geotechnical properties of the original soil at P-5 under the landfill

Property	Value	Test method
Specific gravity (Gs)	2.73	ASTM_D854 (2014)
Passing sieve #200 [%]	80	ASTM_D6913 (2017)
Gravel [%]	3	ASTM_D6913 (2017)
Sand [%]	17	ASTM_D6913 (2017)
Silt [%]	45	ASTM_D6913 (2017)
Clay [%]	35	ASTM_D6913 (2017)
Liquid limit [%]	49	ASTM_D4318 (2017)
Plastic limit [%]	24	ASTM_D4318 (2017)
Plasticity index [%]	25	ASTM_D4318 (2017)
Soil group symbol	CL	ASTM_D2487 (2017)
Soil group name	Lean clay with sand	ASTM_D2487 (2017)
Lab. vane shear [kPa]	>200	ASTM D4648 (2016)

4. In-situ Plate Load Test

Field plate load tests were performed in accordance with the designation ASTM D1194 (ASTM, 1994) as shown in Figure 2d, utilizing a circular steel bearing plate and applying incremental loads. The settlement of the bearing plate was monitored until it became negligible, and additional loads were applied accordingly. The test load was generated by a hydraulic jack positioned beneath a heavy-weight excavator. Dial gauges with a precision of 0.01mm were employed to measure the settlement and displacements, offering a wide travel range of 50 mm. Three dial gauges were uniformly distributed on the bearing plate to ensure comprehensive data collection and prevent any missing information, see Figure 2d. Additionally, three rulers were securely mounted on the plates, guaranteeing precise monitoring of the vertical displacements throughout the entire duration of the tests. To record the data accurately, a digital laser device (DEWALT) was used, enabling precise measurements of the vertical displacements of the plates, see Figure

2d. Furthermore, the use of a digital level was deemed necessary as the length of the dial gauge alone proved insufficient in capturing the complete settlement range, thus ensuring no valuable information was overlooked.
Nine plate load tests were conducted at various locations within the study area to assess the load-bearing capacity. Among these, four tests were carried out on the landfill area at the existing ground level (G.L.), see Figure 2e and 2f, where construction waste materials were presented, while the remaining five tests were performed after removing the construction waste materials to analyze the behavior of the underlying soil independently from the landfill influence, see Figures 2b, 2c and 2d. Table 2 provides information about the plate load test program conducted at different locations. Table 2 also includes the test code, test level from ground level, soil conditions, and additional notes. It specifies the depth of landfill removal, soil moisture conditions, and any specific procedures followed during the tests. These variations in test conditions allow for a comprehensive evaluation of the load-bearing capacity and behavior of the site under different scenarios. It is necessary here to mention that when the landfill inundated at the constant pressure of 200kPa, the pressure was maintained by continuous observation of the pressure gauge. Whenever the pressure slightly reduced due to settlement, it raised to 200kPa using the handle of the hydraulic jack.

Table 2: Plate load test program.

Test code	Test level from existing ground level	Soil type	Test ground conditions	Note
P_1	The landfill removed to 2.5 m	Coarse-grained[a]	Dry	Natural state of the soil at the site
P_2	The landfill removed to 2.5 m	Coarse-grained[a]	Saturated	Submerged three days prior the test
P_3	The landfill removed to 1.5 m	Coarse-grained[a]	Saturated	Submerged three days prior the test
P_4	The landfill removed to 1.5 m	Coarse-grained[a]	Saturated	Submerged three days prior the test
P_5	The landfill removed to 1.5 m	Fined-grained[a]	Saturated	Submerged three days prior the test
P_6	On the landfill at G.L.	Waste materials	Saturated	Submerged three days prior the test
P_7	On the landfill at G.L.	Waste materials	Saturated	Submerged at 200 kPa
P_8	On the landfill at G.L.	Waste materials	Saturated	Submerged at 200 kPa
P_9	On the landfill at G.L.	Waste materials	Saturated	Submerged at 200 kPa

[a] Confirmed in a geotechnical site investigation report by the Engineering Consulting Bureau (ECB), Salahaddin University -Erbil.

5. Results and Discussion

5.1. Pressure-Settlement Relationships of the Original Soil

The results obtained from the plate load tests revealed the pressure-settlement relationships of the original soil at five different locations labeled as P_1, P_2, P_3, P_4, and P_5, as shown in Figure 3. At P_1, as the stress increased to 150 kPa, a settlement of 0.5 mm was observed. Similarly, at P_2, P_3, P_4, and P_5, the settlements increased with increasing stress levels, indicating the soil's response to higher loads. As the stress level doubled from the previous level at each location, the settlements generally increased. For example, at P_1, the applied stress of 300 kPa resulted in settlement of 1.24 mm, while the applied stress 600 kPa resulted in a settlement of 2.58 mm. This trend of increasing settlement with increasing stress was seen at all locations. However, the behavior of soil was different at different locations. For instance, at P_5, settlement increased significantly than seen at any other location. This could be because of variation in settlement due to different types of soils regarding their composition and other conditions at each location.

The test results at location P_5 clearly indicated that the soil significantly saturated. At this location, since the soil had previously been saturated for a period of three days, the influence of water was more pronounced on the settlement response compared to the other locations. This probably attributed to a decrease in soil strength (cohesion and angle of internal friction) due to increase moisture content. Increasing stress levels significantly increased the settlement. At applied stress of 200 kPa and 400 kPa, the settlements were 6.22 mm and 30.51 mm, respectively. This large settlement indicated that the fine-grained soil was easily deformed under higher loads due to its saturated state. To reduce such settlements of foundations due to change in moisture content, during design of foundations some considerations should be taken such as the depth of foundations or the type of foundations. The limitation of this test was in checking water percolation after the three days of saturation. At the end of the test, it was observed that the moisture content was changed with depth at least to 0.5 m.

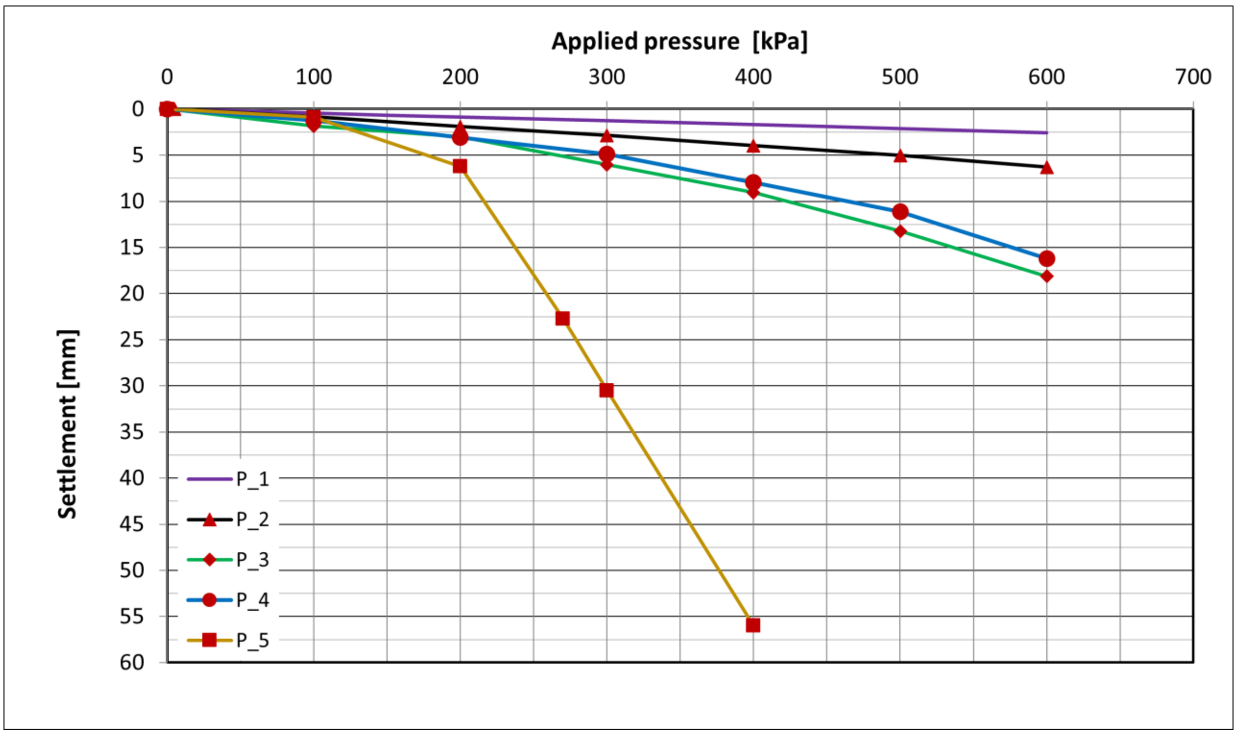


Figure 3: Pressure–settlement curves obtained from the plate load tests conducted on original soil both in dry condition (P_1) and under saturated conditions (P_2, P_3, P_4, P_5)

During saturation, water fills the voids between the particles of the soil, reducing inter-particle friction and increasing the pore water pressure. This leads to a decrease in the shear strength and stiffness of soils and an increase in their compressibility, hence higher settlement under applied loads (Briaud, 2013). In addition, the maximum settlement values measured at P_5, which clearly suggests the occurrence of yield of the soil in the pressure-settlement curve. Special attention must, therefore, be paid to fine-grained soils, where it might be found, at the time of inundation for the adequate design of foundation and construction methodologies to accommodate the probable settlement and stability issues (Hasan et al., 2022).

5.2. Pressure-Settlement Relationships of the Landfill

The plate load tests conducted on the landfill area represent the pressure-settlement relationships for the landfill at four different locations labeled as P_6, P_7, P_8, and P_9. It crucial to mention that the landfill was consolidated under its own weight. In test P_6, the submerged duration was three days prior to the start of the test, whereas in the tests P_7, P_8, and P_9, a trench around the plate was filled with water at an applied pressure of 200 kPa.

5.2.1. Pre-wetting Pressure-Settlement Relationships

Figure 4 shows the pre-wetting pressure-settlement relationships for tests P_7, P_8, and P_9. The tests were conducted before submerging the trench with water at an applied pressure of 200 kPa. This gives some insight into how the soil behaved under different stress levels prior the saturation. The settlement increased gradually with an increase in stress levels for test P_7. At a stress of 100 kPa, the settlement was 0.79 mm, increased to 1.37 mm when the applied stress reached 200 kPa. In Test P_8, similar behavior was observed, as the settlements were 0.53 mm and 1.01 mm at 100 kPa and 200 kPa, respectively. Even though these values were minutely lower than those captured at P_7, the trend of increasing settlements towards an increased stress level was similar. Settlement values for Test P_9 showed a similar pattern. The settlement at 100 kPa was 1.14 mm, which increased to a value of 2.24 mm at 200 kPa. This indicates that compared to the other two tests, the soil at P_9 was relatively more compressible. Comparing the results in this work to others in the literature (for example, results from Tian et al. (2021)) indicating that their settlement value from a plate load test of a landfill were much more than the deformation settlements in the current study. Their landfill settlement was 220mm at 200kPa. In addition, plate load test was performed by Dalal et al. (2011) on a landfill in yielded 40mm settlement at 200kPa. They improved the landfill by adding a geotextile mat and stone filled wire mess mattress.

The results obtained from the pre-wetting pressure-settlement relationships show (see, Fig. 4) that settlements indicate the low compressibility of the landfill and its capability to slightly deform under the applied loads. Observed settlement values in this regard can be very useful for foundation design and construction by demonstrating the potential of soil settlement and keeping this factor in mind to ensure the stability and performance of structures in the Red Zone area.

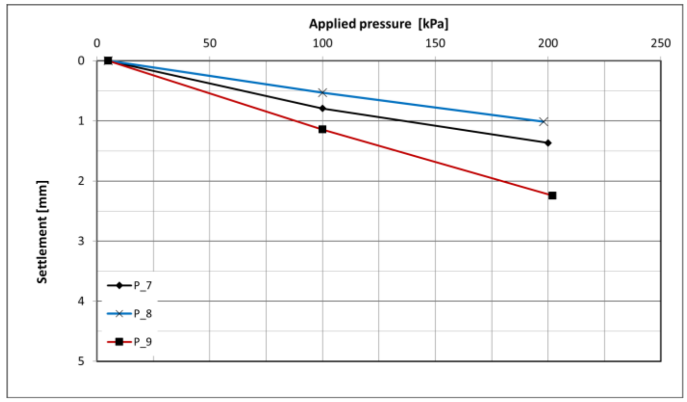


Figure 4: Pre-wetting stage of pressure–settlement curves of plate load tests on the landfill

The test results provide preliminary insight into the behavior of such landfill before soaking it at the applied pressure of 200 kPa. Further testing and analysis are needed in assessing landfills for their load-carrying capacity and deformation features under increasing moisture content conditions. Such findings can provide engineers with guidance in making decisions concerning foundation design, construction techniques, and measures to prevent settlement-related problems in those areas.

5.2.2. Pre- and post-wetting Pressure-Settlement Relationships at 200kPa

These tests were conducted by submerging the landfill using a trench filled with water to simulate the effects of water on the settlement response after the applied pressure reached 200 kPa in tests P_7, P_8, and P_9. On the other hand, P_6 was submerged for three days before starting the test. The pre- and post-wetting pressure-settlement curves provide valuable information on how the landfill responds to inundation before reaching a certain pressure level (see Figure 5).

Starting with P_6, it is convenient to note that the sudden collapse response was relatively small compared to the other tests. At the applied stress of 200 kPa and after inundation, the settlement was 1.55 mm. The small settlement was observed in P_6, despite being submerged for three days before the test. This could be attributed to different factors including the presence of large construction waste materials under the plate during the test. These materials, being less compressible compared to the surrounding area, which would have hindered the overall settlement of the plate. The waste materials might have provided more rigid support, limiting the deformation and settlement of the ground beneath. To support that, at the end of the plate load tests on the landfill, the soil directly under the plate was excavated, and a large construction waste material was found.

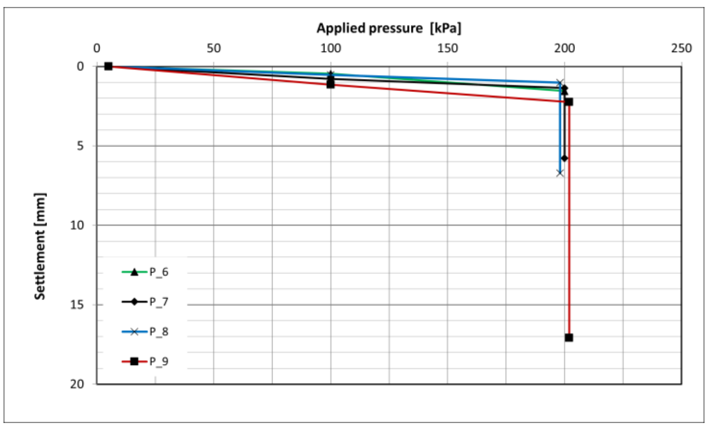


Figure 5: Pre- and post-wetting at 200kPa stage of pressure–settlement curves of plate load tests on the landfill

In Tests P-7, P-8, and P-9, the ground was subjected to inundation by introducing water into a trench while maintaining a constant applied stress of 200 kPa. As illustrated in Figure 5, a pronounced increase in settlement was observed relative to the pre-wetting condition. Under the same applied stress, Test P-7 recorded a settlement of 2.81 mm, Test P-8 exhibited 5.78 mm, and Test P-9 showed a markedly higher settlement of 17.08 mm. These results clearly indicate that inundation substantially amplifies the compressibility of the landfill material. The wide variation in settlement among the three tests further reflects the inherent heterogeneity of the backfill, arising from the random spatial distribution, gradation, and stiffness of the construction waste constituents within the landfill matrix.

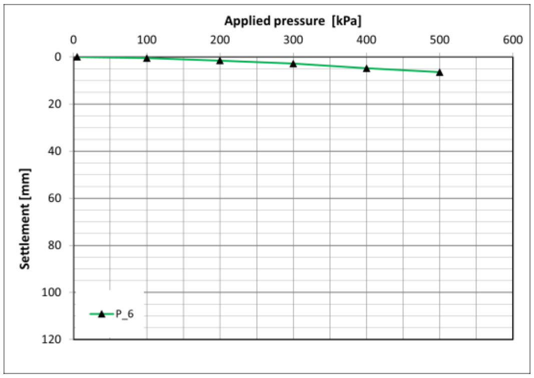
Comparing the settlement values in Tests P_7, P_8, and P_9 to their corresponding pre-wetting values, it is clear that the inundation of the landfill led to a substantial increase in settlements (i.e. collapse compression). This suggests that the soil became more compressible and susceptible to deformation when saturated. For comparative purposes, a comprehensive review of the available literature was conducted; however, no published experimental data were found that document the post-wetting deformation behavior of similar materials.

5.2.3. Post-wetting Pressure-Settlement Relationships beyond 200kPa

In Test P_6, the settlement values are relatively small at pre- and post-wetting conditions at different stress levels, as discussed in the previous paragraph. For example, at a stress of 100 kPa, the settlement is 0.47 mm. However, as the stress level increases at the end of wetting at 200kPa to 500kPa, the settlements slightly increased, see Figure 6a. Differently, in Tests P_7 and P_8, the settlements significantly increased at the end of wetting at 200kPa to 500kPa. This significant increase in settlement suggests a substantial deformation of the landfill under higher loads. Additionally, in Test P_9, the settlements also exhibit a similar trend, with higher settlements were observed at higher stress levels.

These findings bring into focus the need to consider the inundation effects on landfill behavior for ensuring suitability for and support of structures. Large settlement recorded with water-saturated conditions, such measures as provision of proper drainage systems may be required to avoid undesirable settlement in the long term for integrity of the foundation. Furthermore, it is important to note the possible presence of different kinds of construction waste materials, which might have introduced heterogeneity or localized effects on the overall settlement behavior.

a



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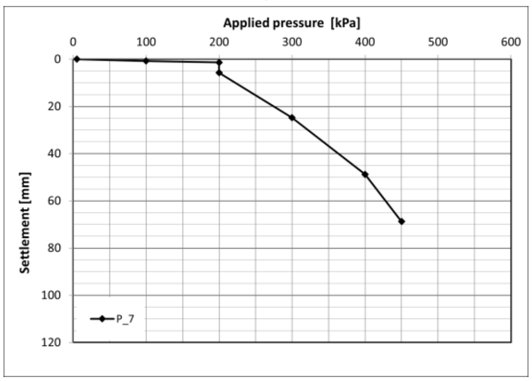

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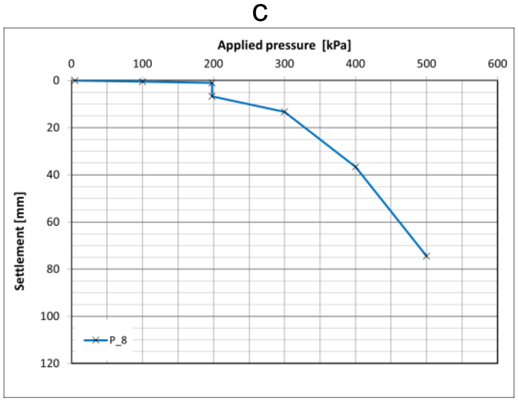

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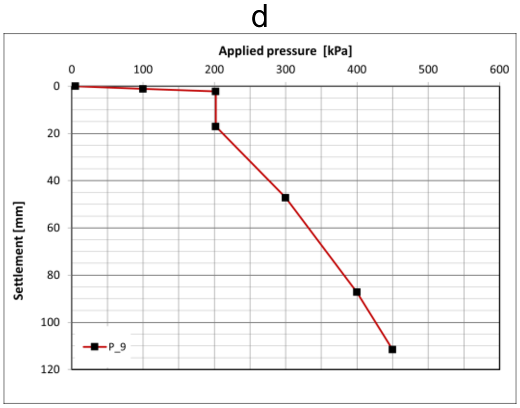

Figure 6: Complete pre- and post-wetting stage of pressure–settlement curves of plate load tests on the landfill: (a) at location P_6 (b) at location P_7 (c) at location P_8 (d) at location P_9

This factor is responsible for creating variation in stress distribution, which in turn brings about variation in settlement patterns at different locations. The relatively small settlement observed in P_6 can be attributed to such evidence. A clear comparison among P_7, P_8, and P_9 in the post-wetting can be seen in Figure 7. It was found that the landfill at locations P_7 and P_8 were suitable to be used as a foundation for lightweight Villa (75kPa) as they show settlements within allowable limits.

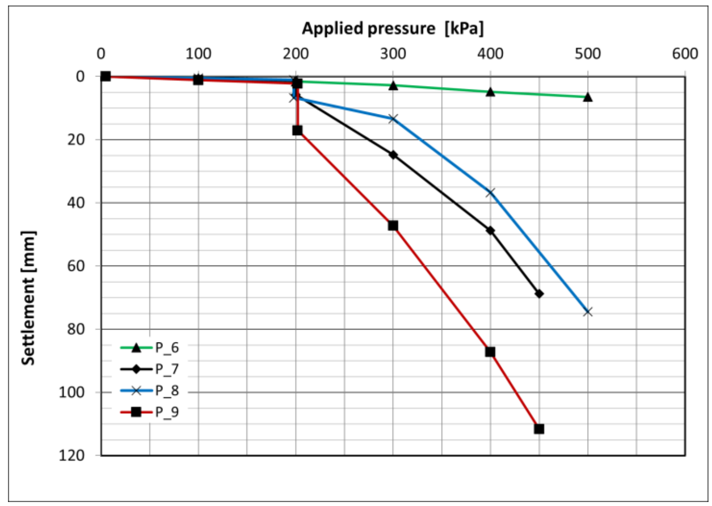

Figure 7: Pre- and post-wetting stage of pressure–settlement curves of plate load tests on the landfill

The pressure-settlement curves as shown in Figure 7, can be employed to check the limitations of building settlements under pre- and post-wetting conditions.

Even the behavior of this landfill under load compared to that of the original soil was different. At the same time, landfills contained construction waste material may have different engineering properties and sometime different load-carrying capacities.

These results highlight the importance of considering the behavior of the landfill when evaluating its suitability as a foundation for supporting lightweight residential buildings. The high and low settlements observed at different locations in the landfill suggest the need for further investigation and potentially additional measures to ensure the stability and integrity of the foundation when constructing on such areas.

6. Conclusions

Based on the interpretations of the pressure-settlement results from plate load tests on the landfill and the original soil, the following conclusions could be suggested:

1. For the original soil, yield stress was clearly observed for fine-grained when saturated, whereas this stress was not observed for coarse-grained original soil at dry and even saturated conditions. This, as expected, indicates that the coarse-grained soil is not sensitive to change in the degree of saturation.
2. The bearing resistance and the amount of the settlement of the landfill at dry conditions (pre-wetting) were very satisfied for construction residual buildings. As the applied pressure by the buildings was about 75 kPa.
3. When the landfill wetted under 200kPa, which is much higher than the pressure applied by the buildings (75kPa), the number of sudden settlements was not exceeded 25mm. This is a clear indication that the landfill can resist the low pressure applied by the buildings, even in the worst case (i.e. saturation condition).
4. During loading at the post-wetting conditions beyond 200kPa, as expected, a significant amount of settlement was observed when the applied pressure increased, indicating the sensitivity of the landfill to the change of applied stress at this stage.
5. In the case of using a landfill as the foundation of buildings, it is better to protect the landfill foundation from the high change of moisture content by compaction a layer of very low permeable clay soil on and beside the landfill to prevent seeping water into it.

Acknowledgment: Not applicable.

Financial support: No financial support.

Potential conflicts of interest. All authors report no conflicts of interest relevant to this article.

References

Abdulhamid, S. N., Hasan, A. M. & Aziz, S. Q. 2021. Solidification/stabilization of contaminated soil in a south station of the Khurmala oil field in Kurdistan region, Iraq. *Applied Sciences,* 11**,** 7474.

Ahmed, S., El-Zohairy, A., Eisa, A. S., Mohamed, M. a. E.-a. B. & Abdo, A. 2023. Experimental Investigation of Self-Compacting Concrete with Recycled Concrete Aggregate. *Buildings,* 13**,** 856.

Andersen, E. O., Balanko, L., Lem, J. M. & Davis, D. H. 2004. Field monitoring of the compressibility of municipal solid waste and soft alluvium.

Astm 1994. D 1194. Standard test method for bearing capacity of soil for static load and spread footings. West Conshohocken: ASTM International

Batayneh, M., Marie, I. & Asi, I. 2007. Use of selected waste materials in concrete mixes. *Waste management,* 27**,** 1870-1876.

Begum, R. A., Siwar, C., Pereira, J. J. & Jaafar, A. H. 2006. A benefit–cost analysis on the economic feasibility of construction waste minimisation: The case of Malaysia. *Resources, Conservation and Recycling,* 48**,** 86-98.

Bolden, J., Abu-Lebdeh, T. & Fini, E. 2013. Utilization of recycled and waste materials in various construction applications. *American Journal of Environmental Science,* 9**,** 14-24.

Briaud, J. L. 2013. Geotechnical Engineering: Unsaturated and Saturated Soils, Wiley.

Dalal, N., Solanki, C. & Desai, A. 2011. Plate Load Tests on Municipal Solid Waste Dump Site to Assess Ground Improvement Alternatives. *Journal of Environmental Science and Engineering,* 5.

Elgizawy, S. M., El-Haggar, S. M. & Nassar, K. 2016. Approaching sustainability of construction and demolition waste using zero waste concept. *Low carbon economy,* 7**,** 1-11.

Guo, Z. & Chen, Z. 2022. Utilization of Construction Waste Recycled Powder as Filler in Asphalt Concrete. *Materials,* 15**,** 5742.

Hasan, A. M., Abdulhamid, S. N. & Ibrahim, H. H. 2022. Preliminary experimental investigation on the inundating-induced collapse in collapsible soils improved by encased sand column. *Geomechanics and Geoengineering,* 17**,** 1499-1515.

Minunno, R., O'grady, T., Morrison, G. M. & Gruner, R. L. 2020. Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building. *Resources, Conservation and Recycling,* 160**,** 104855.

Mohajerani, A., Burnett, L., Smith, J. V., Markovski, S., Rodwell, G., Rahman, M. T., Kurmus, H., Mirzababaei, M., Arulrajah, A. & Horpibulsuk, S. 2020. Recycling waste rubber tyres in construction materials and associated environmental considerations: A review. *Resources, Conservation and Recycling,* 155**,** 104679.

Mostert, C., Weber, C. & Bringezu, S. 2022. Modelling and Simulation of Building Material Flows: Assessing the Potential for Concrete Recycling in the German Construction Sector. *Recycling,* 7**,** 13.

Robayo-Salazar, R., Valencia-Saavedra, W. & Mejía De Gutiérrez, R. 2022. Reuse of Powders and Recycled Aggregates from Mixed Construction and Demolition Waste in Alkali-Activated Materials and Precast Concrete Units. *Sustainability,* 14**,** 9685.

Rojas-Valencia, M. N., Rivas-Torres, B. I., Fernández-Rojas, D. Y. & Gómez-Soberón, J. M. 2022. Recovery of Mixtures of Construction Waste, PET and Sugarcane Bagasse for the Manufacture of Partition Blocks. *Materials,* 15**,** 6836.

Schützenhofer, S., Kovacic, I., Rechberger, H. & Mack, S. 2022. Improvement of Environmental Sustainability and Circular Economy through Construction Waste Management for Material Reuse. *Sustainability,* 14**,** 11087.

Shamsaei, M., Carter, A. & Vaillancourt, M. 2023. Using Construction and Demolition Waste Materials to Develop Chip Seals for Pavements. *Infrastructures,* 8**,** 95.

Thormark, C. 2001. Conservation of energy and natural resources by recycling building waste. *Resources, conservation and recycling,* 33**,** 113-130.

Tian, T., Hu, J., Yao, X. & Gang Hu, S. Large scale plate loading tests of refuse soil. IOP Conference Series: Earth and Environmental Science, 2021. IOP Publishing, 032074.

Wahi, N., Joseph, C., Tawie, R. & Ikau, R. 2016. Critical review on construction waste control practices: legislative and waste management perspective. *Procedia-Social and Behavioral Sciences,* 224**,** 276-283.

Wali, K. I. 2020. An investigation into the factors influencing the reduction of construction materials wastage in erbil city-krg-iraq. *Zanco Journal of Pure and Applied Sciences,* 32**,** 1-11.

Yanev, P. I. & Books, C. 1975. Peace of Mind in Earthquake Country: How to Save Your Home and Life, Chronicle Books LLC.