Journal of Petroleum Research and Studies

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

DOI: http://doi.org/10.52716/jprs.v15i2.952

Suggesting Some Criteria for The Foundations of Oil Tanks

Salah M. Salih

Ministry of Oil, Midland Refineries Company, Baghdad, Iraq.

*Corresponding Author E-mail: salam.baghdadi22@gmail.com

Received 28/04/2024, Revised 08/09/2024, Accepted 12/09/2024, Published 22/06/2025

Abstract

The tank foundation serves as a support base for oil tanks, ensuring their stability by withstanding the tank's weight. Foundation failure commonly occurs when it cannot support the tank's weight or when the soil's bearing capacity cannot resist the stress imposed by the tank and its foundation. This study aims to ensure the stability of the tank-foundation system by selecting an appropriate foundation system that considers the soil's bearing capacity. The deformation behavior of slab-foundations for tank foundations under different conditions, with the objective of determining the optimal design for such foundations was investigated. The models used in the study are based on previous research and employ finite element analysis using STAAD Pro Foundation CONNECT Edition V.9 software to assess the stability of the structure-foundation system. The study examines three different types of foundation systems, considering parameters such as thickness, bearing capacity, and elasticity. Results indicate that the raft foundation is the most optimal design for stiff residual soils, the pile-raft structure-foundation is most suitable for marine sediment deposits, and the pile foundation is highly recommended for soft peaty soils. Finally, this research presents a specific process for determining the features of slab foundations according to soil factors and variables, which can be used to select better designs for oil tank foundations.

Keywords: STAAD, Oil Tank, Foundation, Structure, Piles.

مقترحات لبعض المعايير لأساسات خزانات النفط

الخلاصة:

تعمل قاعدة الخزان كقاعدة دعم لخزانات النفط، مما يضمن استقرارها من خلال تحمل وزن الخزان. فشل الأساس يحدث عادة عندما لا يتمكن من دعم وزن الخزان أو عندما لا تتمكن قدرة تحمل التربة من مقاومة الإجهاد الذي يفرضه الخزان وأساسه. تهدف هذه الدراسة إلى ضمان استقرار نظام الخزان-الأساس من خلال اختيار نظام أساس مناسب يأخذ في الاعتبار قدرة تحمل التربة. تم التحقيق في سلوك تشوه الأساسات الخرسانية لأساسات الخزان في ظل ظروف مختلفة، بهدف تحديد التصميم الأمثل لمثل هذه الأساسات. تستند النماذج المستخدمة في الدراسة إلى أبحاث سابقة وتستخدم تحليل العناصر المحدودة باستخدام برنامج STAAD Pro Foundation CONNECT Edition V.9 لتقييم استقرار نظام

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

الهيكل-الأساس. تدرس الدراسة ثلاثة أنواع مختلفة من أنظمة الأساس، مع مراعاة عوامل مثل السُمك وقدرة التحمل والمرونة. تشير النتائج إلى أن أساس الطوافة هو التصميم الأمثل للتربة المتبقية الصلبة، وأن أساس هيكل الطوافة هو الأنسب لرواسب الرواسب البحرية، وأن أساس الخوازيق موصى به بشدة للتربة الخثية اللينة. أخيرًا، يقدم هذا البحث عملية محددة لتحديد ميزات أساسات البلاطة وفقًا لعوامل التربة والمتغيرات، والتي يمكن استخدامها لاختيار تصميمات أفضل لأساسات خزانات النفط.

1. Introduction

These crucial structures called the oil tank foundations always in the need of enhancing the design of it to take in different soil types that produce an important provocation in two directions the construction and progress maintenance [1]. The foundation is reported as the essential support system for oil tanks, confirming that stability and preventing potential failures that could lead to environmental disasters and financial damages [2]. Though, a distinct engineering challenges cleared shown in the different soil conditions which present that required solicitous analysis and design. Mainly Type of the soil, containing its compaction, composition, and bearing capacity, crucially effect on the behavior and durability of the foundation [3].

This type of soils: expansive soils, soft clay or loose sand showed challenges in demanding accurate measures to relieve potential settlement, differential movement, or collapse. consultant engineers must conduct the geotechnical investigations to evaluate the properties of soil accurately and modifying the foundation design according to that. The previous introduction spots the lights on the importance of enhancing the design of oil tank to give accommodation to different and various soil types, putting attention on the key obstacles and considerations included [4]. Applying innovative geotechnical strategies for instance: soil settlement methods, ground advancement practices, and suitable system of the foundation systems, specialists can ensure the safe and optimal behavior of oil tanks across diverse soil conditions. This enhancement is crucial for upholding the safety of oil storage facilities and keeping the environment safe [5].

These crucial structures called the oil tank foundations always in the need of enhancing the design of it to take in different soil types that produce an important provocation in two directions the construction and progress maintenance [1]. The foundation is reported as the essential support system for oil tanks, confirming that stability and preventing potential failures that could lead to environmental disasters and financial damages [2]. Though, a distinct engineering challenges cleared shown in the different soil conditions which present that required solicitous analysis and design. Mainly Type of the soil, containing its compaction, composition, and bearing capacity, crucially effect on the behavior and durability of the foundation [3].

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

This type of soils: expansive soils, soft clay or loose sand showed challenges in demanding accurate measures to relieve potential settlement, differential movement, or collapse. consultant engineers must conduct the geotechnical investigations to evaluate the properties of soil accurately and modifying the foundation design according to that. The previous introduction spots the lights on the importance of enhancing the design of oil tank to give accommodation to different and various soil types, putting attention on the key obstacles and considerations included [4]. Applying innovative geotechnical strategies for instance: soil settlement methods, ground advancement practices, and suitable system of the foundation systems, specialists can ensure the safe and optimal behavior of oil tanks across diverse soil conditions. This enhancement is crucial for upholding the safety of oil storage facilities and keeping the environment safe [5].

The commercial finite element software STAAD CONNECT Edition V.9 was used in the study to conduct the analysis [6]. The main target of the study is to spot lights on the deformations that may founded in the foundations of the oil tanks and evaluate their performance in many different conditions [7]. The STAAD CONNECT, V.9 software was used to carry out the analysis.

The specifics reasons and strategies beside failures, surrounding subjects like, the weld imperfection, corrosion, and structural failures has been founded through the accurate analysis of failures founded in oil storage tanks. Studies highlighting the included factors for example the loading phases, material properties, and keep the practices to well define the failure modes and suggest safeguarding measures. A deep comprehension of the different failure modes and c factors affect in oil storage tank failures is necessary to verify them protecting procedure and structural probity. Researchers and manufacturing professionals can develop successful mechanism for tank design, by studying preservation, failure analysis, and examination, so, for that the results will appear in reducing risks and stopping future failures [5].

The elementary reasons and strategies of failures in the base of the plate of oil storage tanks can be seen in material degradation, corrosion, and loading phase, also disclosed over the failure of analysis. Studies have inspected factors have a rule in these failures and have suggest development in tank design, beside keeping the practices, to stop bottom base failures. Managing failure analysis located at the base in the plate of oil storage tanks come up with worthy insights into failure methods and can help in developing ways to improve tank safety. Prophylactic measures can be executed to diminish the risk of bottom plate collapse and verify the operation

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

safes of the tanks by labeling factors such as material properties, corrosion, and loading phases [8].

For examine failure modes like settlement, fatigue, and corrosion, used failure analysis and hazard evaluation of aboveground in the storage tank of floors. These studies targeted to examined the deep reasons of failures, appraise related risks, and suggest strategies in order to lessen these risks by keeping practices, the development of tank design, and scrutiny agreement. Maintaining the safety of the structure of tanks are critical and can be done by the failure analysis and risk evaluation of aboveground storage tank floors. By using effective measures that can be applied to reduce floor failures, ensuring the safe storage of liquids and minimizing the potential for environmental pollution and incidents can help in this the good discriminatory between failure phases and evaluating risks, [10].

The academic work of failures in basic oil storage tanks is concentrate in recognizing the implied factors and reasons that lead to such failures, including corrosion and material degradation. Researchers targeted to get insights into failure methods by analyzing case studies, beside the need of perception failure mods, recommending examination and keeping protocols, also refining the tank designs to stop any future collapse. Worthy learning concerning the beginning of failures and mechanisms for prohibition can be obtained by using the analysis of case studies recording failures in crude oil stockpiling tanks. By inscribing matters such as material selection, corrosion, , and maintenance agreements , the industry may develop the safety and reliability of the base oil in stockpiling facilities, following to that reducing the probability of calamitous failures and the connected environmental risks [12].

Recently, Rauan L., et al. used conduct model tests in a metallic tank with particular dimensions, allowing for a 1:25 scale to handle the difficulty of selecting an analogous material for soil testing utilizing piles on a large-scale experimental setup. Fine and medium-grained sand were served as the corresponding soil material. They include the methodologies used to successfully evaluate the load-bearing capability of foundation piles, as well as insights into improving designs for increased stability in a variety of soil situations. This technique lays the path for constructing sustainable and environmentally efficient engineering structures in diverse soil settings. [16].

Mwansa Andrew et al., investigated Foundation Treatment, Reinforcement and Design Optimization for Oil Storage Tanks at TAZAMA Pipelines Limited Ndola Site, (a key player in the transportation of petroleum products between Zambia and Tanzania). They considered a 50,000m3 floating roof oil storage tank foundation for soil consolidation optimization, analyzing

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

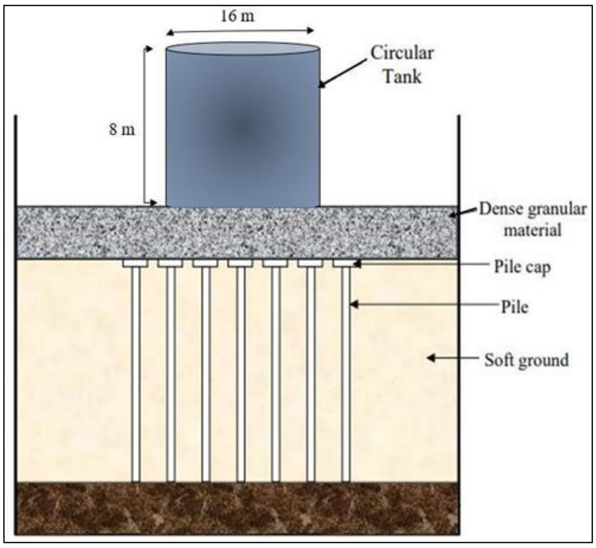
the study's practicality and feasibility, and analyzing the engineering characteristics and distribution patterns of soft soil foundations in the site area through systematic analysis of survey data from the target area, as well as considering appropriate foundation treatment and reinforcement methods for oil storage tanks in the area. Finally, they achieve a way of optimization to handle the soil consolidation difficulties, which is provided through level-by-level examination of the application model. [17]

2. Materials and Method

2.1. Foundation of Oil Tank

The foundation of an oil tank act as a very climacteric part in verifying its stability and immortality of the structure. It presented as the interface between the tank and the implicit soil, bearing the weight and moving loads to the ground. Designing a robust foundation include precise consideration of effective elements for instance, soil type, bearing capacity, settlement, and potential environmental influence [8]. In this paper, the diameter of circular tank is 16 m and its height reach to 8m as shown in Figure (1). The circular tanks are rested on dense granular material and then soft ground. The soft ground is containing piles system with pile cap.

By realization convenient engineering rules and techniques, the foundation can successfully support the tank, decrease the risk of failure, and be sure the safe storage and transmission of oil. General, a well-designed oil tank foundation is pivotal for confirming the structural safety of the tank, stopping any leaks or spills, and saving the environment. It needs accurate analysis of the soil qualifications, appropriate engineering mechanism, and commitment to suitable regulations and criterion to improve the foundation's behavior and immortality [9].



Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

Fig. (1): Dimensions of the study tank

2.2. Bearing Capacity

Bearing capacity is a fundamental concept in geotechnical engineering that playsan important role in the design and construction of different structures. It refers to the maximum load that a soil or rock stratum can support without experiencing excessive settlement or shear failure. Understanding the bearing capacity of the ground is important for achieving the stability and safety of structures such as buildings, bridges, dams, and foundations [10]. The determination of bearing capacity includes inclusive geotechnical examination, containing, laboratory testing, soil sampling and in-situ measurements. Parts such as soil type, moisture content density, and compactionsignificantly affect the bearing capacity. Engineers use different ways, like plate load tests, standard penetration tests, or cone penetration tests, to get the soil's strength and prophesy its load-bearing capacity [11]. The accurate estimation of bearing capacity is for designing the foundations and selecting appropriate construction techniques.It permits engineers to be sure that structures can safely resist the expected loads, reducing the too much deformation, risk of settlement, or structural failure [12].

2.3. Failure of Oil Tank Foundations

There are different factors that result in failure for oil tank foundations. Some of the popular factors contributing to foundation failures contain:

1. Poor soil conditions: Inadequate soil investigation and analysis can result in theexpansive properties, or high groundwater levels can lead to settlement, differential movement, or even collapse of the foundation as shown in Figure (2)
2. Inappropriate foundation design: problems in loads like underestimating the loads or failing to reflect on the soil properties, can be seen in excessive stress on the foundation. This may bring displacement, cracking, or failure of the foundation by time[13].
3. Construction deficiency: misleading of the time of the design return period, such inappropriate reinforcement placement, unsuitable compaction of the soil, or inadequate concrete curing, may made the foundation more week in compromise itsstructural
4. Environmental failure risk factors: Environmental conditions, such floods, earthquakes, or soil erosion, can do excessive forces on the foundation, bring about it fail. Poor drainage or water accumulation around the foundation can also lead to instability [14].
5. Age and deterioration: Over time, foundations can deteriorate due to aging, corrosion, or

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

exposure to harsh environmental conditions. This can make the foundationmore week and raise the risk of failure.

6. Unsuitable maintenance: Lack of constant visitation, repairs, and maintenance,help to contribute to the damage happened to the foundation, leading to definitive failure.

Recognizing these possibility causes of failure is effective in designing and maintaining oil tank foundations. By investigation adequate engineering practices, conducting overall soil investigations, and ensuring uniform rummage and maintenance, the risk of foundation failure might be decreased, making sure that the safe and dependable procedure of oil storage facilities [15].

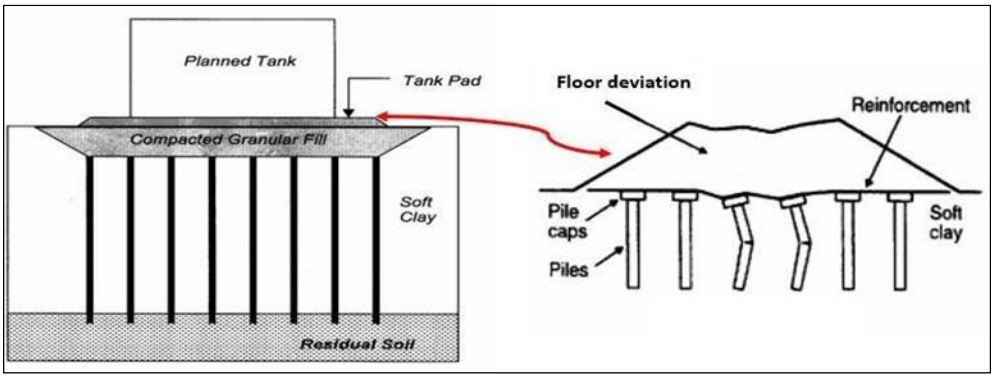


Fig. (2): Deflection of the tank foundation surface

2.4. Material and methodology

In this research, three types of foundation systems are used (Raft, Raft pile, pile-cap). They performed using STAAD Foundation Advanced CONNECT V.9 software as shown in Figures (3, 4, and 5) respectively. In addition, a triangular grid was formed to appear the foundation structure. the coefficient of the subsoil layers is calculated based on the bearing capacity of the soil layers, which is known as the assumed capacity. Three different soil bearing capacities are used (50 kPa, 100 kPa, and 150 kPa). Different parameters, such as thickness, bearing capacity, elasticity the optimizing design of the appropriate foundation system for the soil was identified based on the deformation. A slab thickness of 2200 mm was used for foundation. The results like moments and stresses are calculated using STAAD software.

A dead load of 3000 KN was applied to the foundation surface to represent the own weight of the tank.

The required number of piles was determined manually. A design safety factor of 3 was taken to design the basic structure to obtain the critical results. Model analysis and calculation sheets were

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

carried out for each structurefrom the foundation. Information about failure and distributed stress in a vertical way was recorded. The assumed design strength was 700 N/mm2 for steel and 50 N/mm2 for concrete, based on the International Design Code. After designing, the cutting option was chosen for the purpose of making a section of the current distribution by drawing aline. The elastic modulus of concrete is calculated based on equation (1) existing in Euro code 2 (CEN 2004).

$E_{cm} = 22000 * (0.1 * f_{cm})^{0.3}$

$f_{cm} = f_{ck} + 8$ Equation (1)

E_{cm} = Elasticity modulus of concrete

f_{cm} = Average compressive strength of concrete

f_{ck} = Characteristic compressive strength of concrete

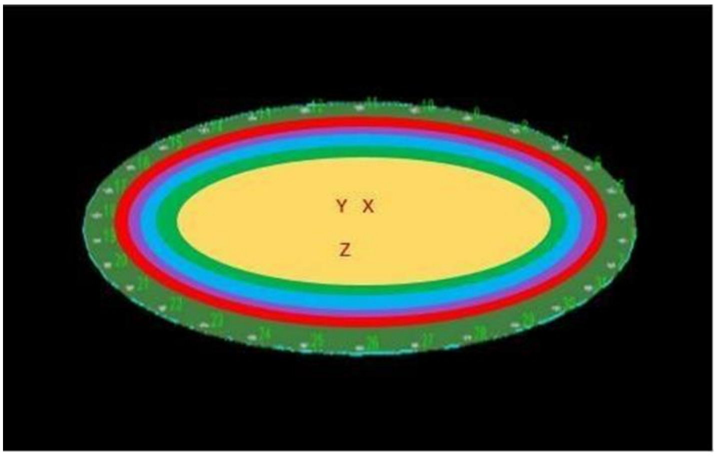


Fig. (3): Raft, S.T.A.A.D Model.

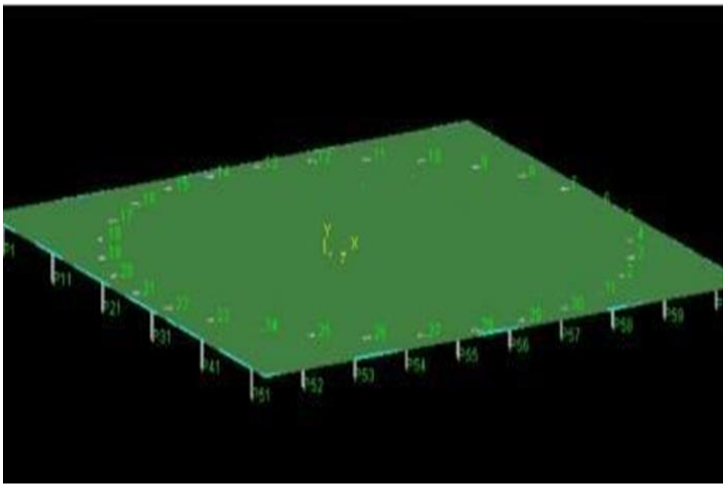


Fig. (4): Raft -pile, S.T.A.A.D Model.

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

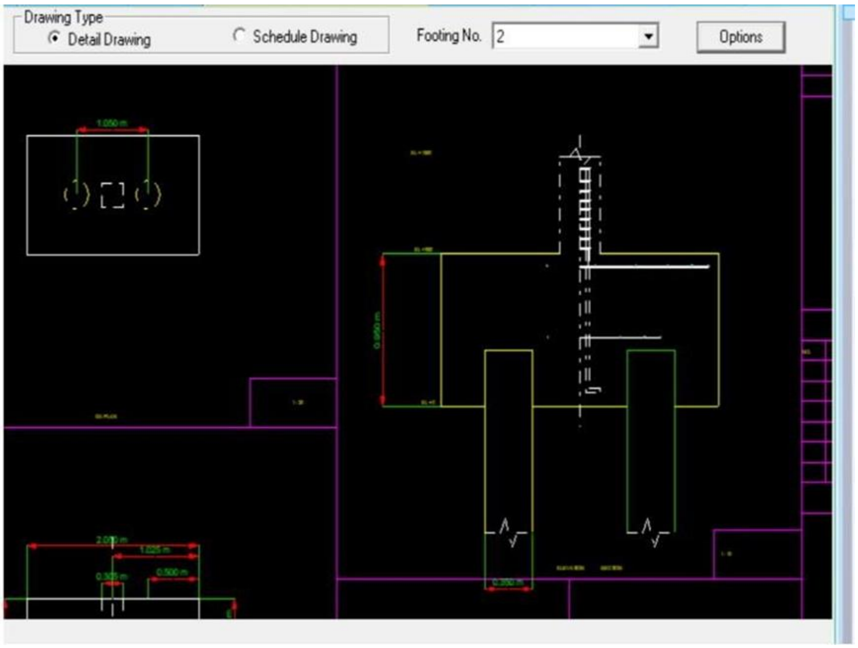


Fig. (5): Presents the pile cap as depicted in the STAAD Foundation Advanced software.

3. Results and Discussions

The foundation was simulated using varying bearing capacities of (soil) corresponding to different soil types: (peat, marine, residual). The bearing capacities (soil) for each type were set at 50kPa, 100 kPa, and 150 kPa. The bearing capacity values were obtained from building by laws. although using the same foundation types, different results of moment distribution are obtained. The analysis results are shown in Table (1).

Table (1): Results from STAAD foundation program

Soil type	Foundation type	Soil Bearing capacity (KPa)	Moment distribution (kNm/m)	Displacement (mm)
Peat	**raft**	50	1765.43	16.44
Marine	**raft**	100	1655.11	8.22
Residual	**raft**	150	1467.56	5.11
Peat	**raft- Pile**	50	33.890	1.23
Marine	**raft- Pile**	100	42.878	1.23
Residual	**raft- Pile**	150	66.543	2.70
Peat	**Pile**	50	1456.221	16.21
Marine	**Pile**	100	1455.332	19.22
Residual	**Pile**	150	1043.564	20.87

Based on Table (1) and Figures (7, 8, and 9), for the Raft foundation type, peat soil has the

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

greatest moment and medium displacement values about1765.43KNm/m and 16.44 mm respectively than other soil types (marine and residual). In addition, the allowable settlement for the foundation is 25 mm, so deformation value is allowable and acceptable.

Based on Table (1) and Figures (7, 8, and 9) and for Raft pile foundation, the residual soil type has the highest value of moment and deflection. The values of moment and deflection are 66.543 KNm/m, 2.70 mm respectively. The lower value of moment and deflection are in using peat type 33.89KNm/m and 1.23 mm respectively. In addition, the allowable settlement for the foundation is 25 mm, so deformation value is allowable and acceptable.

Based on Table (1) and Figures (7, 8, and 9), the pile foundation type has higher value of moment at peat soil type and higher displacement value at residual soil type. The higher value of moment re and deflection are 1456.221 KN.m/m, 20.87 mm respectively. In addition, the allowable settlement for the foundation is 25 mm, so deformation value is allowable and acceptable.

Also, for both of (Raft & piles) types, the moment is decreases slightly then decrease by large value unlike (pile-raft type), the moment is increases slightly then increases by large values. The moment behavior is nearly in raft types and piles types unlike pile-raft types.

The behavior of displacement 2 Foundation types (pile raft types – piles types) are almost the same. The displacement increases when change the soil type from peat then marine to residual. But, for Raft foundation type the displacement in decreases.

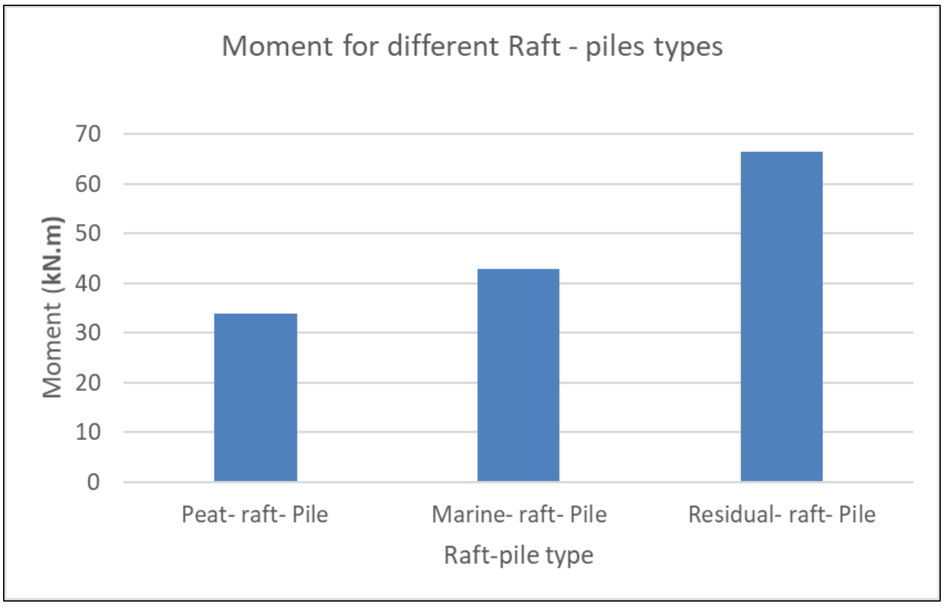


Fig. (7): The moment values for different Raft-piles types

Journal of Petroleum Research and Studies

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

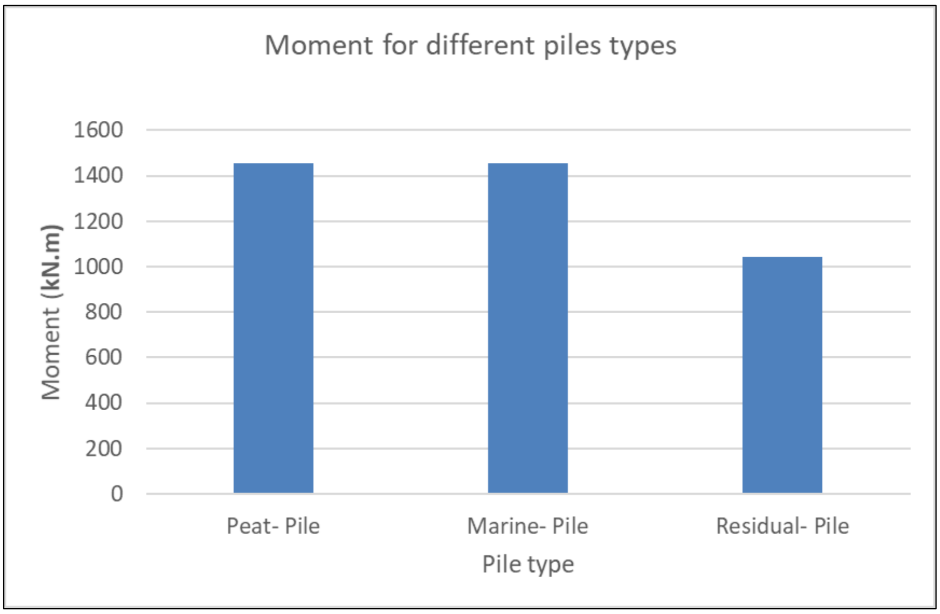


Fig. (8): The moment values for different Piles – types

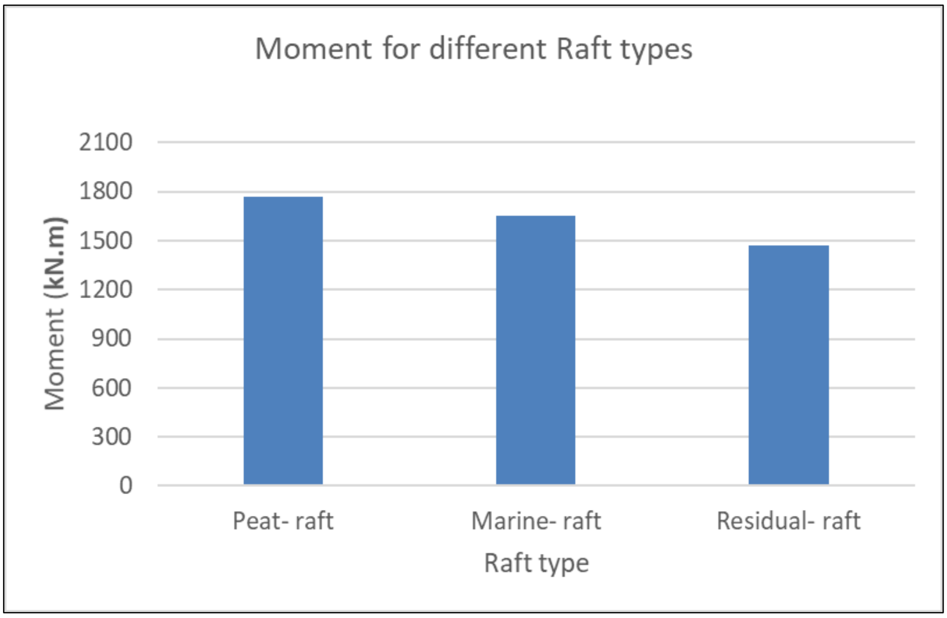


Fig. (9): The moment values for different Raft- types

Journal of Petroleum Research and Studies

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

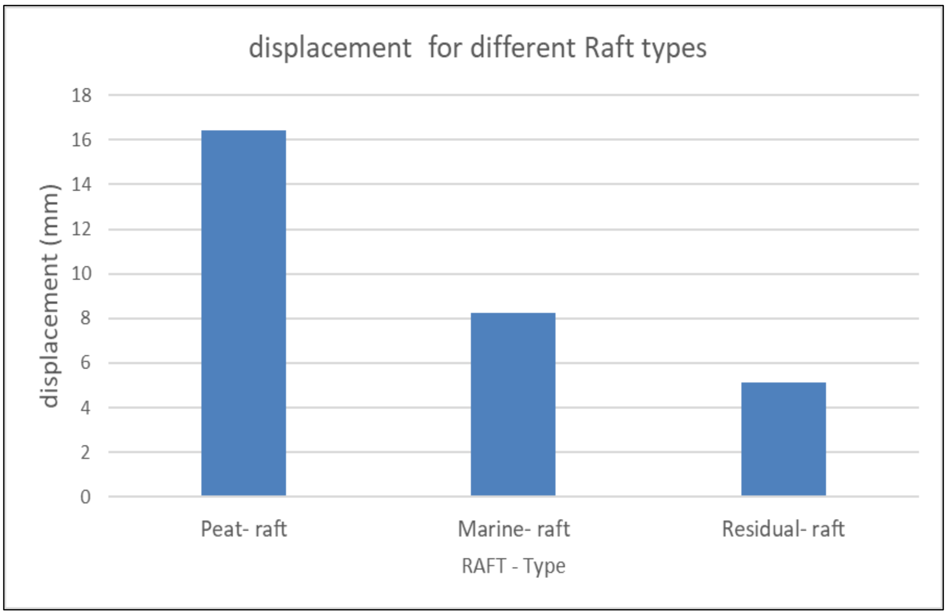


Fig. (10): The displacement values for different Raft- types

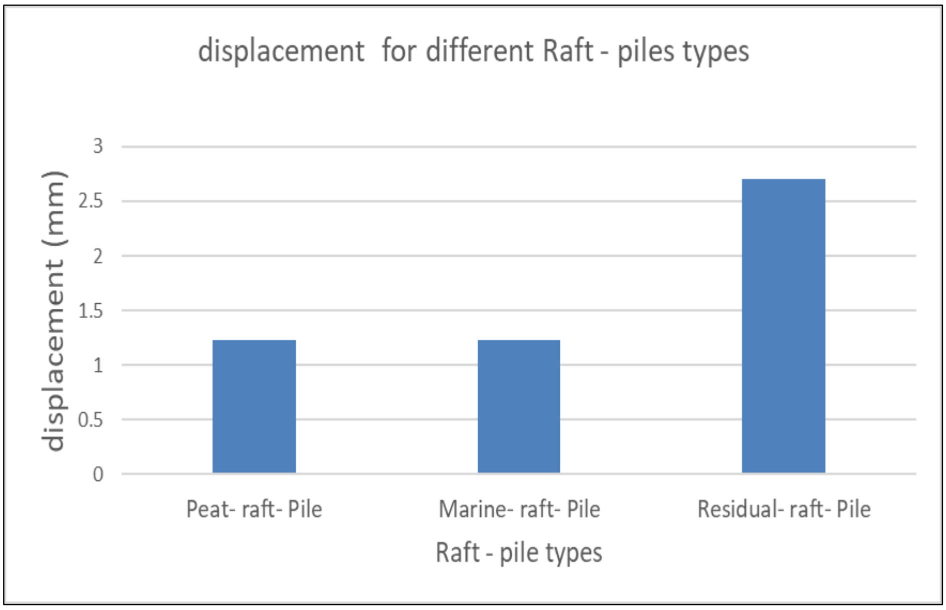


Fig. (11): Displacement values for different Raft- piles types

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

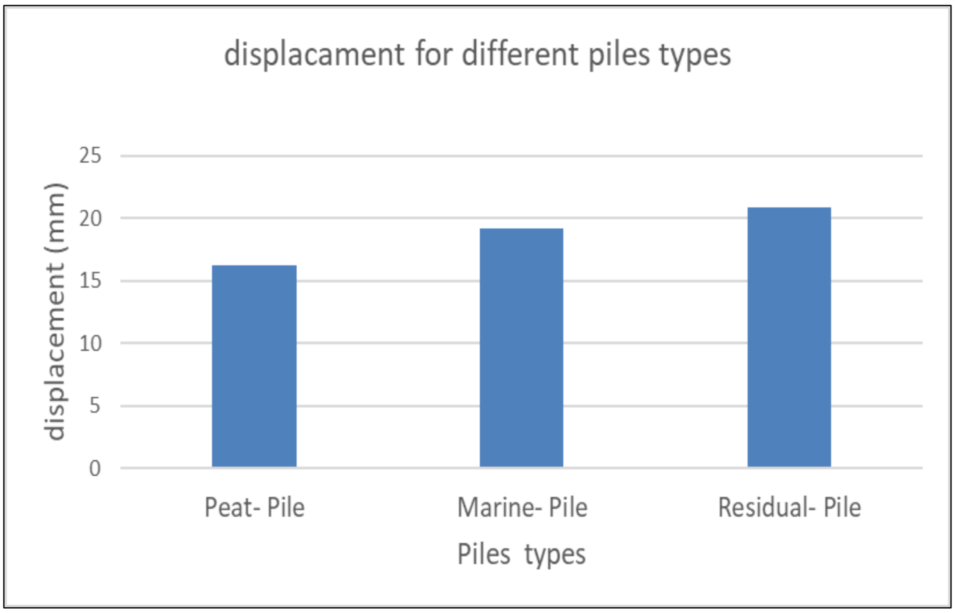


Fig. (12): Displacement values for different Piles- types

From Figures (13, 14, and 15), in case of using Bearing capacity = 50, 100, 150 KPa, by comparing the moment and displacement values for the three systems (peat raft – peat pile – peat raft pile) we found that the moment in both peat raft and peat-pile is very high but in peat raft pile is very small, and in case of settlement the values is very small in the three systems. The moment behavior is nearly in raft types and peat types unlike raft pile types.

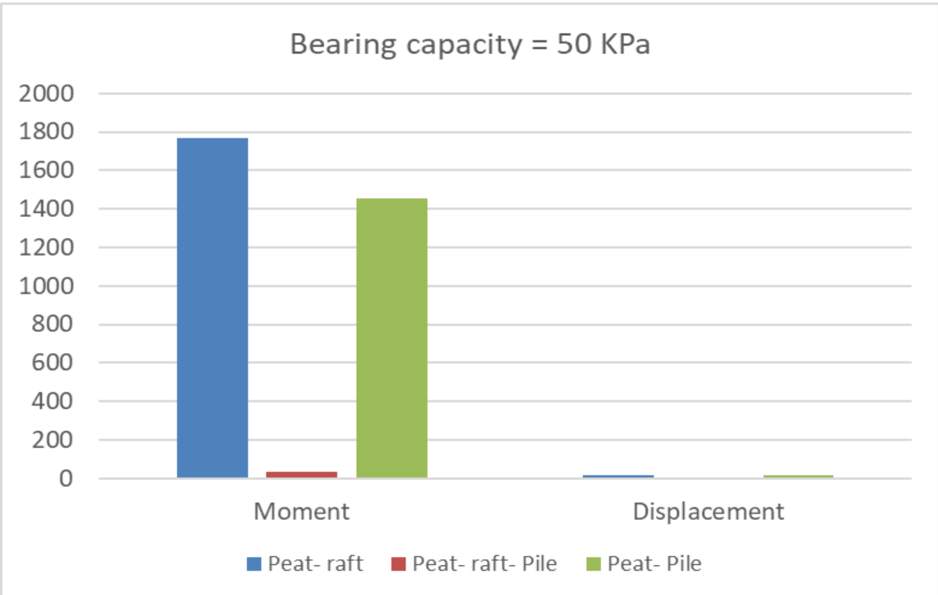


Fig. (13): The values of moment and displacement for the three systems using bearing capacity = 50 KPa

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

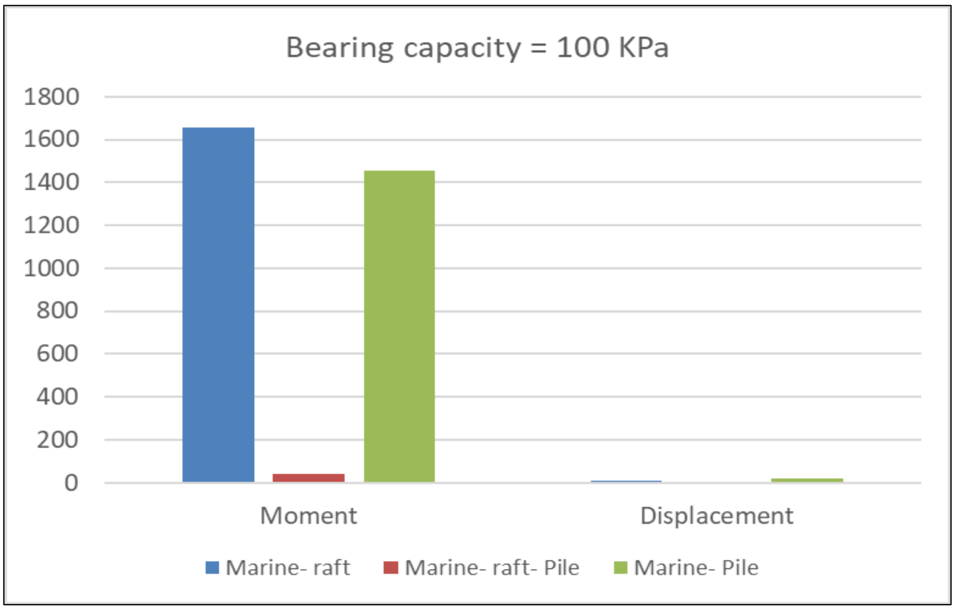


Fig. (14): the values of moment and displacement for the three systems using bearing capacity = 100 KPa

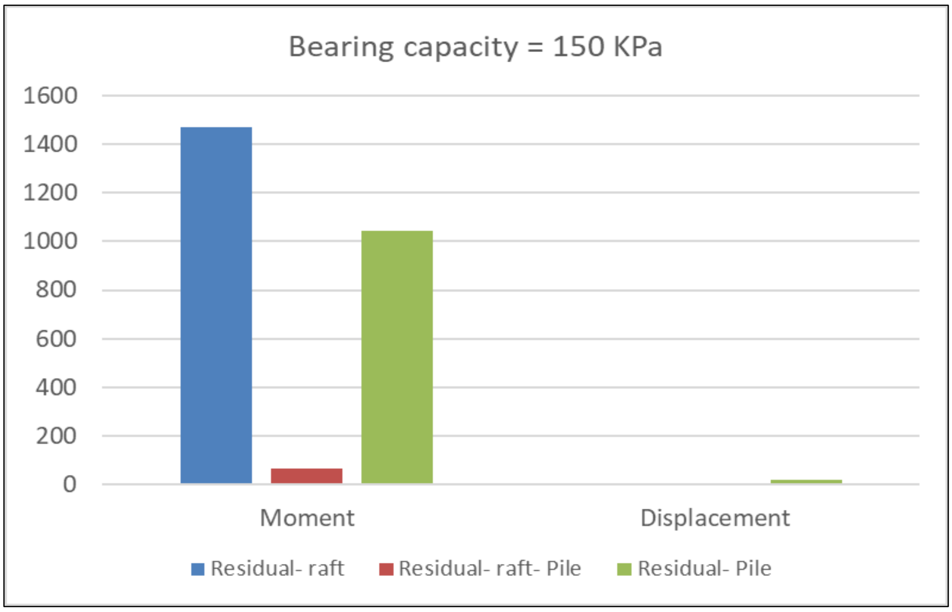


Fig. (15): The values of moment and displacement for the three systems using bearing capacity = 150 KPa

The foundation structure is influenced by the sensitivity of bearing capacity, asrevealed by analysis. As well, in spite of having conformable foundation structures, different soil bearing capacities may lead to differing outputs in terms such as (moment, stress distribution, displacement).

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

4. Conclusions

This study investigated the stability of the tank-foundation system by selecting the suitable foundation system that considers the soil's bearing capacity. three common foundation systems (Raft, pile-raft, & pile) and simulating their behavior under varying soil conditions using three values of bearing capacities (50, 100, 150 KPa). This modeling's are performed using STAAD Foundation Advanced CONNECT V.9 software. To determine sensitivity of the soil bearing capacity to the foundation construction, three types of soils (peat, marine, and residual soil) were used to support the foundation structures. Results showed that the soil bearing capacities affect the values of moment and displacement for all foundation types. In this research, the minimum displacement used as guideline with the results. The conclusions for the study are as the following:

1. Raft foundation type, which has the highest values for moment and medium displacement, is the best foundation type for all tested soils.
2. For the Raft foundation type, peat soil has higher of moment value by 106%, and 120.3% than moment values in marine and residual soils, respectively. Furthermore, the displacement values are higher by 200%, and 321.7% respectively than other soil types (marine and residual).
3. The deformation value, for the Raft type, is allowable and acceptable.
4. For both of (Raft & piles) types, the moment is decreases slightly then decrease by large value unlike (pile-raft type), the moment is increases slightly then increases by large values. The moment behavior is nearly in raft types and piles types unlike pile-raft types.
5. The behavior of displacement 2 Foundation types (pile raft types – piles types) are almost the same. The displacement increases when change the soil type from peat then marine to residual. But, for Raft foundation type the displacement in decreases.

Acknowledgements

First of all, thanks Allah for enabling me to complete this Work. Grateful thanks to the staff of department of civil engineer at Midland Refineriescompany for their help and support.

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

References

[1] J. Atkinson, “The mechanics of soils and foundations”, *CRC press*, 2007. https://doi.org/10.1201/9781315273549

[2] F. Zhu, W. Zhang, W. Dong, and M. Sun, "A new calculation way for the bearing capacity of soft soil foundation", *Advances in Mechanical Engineering*, vol. 9, no. 10, 2017. https://doi.org/10.1177/1687814017732520

[3] D. Sotiriadis, N. Klimis, B. Margaris, and A. Sextos, "Influence of structure–foundation–soil interaction on ground motions recorded within buildings", *Bulletin of Earthquake Engineering*, vol. 17, pp. 5867–5895, 2019. https://doi.org/10.1007/s10518-019-00700-6

[4] De Silva, Filomena, et al. "Non-linear analysis of the Carmine bell tower under seismic actions accounting for soil–foundation–structure interaction", *Bulletin of Earthquake Engineering*, vol. 16, pp. 2775-2808, 2018. https://doi.org/10.1007/s10518-017-0298-0

[5] H. J. Burd, W. N. Yiu, S. Acikgoz, and C. M. Martin, "Soil-foundation interaction model for the assessment of tunnelling induceddamage to masonry buildings", *Tunnelling and Underground Space Technology*, vol. 119, 2022. https://doi.org/10.1016/j.tust.2021.104208

[6] J. Olarte, S. Dashti, and A. B. Liel., "Can ground densification improve seismicperformance of the soil foundation structure system on liquefiable soils", Earthquake Engineering & Structural Dynamics, vol. 47, no. 5, pp. 1193-1211, 2018. https://doi.org/10.1002/eqe.3012

[7] K. Y. Oh, W. Nam, M. S. Ryu, J. Y. Kim, andB. I. Epureanu, "A review of foundations of offshore wind energy convertors: Currentstatus and future perspectives", *Renewable and Sustainable Energy Reviews*, vol. 88, pp. 16-36, 2018. https://doi.org/10.1016/j.rser.2018.02.005

[8] Peng, Bo, et al., "Settlement Calculation Way for Peat Soil Foundations", *InternationalJournal of Geomechanics*, vol. 23, no. 7, 2023. https://doi.org/10.1061/IJGNAI.GMENG-8181

[9] Y. Tang, H. A. Taiebat, and A. R. Russell., "Bearing capacity of shallowfoundations in unsaturated soil considering hydraulic hysteresis and three drainage conditions",*International Journal of Geomechanics*, vol. 17, no. 6, 2017. https://doi.org/10.1061/(ASCE)GM.1943-5622.0000845

[10] R. Ray, P. Samui, and L. B. Roy, "Reliability analysis of a shallowfoundation on clayey soil based on settlement criteria", *Journal of Current Science and Technology*, vol. 13, no. 1, pp. 91-106, 2023. https://doi.org/10.14456/jcst.2023.9

[11] V. Buragadda, and E. R. Orekanti., "Predicting the Allowable Settlement of Reinforced Soil Foundations: A Laboratory Study", *Geotechnical and GeologicalEngineering*, vol. 42, pp. 2271–2291, 2024. https://doi.org/10.1007/s10706-023-02637-9

[12] A. Ads, M. Iskander, and G. Pipin, "Lessons in geomechanics ofdeep foundations from nature",*Acta Geotechnica*, vol. 19, pp. 1421–1434, 2024. https://doi.org/10.1007/s11440-023-01960-y

[13] A. P. N. Bandeira, J. B. de Souza Neto, R. Q. Coutinho, J. M. Xavier, A. M. M. Chaves, and V. L, da Silva Alves, "Investigating the Collapsible Behavior of Sedimentary Soil in Shallow Foundations", *Geotechnical and Geological Engineering*, vol. 42, pp. 2725–2743, 2024. https://doi.org/10.1007/s10706-023-02701-4

[14] B. Aksu Alcan, S. Çelik, "The Effect of Different Fiber Reinforcement onBearing Capacity under Strip Foundation on the Sand Soil: An Experimental Investigation", *Applied Sciences*, vol. 13, no.

Open Access
Vol. 15, No. 2, June 2025, pp. 195-211

P- ISSN: 2220-5381
E- ISSN: 2710-1096

17, p. 9769, 2023. https://doi.org/10.3390/app13179769.

[15] G. D. Skinner, and R. K. Rowe, "Experimental study on the load bearing behavior of geosynthetic reinforced soil bridge abutments on yielding foundation", *Geotextiles and Geomembranes*, vol. 23, no. 3, pp. 234-260, 2023. https://doi.org/10.1016/j.geotexmem.2004.10.001.

[16] M. A. Lupunga, L. Huang, and H. Li, "Foundation Treatment, Reinforcement and Design Optimization for Oil Storage Tanks at TAZAMA Pipelines Limited (Ndola, Copperbelt Province, Zambia)", *Technium*, vol. 21, pp. 1-37, 2024. https://doi.org/10.47577/technium.v21i.10870.

[17] R. Lukpanov, D. Tsygulyov, Z. Zhantlessova, A. Altynbekova, S. Yenkebayev, and M. Kozhahmet, "Selection of Equivalent Material for Soil Testing Using Piles on a Scale Model Testing Apparatus", *INTERNATIONAL JOURNAL OF GEOMATE*, vol. 26, no. 117, pp. 11–18, May 2024.

[18] M. O. Karkush, and A. N. Aljorany, "Analytical and numerical analysis of piled-raft foundation of storage tank", *Construction in Geotechnical Engineering: Proceedings of IGC 2018*, vol. 84, pp. 373-384, Springer Singapore, 2020. https://doi.org/10.1007/978-981-15-6090-3_26

[19] M. O. Karkush, N. A. Ala, "Numerical evaluation of foundation of digester tank of sewage treatment plant", *Civil Engineering Journal*, vol. 5, no. 5, pp.996-1006, 2019. http://dx.doi.org/10.28991/cej-2019-03091306

[20] M. O. Karkush, and Z. A. Kareem, "Investigation of the impacts of fuel oil on the geotechnical properties of cohesive soil", *Engineering Journal*, vol. 21, no. 4, pp.127-137, 2017. https://doi.org/10.4186/ej.2017.21.4.127

[21] M. O. Karkush, and M. S. Abdulkareem, "Deep remediation and improvement of soil contaminated with residues oil using lime piles", *International Journal of Environmental Science and Technology*, vol. 16, no. 11, pp.7197-7206, 2019. https://doi.org/10.1007/s13762-019-02244-3

[22] M. O. Karkush, and T. A. Al-taher, "Remediation of contaminated soil of Thi-Qar oil refinery plant", In *Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering*, vol. 1, 2017.