Analysis of Factors Affecting the Performance of Dynamic Compaction Technique: A Study of Coastal Area of Eastern Province in Saudi Arabia

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Abstract

Coastal areas of the Eastern Province of Saudi Arabia have soil with low bearing capacity due to saturation with water, high contents of salt and inclusion of organic materials. The dynamic compaction (DC) technique, which is the most prevalent method for soil improvement in the area has not been effective in terms of cost, safety, and serviceability of the buildings. Thus, this paper aims to identify and assess the factors that prevent the efficient soil improvement performance using dynamic compaction technique. The desktop search and expert-based survey were used for data collection while the Analytic Hierarchy Process (AHP) was employed to analyze and prioritize the factors. The results indicate “difficulty in using the DC technique within 30m from buildings and 15m from underground services” as the most crucial factor. Above all, the practical and managerial implications implied in this paper are targeting a more efficient DC technique for soil improvement particularly in coastal areas of the Eastern Province of Saudi Arabia with expansive spread of Sabkha soil. Thus, the findings are expected to provide support to policy and decision makers in overcoming the performance shortfalls of DC technique.

Keywords: Analytic Hierarchy Process; Buildings; Dynamic compaction; Soil improvement; Sustainable construction

1 Introduction

The Vision 2030 of the Kingdom of Saudi Arabia driven by the National Transformation Plan has been the backbone of remarkable socio-economic transformation being witnessed in the Kingdom (Kumar & Albashrawi, 2022; Alshihri et al., 2022). The transformation plan pushes the agenda of transforming Saudi

Arabia into a major economic powerhouse and lays the groundwork for the country's shifts towards post hydrocarbon era (Sodangi, 2022; Balabel & Alwetaishi, 2021). In line with this, the construction sector being an integral component of this transformation plan, is projected to deliver by the year 2030, over 500,000 residential buildings, about 6,000,000 m² of new office space, and over 4,000,000 m² of retail space (Vision, 2030, 2022). Thus, to set the ball rolling, various giga projects like the futuristic NEOM city and other infrastructure projects worth over $1 trillion have been duly initiated across all regions in the Kingdom since the inception of the transformation plan in 2016 (Vision 2030, 2022). This inarguably positions the country as one of the biggest global construction sites.

For many decades now, building construction in the coastal areas of the Eastern Province of Saudi Arabia and the Arabian Gulf region in general have been tremendously plagued by the presence of low bearing capacity soils that are highly saturated with water and have high salt content and organic materials (Kazmi & Sodangi, 2021). Not that alone, incessant changes in groundwater table, extensive spread of problematic Sabkha soil, and ineffective earthwork techniques lead to high cost and time overruns during the construction stage while end-users of the buildings are exposed to the dangers of building failure and settlement, which are hurriedly remedied by inefficient, costly, and time-consuming repairs (Kazmi & Sodangi, 2021).

The study area for this paper is Dammam; a coastal city located in the Eastern Province of Saudi Arabia, which encompasses a total land area of 800 km² and a population of about 1.3 million (Almulhim & Aina, 2022). The city being Saudi Arabia's nerve centre for oil businesses and capital of the Eastern Province has been witnessing massive expansion in the construction of residential buildings, basic social and industrial infrastructure due to exponential economic and population growths (AlQahtani et al., 2022). Accordingly, the areas very close to the coastal line being the most preferred by clients and end-users have over the years become a beehive of new construction projects (AlQahtany & Abubakar, 2020). Nonetheless, the massive increase in the number of construction projects in these areas could be equally attributed to the continuous drive in achieving the objectives of the Kingdom's ambitious Vision 2030.

Many residential and industrial areas along the coastal line of Dammam city are affected by the wide spread of Sabkha soil, which is problematic to new construction projects as well as existing buildings in the areas due to its high water and salt contents, loose density, and high compressibility that necessitate ground improvement (Kazmi & Sodangi, 2021). While there are various soil improvement techniques that are utilized for ground improvement in these areas, remarkably, the dynamic compaction (DC) technique has been the most prevalent over the years. However, this technique has been noted to be grossly ineffective in terms of costs savings, safety, and serviceability of the buildings (Alimohammadi et al., 2022). Thus, this study will seek to determine and assess the factors that prevent the efficient soil improvement performance using dynamic compaction technique as evidence from the literature (Alimohammadi et al., 2022; Majik & Savoikar, 2022; Yao et al., 2022; Abdel-Rahman, 2021; Ghorbani et al., 2020; Li et al., 2020; Wu et al. 2020; Zhou et al., 2020; suggests that previous attempts have been made to empirically identify these factors, however, the studies have been mainly based on fragmented perspectives. Above all, the outcomes of the study are expected to provide support to policy and decision makers in overcoming the performance shortfalls of this soil improvement technique.

2 Literature Review

The built environment consists of different structures constructed on various types of soils. While some of these soils are non-problematic and appropriate for building construction in their natural form, other soils are considered problematic as they require significant improvement to be appropriate for construction purposes and withstand the loads imposed on them. For instance, prior to the construction phase, problematic soil like Sabkha requires special treatment due to its high water and salt contents, low shear strength, low bearing capacity, and loose density to prevent causing damages that impair the structural integrity of buildings constructed on it.

Although several soil improvement techniques are utilized in building construction in the coastal areas of Dammam (Figure 1), the dynamic compaction (DC) approach is notably the most widely used over the past few decades (Alnaim et al., 2022). This is not surprising because of the technique's economic advantage, which makes the total costs involved relatively low as material addition or soil replacement are not required and simple equipment are used during the compaction, which shortens the duration. Not that alone, the DC technique is prominent among construction practitioners in the area considering its ability to enhance strength and bearing capacity of the soil while lowering the hydraulic conductivity of the soil.

Fig. 1: Soil Improvement Techniques

However, DC technique has some major shortfalls despite its notable advantages over other soil improvement techniques. For instance, there are many cases where building users, after few years of occupancy, are subjected to untold hardships associated with costly repairs due to serious damages that threaten safety of the buildings and its users (Alimohammadi et al., 2022).

Table 1: Review of factors preventing the efficient soil improvement performance of dynamic compaction technique

Factors	References
• Damage to surrounding structures due to vibrations	Yao et al. (2022); Abdel-Rahman (2021); Ghorbani et al. (2020); Wu et al. (2020)
• Serious danger when applied cohesive soils	Alimohammadi et al. (2022); Majik & Savoikar (2022); Wu et al. (2020)
• Inappropriate for expansive, organic, or clayey soil with low hydraulics conductivity	Li et al. (2020); Ghorbani et al. (2020); Zhou et al. (2020)
• Not suitable for construction sites that are underlain by landfills & soil layer that suffered from large settlements	Alimohammadi et al. (2022); Abdel-Rahman (2021); Ghorbani et al. (2020)
• Difficult to use within 30m from buildings & 15m from underground services.	Yao et al. (2022)
• Unsuitable when water depth is less than 1.5m	Yao et al. (2022); Ghorbani et al. (2020); Li et al. (2020)
• Inappropriate for soft cohesive soils located in the upper part of the compaction	Abdel-Rahman (2021); Zhou et al. (2020); Wu et al. (2020)

On the other hand, the Scopus database was used during the literature search to extract available journal articles that are peer-reviewed and empirically associated with the factors that prevent the efficient soil improvement performance of the dynamic compaction technique (Table 1). Essentially, the rationale for using peer-reviewed articles was to ensure that only authentic studies were retrieved, and the Scopus database provides a much quicker indexing process that improves the prospects of gathering available articles that are closely related to the present study being reported in this paper. While there are several existing studies on examining the disadvantages and challenges associated with the DC technique for improving the ground condition for construction purposes, the studies have been generally on buildings and structures constructed in non-coastal areas. Thus, the outcomes are primarily peculiar and may not be relevant and applicable for improving the efficiency of DC technique in coastal areas like Dammam city due to the peculiarity of the Sabkha soil spread in the area. Considering the poor attributes of the problematic Sabkha soil present in Dammam city, it became pertinent to investigate the factors that affect the efficiency of the DC technique for improving ground condition for construction purposes.

3 Methods

In this section, the techniques that were used to attain the goal of this paper are presented. Most importantly, the desktop search was utilized to review the relevant literatures and to identify factors that prevent the efficient soil improvement performance of DC technique. Subsequently, the authors deemed it is necessary to further consolidate the desktop search findings by improving the authenticity and wider applicability of the findings through an expert-based evaluation survey while Analytic Hierarchy Process (AHP) would be employed to analyze and prioritize the factors.

3.1 Expert-based Evaluation of the Adoption Factors

The expert-based survey was meticulously designed to focus on geotechnical engineers that are actively involved in soil improvement for construction projects in coastal areas of Dammam City.

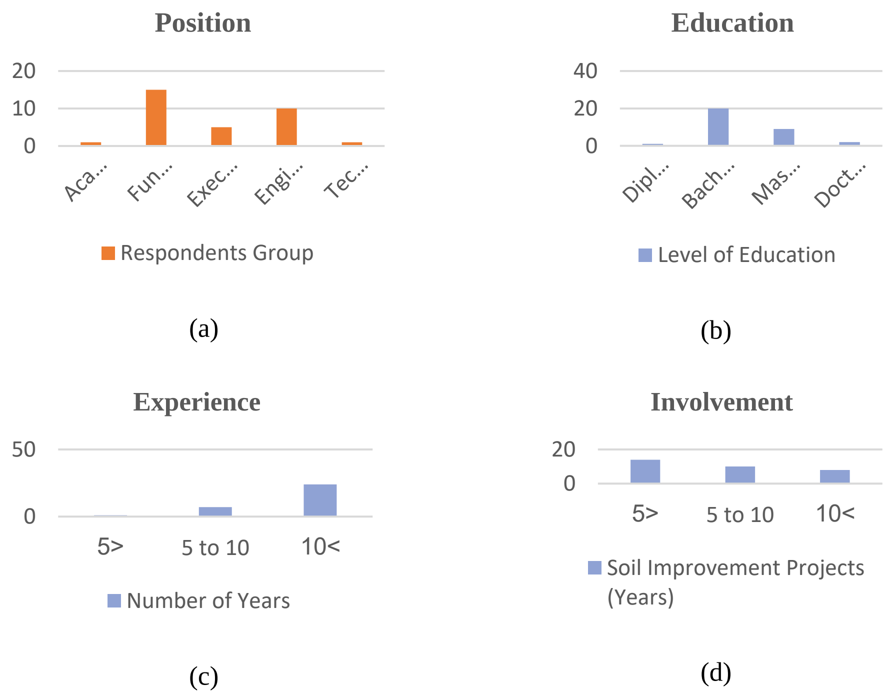

Fig. 2: Demographics and the characteristics of respondents

The list of the experts was generated using judgmental sampling to ascertain that only geotechnical practitioners that fit the requirements were invited to participate in the survey (Makoye et al., 2022). Remarkably, out of the entire 50 questionnaires that were administered, 32 complete responses were received, which are adequate for a study of this nature (Sodangi & Kazmi 2021).

3.2 The Analytical Hierarchy Process (AHP)

Essentially, the AHP was utilized in this study as one of the decision-making techniques to establish the importance weights of alternatives, which would be converted into a structural ranking order. The rationale for the selection of this technique is the ease with which it can be used to form a hierarchal structure of a given set of criteria. While utilizing experts' judgments ensures achieving an ideal solution; reaching out to the experts helps to mitigate the risk of using this technique.

The pairwise was generated using the collected data from 32 respondents which evaluates the factors on a scale from 1-5, where 1 = Very Low and 5 = Very High. The experts were requested to rate the effects of each factor on the performance of DC as a soil improvement technique in the coastal areas of the Eastern province of Saudi Arabia. To start with, the experts examined the importance and general impact of each factor obtained from the review of the relevant literatures and merged similar factors together. Subsequently, other factors that were mainly unique to soil improvement using DC technique in Dammam city which were not obtained from the desktop search were included by the experts. A list of six factors was generated as shown in Table 3 below:

Table 3: List of Factors

Factor Code	Description
F1	Inhibits vegetation growth
F2	Destabilizes the surrounding infrastructure due to strong vibration
F3	Disturbs surface & sub-surface flow of water
F4	Inappropriate where water depth is less than 1.5m.
F5	Difficult to use within 30m from buildings and 15m from underground services
F6	Unsuitable where soft cohesive soils are located in the upper part of the compaction

Furthermore, the pairwise generation was performed automatically by converting the raw data into AHP scale and then generating pairwise comparisons accordingly. Based on the procedure of pairwise comparison in AHP as described by Saaty and Sagir (2009), the comparisons are based on a scale from 1-9. Thus, the raw data needs to be converted from scale 1-5 into scale 1-9. The conversion process utilizes a systematic conversion equation (Eq. 1) that can be used to interchange between the two scales as shown in Table 4.

The conversion of raw data to 1-9 scales transforms the evaluations of participants into the scale recommended by Saaty (1970). However, the implementation of AHP requires the generation of pairwise comparison to evaluate the weights for each factor (i) from each decision maker (k). Equation 2 allows the generation of pairwise comparison between two factors (i.e., i and j) using their respective 1-9 scales given by decision maker (k).

$$X_{ik} = 2 \times Y_{ik} - 1 \qquad (1)$$

where,

X_{ij} represent the values in scale 1 to 9.

Y_{ij} represent the values in scale 1 to 9.

i represents the factor.

k represents the decision maker.

Table 4: Results of the conversion between the two scales

Y_{ij}	1	2	3	4	5
X_{ij}	1	3	5	7	9

$$P_{ijk} = \begin{cases} \frac{X_{ik}}{X_{jk}}, if\ mod\big(\max(X_{ik}, X_{jk}), \min(X_{ik}, X_{jk})\big) = 0 \\ 2^m, if\ mod\big(\max(X_{ik}, X_{jk}), \min(X_{ik}, X_{jk})\big) \neq 0;\ where, m = \begin{cases} -1, & X_{ik} < X_{jk} \\ 0, & X_{ik} = X_{jk} \\ 1, & X_{ik} > X_{jk} \end{cases} \end{cases} \quad (2)$$

After generating the pair wise comparisons, the following AHP procedure is used to calculate the weight score of the evaluation from each decision maker using the equations (3)-(5):

1. Calculate the sum of each column

$$\sum_{j=1}^{j=n} X_{ijk} \quad (3)$$

2. Calculate the normalized values by dividing each value by the sum of its respective column

$$r_{ijk} = \frac{X_{ijk}}{\sum_{j=1}^{j=n} X_{ijk}} \quad (4)$$

3. Calculate weight of each factor by averaging the normalized values of pairwise comparison

$$W_{ik} = \frac{\sum_{i=1}^{i=n} r_{ijk}}{n} \quad (5)$$

The AHP calculation procedure is repeated to calculate the weights provided by all respondents. Eq. (6) is used to calculate the total weight of each factor and to rank all factors in descending order

$$Wi = \frac{\sum_{k=1}^{k=m} W_{ik}}{m} \quad (6)$$

4 Results

The AHP results obtained are presented and discussed in this section. The AHP results include the importance weights and ranks of the factors that prevent the efficient soil improvement performance of dynamic compaction technique. Using the AHP, the six factors were prioritized based on their importance weights as shown in Table 5. The results indicate that the difficulty of using DC where buildings are within a radius of 30 m and underground services are on a depth of 15 m or less (Factor # 5), which represents the main challenges for practitioners. Also, it indicates that the existence of soft cohesive soils on the upper part of compaction (Factor 6) has a considerable effect on the implementation of DC techniques. On the other hand, the disturbs of flow of water (Factor # 3) represents the factor that has the least effects on the implementation of DC technique in improving the soil. Also, the possibility of destabilizing the surrounding infrastructure due to the strong vibration (Factor # 2) has relatively low impact on the implementation of DC techniques. Nevertheless, the inhabitation of vegetation growth (Factor #1) and appropriateness when water table is in a depth of 1.5m or less (Factor #4) has average impact on the implementation of DC technique. Finally, the results highlight the importance and criticality of each factor on implementing the DC technique for soil improvement in under-developed coastal areas where cohesive/organic materials are existing on the upper part of the soil.

While the objective of this study has been accomplished, it is essential to underline the limitations of this paper. The study adopted a judgmental sample, which may seem small. However, a specialized study of this nature requires authentic responses from participants who are experts in the subject. Not that alone, examining a much larger sample size would be complicated and could result in findings that are ambiguous, unreliable, and invalid. Thus, the opinions and judgment of the experts involved in this study were considered reliable and authentic owing to their sheer proficiency in the practice of soil improvement for construction purposes, which in turn adds validity to the findings of the paper. Notwithstanding the aforementioned limitations, the factors evaluated and prioritized in this study symbolize the judgments of experts in ground improvement for construction projects in Saudi Arabia. However, there is a need for future research works to ensure that the findings reported in this paper are empirically validated.

Table 5: Weighting and Ranking Results

	Weights of Factors					
DM#	W1	W2	W3	W4	W5	W6
DM1	0.221	0.221	0.074	0.044	0.221	0.221
DM2	0.23	0.23	0.046	0.033	0.23	0.23
DM3	0.028	0.25	0.083	0.139	0.25	0.25
…	…	…	…	…	…	…
DM31	0.342	0.038	0.049	0.114	0.342	0.114
DM32	0.359	0.04	0.051	0.12	0.359	0.072
Weights	**0.168**	**0.136**	**0.119**	**0.141**	**0.231**	**0.205**
Rank	**3**	**5**	**6**	**4**	**1**	**2**

5 Conclusion

This paper determined and assessed the factors that prevent the efficient soil improvement performance using dynamic compaction technique in the coastal areas of the Eastern Province of Saudi Arabia. The expert-based survey was deployed to strengthen the factors identified in the literature review while the AHP was used for analysis and prioritization of the factors. The results indicate that the most crucial factors are “difficulty in using the DC technique within 30m from buildings and 15m from underground services” and the DC technique is unsuitable where soft cohesive soils are located in the upper part of the compaction. The outcomes of this paper provide thorough understanding of the factors affecting the efficiency of soil improvement performance using dynamic compaction technique. The outcomes can be applied to overcome the effects of these factors as well as to promote efficiency of the DC soil improvement technique. Above all, the practical and managerial implications implied in this paper are targeting more efficient DC technique for soil improvement particularly in coastal areas of the Eastern Province of Saudi Arabia with expansive spread of Sabkha soil. Thus, the findings are expected to be utilized to provide support to policy and decision makers in overcoming the performance shortfalls of DC technique. Although the findings of this paper are largely based on problems related to building construction in coastal areas of the Eastern Province of Saudi Arabia, the outcomes could as well be appropriate and valid to other residential areas along the coastal line of other countries in the Middle East.

References

Abdel-Rahman, M. M. (2021). "Review of Soil Improvement Techniques". In: Shehata, H., Badr, M. (eds) Advancements in Geotechnical Engineering. Sustainable Civil Infrastructures. Springer, Cham. https://doi.org/10.1007/978-3-030-62908-3_14

Alimohammadi, H., Amirmojahedi, M. & Tahat, J. N. (2022). "A Case History of Application of Deep Compaction Method with Comparison to Different Ground Improvement Techniques". *Transportation Infrastructure Geotechnology*. https://doi.org/10.1007/s40515-022-00229-3

Almulhim, A.I. & Aina, Y.A. (2022). "Understanding Household Water-Use Behavior and Consumption Patterns during COVID-19 Lockdown in Saudi Arabia". *Water, 14,* 314. https://doi.org/10.3390/w14030314

Alnaim, A. et al. (2022). "A Systematic Framework for Evaluating the Effectiveness of Dynamic Compaction (DC) Technology for Soil Improvement Projects Using Cone Penetration Test Data". *Applied Sciences*, 12, 9686. https://doi.org/10.3390/app12199686

AlQahtany, A. M. et al. (2022). "Land Reclamation in a Coastal Metropolis of Saudi Arabia: Environmental Sustainability Implications". *Water, 14,* 2546. https://doi.org/10.3390/w14162546

AlQahtany, A.M. & Abubakar, I. R. (2020). "Public perception and attitudes to disaster risks in a coastal metropolis of Saudi Arabia". *International Journal of Disaster Risk Reduction, 44,* 101422.

Alshihri, S., Al-Gahtani, K. & Almohsen, A. (2022). "Risk Factors That Lead to Time and Cost Overruns of Building Projects in Saudi Arabia". *Buildings, 12,* 902. https://doi.org/10.3390/buildings12070902

Balabel, A. & Alwetaishi, M. (2021). "Towards Sustainable Residential Buildings in Saudi Arabia According to the Conceptual Framework of Mostadam Rating System and Vision 2030". *Sustainability, 13,* 793. https://doi.org/10.3390/su13020793

Ghorbani, J., Nazem, M. & Carter, J. P. (2020). "Dynamic compaction of clays: Numerical study based on the mechanics of unsaturated soils." *International Journal of Geomechanics, 20*(10), 04020195. https://doi.org/10.1061/(ASCE)GM.1943-5622.0001840

Kazmi, Z.A. & Sodangi, M. (2021). "Integrated Analysis of the Geotechnical Factors Impeding Sustainable Building Construction-The Case of the Eastern Province of Saudi Arabia." *Sustainability, 13,* 6531. https://doi.org/10.3390/su13126531

Kumar, V. & Albashrawi, S. (2022). "Quality Infrastructure of Saudi Arabia and Its Importance for Vision 2030." *MAPAN 37*, 97–106 (2022). https://doi.org/10.1007/s12647-021-00523-4

Li, X. et al. (2020). "New Method to Evaluate Strengthen Efficiency by Dynamic Compaction." *International Journal of Geomechanics, 20*(4), p.04020024. https://doi.org/10.1061/(ASCE)GM.1943-5622.0001586

Majik, R. K. & Savoikar, P. P. (2022). "Ground modification techniques for deep soft soils sites in Goa region." *Lecture Notes Civil Engineering, 152*, 409 - 421. https://doi.org/10.1007/978-981-16-1831-4_38

Makoye, M., Mlinga, R. S. & Ndanshau, M. O. A. (2022). "Impact of macroeconomic factors on performance of construction industry in Tanzania." *International Journal of Construction Management*. https://doi.org/10.1080/15623599.2022.2084259

Saaty, T. L. & Sagir, M. (2009). "Extending the measurement of tangibles to intangibles." *International Journal of Information Technology & Decision Making (IJITDM), 8*(01), pages 7-27. https://doi.org/10.1142/S0219622009003247

Sodangi, M. (2022). "Towards attaining efficient joint ventures in international construction: the case of Saudi Arabia".

Engineering, *Construction and Architectural Management*, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/ECAM-07-2021-0647

Vision 2030, (2022). “The Progress & Achievements of Saudi Arabia. *Vision 2030 Kingdom of Saudi Arabia*.” Available at: https://www.vision2030.gov.sa/ (Accessed: November 18, 2022).

Wu, S. et al. (2020). “Dynamic compaction of a thick soil-stone fill: Dynamic response and strengthening mechanisms.” *Soil Dynamics and Earthquake Engineering, 129,* 105944. https://doi.org/10.1016/j.soildyn.2019.105944

Yao, Z. et al. (2022). “Effect of dynamic compaction by multi-point tamping on the densification of sandy soil”. *Computers and Geotechnics*, *151*, p.104949. https://doi.org/10.1016/j.compgeo.2022.104949

Zhou, C. et al. (2020). “Evaluation of dynamic compaction to improve saturated foundation based on the fluid-solid coupled method with soil cap model”. *Computers and Geotechnics, 125*, 103686. https://doi.org/10.1016/j.compgeo.2020.103686

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