Effects of Long-Term Soaking on the Load-Bearing Capacity of Bitumen-Treated Saline Sabkha Soil Subgrade

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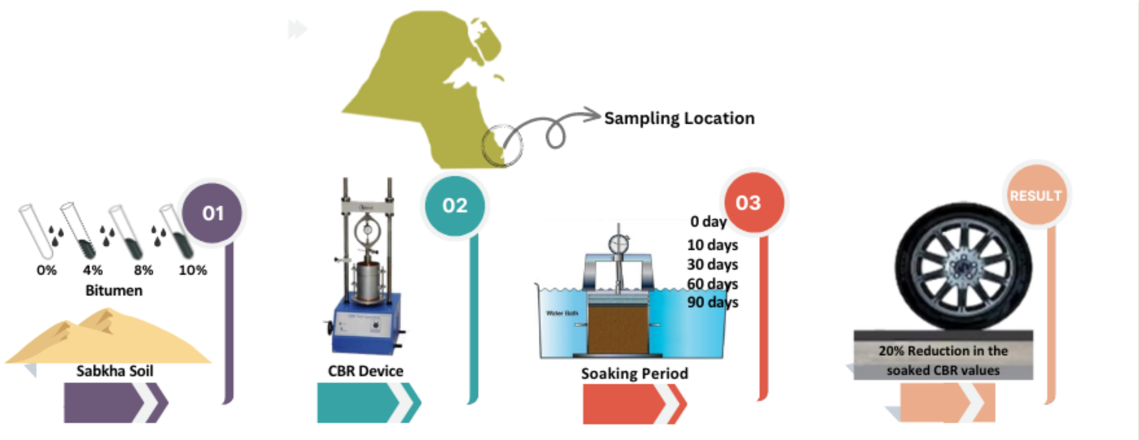

ABSTRACT: This study delves into the potential of using modified sabkha soil, a low-quality material, as a cost-effective solution for road construction in Kuwait, a country grappling with resource limitations. The research evaluates the effects of adding different percentages of bitumen (0%, 4%, 8%, and 10%) to sabkha soil samples, specifically looking at their load-bearing capacity under long-term soaking conditions. The findings indicate that adding up to 8% bitumen enhances the soil's geotechnical properties and its load-bearing capacity. However, any further addition leads to a decline in these properties. Importantly, the soil's load capacity shows significant improvement under soaked conditions. These encouraging laboratory results suggest that utilizing waste sabkha soil could pave the way for effective soil waste management techniques, thereby addressing environmental concerns related to sabkha soil disposal.

الملخص: هٰذِهِ الدِراسَةُ تَسْتَكْشِفُ إِمْكانِيَّةَ اِسْتِخْدامِ التُرْبَةِ السَبْخِيَّةِ المُعَدَّلَةِ، وَهِيَ مادَّةٌ مُنْخَفِضَةُ الجَوْدَةِ، كَبَدِيلٍ فَعّالٍ مِن حَيْثُ التَكْلِفَةُ لِبِناءِ الطُرُقِ فِي الكُوَيْتِ، وَهِيَ دَوْلَةٌ تُواجِهُ قُيُوداً فِي المَوارِدِ. البَحْثُ يُقِيمُ تَأْثِيرَ إِضافَةِ نِسَبٍ مُتَفاوِتَةٍ مِنْ البيتومين (0%، 4%، 8%، وَ10%) إِلَى عَيِّناتِ التُرْبَةِ السَبْخِيَّةِ عَلَى قُدْرَتِها عَلَى تَحَمُّلِ الأَحْمالِ تَحْتَ ظُرُوفِ النَقْعِ طَوِيلَةِ الأَمَدِ. تُشِيرُ النَتائِجُ إِلَى أَنَّ إِضافَةَ ما يَصِلُ إِلَى 8% مِنَ البيتومين يُحَسِّنُ خَصائِصَ التُرْبَةِ الجِيُوتَقَنِيَّةِ وَقُدْرَتَها عَلَى تَحَمُّلِ الأَحْمالِ، بَيْنَما تُؤَدِّي الإِضافَةُ الإِضافِيَّةُ إِلَى التَدَهْوُرِ. بِشَكْلٍ مَلْحُوظٍ، تَحَسَّنَتْ قُدْرَةُ التُرْبَةِ عَلَى تَحَمُّلِ الأَحْمالِ بِشَكْلٍ كَبِيرٍ تَحْتَ ظُرُوفِ النَقْعِ، مَعَ اِنْخِفاضِ مُعَدَّلِ تَخْفِيضِ قِيَمِ CBR المَنْقُوعَةِ تَحْتَ ظُرُوفِ النَقْعِ طَوِيلَةِ الأَمَدِ مِن 90% لِلتُرْبَةِ الطَبِيعِيَّةِ إِلَى أَقَلَّ مِن 18% لِلتُرْبَةِ الَّتِي تَحْتَوِي عَلَى 10% بيتومين. تُشِيرُ هٰذِهِ النَتائِجُ المُشَجِّعَةُ فِي المُخْتَبَرِ إِلَى أَنَّ اِسْتِخْدامَ التُرْبَةِ السَبْخِيَّةِ النِفايَةِ قَدْ يُؤَدِّي إِلَى تِقْنِيّاتٍ فَعّالَةٍ لِإِدارَةِ النُفاياتِ التُرْبِيَّةِ، مُعالَجَةً بِذٰلِكَ المَشاكِلَ البِيئِيَّةَ المُرْتَبِطَةَ بِالتَخَلُّصِ مِنَ التُرْبَةِ السَبْخِيَّةِ.

Keywords: Physical Soil Analysis; Compaction; Sabkha Soil; California Bearing Ratio; Soaked; Bitumen.

الكلمات المفتاحية: تحليل التربة؛ دمك ؛ التربة السبخية؛ نسبة تحمل كاليفورنيا ؛ النقع ؛ بتيومين.

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1. INTRODUCTION

Kuwait is located on the northwest corner of the Arabian Gulf, as shown in Fig (1). The country is undergoing a major expansion in its transport infrastructure; new highways and roads are already being built or included in medium- and long-term development plans. Owing to the country's small area of 17,818 km^2 and its limited natural soil resources, the shortage of soil resources suitable for construction could pose a major problem in the future. Available, suitable natural soil resources for construction must be managed sustainably to rehabilitate degraded land using proper restoration techniques (Ahmed, 2021).

Figure 1. Map of the study area in southern Kuwait.

Salt-encrusted sabkha flats that extend along Kuwait's northern and southern coasts are considered waste material because of their poor geotechnical properties and significant challenges to land development plans. Under dry conditions, the compacted sabkha soil has good geotechnical properties such as shear strength and California bearing ratio (CBR). However, the shear strength parameters and CBR values deteriorate upon soaking (Elsawy and Lakhouti, 2020). Sabkha soil is problematic because it collapses upon wetting owing to the dissolution of cementing materials, such as gypsum, carbonate, and chloride (Ismael, 1993, Al-Shenawy, 2021), between soil particles. Several studies carried out by Al-Otaibi (2020a and 2020b) indicated their problematic behaviour due to leaching. The continuous water flow increases the dissolution of the salts and reduces their geotechnical properties. There exists a direct relationship between long-term permeability and the rate of salt dissolution (Al-Otaibi and Wegian, 2012). The main dissolute salts are those containing calcium (Ca^{2+}), sulfate (SO_4^{2-}), chloride (Cl^-), magnesium (Mg^{2+}), and sodium (Na^+) Al-Otaibi et al. (2012). The lack and the high cost of bulk-fill construction materials in Kuwait make upgrading and utilizing waste sabkha soil imperative. This has the double advantage that waste materials can be reused, and waste-disposal problems are reduced while improving the sustainability of the environment. Modifying sabkha soil will conserve natural resources for the future, thereby meeting a part of the main sustainable development goals for the world as proposed by the United Nations in 2015.

Stabilization of the problematic subgrade soil is considered a sustainable solution for road construction, and it depends on the required strength characteristics (Sarsam, 2021). Bitumen stabilization is generally accomplished using bitumen, cut-back bitumen, bitumen emulsion, or foamed bitumen additives. The suitable type of bitumen for stabilizing the soil is selected depending on the soil type, construction method, and weather conditions (USACE, 1984). Adding viscous materials to sabkha soil increases soil cohesion (Asi et al., 2002, Al-Otaibi and Aldaihani, 2018). Hence, the viscosity of the bitumen materials modifies the compaction and shear characteristics of the treated sabkha soil (Al-Otaibi and Aldaihani, 2018). The feasibility of reducing the undesirable characteristics of sabkha soil under soaked conditions will allow these materials to recycle and reduce the environmental problems that result from the disposal of these materials.

Thus, the above discussion clarifies that sabkha soils cannot be used for road construction in their natural conditions because of their undesirable characteristics in submerged conditions, such as low bearing capacity, low strength, excessive plasticity, and a tendency to shrink or swell. The traditional way of dealing with sabkha soil is to excavate it up to a certain depth and discard it as waste materials. This treatment is considered problematic because of the high costs and environmental reasons, as Kuwait has some of the world's highest dust precipitation rates (Al-Dousari et al., 2014). The wide variations of sabkha soil constituents and variable and complex behaviour necessitate continuous searching for the improvement of these materials.

This study evaluated the bitumen sabkha soil as a construction material for subgrade in road construction. For this purpose, the load-bearing capacity of sabkha soil samples from southern Kuwait mixed with different amounts of bitumen was examined in terms of their CBR values. Considering these soils' collapsibility upon soaking, their behaviour under soaking for 10, 30, 60, and 90 days was examined in the experiments. These periods were selected to simulate the field conditions during heavy rains that might lead to waterlogging.

2- MATERIAL AND METHODS

2.1 Soil Sampling

The soil samples for the experiment came from the location shown in Fig (1), a region previously surveyed by Al-Otaibi (2020a and 2020b). The field-sampling location is within scattered sabkha flats in the southern coastal area of Kuwait. The area of the target location, number of samples taken, sampling size, and depth was based on previous soil surveys carried out by Al-Otaibi (2020a and 2020b) for this area. More than 16 soil samples were collected at 10 m intervals based on a grid distribution that covered the study area of 900 m². The sampling process was carried out in November 2020, during the hot season when the sabkha surface is dry and the ground is stable because of the salt cementation effect. Figures (2) and (3) show the photographs of the sampling location recorded during site visits and during the summer and winter seasons, respectively.

Figure 2. Site conditions of the sampling location during the summer season.

Figure 3. Waterlogging and flooding of the sampling location during the winter season.

Twenty-kilogram soil samples each were collected from the virgin soil after removing the 5-cm-thick surface layer. Samples were collected from the selected location based on a 10 m grid system.

The soil samples were dried at a temperature of 60°C to reduce the effect on salt-bearing soil properties (Ismael, 1993). Then, the disturbed soil samples were screened using a 4.75-mm sieve to remove any large particles which were in very low quantities. Soil samples were homogenized by thoroughly mixing the sieved soils. Part of the sieved soil was used to determine the soil index properties.

The other soil samples were weighed and mixed with 4%, 8%, or 10% bitumen by weight. Kerosene was added to bitumen as a solvent to reduce viscosity and increase the workability of the mixing process. Cut-back bitumen was prepared per the manufacturer's specifications. The bitumen mixing percentages were selected based on previous studies that showed that the optimum bitumen contents were within 4%–12% (Al-Otaibi, 2006, Al-Otaibi and Wegian, 2012, Al-Otaibi and Aldaihani, 2018, Al-Otaibi and Aldaihani, 202).

The cut-back bitumen was mixed gently with sabkha soil till the mixture appeared homogeneous visually. Subsequently, mechanical mixing was performed for a few minutes. The mixture was exposed to temperatures less than 60°C for three days to evaporate the solvent in the soil–bitumen mixture to simulate the field conditions.

2.2 Experimental Program

2.2.1 Index properties

The soil samples were subjected to characterization tests such as grain size analyses using a dry sieving analysis method according to ASTM D422 standards (ASTM D422-04,1998). Dry sieving was selected since large variations were observed between grain size distribution curves determined by the dry and wet sieving methods due to soluble minerals, which are significantly affected by washing. (Al-Homidy et al., 2017, Al-Amoudi, 1994).

Consistency tests according to ASTM D4318 standards (ASTM D4318-04,1999), soil classification tests according to the Unified Soil Classification System (ASTM D2487, 1999), and AASHTO soil classification system (AASHTO M 145-91.2017), particle density (Gs) tests according to ASTM D-854-14 standards (ASTM D854-14,2014) were carried out. Soil compaction parameters were evaluated by the modified Proctor test, which was conducted according to ASTM D-1557-12 standards (ASTM D1557-12,2008). Soil chemical testing was performed to evaluate primary salt compositions.

2.3 Testing Program

2.3.1 California bearing ratio test (CBR)

The CBR test was used to evaluate the suitability of bitumen-treated sabkha soil for pavement construction. As the highest CBR value is achieved for soil compacted to its maximum dry density value (Aiban, 1995), CBR tests were performed according to ASTM D 1883-16 (2016). Samples with different bitumen percentages were prepared, and their compaction parameters were obtained from a compaction test.

Unsoaked testing (D) was performed on samples directly after compacting them at their optimum moisture content (OMC), whereas the soaked samples (S-10, S-30, S-60, and S-90) were prepared at their OMC and then soaked for 10, 30, 60, and 90 days, respectively, as shown in Fig (4). The soaked samples were left to drain for 10 min before testing.

Figure 4. Soaked samples.

3- RESULTS AND DISCUSSION

3.1 Soil Chemical Composition

Figure (5) presents the chemical test results of the representative soil sample. SiO_2 (41.80%) is the major component of the sabkha soil, followed by $CaCO_3$ (18.20%), CaO (16.20%), and SO_4^{2-} (12.17%). The results are consistent with previous investigations on sabkha soils in southern Kuwait (Al-Otaibi, 2006, Al-Otaibi et al., 2012, Al-Otaibi and Aldaihani, 2018).

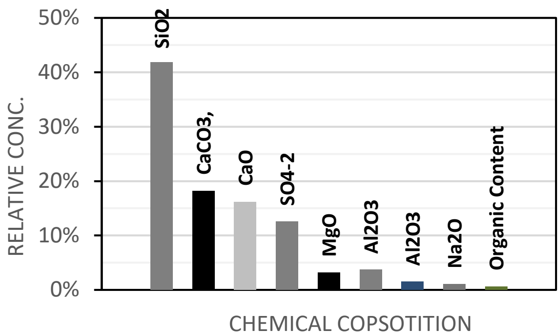

Figure 5. Sabkha soil chemical analysis.

3.2 Soil Physical Properties

The average specific gravity of the collected soil samples was 2.75. This value is within the range of the specific gravity values reported by Al-Otaibi (2006) and Al-Otaibi et al. (2012) in their investigations on sabkha soils from southern Kuwait.

For ease of understanding, the results for the central sampling pit in the study area are provided along with the limits of the grain size distributions for the tested soil samples. Figure (6) shows the grain size distribution curves for 16 soil samples collected from the selected location and the upper and lower ranges for the tested samples. Because of the gradation of the narrow variation range of the collected soil samples, sabkha-1, a soil sample was selected for detailed characterization and testing.

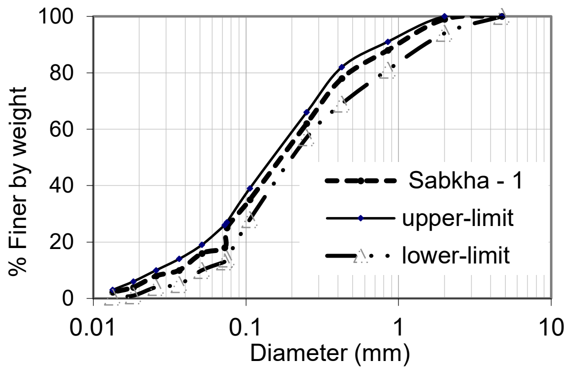

Figure 6. Grain size distribution of the tested soil samples.

Figure (7) shows the grain size distribution curves for the natural and bitumen-mixed sabkha soil samples with different bitumen contents.

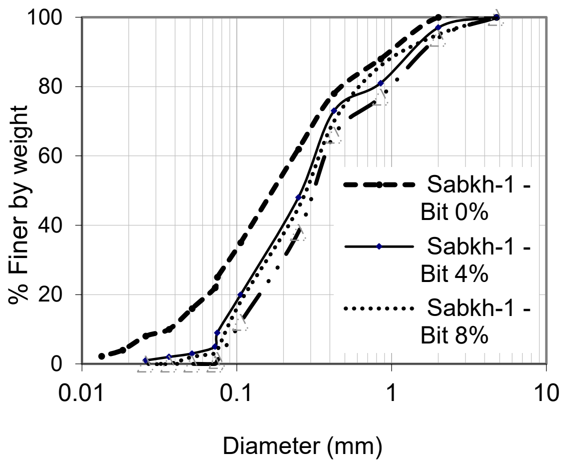

Figure 7. Grain size distribution of the tested soil samples.

As shown in the figure, bitumen-mixed sabkha soil becomes coarser with increasing bitumen percentages. The fine soil content almost disappeared because of soil aggregation, which may be attributable to the effect of the adsorption of viscous bitumen on the surfaces of soil particles.

The liquid and plastic limits for the natural sabkha were 38% and 28%, respectively. Soil consistency limits were not measured for the bitumen-treated sabkha soil samples because the reduced fine content observed in the gradation curves indicated nonplastic behaviour. Due to the addition of bitumen, the soil classification varied from clayey sand (SCL) for the natural sabkha to poorly graded sand (SP) for bitumen-mixed soil samples. According to the AASHTO classification, sabkha soil samples showed the A-2-6 type, and the bitumen-mixed sabkha showed the A-3 type.

Table 1 summarizes the physical properties of the tested soil samples.

The physical properties of the soil from the study area are in agreement with the values reported by Al-Otaibi et al. (2012) and Al-Otaibi and Aldaihani (2018) in their investigations on bitumen-stabilized sabkha soil in Kuwait.

Table 1: Index properties of the bitumen-mixed soil samples.

	Bitumen mixed sabkha			
	0%	4%	8%	10%
D_{10} (mm)	0.038	0.075	0.085	0.10
D_{30} (mm)	0.09	0.15	0.16	0.20
D_{60}(mm)	0.23	0.32	0.35	0.38
C_U	6.10	4.30	4.10	3.80
C_C	0.9	0.9	0.9	1.1
LL (%)	38.0	--	--	--
PL (%)	28.0	--	--	--
PI (%)	10.0	NP	NP	NP
USC	SCL	SP	SP	SP
AASHTO	A-2-6	A-3	A-3	A-3
MDD (g/cm³)	1.885	1.865	1.925	1.875
OMC (%)	13.2	14.3	9.25	9.15
GS	2.75	NM	NM	NM

3.3 Compaction Parameters Results

The variation in the compaction parameters of the tested soil samples with bitumen is summarized in Table (1) and displayed graphically in Fig (8).

Figure (8) shows that adding up to 8% bitumen modifies the compaction characteristics of the sabkha soil. Beyond this bitumen content, the maximum dry density decreases and becomes lower than that of the natural sabkha soil. The increase in the soil density is attributed to the viscous bitumen layer around the soil particles. This viscous layer allows the soil particles to slide around each other and minimizes the voids at the lower optimum moisture content (OMC), as shown in the figure.

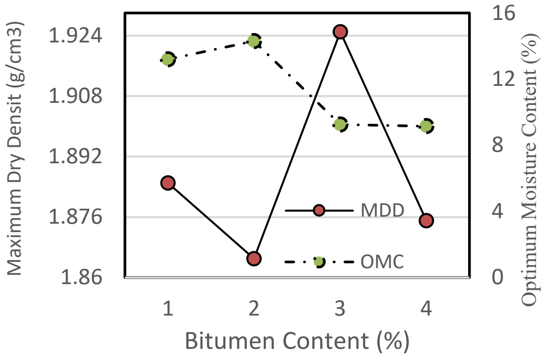

Figure 8. Compaction test results.

3.4 California Bearing Ratio (CBR) Results

3.4.1 Unsoaked Testing Results

Figure (9) shows that with the addition of bitumen, the load-penetration curves become steeper, indicating greater load resistance. Adding up to 8% bitumen improved the load resistance of the tested soil samples considerably. For example, the recorded penetration readings for an applied load of 2 kN were 0.5 mm,0.0 mm, 1.0 mm, and 1.35 mm for 4%, 8%, 0%, and 10% bitumen mixed sabkha soil samples, respectively.

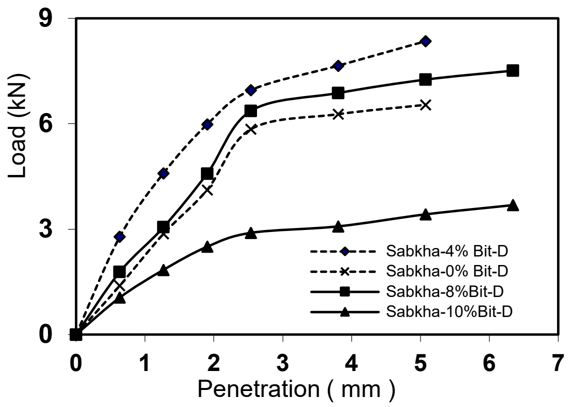

Figure 9. Stress-strain curves - unsoaked conditions (D).

The loading curve of the sabkha sample containing 10% bitumen is flatter than that of the other samples, indicating the higher penetration under lower loads and, ultimately, the lower strength of this sample. The CBR values calculated from Fig (9) for sabkha soil samples containing 0%, 4%, 8%, and 10% bitumen under unsoaked conditions are shown as bar graphs in Fig (10). The percentage of variation in CBR, which was calculated with respect to the CBR of the natural sabkha soil, is shown as a dotted line in this Fig (10).

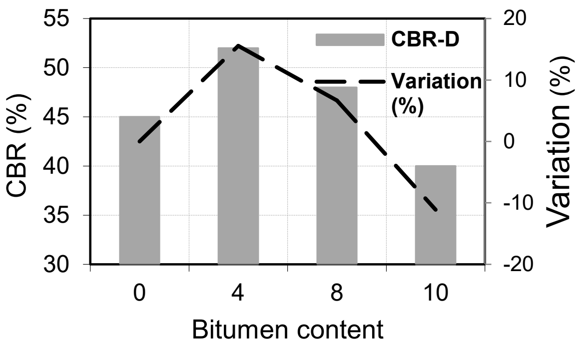

Figure 10. CBR of the tested soil samples under unsoaked (D) conditions and the percentage of variation.

The CBR of the natural sabkha soil sample (with 0% bitumen) is 45%, which is within the CBR values recorded by Al-Sanad et al. (1990) and Ismael and Mollah (1998) for cemented sand. The high CBR values for cemented sand were attributed to the high salt contents that created stronger bonding among the soil particles and increased the bearing capacity of the soil. CBR values may also vary with depth for the same location because of the variations in the textural and chemical characteristics of sabkha with depth (Al-Hurban and Gharib, 2004, Al-Sanad, 1986, Livneh et al., 1998, Sabtan and Shehata, 2002 and 2003, Saleh et al., 1999).

With up to 8% bitumen addition, the soil density increases and moisture content decreases, as in Fig (8), improving the soil deformation characteristics and increasing the CBR value up to 15%. Beyond the 8% bitumen content, the 11% reduction in the CBR value may be related to the reduction in the soil density and lubrication effect of the high bitumen content, which reduces the load resistivity. A similar effect was reported by Al-Otaibi and Aldaihani (2018) in their investigation of the shearing characteristics of bitumen-mixed sabkha soil.

3.4.2 Soaked Testing Results

The effect of the soaking period on the soil strength was evaluated by obtaining the load-penetration curves of the soil samples at 10, 30, 60, and 90-day soaking periods. The curves for the natural sabkha and 8% bitumen-mixed sabkha samples under soaked conditions are shown in Figs (11) and (12).

The curves of the natural sabkha samples (Fig (11)) become flattened as the soaking period increases, a sharp reduction in the bearing capacity of the soil during prolonged soaking. The recorded penetration readings for an applied load of 1 kN were 0.5, 0.8, 1.8, 2.0, and 4.0 mm for unsoaked, S-10, S-30, S-60, and S-90 sabkha soil samples, respectively.

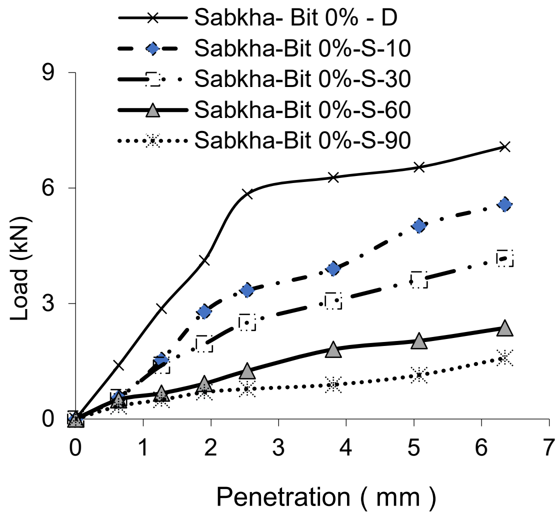

Figure 11. Stress-strain curves for natural sabkha

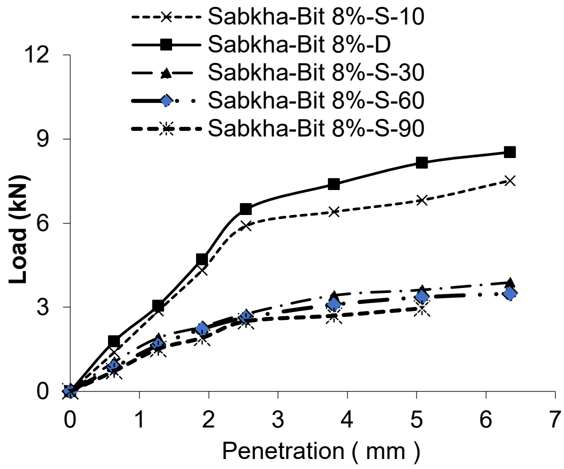

Figure 12. Stress-strain curves for the 8% bitumen-mixed sabkha soil samples

On the other hand, for the sabkha samples containing 8% bitumen, Fig (12), the variation between the curves was minimal in unsoaked (D) and S-10 samples, indicating the improvement of the load-resisting capacity even under prolonged soaking.

The calculated CBR values for the soaked natural sabkha and bitumen-mixed sabkha soils are listed in Table 2 and displayed graphically in Fig (13).

Table 2: CBR values for the tested soil samples.

	Bitumen mixed sabkha			
	0%	4%	8%	10%
CBR_D	45%	52%	48%	40%
CBR_{S-10}	25%	41%	44%	39%
CBR_{S-30}	17%	36%	40%	37%
CBR_{S-60}	9%	29%	40%	36%
CBR_{S-90}	6%	23%	36%	33%

The CBR value decreased sharply to a very low for the natural sabkha samples with a long soaking period, as shown clearly in Fig (13). In contrast, the variation between the dry and soaked CBR values for different soaking periods diminishes upon adding more bitumen. This behaviour can be seen clearly in Fig (14), which shows the percentage reduction of CBR values with bitumen content at different soaking periods. Figure (14) shows the effect of increasing bitumen amounts in conserving the CBR value of the soil under soaking conditions for different soaking periods and different bitumen contents. The difference between the unsoaked and soaked CBR values diminishes with additional bitumen content.

The reduction in the CBR value was calculated for each soil sample concerning its value under dry conditions. These reductions are presented graphically in Fig (15)

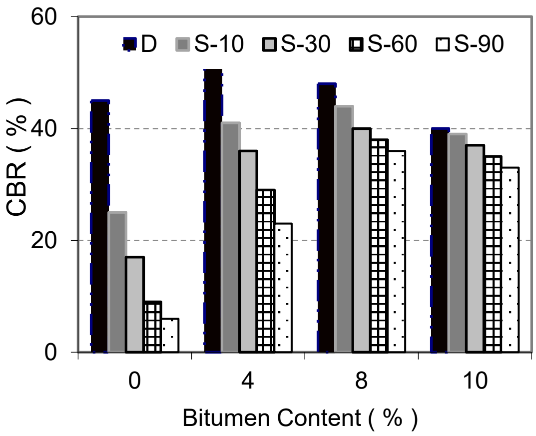

Figure 13. CBR values of the tested soil samples.

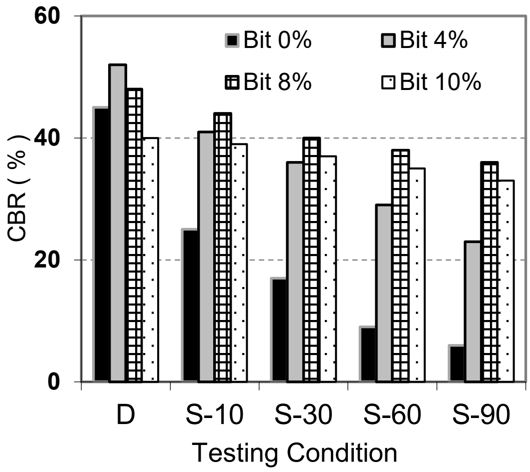

Figure 14. CBR values of the tested soil samples.

Figure (15) clearly shows that the CBR values continue to decrease from 50%–90% under 10 to 90 days of soaking conditions for the natural sabkha soil samples. The reduction in the soaked CBR values reaches less than 20% for the sabkha soil sample containing 10% bitumen at the same soaking periods.

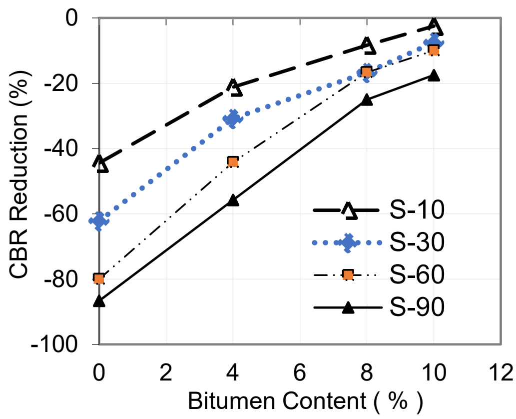

Figure 15. Percentage of reduction in the CBR of the tested soil samples.

Thus, bitumen addition causes an improvement in preventing the sharp deterioration of the CBR values under prolonged soaking. The dissolution of salts and softening of the soil structure upon soaking reduced the cementing among soil particles (Aiban, 1995, Al-Amoudi and Abduljauwad, 1995). The drastic reduction of the strength of the sabkha soil is attributable to this effect. Soaking may have resulted in the leaching of bonding salts, as shown by Al-Otaibi (2020a and 2020b), possibly leading to a decrease of 50% in the CBR value upon flooding (Al-Amoudi et al., 1992, Al-Amoudi and Abduljauwad, 1995).

The waterproofing effect of the hydrophobic bitumen layer around soil particles and the cemented soil lumps minimize the water absorption of fine constituents and minimize the reduction of the CBR values upon soaking. The differences between the CBR values of the unsoaked and soaked soils indicate the modification of sensitivity of the sabkha soil to moisture damage. Several studies on contaminated soils revealed that the improved hydrophobic property of soil particles coated with oil is the main cause of the waterproofing effect that minimizes the water adsorption and dissolution of the cementing materials (Andrade et al., 2004, Al-Otaibi, 2006, Al-Sarawi et al., 1998). Adding 10% bitumen seems sufficient for conserving the CBR under prolonged soaking. The chemical bonding between the bitumen and the soil is expected to be based on weak physical adsorption (Al-Otaibi, 2006). However, adding more than 10% of bitumen is expected to provide thicker soil particle coating and alternatively better waterproofing characteristics but will highly deteriorate the compaction characteristics of the stabilized sabkha, where the compacted soil maximum dry density dropped as shown in Fig (8). Dealing with a large amount of bitumen and

Sabkha soil in the field may affect the efficiency of drying soil, mixing, and compaction processes which will reduce the efficiency of bitumen distribution around soil particles and alternatively affect the geotechnical properties of the stabilized soil.

The results of this paper reveal that bituminous materials were effective in reducing the dissolution of salts in the sabkha soil under soaked conditions. The efficient utilization of bitumen-stabilized sabkha materials in subbase construction requires further research to use additional materials, such as cement, to reach CBR requirements for usage as a subbase material. Values with considering the levels of targeted hydraulic conductivity and other considered parameters. Environmental benefits achieved from using sabkha materials makes the economic issue a second-order priority.

CONCLUSIONS

This study aimed to investigate the feasibility of modifying the bearing capacity of the sabkha soil in Kuwait under long-term soaking conditions by adding bitumen. Reducing the undesirable characteristics of the sabkha soil under soaked conditions will allow these materials to recycle and participate in solving environmental problems that are a result of their disposal. A series of CBR tests were conducted on natural sabkha samples and sabkha samples containing 0%, 4%, 8%, and 10% bitumen for soaking periods of 10, 30, 60, and 90 days. The following conclusions are drawn based on the results of the experimental investigations:

- The CBR of the natural sabkha soil indicates its high susceptibility to collapse upon soaking. The CBR deteriorated to 50% upon soaking and continued to decrease with prolonged soaking.
- Upon adding 4% and 8% bitumen, the sabkha soils showed improvements of 15% and 7% in the dry CBR, respectively.
- Adding bitumen reduced the difference among the CBR values under dry and soaked conditions.
- The soaking duration influences the natural sabkha soil. However, waterproofing by bitumen reduces this effect.
- Adding 10% bitumen conserves the CBR of the soaked sabkha samples. However, adding more than 10% bitumen will cause deterioration of the compaction characteristics of the stabilized sabkha soil.

Further large-scale field investigation is required to gain a sufficient understanding of the behaviour of stabilized sabkha in the actual field conditions and under actual field temperature.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding this article.

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