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STUDIES ON THE CONTROL OF SWELL AND COLLAPSE POTENTIAL OF SELECTED JORDANIAN SOILS USING ASPHALT STABILIZATION

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ABSTRACT

The basic objective of this research was to investigate the effectiveness of "bitumen" as a soil stabilizing agent. For this purpose, four different soils from Northern Jordan, which exhibit certain engineering problems, such as swelling and collapsibility, were selected. Two of these soils are swelling soils (Irbid and Ramtha), while the other two are collapsible (JUST and Mafraq).

To conduct this work, soil-bitumen mixtures were prepared at 3%, 5%, 7% and 10% bitumen by dry weight of soil. Both natural and bitumen treated soils were subjected to similar laboratory tests to observe the influence of bitumen on swelling and collapse potential.

The test results showed that bitumen is effective in stabilizing the tested soils. Upon mixing with soils, bituminous materials act as a binding agent between soil particles. Additionally, test results showed that cutback bitumen percentages in excess of 7% do not show a substantial reduction in swelling and collapsibility potentials.

Key words: bitumen, control, heaving, laboratory tests, settlement, soil stabilization (**IGC**: D5/D10)

INTRODUCTION

Excessive heave, settlement, low shear strength and internal erosion of some soils present problems for civil engineers. Problem soils may cause damage to many civil engineering structures, such as: (1) spread footings founded on expansive or collapsible soils, (2) roads, highways and airport runways constructed on expansive or collapsible subgrade, (3) earth dams constructed with a soil which can be eroded (i.e. dispersive soil), and many others. In order to avoid damage to such structures, soil stabilization using some agents is often useful. One such agent is bitumen.

Some of the buildings and roads constructed in Northern Jordan have problems caused by large upward and downward movements of the underlying soils. Evidence of distress appears within a short period of time following construction, necessitating rapid remedial measures. Such measures may include considerable maintenance or total reconstruction. Mechanical compaction, which is a common practice, apparently is not effective in stabilizing the soil in this area.

Water is a major factor in numerous "geotechnical problems". Wetting causes swell in certain soil types, or additional settlement in others, or both swell and collapse of specific soil types under different conditions. Moreover, most soils which have satisfactory bearing capacity at low moisture contents tend to become unstable at high moisture content. Bituminous materials are often used with soil as waterproofing and binding agents. They maintain the low moisture content and act as a stabilizing agent.

According to Yoder (1975) "Bituminous soil stabilization is the name given to those methods of construction in which bituminous materials are incorporated into a soil or soil-aggregate mixture to provide base coarse and occasionally surface courses which can carry the applied traffic loads under all normal conditions of moisture and traffic".

Asphalt is normally too viscous to be incorporated directly with soil. In order to increase its fluidity sufficiently it can be heated, or emulsified in water (emulsions), or cut back with some solvent like gasoline, kerosene, or diesel oil which evaporates after placement. Nevertheless, the term "bitumen" is often taken to include both tar and asphalt. The use of these materials for subsoil modification is called bituminous stabilization (Manfred, 1988).

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As a stabilizing agent, bitumen can improve the soil properties to some degree depending on the type of soil. These improvements are divided into three groups as follows (Leonards, 1962; Road Research Laboratory, 1952; Winterkorn and Fang, 1975; Woods et al., 1982):

1—Strengthening to cohesionless materials, such as clean sands, by acting as a binding or cementing agent. This type of material is usually termed "sand bitumen".

2—Stabilizing the moisture content of cohesive, fine-grain soils. This material is usually known as "soil bitumen".

3—Providing cohesive strength and waterproofing materials that inherently possess internal friction. This type is usually known as a sand gravel-bituminous mixture.

Bituminous stabilization, in which cutback bitumen, tars or bituminous emulsions are added to soil, has been used in the construction of wearing surface and base courses for roads thus reducing the potential for collapse and swelling. The bituminous material may either increase the cohesion of the soil by binding the solid particles together, or it may act as a waterproofing agent (and maintain the cohesion) due to thin films of bitumen forming between the particles. The amount of bituminous material required depends upon which of these two effects is desired and upon the soil type. Climatic conditions also influence the amount of bitumen required for stabilization since the amount of fluid is affected, i.e. the natural moisture content of the soil.

OBJECTIVES

The main objective of the research conducted was to study the potential for the bitumen to act as a stabilizing agent for some selected soils in Northern Jordan which have exhibited certain engineering problems such as swelling and collapse potential.

A laboratory testing program was carried out on four types of soil from different locations in Northern Jordan. Two of these soils were chosen as having potential for "collapse" (collapsible) and the other two as swelling soils. The collapsible soil samples were obtained from a site in Mafraq and a site within the Jordan University of Science and Technology campus (JUST). The swelling soil samples were obtained at a site in Irbid and another site in Ramtha. The selected soils were treated with bitumen and the following tests were performed on the mixture:—Compaction (Standard Proctor), Unconfined Compression, Swelling and Collapse potential.

Soil-bituminous mixtures were prepared with four different percentages, namely; 3%, 5%, 7% and 10% by weight of dry soil. Both the natural and the bitumen treated soils were subjected to these laboratory tests in order to study the influence of bitumen on the strength and deformation properties.

LABORATORY INVESTIGATION AND EXPERIMENT RESULTS

A laboratory testing program was carried out on four types of soils from different locations in Northern Jordan. Two of them were chosen as collapsible soils while the others were considered to be "expansive" soils. The collapsible soil samples were obtained at a site in Mafraq (soil A) and another site within the Jordan University of Science and Technology campus (JUST) (soil B). The expansive soil samples were obtained at a site in Irbid (soil C) and another site in Ramtha (soil D).

Liquid bitumen materials are suitable for soil stabilization because of their low softening temperatures and low melting viscosity (Leonards, 1962; Road Research Laboratory, 1952; Winterkorn and Fang, 1975; Asphalt Institute, 1977; ASTM Committee, 1984). The asphalt which was used for this study was cutback asphalt (MC-70), which is an asphalt with some solvent (kerosene). The properties of MC-70 are listed in Table 1.

Soil-bitumen mixtures are prepared with 0%, 3%, 5%, 7%, and 10% by weight of dry soil. The optimum water content and maximum dry density are evaluated from compaction tests for each percentage of bitumen added to the soil.

Swelling tests were made on Irbid and Ramtha soils, whereas, for soils from Mafraq and JUST, single-Oedometer Collapse tests were conducted on the natural soils and the bitumen-treated soils for each percent of bitumen, where the specimens were prepared both at optimum water content and 80% of maximum dry density.

General Physical Properties of Natural Soil

Soil samples obtained from different locations in Northern Jordan were prepared and tested. The tests eval-

Table 1. Properties of medium cured cutback asphalt (MC-70) used

Property	Units	Result
Viscosity		
Kinematic viscosity at 140° F	cSt	125
Saybolt furol viscosity at 122° F	sec.	85
Flash point	°C	100
Fire point	°C	105
Distillation test		
Distillate by volume of total distillate to 225°C	%	20 Maximum
260°C	%	20–60
316°C	%	65–90
Residue from distillation to 360°C	%	55 Minimum
Percent volume by test on residue from distillation		
Penetration at 25°C, 100 gr., 5 sec.	mm	12–25
Ductility at 25°C	cm	100 Minimum
Solubility in trichloroethylene	%	99 Minimum
Water	%	0.2 Maximum
Specific gravity	—	0.960

Table 2. General properties of soils studied

Property		Soil A	Soil B	Soil C	Soil D
Location		Mafraq	JUST	Irbid	Ramtha
Depth of sample (m)		0.5	0.5	0.5	0.5
Liquid limit LL(%)		39.5	33.7	72.0	53.0
Plastic limit PL(%)		22.7	20.5	35.0	30.0
Plasticity index PI(%)		16.8	13.2	37.0	22.4
Initial water content (%)		3.2	3.8	11.1	6.5
Maximum dry density ρ_d (g/cm^3)		1.712	1.823	1.416	1.596
Optimum water content (O.W.C)%		17.8	15.2	29.0	19.9
Specific gravity of solid (Gs)		2.74	2.72	2.71	2.56
Grain size	Sand (%)	12.33	47.80	4.00	32.00
	Silt (%)	54.67	32.20	30.00	30.00
	Clay (%)	33.00	20.00	66.00	38.00
Symbol according to Unified Soil Classification System		ML[a]	CL[b]	CH[c]	MH[d]

a—Low plasticity silt.
b—Low plasticity clay.
c—High plasticity clay.
d—High plasticity silt.

uated their natural physical and engineering properties according to the American Society for Testing and Materials (ASTM) standard specifications. These properties include: grain size distribution, specific gravity, liquid limit, plastic limit and natural water content. In addition, maximum dry density and optimum water content were obtained using the Standard Proctor test. The four soils were classified according to the Unified Soil Classification System (USCS). These properties together with the classification are listed in Table 2 for each of the four soils. The grain size distributions of the soils are shown in Fig. 1.

The selected soils were treated with different percentages of bitumen and the following tests were performed on the mixture:

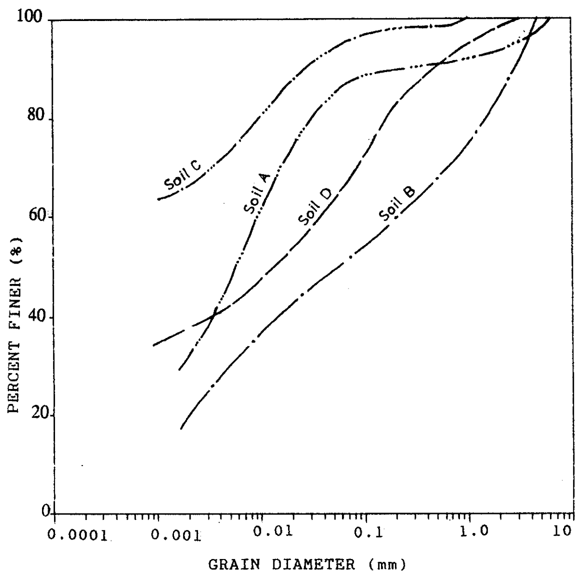

Fig. 1. Grain size distribution of soils tested

1—Standard Proctor Compaction (for all soil),
2—Swelling (for Irbid and Ramtha soils),
3—Collapsibility (for Mafraq and JUST soils).

Soil passing sieve No. 4 was used for the compaction test and the soil passing No. 10 was used for the swelling and collapsibility tests.

Standard Proctor Compaction Test

A large sample of each soil under investigation (15–20 kg) was air-dried, and the moisture content was determined. Each sample was then quartered into a number of 2 to 2.5 kg batches. Suitable quantities of water were then added to the soil to enable a range of moisture contents covering the probable optimum moisture content to be obtained. The moisture contents used were about 1.5 to 3 percent apart. For a certain water content, the required amount of water was then mixed with the soil until the moisture become uniformly distributed throughout the soil. Three samples from each batch were placed in an oven for 24 hours drying at 110°C, and the water content was determined.

The required proportion of bitumen was then added and initially mixed using a spoon. This was followed by mixing the sample by placing in a mechanical mixer for two minutes to obtain a uniform mixture condition. In calculating the dry density of the soil the weight of both bitumen and water must be subtracted from that of the compacted sample. The water content corresponding to the peak of the curve of dry density versus moisture content is referred to as the optimum moisture content. Alternatively, the percentage of bituminous material present may be added to the optimum water content in order to obtain an optimum total fluid content. The results from compaction tests are shown in the compaction curves presented in Figs. 2, 3, 4, and 5, for soils A, B, C, and D, respectively.

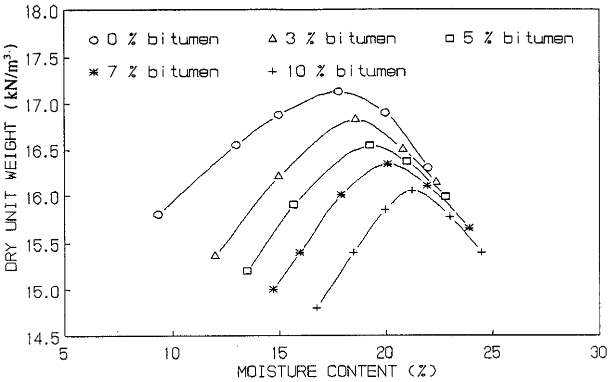

Fig. 2. Results of compaction tests on soil (A) containing various proportions of bitumen

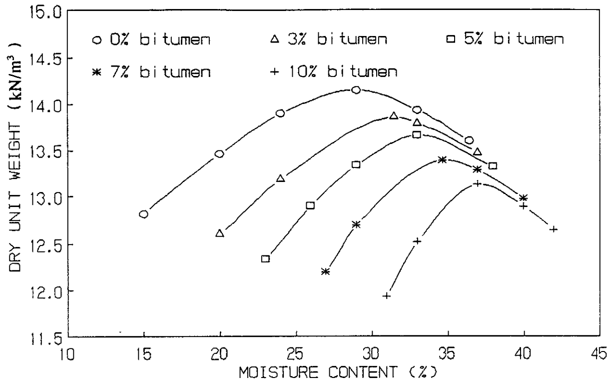

Fig. 4. Results of compaction tests on soil (C) containing various proportions of bitumen

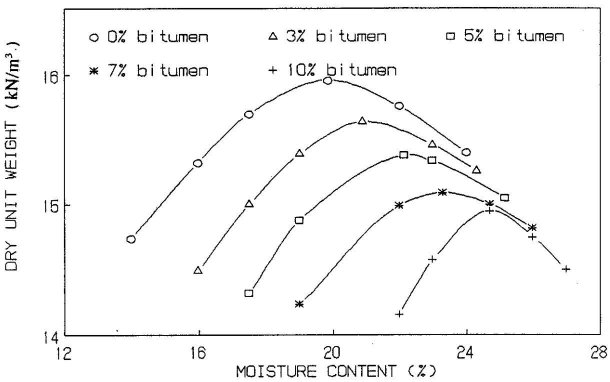

Fig. 3. Results of compaction tests on soil (B) containing various proportions of bitumen

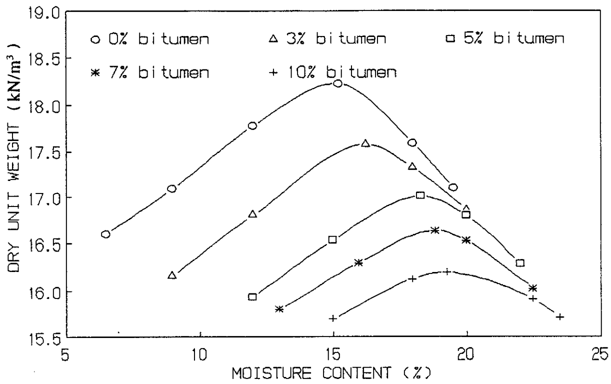

Fig. 5. Results of compaction tests on soil (D) containing various proportions of bitumen

Swelling Test

"Swell potential" tests were conducted on Irbid soil (soil C) and Ramtha soil (soil D). Swell potential by definition is the percent swell under an applied pressure of 7.0 kN/m^2 of a specimen compacted to maximum density and optimum water content based on AASHTO standard proctor compaction test.

The soil passing sieve No. 10 (2 mm) was placed in the oven for 24 hours for drying at 110°C. Before preparing the specimens, the soil was kept in a desiccator for an average period of 15 hours so it would attain room temperature without absorbing any moisture from the surrounding air.

The soil was then prepared at optimum moisture content and maximum dry density as obtained from the standard proctor test for each percent of bitumen. A standard assembly was used to compact the soil after thoroughly mixing it with water, then with bitumen, to obtain an exact standard specimen with 20 mm height and 76 mm diameter.

Samples were placed immediately after moulding in a standard one dimensional oedometer device with seating pressure of 7.0 kN/m^2 thereby representing the overburden pressure at a depth of 0.5 meter for each soil. The samples were then submerged in water and allowed to swell with deformation readings taken at 0.25, 0.5, 1, 2, 4, 8, 15, 30, 60, 120 and 1440 minutes. For each sample tested in this way, the maximum swell potential was defined as the ratio of the maximum sample height change upon wetting to the initial sample height. The swell test data for soils C and D mixed with different percentages of bitumen at optimum moisture content and maximum dry density were then plotted as shown in Figs. 6 and 7, respectively to indicate the variation in swell potential with time for these two soils.

Single-Oedometer Collapse Test

Single-oedometer collapse tests were carried out on Mafraq soil (soil A) and JUST soil (soil B).

There are currently two methods used to determine the amount of soil collapse upon wetting. The first is the single Oedometer test and the second is the double Oedometer test.

Basma and Tuncer (1990) found that the results obtained with both tests were almost the same and suggested using the single oedometer collapse test for two reasons: (1) it is difficult if not impossible, to obtain similar or identical specimens for the double oedometer test, and more important, (2) the single oedometer test or the wetting after loading approach simulates more closely the

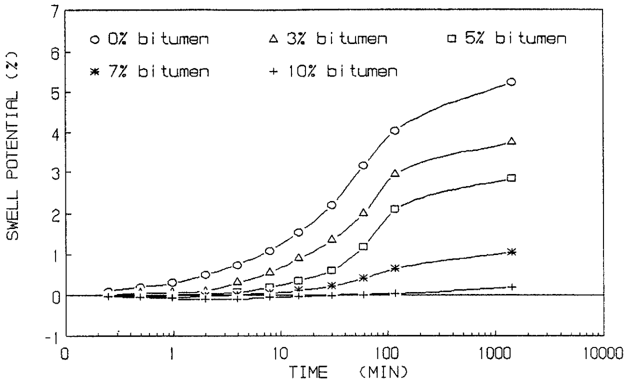

Fig. 6. Variation of swell potential with time for soil (C) treated with different bitumen contents

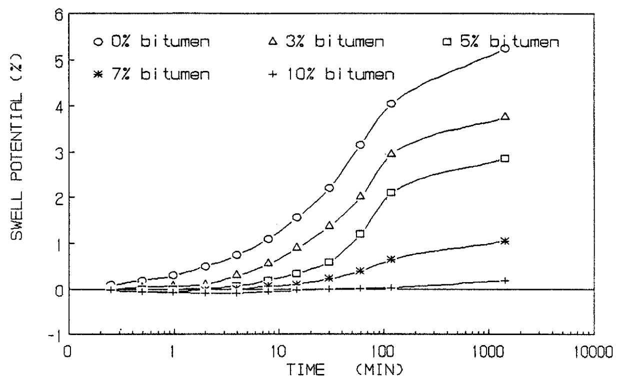

Fig. 7. Variation of swell potential with time for soil (D) treated with different bitumen contents

conditions of compacted soils in the field.

For this study single-oedometer collapse tests were conducted on specimens which were compacted in the Oedometer ring at optimum water content and 80% of the maximum dry density obtained using the standard proctor compaction test for each percent of bitumen. Tests were conducted at seating pressures of 25, 100 and 400 kN/m^2. The specimens were permitted to attain equilibrium deformation for each pressure, then the sample was inundated and the final deformation was measured.

This deformation, induced by the addition of water, divided by the initial height of the specimen, expressed as a percent, defines collapse potential. The results of the test are listed in Tables 3 and 4 for soils A, and B, respectively at different bitumen contents.

Table 3. Collapse potential results for soil A treated with bitumen

Bitumen %	Collapse potential corresponding to applied pressure		
	25 kN/m^2	100 kN/m^2	400 kN/m^2
0	1.15	2.63	0.78
3	1.30	2.88	0.81
5	0.90	2.28	0.56
7	0.38	1.08	0.06
10	0.07	0.22	0.01

Table 4. Collapse potential results for soil B treated with bitumen

Bitumen %	Collapse potential corresponding to applied pressure		
	25 kN/m^2	100 kN/m^2	400 kN/m^2
0	1.35	3.85	5.68
3	1.56	4.20	5.75
5	1.25	3.38	4.83
7	0.55	1.75	2.50
10	0.10	0.39	0.58

ANALYSIS AND DISCUSSION OF RESULTS

In comparing the compaction process of natural soil to that of bitumen treated soil it was observed that during the compaction process, it was difficult to pulverize the compacted samples of soil-bitumen-water mixture after extraction from the compaction mould. This was even more evident when the water content increased. Five or six different samples were therefore prepared at different water contents for each percent of bitumen.

The standard proctor compaction test results were discussed previously as presented in Figs. 2, 3, 4, and 5. Figure 8 summarizes the results of the effect of bitumen percent on maximum dry density for the four soils studied. Figure 9 summarizes the results of the effect of bitumen percent on optimum total moisture content. In studying these results, it can be seen that increasing the amount of bitumen progressively reduced the maximum dry unit weight, while increasing the corresponding optimum moisture content. This is due to the fact that the bitumen films surrounding the soil particles have high viscosity which caused a resistance of the mixture to compaction.

Referring to Figs. 8, and 9, soil B (JUST) has a relatively low optimum moisture content and high maximum dry unit weight for each percent of bitumen when compared to the other soils. This is related to its low plasticity (see Table 2, PI=13.2%). Soil C (Irbid), has relatively

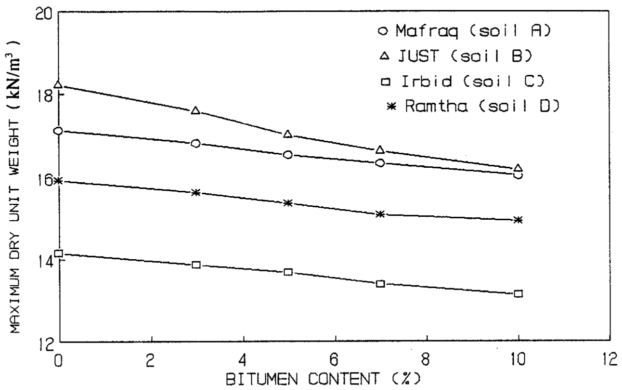

Fig. 8. Effect of bitumen treatment on maximum dry unit weight for all soils tested

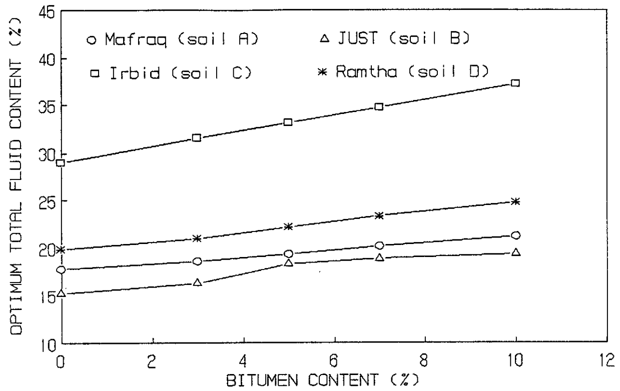

Fig. 9. Effect of bitumen treatment on optimum total moisture content for all soils tested

the highest optimum moisture content but the lowest dry unit weight for each percent of bitumen. This is due to its high plasticity (PI=37%).

For the natural soil (i.e. untreated soil), the decrease in maximum dry unit weight with increasing plasticity can be attributed to a high affinity for water in highly plastic soils. In order for the double layer to develop fully, a larger amount of water is required to balance the charge deficiency present, so that the absorbed layers of water will be thicker for highly plastic soils, and therefore, the dry unit weight will be lower (Singh and Prakash, 1976; Lambe and Whitman, 1969). This explanation applies also to bitumen treated soils.

Soils A and D with respective plasticity index values of 16.8% and 22.4% have their compaction parameters for each percent of bitumen in between soils B and C in the order expected (i.e. a soil with a lower plasticity (soil A) has a lower optimum moisture content and a higher dry density than higher plasticity soil (soil D) (Figs. 8 and 9).

Swell Potential

The results of variation in swell potential with time for each percent of bitumen for soils C and D are shown in Figs. 6, and 7, respectively. The values of maximum swell potential versus bitumen content for soils C and D are shown in Fig. 10. This figure shows clearly the effectiveness of bitumen in reducing the swell potential for soils C and D.

When bituminous materials are mixed with soil, the resulting mixture does not absorb water in the same way that the untreated soil does. The waterproofing effect is caused by the formation of a film of bituminous material on the surface of the water in the interstices of the soil (Road Research Laboratory, 1952), or by acting as plugs in the soil-void spaces, or continuously coating the individual soil particles. The entry of additional water into the soil is then hindered by the bituminous film. As the bitumen content increases the waterproofing effect increases. This fact explains the decrease in swell potential with increasing bitumen content as shown in Fig. 11 for soils C, and D.

Referring to Fig. 10, soil C has relatively high swell potential when compared to soil D. This is related to its high plasticity (PI=37%). The increase in swell potential with increasing plasticity is attributed to high affinity for water in highly plastic soil (i.e. a greater volume of water is required to balance the charge deficiency present). The amount of bitumen required to cover the clay particles to cause waterproofing in the soil C (Irbid) is greater than in soil D (i.e. apparently at the same percentages of bitumen the amount of bitumen covers a larger number of clay particles for soil D than for soil C).

A parameter showing the effect of bitumen on swell potential characteristics of soil could be very useful. A parameter termed Bitumen Treatment Swell Reduction Ratio (BSRR) is introduced. This parameter is defined as the ratio of maximum free swell of treated specimen to an untreated one. Figure 11 indicates the variation in BSRR with varying bitumen content for soils C and D.

Referring to Figs. 10 and 11, the slope of these curves below 7% bitumen is greater than that above 7% bitumen, indicating that bitumen percentages in excess of 7% does not show a substantial reduction in the swelling potential, i.e. larger proportion of bitumen will not be considered very useful.

There is no readily available method for measuring the rate of swelling. The rate of swell, however, can be iden-

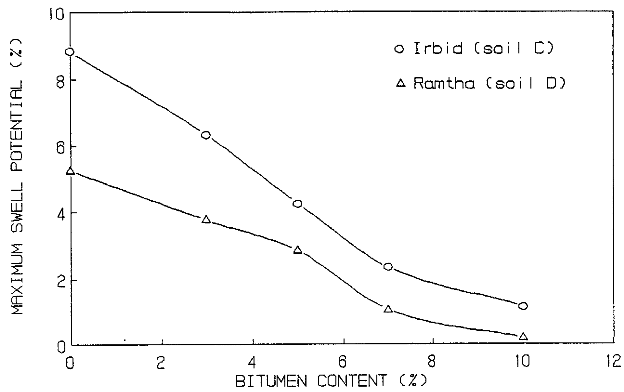

Fig. 10. Effect of bitumen treatment on maximum swell potential for soil (C) (Irbid) and (D) (Ramtha)

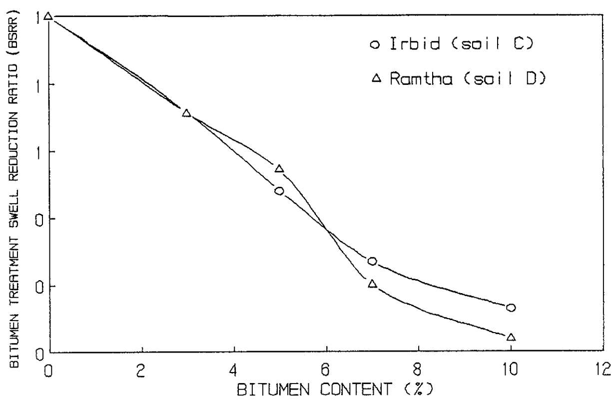

Fig. 11. Variation of bitumen treatment swell reduction ratio (BSRR) with bitumen content for soil (C) (Irbid) and (D) (Ramtha)

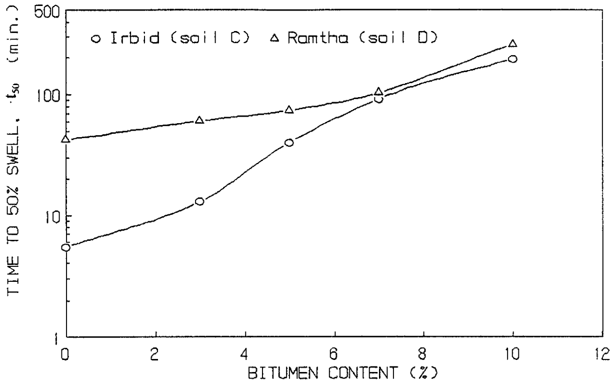

Fig. 12. Variation of time to 50% swell (t_{50}) with bitumen content for soil (C) (Irbid) and (D) (Ramtha)

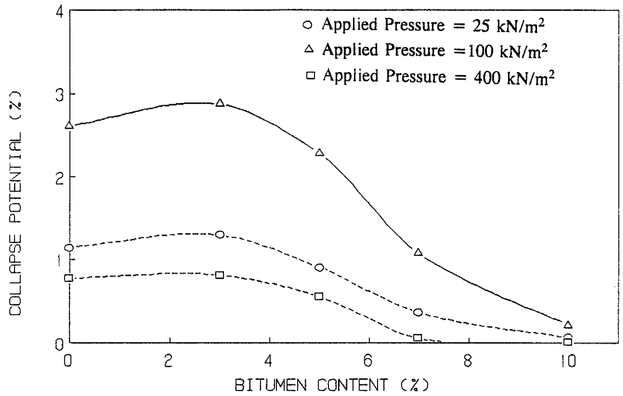

Fig. 13. Variation of collapse potential with bitumen content under different applied pressure for soil (A) (Mafraq)

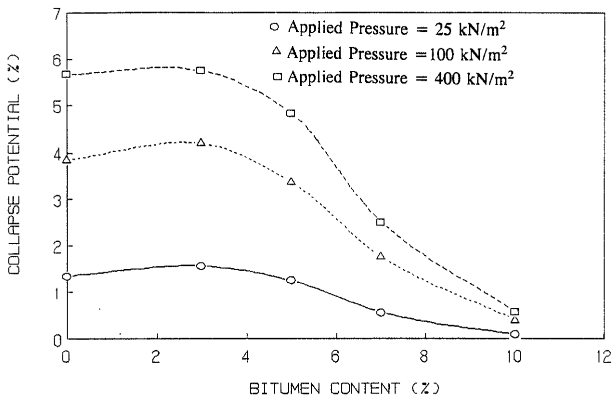

Fig. 14. Variation of collapse potential with bitumen content under different applied pressure for soil (B) (JUST)

tified by the time elapsed until 50 percent swell occurs, t_{50}, i.e. the time to half the full swell. The t_{50} values are evaluated as shown in Figs. 6 and 7, and plotted in Fig. 12 as a function of percent bitumen for soils C and D. From this figure it can be seen that the rate of swell decreases (i.e. t_{50} increase) with increasing bitumen content. This is explained by the already established fact that, as the percent bitumen increases, the soil prevents the free entry of water. This implies that the permeability decreases.

Referring to Fig. 12, soil D has a relatively higher rate of swell (t_{50}) for each percent of bitumen when compared to soil C. This is due to the relatively low percent of clay (38%) compared to soil C (66%). For bitumen portion less than 7%, apparently the amount of bitumen is not sufficient to cover all the clay particles in soil C while most clay particles in soil D appear to be covered. Beyond this percent however, the amount of bitumen is approximately sufficient to cover all clay particles for both soils.

Collapse Potential

Tables 3 and 4 summarize the results of collapse potential for different bitumen content for soils A (Mafraq) and B (JUST), respectively.

Figures 13 and 14 show the variation of collapse potential with bitumen content for different applied pressure for soils A and B, respectively. As seen in these figures, the addition of 3% of cutback bitumen causes an increase in the collapse potential for soils A and B for all applied pressures considered, due to the fact that adding this percent of bitumen reduced the dry density without a significant reduction in water absorption.

The addition of bitumen content of 5% or more, caused a substantial reduction in the water absorption. In this case, the bitumen serves initially to increase the collapse potential due to a decrease in dry density. Beyond a certain point, the substantial reduction in the water absorbed, due to bituminous film surrounding the particles, offsets the decrease in dry density due to the resistance of the mixture to compactive effort.

In addition, the presence of bitumen as a cementing agent on the grain contacts, could prevent these grains from rotating in a more dense arrangement upon loading. Also, upon inundation with water this cementing agent does not lose its effectiveness.

Referring to Figs. 13 and 14, it was observed that the slope of these curves for different applied pressures below 7% bitumen is greater than that in excess of 7% bitumen. This indicates that bitumen percentages in excess of 7% do not show a substantial improvement in reducing collapse potential. This is similar to what is observed when adding bitumen to swelling soils (Figs. 10 and 11).

In Figs. 13 and 14 it can be seen that the magnitude of collapse potential (for a given soil, at a given water content and dry density) is maximum at a certain value of applied pressure. Furthermore, any increase in pressure beyond this point, collapse potential decreases. The applied pressure at which maximum collapse potential occurs is called the critical applied pressure. This behaviour is explained on the basis of the induced prestress during the process of sample preparation (Nwaboukel and Lovell, 1984).

The compactive prestress depends on the amount of energy used to compact the soil (Manfred, 1988). For applied pressures lower than the compactive prestress, very little compression takes place before inundation by water. The collapse potential therefore, at applied pressures lower than the compactive prestress increases with increasing applied pressure. If the applied pressure exceeds the critical applied pressure (compactive prestress) however, the soil is compressed to a stage after which there is no effect when water is added. The critical applied pressure for soil A was determined to be 100 kN/m^2, and the critical applied pressure for soil B was 400 kN/m^2.

Referring to Figs. 13 and 14, soil B (JUST) has a collapse potential greater than soil A (Mafraq) at the same applied pressure. This is related to its high coefficient of uniformity (CU=308.32) compared to soil A which has a relatively low value (CU=16.35). Findings by Basma and Tuncer (1990) indicated that soils with higher uniformity coefficient, CU, have high collapse potential. The explanation for this finding was given by Basma and Tuncer, in which they stated that soils with high CU contain a wide range of particle sizes compared to those which are poorly graded. Upon wetting the smaller particles or fractions of the well graded soil tend to fill in the existing voids, resulting in a lower void ratio, compared with the poorly graded one. This explanation applies also for bitumen treated soils.

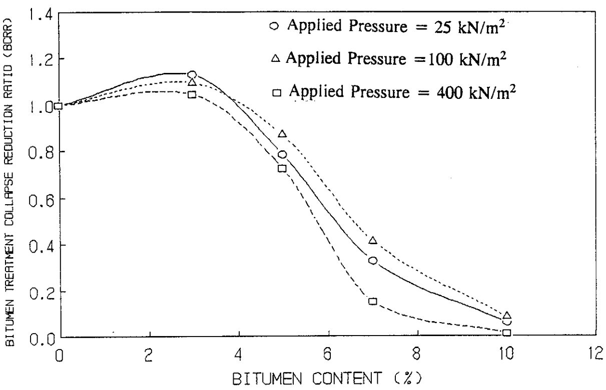

Fig. 15. Variation of bitumen treatment collapse ratio reduction (BCRR) with bitumen content for soil (A) (Mafraq)

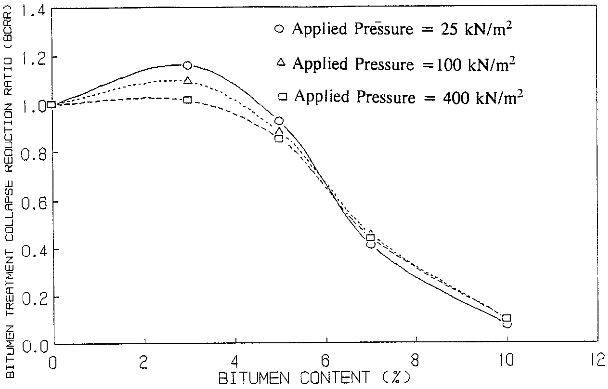

Fig. 16. Variation of bitumen treatment collapse ratio reduction (BCRR) with bitumen content for soil (B) (JUST)

A parameter designated Bitumen Treatment Collapse Reduction Ratio (BCRR) is introduced to show the effect of bitumen on collapse potential characteristics.

BCRR is defined here as the ratio of maximum collapse potential for a treated specimen to an untreated one. Figures 15 and 16 show the variation in BCRR with bitumen percentage for different applied pressures for soil A and B, respectively. In general, these figures show a reduction in BCRR with increasing bitumen percentages in excess of 3%.

CONCLUSIONS

The potential for use of bitumen as a stabilizing agent, was investigated for some selected soils in Jordan which exhibit certain engineering problems, such as swelling and collapsibility. The study included the following:

(a) An investigation and comparison of soil strength in natural and bitumen treated states as obtained from unconfined compression tests.

(b) An investigation of the effectiveness of bitumen in reducing the swelling potential for some selected soils.

(c) An investigation of the effectiveness of bitumen in reducing the collapse potential for some selected soils.

Based on the results of the laboratory tests conducted, the presentation and evaluation of the results, the following conclusions can be drawn:

(1) The cutback bitumen may either increase the cohesion of the soil by binding the particles together, or it may act as a waterproofing agent and maintain the cohesion due to the thin films of bitumen formed between the particles.

(2) An increase in cutback bitumen content reduces both the maximum dry density and susceptibility to water and increases the total moisture content.

(3) Soil swelling and collapse potential are significantly reduced by cutback bitumen treatment.

(4) Cutback bitumen percentages in excess of 7% do not cause a substantial reduction in swelling and collapse potential, indicating that larger proportions will not be very useful.

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