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Cement Stabilization of Kuwaiti Soils

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ABSTRACT. Soil stabilization has come into increasing use due to its economic advantage and because of the scarcity of good natural aggregates. Cement stabilization of Kuwaiti soils is examined herein by means of an extensive laboratory testing program. The amount of cement used varied from 2% to 10% to improve the stability, strength and durability of surface soils. The results are encouraging and indicate the possible use of cemented soils in many application, such as road construction, embankment protection, pipe bedding, and conventional backfills.

Large deposits of sandy soils cover the desert terrain of Kuwait and much of the gulf region. This situation offers great opportunities for skillful use as an engineering material. Since most applications require high strength, stability and durability, the properties of natural soils may have to be altered to create a new material capable of meeting specific requirements. This can be done by several methods, among which are chemical, thermal and mechanical stabilization. In general, no one method is suitable for all soils or all applications.

The use of additives, such as cement or lime, in small quantities is known to improve the strength of the soil well in excess of their proportion (Ingles and Metcalf 1972, Ismael 1976). Even 2% of a given additive will modify considerably the properties of a soil, whereas large amounts will radically alter its properties. This is due, in many cases, to the hydration process which occurs in the presence of water. The use of cement is more suitable than lime for granular soils, but lime is frequently used for soft clayey soils. The strength of a stabilized soil depends on the soil type, its moisture content, the amount of additive used, the density achieved and the curing conditions.

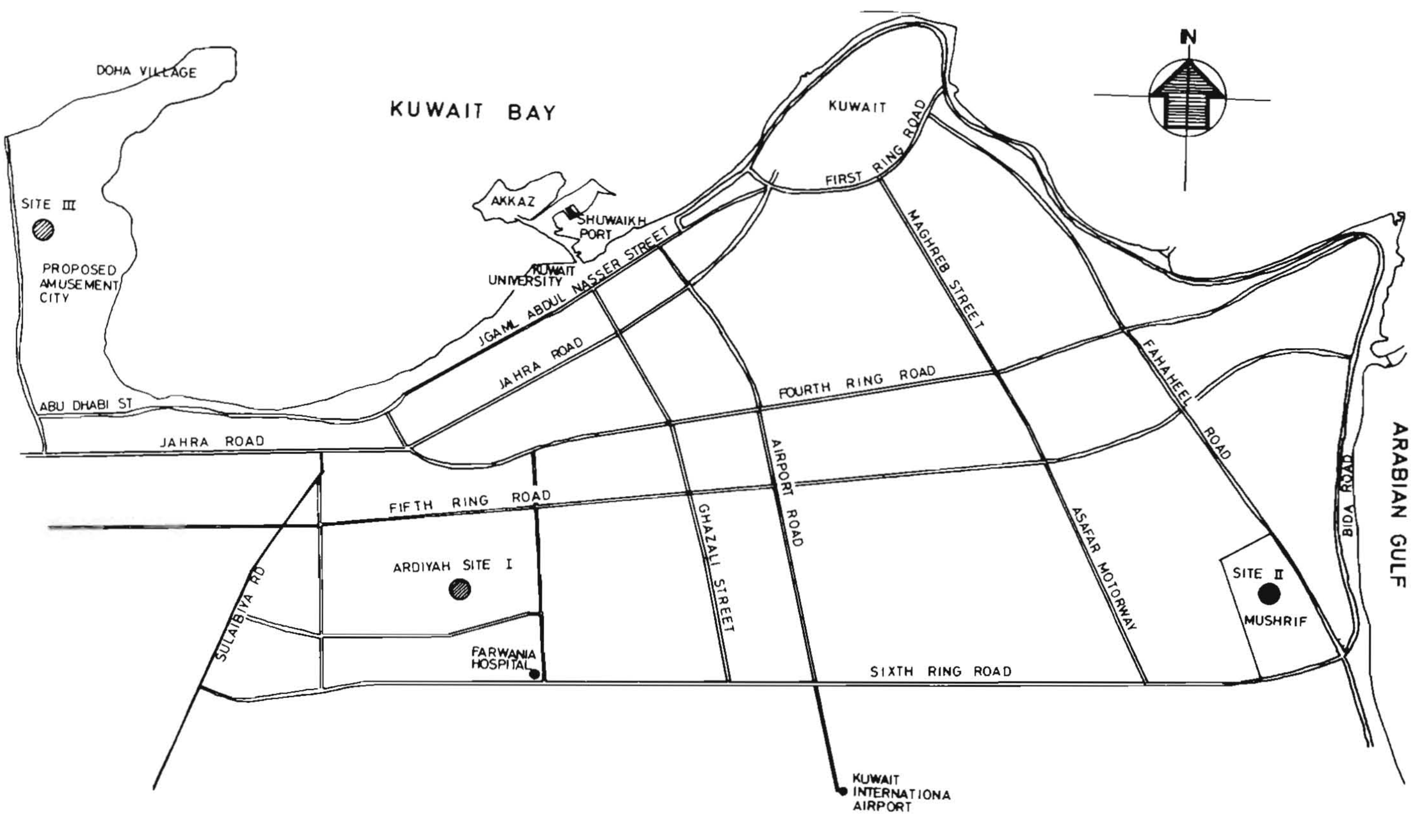

Fig. 1. Plan showing test site locations

To examine the potential use of stabilized soils in Kuwait, three sites were selected for laboratory and field testing and monitoring. These sites were in Ardiyah, Mushrif and Doha, where large urban projects are expected to be built in the next few years and stabilized soils may be used in many applications, such as road construction, paving slopes and lining ditches, embankment protection and cement-treated pipe bedding.

This paper deals with the laboratory tests and results obtained from soil samples recovered from the above sites and stabilized with ordinary Portland cement. The results are presented and interpretations are made as to the suitability of the various mixes for engineering applications. Several model and field applications were subsequently examined and monitored, and these will be presented in a separate follow-up paper.

Soil Conditions

Figure 1 is a location plan showing the three test sites. Surface samples were recovered from the upper 0.6 m with shovels and placed in plastic bags. The bags were sealed and transported to the laboratory for testing.

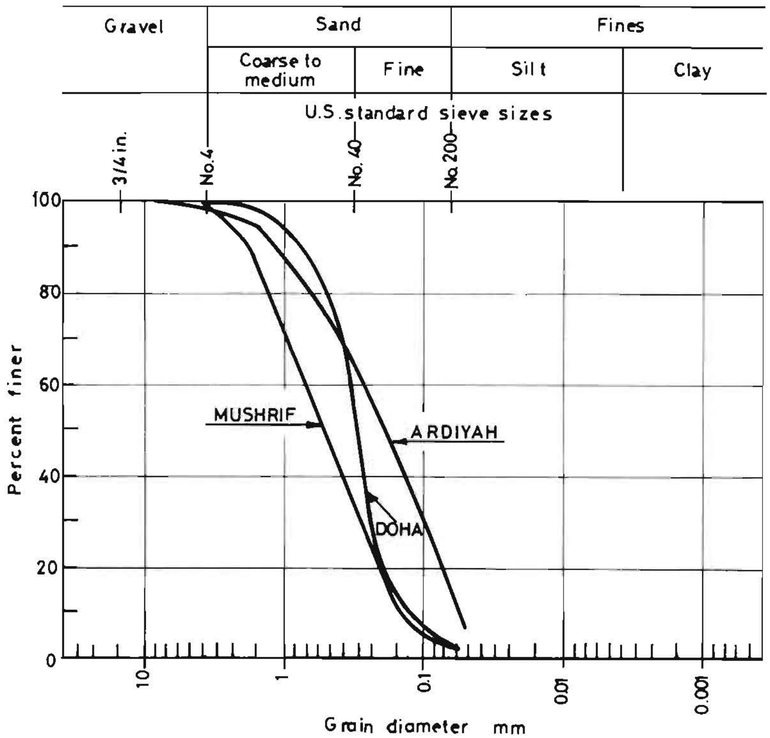

Fig. 2. Grain size distribution curves.

Tests carried out in the laboratory included visual classification and sieve analysis to determine the grain size characteristics. The grain size distribution shown in Fig. 2, for the three soils, indicates fine to medium cohesionless sands with a trace to little silt (SP according to the unified soil classification system). The soil from Doha was found to contain numerous sea shells, indicating shoreline deposits.

Program and Procedure of Laboratory Testing

Ordinary Portland cement produced locally was used as an additive to the three sands. It was added in amounts of 2, 5, or 10% by weight. The soil was first mixed thoroughly with the specified amount of cement at the optimum moisture content. Ten specimens from each mix were then compacted to standard Proctor density in a mould measuring 0.1 m (4 in.) in diameter by 0.11 m (4.5 in.) in height. The specimens were cured in a moist room at the standard room temperature of 20°C and a relative humidity near 100%. Unconfined compressive strength tests were performed after 7, 14. 28 and 90 days. Duplicate tests were conducted and the average value was taken as the compressive strength. Some tests were repeated when suspect results were obtained. All tests were quasistatic and specimens were loaded in equal stress increments of approximately 1/10 the anticipated ultimate strength.

To examine the effect of compacting to less than the maximum Proctor density on the strength characteristics of stabilized soils, unconfined compression tests were performed on samples compacted to 95% relative compaction. The corresponding moisture content did have, of course, two values, one on the wet side and the other on the dry side of optimum. These values were determined from the compaction curve of each test mix prior to sample preparation. As before, tests were carried out after 7, 14, 28 and 90 days of curing.

Special Tests

A few tests were performed to examine the effect of delayed compaction in the field on the strength of cemented soils. To do this, samples were prepared in the standard manner at optimum moisture content and then placed and compacted in the Proctor mould after a delay ranging from 1 to 4 hr.

The durability of cemented soils was investigated by wetting and drying tests on compacted soil-cement mixtures according to ASTM designation D559-57. The soil used here was from the Ardiyah site only and the objective was to determine the losses produced by repeated wetting and drying of hardened soil-cement specimens.

Analysis and Discussion of Test Results

A summary of the mix characteristics and the test results is given in Table 1 for all mixes. Figures 3 to 5 show the strength versus curing time curves up to 90 days of curing for each of the three soils tested. A close examination of Table 1 and Figures 3 to 5 indicates that the strength increases nearly linearly with the cement content and increases at a decreasing rate with time. It is also evident that the values obtained for the Doha soil were the lowest in comparison with Ardiyah and Mushrif soils. This is possibly due to the uniformity of the particle sizes for the Doha soil and the presence of numerous sea shells. Adding 10% cement yielded 90-day strength values ranging from 8500 to almost 15,000 KN/m^2 (1234-2130 psi). The addition of 5% cement resulted in intermediate values between 2750 and 8000 KN/m^2 (400-1164 psi). Based on the minimum strength requirement of 2790 KN/m^2 (405 psi) recommended by several agencies (US TRB 1976) for strength and frost durability, it appears that mixtures with 5% cement and above are acceptable as a road base material. With 2% cement the strength values achieved were unsatisfactory for road construction, but highly desirable for many other applications, such as backfilling, protection of slopes and lining of ditches. These values were about 500 KN/m^2 (73 psi) for the Doha soil, 1760 KN/m^2 (256 psi) for the Ardiyah soil, and 3540 KN/m^2 (514 psi) for the Mushrif soil.

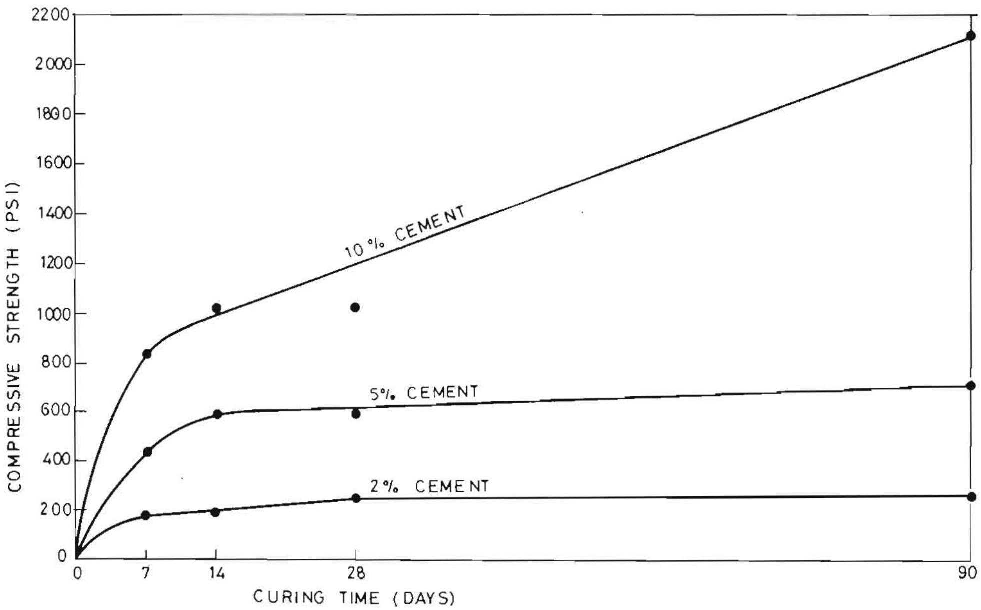

Fig. 3. Compressive strength versus curing time for cement stabilized mixes (Ardiyah).

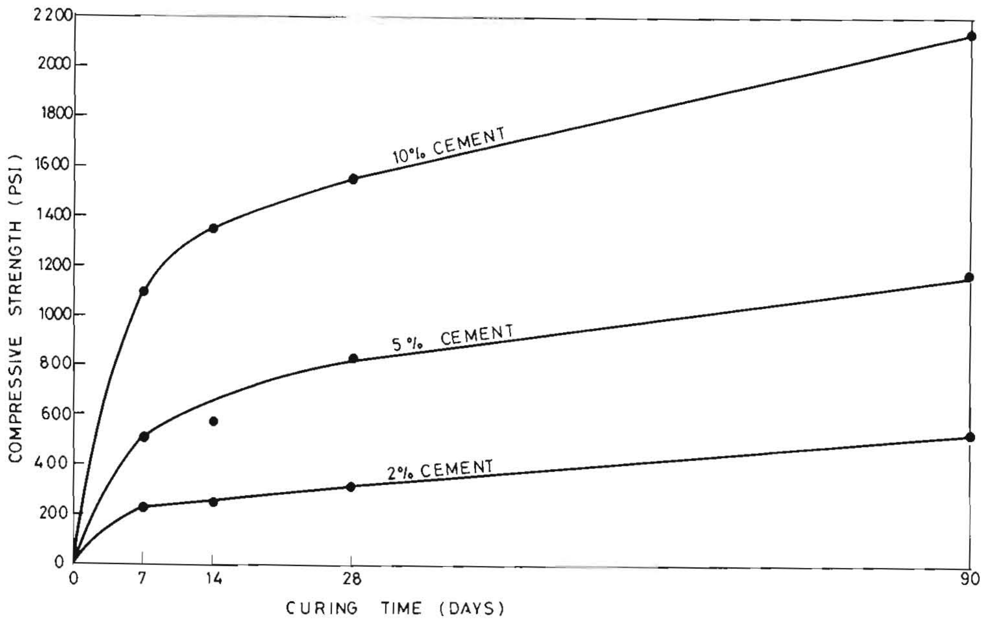

Fig. 4. Compressive strength versus curing time for cement stabilized mixes (Mushrif).

Table 1. Summary of test results for soil cement mixes.

Site Location	Cement Content %	Optimum Dry Density (pcf)	Optimum Wet Density (pcf)	Optimum Moisture Content (%)	28 Days Compressive Strength (psi)	90 Days Compressive Strength (psi)
Ardiyah	10	130.0	141.8	9	1017	2117
Ardiyah	5	129.1	140.8	9	588	709
Ardiyah	2	127.0	138.5	9	242	256
Mushrif	10	132.2	143.5	8.5	1537	2130
Mushrif	5	131.8	143.0	8.5	821	1164
Mushrif	2	130.6	141.7	8.5	314	514
Doha	10	119.0	133.9	12.5	597	1234
Doha	5	115.1	129.5	12.5	187	400
Doha	2	114.2	128.5	12.5	46	73

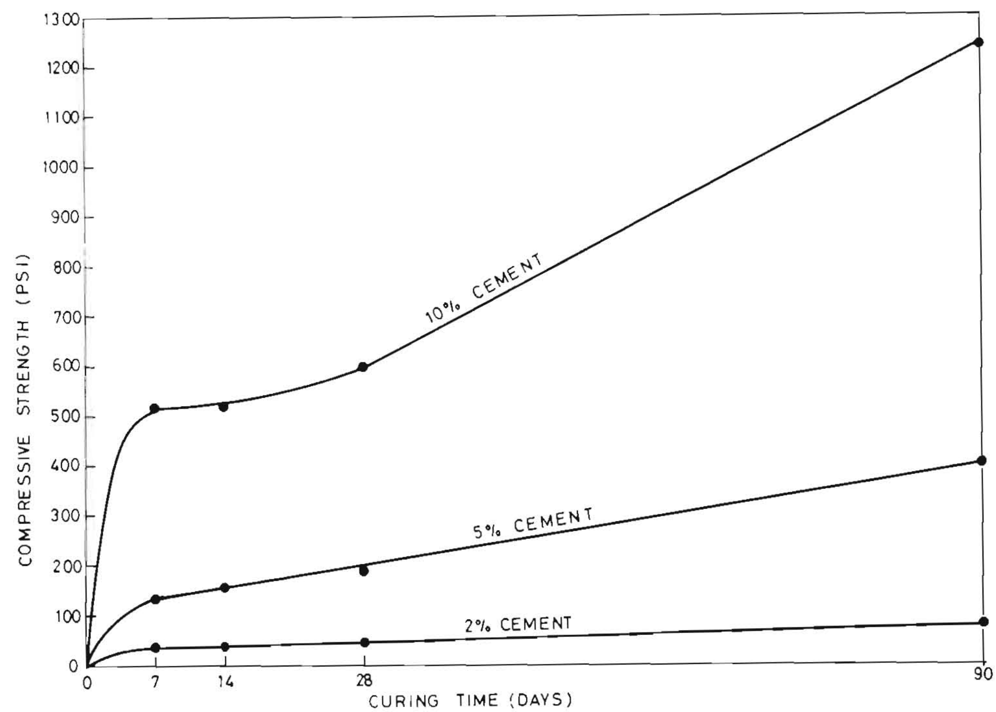

Fig. 5. Compressive strength versus curing time for cement stabilized mixes (Doha).

The stress-strain curves for the test cylinders indicate a linear stress-strain relationship at low stress levels. Figure 6 shows these curves for specimens from Ardiyah tested after 90 days of curing. From these figures the secant modulus, E_{50}, corresponding to a stress of 50% the ultimate strength was determined. Table 2 shows these modulus values.

If a soil cement pavement fails under a wheel load, the failure may be caused by tensile stresses on the underside of the slab or by surface stresses some distance away from the load. Hence, the tensile strength may, therefore, govern the behavior. Although the tensile strength was not investigated herein, other workers (Metcalf 1962) have found that its value, at optimum moisture content and maximum density, will be about 10% of the compressive strength at this condition.

The aforementioned results pertain to samples prepared at optimum moisture content and maximum Proctor density, or at 100% relative compaction. A relative compaction of 95% is probably more realistic in many field conditions. Test results from samples prepared in a similar manner, but at 95% relative compaction, are summarized in Table 3. This table shows, from left to right, the site location,

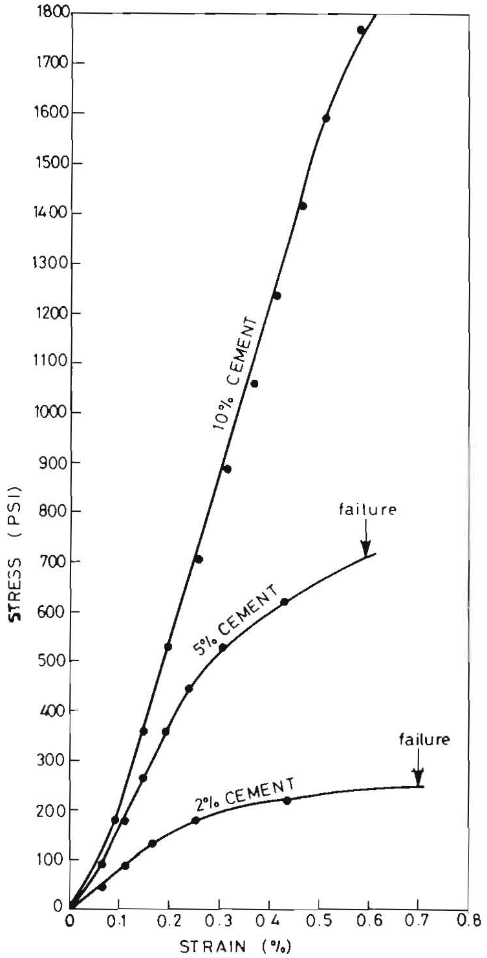

Fig. 6. Stress-strain diagrams for soil cement mixes after 90 days of curing (Ardiyah).

Table 2. Secant modulus values E_{50} of soil cement mixes.

Site Location	Modulus Values in psi (90 Days of Curing)		
	2% Cement	5% Cement	10% Cement
Ardiyah	79,000	186,300	254,700
Mushrif	62,700	196,200	298,500
Doha	16,700	73,100	182,000

Table 3. Comparison between test results at 100% and 95% relative compaction.

Site Location	Cement Content %	90-Day Strength (psi)			% of Maximum Strength	
		$\gamma = 100\%$ (Optimum)	$\gamma = 95\%$ (Dry)	$\gamma = 95\%$ (Wet)	$\gamma = 95\%$ (Dry)	$\gamma = 95\%$ (Wet)
Ardiyah	10	2117	980	1173	46	55
Ardiyah	5	709	345	527	49	74
Ardiyah	2	256	192	223	75	87
Mushrif	10	2130	1304	1361	61	64
Mushrif	5	1164	382	545	33	47
Mushrif	2	514	307	426	60	83

percent additive used, and strength values after 90 days of curing corresponding to 100% and 95% compaction. There are two values for 95% compaction, one corresponding to the dry side and the other to the wet side of optimum. The last two columns show the strength values as a percent of the maximum values.

A close examination of Table 3 indicates that the strength decreased substantially when the relative compaction changed from 100% to 95%. A reduction of nearly 50% was observed in all cases, except those corresponding to 2% cement, where a substantially smaller reductions were recorded. In general, specimens compacted on the wet side of optimum gave more favourable results. Thus, if compaction is to be done at less than 'maximum' density, it is recommended that it be done on the wet side of optimum. This is especially true in hot regions, such as those prevailing in Kuwait and other parts of the Arab Gulf region, because of the possible loss of moisture due to evaporation, particularly in the summer months.

Results of Special Tests

The effect of delayed compaction was explored by laboratory tests on soil-cement mixes from the Ardiyah site cured for 7 days. These results are plotted in Fig. 7. As shown, a marked decrease in strength occurred due to delayed compaction. For samples prepared 4 hr after mixing the strength was less than one half the value achieved if no delay occurred. Hence, it appears appropriate to recommend that, where cemented soils are used, every effort should be taken to prevent compaction delay to avoid substantial loss of strength.

Wetting and drying tests were carried out on cement stabilized Ardiyah soil specimens to examine their durability under repeated cycles of wetting and drying (Ingles and Metcalf 1972). The results were satisfactory for the specimens with 10

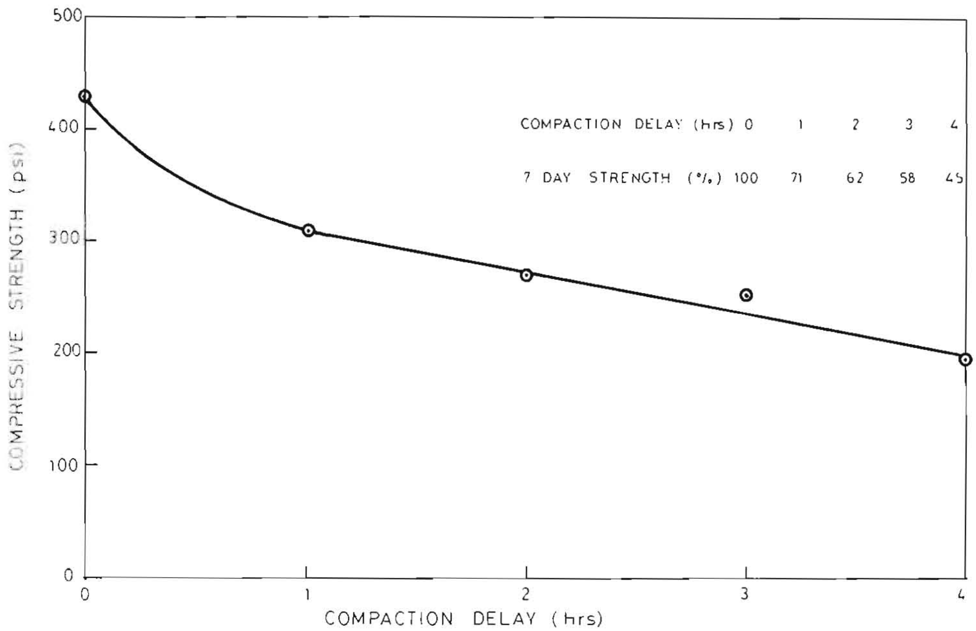

Fig. 7. Reduction in strength due to compaction delay (Ardiyah).

and 5% cement, since the measured weight losses at the end of the test were generally below 10%. For the specimens with a 2% cement additive, however, the results were not satisfactory, because a substantial weight loss was observed.

Conclusion

Based on the results obtained from an extensive laboratory testing program on three local soils stabilized with cement, the following conclusions could be drawn:

1) Sandy surface soils could be stabilized effectively with cement as an additive.

2) The strength increased more-or-less linearly with cement content for all soils; hence, cement stabilized mixes could be recommended for road base materials provided the cement content is 5% or more.

3) When the relative compaction decreased from 100% to 95%, the strength of cemented soils decreased by about 50%.

4) Mixes on the wet side of the optimum moisture content yielded generally more favourable strength values than mixes compacted on the dry side.

5) Delayed compaction of about 4 hr resulted in a significant loss of strength; hence, such practice should be avoided whenever possible.

6) Durability (wetting and drying) tests on cemented soil specimens indicated that soils with 5% to 10% cement are durable.

7) The soils stabilized in this test program could be used for a variety of engineering purposes, such as road bases, paving slopes and lining ditches, embankment protection, cement-treated pipe bedding and backfilling.

Acknowledgements

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The laboratory tests were carried out in the Civil Engineering Department of Kuwait University.

References

Ingles, O.G., and **Metcalf, J.B.** (1972) *Soil Stabilization Principles and Practice*, Butterworths & Co. Ltd., Melbourne, Australia, pp. 103-143.

Ismael, N.F. (1976) Lakeview GS-Coal ash stabilization study, *Ontario Hydro Research Division Report No.* 76-441-H, pp. 1-4.

Metcalf, J.B. (1962) A preliminary study of the tensile stresses in stabilized soil pavements, *Proc. 1st Conference of the Australian Road Research Board*, Vol. 2, pp. 1048-1057.

National Cooperative Highway Research Program, Synthesis 37 (1976) *Lime-Fly Ash Stabilized Based and Subbases*, U.S. Transportation Research Board, pp. 61, 66.

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تثبيت التربة السطحية الكويتية بالأسمنت

نبيل فتحى إسماعيل
كلية الهندسة والبترول - جامعة الكويت - الكويت

تثبيت التربة يعنى معالجتها بإضافات قليلة من مواد أخرى لتحسين خواصها واستخدامها فى الأغراض الهندسية. وقد ازداد استخدام هذه الطريقه حديثا لنقص الركام الطبيعى الجيد فى مناطق كثيرة ولما لها من فائدة اقتصادية ملموسة.

ويقدم البحث نتائج دراسة مختبرية عن تثبيت التربة الكويتية بالأسمنت البورتلاندى العادى. وقد استخدم الأسمنت بنسبة تتراواح بين ٢٪، ١٠٪ بالوزن لتحسين خواص التربة. وتشمل هذه الخواص قوة تحملها وثباتها تحت تأثير الأحمال. ويظهر البحث نتائج طيبة تشجع على استخدام التربة المعالجة بالأسمنت فى أغراض عديدة منها إنشاء الطرق، وحماية الجسور، وكقاعدة تحت شبكات المواسير، وفى أعمال الردم حول الأساسات والحوائط.