RESEARCH NOTE

COMPRESSIVE STRENGTH-FREEZE AND THAW DURABILITY CORRELATION IN SOIL-CEMENT DESIGN

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Abstract This paper explains the procedure and results of an experiment on the relationship between the unconfined compressive strength and percent weight loss due to freeze and thaw durability test of laboratory compacted soil-cement specimens. The tests were carried out on soil cement mixtures of 10 different soil types. It was shown that the percent weight loss due to freeze and thaw durability test (F&T) and the 28-day compressive strength (UCS) may be correlated with some error. However, using the graph given in this paper, the designer may estimate the percent weight loss with an error in the order of 2 percent. The 28-day UCS values are linearly correlated with the UCS values of the similar specimens subjected to the F& T durability tests with a regression factor of o.96.

Key Words SoilöCement, Compressive Strength, Freeze and Thaw Test, Slope Protection

[illegible]

INTRODUCTION

Soil-cement is a highly compacted mixture of soil, portland cement, possibly admixtures including pozzolans and water [1,2]. In concrete, for example, strength of soilö cement increases with time and development of strength begins as soon as water and cement are mixed [3]. Density of soilö cement is usually measured in terms of dry density, and the moistureö density test (ASTMö D558-82) is used to determine optimum moisture content and maximum dry density [4]. Adding of cement to a soil generally causes some change in both the optimum moisture content and maximum dry density for a given compaction effort. Of course, the direction of this change is not usually predictable [2], however, for a given cement content the higher the density, the higher the compressive strength of cohesionless soilö cement mixture [5]. Delays between the mixing of soilö cement and compaction influence both density and strength. A delay of longer than 2 hours between mixing and compaction considerably decreases both density and compressive strength [6]. Under otherwise identical conditions, properties of soilö cement depend on the base soil plasticity index and fines content. Generally, as the clayey portion of the soil increases, the quantity of the required cement increases [2]. In order to maintain a uniformity of soilöcement properties the sample preparation requires closely controlled mixing,compacting and curing condition [3].

Cement stabilized soils are most frequently characterized by the unconfined compressive strength (UCS) and the required cement is generally based on this parameter [7]. However, design of soilö cement solely in terms of compressive strength is not satisfactory and some other requirements should be met with respect to the nature of project and environmental conditions. With respect to channel and earth dam upstream linings using soil-cement the freeze and thaw (F&T) durability is considered as a second requirement [1]. According to USBR for slope protection of dams and similar cases, using soilö cement, the minimum specimen 7, 28 day UCS and maximum specimen weight loss after 12 cycles F & T test should be 4000, 6000 kN/m^2 and 8 percent, respectively [1]. To withstand the abrasive force of storm water flows of 700 to 1300 m^3/sec at velocities up to 6 m/sec, the soil cement is designed for a minimum 7 day UCS of 5000 kN/m^2 [7].

In practice, engineers are interested in making an estimation of durability with respect to the results of UCS test only. The reason is that UCS test is simple and straightforward, while the durability tests generally are time consuming and comparatively difficult to conduct. Durability tests also depend, to a great extent, on the skill and consistency of the operator, which might affect the reliability and reproducibility of the tests [8]. An attempt to establish the relationship between compressive strength and percent of samples passing ASTM freezeö thaw and wetö dry durability tests disclosed that a compressive strength of 5500 kN/m^2 would be adequate for all soils, but this strength would be higher than that of needed for most soils and would result in a conservative and more costly design [2,9].

This paper explains the procedure and results of an experiment designed to investigate the relationship between UCS and percent weight loss due to F&T durability test. The other point of intrest of this research was to evaluate the change of UCS value after termination of F & T cycles. This is valuable as a long term field strength index. The soil cement specimens of 10 different soil types were prepared and cured under the specified condition, and then tested for UCS and F & T durability.

EXPERIMENT

Materials Ten different types of soils were collected from 10 different borrow pits in Moghan flat in the north of Azarbaijan province of Iran. Moghan flat is an agricultural area where important main irrigation channels are propsed to be protected with soilöcement.

The soil specimens were tested for the usual engineering properties, and the results are summarized on Tables 1 and 2.

Type 2 Portland cement was mixed with all soils except soil No. 8. This soil which had comparatively higher sulfate content, was mixed with a type 5 Portland cement.

Water is necessary to help obtain maximum compaction and hydration of the Portland cement. Potable water, free from harmful chemicals, was used in this research.

Specimens Preparation and Tests Procedures In order to achive comparatively consistent and

TABLE 1. Physical Properties of Natural Soils.

Soil No.	Proctor Compact.		Classification		Percent Finer[1]			Atterberg Limits		
	m_{opt} %	g_{dmax} kN/m^3	USCS	AASHTO	4.75 mm	0.076 mm	0.002 mm	LL %	PL %	PI %
1	19.0	17.3	CL	Aö6	100	82	25	33	22	11
2	18.5	17.4	CL	Aö4	99	79	22	31	20	10
3	17.0	17.5	CL	Aö4	98	75	16	30	22	8
4	15.0	18.1	ML	Aö4	93	75	3	21	ö	NP
5	15.0	17.9	ML	Aö4	100	73	4	20	ö	NP
6	16.0	17.7	ML	Aö4	100	82	6	25	22	3
7	14.0	18.9	CL	Aö6	68	52	16	38	22	16
8	9.0	21.5	GM	Aö2ö4	53	25	6	25	18	7
9	16.0	18.2	CL	Aö6	84	66	19	37	21	16
10	13.5	18.6	SM	Aö4	90	45	2	19	ö	NP

1. D_{max} = 19 mm

TABLE 2. Chemicals Contents of Natural Soils.

Soil No.	1	2	3	4	5	6	7	8	9	10
Total So_3 (%)	0.05	0.20	0.15	0.54	0.54	0.10	0.40	4.6	0.13	0.03
Waterö Soluble So_3 (%)	0.01	0.05	0.07	0.23	0.15	0.08	0.36	0.13	0.05	0.01
Chloride Content. (%)	0.005	0.003	0.002	0.004	0.003	0.002	0.001	0.002	0.021	0.003

comparable strength and durability values, the cement content ranges were adopted with respect to the plasticity indexes and fines contents of the soils.

With each of the soils, three series of compacted soil-cement specimens of different cement contents were prepared, cured and tested for UCS and F & T durability.

The specimens were prepared according to ASTMö D 1632ö 87 using proctor compaction effort, ASTMö D 688 [4]. The specimens were 101 mm in diameter and 116 mm in height. The compaction maximum densities (g_{dmax}) and the optimum moisture contents were determined according to ASTM Dö 558ö 82 (approved 1990) [4]. The soil, cement, and water contents of the specimens, together with the densities and moisture contents are summarized in Table 3. In this table, the C/S, m_o, g_{dmax}, and g_m, denote the cement/soil weight ratio, optimum moisture content, maximum dry density, and wet density, respectively.

The specimens, produced according to Table 3, were cured in comply with ASTMö D 1632, and then tested for UCS, and 12 cycles F&T durability, according to ASTMö D 1633ö 38, and ASTMö D 560ö 89, respectively [4]. Two specimens were used for each test and the results were averaged. The UCS tests were carried out on 7, 28 and 52 day specimens under 2 mm/min constant strain rate. The resulted strengths were modified according to ASTMöD 1633 for diameter/height ratio effect [4]. The F&T durability tests were conducted only on 28-day specimens.

In order to evaluate the effect of F&T process over UCS, the specimens which had been tested for F&T durability were also tested for UCS, immediately afterward. This was carried out to gain insight on the long-term

TABLE 3. Compositions and Densities of Specimens.

Soil No	C/S %	m_o %	g_m kN/m^3	g_{dmax} kN/m^3	Soil kg/m^3	Cement kg/m^3	Water kg/m^3	Soil No	C/S %	m_o %	g_m kN/m^3	g_{dmax} kN/m^3	Soil kg/m^3	Cement kg/m^3	Water kg/m^3
	20	17.0	20.50	17.52	1461.7	286.5	292.3		15	16.0	20.45	17.63	1503.9	225.6	276.6
1	25	17.5	20.65	17.57	1378.3	344.3	302.1	6	20	16.5	20.60	17.68	1445.0	289.4	286.4
	30	19.0	20.70	17.39	1312.6	393.4	324.7		25	16.5	20.75	17.81	1397.9	349.5	288.4
	20	17.0	20.55	17.56	1435.2	287.4	293.3		15	15.0	21.65	18.83	1605.9	241.3	276.6
2	25	17.0	20.60	17.61	1382.2	345.3	293.3	7	20	15.5	21.70	18.79	1536.2	307.0	285.5
	30	18.0	20.70	17.54	1323.4	397.3	310.0		25	15.5	21.80	18.87	1481.3	369.8	287.4
	20	16.0	20.55	17.71	1448.0	289.4	278.6		10	9.5	22.95	20.95	1958.1	187.4	195.2
3	25	16.5	20.70	17.77	1395.0	348.3	287.4	8	15	10.0	22.85	20.72	1694.2	338.4	223.7
	30	17.0	20.70	17.69	1335.1	400.2	295.3		20	11.0	23.00	20.72	1694.2	338.4	223.7
	15	15.5	20.55	17.79	1517.6	227.6	270.8		25	16.0	20.80	17.93	1406.8	352.2	281.5
4	20	16.5	20.75	17.81	1455.8	291.4	288.4	9	30	16.0	20.70	17.84	1345.9	404.2	280.7
	25	16.0	20.95	18.06	1417.5	354.1	283.5		35	16.5	20.60	17.68	1285.1	449.3	286.4
	20	15.5	20.65	17.88	1461.7	292.3	271.7		10	13.5	20.60	18.15	1618.7	161.9	240.3
5	25	16.5	21.10	18.11	1421.5	355.1	293.3	10	15	13.5	20.80	18.33	1563.7	234.5	242.3
	30	16.5	21.20	18.20	1373.4	412.0	294.3		20	14.0	20.90	18.33	1499.0	299.2	252.1

C = Cement, S = Soil, m_o = Optimum moisture content, g_{dmax} = Max. dry density, g_m = Wet density

compressive strength of soil-cement during the service life.

The results of these tests all are plotted in Figures 1 to 4.

DISCUSSION

The UCS development trends of soil-cement specimens are all plotted in Figure 1. The soils 3 and 4, and also the soils 1 and 6 are the same in fines contents, while they are different in Atterberg limits. Both soils 4 and 6 are of 8 percent less plasticity (PI) than soils 3 and 1, respectively, For identical cement contents, soil-cement specimens of both soils 4 and 6 show a 28 day UCS increase in the order of 12 percent in comparison with that of soils 3 and 1, respectively.

It appears that for a constant percent of cement and fines content, any 8 percent increase or decrease in plasticity index causes about 12 percent decrease or increase in 28 day UCS value. In the same figure, soils 7 and 9 are the same in plasticity index but different in fines content. For identical cement contents, the soil-cement specimens of soil 7 indicate higher compressive strengths than that of soil 9. These behaviors indicate that the higher the fines content and/or plasticity index the lower the UCS values. A comparison between the results of UCS values of soils 9 and 10 indicates that, as the fines content and/or plasticity index increases, the required cement content to achive the required strength increases and makes the job uneconomical.

In Figure 2 the results of 28 day UCS tests and F&T durability tests are shown. It is seen that the lower and the upper limits of the changes of percent weight loss in terms of UCS values are comparatively apart and a correlation between the percent weight loss due to F&T test and 28 day UCS value is possible with some error only. This may be partially attributed to the percent and the electrostatic charge of fines content. However, the average curve may help

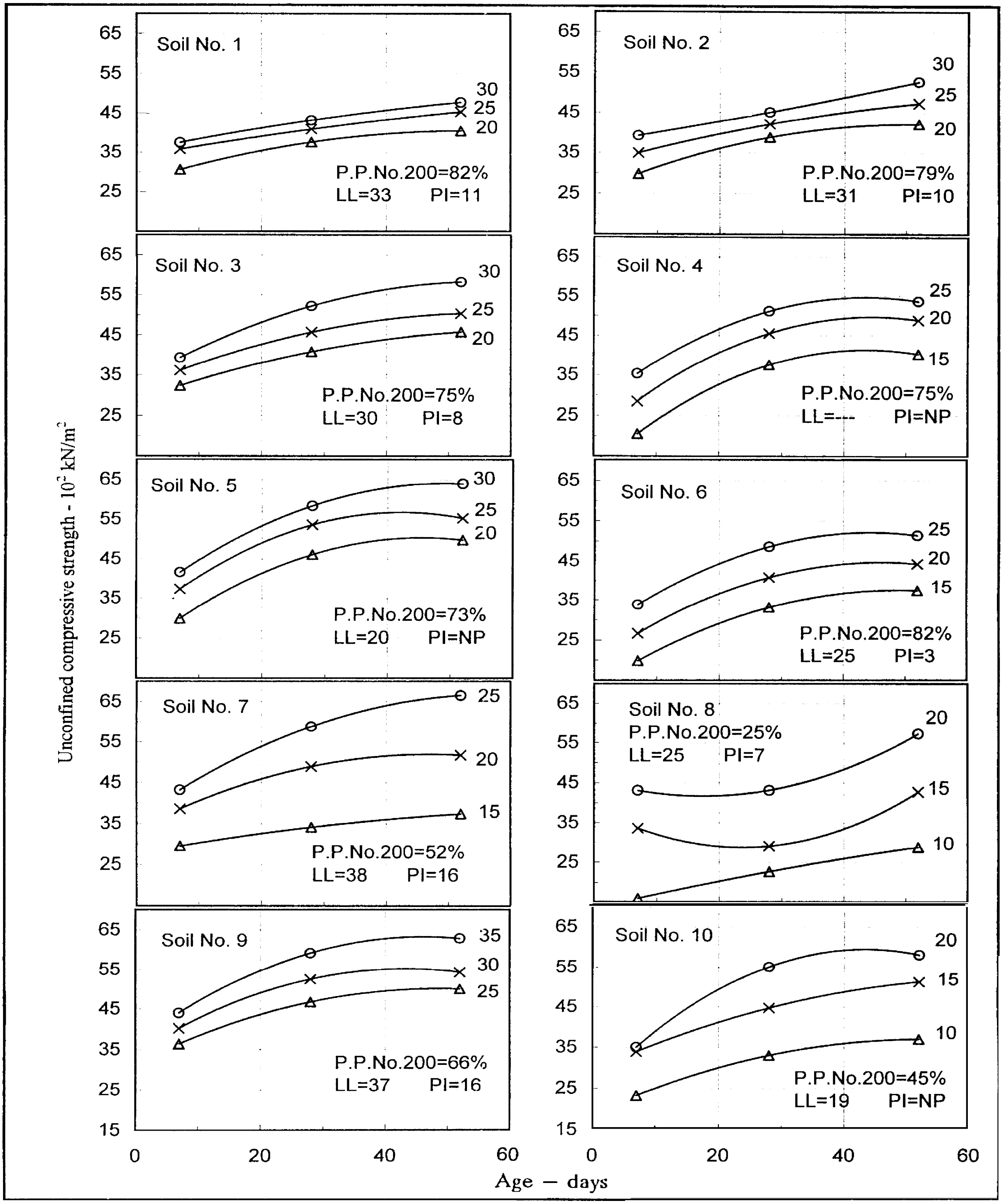

Figure 1. UCS development of soilöcement specimens.
Numbers on each graph are the cementösoil ratios in percent.

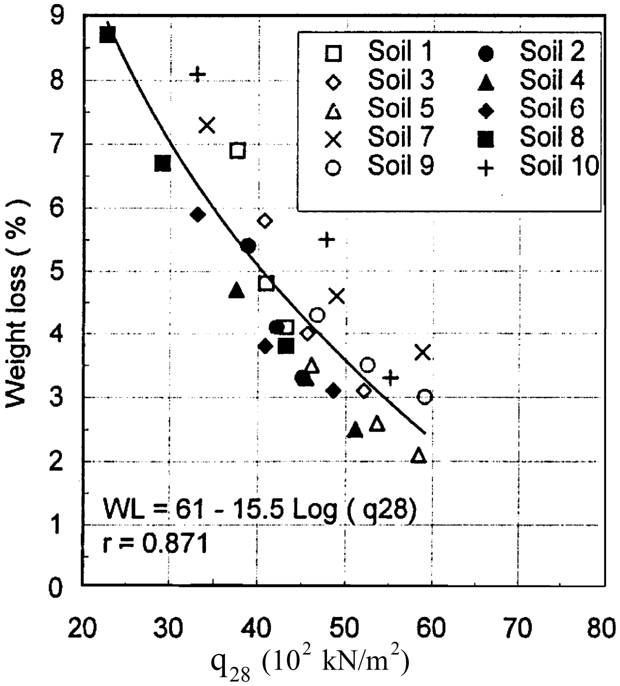

Figure 2. Relation between 28 day UCS and percent weight loss due to F&T durability test.

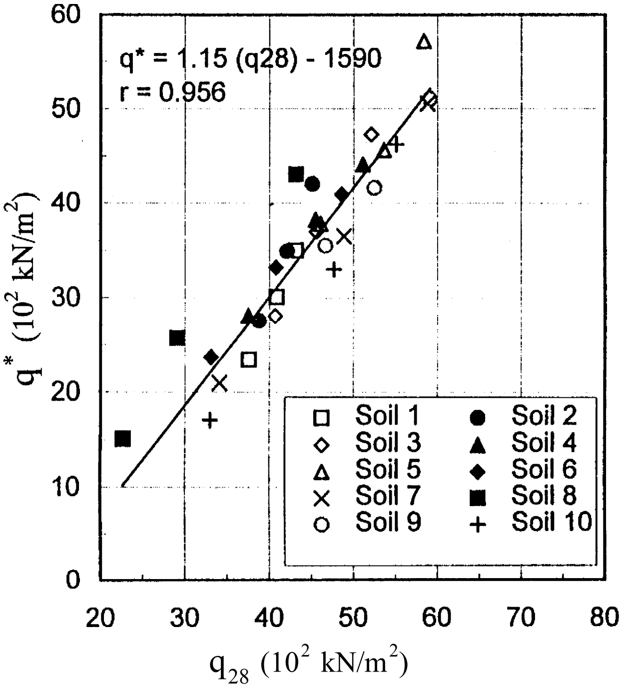

Figure 3. Relation between 28 day UCS values and UCS values after F&T test.

the designer to estimate the percent weight loss with an error in the order of 2 percent. Finally, the results obtained appear to encourage further pursuit of this concept.

In Figure 3 the 28 day UCS values (q_{28}) are correlated with the UCS values of the similar specimens subjected to the F&T durability tests (q^*). It is observed that these behaviors are linearly correlated with a regression factor of 0.96. If it can be assumed that the q^* is the end of service life UCS value, then one can visualize the strength of a soil-cement work in long term.

In Figure 4 the percent weight loss due to F&T test and the percent UCS loss Dq* due to the same test are correlated. The Dq* is defined as (q_{28}ö q^*)/ q_{28}, in percent. It is seen that these behaviors are also linearly correlated with a regression factor of 0.95, which is satisfactory.

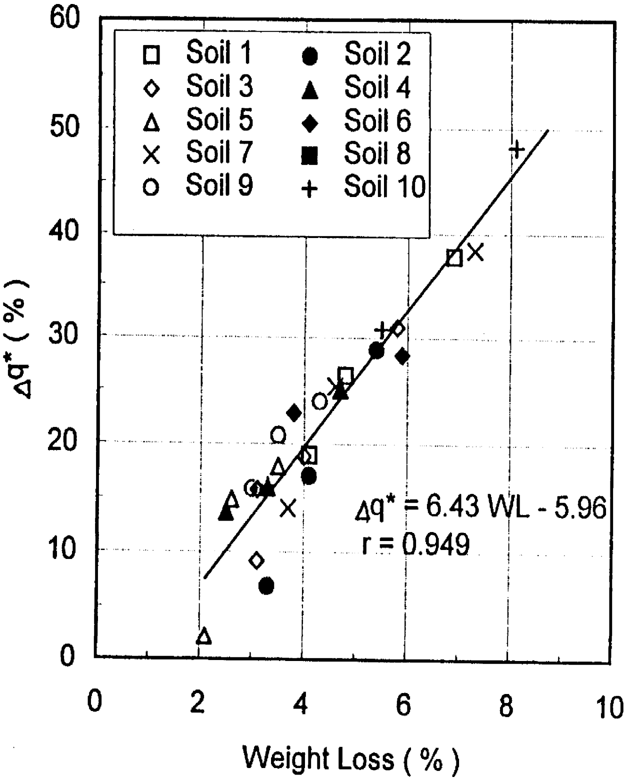

Figure 4. Relation between percent weight loss due to F&T test and percent UCS loss due to the same test.

CONCLUSIONS

1. For identical cement contents, the higher the

fines content and/or plasticity index the lower the unconfined compressive strength (UCS).

2. The percent weight loss due to F&T test and the 28 day UCS value can be correlated with some error. However, the average curve in Figure 2 may help the designer to estimate the percent weight loss with an error in the order of 2 percent. The results obtained appear to encourage the further pursuit of this concept.
3. The 28 day UCS values (q_{28}) are linearly correlated with the UCS values of the similar specimens subjected to the F&T durability tests (q^*) with a regression factor of 0.96.
4. The percent UCS loss (Dq*) and the percent weight loss due to the F&T test are linearly correlated with a regression factor of 0.95.

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