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The Effect of Treated Waste-Water on Compaction and Compression of Fine Soil

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***Abstract*—**The main objective of this paper is to study the effect of treated waste-water (TWW) on the compaction and compressibility properties of fine soil. Two types of fine soils (clayey soils) were selected for this study and classified as CH soil and Cl type of soil. Compaction and compressibility properties such as optimum water content, maximum dry unit weight, consolidation index and swell index, maximum past pressure and volume change were evaluated using both tap and treated waste water. It was found that the use of treated waste water affects all of these properties. The maximum dry unit weight increased for both soils and the optimum water content decreased as much as 13.6% for highly plastic soil. The significant effect was observed in swell index and swelling pressure of the soils. The swell indexed decreased by as much as 42% and 33% for highly plastic and low plastic soils, respectively, when TWW is used. Additionally, the swelling pressure decreased by as much as 16% for both soil types. The result of this research pointed out that the use of treated waste water has a positive effect on compaction and compression properties of clay soil and promise for potential use of this water in engineering applications.

***Keywords*—**Consolidation, proctor compaction, swell index, treated waste-water, volume change.

I. INTRODUCTION

THE depletion of natural resources, the global water stress and the emissions of greenhouse gases are the environmental issues of greatest concern nowadays. As a result, sustainable development, which involves meeting humans' demands while causing minimal damage to the environment, is encouraged in every aspect of a society. The construction industry is one of the largest industries in the world, and is one of the largest contributors to greenhouse gas emissions and to depletion of natural resources. The construction industry worldwide is responsible for about 25% of the global yearly wood harvest, 40% of stone, sand and gravel use, 16% of water use and 50% of the global emissions of greenhouse gases [1]. Chappat and Bilal have conducted an extensive investigation into the contribution of road construction in energy consumption and greenhouse gases emissions for every one ton of product used in road construction from extraction to sale. Some of the results of the study have shown that 1 ton of bitumen produces 4900 MJ of energy and 285 kg of CO_2; 1 ton of cement produces 4976 MJ of energy and 980 kg of CO_2; 1 ton of crushed aggregates produces 40 MJ of energy and 10 kg of CO_2; and 1 ton of water produces 10 MJ of energy and 0.3 kg of CO_2 [2]. Therefore, several studies have been conducted on the use of recycled aggregates or other recycled materials in pavements. A study assessed the effects of using recycled concrete aggregate (RCA) with reclaimed asphalt pavement (RAP) in pavement subbase on the California bearing ratio (CBR), proctor compaction, LA Abrasion as well as on other properties of the subbase, and the results showed that RCA with 15% RAP content can be used for low traffic usages [3]. Another study has shown that pavement subbases constructed from 100% RAP resulted in uneven distribution of stresses and caused large deformations; however, RAP or cemented limestone quarry fines (CQF) stabilized with lime or cement or virgin aggregate can improve their performance as base material [4]. Several other studies have shown that wastewater treatment sludge stabilized with fly ash can be used for soil stabilization or as construction material in road embankments [5]-[7]. However, there is very limited research on the use of treated wastewater or reclaimed water in pavement construction. A study by Urena et al. investigated the effect of using olive mill wastewater (OMW), which is a byproduct of the olive oil industry, on the physical properties of expansive soils. The results have shown that the use of OMW reduced the swelling pressure and the plasticity index, and increased the maximum dry density and CBR of the soil [8]. In addition, a study by Chola et al. investigated the use of wastewater effluents in concrete pavements and the results have shown that at 95% confidence interval, the compressive strengths of the concrete specimens prepared using the wastewater effluents were not statistically different from the control samples [9]. Another study by Mahdy and Kandil has shown that the CBR results of unbounded crushed limestone base course material using reclaimed water varied only from -2.3% to -6.3% from the control samples, and the CBR results of unbounded crushed dolomite base course material with reclaimed water varied from -1.2% to -2.4% from the control samples. Thus, the results of the study have shown that reclaimed water can be used in the compaction of unbounded road base course materials [10].

II. METHODOLOGY

Two types of soil were selected and used in this research. The initial physical properties of the two soils such as

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gradation, Atterberg's limits, and compaction properties were determined in accordance with ASTM standard procedures. The physical properties were evaluated using tap water. Unified soil classification system was used to classify the soil. It was classified as CH (Highly plastic clay) and Cl (Low plastic clay).

To determine the effect of replacing the tap water with TWW on the properties of the soil, Chemical analysis tests were conducted on the two water types. The results were compared with the USEPA 2012 guidelines for Water Reuse and with the ASTM C1602 specifications, to determine the acceptability of the use of the water in soil. The results have shown that both water types comply with the specifications and can be used in the construction industry.

Standard proctor density test was conducted on the two soils using the two types of water. Then, identical specimens that have the same initial dry densities and water contents from each type of soil were prepared using both tap water and TWW.

To evaluate the consolidation parameters such as consolidation index C_c and swell index C_r, standard consolidation test was conducted on the prepared samples. The soil was prepared in the consolidometer ring with predetermined dry density and initial water content. The specimen was placed in the one consolidometer device. The water is added to the sample under the standard seating load. Increment of pressure is added on the soil for consolidation. Also, Consolidation test is used to evaluate the effect of TWW on volume change of the soils.

Zero swell test was conducted to determine the swelling pressure value of soils treated with TWW. In this test, the sample is prepared in the consolidometer ring and placed in the one dimensional consolidometer device. The sample is not allowed to swell due to the addition of water by adding convenient load through the test. The maximum pressure that prevents the sample from further swelling is defined as the swelling pressure of the soil.

III. PROPERTIES OF SOIL SAMPLES

Tests were conducted on the two types of soil used in the study, and the results of the gradation, Atterberg's limits and compaction properties were determined as shown in Table I.

TABLE I
SOIL PROPERTIES

	Soil 1	Soil 2
Grain size distribution		
Clay, %	64	41
Silt, %	27	40
Sand, %	9	19
Atterburg's limits		
LL, %	59	37
PL, %	21	17
PI, %	38	20
Compaction		
γd,max	13.3	14.1
wop	33	20.8
Gs	2.67	2.65
USCS Classification	CH	CL

IV. PROPERTIES OF WATER SAMPLES

Chemical analysis tests were conducted on both the tap water and the treated wastewater, and the results of the tests were compared with both the USEPA 2012 guidelines for Water Reuse and with the ASTM C1602 specifications. The results have shown that both water types comply with the specifications and can be used in the construction industry, as shown in Table II.

TABLE II
CHEMICAL ANALYSIS RESULTS OF WATER

Test	**Test Method**	**Test Result**		**USEPA Guidelines**	**ASTM Specifications**
		Tap Water	TWW		
Chemical Oxygen Demand (mg/L)	APHA 5220 B	< 10	< 10	-	-
BOD 5 Days (mg/L)	APHA 5220 B	6	7	≤ 30	-
Total Dissolved Solids (mg/L)	APHA - 2540 C	170	670	-	< 50000
Total Suspended Solids (mg/L)	APHA - 2540 D	12	14	≤ 30	
pH Value at 22.3 C	BS1377:1990 Part 3 Cl. 9	7.9	8	6-9	-
Ammonia Nitrogen as $\boldsymbol{NH_3 - N}$ (mg/L)	SALICYLATE METHOD	0.01	0.01	-	-
Sulphate Content as $\boldsymbol{SO_4}$ (g/L)	BS1377:1990 Part 3 CI. 5.5	0.03	0.1	-	< 3
Chloride Content (%)	BS1377:1990 Part 3 CI. 7.2	0.01	0.01	-	< 0.05
Total Hardness (mg/L)	APHA 2340 B / IHTP 17	64	172	-	-
Calcium Carbonate as CaCO3 (mg/L)	APHA 3120 B	48	69	-	-

V. RESULTS

A. Proctor Compaction Test Results

Standard Proctor compaction tests were conducted on both soil types: low plastic soil and highly plastic soil, using the two water types: tap water and TWW, and the proctor compaction curves obtained as shown in Figs. 1 and 2 for low and high plastic soils, respectively. The results of the tests have shown that for the low plastic soil, the optimum moisture content was slightly higher when tap water was used than when TWW was used. Also, the maximum dry unit weight was slightly higher with TWW than with tap water, as shown in Fig. 3. For the highly plastic soil, the optimum moisture content was lower for the TWW water than with the tap water. The optimum water content decreased as low as 13.6%. However, the maximum dry unit weight was higher for the

TWW than for the tap water, as shown in Fig. 4. The differences in the results are displayed as the percentages reduction in moisture content when TWW was used over tap water, and as percentage increases in maximum dry unit weight when TWW was used over tap water. Those results are shown in Fig. 5.

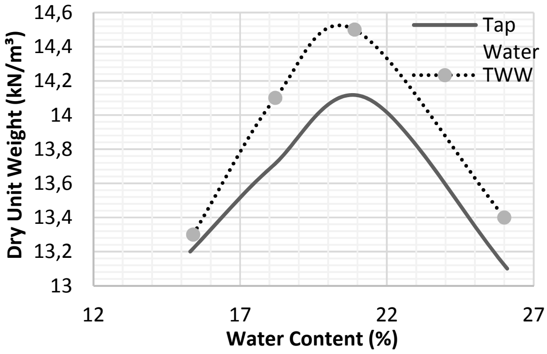

Fig. 1 Compaction Curve for low plastic soil

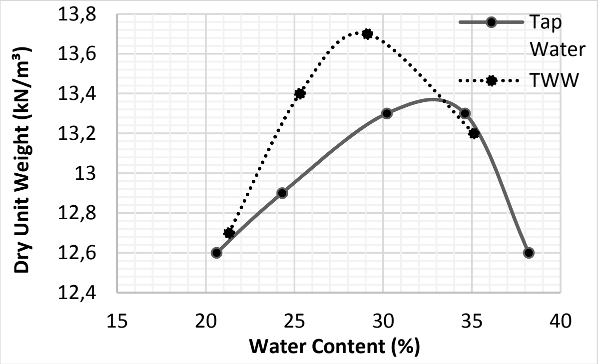

Fig. 2 Proctor Compaction Curve for high plastic soil

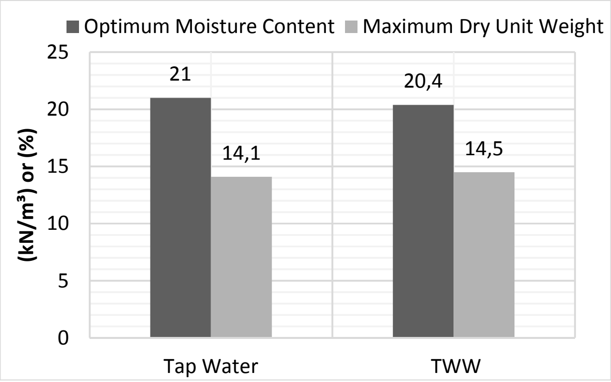

Fig. 3 Optimum moisture content and maximum dry unit weight for low plastic soil

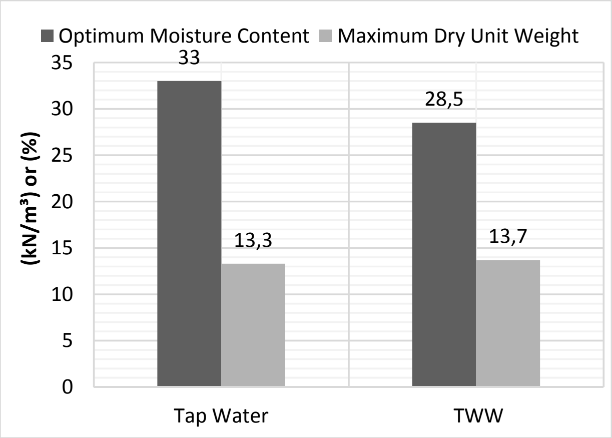

Fig. 4 Optimum moisture content and maximum dry unit weight for high plastic soil

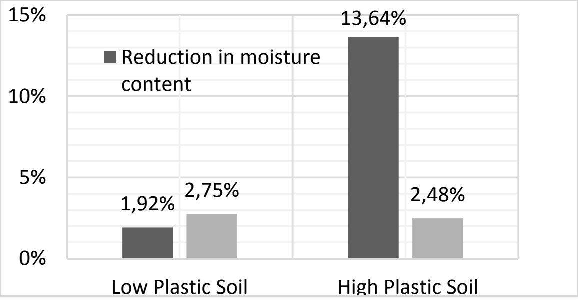

Fig. 5 Reductions in moisture contents and increases in maximum dry unit weight due to TWW

B. *Consolidation Test Results*

One dimensional consolidation tests were conducted on both soil types using the two water types. The e-log p curves for low and highly plastic soil are shown in Figs. 6 and 7 respectively. The values of consolidation and swelling properties of low plastic and highly plastic soil are shown in Tables III and IV respectively. The results showed that, for the low plastic soil, both the compression index and the swell index are lower with TWW than with tap water. Also, the maximum past pressure is 1.62 kg/cm² for TWW, which is lower than the 2 kg/cm² for tap water. For the highly plastic soil, the results are similar as to those of the low plastic soil, showing that the consolidation index and the swell index are also lower when TWW was used. Additionally, the maximum past pressure of the soil was decreased when TWW was used. It decreased from 1.9 kg/cm² for TWW water to 1.7 kg/cm² for tap water. The swelling pressure of the two soils has been also evaluated. The test results showed that both the swelling pressure and volume change have been affected by TWW water. The swelling pressure for the low plastic soil decreased from 3.1 kg/cm² for tap water to 2.6 kg/cm² for TWW water and the volume change decreased from 17% for tap water to 9% for TWW. For the highly plastic soil, the same trend was observed. The swelling pressure decreased from 4.3 kg/cm² for tap water to 3.6 kg/cm² for TWW and the volume change decreased from 30% for tap water to 21% for TWW. Overall, the results showed that, for soil types, the consolidation index, swell index and maximum past pressure were less when TWW was used in-place of tap water. Also, for both soil types, the swelling pressure and the volume change decreased when TWW was used.

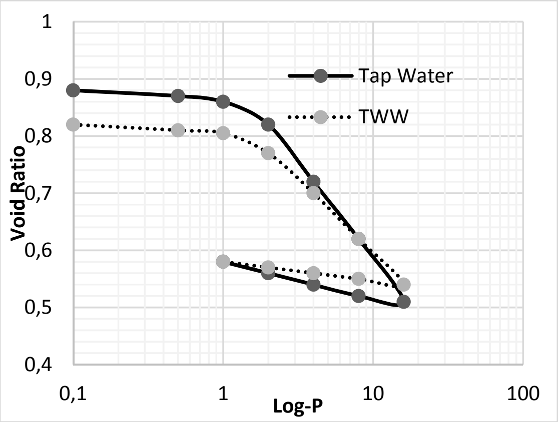

Fig. 6 Consolidation Curve for low plastic soil

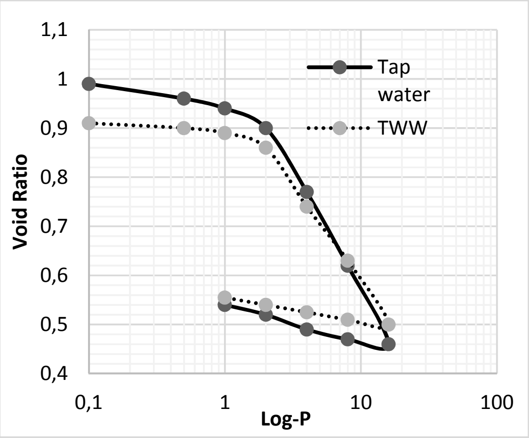

Fig. 7 Consolidation Curve for high plastic soil

Figs. 8 and 9 compare between the use of tap water and TWW on the consolidation index and swell index properties for low plastic soil and highly plastic soil, respectively. It is clear from these two figures that the use of TWW decreased both the consolidation index and swell index of the two soils. The consolidation index decreased for low plastic soil from 0.32 for tap water to 0.27 for TWW. Additionally, the swell index decreased when TWW is used for both soil.

Figs. 10 and 11 show the percentages decrease in compression and swelling properties of the two soils. It can be concluded from these two figures that the use of TWW reduced the consolidation index by 42% for highly plastic soil. Also the swelling pressure may be reduced as much as 16.0% for highly plastic soil and volume change as much as 9% for the low plastic soil.

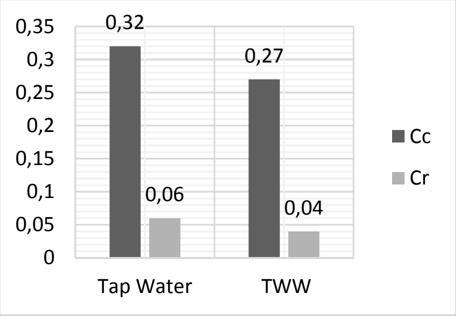

Fig. 8 Differences in consolidation and swell indices between tap water and TWW for low plastic soil

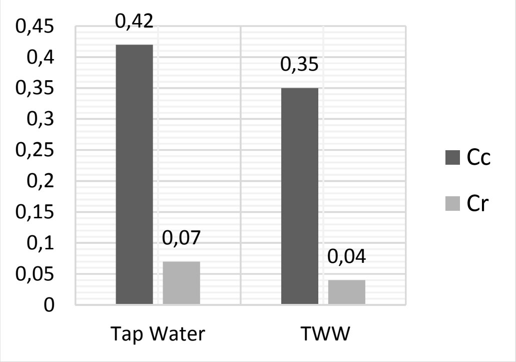

Fig. 9 Differences in consolidation and swell indices between tap water and TWW for high plastic soil

TABLE III
LOW PLASTIC SOIL PROPERTIES

	Cc	Cr	σ'c	Swelling pressure (kg/cm^2)	volume change
Tap	0.32	0.06	2.0	3.1	17%
Treated	0.27	0.04	1.62	2.6	9%

TABLE IV
HIGH PLASTIC SOIL PROPERTIES

	Cc	Cr	σ'c	Swelling pressure (kg/cm^2)	volume change
Tap	0.42	0.07	1.9	4.3	30%
Treated	0.35	0.04	1.7	3.6	21%

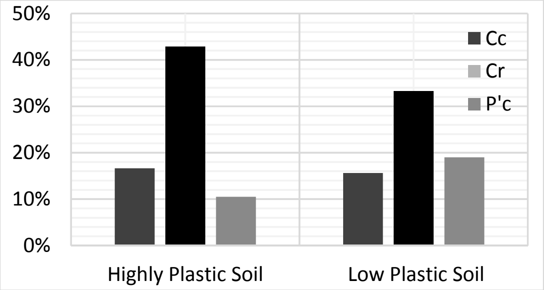

Fig. 10 Percentage decreases in the consolidation indices, swell indices and maximum past pressures due to TWW

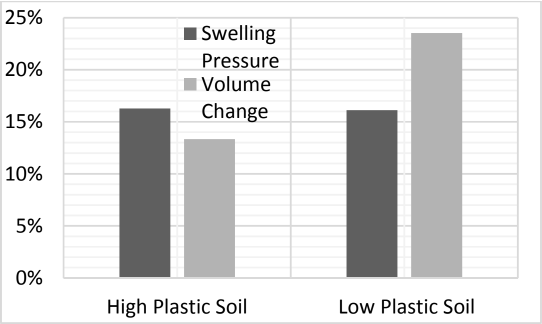

Fig. 11 Percentage decreases in swelling pressure and volume changes due to TWW

VI. CONCLUSION

Based on the results of this research, it was found that TWW affects both the compaction and compressibility properties of fine soil. It increased the maximum dry unit weight for soils and reduced optimum moisture content for highly plastic soil. It also reduced the compressibility index and swell index and the maximum past pressure of the soil as well. It was also found that the use of TWW with soil will reduce both the swelling pressure and the volume change. This research recommended replacing the tap water with TWW in the engineering applications that use fine soil.

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