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Geotechnical Investigation of Soil Foundation for Ramps of Dawar El-Tawheed Bridge in Jizan City, Kingdom of Saudi Arabia

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Abstract**—**The soil profile at site of the bridge project includes soft fine grained soil layer located between 5.0 m to 11.0 m in depth, it has high water content, low SPT no., and low bearing capacity. The clay layer induces high settlement due to surcharge application of earth embankment at ramp T1, ramp T2, and ramp T3 especially at heights from 9m right 3m. Calculated settlement for embankment heights less than 3m may be accepted regarding Saudi Code for soil and foundation. The soil and groundwater at the project site comprise high contents of sulfates and chlorides of high aggressively on concrete and steel bars, respectively. Regarding results of the study, it has been recommended to use stone column piles or new technology named PCC piles as soil improvement to improve the bearing capacity of the weak layer. The new technology is cast in-situ thin wall concrete pipe piles (PCC piles), it has economically advantageous and high workability. The technology can save time of implementation and cost of application is almost 30% of other types of piles.

Keywords**—**Soft foundation soil, bearing capacity, bridge ramps, soil improvement, PCC piles.

I. Introduction

GEOTECHNICAL investigation is always required for any engineering or building structure. The investigation may range from simple examination of the surface soils with or without a few shallow trial pits, to detailed study of the soil and ground water conditions by means of boreholes and in-situ and laboratory tests.

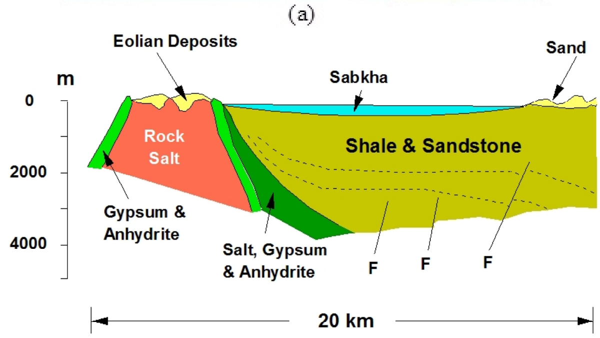
Jazan region is located in the south western part of Saudi Arabia on the red sea (E: 42.0°-43.8° and N: 16.5°-17.0°). It`s area is 13,500 km^2. It is part of Arabia shield which is a part of the Precambrian crustal plate and consists of igneous and metamorphic rocks. It is located in an active zone of earthquakes classified as zone 2B. One of the major problems in geotechnical earthquake engineering is the phenomenon of liquefaction of loose to medium-dense sands below the ground water table.

The dominant rocks are granite, basalts, diorite, gabbro and mica-schist. During the Tertiary period, the shield was separated from the adjacent African shield by a rift of earth`s crust that currently occupied by the red sea. Sedimentary coastal plain has formed on the area between the escarpment of the shield and the red sea. The climate of Jazan region is considered arid with annual mean temperature 28°C, relative humidity 62% and annual precipitation 62 mm.

The landforms, developed in Jazan region, are mainly of alluvial nature, formed as a result of the downward transportation of soil material from the highlands by the many valleys and drainage channels that drain out in the red sea. Moreover, Jazan embodies variant landforms such as marshland, coastal plain, alluvial plain and valleys.

The geotechnical aspects of Jazan soil were studied by many researches as [1]–[4]. The city of Jazan is situated on an elevated terrain underlain by a salt dome measuring 4 km^2 in area and reaching about 50 m above sea level, (see Fig. 1).

(a)



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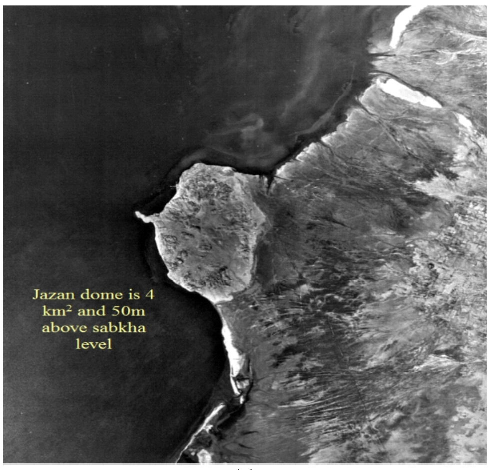

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Fig. 1 (a) Simplified Geological Map, (b) Geologic section across Jazan [2] (c) Map of salt dome in Jazan city

The salt dome is surrounded by vast areas of sabkha flats and wind-blown sand stretching north and south for approximately 190 km. The sabkha sediments possess highly variable profile characteristics with regard to the soil composition. The subsoil profiles in the costal zones (close to shoreline) consist of loose fine sand, whereas the subsoil profile of inland zones are characterized by very soft clay and silt with appreciable organic material [2]. The three zones characterize this soil profile include: (1) sabkha crust; (2) complex compressible sabkha; (3) sabkha base. The sabkha crust is relatively thin dry silt sand soil with an average thickness of about 2.0 m existing above the water table which is 1-2 m below the ground surface. This layer appears to be of a hard nature but highly susceptible to loosen its strength instantaneously upon saturation. The complex compressible sabkha is soft, loose material composed of soils varying from non-plastic silty, clayey fine sand to highly plastic organic clays and silts with thickness up to 8 m. The sabkha is a firm stratum consisting mainly of medium dense to dense sand with relatively high bearing capacity and low compressibility characteristics.

A. Soil in Jazan

Sabkha is soils have high concentrations of salts. These soils originate due to capillary suction and intense evaporation in the coastal and inland flat plains of Saudi Arabia. Sometimes the salinity of the pore fluid reaches as higher than sea water. The high salt content has great impact on the strength properties of soils and also on structures in contact with the soil. Salt-bearing soils are extensively found on the eastern coastal plains and at locations on the western coastal plains of KSA.

Sabkha deposits are usually very soft, problematic, susceptible to salt leaching, and not suitable for foundation support. Salt-bearing plains in Saudi Arabia are generally categorized by layered sediments of fine silty clay covered with few meters of fine sand dunes.

B. Sabkha in Jazan

Jizan city is located on a salt dome surrounded by low-lying flat terrain consisting of silty-sandy soils. Being on the sea-shore, water immigrates to the surface leaving a salt crust on the top surface, which is known as 'Sabkha' soil .This salt bearing (saline) soil and the salt dome affected the foundation. Buildings are experiencing foundation problems as a result of the low bearing capacity of the 'Sabkha' soil and the dissolution of the salt rock underneath the footings of the low-rise buildings, causing tilting of such structures.

1. Sabkha Properties

Sabkha properties of Jazanarea are depicting in Table I [5].

TABLE I
SABKHAPROPERTIESIN JAZAN AREA

Layer	Average Thickness (m)	Description	SPT (Soil class)
Crust	1.0-1.5	Fine sand-silt cemented with salts	9-16 (ML-SM)
Compressible zone	8.0-10.0	Non plastic fine sand to highly plastic organic clay	1-6 (SM, CL, SC, OH)
Base	More than 10.0	Dense to very dense fine sand	Variable up to refusal

Fig. 2 Flood in Jazansabkha in the 1980's

Fig. 3 Salt concentrations in sabkha crust

2. Potential Engineering Problems of Sabkha

Sabkha soils present a series of engineering problems that result from their variable nature, high evaporate, and organic contents, see Figs. 2 and 3. The general potential problems associated with building on sabkha deposits are: (1) susceptibility of sabkhas soil to flooding due to low elevation and the difficulty of excavation below the water table, (2) extreme variation in cementation of sandy sabkhas attributed to unequal precipitation of soluble and relatively insoluble salts within the sabkhas sediments. Soluble salts in the upper part of the sabkha sediments can be washed away by floods tides or merely due to absorption of water from atmosphere, so that sabkhas strength may be decreased, (3) variation of compressibility characteristics of sabkha sediments lead to excessive differential settlement. Sabkha deposits could vary from a very loose state to a dense state and they invariably contain an appreciable amount of organic matters. Therefore, they are characterized by being highly compressible with a significant part of the settlement taking place as secondary compression. Thus, serious foundation instability problems are to be expected if the sabkha-distributed areas are planned for urban development, (4) the potential adverse reactions and chemical changes that may influence sediment properties and structures embedded in sabkhas, it could be explained by the potential instability of gypsum and the associated volume change resulting from alternate hydration and dehydration under hot and humid conditions. The high concentration of chlorides and sulphates in sabkha sediments and ground water is very corrosive to both steel and concrete, (5) evaporative processes in a desert environment are responsible for the accumulation of evaporate minerals, particularly at shallow depth in the Aeolian deposits. The collapse potential of the Aeolian deposits is attributed to the week cementation of the soil grains by evaporates, and to be considered as a major geotechnical problem in new construction sites, (6) potential carbonate leaching in high carbonate content soils and potential volume changes that may occur in gypsum dominated layers.

3. Sabkha Problem in Jazan

a. The salt crystallization between the soil particles may cause heave.
b. The transformation between gypsum and anhydrite may cause heave or collapse.
c. The sabkha salt crust is stable but tends to be weak when wet due to the dissolution of binding salts [2], see Fig. 4.
d. The salts present in the soil and shallow groundwater may causes corrosion to both concrete and rebar, see Fig. 5.
e. The low water infiltration rate may cause flooding.

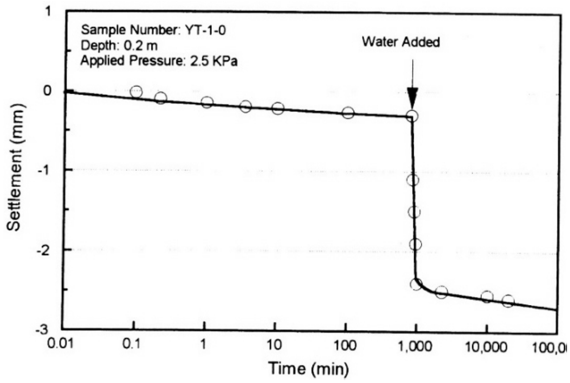

Fig. 4 Loading - settlement within addition of water

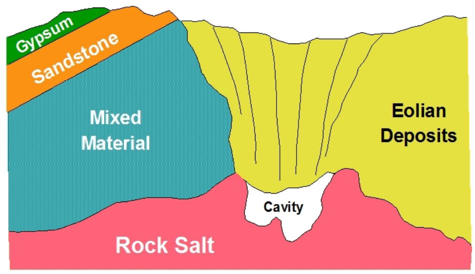

Fig. 5 Cavity formation and collapse of Aeolian deposits in old Jazan

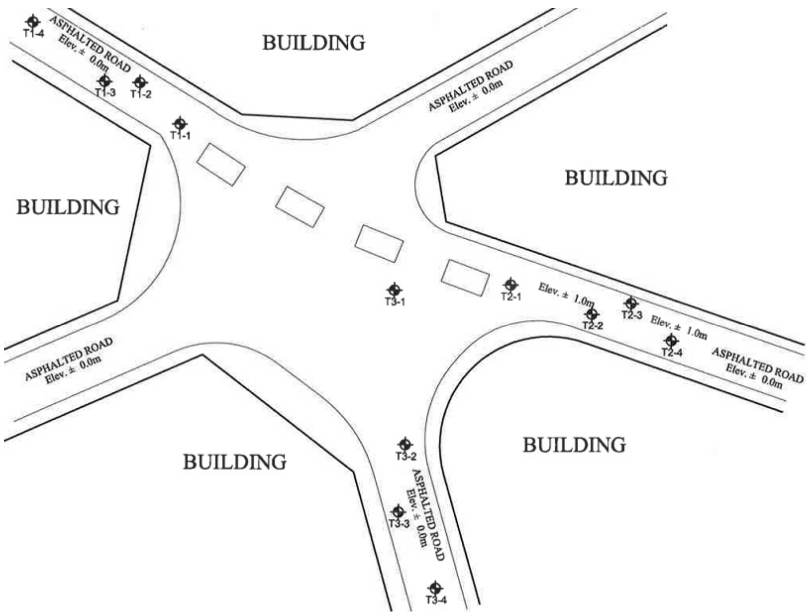

Fig. 6 Location map of ramps of Dawar El-Tawheedbridge and boreholes layout

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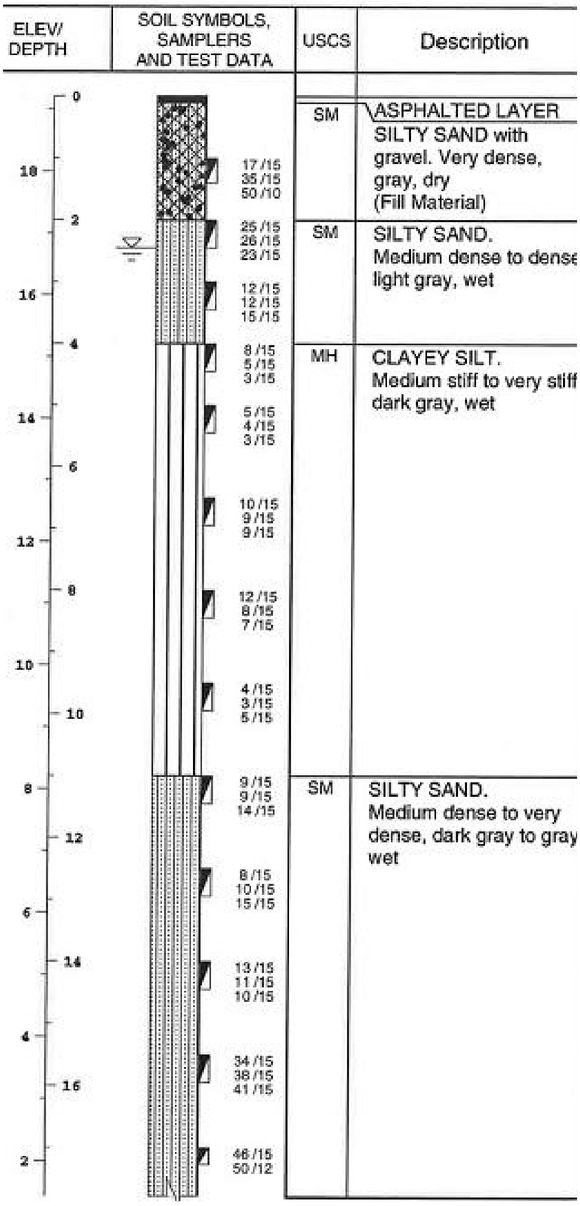
II. Boreholes Logging

A. Project Description

The project of Dawar El-Tawheed bridge is biggest national project in Jizan city- KSA will be solving traffic problem of crowding, see Fig. 6 which comprise the location map of DWAR ELTAWHEED bridge and its three ramps with layout of boreholes - sampling taken for field and laboratory tests. Twelve boreholes have been done at the three ramps of Dwar El-Tawheed bridge project as four boreholes at each ramp as depicting in location map, boreholes logs are shown in Fig. 7. Ramps dimensions are 17m, 17m, and 6m in widths and 252m 235m, and 147m in lengths for ramps T1, T2, and T3, respectively. The maximum height of each ramp has been planned to be 9.0 m above the ground surface.



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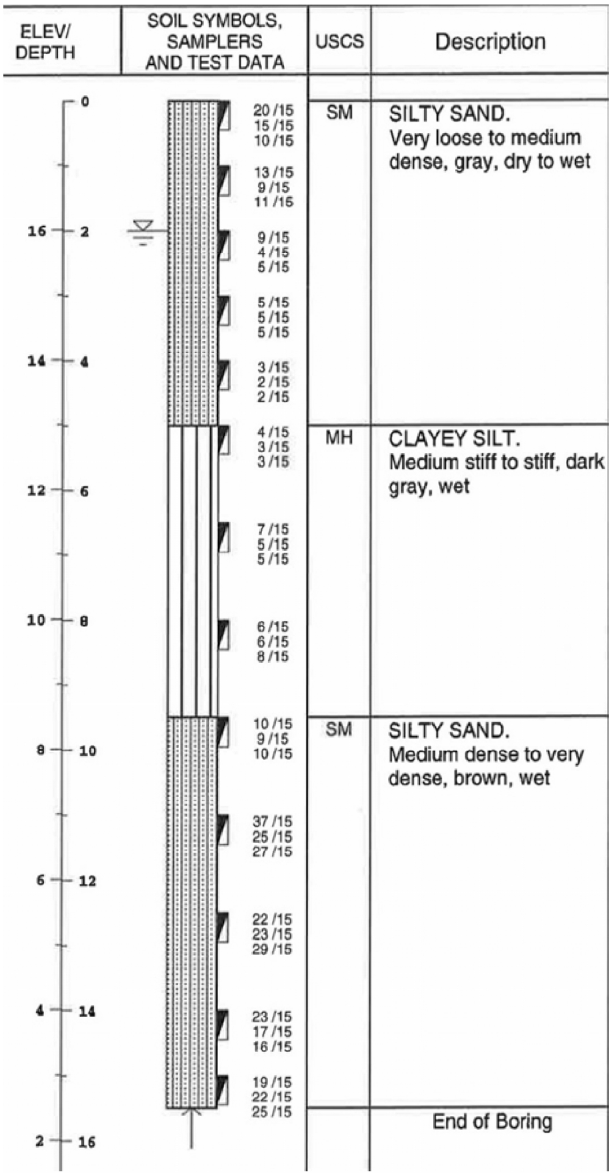

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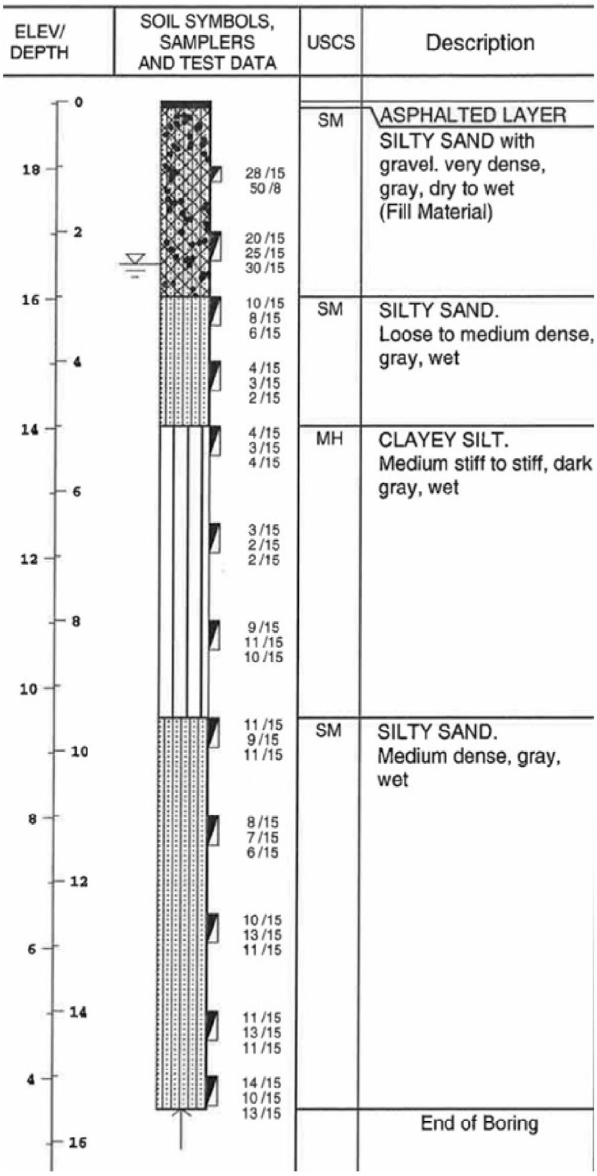

(c)

Fig. 7 Borehole log at: (a) T1-1, (b) T2-2, and (c) T3-2

III. Field and Laboratory Tests

A. Field Tests

1. Natural Water Content

Natural water content (Wc %) has been calculated at deferent depths of all boreholes for ramps T1, T2, and T3, results are shown in Fig. 8.

2. Standard Penetration Test (SPT)

This test has been carried out on all layers of soils at all boreholes with different depths, results are shown as in Fig. 9.

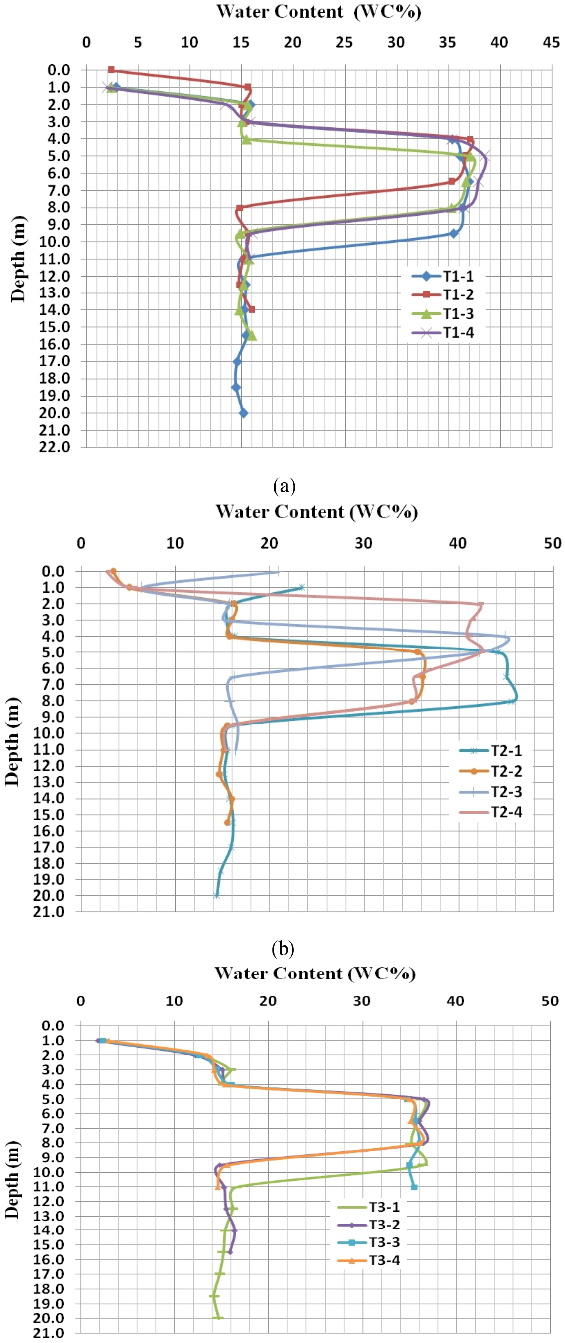

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Fig. 8 Water content with depth at: (a) Ramp no. T1 (b) Ramp T2, and (c) Ramp T3

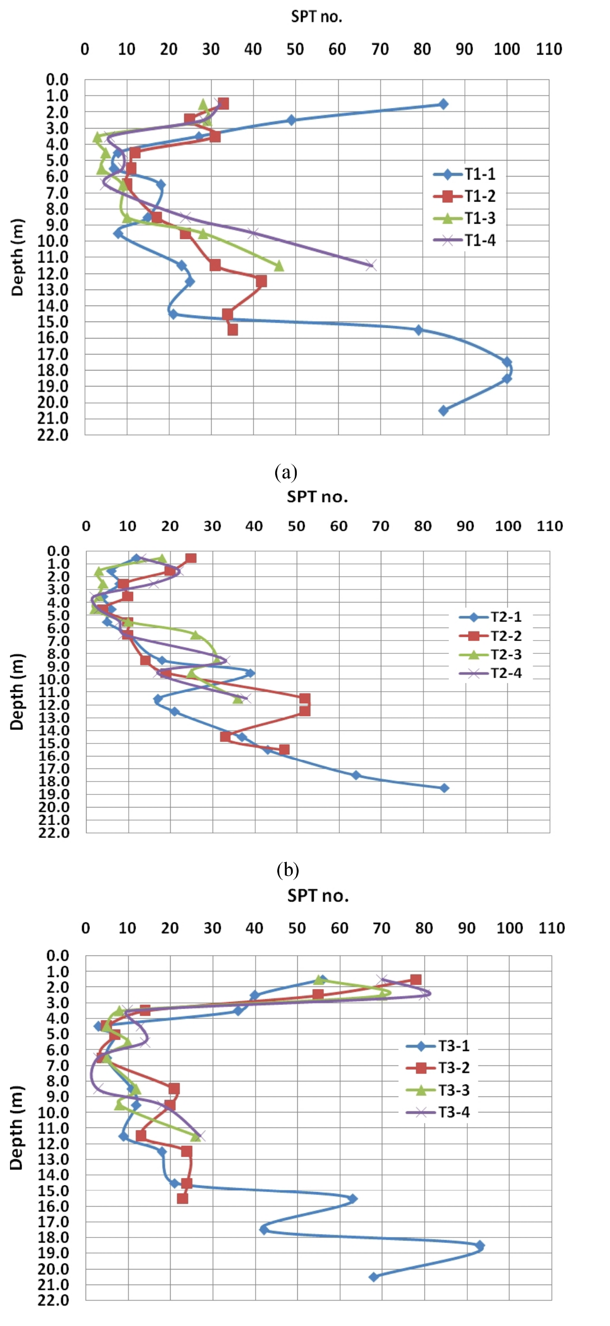


Fig. 9 Standard Penetration No. Vs. Depth at: (a) Ramp T1, (b) Ramp T2, and (c) Ramp T3

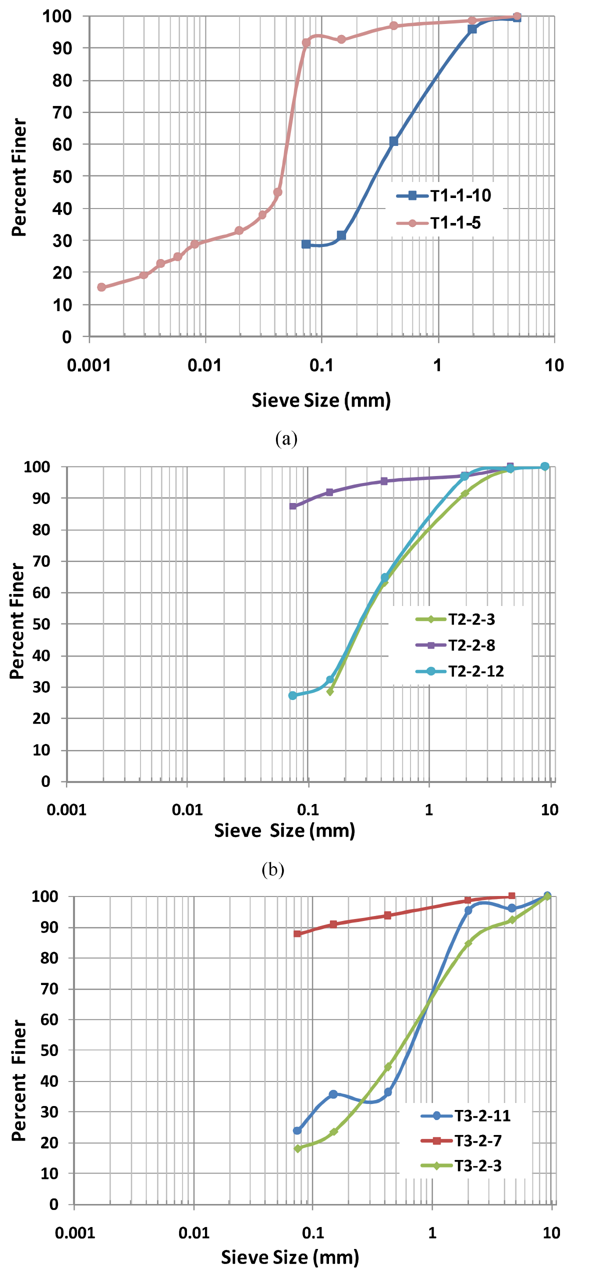


Fig. 10 Grain size distribution of soil at: (a) Ramp T1 (b) Ramp T2, and (c) Ramp T3

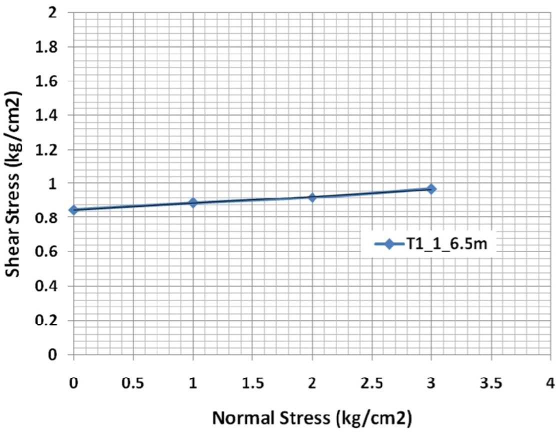
B. Laboratory Tests

1. Grain Size Distribution

Grain size distribution for all samples collected from boreholes at different depths of ramps T1, T2, and T3 are shown in Fig. 10.

2. Direct Shear Test

Direct shear test has been conducted on soil samples collected from boreholes at ramp T1, T2, and ramp T3 at different depths, physical and mechanical properties of soil at Ramps are depicting in Table II. The test has performed under drained condition, test results and relation curves are shown in Fig. 11.



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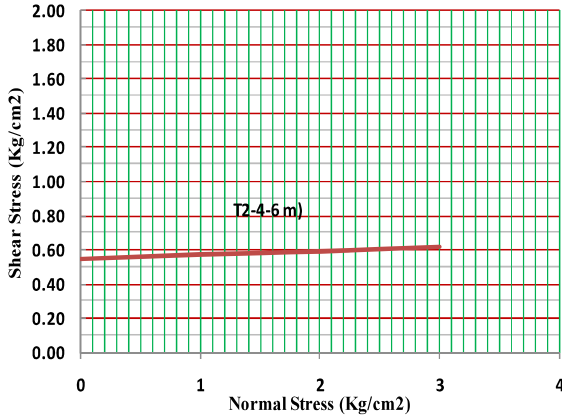

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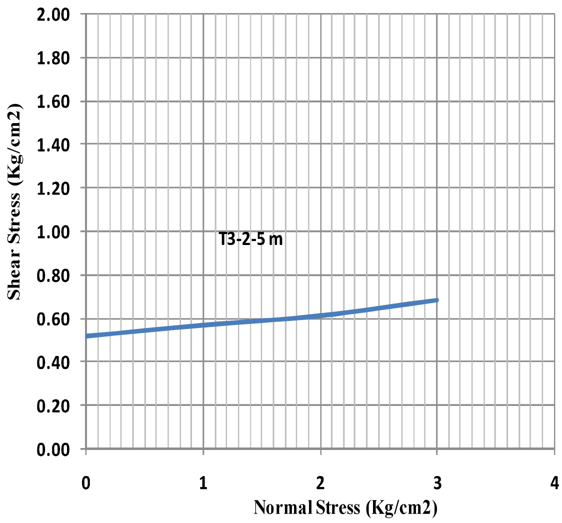

(c)

Fig. 11 Shear stress Vs. Normal stress curve of soil at: (a) Ramp T1 borehole no. 1 at depths 6.5 m, (b) Ramp T2 borehole no. 4 at depths 6 m, and (c) Ramp T3 borehole no. 2 at depths 5 m

TABLE II
MECHANICAL AND PHYSICAL PROPERTIES OF SOIL AT RAMPS T1, T2, AND T3

Borehole No.	Depth (m)	Soil description	$\Phi^{(o)}$	Cohesion (C) (kg/cm^2)	Dry density (gm/cm^3)	Water content (Wc) %
T1-1	6.5	Clayey silt	2	0.85	1.34	37
T2-4	6	Fat Clay	1	0.53	1.40	42.3
T3-2	5	Fat Clay	3	0.51	1.32	36.6

3. Water Content and Atterberg Limits

Results of natural water content and Atterberg limits are depicting in Table III.

TABLE III
RESULTS OF WATER CONTENT AND ATTERBERG LIMITS

Sample No.	Wc%	L.L	P.L	P.I	I_C	I_L
T1-1-05	36.2	52	35	17	0.93	0.071
T1-1-10	15.4	18	--	NP		
T1-2-02	15.6	17	--	NP		
T1-2-05	37.1	54	35	19	0.89	0.111
T1-3-03	16.4	19	--	NP		
T1-3-07	36.1	51	34	17	0.71	0.124
T1-4-05	38.5	55	34	21	0.79	0.214
T1-4-08	16.1	20	18	2	1.95	-0.95
T2-1-04	16.3	18	--	NP		
T2-1-06	45.1	63	32	31	0.58	0.423
T2-2-03	16.1	16	--	NP		
T2-2-06	35.7	50	31	19	0.75	0.247
T2-2-12	16	16	--	NP		
T2-3-05	44.9	60	31	29	o.52	0.479
T2-4-06	42.3	65	32	33	0.69	0.318
T2-4-08	35	52	32	20	0.85	0.150
T3-1-03	16	17	--	NP		
T3-1-05	36.3	54	37	17	1.04	-0.041
T3-1-11	15.4	19	--	NP		
T3-2-03	15.1	16	--	NP		
T3-2-07	36.5	52	34	18	0.86	0.139
T3-2-11	16.4	19	--	NP		
T3-3-03	14.5	17	--	NP		
T3-3-04	16.1	19	17	2	1.45	-0.450
T3-3-06	35.6	53	33	20	0.87	0.130

4. Pocket Pentrometer Test

The test has been done on undisturbed soil samples collected at ramps T1, T2, and T3 at depths of 5.5m – 6m of each ramp and results recorded respectively as 0.48, 0.45, and 0.49 kg/cm^2.

5. Unconfined Compressive Strength Test

The test has been conducted regarding ASTM D 2166, the soil sample collected at ramp T2 in borehole no. 4 with depth of 5.5 m. The result recorded unconfined compressive strength $q_u = 1.11\ kg/cm^2$, see Fig 12.

6. Free Swelling Test

The test has been done on soil samples, data and results of free swelling test are recorded as in Table IV.

7. Specific Gravity Test

The soil is tested to determine its specific gravity, the soil sample taken at T1, T2, and T3 at different depths, by using (1) can get specific gravity. Results of specific gravity test are shown in Table V.

$$G_s = \frac{W_1}{W_1 - (W_3 - W_2)} \tag{1}$$

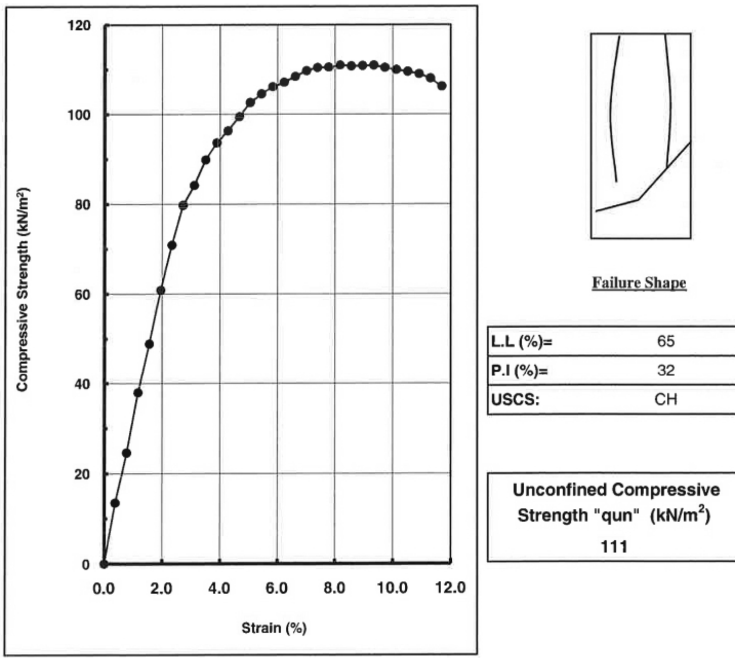

Fig. 12 Compression strength Vs. Strain curve on sample at ramp T2 borehole no. 4 at depth 5.5m

8. Odeometer Consolidation Test

The test has been carried out on sample collected from borehole no 4 at ramp no. T2 with depth of 5.5m below the ground surface, soil can be classified as "Gray Fat Clay", physical and mechanical properties of the soil sample are summarized as in Table VI. The test has been conducted as stress versus void ratio (see Fig. 13) regarding specification of ASTM D2435.

9. Chemical Analysis Test

a. Chemical Analysis Test on Soil Sample

The test has been done on soil sample that mixed with distilled water with ratio of water to soil as 2: 1 by weight. Results are shown in Table VII.

TABLE IV
FREE SWELLING TEST RESULTS

Sample no.	Depth (m)	Initial Volume (ml)	Final Volume (ml)	Free of swelling (%)
T1-3	5.0	10.0	12.0	20.0
T2-1	8.0	10.0	12.8	28.0
			Average	24.0

TABLE V
SPECIFIC GRAVITY TEST RESULTS

Sample no.	Dry weight (W1) (gm)	Weight of bottle filled with water (W2) (gm)	Weight of bottle filled with sample &water (W3) (gm)	Specific Gravity
T1-3-6	100	648.6	711.3	2.681
T2-4-6	100	647.9	710.2	2.653

TABLE VI
PHYSICAL AND MECHANICAL PROPERTIES OF SOIL AT T2-4-5.5M

Initial Wc%	LL	PL	γ_b (t/m³)	γ_d (t/m³)	G_s	e_o
40	65	33	1.79	1.28	2.65	1.067
S_r (%)	C_c	C_s	P_o (kg/cm²)	P_c (kg/cm²)	OCR	
99	0.289	0.063	0.65	0.68	1.05	

TABLE VII
RESULTS OF CHEMICAL ANALYSIS OF SOIL SAMPLE

Soil Sample No.	T1-2-4	T2-4-4
Depth (m)	4.00	3.00
pH	8.0	7.9
Total Sulphate%	0.0900	0.0870
Total Chloride%	0.1120	0.1260

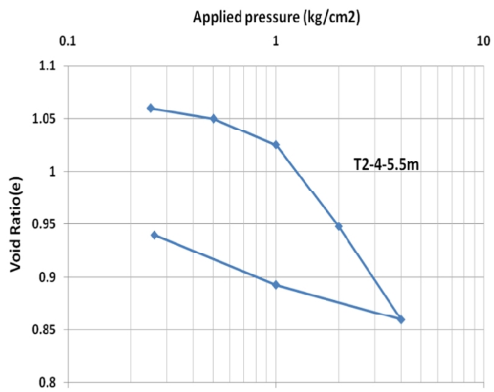

Fig. 13 Stress Vs. void ratio curve at Ramp T2 borehole no. 4 at depths 5.5 m

b. Chemical Analysis Test on Groundwater Sample

The test has been done on groundwater sample that collected at ramp T1 and ramp T2, results are shown in Table VIII.

TABLE VIII
RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER SAMPLE

Borehole No.	T1-2	T2-4
pH	8.0	8.2
Total Sulphate (PPM)	1070	1020
Total Chloride (PPM)	1465	1375

IV. RESULTS AND DISCUSSION

A. Bearing Capacity Calculations

Ultimate Bearing capacity =(qu) is calculated as in (2)

$$q_u = (C.N_c.F_{cs}.F_{cd}.F_{ci}) + (q.N_q.F_{qs}.F_{qd}.F_{qi}) + (0.5\gamma BN_\gamma F_{\gamma s}.F_{\gamma d}.F_{\gamma i}) \tag{2}$$

where; C: cohesion, q: effective stress at the level of the bottom of foundation, γ: unit of soil, B: width of foundation, Sc, Sq, Sγ: shape factors, dc, dq, dγ: depth factors, ic,iq,iγ: inclination factors, Foundation Information: Df=1m, shape factor can be estimated using (3):

$$F_{cs} = 1 + \frac{N_q}{N_c} \times \frac{B}{L} \tag{3}$$

By using soil information: Dw=2.5, $\gamma_{water} = 10\,kN/m^3$, $\gamma_1 = 18\,kN/m^3$, $\gamma_2 = 18\,kN/m^3$, $\gamma_{1sub} = 8\,kN/m^3$, $\gamma_{2sub} = 8\,kN/m^3$. Factor of safety (FS) = 4.00. Calculations of bearing capacity for ramp T1, ramp T2, and ramp T3 are depicting in Table IX:

TABLE IX
BEARING CAPACITY RESULTS OF RAMP T1, RAMP T2, AND RAMP T3

Element	Ramp No.		
	T1	T2	T3
Angle of friction $\phi^{(o)}$	0	0	0
Cohesion C (kN/m2)	60	45	50
Width B (m)	17	17	6
Length L (m)	25	25	25
Gross ultimate bearing capacity qu (kN/m2)	366	279.4	286.8
Q (kN/m2)	18	18	18
Net ultimate bearing capacity (kN/m2)	366	279.4	308
Net Allowable (kN/m2)	91.5	67	71.7

B. Settlement Calculations

Settlement calculations of soil layer formation at ramp T1, ramp T2, and ramp T3 have been estimated depending on load conditions and soil parameters as shown in Table X.

Accordingly accounts that were introduced at each ramp using the stresses induced at ramp height of 1 m, 2m, 3m, … , and 9m as depicting in Fig. 14. Cc can be calculated using empirical (4), Δσ using (5), and Sc using (6):

$$C_c = 0.009 \times (LL - 10) \tag{4}$$

TABLE X
SOIL PARAMETERS

Soil Parameter	Clay	Silt
Average liquid limit	60%	50%
Average water content	41%	36%
Gs	2.65	2.68
$e_\circ$	1.06	0.938
Cc	0.29	0.360
Cr	0.060	0.048
OCR	1.00	1.00

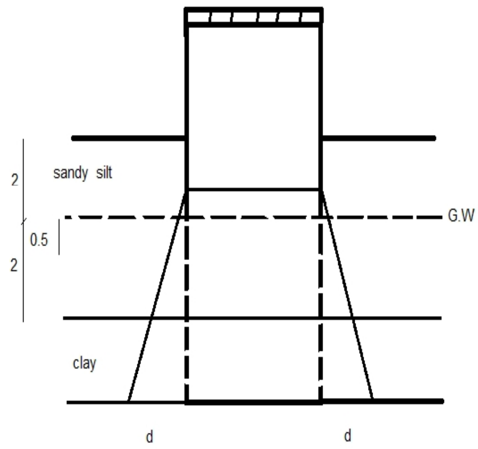

Fig. 14 Sketch of approximation method for stress distribution

$$\Delta\sigma = \frac{P \times L \times B}{(L+d)\times(B+d)} \tag{5}$$

$$Sc = \frac{Cc}{1+e_\circ} \times Hc \log \frac{\sigma v + \Delta\sigma}{\sigma v} \tag{6}$$

Assume $\gamma_{b(sand)} = 20t/m^3$, $e_\circ$=0.938 $\gamma_{b(clay)} = 20t/m^3$, $e_\circ$=1.06

$$\gamma_{sub(sand)} = \frac{2.65-1}{1+0.938} = 8.5t/m^3$$, Cc=0.009(52-10) = 0.378

$$\gamma_{sub(clay)} = \frac{2.65-1}{1+1.06} = 8.t/m^3$$

The estimated settlements at ramp T1, ramp T2, and ramp T3 are shown in Table XI.

TABLE XI
CALCULATION OF SETTLEMENT WITH EMBANKMENT HEIGHT

Height (m)	**Average Sc (cm) at ramp No. (allowed settlement≯10cm)**		
	T1	**T2**	**T3**
	$B\times L$ **(m)** 17× 25	$B\times L$ **(m)** 17×25	$B\times L$ **(m)**6×25
1	5.10	4.23	3.10
2	9.58	8.28	5.99
3	13.75	11.88	8.72
4	16.40	15.10	11.27
5	20.78	18.08	12.93
6	23.78	20.85	16.03
7	26.88	23.18	18.20
8	29.45	25.30	20.14
9	31.98	27.55	22.26

1. Compaction Test

Firstly, a mechanical sieve analysis has been done on a man-made fill sand sample collected from the site which used as sand cushion for ramp T1, ramp T2, and ramp T3 of the bridge (sieve analysis is depicting in Fig. 15). Mechanical sieve analysis has been done according to ASTM-D2217-85 (Reapproved 1998).

Then modified proctor test has been carried out on the same man-made fill sand sample regarding ASTM D-1557-Method C. Result is shown in Fig. 16.

2. Plate Load Test

Plate load test has been done on the compacted man-made fill sand at the site at ramp no. T2. The plate used was 45cm in diameter and the maximum applied load was 13000kg, hence the ultimate stress equal 8.17 and if we consider factor of safety equal 3 or little bet more than 3 the allowable bearing capacity may be considered as 2.5kg/cm2 that induce plate settlement of 2.43mm, results are shown in Fig. 17.

The results show that the estimated bearing capacity is 2.5kg/cm2. Because of ramp T2 area is huge and the few test points of plate load and small diameter of the plate load, consequently the net allowable bearing capacity should not be more than 2.0kg/cm2.

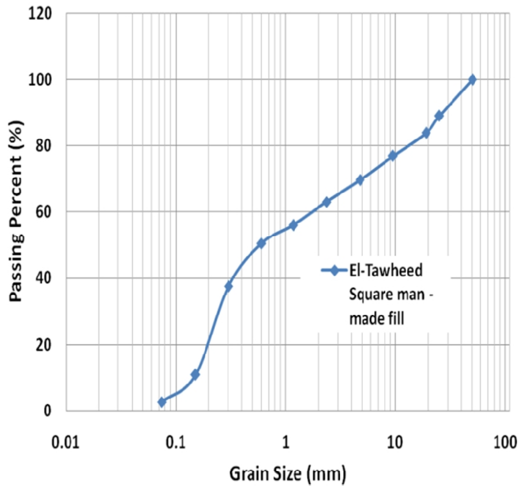

Fig. 15 Grain size distribution curve of man-made fill

V. Conclusion and Recommendations

A. Conclusion

According to previous results of this study, foundation soil of Dawar El-Tawheed bridge ramps is soft soil that has low bearing capacity and induces a high settlement under surcharge loads. The study may be concluded to the following points:

a. The soil profile of very soft fine grained soil located between 5.0 m to 11.0 m in depth has high water content, low SPT no.,

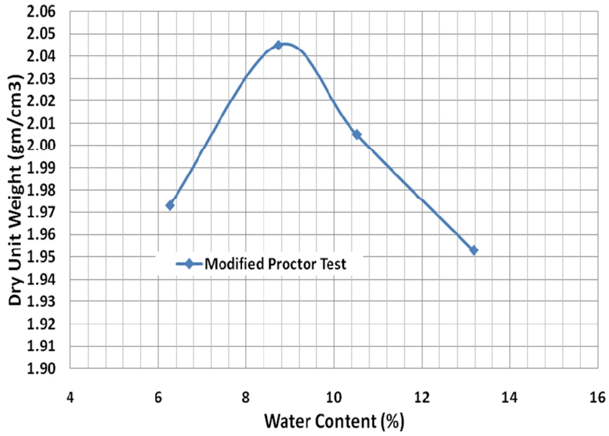

Fig. 16 Dry unit weight Vs. water content for man-made fill (modified Proctor test)

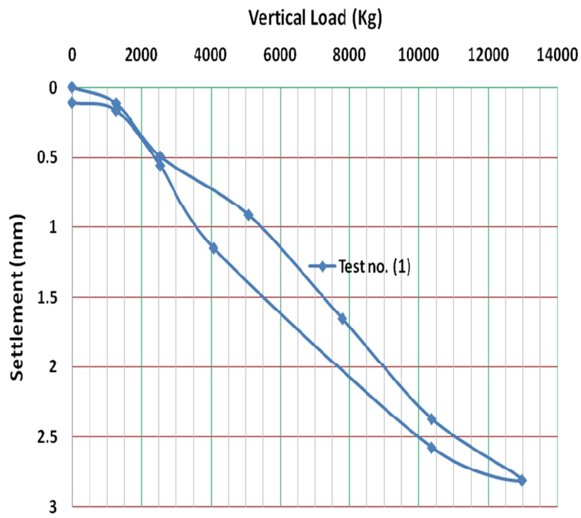

Fig. 17 Load –settlement curve at ramp no. T2: Point (1)

b. The soil has low bearing capacity of 91.5 kN/m^2, 67 kN/m^2, and 71.7 kN/m^2 at ramp T1, ramp T2, and at ramp T1, respectively.

c. The clay layer induces high settlement more than 10 cm due to surcharge application of earth embankment at ramp T1, ramp T2, and ramp T3 especially at heights from 9 m right 3 m.

d. The soil and groundwater have high aggressively salt content of sulfates and chlorides at the project site.

e. Bearing capacity of replacement sand (man-made fill) should not be more than 2.0kg/cm2 (200kN/m2)

B. Recommendations

Regarding results above it may be recommended to use compaction for the first third lengths of the ramps towards the ground level and the remaining lengths of ramps can be improved by using another soil improvement technology to increase the bearing capacity of the weak layers. Stone columns may be used to improve the soil foundation or other new technology that has economically advantageous and high workability that recently used in China. The new technology named cast in-situ thin wall concrete pipe piles (PCC piles) that can save time of implementation and application cost of about 30% of other types of piles [6]-[14].

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