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Effect of swelling of subgrade soil on the flexible pavement

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ABSTRACT: To investigate the effect of swelling pressure on road pavement, two different apparatus (Oedometer cell and CBR mold) were adopted to predict directly swelling percent and swelling pressure of sub grade soil under pavement at different moisture contents. CBR tests were carried out to investigate the strength of soaked subgrade soil. The effect of subgrade moisture contents on soil strength, and swelling pressure were investigated for soaked samples. Flexible pavement was design to resist swelling pressure predicted from the subgrade soil. The results show that a significant increase in pavement thickness to resist swelling pressure for lower moisture content than that design based on CBR curves only.

1 INTRODUCTION

During the past three decades, Iraq witnessed a fast development in all aspects; enormous projects including road networks have swept the country. The fast rate of construction together with the lack of adequate past geotechnical knowledge of existing soils resulted in some structural damages that significantly affected the proper performance of buildings projects.

El-Baiati (2001) reported that one of the major causes of these damages is attributed to differential soil heave, and the condition of moisture change that may occur in cycles of wetting and drying which lead to cycles of swelling and shrinkage of the soil.

Prasad et al. (2010) present evaluation studies on flexible pavement system were carried out by using different reinforcement material in the gravel sub base course such as geogrid reinforced stretch followed by bitumen coated chicken mesh, bitumen coated bamboo mesh, waste plastics and waste tire rubber reinforced stretch in the flexible pavement system laid on expansive sub grade.

Tank R.R. & Solanki U.J. (2012) study the geotechnical properties of the expansive soil and the effect of stabilizers i.e by adding fly ash, lime and combination of both on the properties of expansive soil especially C.B.R behavior.

Expansive soils have been found in many parts of the world, these soils causes damage pavements, runways, and building structure foundations.

2 LABORATORY TESTS

2.1 *Physical and chemical properties of the soil used*

A brown clayey soil was used to conduct all the laboratory tests. The soil was air dried and sieved on sieve no. 4, then stored in a steel container ready to use in laboratory tests. Standard tests were performed to determine the physical and chemical properties of the soil.

Table 1. Physical and chemical properties of natural soil used.

Index Property	Specification No.	Index value
Liqid Limit %	ASTM D_{4318}	43
Plastic Limit %	ASTM D_{4318}	23
Linear Shrinkage	ASTM D_{4318}	14
Plastic Index %		20
Activity (Ac)	BS(1377)	0.8
Specific gravity	ASTM D_{422}	2.65
Gravel Cont. %	ASTM D_{422}	0.0
Sand Cont. %	ASTM D_{422}	7.5
Silt Cont. %	ASTM	62.5
Clay Cont. %	D_{422}	30.0
Gypsum Cont. %		0.65
$CaCo_3$ Cont. %		37.8
Tss %	BS(1377)	0.79
So_3 Cont. %	BS(1377)	0.3
Organic Matter %	BS(1377)	0.59
PH value	BS(1377)	7.62
Soil Symbols (U.S.C.S)	ASTM D_{422}	CL
AASHTO Classification	AASHTO M_{145-82}	A-7-6(20)

Table 1 shows the results of physical and chemical properties of the soil sample, used as a sub grade material. All the tests were carried out a according to ASTM and B.S (1377).

Figure 1 shows particle size distribution of the soil used.

2.2 *X-ray-diffraction*

X-ray diffraction is the most widely used method for identification of fine-grained soil minerals and the

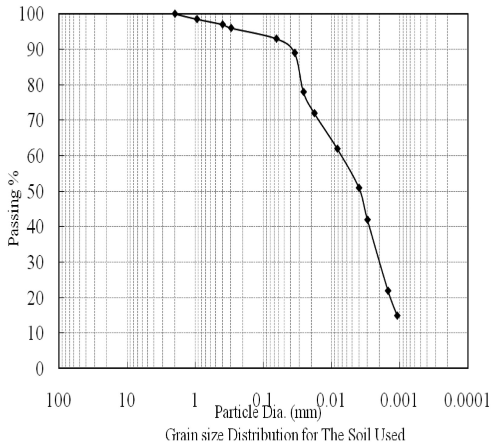

Figure 1. Particle size distribution of the soil used.

Table 2. Percentage of clay minerals.

Mineral	%
Quartze	22
Carbonate	35
Feldspar	3
Motmorillonite + Chlorite	14
Plagoskite + Illite	12.4
Kaolinite	13.2

mineralogical composition of soil. Table 2 shows the percentage of clay minerals.

The Montmorilonite plus Chlorite are the main components of the soil. In addition, soil contains Quartz, Carbonite, Fedspar as non-clay minerals, while the Palgoskite, Illite and Kaolinite are the remaining clay minerals.

2.3 *Compaction test*

The moisture – density relations for both standard and modified compaction tests were carried out according to (ASTM $D_{1557\text{-}78}$ Method B) for modified compaction test and according to ASTM $D_{698\text{-}78}$ method A) for standard compaction test. Figure 2 shows the compaction characteristics of soil.

2.4 *Consolidation tests*

Standard consolidation tests were carried out according to ASTM D_{2435} on remolded samples obtained from proctor mold, which compacted according to ASTM-$D_{1557\text{-}78}$ at optimum moisture content of 16%. The index consolidation soil properties of the remolded clay samples are listed in Table 3.

2.5 *Swelling tests*

2.5.1 *Using Oedometer cell*

Simple Oedometer cell was used to investigate swelling percent and swelling pressure. Modified

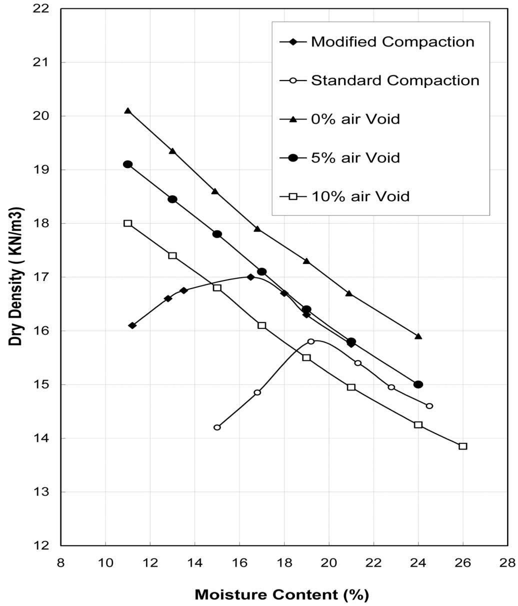

Figure 2. Compaction characteristic of the soil used.

Table 3. Index consolidation soil properties of the remolded clay sample obtained from consolidation tests.

Index Property	Index Value
Initial void ratio (e_o)	0.85
Compression Index (Cc)	0.129
Swelling Index (Sr)	0.036
Av. Coefficient of Compressibility (m^2/kN)	$1.52 * 10^{-4}$
Coeff. of Consolidation (Cv) (m^2/year)	0.89
Coeff. of Permeability (k) (cm/min.)	$2.5 * 10^{-7}$
Saturated Unit weight (γ_{sat}) (gm/cm^3)	20.9
Dry Unit Weight (γ_{dry}) (gm/cm^3)	18.05
Initial molding moisture content % (m_i)	16.0

Proctor compaction test were used to prepare remolding samples. These samples were compacted at 100% relative modified proctor compaction and then used to measure the swelling percent and swelling pressure at different molding moisture contents (13, 14, 15, 16, 17, 18 and 19%). The soil samples were soaked immediately at the seating pressure of (5 kN/m^2) and allow to swell freely until equilibrium condition is achieved then the sample was subjected to stress increments to back the swelling sample to initial condition.

2.5.2 *Using C.B.R mold*

C.B.R molds were also used to investigate swelling pressure and swelling percent. The soil was compacted in the C.B.R mold according to ASTM $D_{1883.87}$.

Different Surcharge loads of (10, 20, 40 & 60 lbs) respectively were used to give the same applied stresses used at the oedometer cells (100, 200, 400, and 600 gm) respectively. The soil samples compacted

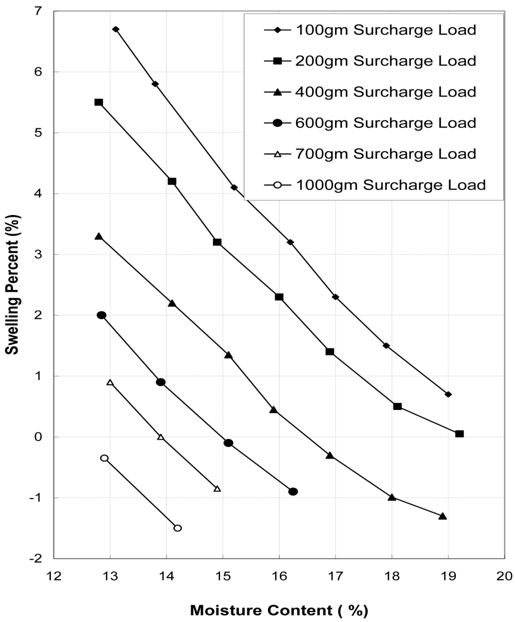

Figure 3. Relationship of swelling percent under different applied loads and different moisture Cont. by using Oedometer cell.

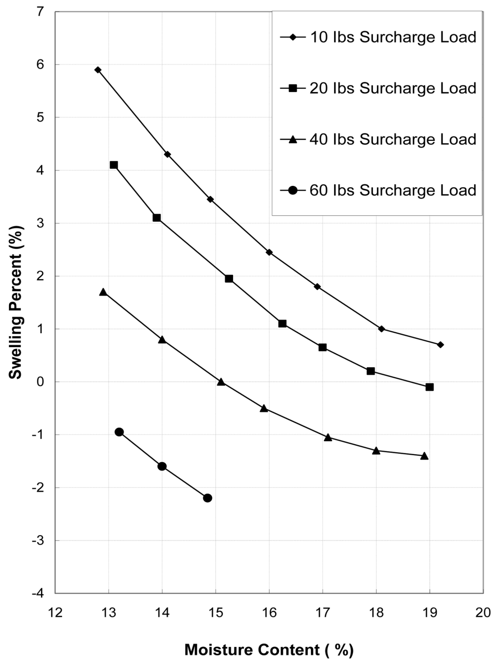

Figure 4. Relationship of swelling percent under different surcharge loads and different moisture cont. by using CBR molds.

also at the same different moisture contents which used at the oedometer cell. Swelling percent and swelling pressure were measured for each value of moisture content.

3 TEST RESULTS AND DISCUSSION

3.1 *Results of swelling percent*

3.1.1 *From Oedometer tests*

The results of the swelling percent under different applied loads and moisture contents are shown in figure 3.

It shows that for each surcharge load, a decreasing in swelling percent as increasing in moisture content.

3.1.2 *From CBR mold*

The results of swelling percent by using CBR molds under different applied loads and moisture contents are shown in figure 4. It should be noticed that the swelling percent observed at 10 lbs. surcharge load which is equivalent to a minimum pavement thickness.

3.2 *Results of swelling pressure*

Al-Asshou (1977) mentioned that the result of swelling pressure obtained from free swell procedure is very close to field case. Moreover, Al-Saeegh (1988) state that the free swell procedure is usually used to obtain the swelling properties for highway working because the stress applied is very limited.

3.2.1 *From the Oedometer test*

Figure 5 shows the relationship between swelling percent and applied pressure for different moisture contents.

Swelling pressure are the applied pressure obtained at the intersection points with zero swelling percent for curves of swelling percent under applied pressure and different moisture content. Higher swelling pressure is obtained at lower moisture content and vis versa.

Values of swelling pressure for different moisture content are tabulated in Table 4. These values are used to design flexible pavement. This table shows that the increase in molding moisture content leads to lower swelling pressure and such behavior is in full agreements with the results obtained by Rasheed, K.A 1985.

3.2.2 *By using C.B.R mold*

Figure 6 shows that the relationship between swelling as a percent and applied pressure for different moisture contents. The figure shows that clear reduction in swelling pressure with increasing moisture content at a given applied load.

4 RESULTS OF STRENGTH TESTS

Table 6 shows CBR values using different surcharge loads with different moisture content.

Generally, the thickness of flexible pavement depends on the strength of underlying subgrade soil which is a function of surcharge load. The effect of

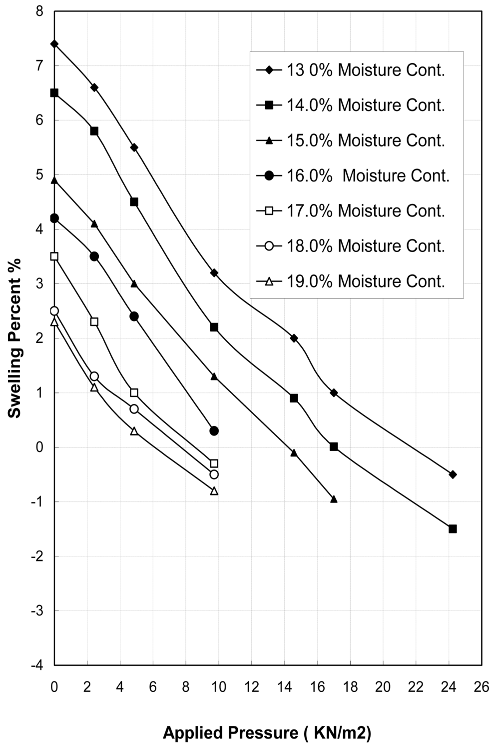

Figure 5. Relationship between swelling percent and applied pressure for different moisture contents.

Table 4. Values of swelling pressure obtained from Oedometer cell.

Swelling Pressure (Oedometer cell)	
Moisture Content (%)	Swelling Pressure (kN/m^2)
13	21.8
14	17.3
15	14.3
16	11.0
17	8.3
18	7.5
19	6.4

increasing moisture content on CBR values are shown in figure 7.

The figure shows that C.B.R values are increased with increasing moisture content for all surcharge loads. The higher values will be adopted for 17% molding moisture content, and then CBR values will be reduced.

This is because that the strength of compacted soil in dry side increases with increasing moisture content due to the increase of interlocking of particles. While at the wet side the strength will be reduced with increasing moisture content due to the adverse effect of adding water to soil.

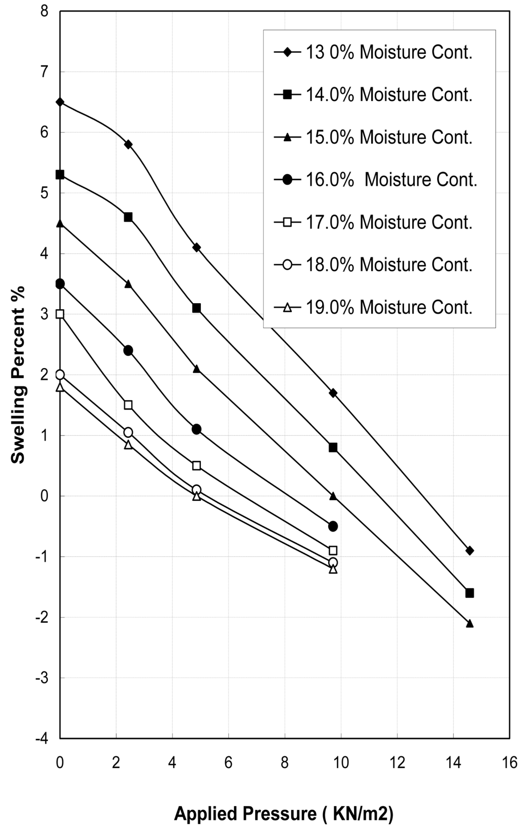

Figure 6. Relationship between swelling percent and applied pressure for different moisture contents using CBR molds.

Table 5. Values of swelling pressure obtained from CBR mold.

Swelling Pressure (CBR Mold)	
Moisture Content (%)	Swelling Pressure (kN/m^2)
13	12.9
14	11.4
15	9.8
16	7.8
17	6.4
18	5.3
19	4.9

5 DESIGN OF FLEXIBLE PAVEMENT

Jabbar, F.S. (1988) mentioned that to reduce the effect of swelling pressure on structures, enough resisting pressure may be applied, and design the structure to resist swelling pressure.

To find flexible pavement thickness, which equated to swelling pressure, equate the swelling pressure to the applied pressure ($\gamma_1 h_1 + \gamma_2 h_2$) where: γ_1 = unit weight of sub base layer which is about (22 kN/m^3),

Table 6. CBR values using different surcharge loads.

Moisture Cont. %	CBR Values (%) Surcharge Loads (lbs) 10	20	40	60
13	2.04	2.40	8.24	12.8
14	2.60	5.00	9.20	14.53
15	4.69	8.10	11.20	18.23
16	8.00	10.34	13.3	
17	9.60	11.40	14.9	
18	7.56	9.38	12.49	
19	5.09	7.20	10.10	

Table 7. Total pavement thickness obtained from swelling pressure by different methods.

Moisture Cont. (%)	Total Pavement Thickness (cm) CBR	Odeometer
13	57.86	98.10
14	50.82	77.64
15	43.50	64.0
16	34.45	49.00
17	28.10	36.73
18	23.10	33.10
19	21.30	28.10

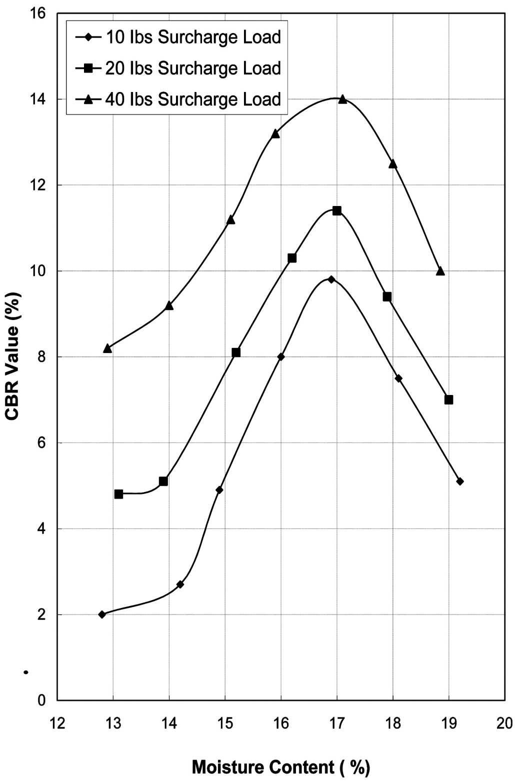

Figure 7. CBR values with increasing moisture content for all surcharge loads.

Table 8. No. of Commercial Vehicles per day exceeding 3 tones Laden weight.

Traffic Classification	
Traffic Type	No. of commercial vehicles/day
A	0–15
B	15–45
C	45–150
D	150–450
E	450–1500
F	1500–4500
G	Above 4500

Table 9. Thicknesses of pavements obtained from C.B.R curves.

Moisture Content (%)	C.B.R Value (%)	Pavement Thickness (cm) A	B	C	D	E	F	G
13	2.014	38	46	53	60	67	75	85
14	2.60	33	40	47	53	59	67	75
15	4.69	23	27	33	37	42	47	52
16	8.00	17	21	25	28	31	34	37
17	9.60	16	18	23	25	27	30	33
18	7.56	17	22	26	29	32	35	38
19	5.09	22	27	32	36	41	45	50

γ_2 = unit weight of asphaltic pavement layer which is about (24 kN/m^3), h_1 = thickness of subbase layer (m), h_2 = thickness of asphaltic pavement layer (m). Assuming thickness of the asphaltic pavement layers (base + surface) = 11 cm, the thickness of the subbase layer can be found. The applied pressure by these layers used to resist the swelling pressure of subgrade.

For example, if the swelling pressure by using oedometer test at moisture content of 13% is (21.8 kN/m^2).

So, $21.8 = \gamma_1 h_1 + \gamma_2 h_2 = 22{*}h_1 + 24{*}0.11 \quad h_1 = 0.871\,\text{m} = 87.1\,\text{cm}$ and the total pavement thickness is 87.1 + 11.0 = 98.1 cm.

Table 7 shows the values of total pavement thickness to resist swelling pressure predicted by different methods. The table also shows that the values of total pavement thickness decreases with decreasing of swelling pressure.

These values were compared with the thickness of pavements calculated from the design curves of C.B.R values for different traffic classifications (A, B, C, D, E, F, & G). Theses classifications represent no. of commercial vehicles per day exceeding 3 tones laden weight according to table 8.

The thickness of pavements obtained by this method is tabulated in table 9.

These values of pavement thicknesses show that there is no large differences with the pavement thicknesses obtained to resist swelling pressure as shown in percent.

6 CONCLUSIONS

1. Swelling percent and swelling pressure are decreased as moisture content increase at any surcharge load.
2. The swelling percent and swelling pressure at the same moisture content and the same applied pressure predicted by using oedometer cell more than that predicted by using CBR molds.
3. CBR values increases with increasing moisture content up to the optimum moisture content then decrease with increasing moisture content.
4. The swelling percent and swelling pressure is considered high for the soil used to be as a subgrade material.
5. Total pavement thickness to resist swelling pressure predicted by oedometer cell more than that predicted by CBR molds at the same moisture content.
6. The pavement thicknesses determined to resist swelling pressure can be used also to check the pavement thickness which determined by the other methods used for pavement design.

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