Statistical analysis of the physical and mechanical properties of expansive soil under footings

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Abstract

Expansive soil is a clay or soil that is susceptible to large volume changes (shrinking and swelling) that are directly linked to changes in the content of water. Soil with a high content of expansive minerals can form deep cracks in drier seasons. Expansive soil in some parts of Kurdistan regions has significant risk to foundation for light weight structures. Swelling clay can exert uplifting pressure to the foundation structure leading to structural cracks and damage to light-load frame structures. The previous data showed that the cycles of wetting-drying caused an increase in the swell potential of the soils which undergone to full swell-full shrinkage cycles whereas a decrease in the swell potential of the soils was observed for the soils which were subjected to full swell-partial shrinkage cycles. In this study some physical and mechanical properties of the expansive soil such as free swelling, compressive strength was developed.

Keywords: Swelling; Shallow foundation; Expansive soil; Volume change

1. Introduction

Geotechnical issues due to swelling of expansive soils have been discussed in many Studies all around the world. Million dollars were spent to tackle these problems and fix the severe damage caused on the structure. Arid and semi-arid regions are the most common places to develop these damages. Clay mineral montmorillonite with clay stones, shales, sedimentary and residual soils contained in expansive soil shall lead to absorb a large amount of water and expand soil. If the expansive soils are subjected to water, the more volume change will occur. For example, adding water to expansive soils can increase swelling. However, shrinkage can happen if the soils dry out. In addition, swelling and shrinkage cause fissure that can help water to penetrate to deeper layers of the ground. As a result, cycles of swelling and shrinkage are produced beneath the earth surface that the soil will undergo the huge amount of volume change. The variation in the soil will probably result in the structural member to be damaged in particular in light weight structures such as sidewalk, driveway and pipeline (Chen & Ma, 1987; Subba Rao & Satyadas, 1987; Dif & Bluemel, 1991; Day, 1994; Bilsel, 2002; Tripathy, Rao, & Fredlund, 2002; Mokhtari & Dehghani, 2012). Moreover, A better understanding of the behavior of swelling soil and a Structure exposed to wetting or drying phase is therefore crucial to the effective design of foundations and buildings on expansive soils and to assess existing buildings' vulnerability. In unsaturated clayey soils, the ground settlement during a drying (or wetting) phase is a consequence of both the variation in suction (negative pressure in soil) due to weather conditions (the hydraulic part) and the variation of vertical stresses due to soil–structure interaction (the mechanical part), with a coupling between the hydraulic and mechanical parts(Alonso, Gens, & Josa, 1990; Zemenu, Martine, & Roger, 2009). It is well known that larger stresses can be created when volume change of a material is obstructed. The value of these stresses can decrease rapidly when volume changes are partly allowed. Therefore, in order to decrease swelling pressure on structures, a material, which has a high capacity of compressibility, must be placed between expansive soils and the structures in both horizontal and vertical directions (Horvath, 1997). The previous studies have focused on the behavior of expansive soil and the effect of swelling on the shallow foundation. This study makes specific relationship between soil properties so as to know the properties of expansive soil taking into consideration, swelling. The stabilization of expansive soil will not be dealt with in the present work.

1.1.Objectives

The objectives of this study were to evaluate the effect of swelling on expansive soil beneath shallow foundation, as well as developed useful correlation between soil properties. Also to create the model between (liquid limit vs Plasticity index, liquid limit and Plasticity index vs free swelling, liquid limit and Plasticity index vs unconfined compressive strength ,plasticity index vs polymer, unconfined compressive strength vs polymer, and maximum dry density vs Liquid limit).

2. Materials and methods

2.1. Data collection

This study was focused on the correlations between Liquid limit, Plasticity Index, Unconfined compression strength, Maximum dry density, Compression index and Free swelling properties of expansive soil, based on the data collected from various research studies.

2.2. Expansive soil properties

In this study, more than 400 data of Liquid limit, Plasticity Index, Unconfined compression strength, Maximum dry density, Compression index and Free swelling were collected from various research studies. The data were quantified using Linear correlation model.

3. Results and discussion

3.1. Liquid limit, LL%

The LL of previous studies is presented in Table 2. based on the total of 76.0 LL data for expansive soils, the variation of data was from 24 to 139% with a mean of 61%, standard deviation of 24 and COV of 39 % as summarized in Table 2.

3.2. Plasticity Index, PI%

The PI collected from other studies is summarized in Table 2. based on the total of 45 PI data for expansive soils, the data varied from 3 to 104% with a mean of 44 %, standard deviation of 27.0 and coefficient of variation (COV) of 61 % as summarized in Table 2.

3.3. Unconfined compressive strength, UCS (MPa)

Based on the total of 11 UCS data for expansive soils, the range of data was from 0.020 to 0.14 MPa with a mean of 0.10 MPa, standard deviation of 0.035 and COV of 36.0 % as summarized in Table 2.

3.4. Maximum dry density, MDD (gm/cm^3)

All the collected data of 108 MDD for expansive soils collected from the literature presented a variation from 1.2 to 1.9 gm/cm3 with a mean of 1.70 gm/cm3 , standard deviation of 0.25 and COV of 25 gm/cm3 as summarized in Table 2.

3.5. Compression index, Cc

The statistical analysis of total collected data of 26 Cc for expansive soils collected from the literature gave a variation from 0.17 to 0.9 with a mean of 0.39 , standard deviation of 0.19 and COV of 48 as summarized in Table 2.

3.6. Free Swelling, FS (%)

The statistical analysis of total collected data of 76 FS for expansive soils collected from the literature presented a variation from 1.0 to 47 % with a mean of 10 % , standard deviation of 8.0% and COV of 80.0 % as summarized in Table 2.

3.7. Relationships between plasticity index and liquid limit

A total of 20 data were collected from various research studies. The data collected from the literature were quantified using (Eq. 1) as shown in Fig. 1. The change in the X with Y was represented using relationship (Eq. 1) it can be seen that by increasing LL increased PI and the model parameters Yo, A and B are summarized in Table 3. The coefficient of determination (R2) and root mean square error (RMSE) for the relationship were 0.94 and 7.0 respectively as summarized in Table 3.

$$PI=1+\frac{LL}{2-0.0055\,LL} \qquad (1)$$

3.8. Relationships between Unconfined Compressive Strength and liquid limit

A total of 7 data were collected from various research studies. The data collected from the literature were quantified using (Eq. 2) as shown in Fig. 2. The change in the X with Y was represented using relationship (Eq. 2) and the model parameters A and B are summarized in

Table 3. The coefficient of determination (R2) and root mean square error (RMSE) for the relationship were 0.97 and -0.0036 respectively as summarized in Table 3.

$$UCS=0.2585-0.0036\ LL \qquad (2)$$

3.9. Relationships between Unconfined Compressive Strength and Plasticity Index

Seven data were collected from numerous research studies. The collected data from the studies were calculated using (Eq. 3) as shown in Fig. 3. The change in the X with Y was shown using the relationship (Eq. 3) and the model parameters A and B are summarized in Table 3. The coefficient of determination (R2) and root mean square error (RMSE) for the relationship were 0.96 and 0.003 respectively as summarized in Table 3.

$$UCS=0.2723-0.0072\ PI \qquad (3)$$

3.10. Relationships between Maximum Dry Density and Liquid limit

From various research studies 48 data were collected. Based on The coefficient of determination (R2) and root mean square error (RMSE) no relationship was observed as shown in Fig. 4.

3.11. Relationships between Compression Index and Liquid limit

A total of 26 data were collected from various research studies. The collected data from the studies were calculated using (Eq. 4) as shown in Fig.5. The change in the X with Y was shown using the relationship (Eq. 4) and the model parameters Yo, A and B are summarized in Table 3. The coefficient of determination (R2) and root mean square error (RMSE) for the relationship were 0.94 and 0.045 respectively as summarized in Table 3.

$$Cc=0.04+\frac{LL}{209-0.3\,LL} \quad (4)$$

3.12. Relationships between Free swelling and Liquid limit

From various research studies 18 data were collected. The collected data from the studies were calculated using (Eq. 5) as shown in Fig.6. The change in the X with Y was shown using the relationship (Eq. 5) and the model parameters Yo, A and B are summarized in Table 3. The coefficient of determination (R2) and root mean square error (RMSE) for the relationship were 0.96 and 2.0 respectively as summarized in Table 3.

$$FS=1+\frac{LL}{4.9\text{-}0.017\,LL} \quad (5)$$

3.13. Relationships between Free swelling and Plasticity index

From numerous research studies 18 data were collected. The collected data from the studies were calculated using (Eq. 6) as shown in Fig.7. The change in the X with Y was shown using the relationship (Eq. 6) and the model parameters Yo, A and B are summarized in Table 3. The coefficient of determination (R2) and root mean square error (RMSE) for the relationship were 0.95 and 2.2 respectively as summarized in Table 3.

$$FS=5.3+\frac{PI}{4.0\text{-}0.015\,PI} \quad (6)$$

4. Conclusions

In this study, the effect of some geotechnical properties on expansive soil was investigated. Based on the literature and analytical data, the swelling behaviour of expansive soil, the following conclusions are advanced:

1. The compressive strength of the expansive soil decreased 65% by increasing plasticity index and liquid limit by 57% and 42% respectively.
2. The free swelling of the expansive soil increased 5 times when the plasticity index and liquid limit increased by 4 times and 3.5 times respectively.
3. Liquid limit had great effect on expansive soil when liquid limit increased 4 times the plasticity index and compression index increased 11times and 5 times respectively.
4. Based on Root Mean Squre Error (RMSE) and coefficient of determination (R^2) values, the good relationships were observed between Expansive soil properites .

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Table 1. Literature Review of Expansive soil

Reference	Soil Type	Tests	L.L%	P.I%	Footing Type	Temperature	USC (MPa)	Maximum dry density(gm/cm^3)	Free Swelling	Remarks
Nayak et al. (1971)	Clay soil	Oedometer test	41-129	23-110	Shallow	24°C	-		7.0-47	Linear relation was obtained between Predicted Swelling Potential and measured Swelling Potential
Al-Homoud et al. (1995)	Clay soil	Oedometer test	35-21	15-38	shallow	-	not specified	1.60-1.75	-	Linear L.L- Plasticity Index relation was observed
Al-Rawas et al. (1998)	Silt, Clay soil	X-ray diffraction analysis, ,swelling test	24-139	3-104	-	35^{o}C	-		Low-extra high	Linear L.L- Plasticity Index relation was observed
Kayabali et al. (2011)	Silt, Clay, sand	Oedometer test	52-93	28-61	-	Room Condition	-	1.9-2.1	1-12	Linear relation was obtained between free Swelling and Swelling pressure
ME Zumrawi (2012)	CH	Oedometer test	-	20-50	-	not specified	-	1.30-1.8	1.1-29.8	Linear relation was obtained between measured swelling and calculated swelling pressure
Azzam (2014)	CH	Oedometer test	33-50	19-27	-	25 °C	0.08-0.14	1.60-1.75	-	Linear relation was obtained between Split Tensile strength and fiber content
Budi (2017)	Clay soil	Based on investigation report	66-87	43-61	Pile foundation	23± 2°C	0.02-0.075	1.2-1.35	-	No relation was observed
Hatmoko et al. (2017)	Clay soil	Oedometer , direct shear test, UCS		16-48	-	Room Condition	-	-	2.3-12.10	Linear relation was observed between CBR and UCS values
Remarks	Clay soil types were used	Oedometer is the popular test to characterize the swelling	Up to 139% liquid limit were used	Up to 110% plasticity index were used	Different type of shallow foundation were used	Mainly 25^{o}C temperature was used	UCS varied from 0.020 to 0.14 MPa	varied from 1.2 to 1.90 (gm/cm^3)	Free Swelling varied from 1 to 47	

Table 2. Statistical Variation of Expansive soil properties

	Statistical Parameters	L.L%	P.I%	USC (MPa)	Maximum dry density(gm/cm^3)	Free Swelling, FS (%)	Compression Index,Cc
Expansive soil	No. of Data	76.0	45.0	11.0	108.0	76.0	26.0
	Range	24-139	3-110	0.020-0.14	1.2-1.90	1-47	0.17-0.9
	Mean (μ)	61. 0	44.0	0.10	1.70	10	0.39
	Std. Deviation (σ)	24.0	27.0	0.035	0.25	8.0	0.19
	COV (%)	39	61	35	14	80.0	48

Table 3. Model parameters for Expansive soil properties

		Model						
depended Variable (Y-axis)	In depended Variable (X-axis)	Y_o	A	B	RMSE	R^2	No. of Data	Fig. No.
Plasticity Index, PI (%)	Liquid Limit, LL (%)	1	2	-0.0055	7.0	0.94	20	Fig.1
Unconfined Compression Strength, USC (MPa)	Liquid Limit, LL (%)	-	0.2585	-0.0036	0.003	0.97	7	Fig.2(a)
Unconfined Compressive Strength, (MPa)	Plasticity Index, PI (%)	-	0.2723	-0.0072	0.003	0.96	7	Fig.2(b)
Maximum Dry Density, MDD (gm/cm^3)	Liquid Limit, LL (%)	No relation was observed					48	Fig.3
Compression Index, Cc	Liquid Limit, LL (%)	0.04	209	-0.3	0.045	0.94	26	Fig.4
Free swelling, FS (%)	Liquid Limit, LL (%)	1.0	4.9	-0.017	2.0	0.96	18	Fig.5(a)
Free swelling, FS (%)	Plasticity Index, PI (%)	5.3	4.0	-0.015	2.2	0.95	18	Fig.5(b)

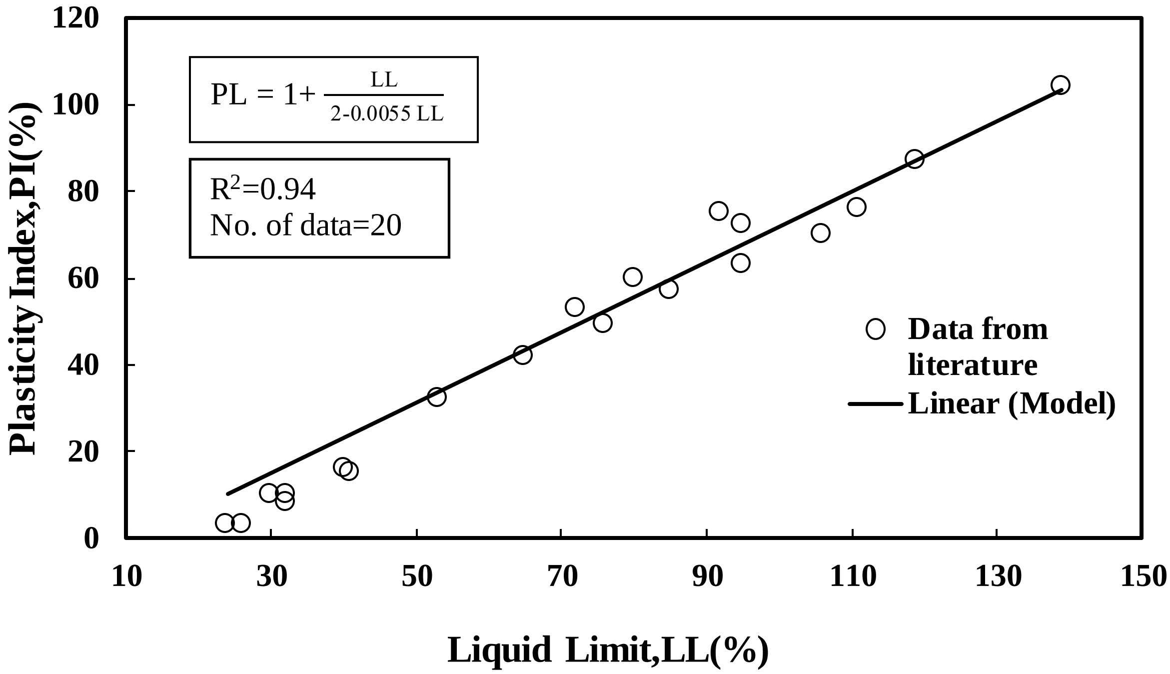

Fig. 1 Plasticity Index vs Liquid Limit

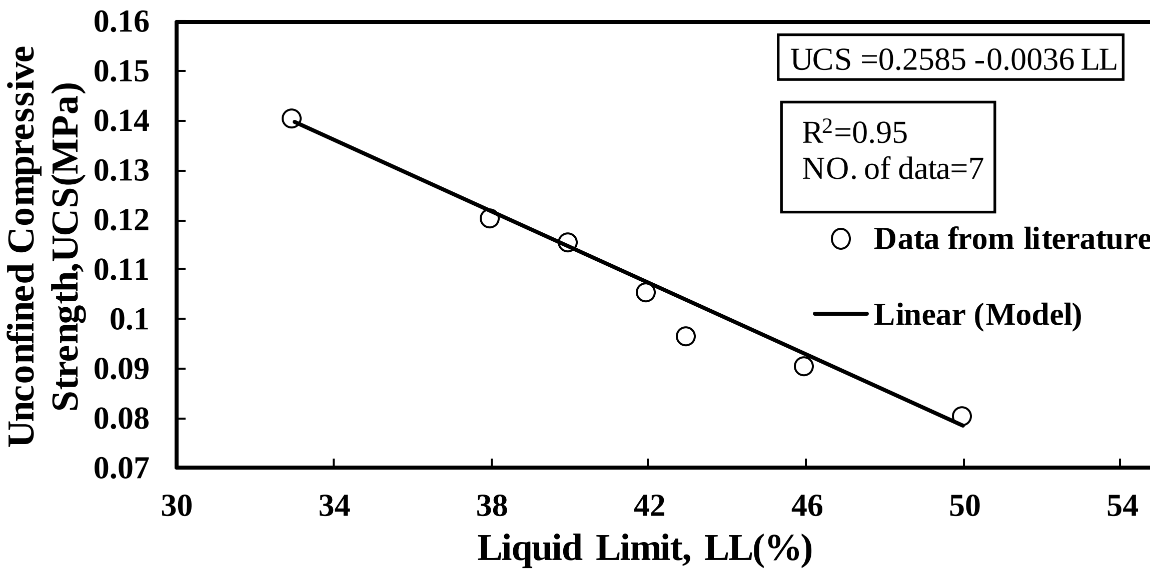

Fig. 2 (a) Unconfined Compressive Strength vs Liquid Limit

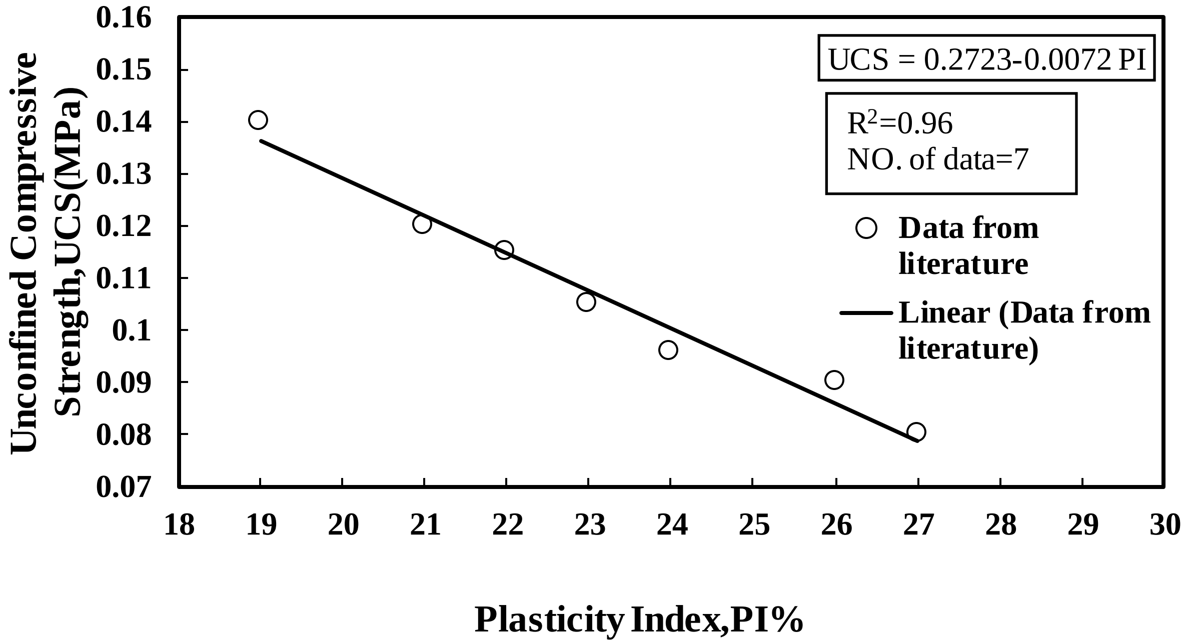

Fig. 2 (b) Unconfined Compressive Strength vs Plasticity Index

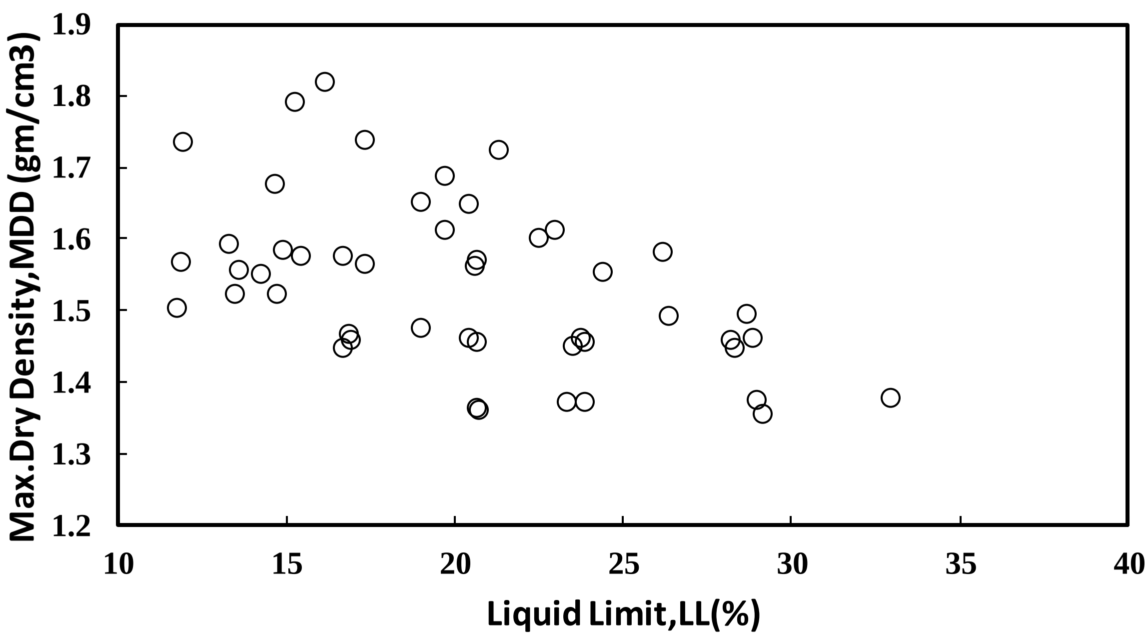

Fig. 3 Maximum Dry Density vs Liquid Limit

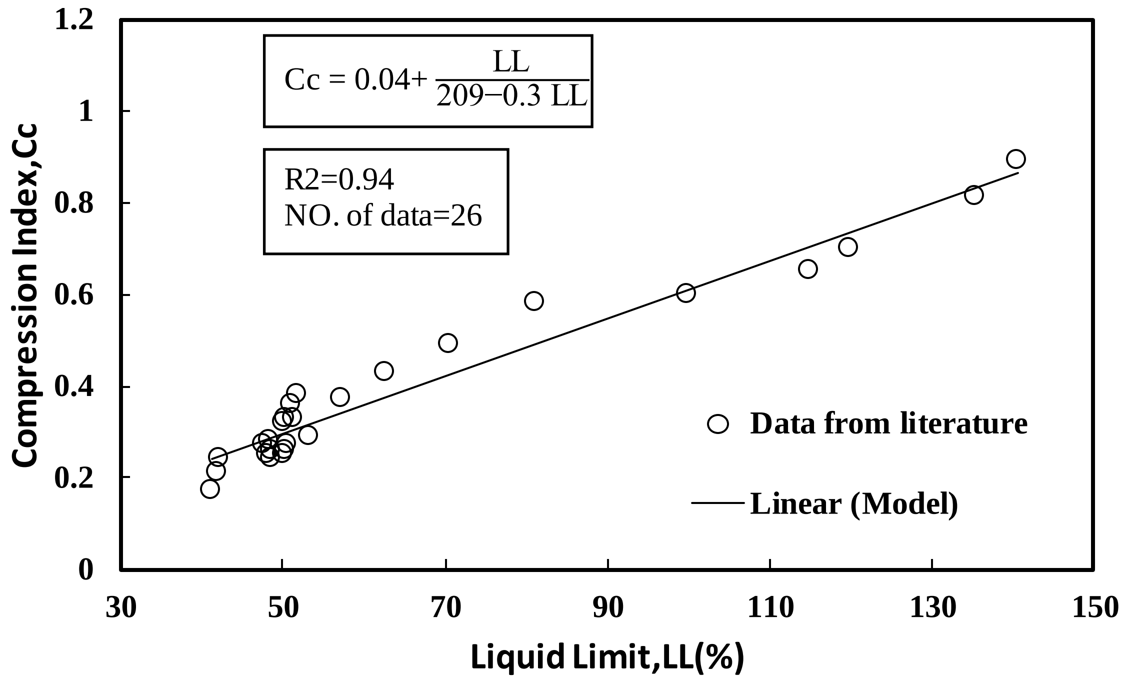

Fig. 4 Compression Index vs Liquid Limit

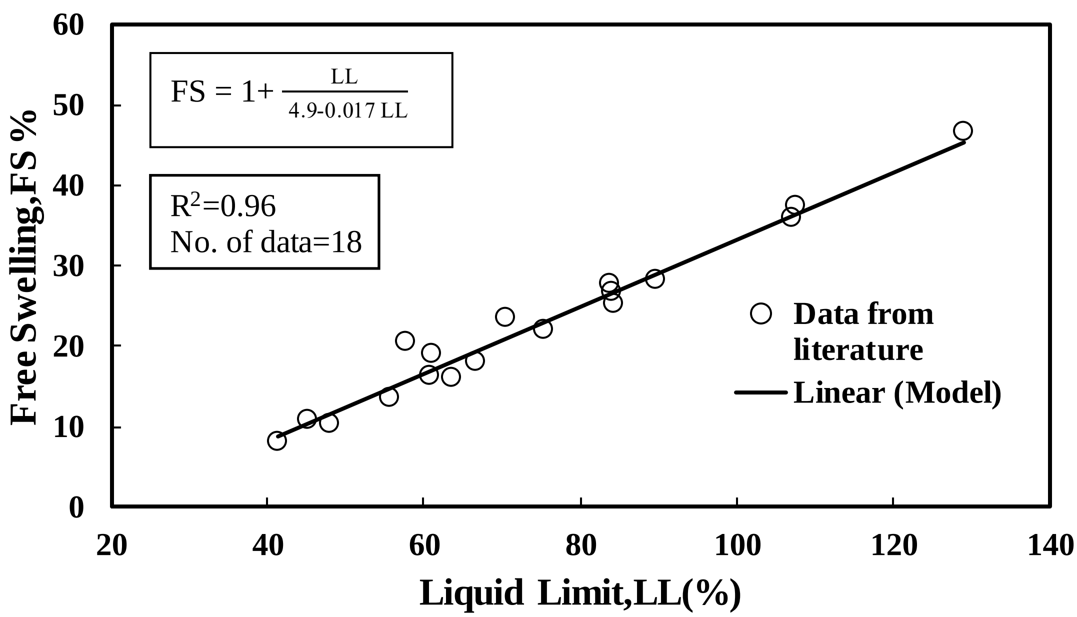

Fig. 5 (a) Free Swelling vs Liquid Limit

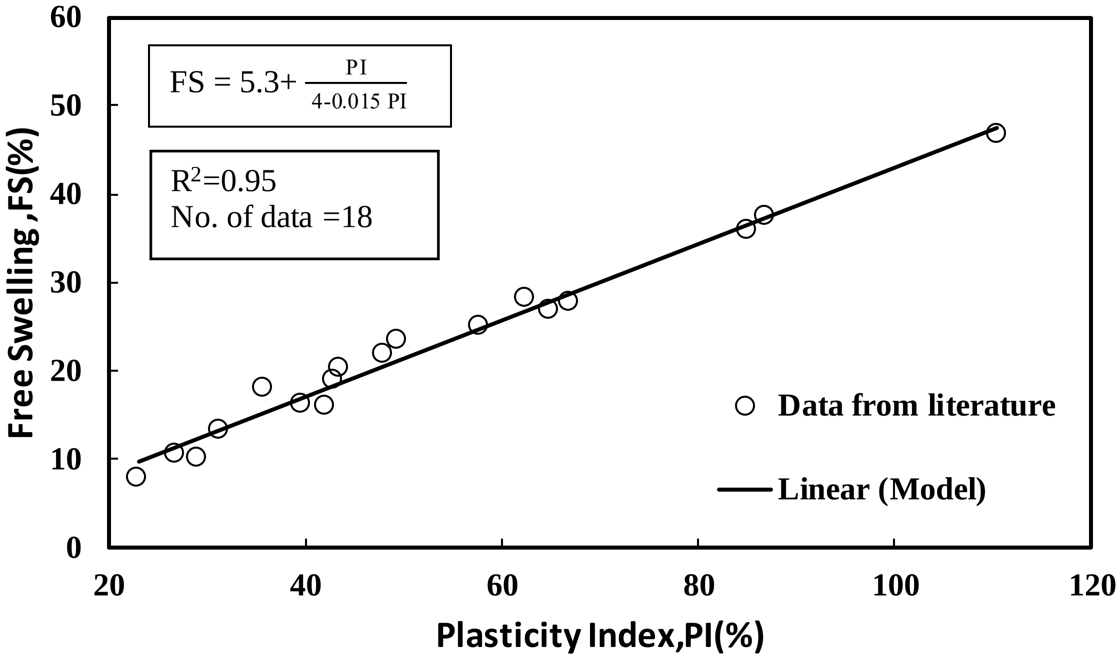

Fig.5 (b) Free Swelling vs Plasticity Index