Mansoura Engineering Journal

Volume 40 | Issue 3 Article 20

7-9-2020

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Recommended Citation

EL-Masry, A.; Ibrahem, A.; EL-Miligy, M.; and Ashour, M. (2020) "Characterization of Collapsible Soils due to Saturation.," *Mansoura Engineering Journal*: Vol. 40 : Iss. 3 , Article 20.
Available at: https://doi.org/10.21608/bfemu.2020.101864

Characterization of collapsible soils due to saturation
تحديد خصائص التربة الإنهيارية نتيجة التشبع

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الخلاصة
تهتم هذه الدراسة بالتربة الانهيارية و تحديد العلاقات بين خصائص التربة المختلفة بعد الوصول الى حالة التشبع، و من المعروف ان التربة الانهيارية تواجه مشاكل الهبوط المفاجئ و الملحوظ و ذلك بسبب زيادة نسبة الرطوبة مع وجود حمل خارجى او عدمه و يندرج ئهذا النوع من التربة ضمن التربة الغير مشبعة فى الحالة الطبيعية. و يرجع السبب الرئيسى وراء هذا الانهيار المفاجئ هو البنية الداخلية القابلة للانهيار و قلة نسبة الرطوبة وتعتبر محاولة ايجاد علاقات واضحة تجمع بين خصائص التربة اسهاما فى تسهيل فهم هذا النوع من التربة، حيث انه من الصعب اجراء بعض الاختبارات على التربة فى المختبرات او المواقع مع ارتفاع التكلفة. لتحقيق الهدف من الدراسة تم الحصول على قاعدة بيانات لعينات مختلفة حول العالم تتضمن الخواص الرئيسية للعينات من عدة ابحاث و تقارير فنيه.

Abstract
This study is concerned with Collapsible soils which have significant volume decrease suddenly due to an increase in soil moisture content, with or without an increase in the in-situ stress level. Since the collapsible soils contain low levels of moisture content when they are formed naturally, they are considered to be such a problematic type of unsaturated soils. Reliable simple correlations between basic soil properties would be valuable because of the cost and difficulty of performing collapse tests either in the laboratory or in-situ. This study focuses on silty sand and sandy silt types of the collapsible soils. In order to fulfill the study objectives, a large database was developed from different researches works. The database contains information regarding basic soil properties of laboratory and field samples.

Introduction
Schwartz (1985) states the following: “Collapse problems are generally associated with silty or sandy soils of low clay content (low plasticity index). It is important to take into consideration that high clay content does not necessarily imply that collapse will not occur. Soils with collapsible fabric frequently have a low dry density.”

Based on the structural composition of these soil samples, recent study focused on the samples formed from sand and silt with various proportions.

Methodology
The methodology refers to the process through which representative data were collected and analyzed to gain a better understanding of the behavior of collapsible soils before and after saturation.

Data of soil samples includes different properties as follows:

- Depth of sample
- Water content (w_c)
- Initial voids ratio (e_0)
- Initial degree of saturation (S_{r0})
- Liquid limit (LL)

Received: 10 June, 2015 – Revised: 4 August - Accepted: 10 August, 2015

- Plasticity index (PI)
- Dry unit weight (γ_{dry})
- Unified soil classification system (USCS)
- Angle of internal friction before wetting (φ)
- Angle of internal friction after wetting (φ_f)
- Collapse potential (C_p)
- Voids ratio upon wetting under 200 kPa pressure (e_{200})
- Difference in degree of saturation upon wetting (ΔS_r=100% - S_{ro})
- Difference in void ratio due to inundation ($\Delta e = e_0 - e_{200}$)

Procedures of Collecting Soil Samples data

Data of soil properties of 588 different collapsible soil samples have been gathered from twelve different geotechnical reports and researches; data of these samples was divided according to their sources as shown in table (1) and (2).

Table (1) Sources of gathered data

No.	Source	No. of samples
1	Owens (1990)	26
2	Dames and Moore (Salt Lake City, UT)	79
3	Applied Geotechnical (Salt Lake City, UT)	9
4	Kleinfelder & Associates (Diamond Bar, CA)	2
5	Southwest testing (St. George, UT)	8
6	Rollins et al. (1992)	73
7	Roullier (1992)	80
8	NCS Consultants [LLC] (2006)	7
9	NCS Consultants [LLC] (2011)	4
10	Jones & Wagener consulting civil engineers (2006)	4
11	Habibagahi et al. (2004)	25
12	Rollins & Williams (1991)	57

Table (2) Example of gathered samples data

Sample no.	Source	Depth (m)	USCS	W_C %	γ_{dry} kN/m3	γ_{eff} kN/m^3	e_0	e_{200}	Δ e	S_{r0}	ΔS_r	C_P	LL	PI	φ°	φ_f°
1	1	1.83	ML	9.1	12.36	13.49	0.90	0.53	0.38	24.15	75.85	19.70 %	---	---	30.79	40.02
69	2	3.20	SM-ML	6.3	15.87	16.87	0.48	0.44	0.04	31.25	68.75	2.90%	---	---	39.52	40.88
114	3	5.79	SM	10.8	15.07	16.69	0.56	0.52	0.04	46.06	53.94	2.80%	---	---	37.02	38.40
115	4	2.44	ML	13.7	13.21	15.02	0.78	0.70	0.08	42.05	57.95	4.66%	---	---	33.80	35.84
119	5	0.91	ML	6.9	15.41	16.47	0.53	0.48	0.04	31.38	68.62	2.91%	19	1.6	40.06	41.15
197	6	1.37	SM	2.3	15.55	15.91	0.51	0.47	0.04	10.74	89.26	2.80%	---	---	38.57	39.91
198	7	0.61	ML	7.1	12.25	13.12	0.92	0.66	0.26	18.49	81.51	13.40 %	---	---	30.37	36.70
285	8	0.91	SC-SM	6.9	13.13	14.04	0.79	0.69	0.10	20.89	79.11	5.68%	---	---	25.67	29.42
286	9	1.52	---	2	15.73	16.04	0.50	0.39	0.11	9.65	90.35	7.20%	---	---	---	---
292	10	0.61	SC-SM	7.38	15.52	16.67	0.52	0.48	0.04	34.27	65.73	2.57%	17.5	5.2	35.83	37.27
318	11	---	ML	16.9	16.09	18.81	0.46	0.41	0.05	87.55	12.45	3.40%	---	---	41.64	42.87
375	12	1.37	SM	2.3	15.55	15.91	0.51	0.47	0.04	10.74	89.26	2.80%	---	---	38.57	39.91

Table (3) Classification of Collapse Potential, (C_P)

Degree of Specimen Collapse	Collapse Potential (C_P) %
None	0
Slight	0.1 to 2.0
Moderate	2.1 to 6.0
Moderately Severe	6.1 to 10.0
Severe	> 10

Records of some samples were excluded due to missing data from the original references. Thus, total of 375 records of collapsible soil samples were used in this study.

The collapse potential, C_p, of the used samples were in the range of 2.1% (moderate) to > 10% (sever), As introduced by (ASTM, D 5333-03) a classification of collapsible soils according to severity of problem putting into consideration collapse potential is shown in the table (3).

Depth of Samples

Depth of the sample refers to the depth at which the sample was collected. The deepest sample was taken from a depth of 10.50 meter below ground surface. The distribution of samples with respect to their sampling depth is shown on Figure (1).

Dry Unit Weight of Samples (γ_{dry})

The dry unit weight of the sample is defined as the weight of the soil particles divided by the volume of the sample. Figure (2) shows the distribution of used samples with respect to their dry unit weight.

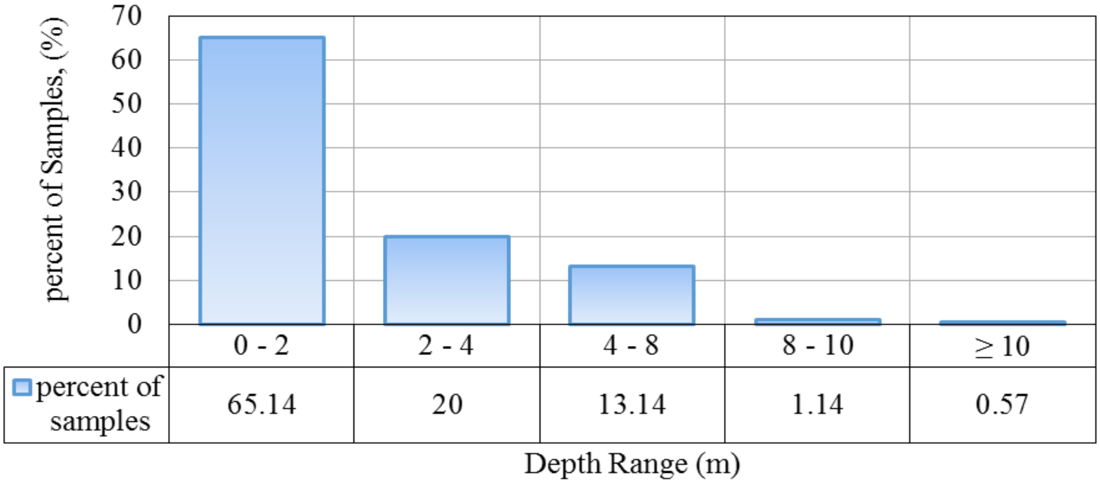

Fig. (1): Histogram of sampling depths

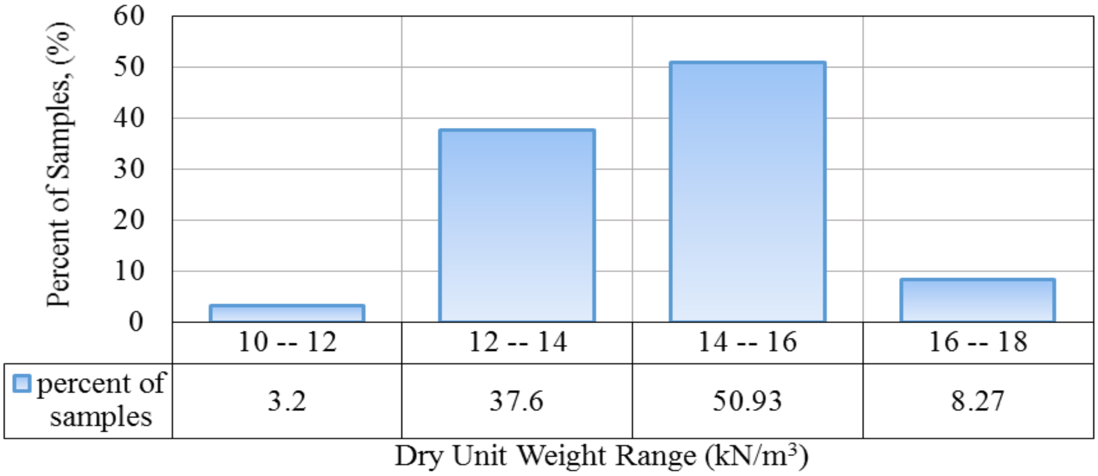

Fig. (2): Histogram of Dry Unit Weight of collected samples

In-Situ Water Content of Samples (w_C)

The in-situ water contents in this database range from 1.0% to 22.6%. Figure (3) shows the distribution of samples with respect to their in-situ water contents.

Unified Soil Classification System of Samples (USCS)

The USCS classification is given for most samples. Sometimes the USCS classification is determined by the author based on available sieve analyses. The distribution of samples with respect to their USCS classification is shown on Figure (4); the most frequently cited classification for the collapsible soils was ML (silts with very fine sand) which form (56%) of the database. The ML classification was followed in frequency by SM (silty sand) (32.8%), SC (clayey sand) (3.75%), SM-ML (1.87%) and SC-SM (1.6%).

Collapse Potential of Samples (C_p)

Collapse potential is the collapse strain due to inundation of the undisturbed sample under 200 kPa pressure. Figure (5) shows the distribution of samples and their collapse potential (C_P).

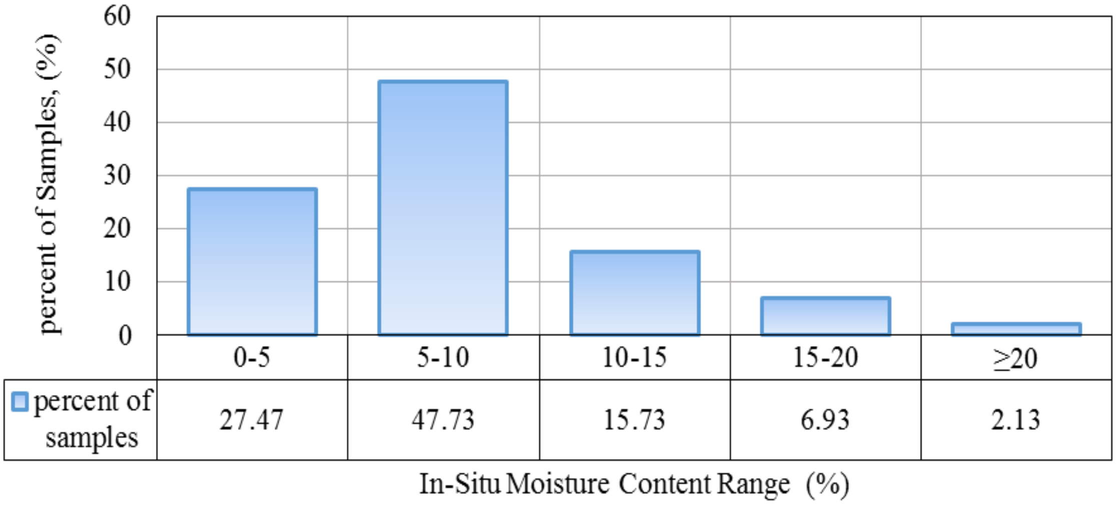

Fig. (3): Histogram of sampling in-situ water content

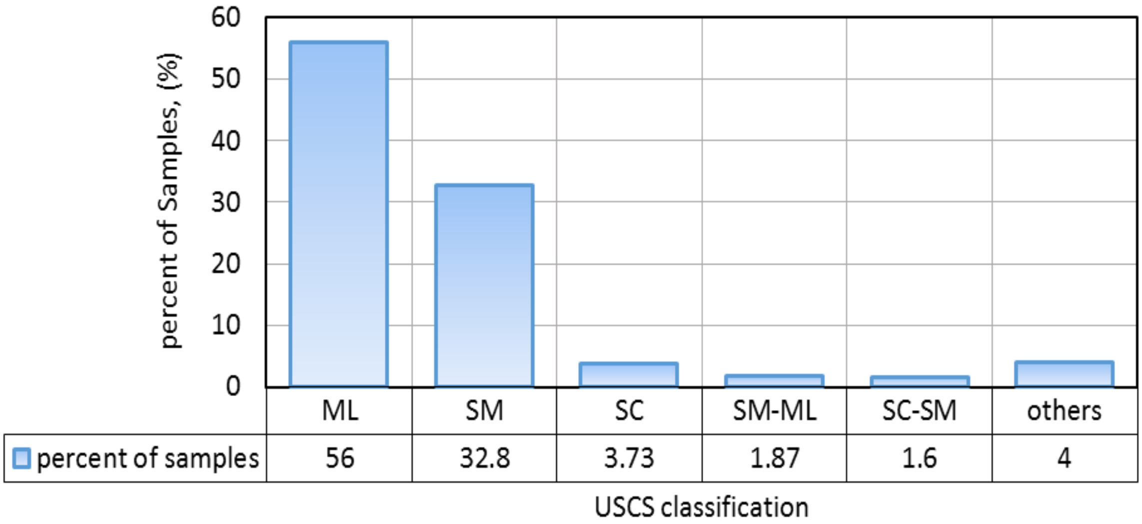

Fig. (4): Histogram of sampling USCS Classification

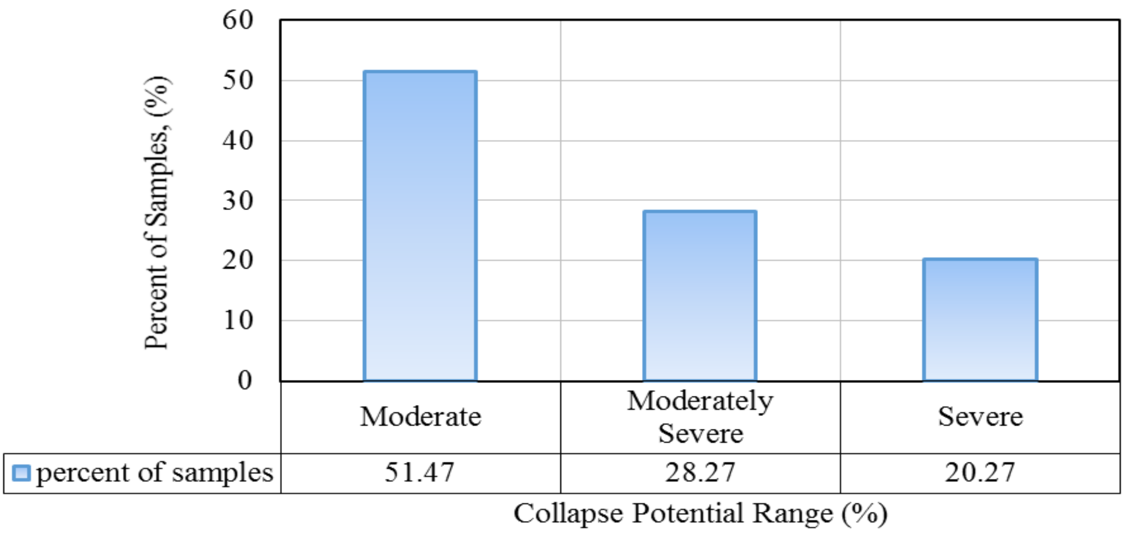

Fig. (5): Histogram of sampling collapse potential

In-Situ Void Ratio of Samples (e_0)

The in-situ void ratio (e_0), is defined as the initial void ratio before inundation. The void ratio can be determined from the following expression:

$$e_0=\frac{G_s \times \gamma_w}{\gamma_{dry}}-1 \qquad (1)$$

Where:

- G_s : Specific gravity of the soil particles.
- γ_w : The unit weight of water and.
- γ_{dry} : The dry unit weight of the soil.

Initial Degree of Saturation (S_{r0})

The degree of saturation (S_{r0}) can be found by using the specific gravity (G_S) of the soil, the unit weight of water (γ_W), the dry unit weight (γ_{dry}) and the in-situ water content (W_C) in the following expression:

$$S_{r0}=\frac{G_s \times W_c}{e_0} \qquad (2)$$

Difference in Saturation (ΔS_r)

The Difference in saturation can be calculated by subtraction the initial degree of saturation from the full saturation upon wetting that can be defined as:

$$\Delta S_r = 100\% - S_{r0} \qquad (3)$$

Angle of Internal Friction (φ)

The angle of internal friction is the measure of the shear strength of soils due to friction and it can be approximated from the correlation shown in Figure (6) before and after saturation because the soil has the same classification.

Derived Relations:

Graphs are constructed to visualize potential relationships that exist between different soil parameters and determine if mathematical relationships could be developed between these different soil parameters.

Relation between collapse potential (C_P) and difference in saturation (ΔS_r)

Figure (7) plots collapse potential (C_P) versus difference in degree of saturation (ΔS_r). The curve suggests that they related somewhat to each other.
To create a better fit, the natural logs of all the variables are taken; the relation takes the form:

$$C_p(\%) = (1.4 \times 10^{-14})(\Delta S_r)^{7.84} \qquad (4)$$

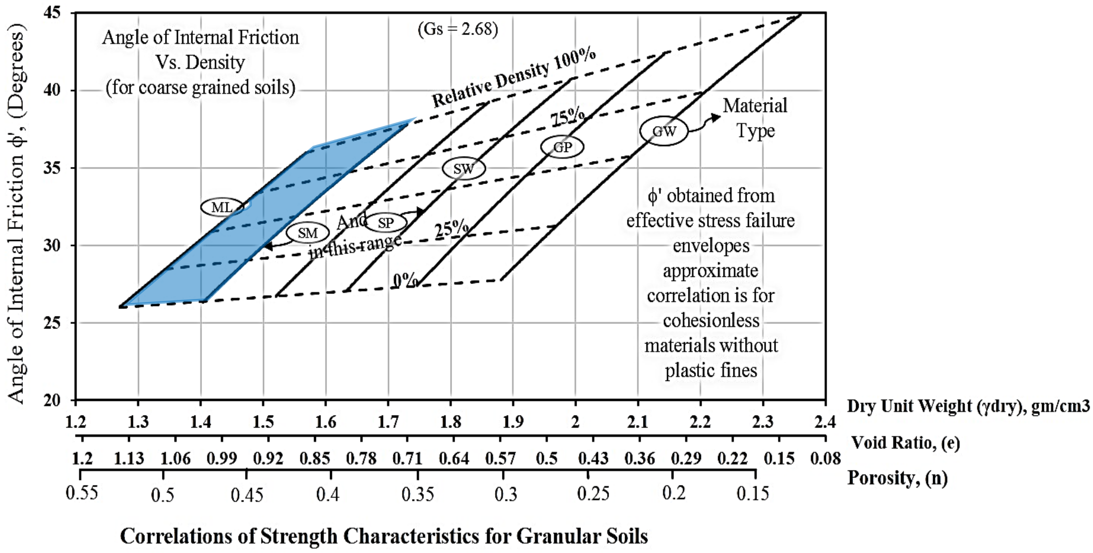

Fig. (6) Correlations of strength characteristics for granular soils (DM 7.01), 1986

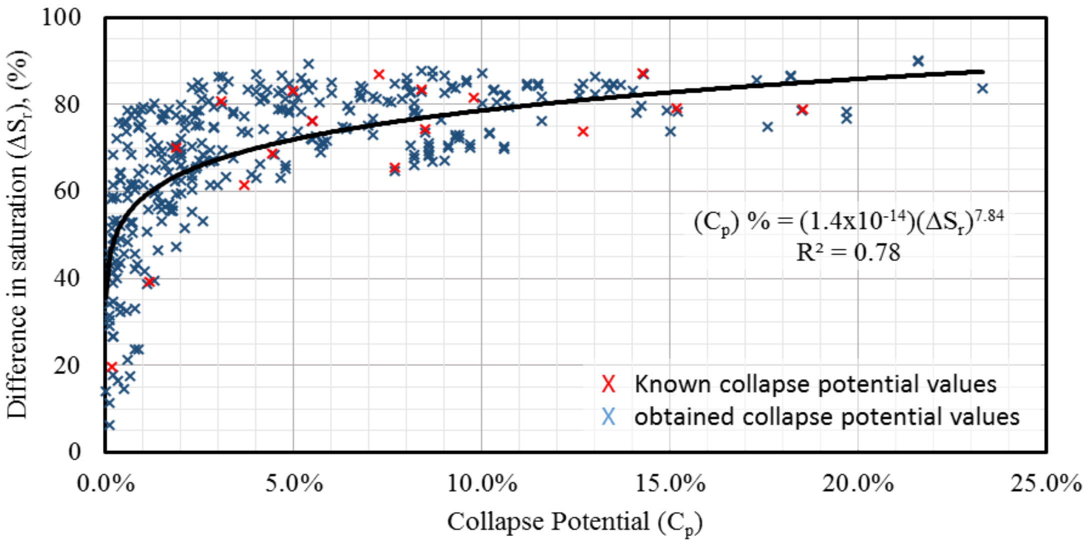

Fig. (7) Relation between collapse potential (Cp) & difference in degree of saturation (ΔSr)

Relation between collapse potential (C_P) and difference in void ratio (Δe)

Figure (8) includes a plot between collapse potential (C_P) versus difference in void ratio (Δe). The curve suggests that they related somewhat to each other.

To create a better fit, the natural log is taken for (C_p) and logarithmic log for (Δe); the relation takes the form:

$$C_P = 0.5169(\Delta e)^{0.9342} \qquad (6)$$

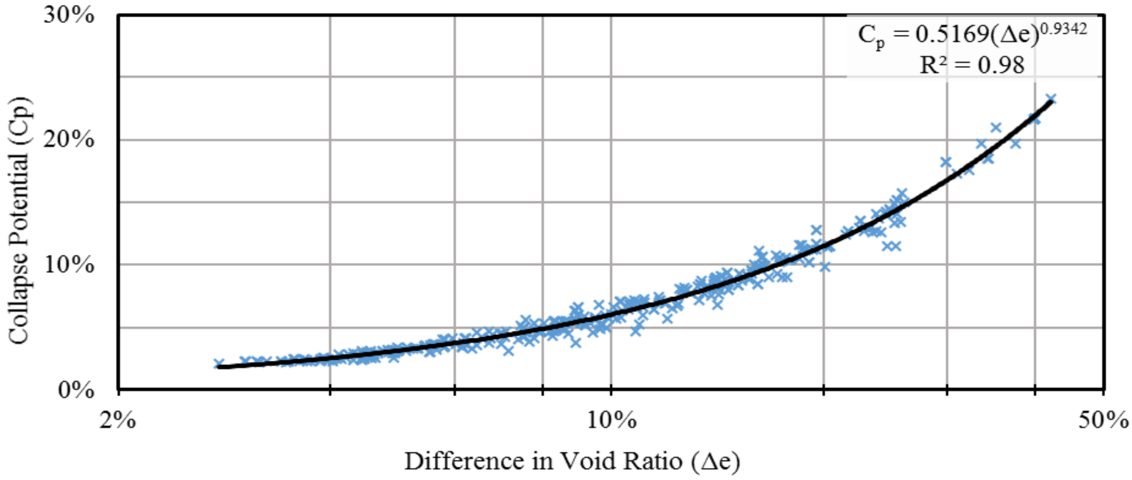

Fig. (8) Relation between collapse potential (CP) & difference in void ratio (Δe)

Relation between difference in saturation (ΔS_r) and soil strain at 50% stress level (ε_{50})

The (ε_{50}) represents the axial strain (ε_1) at a stress level equal to 50 percent in the stress strain relationship that would result from a drained triaxial test.

It is not known the conditions and variation in the experimental set of data by Norris (1986) Fig.(9) particularly, the fines content, clay content and degree of saturation. However, in order to obtain approximate estimation of parameter such as (ε_{50}), the set of data was used in absence of data available to estimate (ε_{50}) that is important parameter to estimate the load versus deformation curve for soil surrounding laterally loaded piles.

As a result of obtaining (ε_{50}), relationships between (S_{r0}), (ε_{50}), ($\varepsilon_{50sat.}$) and (ΔS_r) can be illustrated.

The difference in (ε_{50}) due to reaching full saturation for different initial degrees of saturation as shown in the following Fig. (11) through (19) for different cases of study, different values of (Cu) and (e0) were assumed as initial properties for collapsible soils.

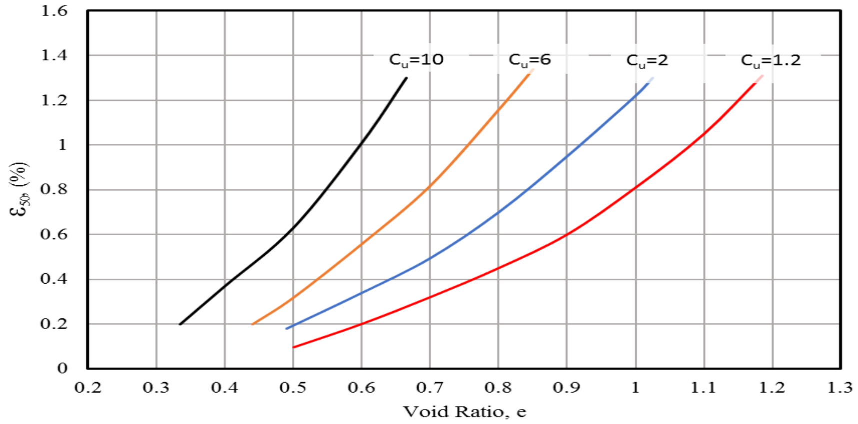

Fig. (9) Relation between (ε_{50}), uniformity coefficient (C_u) and void ratio (e) (Norris; 1986)

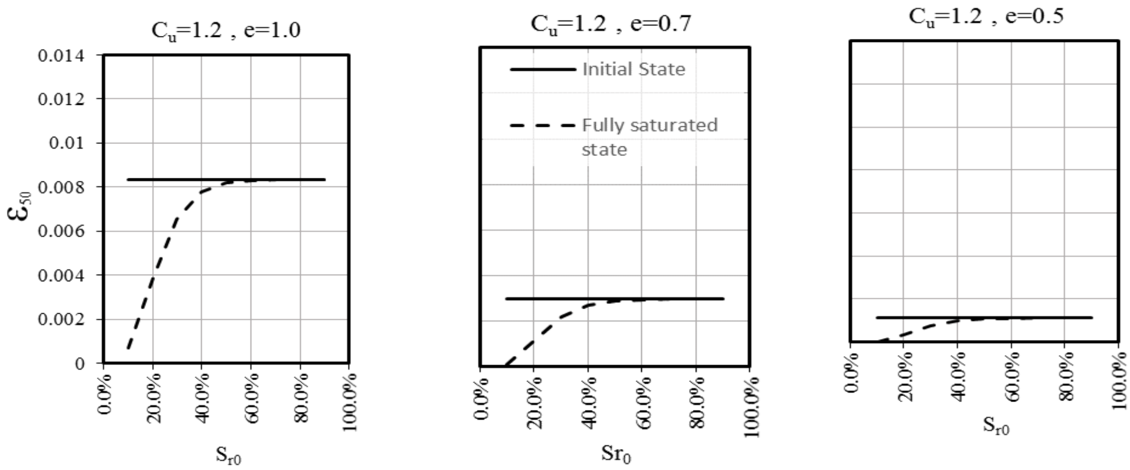

Fig. (10) Relation between (ε_{50}), uniformity coefficient (C_u=1.2), initial void ratio (e) and degree of saturation (S

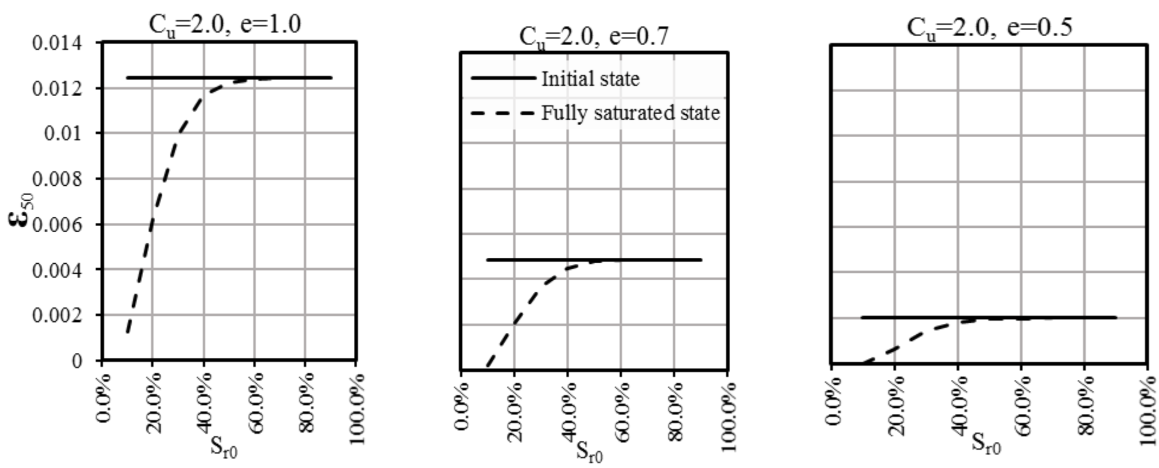

Fig. (11) Relation between (ε_{50}), uniformity coefficient (C_u=2.0), initial void ratio (e) and degree of saturation (S_r)

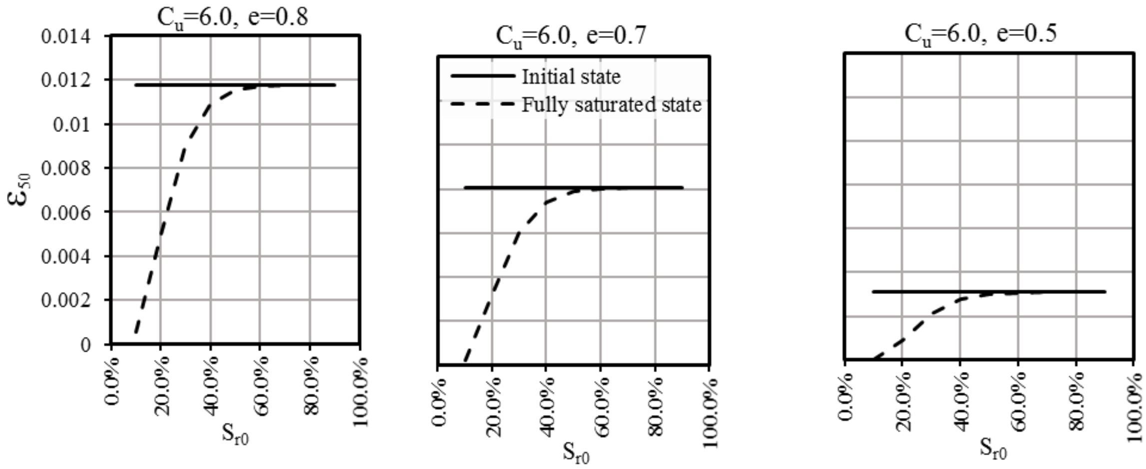

Fig. (12) Relation between (ε_{50}), uniformity coefficient (C_u=6.0), initial void ratio (e) and degree of saturation (S_r)

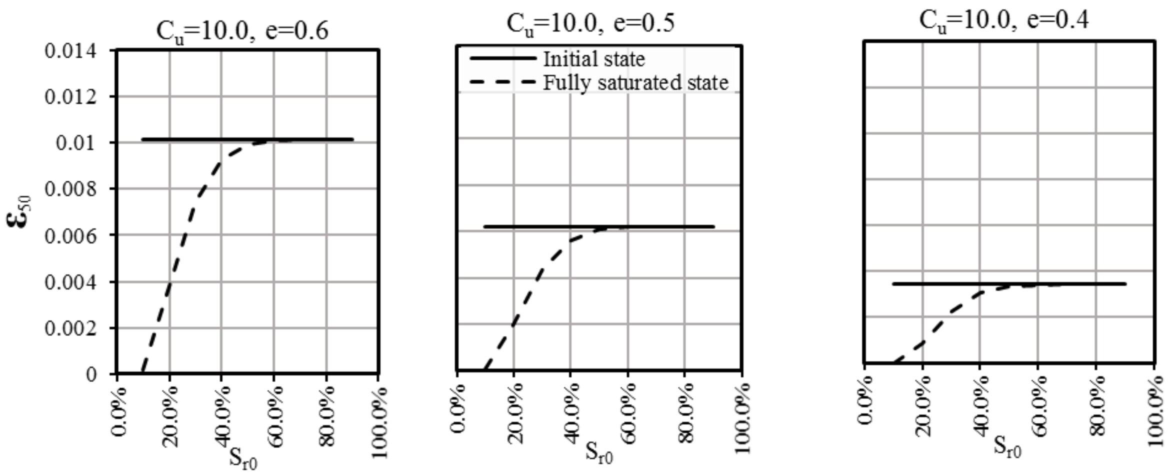

Fig. (13) Relation between (ε_{50}), uniformity coefficient (C_u=10), initial void ratio (e) and degree of saturation (S_r)

Figures (14) through (3.17) shows relation between the change in 50% strain ($\Delta\varepsilon_{50}$) before and after saturation and (ΔS_r) for different cases of (C_u) and (e_0).

The value of ($\Delta\varepsilon_{50}$) is important for studying the behavior of laterally loaded piles embedded in collapsible soil before and after inundation.

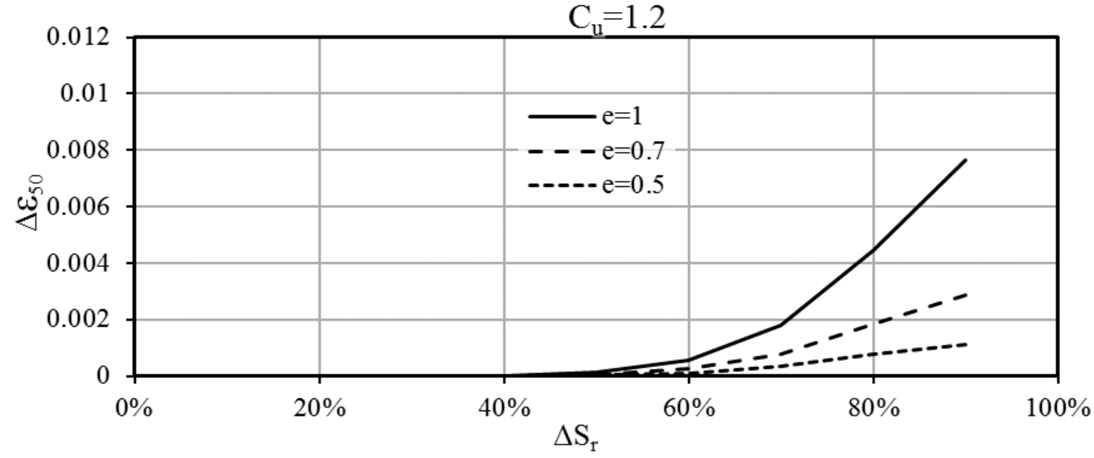

Fig. (14) Relation between ($\Delta\varepsilon_{50}$), and difference in degree of saturation (ΔS_r) for coefficient of uniformity (C_u=1.2)

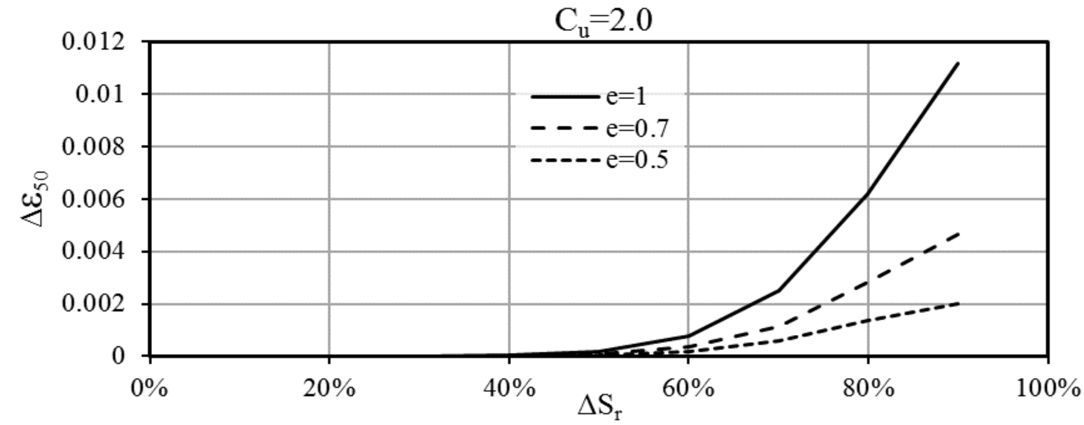

Fig. (15) Relation between ($\Delta\varepsilon_{50}$), and difference in degree of saturation (ΔS_r) for coefficient of uniformity (C_u=2.0)

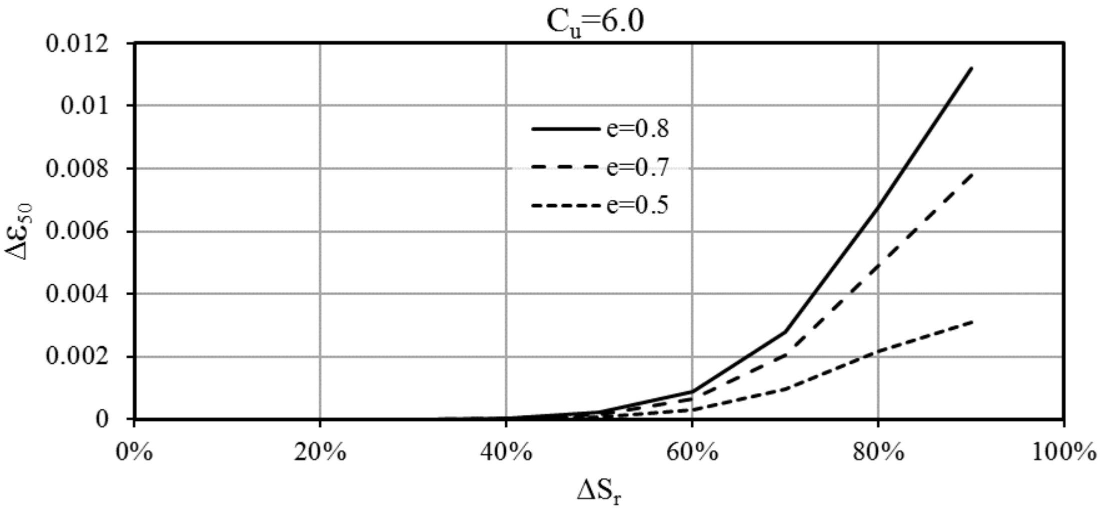

Fig. (16) Relation between ($\Delta\varepsilon_{50}$), and difference in degree of saturation (ΔS_r) for coefficient of uniformity (C_u=6.0)

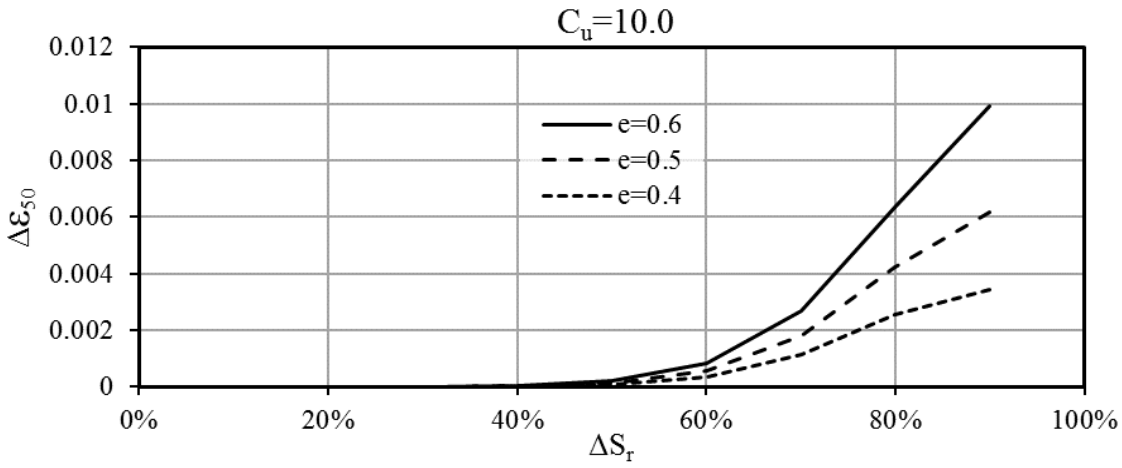

Fig. (17) Relation between ($\Delta\varepsilon_{50}$), and difference in degree of saturation (ΔS_r) for coefficient of uniformity (C_u=10)

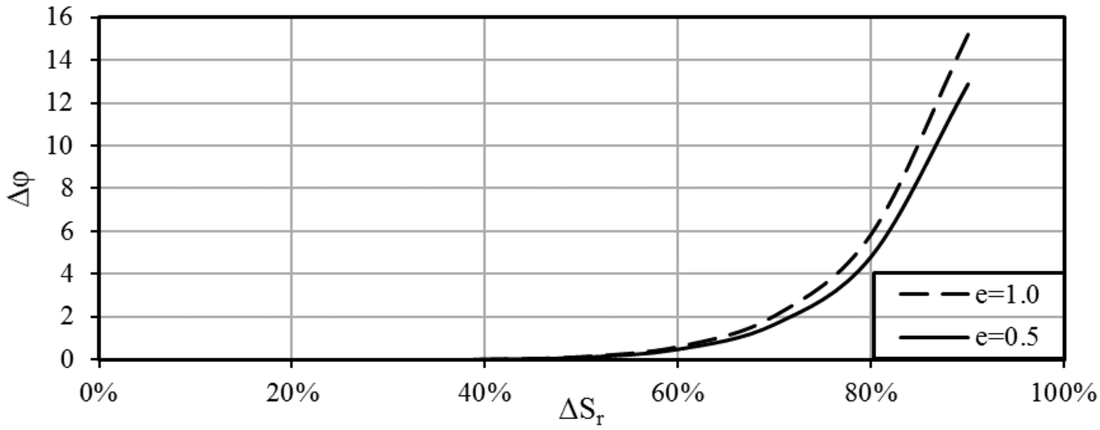

Fig. (18) Relation between ($\Delta\varphi$), and difference in degree of saturation (ΔS_r)

Conclusions

After analyzing the properties of the collected soil samples, as illustrated in this study, it can be concluded that:

- Large number of collapsible soil relations (soil properties) was prepared for the parametric study.
- Difference between initial state and fully degree of saturation state for collapsible soils in this study can be related to the value of the collapse potential.
- Difference in void ratio before and after full saturation (Δe) can be related to the value of collapse potential (C_p).
- Value of (ε_{50}) had no change before and after fully saturation if the initial degree of saturation is more than 50% for different values of uniformity coefficient (C_u) and void ratio (e).

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