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Geotechnical Properties of Problematic Soils Emphasis on Collapsible Cases

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ABSTRACT

Soils are unconsolidated materials that are result of weathering and erosion process of rocks. When water content of some soils change, it makes problems to civil activities. These problems include swelling, dispersing and collapse. The change of water content of expansive soils causes to changes their volume. The volume change can damage structures that have built on the soils. In dispersive soils, particles move through soils with water flow. It may be conduits form in the soils. Collapsible soils are settled when saturated under loading. The rapid collapse of soils damages the structures which have built on soil. Problematic soils are formed in especial geological conditions. For example, collapsible soils are often founded in semi-arid area. Field observation and laboratory test can be useful to identify problematic soils. Some properties of soils such as dry density and liquid limit are helpful to estimate collapsibility potential of soils. In this regard, it was done a series laboratory tests to evaluate the collapsibility rate.

Keywords: Soil; Collapse; South Rudasht; Dorcheh; Sivand

1. Introduction

The earth's crust is composed of soil and rock. Rock is often considered a consolidated material but soil is defined an unconsolidated sediment and deposits of solid particle that have resulted from the disintegration of rock. Soils can be grouped into two categories depending on the method of deposition. Residual soils have formed from the weathering of rocks and remain at the location of their origin. Residual soils can include particles having a wide range of sizes, shapes and compositions depending on amount and type of weathering and the minerals of parent rock. Transported soils are those materials that have been moved from their place of origin. Transportation may have resulted from the effect of gravity, wind, water glaciers or human activities. Transported soil particles are often segregated according to size during the transportation process. The method of transportation and deposition has significant effect on the properties of the resulting soil mass [1].

Many large land areas have been formed with transported soils which deposited primarily by one of the transportation methods. The type and condition of soil deposits underlying proposed construction site must be recognized. Therefore engineers that engaged with construction has to be considered soil origin and properties of site especially problematic soils.

2. Problematic Soils

Many soils can prove problematic in geotechnical engineering, because they expand, collapse, disperse, undergo excessive settlement, have a distinct lake of strength or are soluble. Such characteristics may be attributable to their composition, the nature of their pore fluids, their mineralogy or their fabric [2].

There are many types of problematic soils, some of the most noteworthy being swelling clay, dispersive soils and collapsible soils that discuss subsequently. Present study is mainly in reflection with collapsible soils. In following, briefly pay attention to expansive and depressive soils and finally collapsible soils have been explained.

2.1. Expansive Soils

Some soils undergo slow volume changes when change water content that occur independently of loading and are attributable to swelling or shrinkage [3]. These volume changes can give rise to ground movement which can cause damage to low-rise buildings that they don't have sufficient weight to resist [4,5]. These soils also represent a problem when they are encountered in road construction, and shrinkage settlement of embankments composed of such clays can lead to cracking and breakup of the roads they support. Construction damage is notable, especially where expansive clay forms the surface cover in regions which experience alternating wet and dry seasons leading to swelling and shrinkage of these soils [6].

The principle cause of expansive soils is the presence of swelling clay minerals such as Montmorillonite. The potential for volume change in soil is governed by its initial moisture content; void ratio and vertical stress as well as the amount and type of clay minerals [7]. Cemented or undisturbed expansive soils have a high resistance to deformation. Therefore, remolded expansive soils tent to swell more than undisturbed ones.

2.2. Dispersive Soils

Dispersion occurs in soils when the repulsive forces between clay particles exceed the attractive forces, thus bringing about deflocculation, so that in the presence of relatively pure water the particles repel each other to form colloidal suspensions [8]. In non-dispersive soil there is a definite threshold velocity below which flowing water causes no erosion. The individual particles cling to each other and are only removed by water flowing with a certain erosive energy. By contrast, there is no threshold velocity for dispersive soil; the colloidal clay particles go into suspension even in quiet water and therefore are highly susceptible to erosion and piping. Dispersive soils contain a moderate to high content of clay material but there are no significant differences in the clay fractions of dispersive and non-dispersive soils, except that soils with less than 10% clay particles may not have enough colloids to support dispersive piping. Dispersive soils contain a higher content of dissolved sodium (up to 12%) in their pore water than ordinary soils. The clay particles in soils with high salt contents exist as aggregates and coatings around silt and sand particles and the soil is flocculated [9].

The mechanism by which dispersive soil is eroded involves the structure of the soil and the character of the interaction between the pore and eroding fluids. It would appear that the stress required to initiate erosion is affected by the type of clay minerals present, pH value, organic matter, temperature, water content, thixotropy, and type and concentration of ions in the pore and eroding fluids. The structure of the soil and the osmotic influences set up at the surface of clay particles produce swelling at the particle surfaces. This swelling reduces the interparticle bonding forces and is a significant factor in the erosion of cohesive soils by water. The more dispersed the soil system is, the greater is the swelling caused by the concentration gradients at the clay particle water interface. For a given eroding fluid the boundary between the flocculated and deflocculated states depends on the value of the sodium adsorption ratio, the salt concentration, the pH value and the mineralogy [10].

2.3. Collapsible Soils

Collapsible soils are moisture sensitive in that increase in moisture content is the primary triggering mechanism for the volume reduction of these soils [7]. Soils such as loess and certain wind-blown silts may have the potential to collapse. However, these wind-blown deposits are not the only soils which are capable of collapsing [11]. Collapsible soils normally possess porous textures with high void ratios and have relatively low densities. They often have sufficient void space in their natural state to hold their liquid limit moisture content at saturation. At their natural low moisture content these soils possess high apparent strength but they are susceptible to large reductions in void ratio upon wetting [12]. In other words, the metastable texture collapses as the bonds between the grains break down when the soil is wetted. Hence, the collapse process represents a rearrangement of soil particles into a denser state of packing. Collapse on saturation normally takes only a short period of time [13].

Identification of collapsible soil is best accomplished by testing specimens [14]. However, geologic and geomorphologic information can be useful in anticipating collapsible soil deposits. Dry density and liquid limit of soils can be used to evaluate the collapsibility of soils. **Figure 2**, shows the relation between dry density, liquid limit and collapsibility of soils [15].

Geotechnical and geological engineers know from experience that alluvial and wind-blown deposits in arid regions are likely to exhibit some collapse potential [16, 17]. Since, soils in case studies are mainly collapsible, it's necessary to explain the test procedure that employed in this research.

The collapsible test procedure is that tested an undisturbed sample at natural moisture content in oedometer. A load of 5 kPa is placed on the sample and set the dial gauge zero. Vertical stress is incrementally increased until the rate of strain becomes less than 0.1 percent per hour. Then, increasing the stress is continued until the stress become more than or at least equal to expected structure pressure. At this point the sample is inundated and the resulting collapse strain recorded [5]. Collapsible index is calculated by Equation (1) [5]:

$$I_c = \left(\left(H_1 - H_2 \right) / H_1 \right) \times 100 \qquad (1)$$

where:

I_c: collapsibility index

H_1: Initial soil sample thickness (before saturation)

H_2: Final thickness of the soil sample (after saturation).

The collapsed sample then is subjected to further loading to develop the inundated compression curve. The amount of collapse of a soil layer is simply obtained by multiplying the thickness of the layer by the amount of collapse strain. **Table 1** provides an indication of the potential severity of collapse [7].

3. Case Studies

Conditions in arid and semi-arid climates favor the formation of the most problematic collapsible soils. Collapsible soils are to be found in many parts of the Iran, particularly well-known examples being the extensive deposits of collapsible soils in Esfahan, Fars and Khorasan provinces. In this section it will be considered three locations as case studies.

3.1. South Rudasht Irrigation Network Channel

South Rudasht irrigation channel network is located on south east of Isfahan province. Foundation of main channel from distance 5 to 13 kilometer composed of fine grain materials, 2.5 to 3 meters in depth. To identifying geotechnical properties of the soils, picked 6 undisturbed samples from 6 points or channel route and done laboratory test. General properties selected samples are shown in **Table 2**.

After determine the physical and plasticity properties of soil samples, liquid limit of samples are plotted versus dry density as **Figure 2**. This figure shows that samples 2 and 3 set under collapse limit line. These samples are collapsible probably. Other samples set above collapse line. But they are near the line and it may be collapsible in low degree.

The soil samples classified in unified system. Results of classification tests are shown in **Figure 1** and **Table 3**.

Regarding to field observations and **Figure 2**, samples 2 and 3 have collapse potential. Laboratory tests have been done in all samples. These results are also certified the field observation. Results of the collapsibility tests are shown in **Figure 3** and **Table 4**. Generally, pay attention to **Table 4**, samples 2 to 5 are high or severe collapsible and need improvement. Samples 1 and 6 have no critical collapse problem and no need to any improvement.

As a result, in comparison between samples 2 and 6, both soils are almost similar. The only difference is in unit weight. Due to this difference, sample 2 has more potential for collapse. As it is shown in **Figure 2**, strain in sample 2, under vertical stress equal to 100 kPa, has been changed from 4% to about 17% in saturation conditions. Regarding to **Table 1**, it is concluded that sample 2, from point view of collapsibility, has sever trouble. In contrary, regarding to sample 6, strain value has been changed from 2% to about 4%, under the same conditions. This sample has moderate trouble.

3.2. Dorcheh City Health Center

Dorcheh city is located in west of Isfahan city. In order

Table 1. Collapse percentage as an indication of potential severity.

Collapse (%)	Severity of problem
0 - 1	No problem
1 - 5	Moderate trouble
5 - 10	Trouble
10 - 20	Severe trouble
Over 20	Very severe trouble

Table 2. General properties of picked samples.

Sample no.	Situation (Km)	Sample Depth (m)	Soil class	w (%)	γ_d (gr/cm^3)
1	5 + 700	1	CL	21.12	1.61
2	7 + 000	0.8	CL	14.19	1.21
3	8 + 400	1	CL	9.15	1.61
4	9 + 800	1	CL	9.39	1.63
5	11 + 200	0.8	SC	7.17	1.73
6	12 + 600	0.7	CL	14.37	1.67

Table 3. Plasticity index of samples.

Sample no.	LL (%)	PL (%)	PI (%)
1	26.16	13.73	12.43
2	27.89	16.89	11.00
3	22.39	11.79	10.60
4	23.58	12.23	11.35
5	24.35	12.89	11.46

Table 4. Severity of collapse in tested soils in south Rodasht.

Sample no.	Ic (%)	Severity of problem
1	0.498	No problem
2	12.816	Severe trouble
3	14.960	Severe trouble
4	5.659	Trouble
5	6.740	Trouble
6	1.931	Moderate trouble

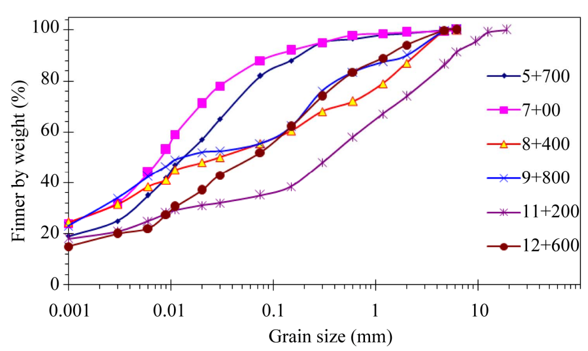

Figure 1. Grain size distribution results.

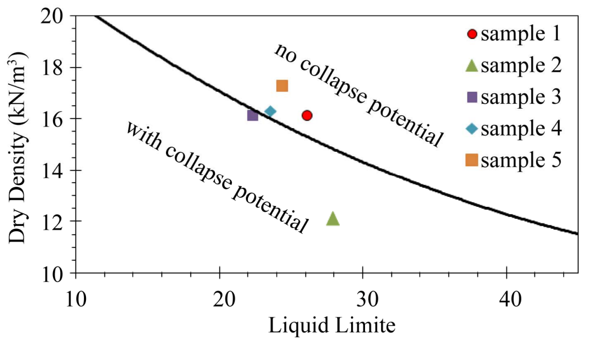

Figure 2. Collapse potential attention to LL and dry density.

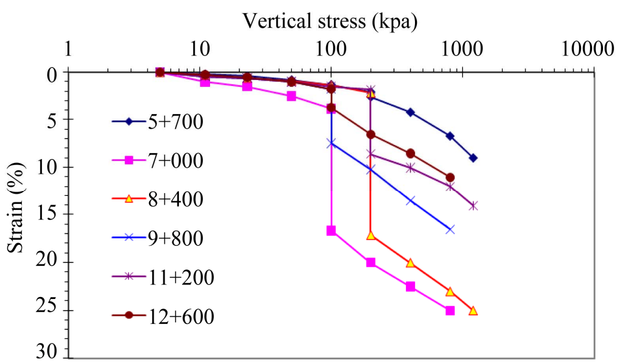

Figure 3. Collapse tests results in south Rodasht.

to subsurface of health center foundation, 3 test pits in predetermined area is excavated and 8 specimens picked up to laboratory tests. Laboratory test index has been done in specimens which results are listed in **Table 5**. Also, collapsibility tests were done on 2 samples. As it can be seen in **Figure 4**, under 200 kPa loading, strain percent raised from 2 to more than 4. Regarding to **Table 1**, it is concluded that soil has moderate collapse potential.

3.3. Sivand Dam Site

Sivand dam site is located in Fars province at north of Shiraz. Foundation of dam consists of high thickness of fine grain alluvium underlying by coarse grain deposits. **Table 6** summarizes some properties on the fine grain soils. Because of low dry density of some soil samples, it was possible that collapsible soils be present at the foundation of dam. Therefore, collapsibility tests were done on selected specimens. Pay attention to dam height and stresses that will be applied on foundation, saturation process during tests were done under 600 kPa loading. Test result shows various amount of collapse potential in soils. Result of one sample test is shown in **Figure 5** that strain percent changes from 6 to 10 due to saturation. According to **Table 1**, this sample category as a moderate trouble from collapsibility view point.

Table 5. General properties of soil samples in Dorcheh city.

Test pit	Depth (m)	Soil class	LL (%)	PI (%)	C (kg/cm^2)	γ (gr/cm^3)
	1.5 - 2.0	CL	36.0	17.0		
TP-1	3.5 - 4.0	CL	33.7	16.2	0.14	1.53
	5.5 - 6.0	CL	25.0	8.5		
TP-2	1.5 - 2.0	CL	35.0	17.5		
	3.5 - 4.0	CL	36.0	17.5	0.41	1.54
	1.5 - 2.0	CL	35.0	16.5		
TP-3	3.5 - 4.0	CL	34.0	16.5		
	5.5 - 6.0	CL	24.5	7.8	0.36	1.57

Table 6. Summery of general properties of fine grain soils in Sivand damsite.

Thickness (m)	Finer than 0.074 mm (%)	Dry density (gr/cm^3)	LL (%)	PI (%)
18 - 20	65 - 75	1.3 - 1.6	25 - 45	15 - 22

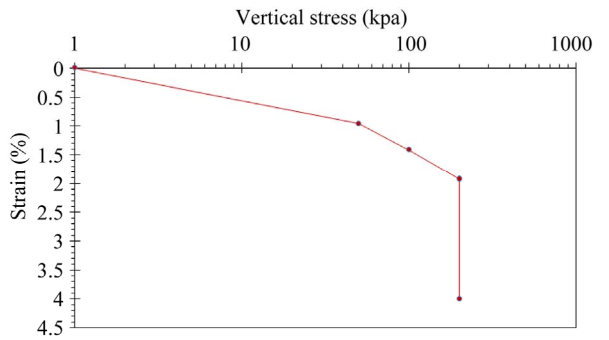

Figure 4. A sample of collapse test result in Dorcheh cit.

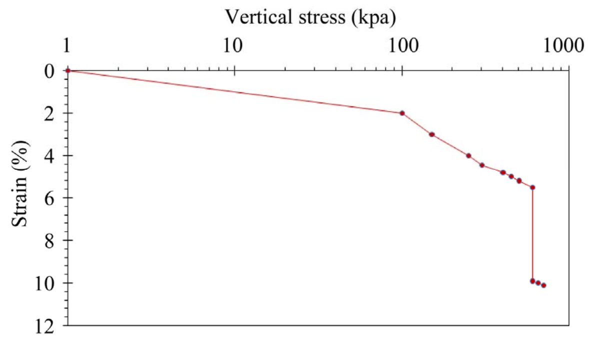

Figure 5. A sample of collapsibility test in Sivand damsite.

Base on collapsibility studies in other parts of Iran and laboratory tests especially in central of Kerman and Mashhad-Sarakhs road, it is concluded that east and north-east of Iran has also potential of collapsibility.

4. Improvement Methods of Collapsible Soils

There are various methods to improvement of collapsible soils as following:

Since collapse take place when soils are wetted, flooding of soils before construction can be helpful to stabilized collapsible soils. Flooding method is useful. But, in low collapse potential soils, if flooding and loading be together, its result will be better.

Various methods of compaction have been used to densify collapsible soils such as dynamic compaction, vibroflotation, vibroreplacement, compaction piles, concrete compaction piles, compacted soil-cement piles.

However, if the soils contains a high relatively carbonate content, it may be difficult to achieve the desired result with dynamic compaction.

Some types of grouting such as cement, clay, bitumen, phosphoric acid, silicate and lime grout being injected under pressure within collapsible soils to stabilize.

Aforementioned methods can be used in various conditions that explain subsequently:

Moistening and compaction with extra heavy impact or vibratory rollers for thickness of soils about 1 meter can be useful [5]. In south Rudasht project used flooding method as channel made without concrete lining and applied channel for one irrigation period, existence of water and weight of channel embankment caused occur collapses in soils. Then, it has been made concrete lining of channel.

Over-excavation and re-compaction with or without additives such as cement or lime, vibroflotation, vibro-replacement, dynamic compaction, compaction piles injection of lime, lime piles and columns, Jet grouting and Ponding or flooding when no impervious layer exists and heat treatment to solidify the soils in place are useful for soil about 1.5 to 10 meters thick. Dynamic compaction is used in Sivand dam foundation for collapsible soils treatment. But, it isn't being useful because of high thickness of soils and used replacement of soils with suitable soils [7,9,13].

When collapsible soil thickness is more than 10 meters, any of the aforementioned or combinations of the aforementioned methods, where applicable can be used.

Possible future methods may be used listed follow:

- Ultrasonic waves to produce vibrations that will destroy the bonding mechanics of the soil.
- Electrochemical treatments.

5. Conclusions

- There are many types of problematic soils. Some of the most noteworthy are swelling clay, dispersive soils and collapsible soils.
- Collapsible soils are often found in arid and semi-arid areas. In most part of Iran especially in central parts, collapsible soils were founded.
- Although wind-blown soils have more collapse behavior, but collapsibility behavior are seen in other type of soils such as clay and silt.
- Significant settlements can take place in foundation of structures on collapsible soils after they have been saturated. These have led to structure damage.
- Determining of physical properties such as dry density and liquid limit of soils can be helpful to identify collapse potential of soils.
- Collapse potential reduces by increasing dry density and liquid limit of soil. To identify detail of collapse potential, laboratory tests have needed.
- Collapsible soils have high porosity. During collapse test, bonds between soil particles destroy and soil particles re-arranged in denser array, and it caused to collapse the soil.
- There are several methods to improvement of collapsible soils. It can be used one method or combination of different methods, depend on project conditions.
- In most conditions, saturation of soils before construction can be helpful to stabilized collapsible soils. It will be best result when saturating and loading is done together.

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