Study the Behaviour of Collapsible Soil of Okanagan Valley

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ABSTRACT
Problematic soil is divided into dispersive, swelling, and collapsible soil. The latter is the most common type of problematic soil which can be found in vast areas of Okanagan valley. Present study is mainly focused on predicting the collapse potential and analyzing the properties of collapsible soil throughout two case studies. In each case, the collapse potential was obtained in three different ways (densometer, Gibbs theory, and consolidation machine) and compared with each other. This paper has proved that in all case studies the collapse potential of soil measured through different methods are in agreement with each other. Moreover, the collapsibility of the soil is highly dependent on wet density of the soil in a way that samples with lower wet density will face higher collapse.

RÉSUMÉ
Les sols problématiques sont divisés en sols dispersifs, gonflables et vulnérables à la rupture. Ce dernier est le type le plus répandu des sols problématiques qui peut être trouvé dans de vastes régions de la vallée de l'Okanagan. La présente étude est principalement axée sur la prédiction de la rupture potentielle et sur l'analyse des propriétés du sol vulnérable à la rupture à partir de deux cas étudiés. Dans chaque cas, l'effondrement potentiel a été obtenu de trois manières différentes (densitomètre, la théorie de Gibbs, et la machine de consolidation). Dans les deux cas et quelques soit la méthode utilisée, l'effondrement mesuré est en accord. En outre, l'effondrement du sol dépend grandement de la densité humide du sol, de manière que les échantillons ayant une faible densité humide devront subir des effondrements plus spectaculaires.

1 INTRODUCTION

Expansion, dispersion, and collapsibility of soil are the geological problems that give rise to many geotechnical difficulties including inadequate bearing capacity, the potential for unacceptable settlements and slope instability. These soil types are referred to as “Problematic Soil”. Problematic soil can occur naturally or by human activities. Present study is mainly in reflection with collapsible soil.

2 COLLAPSIBLE SOIL

Collapsible soil or moisture-sensitive soil is one of the most critical areas in geotechnical engineering (Kalantari 2012; Houston et al. 2001). The properties and strength of collapsible soil are highly dependent on moisture content, such that an introduction of a small amount of water destroys the structure of the soil particles (Lawton et al. 1992). Collapsible soil starts to fail even when not fully saturated (Abbeche et al. 2010). As soon as the moisture content of collapsible soil surpasses 50 percent, the inner-bindings between soil particles loosen, followed by a sudden reduction in soil volume and subsequent collapse (Houston et al. 2001; Abbeche et al. 2010). Existence of cementing agents in the structure of collapsible soil, which stabilizes the open and partially unstable fabric of this type of the soil, will result in high bearing capacity in the unsaturated condition. However, addition of water to the system, along with high pressure on top of the soil, softens the inter-particle bindings and leads to severe reduction in volume (Kalantari 2012; Barden et al. 1973). The settlements associated with penetration of water to the system often lead to expensive repairs (Gaaver 2012). A sudden reduction of volume, due to an increase in the moisture content, has caused this type of soil to become one of the most costly geological hazards (Cerato et al. 2009; Clemence & Finbarr 1981).

2.1 Formation

Generally, soil can be displaced naturally or by human activities. Collapsible soil is either debris flow deposits (Alluvial) or wind-blown deposits (Loess) (Pye & Tsoar 1990; Das 1995). The formation of collapsible soil is limited to arid and semi-arid environments (Houston et al. 2002). The rapid evaporation of moisture from the soil in dry environments prevents the self-weight consolidation of deposits. As a result, different types of salts bind the soil particles together by a “Clay Bridge”. In addition, climate change, due to global warming and urbanization, can create new arid and semi-arid environments or change a dry climate to a humid climate. San Diego exemplifies an increase in rainfall by 140 centimeters per year following urbanization (Houston et al. 2002; Houston et al. 1998). Collapsible soil contain more than 10 percent of the Earth’s landmass (Jefferson et al. 2008). In Eastern Canada and vast areas of Russia, China, UK, and Eastern Europe, the land is covered with large amounts of collapsible soil (Rust et al. 2010). Some common features between all collapsible soils are high porosity, high void ratio, high sensitivity to water, low dry density, low inter-particle bonds, loosely cemented and geologically younger deposits (Noutash et al. 2010; Derbyshire et al. 1995; Rogers 1995; Rust et al. 2010).

2.2 Geological Hazard

Collapsible soil mainly consists of silt-sized particles. These particles form a loosely cemented honey-combed structure which can be destroyed with an increase in moisture content of the soil (Kalantari 2012). Various sources can increase the percentage of saturation in the collapsible soil. Some of the most common reasons behind the introduction of water to the collapsible soil are sewer lines, broken pipes, water runoff, pools and basins (Kalantari 2012; Aiban 1994; Al-abdul wahhab & Ramadhan 1990). Intruded water to the system dissolves the water-soluble cementing agents which bind the soil particles together (Lawton et al. 1992). Loose silt particles initiated from the destroyed honey-combed structure are allowed to fill the voids in the soil and take a denser packing formation under a small amount of compressive load (Lawton et al. 1992; Rust et al. 2010). Therefore, the soil faces abrupt reduction of volume causing vast geological hazards. Different settlements occur due to the variability in strength and compressibility of the soil, however, all types of structures, especially foundations and highways that are susceptible to the formation of depressions and settlement are highly affected by this incident (Aiban 1994; Al-amoudi 1994; Farawan & Majidzadeh 1988). Therefore, the identification and characterization, along with the calculation of amount of collapse, are of great concern to geotechnical engineers while dealing with collapsible soil.

3 CASE STUDIES

The first step is to identify the potential of a soil for collapsibility.Many researchers have conducted experiments, in order to characterize collapsible soil and predict if failure will occur. Calculating the amount of collapse is the next step after identification. Different parameters are related to the amount of collapse. The amount of collapsibility of a type of soil is a function of soil permeability, soil particles, and the degree of saturation, initial void ratio, over-consolidation ratio, and thickness of the collapsible layer (Houston et al. 2001; Murthy 2010; Holtz & Hilf 1961; Basma & Kallas 2004). Potential severity of collapsible soil is presented in Table 1.

Table 1. Severity of problem associated with percentage of collapse

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

Some of the features of collapsible soil are low dry density, open structure, low inter-particle bonds, high void ratio, low natural moisture content, high porosity, and high sensitivity to increased water content (Noutash et al. 2010). One of the in-situ methods to check the collapsibility of the soil is by using a nuclear densometer to measure the wet density of the soil. In this section two locations in Okanagan Valley will be considered as case studies.

3.1 Kamloops

The site is located immediately east of the ValleyView subdivision in Kamloops, BC. The Trans Canada Highway forms the north boundary of the site, with steep silt bluffs forming the south boundary. The property is approximately 1000 meters long in the east-west direction (parallel to Highway 1) and is roughly 250 meters deep. The site has a moderate grade sloping up from Highway 1 to the base of the silt bluffs. Based on topographic mapping for the site, elevations vary from a local low of 350 meters, to a high elevation of roughly 362 meters.

In order to identify the geotechnical behavior of the soil, a truck mounted excavator was used to excavate four test pits at locations marked as M10, M11, M14/15, and M22. The test holes were excavated to a depth of 4 meters in 1 meter increments. At each excavation increment, in-situ density tests were performed using a Campbell nuclear densometer and several blocks of undisturbed sample were carefully recovered for laboratory testing. In addition, smaller grab samples were recovered for confirmation of the field moisture content as compared to the densometer test results, as is common practice when assessing densities within trenches. Field and laboratory test results of soil samples from test pit M22 are presented in Table 2 and Table 3 respectively. Liquid limit, plastic limit, and plasticity index of the soil sample were measured to classify the soil and predict the potential for collapse.

Table 2. Field testing data of samples from test pit M22

Depth (m)	w (%)	Wet Density (kg/m^3)	Dry Density (kg/m3)
1	6.3	1365.9	1284.9
2	12.3	1478.3	1316.4
3	10.8	1487.5	1342.5
4	14.1	1529.3	1340.3

Table 3. Laboratory testing data of samples from test pit M22

Depth (m)	w (%)	Wet Density (kg/m^3)	Dry Density (kg/m3)	LL (%)	PL (%)	PI (%)
1	7.0	1339.6	1252.0	25.1	19.1	6.0
2	7.6	1521.6	1414.1	26.3	19.8	6.5
3	11.2	1444.0	1298.6	25.7	19.0	6.7
4	13.6	1484.3	1306.6	27.0	20.7	6.3

After measuring the general properties of the soil samples from the field and lab, grain size analysis (sieve and hydrometer) was performed to determine the grain size distribution and classification. Based on the results of the grain size distribution the soil sample was classified as SM-SC and A-2-4 in USCS and AASHTO classification system respectively which represent "Silty or Clayey Sand". Figure 1 the grain size distribution for the soil sample at 4 meter depth in test pit M22.

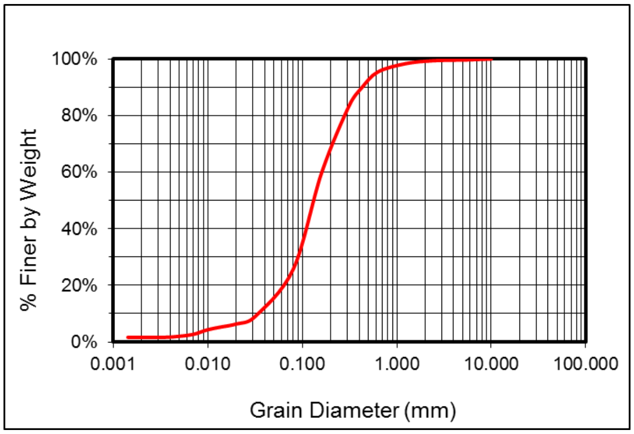

Figure 1. Grain size distribution soil sample at 4 meter depth in test pit M22

Gibbs (1961) provided a criterion to differentiate between non-collapsible and collapsible soils based on their dry unit weight and liquid limit in Eq. 1 (Gibbs 1961). According to this method, the soil is susceptible to collapse when the ratio of the water content at full saturation to the liquid limit is larger than 1. In this condition, void spaces are sufficient for collapse of the soil structure when the soil gets saturated.

$$R = \frac{(\gamma_w/\gamma_d - 1/G_s)}{W_l} \quad [1]$$

Where, R = collapse ratio, γ_w = unit weight of water, γ_d = dry unit weight of soil, G_s = specific gravity of the sample, and W_l = moisture content at liquid limit. Collapse potential can be predicted by this method based on the results of classification tests presented in Table 3. The value of "R" for all different depths is greater than 1 which categorizes this soil as a collapsible soil which is in agree with field observation.

In addition to the theoretical prediction of soil collapse, collapse tests using a consolidation machine were performed on the samples. The test procedure consisted of initially using a small load, increasing the load to the overburden pressure to seat the samples, reducing the load, and increasing the load to 48 KPa. In the next step, the samples were flooded and the collapse was measured. Loading and unloading of the samples then continued in the normal way. The results from the laboratory tests certify the field observation and the theoretical method. Results of the collapse tests are presented in Table 4 and Figure 2.

Table 4. Severity of collapse based on laboratory results of samples from test pit M22

Depth (m)	Collapse at 48 KPa (%)	Severity of problem
1	6.9	Trouble
2	2.8	Moderate trouble
3	0.9	No problem
4	0.9	No problem

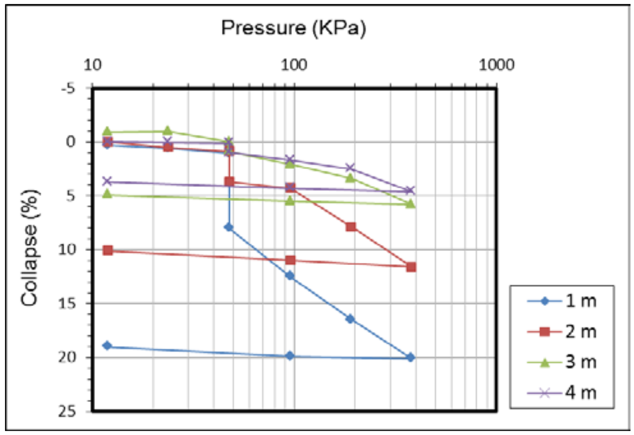

Figure 2. Collapse laboratory test results of sample M22

According to the test results, the soil layer at 1 meter depth has the highest collapse and soil layers at 3 and 4 meter depths have the lowest collapse. Based on the data presented in Table 3, the major difference between soil layers is the unit weight. This difference causes the first layer to have a collapse from 1% to about 8% under the 48 KPa vertical load. Regarding the severity of problem associated with percentage of collapse presented in Table 1, it can be concluded that the soil layer at 1 meter depth causes "Trouble" from the point of view collapsibility and needs attention during foundation design.

3.2 Airport of Kelowna

Kelowna International Airport is located 11.5 kilometers northeast of Kelowna, British Columbia on Highway 97. The average elevation of the site is 433 meters and the length of the runway is 2713 meters. Based on statistics, the airport was reported as one of the busiest airports among all Canadian airports with 1,602,988 passengers in 2014 (Gaffney 2015). Due to the growth in number of passengers, a master plan has been proposed to expand and improve the traffic handling standards of airport of Kelowna by 2025. However, with growth comes the need to plan for future requirements which includes analyzing the airport's soil behavior (Kelowna 2007).

A truck mounted excavator was used to excavate three test pits. 10 meters apart, at the east side of the airport 3 meters inside the curb. The samples were collected at 18 (0.45 m) and 36 (0.9 m) inches depth by the use of truck mounted excavator. Campbell and Troxler nuclear densometer were used at each excavated point with 6 inches depth and 1 minute duration of the shots to collect in-situ density of the soil. Several undisturbed samples were collected at each excavation level for laboratory testing. Moreover, smaller bags of disturbed sample were recovered for measuring the general properties of the soil and confirmation of the field moisture content. Table 5 presents the in-situ properties of the soil by using the Campbell densometer at the depth.

Table 5. Field testing results of soil samples

Test Hole	Depth (in)	w (%)	Wet Density (kg/m^3)	Dry Density (kg/m^3)
#1	18	9.3	1486	1359.6
	36	6.2	1399	1317.3
#2	18	11.2	1478	1329.1
	36	7.8	1465	1359.0
#3	23	6.4	1423	1337.4
	36	5.4	1598	1516.1

Liquid limit, plastic limit, and plasticity index of the soil sample were measured to classify the soil and predict the potential for collapse. Table 6 summarizes the general properties of samples from test pit #1 measured in the laboratory.

Table 6. Laboratory data of samples from test pit #1

Depth (in)	w (%)	Wet Density (kg/m^3)	Dry Density (kg/m3)	LL (%)	PL (%)	PI (%)
18	4.9	1377	1312.7	25.2	21.4	3.8
36	4.6	1325	1266.7	24.7	20	4.7

After measuring the general properties of the soil samples from the field and lab, grain size analysis (sieve and hydrometer) was performed to determine the grain size distribution and soil classification. Based on the results of the grain size distribution the soil sample was classified as SM and A-2-4 in USCS and AASHTO classification systems respectively which represents "Sandy Silt".

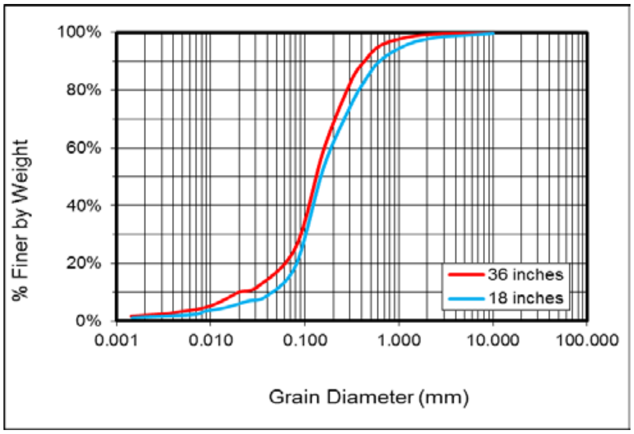

Figure 3. Grain size distribution of sample #1 at different depths

In order to predict the collapse potential of the sample, results presented in Table 6 were used to determine the collapsibility of the soil based on Gibbs (1961) theory. By applying Eq. 1 the value of "R" for our sample was found to be greater than 1% which shows that the soil sample has a tendency to collapse. Collapse tests using a consolidation machine were carried out on the samples. The test procedure consisted of initially using a small load, increasing the load to the overburden pressure to seat the samples, reducing the load, and increasing the load to 48 KPa. The samples were flooded and the collapse was measured. Loading and unloading of the samples then continued in the normal way. The results from the laboratory tests certify the field observation and the theoretical method. Results of the collapsible tests are presented in Table 7 and Figure 4.

Table 7. Severity of collapse based on laboratory results

Test Hole	Depth (in)	Collapse at 48 KPa (%)	Severity of problem
#1	18	2.8	Moderate
	36	2.3	Moderate
#2	18	3.8	Moderate
	36	2.1	Moderate
#3	23	4.3	Moderate
	36	3.3	Moderate

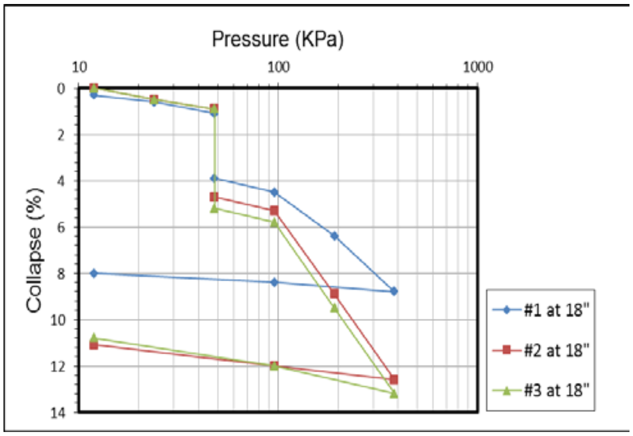

Figure 4. Collapse laboratory test results of samples at 18 inches depth

Based on the laboratory results, soil sample #3 has the highest collapse among all other samples at depth of 18 inches due to low wet density of the soil compared with the other soil samples. According to Table 1 the severity of problem from the collapsibility point of view for this soil is considered to be "Moderate Trouble"

4 CONCLUSION

Generally, problematic soil is divided into dispersive, swelling, and collapsible soil. The latter is the most common type of problematic soil which is formed in arid and semi-arid environments and covers 10 percent of Earth's landmass. The properties of collapsible soil or moisture-sensitive soil are highly dependent on moisture content; small increases in water content can destroy the honey-combed structure of the soil. Loose silt particles initiated from destroyed honey-combed structure are allowed to fill the voids in the soil and take a denser packing formation under any small amount of compressive load. As a result, sudden reduction of volume of the soil causes geological hazard which requires huge amount of resources to compensate the outcome. Although, different settlements occur due to the variability in strength and compressibility of the soil, however, all types of structures are highly affected by this incident. Present study is mainly focused on predicting the collapse potential and analyzing the properties of collapsible soil throughout two case studies. In each case, the collapse potential was obtained in three different ways (densometer, Gibbs theory, and consolidation machine) and compared with each other. This paper has proven that in all case studies the collapse potential of soil measured through different methods are in agreement with each other. Moreover, the collapsibility of the soil is highly dependent on wet density of the soil in a way that samples with lower wet density will face higher collapse.

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