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## On the Procedures of Soil Collapse Potential Evaluation

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**Abstract:** The purpose of the present study was to highlight the different types of soils that could exhibit collapsing and to proposed an approach for more accurate and comprehensive evaluation of this phenomenon. The research showed that conventional oedometer test could underestimate the soil collapse potential. Underestimation of the severity of this problem could cause serious damages to the engineering structures.

**Key words:** Collapse potential, double oedometer, soluble salts, leaching

### INTRODUCTION

Collapsible soil is defined as soil that is susceptible to a large and sudden reduction in volume upon wetting (Day, 2001). Collapsible soil deposits share two main features:

- They are loose, cemented deposits
- They are naturally quite dry

According to Day (2001) collapse behavior could also happen in fill material as a result of decrease in negative pore water pressure (capillary tension), when the fill become wet. The collapse potential increases as the dry density decrease, the moisture content decrease and the vertical pressure increase.

Collapsible soil can withstand a large applied vertical pressure with small compression, but then show much larger settlement upon wetting, with no increase in vertical stress.

This behavior can yield disastrous consequences for structures unwittingly built on such deposits. The process of their collapsing is often called any of hydroconsolidation, hydrocompression, or hydrocollapse.

Another type of collapsing could occur in saturated soil bearing soluble mineral upon subjected to continuous leaching, resulted from infiltration of rainfall or flocculation of water table, for example the Dead Sea Lisan Marl deposits in Jordan. This mechanism could take relatively long time, but by the end it will have a negative impact on the stability and integrity of the existing structures. The geotechnical term that indicate the effects of leaching soluble salts from soil include chemical piping, or leaching and collapse (Karakouzian *et al.*, 1996). The

failure mechanism is not the same in the two types of collapse. In hydrocollapse the particles are arranged in honeycombed structure, held together by small amount of cementing agent like clay or  $\text{CaCO}_3$ ; introducing the water leads to dissolve or soften the bonds between particles and hence undergoes denser packing under loading. In leaching and collapse failure; the leaching of soluble salts from the soil matrix, increased the void ratio and decrease the strength, which in turn causing the collapse of matrix under the compression strength (Karakouzian *et al.*, 1996)

Unsaturated soils or soils with negative pore-water pressures can occur in essentially any geological deposit, such as residual soil, a lacustrine deposit and soils in arid and semi arid areas with deep ground water table.

The most common types of collapsible soil:

- Alluvial (water deposited) and colluvial (gravity deposited)
- Wind deposited (aeolian) soils are fine sands, volcanic ash tuffs and loess
- Residual soils formed by extensive weathering of parent materials. For example, weathering of granite can yield loose collapsible soil deposits

### TYPICAL SOILS SUSCEPTIBLE TO COLLAPSE

Marl behavior changed under dry and wet conditions; the strength is dropped by about 85% upon saturation and exhibited collapsible and swelling potential when exposed to water (Quhda and Yong, 2003).

Lamas *et al.* (2002) conducted a study on marly soil classified as CL (USC) or A-6 (AASHTO) used for construction of impermeable core of earth dam in Spain. The permeability found to be increased with the

increasing of carbonate content; this explained by the leaching or dissolution of carbonate by the distilled water used in the triaxial cell.

A permeability tests on Sabkha soil from Kuwait classified as ML, having high percent of sulphate, carbonate and silica; showed that the permeability coefficient has been doubled after leaching the samples by distilled water (from  $1.75 \times 10^{-5}$  m sec<sup>-1</sup> to  $3.5 \times 10^{-5}$  m sec<sup>-1</sup>); chemical analysis of the leachate showed that the chloride is completely dissolved, partial dissolving of sulphate and no dissolving of calcium carbonate (Ismael, 1993). A decrease is reported on the bulk density, specific gravity, atterberg limits, unconfined compressive strength and slight decrease in clay fraction content, while a significant increase of fine fraction (from 60.4-97.4%) occurred after leaching. The increase in fine fraction to the breaking of sand-size particles containing large amount of gypsum (low hardness mineral) into silt size. Nevertheless, the soil still classified as ML. This result demonstrated also by Al-Amoudi *et al.* (1992); where the wet sieving of sabkha soil classified as SW-SP in Saudi Arabia using distilled water and sabkha brine water resulted in 32 and 13% fine fraction, respectively; but the soil classification in this case has been changed to be SW upon using of distilled water.

Using of distilled water as testing media (soaking) in the oedometer test for sabkha soil did not affect the compressibility (Al-Amoudi *et al.*, 1992), while by allowing the distilled water to percolate through the sample; the compressibility significantly increased ( $C_c$  and  $C_s$  increased by 50%) and the void ratio increase from 1.14 to 1.23 as reported by Ismael (1993). Slight decrease in preconsolidation pressure and effective friction angle as a result of dissolving of salt cementing was recorded also. Depending on the above it is concluded that the collapse potential should be evaluated for these types of soil rather than the compressibility in any geotechnical engineering study.

Karakouzian *et al.* (1996) stated that an insufficient amount of fresh water is used to evaluate the effect of soluble minerals on the engineering behavior of soil; the present salts may not dissolved (named salt saturation condition), which could lead to underestimation of the long term impacts of water in contact with the soil. This could explain the findings of Al-Amoudi *et al.* (1992) and Al-Amoudi and Abduljawwad (1995).

Al-Nouri and Saleam (1994) studied the compressibility characteristics and the collapse potential of Gypseous silty sand soil in Iraq. The gypsum is hydrated calcium sulphate ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) with intermediate

solubility in water (0.2%) but the amount of dissolved is much greater if the water contain salt. The collapse settlement of gypseous sandy soil upon wetting in a plate load test could amount to 50% of the total measured settlement, while if water circulation allowed it could amount to 76-90% of the total settlement. Even the capillary water may cause the collapse of the soil structure in gypseous soils. The study by Al-Nouri and Saleam (1994) conducted on soil samples with gypsum content of 26, 60 and 80%, the gypsum found as cementing material while gypsum lumps (1-15 mm diameter) found also in the samples that have high gypsum content. In the collapse test, a sudden compression observed upon submersion which indicates a collapsible soil, on the volumetric strain-log P graph, this compression appears as vertical line, followed by steep curve resulting from further dissolution of gypsum. It is noticed also that the collapse potential increased progressively with the increase in pressure, which imply that the gypsum dissolution increases in rate as the stress level increases.

Effectiveness of leaching by changing the grain size distribution, density and hydraulic gradient has been evaluated by Al-Sanad (1990), on a non plastic calcareous rounded medium to fine sand soil classified as SP in Kuwait. The cementing materials in that soil are the chloride, sulphate and carbonate (the carbonate content equal to 8.3%). The leaching process increased by increasing the relative density and the fine fraction; this behavior was explained to the increase in the contact area between soil and water.

Changing the hydraulic gradient from 0.77 to 10 insignificantly affect the leaching process as it was clear from the leachate analysis, where the electrical conductivity values ranged between 3.03 to 3.63 m mho cm<sup>-1</sup> through the test for all hydraulic gradient values. Brackish water posses electrical conductivity of 4.69 m mho cm<sup>-1</sup>; has slightly less capability of dissolving salt than distilled water. Leaching was more effective - in relatively short time-for soil rich with NaCl or  $\text{Na}_2\text{SO}_4$  rather than  $\text{CaCO}_3$  or  $\text{MgCO}_3$  which show low solubility. James and Lupton (1978) found that the rate of solution of both anhydrite and gypsum is increased by NaCl and by Carbonate and  $\text{CO}_2$ , so it is important to know the chemical composition of ground water in regions of calcium sulphate minerals.

Soluble salts or minerals that are commonly found in soils can be classified based on the degree of solubility in water as readily soluble, moderately soluble and weakly soluble. Figure 1 shows the solubility for the commonly occurring soluble soil minerals (Lide, 1994). In general, the graph shows that minerals with the highest solubility are Chlorides.

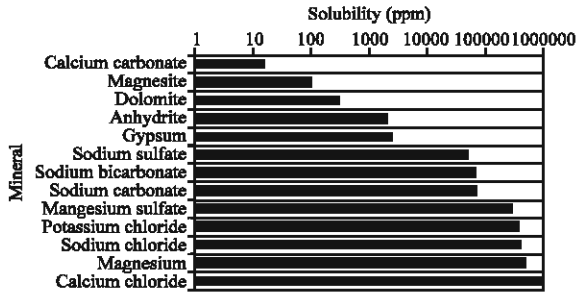


Fig. 1: Solubility of common soil minerals (re-produced after Lide (1994))

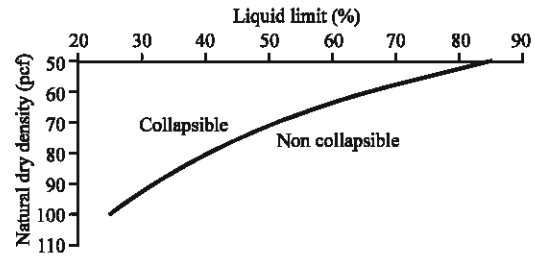


Fig. 2: Commonly used criterion for determining collapsibility (Lutenegger and Saber, 1988)

### LABORATORY DETERMINATION OF COLLAPSE POTENTIAL

The quantification of volume change occurs when soil undergoes collapse is obtained from oedometer test. Once the geotechnical engineer recognizes the possibility of collapsible soils is present, this mainly done depending on the density and consistency limits measurements as shown in (Fig. 2); one or more of the following oedometer tests shall be conducted on undisturbed sample.

**Single oedometer collapse test:** The undisturbed soil specimen at natural moisture content loaded in the conventional oedometer to a stress level ranging between 200 and 400 kPa and then inundation by distilled water is applied to induce collapse. Abelev (1948) used stress level of 300 kPa and defined the collapse potential (Ie) as:

$$I_e = \Delta e_c / (1 + e_i) \quad (1)$$

Where:

$\Delta e_c$  : Change in void ratio resulting from saturation

$e_i$  : Void ratio just before saturation

while, Jennings and Knight (1975), recommended the using of stress level of 200 kPa and calculate the collapse potential according to the following equation:

$$I_e = \Delta e_c / (1 + e_o) \quad (2)$$

Where:

$\Delta e_c$  : Change in void ratio resulting from saturation

$e_o$  : Natural void ratio

The stress level of 200 kPa was adopted by (ASTM D 5333-96, 2000) to classify the severity of the collapse problem (Day, 2001).

Since the idea behind this test is to predict the amount of deformation that a foundation may experienced

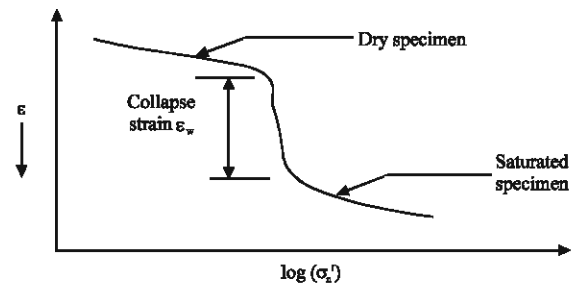


Fig. 3: Typical result from single oedometer test

upon subsurface wetting; a loading to the anticipated field loading conditions is recommended. A typical result obtained from this test is shown in Fig. 3.

**Double oedometer collapse test:** Two identical samples are placed in oedometers; one tested at *in-situ* natural moisture content and the other is fully saturated before the test begins and then subjected to identical loading. Two stress versus strain curves are generated. The difference between the compression curves is the amount of deformation that would occur at any stress level at which the soil get saturated. Results from double oedometer test are shown in Fig. 4. The collapse potential can be determined at any required stress level. Critical stress ( $\sigma_{cr}$ ) represents the stress level at which the dry sample loose structure breaks down and beyond it the two curves converge. This behavior could be explained also by that at high stress level, the limiting void ratio for the saturated sample is approached for particles packing (Lutenegger and Saber, 1988). It is common for natural soil that the initial void ratio of the two samples are not initiating from the same point; in this case adjustment of the two curves according to the procedure proposed by Jennings and Knight (1975) is adopted for the normally and overconsolidated clays.

The above mentioned procedure is applicable for the soils that do not include high percentage of soluble

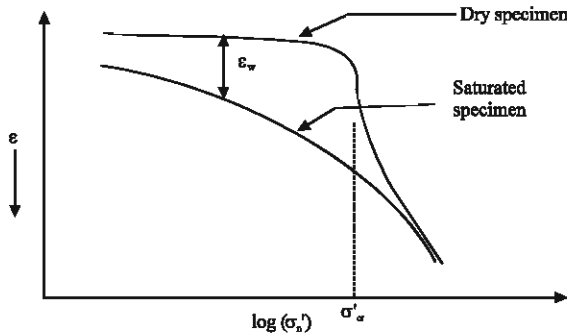


Fig. 4: Typical results from double oedometer test

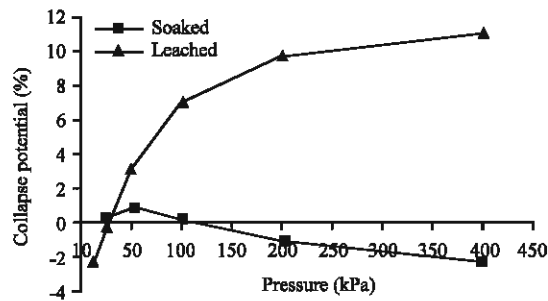


Fig. 5: Collapse potential of clay soil- Dead Sea-Jordan

minerals in its matrix. For soils containing high concentration of soluble salts or minerals (Fig. 1), the conventional inundation of the soil specimen in the oedometer could lead to under estimation of the collapse potential since the amount of water might be not enough to dissolve all the present salts and the water get salt saturated. In this case leaching out of these salts shall be carried out prior to testing. Figure 5 shows the results of double oedometer test conducted by the authors on clayey soil collected from the Dead Sea area. These deposits contain high content of soluble minerals such as Halite and Gypsum as well as high ions concentration in pore water, noting that the salinity of the Dead Sea brine is about 10 times the salinity of the normal seas. It is clear that soaking of the sample failed to induce collapse. While the collapse potential reached around 10% upon allowing water circulation.

### LEACHING APPARATUSES

**Rowe cell:** Leaching process could be performed in Rowe Cell (Fig. 6). The load in this cell is applied hydraulically and it is used to carry out consolidation and permeability tests. Since this is the case, it considered suitable to

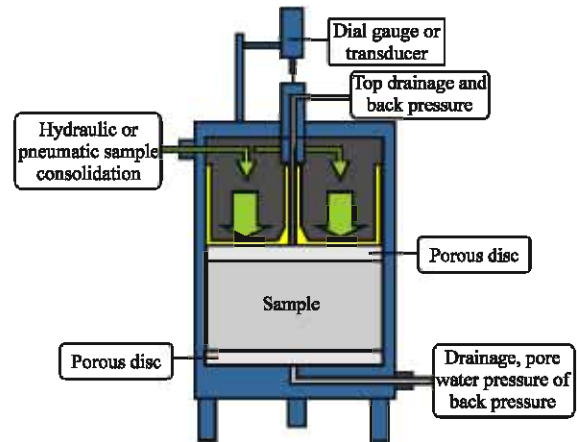


Fig. 6: Schematic diagram of Rowe cell

conduct the leaching on the samples to be evaluated for the collapse potential.

The leaching process could be done according to the following steps:

- Setup the sample under a seating pressure
- Apply a pressure head using an overhead de-aired water reservoir to saturate the sample
- Connect the overhead reservoir to the back pressure line of the cell
- Allow the water to percolate through the sample from the bottom and drain from the top
- Collect the leachate at regular intervals for measuring the electrical conductivity
- Terminate the leaching process when the EC measurements show no further decrease

**Modified oedometer:** Al-Amoudi and Abduljawwad (1995) modified the oedometer to allow for water percolation by making two holes beneath the specimen; an inlet for the distilled water supply and an outlet for the overflow to maintain a constant fluid head (Fig. 7). The leachate is collected at regular intervals for measuring the electrical conductivity and the water flow (leaching) is terminated when the EC measurements show no further decrease. In both method of leaching, the leaching could be started at the overburden pressure and continue the consolidation test according to the related standard and then compared with the stress versus strain curve resulted from other identical sample tested without leaching, or under any desirable pressure (200 kPa for example).

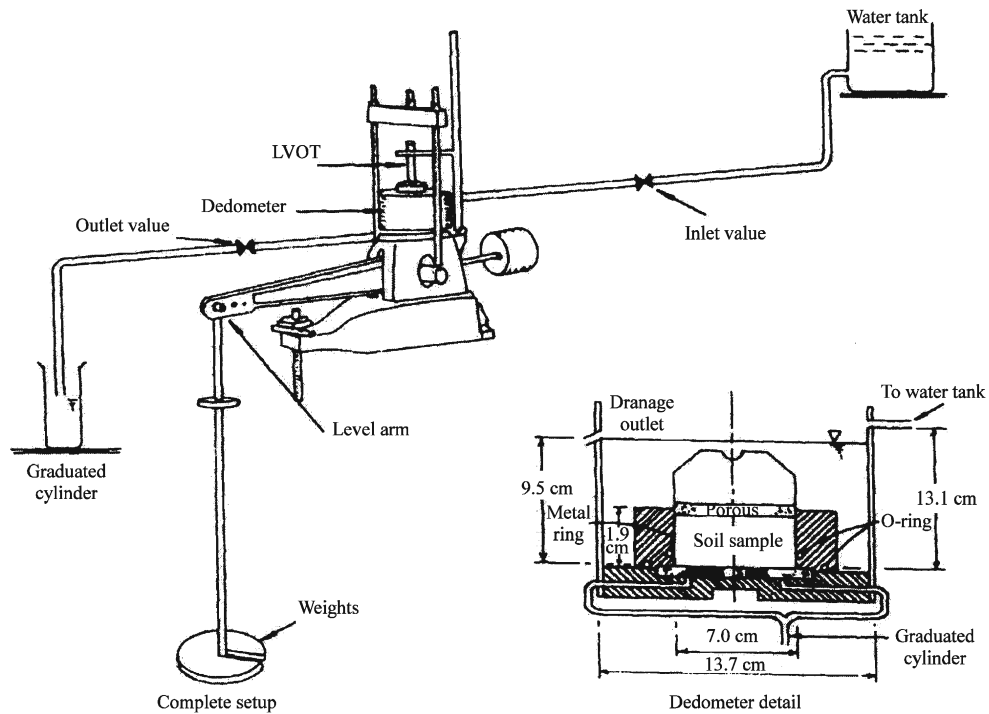


Fig. 7: Modified oedometer setup (after Al-Amoudi and Abduljawad (1995))



Fig. 8: Compacted soil permeability apparatus

**Compacted soil permeability apparatus:** This device used successfully by the author (Fig. 8). The sample sandwiched between two porous disks and the water allowed to percolate from the top and issue from the bottom. When the leaching completed the sample carefully transferred to the oedometer for testing. The disadvantage of this device is that the sample can't be leached under applied pressure and consequently care shall be taken if the sample could exhibit swelling behavior.

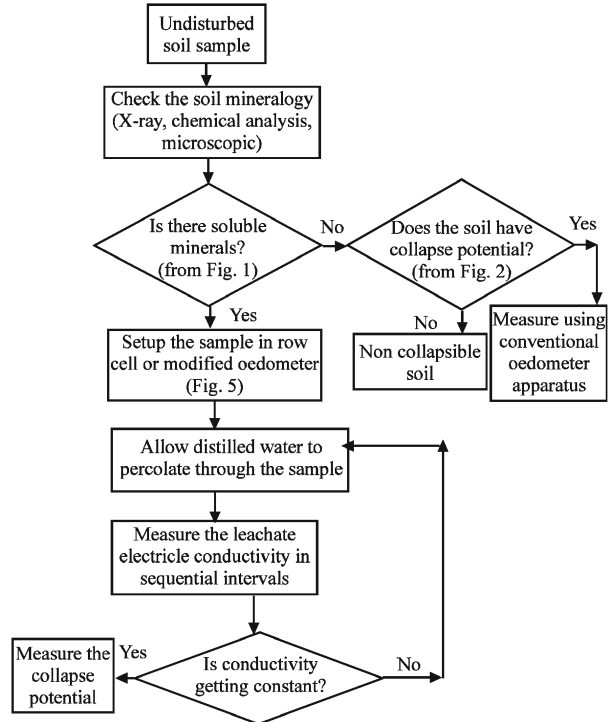


Fig. 9: Proposed flow chart for collapse potential evaluation steps

**Procedure for collapse potential evaluation:** The flow chart shown in Fig. 9 could be used as a guideline regarding the steps and the tests to evaluate the collapse potential of the concerned soil.

## CONCLUSION

In summery and based on this research and literature study, the following conclusions can be drawn:

- The collapse evaluation test shall be conducted on undisturbed samples to account for the effect of soil fabric
- Inundation in oedometer is satisfactory for the measuring of the collapse potential when small amount of  $\text{CaCO}_3$  and/or Clay is acting as the cementing agent
- Inundation of soil specimen in the consolidation test for the purpose of measuring the soil collapsibility could under estimate the collapse potential; if the soil bears high concentration/percentage of soluble salts
- If the soil contains soluble salts; all the salts shall be leached out in the testing apparatus, by using the Rowe cell or the Modified Oedometer; for more accurate evaluation of the collapse potential
- The proposed flowchart (Fig. 8), could provide a simple guide line for better evaluation of soil collapse potential. The flowchart differentiates between the two types of collapse mentioned in the introduction. However, the procedure or the route to be followed in case of the presence of soluble minerals suit also the soil possess collapse potential but don't include soluble salts
- In case of cohesive soil single oedometer is not recommended because of the decreasing of permeability during the loading (200 kPa) which will increase the time required for full leaching
- Single oedometer test is recommended if the soil is not homogeneous

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