# COLLAPSIBLE SOILS

- Foundation engineers who work in arid and semiarid areas of the world often encounter deposits of collapsible soils. These soils are dry and strong in their natural state and appear to provide good support for foundations. However, if they become wet, these soils quickly consolidate, thus generating unexpected settlements.
- Sometimes these settlements are quite dramatic, and many buildings and other improvements have been damaged as a result. These soils are stable only as long as they remain dry, so they are sometimes called metastable soils, and the process of collapse is sometimes called hydroconsolidation, hydrocompression, or hydrocollapse.
- To avoid these kinds of settlements, the foundation engineer must recognize collapsible soils, assess the potential settlements, and employ appropriate mitigation measures when necessary.

## ORIGIN AND OCCURRENCE OF COLLAPSIBLE SOILS

Collapsible soils can be found in arid and semi-arid regions where evaporation rates exceed rainfall. Arid-region deposits are often associated with collapsible soils including alluvium, colluvium and loess.

Naturally occurring collapsible soils are typically formed from debris flow (e.g. alluvial fan materials) such as wind-blown sediments (e.g. loess), cemented high salt content metastable soils (e.g. sabkha), and tropical residual soil.

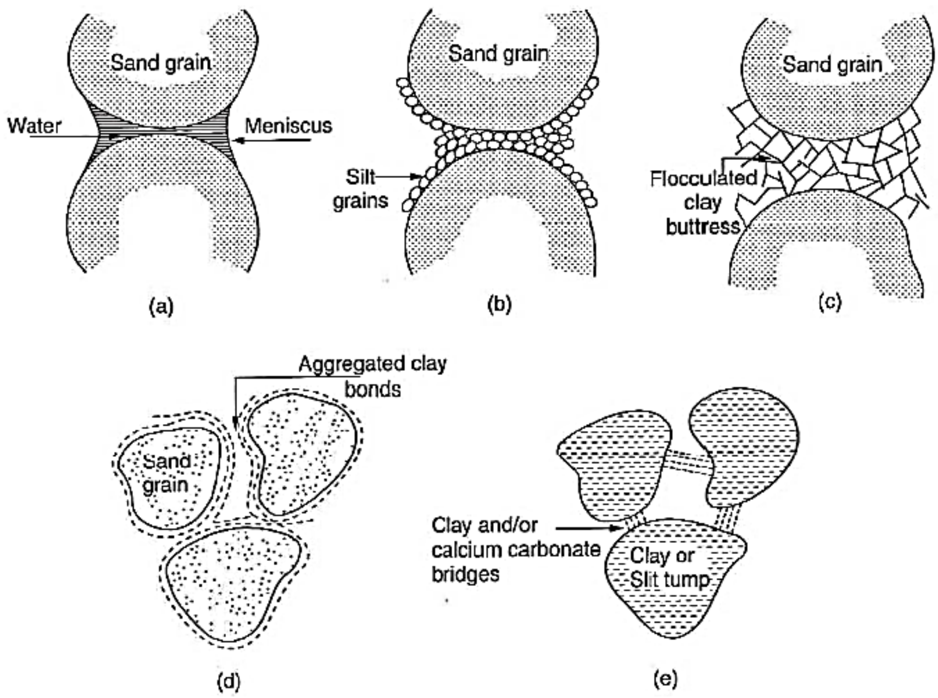
Moreover, non-engineered or poor compaction with low moisture content or waste materials may produce artificially collapsible soil. However, most common collapsible soils are relatively stiff and strong at dry states even with low densities (Madhyannapu et al., 2006; Je erson & Rogers, 2012).

There are three main bonding mechanisms present in collapsible soils (Dudly, 1970; Barden et al., 1973; Clemence & Finbarr, 1981; Rogers, 1995), namely:

(i) Under capillary or matric suction forces, soil consists of sand-sand with meniscus water or sand-sand with a fine silt binder (see Figure a, b).

(ii) Knight (1960) indicated the clay forms a randomly flocculated structure when clay and silt particles have coarser particle contacts, providing a buttress to the bulky grains (see Figure c). The majority of collapsing soils, however, involve the action of clay plates in the bonds between the bulky sand and silt grains. When the clay is formed by authigenesis, it could result in a parallel plate onion skin effect around the quartz particles (see Figure d). Alternatively, when the clay is suspended in the pore-water, gradual evaporation causes the clay plates to retreat with the water into the menisci at interparticle contacts.

(iii) In certain collapsing soils the important bonding effect may be due to chemical cementing agents such as iron oxide, calcium carbonate, etc., which are often the main agent in loessial soils (see Figure e).



## Gypseous soil

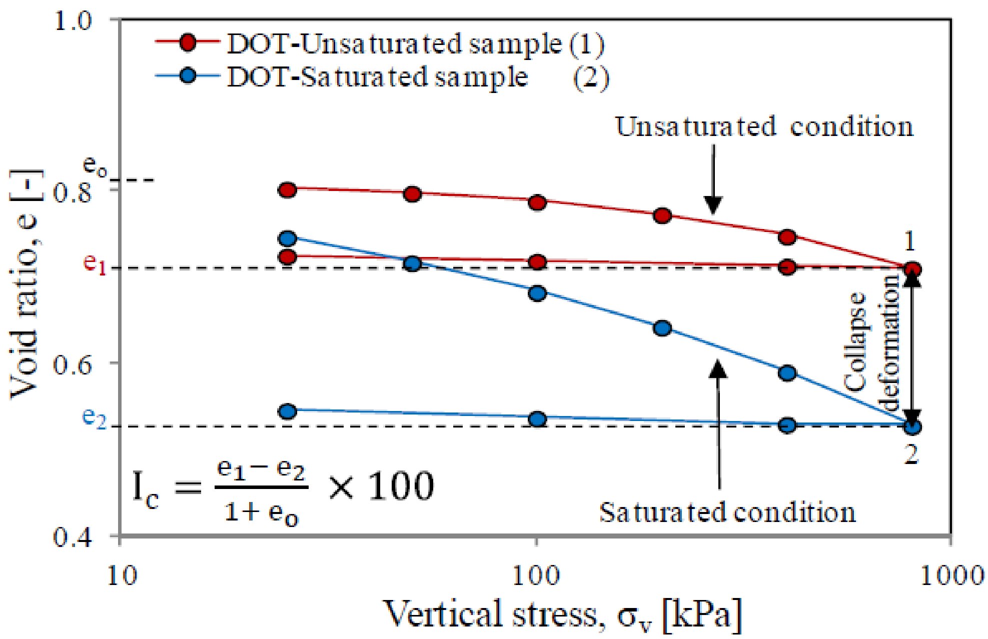
Gypseous soil presents a high collapse potential as a result of its metastable structure. It has low dry density and moisture content in its natural state due to the presence of cementation bonds and an open gypsum structure, particularly at unsaturated states or in arid or semi-arid regions. Moreover, large deformations, rapid settlement and a high decrease in the void ratio of a metastable soil structure can occur. Large volume changes and sudden collapses take place when the soil is inundated under constant vertical stress. Soil deformation occurs as a result of the dissolution of the cemented gypsum bonds, which causes a pronounced increase in the compressibility of the soil. The leaching phenomenon facilitates additional softening as well as large and complex deformations in gypseous soil due to the movement of underground water (Al-Mufty, 1997). According to Seleam (2006), the term "gypsiferous soil" used by Van Alphen & Romero (1971) refers to soils containing more than 2% gypsum, while Saaed & Khorshid (1989) Defined gypsiferous soil as soil that contains more than 6% gypsum. In Iraq, Smith & Robertson (1962) and (FAO, 1990) discovered that 3-10% of gypsum does not signicantly interfere with soil characteristics such as structure, consistency and water holding capacity, while the gypsum crystals tend to break down the continuity of the soil mass in soil containing 10-25% gypsum. In civil engineering a soil can be defined as a gypseous soil when the gypsum content suffices to change the properties of the soil (Nashat, 1990).

The term "gypseous soil" and "gypsiferous soil" are synonymous terms. The term gypsified soil refers to natural soils to which a predefined percent of gypsum is added. Many investigators use this type of soil to study the effect of gypsum on soil properties and behavior. Sometimes it is considered a soil stabilizer, especially for road construction. Reid (2012) described the gypsum in UK as a widespread occurrence in soils and rocks, white crystals and powder. This gypsum is slightly soluble at neutral pH and soluble in acid. Moreover, Barzanji (1973) classified soils according to gypsum content, as shown in the following table.

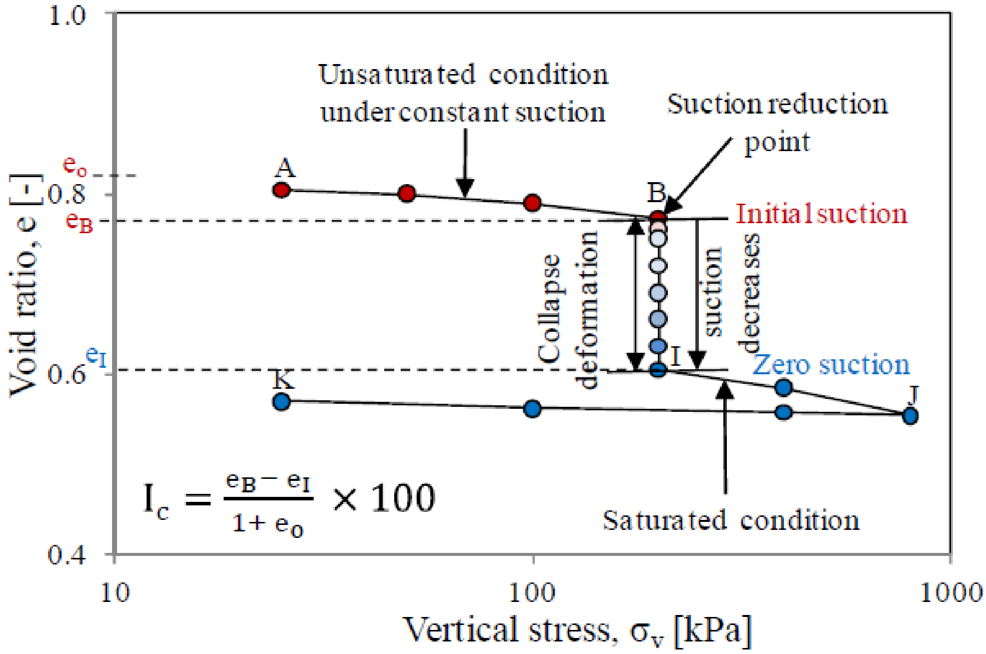
| Gypsum content,% | Classification |
|---|---|
| 0-0.3 | Non- gypsiferous |
| 0.3-3 | Very- slightly gypsiferous |
| 3-10 | Slightly gypsiferous |
| 10-25 | Moderately gypsiferous |
| 25-50 | Highly gypsiferous |
| > 50 | Gypsiferous soil to be described by the other fraction such as sandy gypsiferous soils |

## Collapse potential identification and test methods

The one-dimensional response-to-wetting test, which is performed using conventional consolidation equipment represents the frequently used laboratory collapse test for determining the collapse potential of the soil (Houston et al., 2001). In Oedometer-collapse test, two procedures are commonly followed; single Oedometer (SOT) and double Oedometer  (DOT) methods. The typical output of this test can be represented as in the following figures.




(a)




(b)

*Typical Oedometer-collapse test result: (a) Double Oedometer test (DOT) and (b) Single Oedometer test (SOT).*

The actual collapse potential is determined using the double Oedometer test (DOT) method suggested by Jennings & Knight (1957). In this method, two identical samples are prepared and tested individually in Oedometer device. One sample is tested at its natural moisture content, while the other is tested under saturated conditions. The same load sequence is used in both cases. The difference between the two stress-strain curves represents the amount of collapse deformation that occurs depending on the stress level as shown in Figure a .

Jennings & Knight (1975) suggested a procedure to describe the collapse potential of a soil which is mostly a qualitative evaluation. This procedure was subsequently modified by Houston et al. (1998) and standardized by the American Society for Testing and Materials (ASTM) under code number ASTMD5333 (2003).

Figure b illustrates a typical response in which a seating stress of 5 kPa was used to establish an initial state. Any compression under this stress was attributed to sample disturbance. The initial compression curve (points A-B) represents the response of the soil at its in situ water content. Pressure was applied until the stress on the sample was equal to (or greater than) that expected in the field or up to 200 kPa as suggested by Jennings & Knight (1975) and as standardized by ASTMD5333 (2003). At point B, the specimen was flooded to reach saturation and left for 24 hours (ASTMD5333, 2003). The duration of the load increment following inundation lasted overnight or until primary consolidation was completed (ASTMD2435, 1996). The difference between the strains before and after inundation with water (points B-I) represents the amount of collapse deformation at the specified stress level, after which further loading is undertaken corresponding to points (I-J). The path (J-K) represents the unloading stage of the soil specimen.

According to ASTMD5333 (2003), the following definitions are outlined:

-Collapse: indicates a decrease in the height of confined soil following wetting at a constant applied vertical stress.

-Collapse index (Ie): refers to the percent-relative magnitude of collapse determined and calculated at 200 kPa.

-Collapse potential (Ic) denotes the percent-relative magnitude of collapse determined at any stress level as follows:

$$I_c = \frac{\Delta h}{h_0} \times 100$$

where: $\Delta h$ = the change in specimen height resulting from wetting, mm, ho= the initial specimen height, mm.

or

$$I_c = \frac{e_B - e_I}{1 + e_0} \times 100$$

where: Ic= the collapse potential, $e_B$,$e_1$ = the void ratio at the appropriate stress level before wetting, $e_I$ ,$e_2$= the void ratio at the appropriate stress level after wetting, $e_o$= the initial void ratio.

Based on the Oedometer-collapse test, the collapse potential can be assessed and used to indicate the problem severity of collapse. The following table provides details presented by Jennings & Knight (1975) and ASTMD5333 (2003), showing a slight difference between the two references in the collapse potential range corresponding to problem severity.

Table 2.2.: The severity of the collapse potential.

| Jennings and Knight, 1975 | | ASTM (D5333-2003) standard | |
|---|---|---|---|
| $I_c$,(%) at $\sigma_v$=200 kPa | Severity of problem | $I_c$,(%) at $\sigma_v$=200 kPa | Degree of collapse |
| 0-1 | No problem | 0 | None |
| 1-5 | Moderate trouble | 0.1-2.0 | Slight |
| 5-10 | Trouble | 2.1-6.0 | Moderate |
| 10-20 | Severe trouble | 6.1-10.0 | Moderately severe |
| $> 20$ | Very severe trouble | $> 10.0$ | Severe |

The single oedometer method is faster and easier and it more closely simulates the actual loading and wetting sequence that occurs in the field. It also overcomes the problem of obtaining the two identical samples needed for the double oedometer test. However, this method provides less information because it only gives the hydrocollapse strain at one normal stress. Therefore, the soil should be wetted at a normal stress that is as close as possible to that which will be present in the field.