Module 7

Lecture 1

Swelling and Collapse Behavior

Collapse and swelling phenomena occur in unsaturated soils during the saturation process. The compacted unsaturated soils, on the dry of optimum, have open structure and are more vulnerable to drastic volume changes upon saturation. Two distinct volumetric responses may be observed upon wetting of such soils based on the stress levels in the soil. Swelling of the soil occurs under low normal stresses during the wetting process. On the other hand, sudden decrease in volume followed by a gradual swell will be observed under high normal stresses. The sudden and significant decrease in the volume is referred to as "*volumetric collapse*", a common phenomenon observed in the marine environment. This interesting behavior of an open structure in unsaturated soils is analyzed here using microstructural perspective.

Let us consider unsaturated state of the soil under some applied normal stresses by application of external load, which induces both normal and shear stresses at the particle contacts. The distribution of stresses and, therefore, the developed normal and shear stresses at particle level vary from one contact point to another. The particles will slip when the induced stresses are equal or more than the inter-particle frictional resistance. This slip at the particle level is perceived as a decrease (compression) in the soil volume at the macro-scale. However, the slip may be prevented at some inter-particle contact points by the interfacial negative stresses between the particle and the water as shown in Fig 7.1. These stresses (matric suctions) are generated due to the capillary and adsorption mechanisms at the particle level. Such counter forces due to interfacial forces (degree of saturation is less than 100%) would limit the decrease in the soil volume under applied normal stresses that are more than the inter-particle frictional resistance. Therefore, the soil structure may remain open under external stresses.

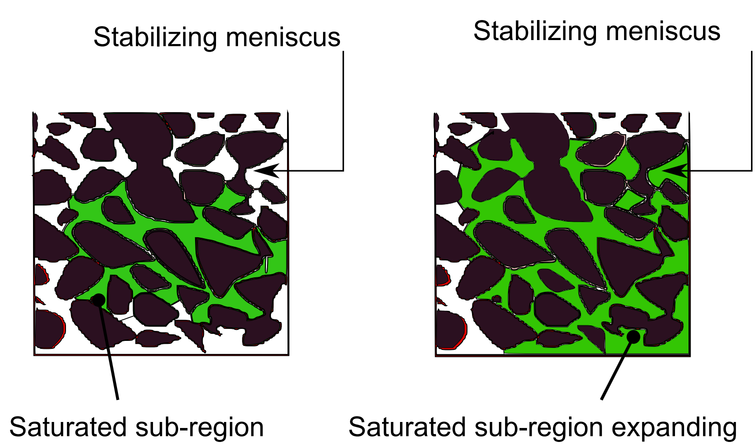


Fig. 7.1. Mechanism of collapse behavior (after, Laloui, 2010)

The increase in the thickness of diffuse double layer is manifested as swelling in the soil upon saturation. However, the stress state changes at the contact points, where the slip was prevented before due to the wetting process. Subsequent decrease in the suction value upon wetting results in the loss of additional strength and particles would slip. This results in the volumetric collapse. The changes in the soil volume during wetting under low and high total stresses are illustrated in the Fig 7.2.

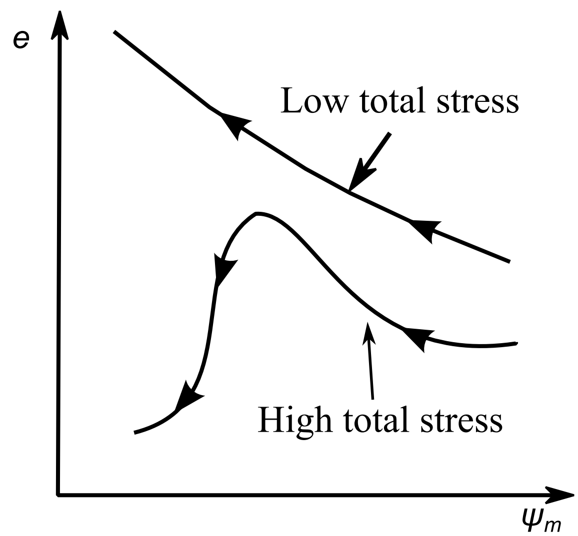


Fig. 7.2.Volumetric behavior of soil upon wetting (after, Laloui, 2010)

It can be noted that the external stresses need to be high for the collapse to occur. The high external stresses induce high shear stresses at the inter-particle contact points.

The additional shear strength due to the presence of interfacial stresses in compacted, unsaturated soils is presented in the Fig 7.3. The additional contribution is the difference between the shear strength of unsaturated soil at given matric suction, τ , and the shear strength of saturated soil, $\sigma \tan\phi'$. The soil remains saturated until the air-entry pressure. The Terzaghi's principle of effective stress can be applied in this range, it can be seen from M-C theory that the increase in shear strength is proportional to $\tan\phi'$. The soil desaturates as the pressure is increased beyond air-entry pressure, ψ_{AEV} , and the additional shear strength $\Delta\tau$ is smaller than the shear strength of the specimen if it had remained saturated under this negative pressure.

It is convenient to analyze and quantify the swelling and collapse behavior based on the definition of swelling pressure of a given soil. The swelling pressure of an undisturbed soil may be defined as the pressure required for maintaining a constant soil volume at its natural density upon wetting. Similarly, the swelling pressure of a disturbed soil may be defined as the pressure required for maintaining a constant soil volume at its proctor density. Therefore, the soil collapses upon wetting, when the externally applied pressure is more than the swelling pressure of the soil. Contrarily, swelling occurs when the applied pressure is smaller than the swelling pressure of the soil.

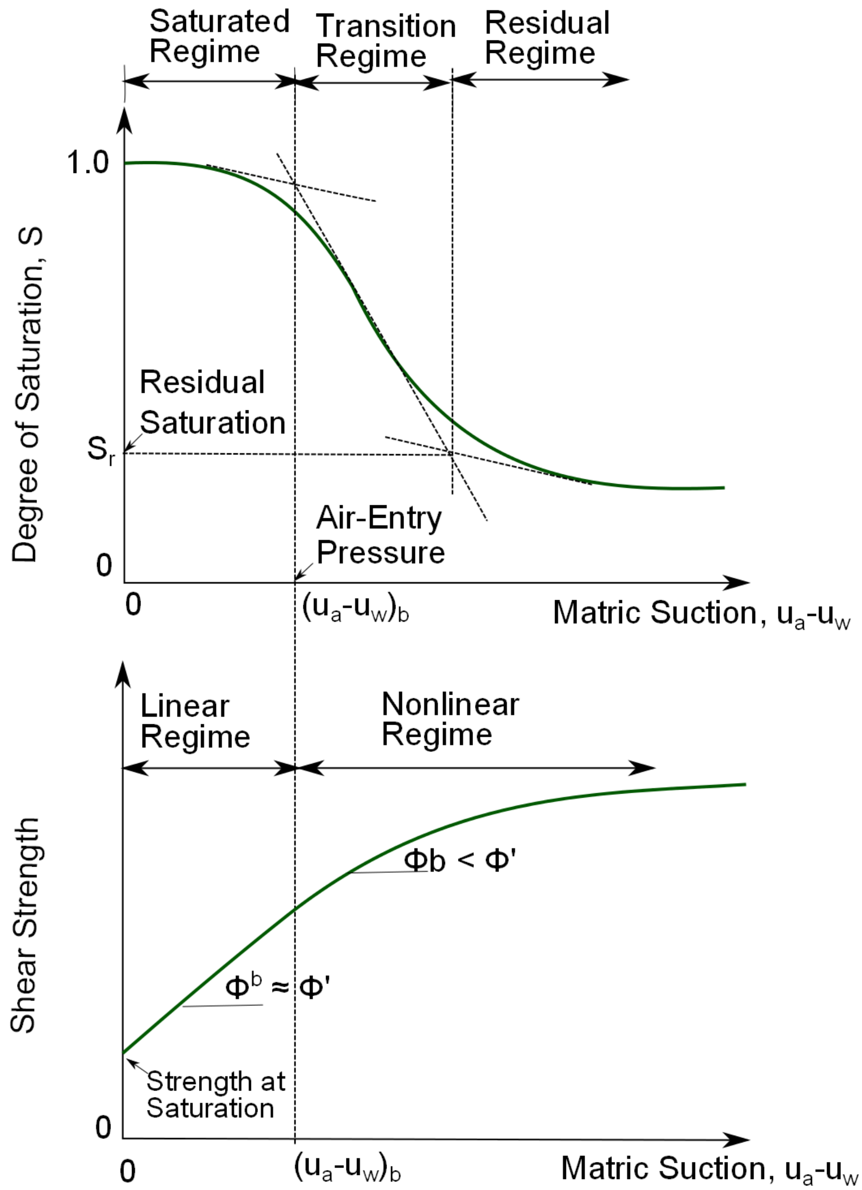


Fig. 7.3 A conceptual shear strength profile (after Vanapalli ct al., 1996)

The swelling pressure of the soil is a material property and, therefore, is independent of the surcharge pressure, the initial moisture content, degree of saturation, and the thickness (Chen, 1975). However, the swelling pressure increases with increase in the initial dry density. Swell-collapse behavior is often modeled by finding the swelling pressure of the soils in the laboratory using consolidation test apparatus.

Lecture 2

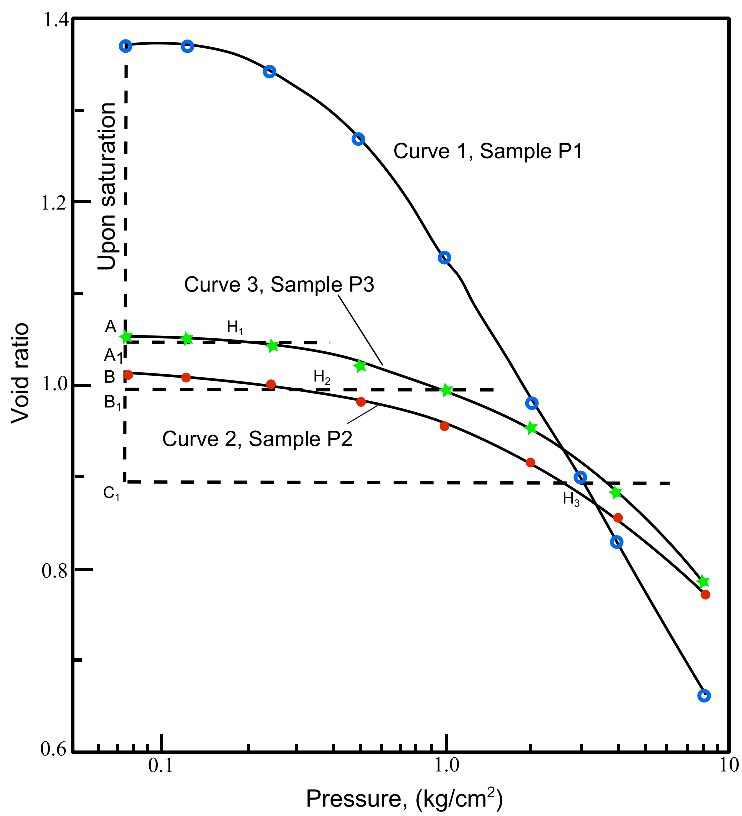
Methods of testing Swelling Pressure

The following three commonly used techniques and experimental procedures for laboratory swelling pressure determination are briefly described here

(i) Conventional consolidation test
(ii) Method of equilibrium void ratios
(iii)Constant volume method

Conventional consolidation test

The following Fig 7.4 illustrates the void ratio versus log*p* plot for a laboratory consolidation test. The soil specimen with known initial void ratio (knowing the initial thickness and dry density) is allowed to swelling on water addition under the seating pressure which is illustrated by the dotted lines in Fig 7.4. After the equilibrium (saturation), the applied load is increased subsequently and consolidated the specimen at each incremental load. The consolidation curve meets the initial void ratio (horizontal dashed line drawn at the initial void ratio level) at one particular effective normal stress. It signifies that the specimen regained its original volume at this pressure. This pressure represents the swelling pressure of the soil.



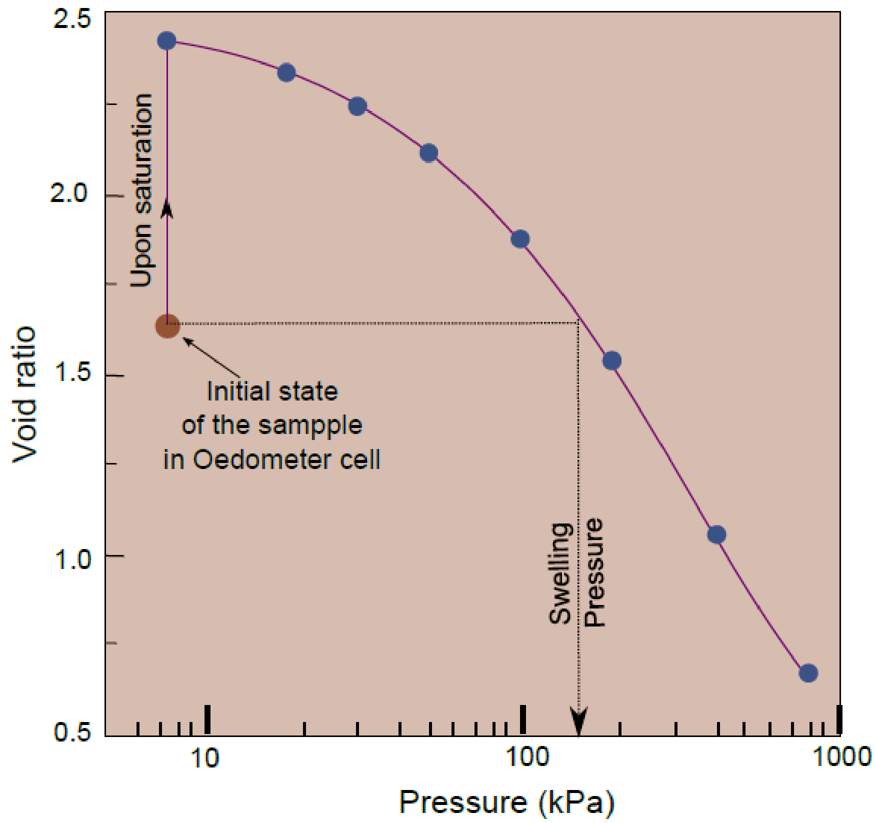
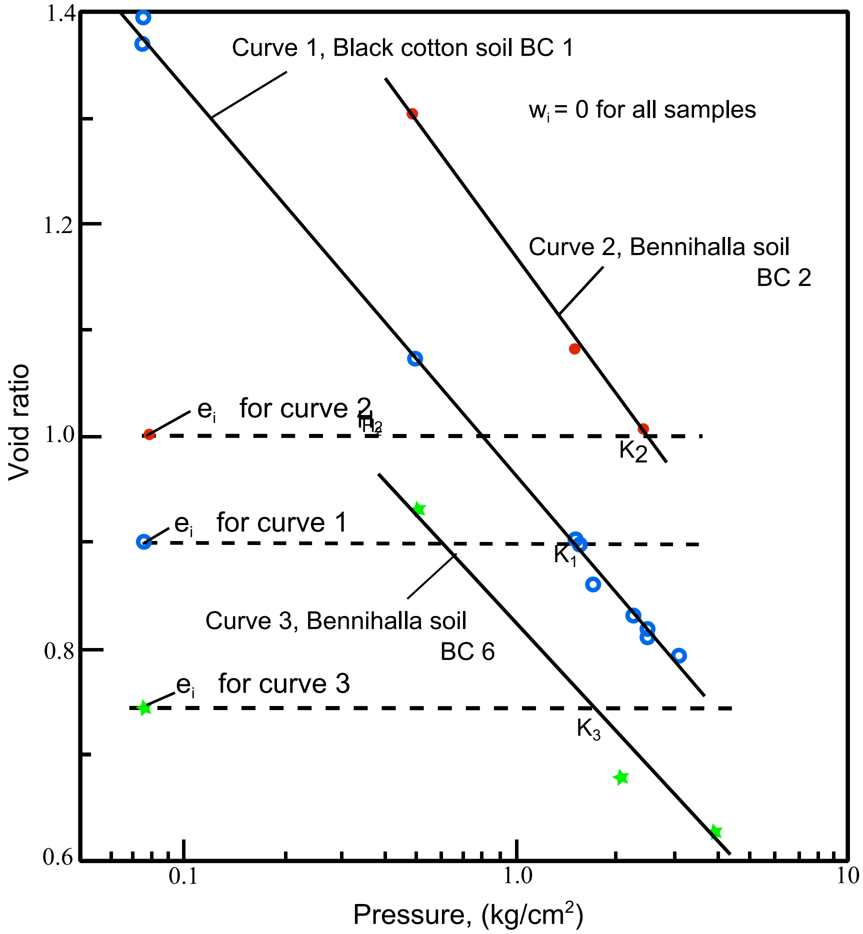


Fig. 7.4. Swelling pressure determination by conventional consolidation test (after Rao ct al.,)

Method of equilibrium void ratios

In this technique, three or more identical dry soil specimens are placed in the consolidation apparatus under the same seating pressure. The dry specimens are then loaded and brought to equilibrium with different normal pressures called p_1, p_2, p_3,…etc. These samples are saturated with water addition. The samples will undergo either swelling or compression under the applied loads, depending on the swelling characteristics of the soil. If the swelling pressure of the soil is more than the applied pressure, the swelling is encountered otherwise, compression is observed. Once the specimens reach equilibrium, the equilibrium void ratios are plotted against the equilibrium pressure on each sample. These data points lie on a straight line and intersect the initial void ratio line as shown in the Fig 7.5. If any applied pressure happens to be the swelling pressure of the soil, the soil undergoes neither swelling nor compression.



1.4
1.2
1.0
0.8
0.6
Void ratio
Curve 1, Black cotton soil BC 1
w_i = 0 for all samples
Curve 2, Bennihalla soil BC 2
e_i for curve 2
K_2
e_i for curve 1
K_1
Curve 3, Bennihalla soil BC 6
e_i for curve 3
K_3
0.1
1.0
10
Pressure, (kg/cm^2)

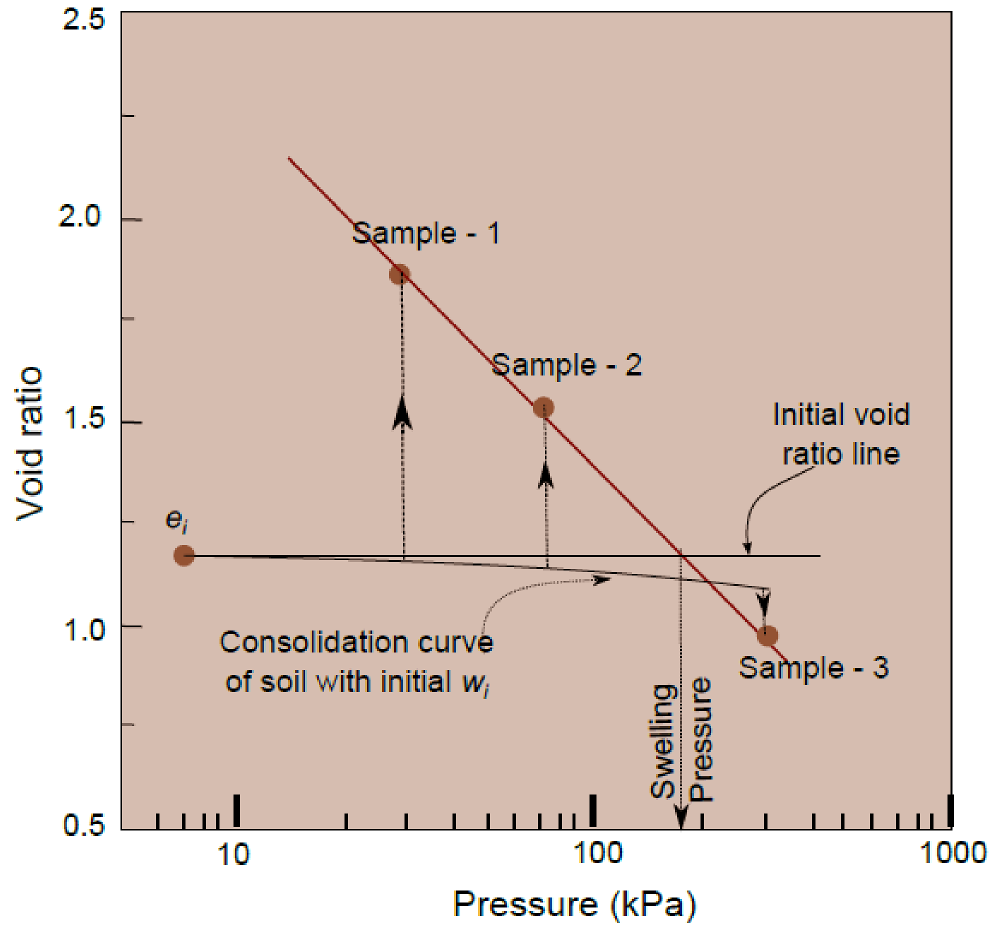
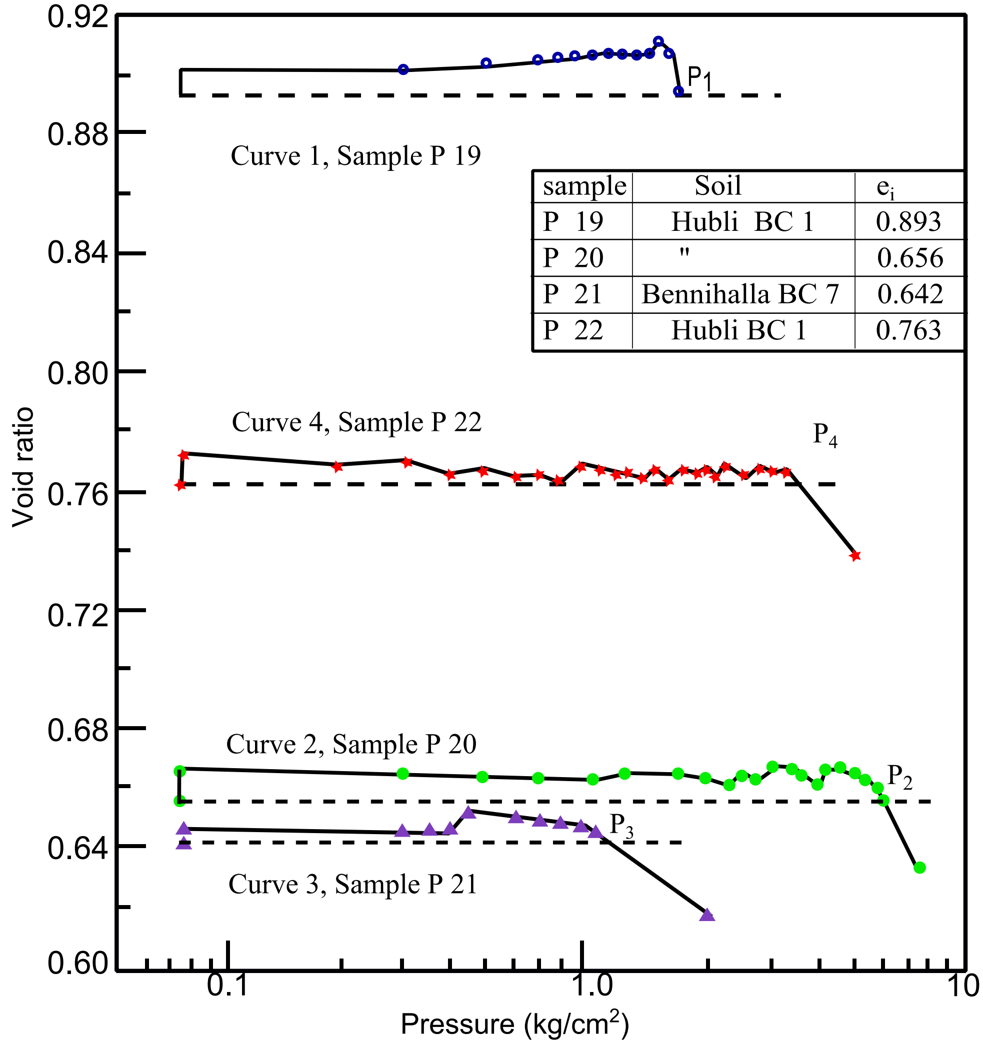


Fig. 7.5. Swelling pressure determination by the method of equilibrium void ratios (after Rao ct al.,)

Constant volume method

This particular method is based on maintaining a constant volume of the soil sample during the saturation process by adjusting the external load application, as the name suggests. A dry soil specimen with known initial void ratio, which is maintained under seating pressure, is saturated by addition of water, which results in increased volume of the sample. However, the changes in the volume are controlled by the addition of supplementary loads as shown in the Fig 7.6. Finally, the application of total normal load on the soil sample causes neither swelling nor the compression. This pressure is the swelling pressure of the soil.



sample	Soil	e_i
P 19	Hubli BC 1	0.893
P 20	"	0.656
P 21	Bennihalla BC 7	0.642
P 22	Hubli BC 1	0.763

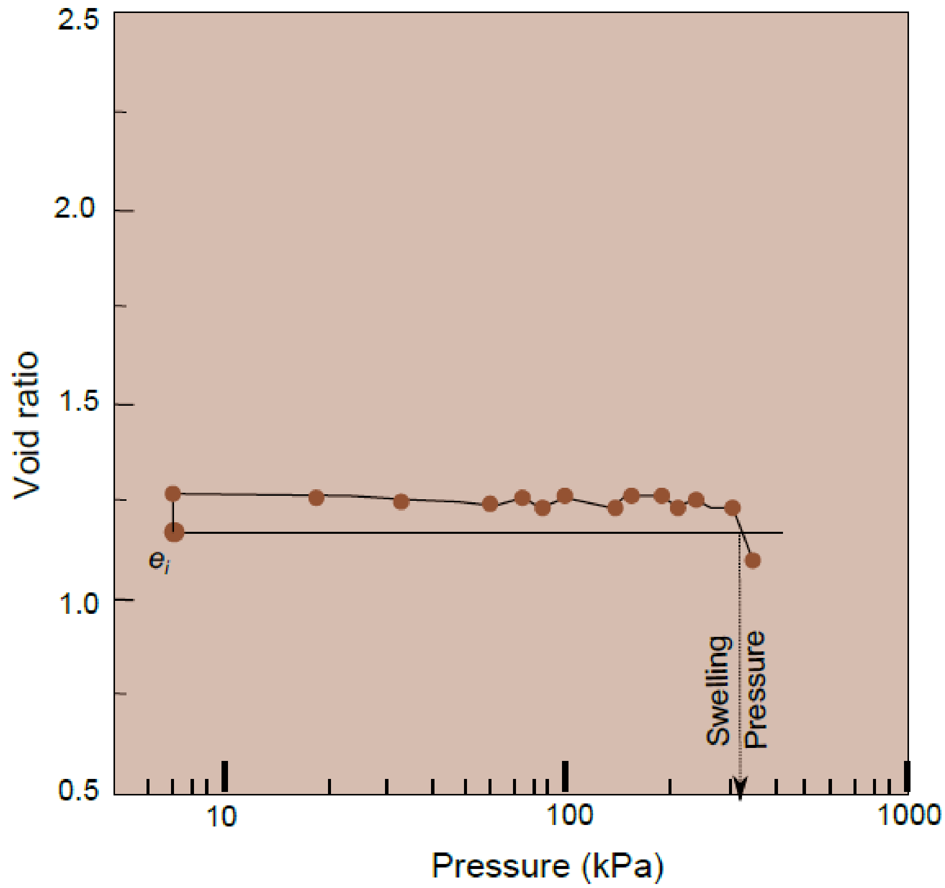


Fig. 7.6. Swelling pressure determination by constant volume method (after Rao ct al.,)