Chapter 8

Compressibility and Consolidation of Soils

ABSTRACT

The total compression of soil under load is composed of three components (i.e. elastic settlement, primary consolidation settlement, and secondary compression). The consolidation component is time-dependent and its analysis is usually based on Terzaghi’s theory. The chapter considers the consolidation characteristics of a soil and their experimental determination. The coefficient of consolidation can be determined by the Casagrande Logarithm-of-Time Fitting Method or the Taylor Square-Root of Time Method. The concepts of preconsolidation and overconsolidation are discussed while ways of determining the preconsolidation pressure, compression index, precompression index, and the coefficient of volume compressibility are explained. Ways to compute the settlement using coefficient of volume compressibility and e-logσ methods for both normally consolidated and overconsolidated soils are provided. The chapter also explains Schmertmann (1955) graphical procedure for approximating the field compression index from the laboratory curve. It includes the derivation of Terzaghi’s 1-D theory of consolidation and its solution using both analytical and graphical methods. Finally, the phenomenon and way of computing the secondary compression index are treated.

8.1 COMPRESSIBILITY OF SOILS

Soil is a multi-phase medium made up of mineral grains which enclose voids that may be filled with gas, liquid or a combination of both. When stress is applied to a soil sample its volume decreases. Such a change in volume may be due to: (a) a compression of the solid soil particles, (b) a compression of water and air within the voids, or (c) an escape of water and air from the voids.

The solid particles and the pore water are relatively incompressible and therefore under the loads usually encountered in geotechnical engineering, they will not undergo appreciable volume changes. Therefore the decrease in volume of a saturated soil mass when subjected to stress increase is due almost entirely to an escape of water from the voids. Some compression also occurs as a result of shifting of position by the soil particles by rolling and sliding under the influence of the applied load. This aspect

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of the compressibility of a soil mass depends on the rigidity of the soil skeleton. The rigidity, in turn, is
dependent on the structural arrangement of the soil particles, and in fine-grained soils, on the degree to
which adjacent particles are bonded together.

As compression occurs in soils the pore water escapes. The escape of water, according to Terzaghi
(1943), takes place in accordance with Darcy’s law. This process which involves a slow escape of water
from the pores, gradual compression and a gradual pressure adjustment is called consolidation. When
the compression takes place in unsaturated soils by mechanical means such as rolling or tamping, it is
termed compaction and mostly air rather than water is driven out from the pores of the soil.

In sand, most of the consolidation takes place during construction and the after-effects are therefore
much smaller than in fine-grained soils. However, the impact on foundation engineering depends on
the sensitivity of the structure to small differential settlements. Therefore, even for sands, it may still be
necessary to estimate the settlement of some structures.

Clay as found in nature has normally undergone a natural process of consolidation, having originally
been deposited in water and then gradually compressed by the weight of the material deposited above it.
The soil is said to be fully or partially consolidated depending on whether or not a state of equilibrium
has been reached under the existing overburden pressure. Some clay deposits are over-consolidated, that
is, they have been compressed at some time in their geologic history by super-imposed loads, such as
the ice sheets of the Pleistocene period or have consolidated because of free draining conditions as in
some lodgement tills, by capillary suction or by lowering of ground water table. It is also possible for
some of the original overburden pressure, which caused the deposit to consolidate, to be removed in the
cause of geological history e.g. by erosion. This will also give rise to overconsolidation.

The total compression of soil under load is therefore composed of three components i.e.

\[ \text{Total Settlement} = S_e + S_p + S_s \]  \hspace{1cm} (8.1)

where

- \( S_e \) = Elastic Deformation (Immediate settlement)
- \( S_p \) = Primary Consolidation
- \( S_s \) = Secondary Compression

The elastic deformation is due to the deformation of soil and rock grains and the compression of air
and water in voids. It is fully recoverable; the primary consolidation is drainage of water and air from
the voids allowing compression of soil skeleton. It is inelastic, time dependent and only partially recov-
erable; while the secondary compression is due to creep movements – plastic adjustment of soil fabric
under a constant effective stress. This is also inelastic, time dependent and unrecoverable. The elastic
deformation of soils is discussed in Chapter 4.

8.1.1 Process of Consolidation

The compression of saturated fine grained soils under applied loads is due to the expulsion of water
from the soil and the rearrangement of the soil grains. It has been found convenient to separate the two