Determination of the coefficient of earth pressure at rest in situ in overconsolidated clay

Eszter Kalman
Budapest University of Technology and Economics, Department of Geotechnics, Hungary

SYNOPSIS: This paper outlines the research of the determination of the coefficient of earth pressure at rest (Ko) in situ in an overconsolidated clay. One of the major difficulties for the geotechnical engineers during the designing project phase is to estimate the correct parameter of Ko. Two ways are available to determine the Ko, one of them is the laboratory tests and the other is the in situ test. The determination of the coefficient of earth pressure at rest in an over consolidated soil/rock is a complex problem, because accurate results could get from in situ measurements. The original environment of the soil/rock is the most important for the determination of the coefficient of the Ko. This study presents two in situ measurements and their results for the determination of the Ko, which are the Stresses Monitoring Station (bore hole cells) and the flat jack.

Key words: Ko, coefficient of earth pressure at rest, overconsolidated clay, in situ measurement, borehole cell

1. INTRODUCTION

This paper outlines the research of the determination of the coefficient of earth pressure at rest in situ in an overconsolidated clay.

At first we have to talk about the overconsolidated clay because it is a special soil/rock and a special problem for the designers, constructors and the client too. The overconsolidated clay is a normal clay which have suffered a bigger load in the ancient geological time than nowadays. This load may have been 400-600 meters soil or sea like in Hungary. The present surface of Kiscelli clay had to hold more than 400 meters soil in the past. Under the ancient load the consolidation must have run its course but this clay was normally consolidated clay at that time. The 400 m overburden soil had been eroded by geological events, forces (erosion, glacial ice etc.). With time the erosion the vertical pressure - was decreasing and the horizontal pressure was not changed much from original volume.

In my research I would like to determine the relationship between the horizontal and vertical earth pressure in the Kiscelli clay with in situ measurements.

Some words about the soil environment and about the Kiscelli marly clay:

A typical geological area from the Buda side in Budapest in Hungary is presented in the Figure 1.

In a typical environment on the Buda site there is a young (Pleistocene) deposit layer and below this layer there are Up-Oligocene or Mid-Oligocene layers. The uppermost layer to a depth of 4 to 5 meters below the ground surface. Below this we can find a Mid-Oligocene formation of clay marl known as Kiscelli clay. This clay is an overconsolidated clay. The upper zone of the clay stratum in a thickness of 1 to 3 m is expanded, heavily fractured and weathered, due to the geological erosion. Below this an expanded, fissured zone is found. This clay is very good environment for a tunnel construction. Somewhere is Tardi clay or Buda Marl on the Buda site in Budapest which layers are Down-Oligocene layers.

In the Kiscelli clay these horizons can be described as:

• the relatively thin, below the young deposit weathered material, called as “weathered Kiscelli Clay”
• below the “weathered Kiscelli clay” termed the unweathered, “fissured Kiscelli clay” over consolidated, and
• the depth zone is the “basal Kiscelli clay”, which is unfissured, unweathered, which has good condition, and it is heavily over consolidated.

Determination of earth pressure with in situ measurements:

We have been using three different methods to determine the coefficient of the earth pressure at rest and another method to determine the pressure between the SCL tunnel lining and the soil/rock.
At first we installed earth pressure cells between the SCL tunnel lining and the soil and we have read the results during the tunnel construction and after it. The Glötzl earth pressure cells were installed in the cross section 0+43 of the tunnel. See the Figure 2.

The radial cells can show the stresses between the SCL and the clay, radial pressure and the tangential cells can show the stresses in the structure.

In the cross section 0+43 there are six radial and two tangential cells. The location of the cells is shown by Figure 3.

The readings were taken twice daily. By the continuous reading we can get a complete image of how the stresses were transposed onto the prop and what was magnitude of the stresses in the SCL.

Figure 3. shows the distribution of stresses around the primary lining. As it can be seen, the state of stress appears to be „quasi hydrostatic”.

After these measurements and results my research group we have come to believe that the horizontal stress could be bigger than the vertical stress in this clay.

After this measurement we installed Stress Monitoring Station(SMS) close to this tunnel. This GLÖTZL SMS was the first which clearly indicated that horizontal and vertical stresses rate higher than 1.

This GLÖTZL SMS installed with 4 horizontally orientated pressure cells to determine the horizontal stresses and one cell vertically orientated pressure cells to determine the vertical stress. See the Figures 4 & 5.
Figure 2. Shows the installation scheme of each cell

Figure 3. The earth pressure cells in the cross section 0+43
Figure 4. The SMS with 3 horizontal and 1 vertical cell

The results of the borehole cells:

Figure 5. The results of the borehole cells
This measurement gave the right of our opinion by weighty arguments because the stresses of the horizontal cells (2-5 cells) are around 4 bar which are 400 kPa and the vertical stress is around 2.5 bar which is 250 kPa.

Karl Terzaghi wrote in his book of Theoretical Soil Mechanics (1943) “The corresponding ratio $\sigma_{h0}/\sigma_{v0}$ between the vertical and the horizontal principle stresses for a mass of the soil, and on the temporary loads which have acted on the surface of the soil. Its value may or may not be independent of depth. If the nature of a mass of soil and its geological history justify the assumption that the ratio $\sigma_{h0}/\sigma_{v0}$ is approximately the same for every point of the mass, it will be called the coefficient of earth pressure at rest and designated by the symbol $K_o$.”

$$K_o = \frac{\sigma_{h0}}{\sigma_{v0}} = \frac{400}{250} = 1.6$$

It is a little bit different than the result of the Jaky-method which is used around the World because the $K_o$ is less than 1 from the Jaky-method. It was the problem in Hungary because in the most area in Hungary the soil is normally consolidated so this $K_o$ was a little bit unusual for the designers, constructors and the client of the newly constructed metro lane in Budapest.

This problem was gone the round to the coefficient of the earth pressure at rest will be right the constructor company (Hídépítő) ordered self boring pressure meter measurements in 3 different places in the Kiscelli clay. The self boring pressure meter tests were carrying out by Geovil Ltd (Hungary) and Cam Insitu Ltd. (United Kingdom). The results of these tests support our opinion about the coefficient of the earth pressure at rest in the overconsolidated clay which is more than 1. (Figure 6).

![Figure 6. The results of the self boring pressure meter measurements](image_url)
2. CONCLUSION
The literature puts the coefficient of earth pressure at rest and it’s determinations among three different groups:

1. Jaky-method:
   \[ K_0 = 1 - \sin \phi \]
   It is an empirical relationship between the horizontal and vertical stresses. It is widespread in Hungary and around the World, but it is valid in normally consolidated soil. The result of \( K_0 \) always is less than 1, when the Poisson number is at maximum volume 0.5. This relationship is applied in the case of geologically young and normally consolidated and soil.

2. \( K_0 = 1 \)
   In the event that the soil environment is soft and plastic.

3. \( K_0 > 1 \)
   It is true if the soil/rock is over-consolidated, because the soil/rock can “remember” the earlier, ancient load-stress.
   So sometimes the horizontal stresses are higher than the vertical stresses in concrete point in the soil.

The coefficient of the earth pressure at rest is more than 1 in over consolidated clay because the surplus stress in the vertical direction have been decreasing with the erosion but the surplus stress in the horizontal direction have not been decreasing because the erosion normally have been vertical direction and not horizontal so the horizontal primary stress is looked upon as permanent.

A further research work is needed to clear up the questions. This research works is going on and the work is heavily supported by companies (Swietelsky Hungary, Hidépítő Ltd. and Geovil Ltd., Glötzl Gmbh.) as well the client DBR 4 metro Project Directorate.

LITERATURE
2. Karl Terzaghi: Theoretical Soil Mechanics (1943)
4. Glötzl Gmbh: Installation of SMS’ manual