Problems concerning clays of very high plasticity in Denmark

Problèmes avec les argiles de très haute plasticité au Danemark

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SYNOPSIS Deposits of clay of very high plasticity are found in the central part of Denmark. The special problems connected with bearing capacity and deformation of foundations and with slope stability are illustrated by case stories. For footings it is normally sufficient to investigate the short term bearing capacity, but the drained state should also be examined in connection with excavations. Natural slopes are just stable with an angle to the horizon of 6-9°. Small excavations can result in creep deformations or failure. Shallow foundations can even in a temperate, coastal climate as the Danish be subject to damaging deformations. Relevant precautions are outlined.

INTRODUCTION

Deposits of clay with very high plasticity are found in the central part of Denmark. The clays are of tertiary origin but can also be found as flakes in the glacial deposits torn up and transported by the glaciers.

The stratification is often so complicated that calculations can be done only for a simplified stratification.

GEOTECHNICAL CHARACTERISTICS

For the fat, tertiary clays the typical properties are as follows:

Classification:

Natural water content	w	~ 35-80 %
Liquid limit	w_L	~ 90-120 %
Plasticity index	I_P	~ 60-100 %
Activity	A	~ 1

Referring to Casagrande's diagram of plasticity the clays are to be classified as "Clays of Very High Plasticity".

Strength parameters

Normally, the tertiary clays are fissured. The shear strength measured by vane tests, c_v, is generally too high compared with the undrained shear strength. From plate loading tests it has been found that the undrained shear strength normally can be assumed to be not less than $c_u \sim 1/3\ c_v$. The clays are normally rather stiff with an undrained shear strength above 100 kPa. The effective parameters determined by triaxial tests range the order of $\varphi' \sim 15\text{-}20°$, $c' \sim 10\text{-}20$ kPa.

Deformation parameters

The clays are normally heavily preconsolidated. The modulus of compressibility, K, depends on the effective normal stress before loading, σ'_A. Based on the recompression curve of the oedometer tests, typical values are $K \sim 5000 + 150\ \sigma'_A$ kPa. The swell index ranges the order of $Q = C_s/1 + e_o \sim 2\text{-}5\%$.

CASE STORY CONCERNING BEARING CAPACITY

The structure in Fig. 1 is a quay wall of blocks constructed in 1912 in an area of 4.5 m depth of water. The wall is erected after dredging to 9.2 m below sea level. The backfill consists of clay. During the period 1959-1967 a horizontal movement of 170 mm corresponding to an average movement of 1.5 mm per month was recorded. In 1967 the recorded movement was about 15 mm per month, and it was observed that the movements occurred in connection with low water in the harbour.

The geotechnical investigations showed that the quay wall is founded on fat, tertiary clay. Behind the wall the clay surface was located 5 m below sea level. Fig.1 shows a cross section in the construction with soil profiles and soil strength parameters. By comparing the properties in front of the wall with the properties behind it is observed that the stress relief from the dredging of 4 m clay caused an increase of water content from $w \sim 40\%$ to $w \sim 50\%$ and a reduction in the undrained shear strength from $c_u \sim 170$ kPa to $c_u \sim 110$ kPa within the upper approximately 4 m below sea bottom. By triaxial tests, effective strength parameters of $\varphi' \sim 20°$, $c' \sim 20$ kPa were found for the tertiary clay, and $\varphi' \sim 24°$, $c' \sim 10$ kPa for the clay fill.

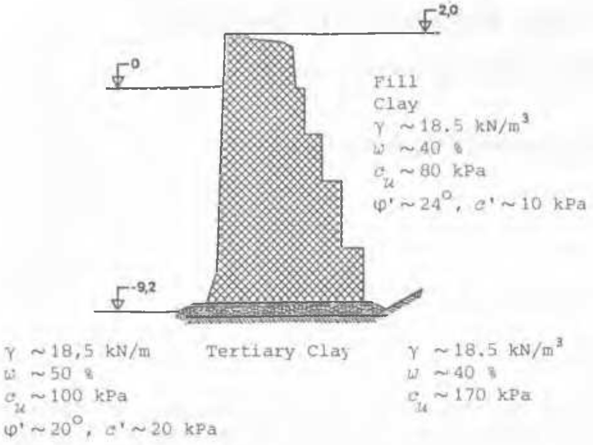

Fig.1 Quay Wall

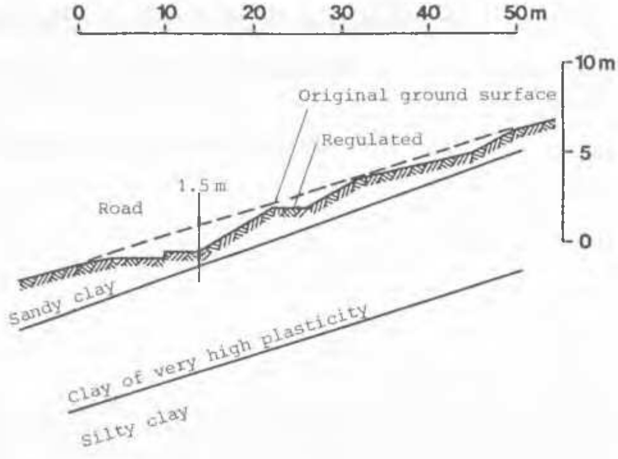

Fig.2 Slope stability

By stability calculations based on the undrained strength parameters a factor of stability of approximately 2 was found, even with the reduced strength in front of the wall. Using the effective parameters in connection with a differential water pressure of 1 m as observed, the stability factor was approximately 1.

The observed movements, therefore, were considered to be the start of a drained failure.

The quay wall was stabilized by anchors to a relieving platform founded on driven piles.

CASE STORY CONCERNING SLOPE STABILITY

Observations have shown that natural slopes of fat, tertiary clays are just stable with a slope angle of 6-9°. Even small excavations can induce creep or failure.

In an area with a slope angle of 8° a road was straightened in 1948 by excavation of approximately 1.5 m. In connection with the regulation of the surrounding ground, the average slope angle was increased to 10° as shown in the cross section on Fig.2. For many years creep movements took place. Measurements to a geodetic point on the road indicated a horizontal movement of 80 cm in 25 years. At that time measurements to points on the slope indicated a creep of 2 cm per year.

Geotechnical investigations showed the soil profile to consist of an upper 2 m zone of sandy clay with $\varphi' \sim 22°$, $c' \sim 20$ kPa, fat, tertiary clay with $\varphi' \sim 17°$, $c' \sim 0$ kPa, and from 8 m below the surface silty clay with $\varphi' \sim 25°$, $c' > 0$ kPa as determined by triaxial tests.

In winter seasons a water table was recorded just below the ground surface. The seasonal changes of the natural water content occurred down to 2-3 m below the ground surface.

Stability calculations with the simple assumption of an endless slope with hydraulic gradients and rupture lines parallel to the ground surface gave a factor of stability of approximately 1.

The calculated factor of stability is less than 1 for the regulated slope with $\beta \sim 10°$. A sufficient increase in stability can be obtained by lowering the water table to 3 m below ground level, corresponding to the depth of the active zone. The drainage system was designed as a combination of drains at the ground surface and another system 3 m below, in both cases placed in a herringbone pattern. This method has been used with success to stabilize several slopes.

CASE STORY CONCERNING DEFORMATIONS

The fat, tertiary clays can be classified as expansive soils. Even in a temperate, coastal climate as the Danish one, seasonal variations of the natural water content of fat clays can induce problems especially for shallow foundations for small houses and slabs on ground.

Damaging settlements and uplift have been observed for a great number of buildings. In general the problems are increased when trees are growing in the vicinity of the foundations, or where trees have been removed just prior to construction.

The problems concerning desiccation by trees are being investigated jointly by the Geotechnical Department of the Danish State Railways and the Danish Geotechnical Institute. The investigation area is located in a beechwood, and below the mould is fat, tertiary clay. Seasonal vertical movements of 10 cm or more have been recorded on bench marks 1.5 m below ground level. Samples extracted during summer and winter have shown a variation in water content of 10 % down to 2.5 m below ground level. In the upper zone, the water content in summer is just above the shrinkage limit.

Experience has shown that shallow foundations on fat clays following the principles outlined on Fig. 3 have proven to be successful:

Foundation depth shall be increased to 1.2-1.5 m below surface compared with a usual foundation depth of 0,9 m. The lower 0.3 m of the foundations shall be cast directly against the supporting soil.

The rest of the footings and the floor slabs shall be made in reinforced concrete.

The excavation level below the floors shall be covered by an impervious membrane.

Peripheral drains shall be placed along the outer strip footings.

The ground surface shall be regulated to slope away from the building.

Casting must not be made on desiccated clay.

Trees shall be removed after reaching a height in excess of two thirds of the distance from the foundations.

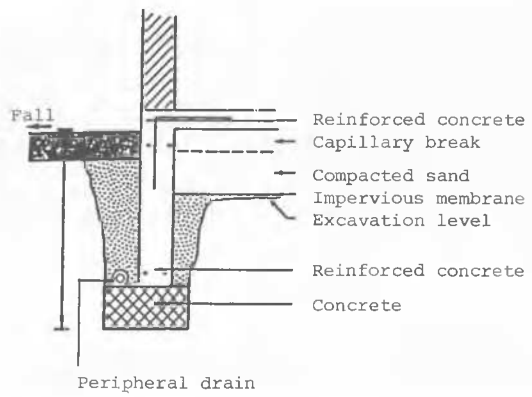

Fig.3 Outline for Footing

FINAL REMARKS

The tertiary Danish clays of very high plasticity have extraordinary strength and deformation characteristics, as it is shown by the preceding case stories. The planning and design of foundations on tertiary clay is consequently one of the most challenging tasks to a geotechnical engineer.