AN ENERGETIC MODEL OF CONSOLIDATION IN COHESIVE SOILS

TYPE A BASE D'ENERGIE DE LA CONSOLIDATION DE SOLS COHERANTS

ЭНЕРГЕТИЧЕСКАЯ МОДЕЛЬ ПРОЦЕССА КОНСОЛИДАЦИИ СВЯЗНОГО ГРУНТА

L.S. KEINONEN, Professor, Tampere University of Technology, Tampere, Finland

SYNOPSIS. When analysing the work done by compressive force in remolded saturated cohesive soils during oedometer tests the Author noted that all observations are not explainable by means of the classic effective pressure theory. The Author submits his opinion that the pressure is transmitted after consolidation in the cohesive soils through the water films surrounding the soil particles. The Author assumes further that the free energy of the water films is the decisive factor determining the amount of compression. When the water films become thinner their free energy decreases, and it is possible to calculate the pressure needed in order to increase the free energy enough to cause the water flow from the soil. The free energy of cohesive soils in different water contents were determined, and the compression was then calculated on the basis of the measured values of the free energy. The calculated values are in agreement with the oedometer tests.

INTRODUCTION

In the investigations into the consolidation of cohesive soil almost exclusively the relation pressure versus compression and time versus compression as well as the permeability of the soil have been made use of. On the other hand the questions of energy in connection with the phenomenon have been left without further attention.

WORK OF COMPRESSION

By taking the term "Work of Compression" into use new basis for the examination of the consolidation are achieved. The work of compression is defined by the equation

$$W_v = \int_0^{\varepsilon} \sigma' d\varepsilon \qquad (1)$$

in which σ' = effective pressure and ε = linear compression. In the best way the work of compression is calculated per one unit of soil volume. The amount of the work of compression is shown by the area between the pressure-compression curve and vertical axis (Fig. 1). To determine the amount of the

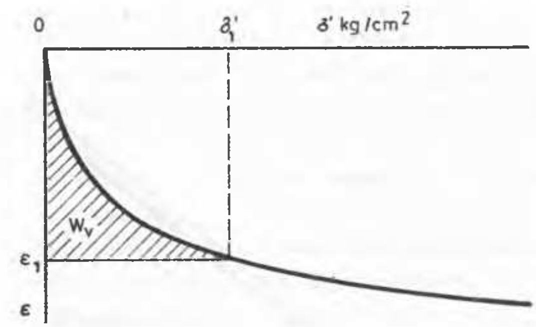

Fig. 1. THE DEFINITION OF THE WORK OF COMPRESSION

work of compression no special tests are necessary but it is very easily calculated e.g. on basis of the oedometer test results. Thus all of the present compression test results can be treated on new basis.

FACTORS AFFECTING THE AMOUNT OF THE WORK OF COMPRESSION

The Author carried out, by applying traditional oedometer technics, consolidation tests with remolded saturated cohesive soils. By analysing the amount of the work of compression W_v in different stages of the tests, following observations were made:

1) W_v is directly proportional to the compressive force (Fig. 2).

2) If the initial water content is increased W_v does not change though the compression is increasing (Fig. 2). Slight difference may occur by small loads.

3) The W_v needed in order to reach a certain void ratio e is strongly dependent on the original water content of the soil (Fig. 3).

4) If soil compressed into the void ratio e is still compressed, the work needed for a compression dε will be strongly dependent on the original water content of the soil (Fig. 4).

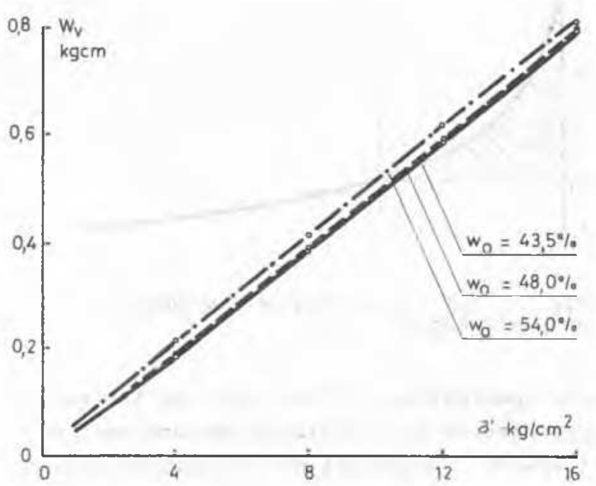

FIG. 2. THE WORK OF COMPRESSION BY DIFFERENT LOADS IN SOME WATER CONTENTS

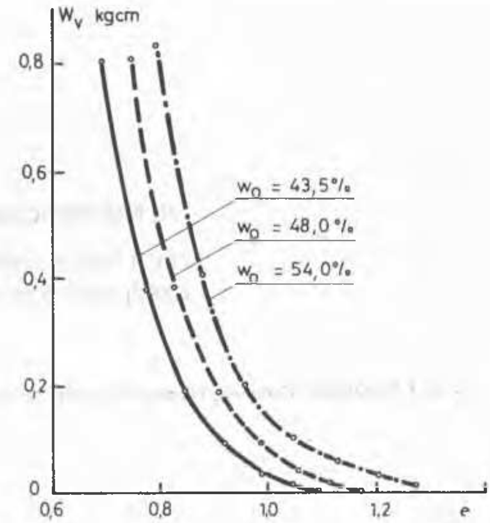

Fig. 3 THE WORK NEEDED TO COMPRESS SOIL FROM DIFFERENT ORIGINAL VOID RATIOS TO AN OTHER VOID RATIO

The Author pays attention to the last mentioned observation, which means that the soil "remembers" its original water content. The phenomenon is closely related to the well known fact that the soil behaves differently

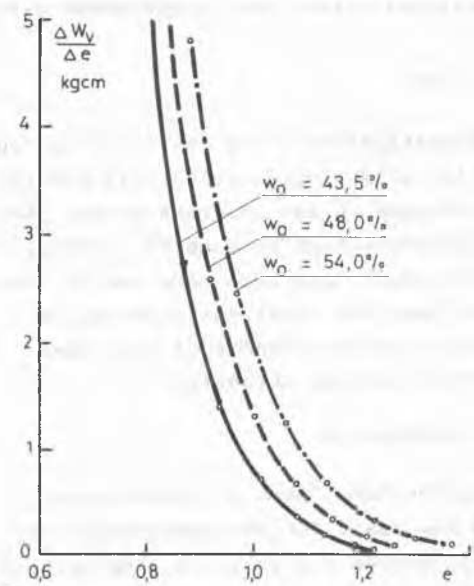

FIG. 4. THE WORK NEEDED TO DECREASE THE VOID RATIO BY A UNIT WHEN THE SOILS HAVE DIFFERENT ORIGINAL WATER CONTENTS

in certain water contents, depending on the fact whether it has reached this water content through the stage of first loading, rebound or reloading. Also the behaviour of overconsolidated soil proves that the cohesive soil has a "memory". The question how the former stress state of soil is preserved in the memory leads to the grounds of the consolidation of cohesive soil. The memory cannot be based on the water content since in the same water content soil behaves in different ways, as just established. Neither can it depend on the effective pressure or on the measurable pore pressure, since they vary as per case and time. As almost the only possibility remains the presumption that the knowledge of the former pressure stage is preserved in the water films of soil particles, i.e. more accurately expressed as thickness of the water films at load bearing points. Though the water films strive to swell to their original thickness when the load is reduced, this has not enough time to occur in a remarkable extent during the observation period on account of the poor permeability of soil. In addition, the negative pore pressure then induced increases the effective pressure and the compressive stress just at the load bearing points.

MODEL OF CONSOLIDATION

On account of the before mentioned the Author introduces following description for the consolidation. Loading of soil increases the pore water pressure for reasons known. Therefore pore water flows out of the soil, whereat the pore pressure decreases and the load is transmitted to the soil fabric. In remolded cohesive soils the soil particles generally are not in contact with each other, but to a greater part the load in the soil fabric is transmitted from particle to particle through the water films. The greater the pressure the thinner the water films between the soil particles are compressed. The Author thus considers that Terzaghi's concept of the dividing the total stress into the effective stress and the pore water pressure is to be thus understood that with the effective pressure also the transmission of pressure through the water films is meant.

Several investigations made into the state of energy of water bound to clay minerals show that the mechanical force needed to remove the water film bound on the clay particles is of that magnitude that within pressures generally prevailing no direct contact is possible to a larger extent. This conclusion can also be made on basis of the well-known great swelling pressure of dry soil. The Author thus assumes that the greatest part of effective pressure is transmitted through the water films, which opinion is supported by the test results which will be introduced later on.

The magnitude of compression can on basis of the forementioned be determined as follows: According to thermodynamics water strives to be transferred thereto where its free energy (Gibbs free energy) is smaller. The free energy of water in soil can approximately be determined e.g. by soil suction tests. They show that in dry soil the water has smaller free energy than in wet soil, i.e. when the water films surrounding the soil particles are thin their free energy is smaller than at times when they are thick.

The dependence of free energy g on different factors is expressed by the formula

$$dg = du + pdv + vdp - Tds - sdT \quad (2)$$

in which u = internal energy, p = pressure, v = volume, T = temperature and s = entropy. The formula shows that the increase of pressure gives cause to the increase of free energy, which is appr. = vdp. Water then flows out of the soil and the water films grow thinner between the soil particles. The soil compression is continued as long as the free energy of the water film has on account of the decrease of the film thickness got so much smaller that it has become as big as the free energy of free water.

According to the Author's opinion the magnitude of the compression is thus controlled by the free energy of the water films at the load bearing points, which in its turn is dependent of the thickness of the water film and the pressure caused by the load. Since the load bearing points represent only a part of the soil cross section, the stress prevailing in them is greater than the average stress in the soil. The measurable pore water pressure is with respect to the compression of secondary significance, in the first place it controls the speed of compression.

CALCULATION OF COMPRESSION ON BASIS OF FREE ENERGY

The Author carried out determinations of the pore water free energy in remolded saturated cohesive soils using in succession tensiometer, centrifuge and vapor pressure methods. Oedometer tests were carried out with soils at different water contents. By assuming that the free energy values achieved at different water contents characterize the free energy of water films of corresponding thicknesses, it simply can be calculated how great an external pressure has to be applied on water films of different thickness, so that the free energy in them would be as great as that of free water. Thus an unequivocal dependence between the external force and the water film thickness is achieved.

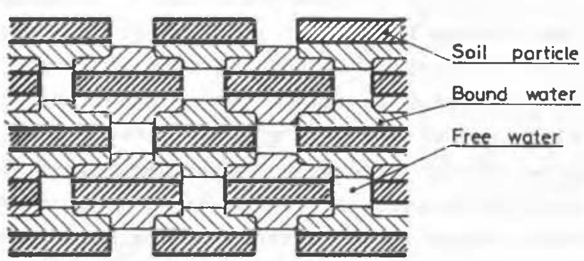

FIG. 5. THE MODEL OF THE SOIL STRUCTURE USED IN THE CALCULATION OF THE COMPRESSION. THE SOIL HAS BEEN COMPRESSED IN VERTICAL DIRECTION.

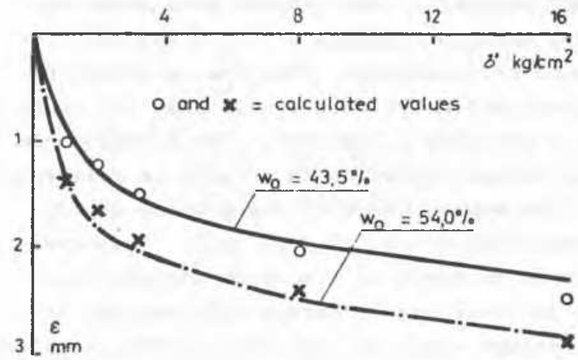

FIG. 6. AN EXAMPLE OF OEDOMETER CURVES AND CORRESPONDING CALCULATED VALUES OF COMPRESSION

Using the model in Figure 5 for the abric of soil the amounts of compression by different loads were calculated on basis of the free energy and the soil surface area. The compressions calculated are marked in Figure 6, in which also the compression curves resulted from the oedometer tests has been presented.

REMARKS

The method is not meant as substitution for the consolidatinn tests. Its purpose is to clear ou which factor determines the amount of compression by each load. In addition, the agreement of the calculation and the test results proves to a certain degree the assumption that in remolded cohesive soil the so called effective pressure mainly is transferred through the water films and not as direct particle contact.

The determining of free energy by tensiometer centrifuge and vapor pressure methods is approximate. Especially the water surface tension causes errors. With the method applied the combined effect of the interaction of soil particles, salts in the soil and other factors affecting the free energy of the pore water are achieved, which can be considered a great advantage.

CONCLUSIONS

The tests support following assumptions concerning the consolidation in remolded saturated cohesive soils.

1) The pressure after consolidation is transmitted through the water films surrounding the soil particles.

2) The thickness of the water films on the load bearing points determines the magnitude of compression.

3) When the free energy in the water films of different thickness is known the compression caused by any load can be calculated.

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