A Basic Study on Swelling Characteristics of Rock and Soil

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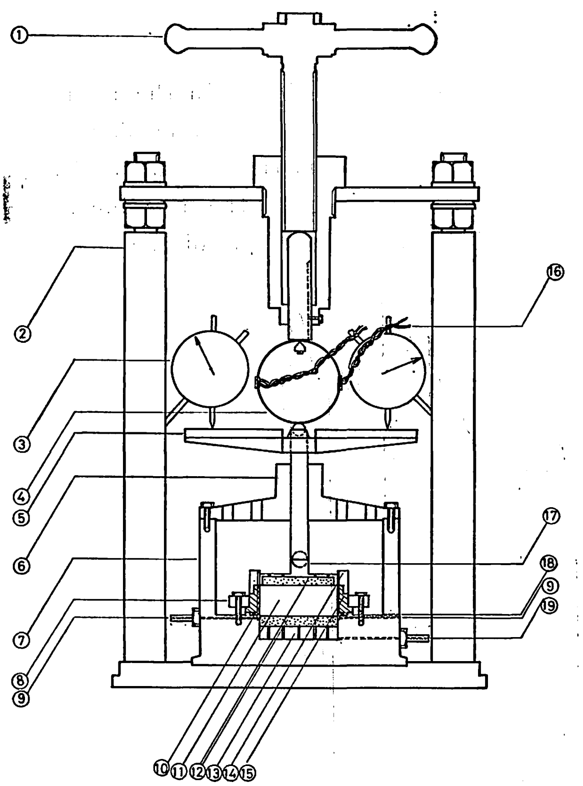
INTRODUCTION

The most common material of swelling rock and swelling soil has been considered as a clay mineral of montmorillonite. Swelling of rock and soil is different from the phenomena such as an expansion resulting from stress relaxaion, plastic flow, and mechanical water absorption. Some of the troubles of constructing works in the field of civil and mining engineering, for example, landslide, change of the shape of tunnel, and the other geological hazards, are caused mainly by the swelling phenomena. There are only a few systematic investigations [1),2),3)] to have a knowledge of the deformation behaviour under infiltration conditions,because of the swelling is complicated due to the number of unknowns involved. Therefore, it has been still remained several problems to be researched especially the mechanism of swelling. This note introduces a newly developped swelling apparatus to analyze the test results, and performs a numerical approach of swelling mechanism. The analysis described herein is based on a method of statistics.

EXPERIMENTS

Fig. 1 shows a new apparatus developped for swelling. Water was supplied from ⑲, and ⑨ are bored holes for preventing the vapour lock since it brings about an irregularity of water distribution to the specimen ⑪. Swelling strain was measured uniaxially by two dialgauges ③, and also swelling pressure was converted through the proving ring ④ and strain meter. Testings were stopped when the swelling velocity became within 0.01 mm/24hrs.

Samples used in this study are mixed powder of glass and high contented sodium montmorillonite by the weight ratio of 1 to 1, the later is known as Kunipia-F produced in Kunimine, Yamagata Prefecture, whose X-ray diffraction



①Strain control handle,
②Flame,
③Dial gauge,
④Proving ring,
⑤Wing,
⑥Guide cap,
⑦Swelling cell,
⑧Ring for swelling vessel,
⑨Water and air outlet,
⑩Gum O-ring,
⑪Sample,
⑫Porous stone,
⑬Porous plate,
⑭Vessel's colour,
⑮Vessel for sample,
⑯Strain lead wire,
⑰Top plate,
⑱Water outlet, and
⑲Water inlet.

Fig. 1. Swelling test apparatus

is shown in Fig. 2. From the figure, all the peaks are peculiar to montmorillonite, besides it is recognized that the clay mineral has no other impurities. Samples were cured in the wetting atmosphere to be reached a certain water content. For all test series, the samples were consolidated isotropically at fixed compaction energy in the swelling cell.

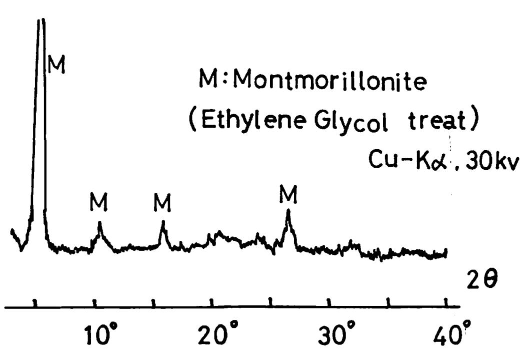


Fig. 2. X-ray diffraction of Kunipia-F.

RESULTS AND ANALYSIS

Swelling tests were carried out with the temperature of 15℃ in the incubator. Owing to the difference of initial water content, each sample showed a characteristic relationship of swelling pressure (p_s) versus time (t) or swelling strain (ε_s) versus time. That is, at higher water content, the relationships are slightly curved as time increased. Fig. 3 shows an example of the characteristic relationships.

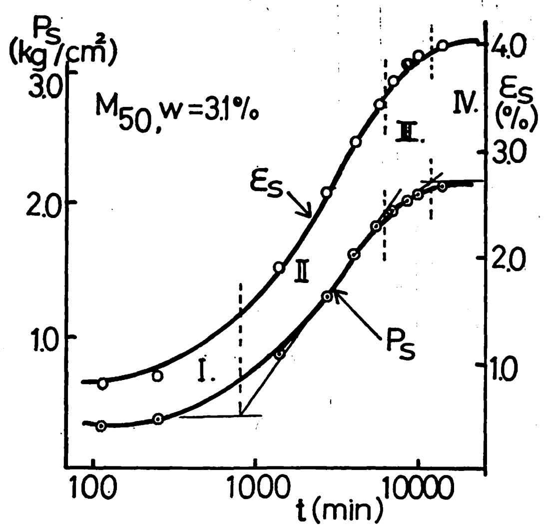


Fig. 3. Step-wise variations of swelling removal.

Since the each curve is the form of S letter, it may be devided into four stages ; I the generation state, II the progressive state, III the loosed progressive state, and IV the stabled state. These step-wise variations are based on the logistic curve in statistics. The trend is remarkable at lower water content. Swelling pressure in the final state is defined here as p_{sf}. This p_{sf} depends on both the compaction energy, Ec (kg · cm/cm³) and initial water content, Wi (%) as shown in Fig. 4. We can see that

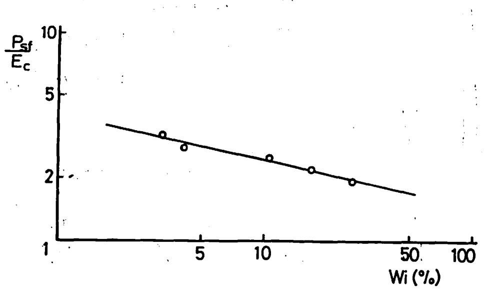


Fig. 4. Swelling pressure as functions of initial water content and compaction energy.

parameter (p_{sf}/Ec) has a linear relationship with initial water content Wi. Therefore, an equation is made from this, thus the relationship among each parameter is found in Fig. 5. It is noted that the trend shown by Ec contours

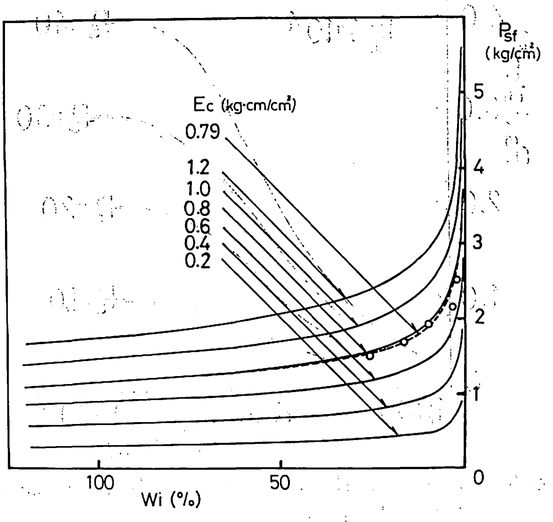


Fig. 5. Comparison derived equilibrium relationship with experimental data.

are proportional to the relationship between Wi and p_{sf}. Dotted line is an approximation for obtained values in this study.

In general, swelling is a function of both the physical and chemical enviro-ment in accord with a general expression of the form:

$$p_s = f\ (Ck,\ Mq,\ Wp,\ Wc,\ Sp,\ Ec,\ Wi,\ T,\ \cdots\cdots)$$

where:

Ck = kind of clay mineral,
Mq = quantity of clay mineral,
Wp = kind of pore water,
Wc = ionic content of water,
Sp = structure or array of clay particle,
Ec = compaction energy or preconsolidationload,
Wi = initial water content,
T = temperature.

Above equation is too general to be of use and simplifying assumptions must be made. However, it is impossible to satisfy all these variables in one testing. In this study, these factors were assumed at constant conditions except Wi. From Fig. 3, an available equation was conducted as follows:

$$p_s = p_{sf}\ (1 - e^{-2.302\, k_1 \cdot t}) \qquad (1)$$

In this case, k_1 is a coefficient of swelling velocity varying as a function of Wi. Fig. 6 shows an example of analytical results derived from eq. (1).

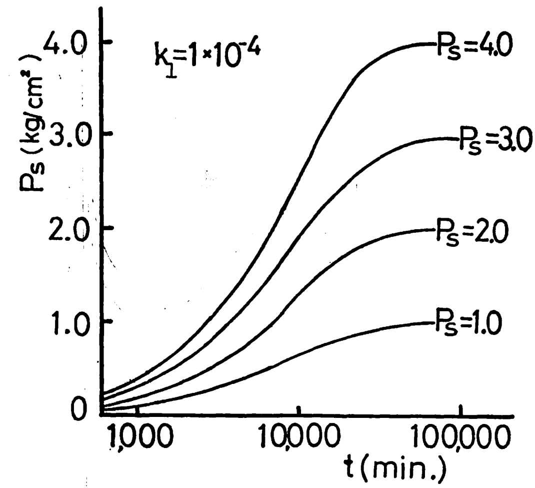


Fig. 6. Theoretical curves of swelling pressure derived eq. (1).

On the other hand, after plotting $\ln\{(p_{sf}-p_s)/p_s\}$ versus t on semilogarithmic graph paper, it was found that they lay almost on a straight line, although the figure was neglected herein. The equilibrium relationships were empirically analyzed and found to follow logistic typed form:

$$p_s = p_{sf}/\{1+e^{(a-k_2\cdot t)}\} \qquad (2)$$

where, a is a constant depending on the material property, and k_2 is also a coefficient of swelling velocity.

Eqs (1) and (2) are the types of prediction formulae in statistics. These are close to the four step-wise variations mentioned above.

As is illustrated in Fig. 7, these two analytical curves show very close

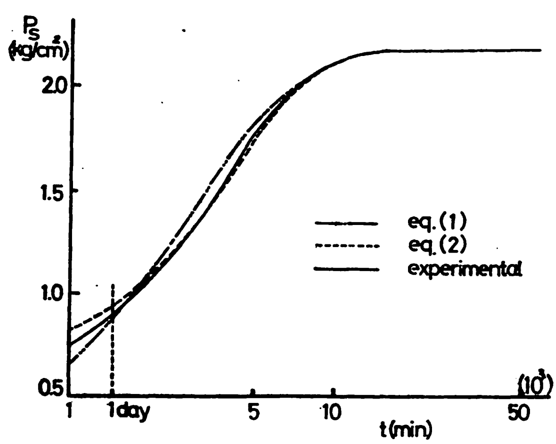


Fig. 7. Comparison of theoritical and experimental data.

agreement between data of this research. As can been seen, the calculated results obtained through the basis of statistics are very reasonable enough to constitute the equations of swelling phenomena. However, additional remarks will be made that eq. (2) is superior to eq. (1) a little from the point of correlation coefficient.

CONCLUSIONS

Reasonable prediction models for swelling phenomena unsolved up to date were established through the research, furthermore probability and statistics method was induced as an influential technique for swelling behaviour.

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