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Abstract

Numerous methods have been proposed for the laboratory measurement of swelling pressure. Four commonly used methods and their corresponding definitions of swelling pressure are discussed. A series of laboratory swelling pressure tests on a highly expansive clay were performed using the four methods described. The test results are presented and discussed in this paper.

Introduction

The one-dimensional consolidometer is widely used for the measurement of swelling characteristics of expansive soils. The swelling pressure in the consolidometer test has been defined as the pressure which prevents the specimen from swelling or the pressure which is required to return a swelled specimen back to its original state (void ratio, height) prior to swelling [1]. However, the procedure for determining the swelling pressure from the results of the consolidometer test has not been standardized or accepted universally. Sridharan et. al. [2] listed three methods for the determination of swelling pressure, namely, the free swell test, the swell under load test, and constant volume test. Justo et. al. [3] gave four definitions of swelling pressure using the "loading after soaking" method, "soaking under load" method, and "constant volume" method. The procedure of the "soaking under loading" method [3] is the same as the "swell under load" method [2], but gives two different values of swelling pressure. For the constant volume test, a correction to the swelling pressure to compensate for soil disturbance during sampling was suggested [4]. Chen [5] used the same procedure as the "loading after soaking" method [3], but defined the swelling pressure as the pressure required to compress the sample to its void ratio prior to soaking. The sample was preloaded and its void ratio prior to soaking is usually smaller than its initial void ratio because of consolidation under the surcharge pressure. In China, many geotechnical engineers determine swelling pressure based on the unloading curve instead of the compression curve [6].

Consolidometer tests on a highly expansive Regina clay were conducted using four different test methods. A detailed description of each method and their test results are presented.

Description of four test methods for laboratory measurement of swelling pressure

The four test methods are described as: 1) "loading after swell" method, 2) "swell under load" method, 3) "constant volume" method, and 4) "unloading" method. The loading and unloading paths for each method are shown in Fig. 1.

Method-1: "Loading after swell" method.

The sample is subjected to a vertical surcharge pressure at its natural water content. The surcharge pressure is determined by the expected field conditions. On the completion of consolidation, water is added to the specimen. When swelling of the specimen has ceased, the vertical pressure is increased in increments until the specimen is compressed to its height prior to swell due to wetting. The loading path is shown as curve-1 in Fig. 1. The free swell test is a special case where the surcharge pressure is a token pressure. Two definitions of swelling pressure for this method are found in the literature [5, 3, 1]. One is defined as $P_{1\text{-}1}$, the pressure required to compress the specimen to its original void ratio (Fig. 1). The other is defined as $P_{1\text{-}2}$, the pressure required to compress the specimen to the void ratio at the end of consolidation under the surcharge pressure. In the case of the free swell test, the two swelling pressures are the same (i.e., $P_{1\text{-}1}$ equals to $P_{1\text{-}2}$).

Method-2: "Swell under load" method

Three or more specimens with identical initial conditions are each consolidated under a different surcharge pressure. The void ratios at the completion of consolidation are plotted to produce the natural water content curve in Fig. 1. The consolidated specimens are inundated and allowed to swell (or compress) under the applied surcharge pressures. The void ratios of the specimens (circle markers) upon attaining saturation are plotted to produce curve-2 in Fig. 1. Two definitions of swelling pressure associated with this method are found in literature [3, 2]; 1) pressure $P_{2\text{-}1}$ at the intersection of curve-2 with the initial void ratio line, e_0, 2) pressure $P_{2\text{-}2}$ at the intersection of curve-2 with the natural water content curve.

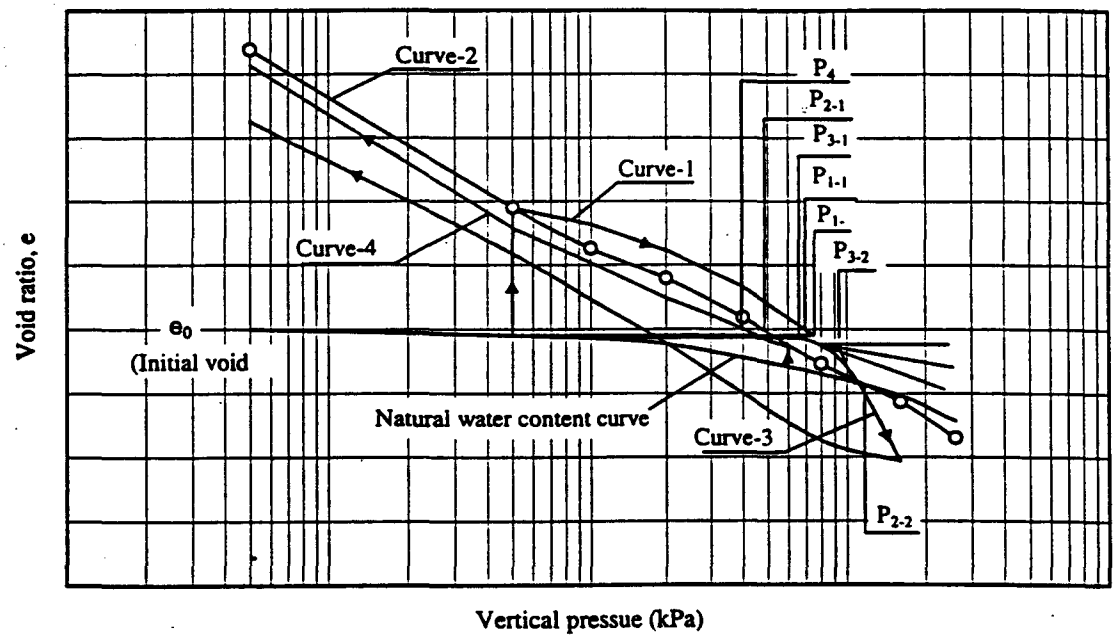

Fig. 1 Loading and unloading path of four test methods for swelling pressure

Method-3: "Constant volume" method

A surcharge pressure equivalent to the estimated in situ overburden pressure or swelling pressure is first applied to the specimen [1]. The specimen is then inundated. As the specimen wets up and attempts to swell, the vertical pressure is increased to prevent swell. When wetting at constant volume is completed, the specimen is loaded, and then unloaded as in a conventional consolidation test to produce curve-3 in Fig. 1.

The vertical pressure, $P_{3\text{-}1}$, corresponding to the end of wetting at constant volume is used by many engineers as the swelling pressure [3, 2, 5, 1]. The pressure, $P_{3\text{-}1}$, can be corrected for sampling disturbance to obtain the corrected swelling pressure, $P_{3\text{-}2}$, using a similar construction procedure as that proposed by Casagrande for the determination of pre-consolidation pressure [4]. Swelling pressure $P_{3\text{-}2}$ has been adopted by the ASTM standards [1].

Method-4: "Unloading" method

The specimen is first consolidated under a surcharge pressure at its natural water content. The surcharge pressure is determined according to construction requirement and should exceed the estimated swelling pressure. With the surcharge pressure still on, the specimen is inundated with water and swelling is allowed to take place. When swelling has ceased, unload the specimen in increments to zero pressure or to a token load. The loading and unloading path is shown as curve-4 in Fig. 1. The swelling pressure is defined as the pressure, P_4, on the unloading curve corresponding to the initial void ratio [6]. This method is used primarily in China.

Test program

A series of swelling pressure tests was conducted on undisturbed Regina clay using the four test methods previously described. Regina clay is a highly expansive, uniformly deposited, overconsolidated soil. Regina clay is composed of 77% calcium montmorillonite, and has a liquid limit of 84%, plasticity index of 49, initial water content of 24.6%, and initial void ratio of 0.80.

Test results and discussion

Results from Method-1 ("Loading after swell" method)

Five specimens were each tested under a different surcharge pressure. The surcharge pressures were 5, 50, 100, 200, 400 kPa, respectively (Fig. 2). The value of the swelling pressure, $P_{1\text{-}1}$ and $P_{1\text{-}2}$, range from 550 to 710 kPa and 710 to 790 kPa, respectively.

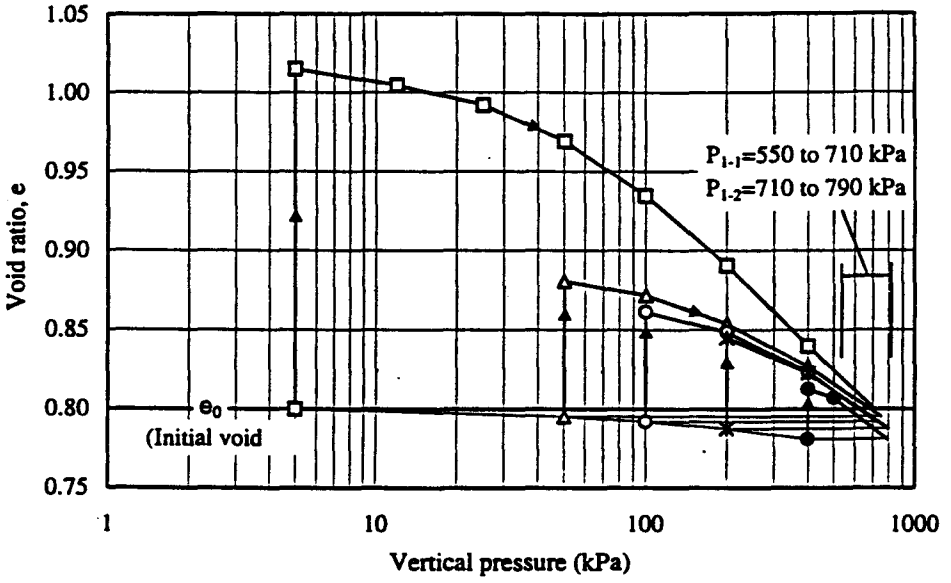

Fig. 2 Results from five test specimens using "Loading after swell" method with each specimen subjected to a different surcharge pressure of 5, 50, 100, 200, 400 kPa respectively

Results from Method-2 ("Swell under load" method)

Eight specimens were each tested with a different surcharge pressure of 5, 50, 100, 200, 400, 800, 1600 and 2600 kPa respectively. Results are shown in Fig. 3.

Values of 490 kPa and 1050 kPa are obtained for swelling pressures, $P_{2\text{-}1}$ and $P_{2\text{-}2}$, respectively. The swelling pressure, $P_{2\text{-}2}$, is more meaningful, since it corresponds to the surcharge pressure under which the soil is consolidated and will undergo no further volume change in future wetting.

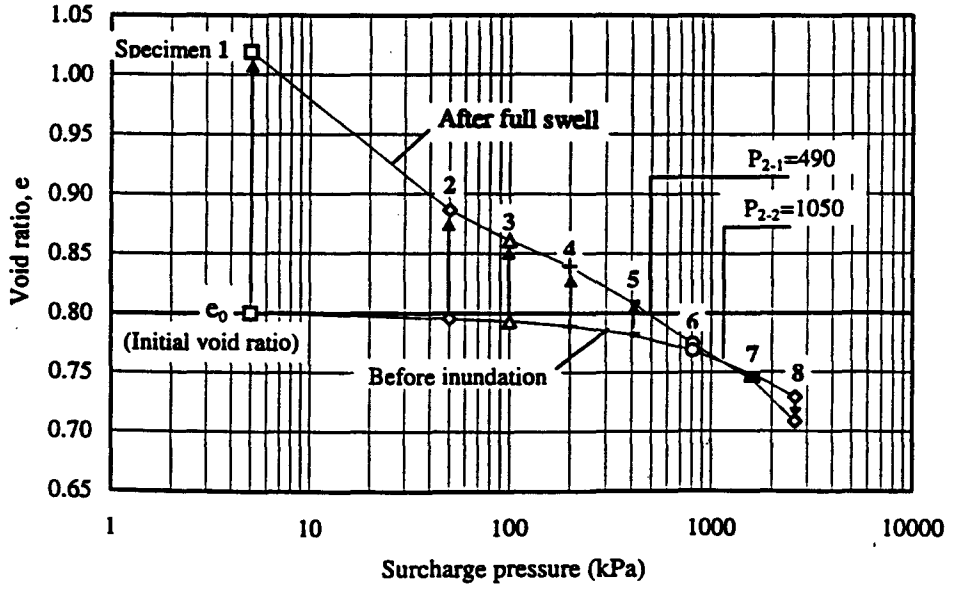

Fig. 3 Results from "Swell under load" method using eight specimens

Results from Method-3 ("Constant volume" method)

Figure 4 shows the test results of six specimens using Method-3 ("constant volume" method). Two specimens were subjected to a surcharge of 5 kPa. The remaining four specimens were each subjected to a different surcharge pressure of 100, 200, 400, and 600 kPa, respectively. After wetting is completed, one of the two specimens with a surcharge pressure of 5 kPa was unloaded to obtain its rebound curve. The value of the uncorrected swelling pressure, P_{1-1}, and the corrected swelling pressure, P_{1-2}, range from 590 to 860 kPa and 700 to 1010 kPa, respectively.

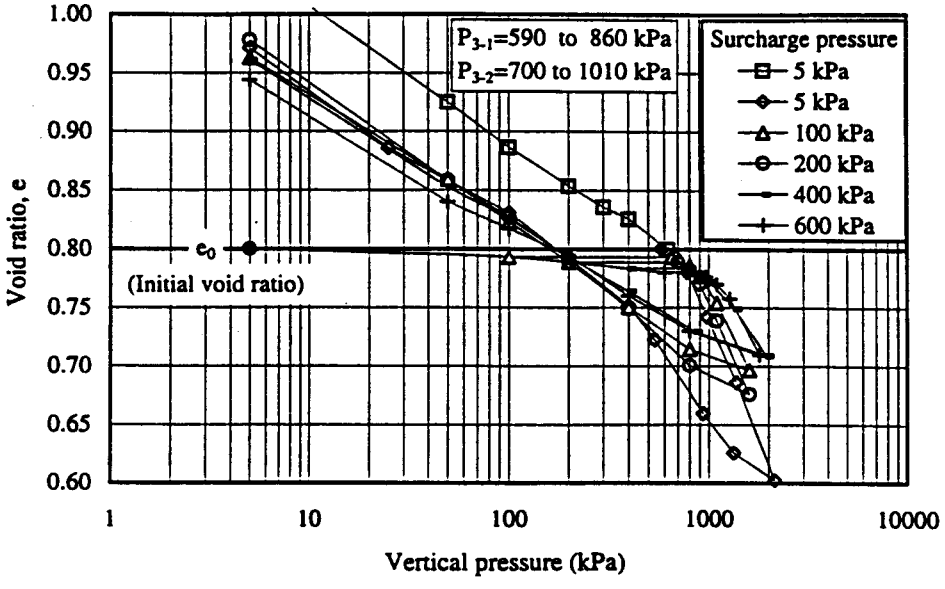

Fig. 4 Results of six specimens using "Constant volume" method with each specimen subjected to a different surcharge pressure of 5, 5, 100, 200, 400, 600 kPa respectively

Results from Method-4 ("Unloading" method)

Figure 5 shows the void ratio versus vertical pressure curves for four specimens tested using Method-4 ("unloading" method). The surcharge pressure does not show significant influence on the swelling pressure, P_4, and the amount of swell during unloading.

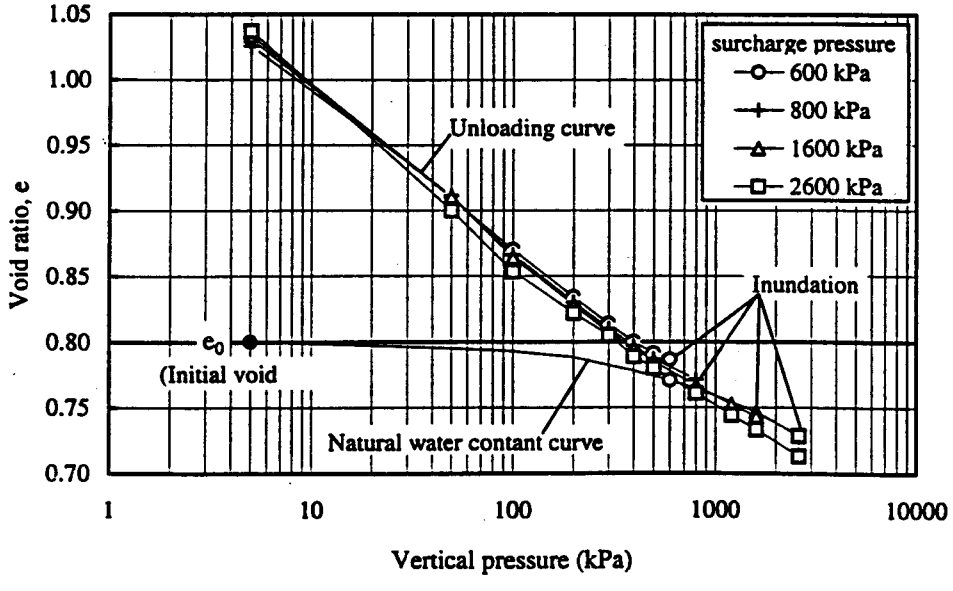

Fig. 5 Results of four specimens using "Unloading" method with each specimen subjected to a different surcharge pressure of 600, 800, 1600, 2600 kPa respectively

Comparison of swelling pressures

The swelling pressures from each method and their relationship to the surcharge pressure are shown in Fig. 6.

The swelling pressure $P_{1\text{-}1}$ (Method-1, "loading after swell" method) shows a tendency to decrease with surcharge pressure, and the swelling pressure $P_{1\text{-}2}$ (Method-1, "loading after swell" method) shows a slight increase with surcharge pressure (also Fig. 6). Results of tests for a clay from EI Arahal (Seville) [3] show that the swelling pressure $P_{1\text{-}1}$ is independent of the surcharge pressure. Tests conducted on various kinds of undisturbed expansive soils in the Rocky Mountain area show that the surcharge pressure does not have significant effects on the swelling pressure $P_{1\text{-}2}$ [5]. Figure 6 shows that both $P_{1\text{-}1}$ and $P_{1\text{-}2}$ change with surcharge pressure. However, the changes are not significant and the average value may be satisfactory for engineering practice.

Both the uncorrected swelling pressure $P_{3\text{-}1}$ and the corrected swelling pressure $P_{3\text{-}2}$ (Method-3, "constant volume" method) show a tendency to increase with surcharge pressure (Fig. 6). Komornik and David [7] arrived at the same conclusion when they examined the effects of pre-loading on the swelling pressure of an undisturbed sample.

The swelling pressure P_4 from Method-4 ("unloading" method) decreases slightly with surcharge pressure (Fig. 6).

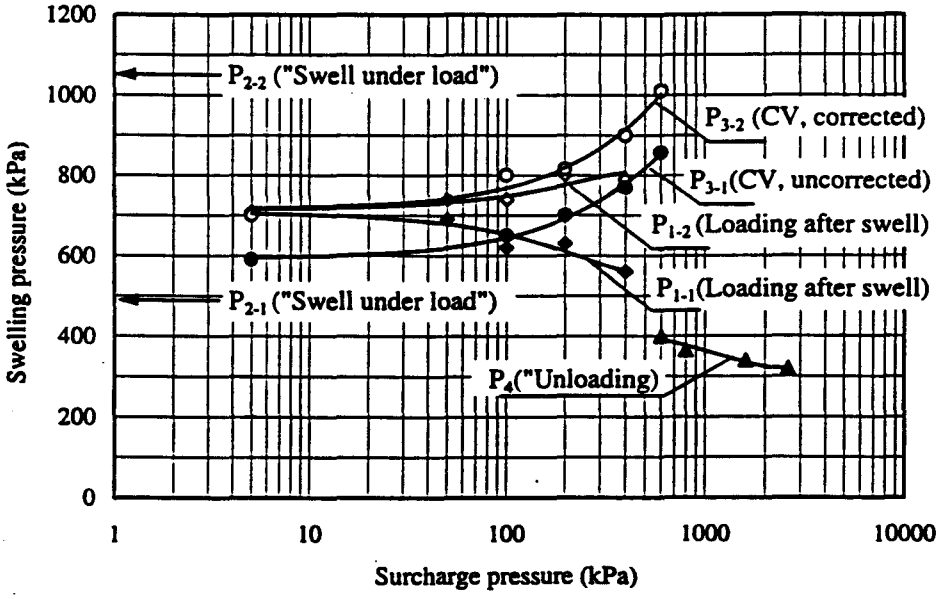

Fig. 6 The relationship between swelling pressure and surcharge pressure for the four test methods

Seven swelling pressures were defined in this paper. A comparison of all seven swelling pressures is shown in Fig. 6. For the Regina clay, the swelling pressure, $P_{2\text{-}2}$, from Method-2 ("swell under load" method) gives the upper limit value of 1050 kPa, and the swelling pressure, P_4, from Method-4 ("unloading" method) gives the lower limit value which is between 310 to 400 kPa. For the same surcharge pressure, the corrected swelling pressure $P_{3\text{-}2}$ from Method-3, "constant volume" method, is always larger than the other swelling pressures except swelling pressure $P_{2\text{-}2}$. The values of the seven swelling pressures defined in the four methods described range from 340 kPa to 1050 kPa.

Conclusion

Seven definitions of swelling pressure from four test methods found in the literature are presented. Each definition yields a different value of swelling pressure. The swelling pressure for a Regina clay, was found to vary from 340 kPa to 1050 kPa, depending on which of the seven definitions associated with the four test methods was used.

For the Regina clay sample used in this laboratory test, the swelling pressures change with surcharge pressure except for Method-2 ("swell under load" method). The influence of surcharge pressure on the swelling pressure for Method-1 ("loading after swell" method) and Method-3 ("constant volume" method) is greater than that for Method-4 ("unloading" method).

For the Regina clay sample used in this laboratory test, the swelling pressure from test Method-4, "unloading" method, gives the lowest value, which is between 310 to 400 kPa. The corrected swelling pressure from test Method-3 gives a higher value of swelling pressure, which is between 700 to 1010 kPa. The swelling pressure, $P_{2\text{-}2}$ from Method-2 ("swell under load' method) gives the highest value for Regina clay, which is 1050 kPa.

Acknowledgments

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