Preconsolidation by Separate-Type Consolidometer

Préconsolidation par l'Oedomètre du Type Séparé

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SYNOPSIS In relation to the construction of a large-scaled sewerage treatment station on a soft alluvial clay, exceeding 20 m in depth, it has become necessary to estimate the residual settlement after the construction of the structures, utilizing preconsolidation techniques. Basic consolidation tests, using a separate-type consolidometer which had been developed to measure the distribution and its change of compression strain and pore pressure inside a clay specimen, have been carried out. It has become clear that a clay layer is not uniformly consolidated even after its 100% primary consolidation, and the residual settlement after preconsolidation is mainly affected by the degree of consolidation, not by the average effective stress, at the time when the surcharge is removed. The construction of the station has now been successfully progressing, using sand drains and surcharge fills without any pile foundations.

INTRODUCTION

In the stabilization of soft subsoils before constructing structures on them, preloading techniques such as sand drains with surcharge load, are commonly used in the last 30 years in Japan. One of the important problems for engineers in the design of these constructions, is the estimation of residual settlement after the completion of the structures. Ordinary method of calculating consolidation settlement is not applicable to this case, because of the complex nature of stress path which differs very much in any part of a clay layer, under compression-rebound-recompression process.

Johnson (1970), discussed the problem in his state-of-the-art report on precompression techniques, and proposed a design method for the case. Based on model experiments, he took into account the effects of surcharge loading on secondary compression settlements after removal of the surcharge. However there must be further researches to establish the theory for estimating residual settlements, especially on the effects of secondary compression which have not sufficiently been recognized.

In this paper, several experimental data concerning the effect of surcharge loading on residual settlements are referred, using a separate-type consolidometer. From the precise measurement of strain and pore pressure inside a consolidating specimen, several interesting experimental facts have been made clear. Settlement characteristics of a practical construction site under surcharge loading are also referred.

APPARATUS

In Fig. 1, the outline of the separate-type consolidometer is diagramatically shown. It consists of five oedometers of standard size, which are connected in series and loaded hydraulically under a constant pressure. Originally, it was developed for the purpose of studying consolidation characteristics of a clay specimen with larger height (Aboshi 1973). In the course of study, however, it is proved to be very convenient to study the condition inside of a consolidating clay layer, because the strain and the pore pressure at each separate specimen can be measured precisely.

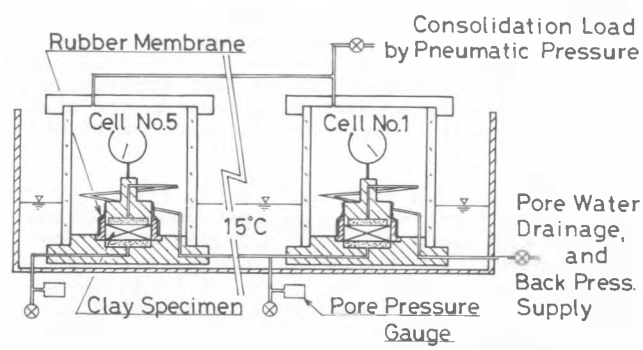


Fig. 1 Separate-type Consolidometer

Table I Physical Properties of Specimens.

	Clay	Silt	Sand	W_L	W_P	$\rho_{s(kg/m^3)}$	Cc
Hiroshima Clay	27%	68%	5%	100.0%	58.2%	2650	0.699
Fukuyama Clay	36%	60%	4%	80.6%	28.7%	2670	0.756

SPECIMEN

Specimens used are alluvial clays from Hiroshima and Fukuyama Bay, both on the coast of the Inland

Sea, western Japan. Specimens from Hiroshima clay are taken from a model ground, which was referred in the preceding paper (Aboshi 1973). As for Fukuyama clay, it is consolidated from slurry state under the pressure of 39.2 kPa, and set in the oedometer. Physical properties of them are shown in Table I.

INHOMOGENEITY AT THE FINAL STAGE OF PRIMARY CONSOLIDATION.

In one-dimensional consolidation, it is ordinarily taken for granted that the final state in a clay layer becomes homogeneous under consolidation of a constant stress. Fig. 2 shows typical consolidation curves, obtained by the separate-type consolidometer. Stress increment ratio $\sigma_f - \sigma_o/\sigma_o$ equals unity in this case.

It shows the settlement of each separate specimen and of the total layer. From the figure, it is clear that the specimen in cell No. 1, which is nearest to the drainage surface, settles most, and the difference of consolidation settlement of each layer is not negligible even after fairly long duration.

The coefficient of consolidation Cv is obtained from the "total layer" curve. However, Cv obtained from No. 1 curve by fitting method, is several times greater than that of total layer. The time process of the settlement, in total, coincides with Terzaghi's theory quite well, as the specimen is reconsolidated from the slurry state. However, it must be stressed here that those of separate layers are somewhat different from the theory.

As is clearly seen from the figure, strain of each layer is not uniform at 100% consolidation. Fig. 3 shows the distribution of strain at the end of primary consolidation (which is determined from the settlement curve of total layer) and the residual pore pressure in the same instant. These residual strain and pore pressure may be related to the following secondary settlement, as Janbu (1965) referred in his theory of secondary compression.

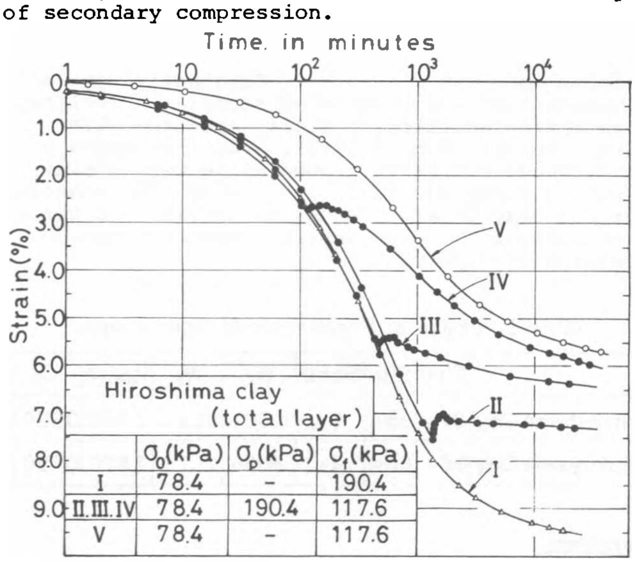


Fig. 4 Settlement of Total Layer in Preconsolidation Techniques.

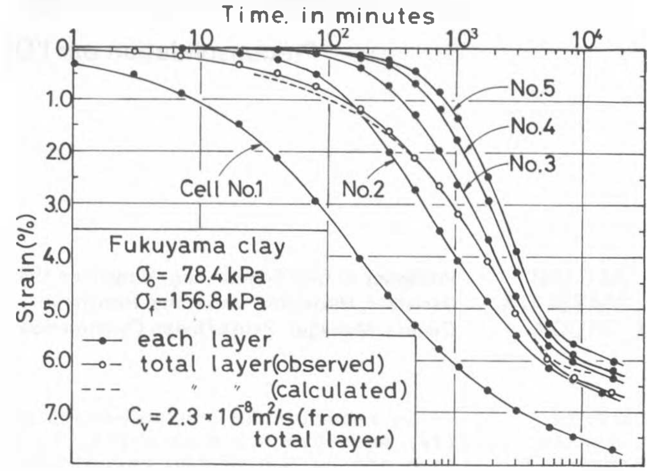
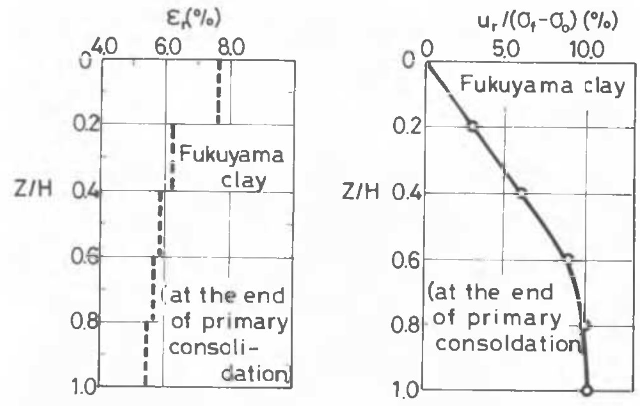


Fig. 2 Typical Consolidation Curves by Separate-type Consolidometer.



(a) Strain : (b) Pore Pressure

Fig. 3 Strain and Pore Pressure at the End of Primary Consolidation.

The tail of each curve in Fig. 3 seems to be almost parallel, and from this fact it is quite questionable that inside of the layer gradually approaches to homogeneous state in the secular compression stage. Also it is important that there remains pore pressure in the undrained side, at the time when the settlement curve proceed to straight creep line, though this value dissipates to zero in comparatively earlier stage.

PRECONSOLIDATION EFFECT

It is very important from the practical point of view, to determine, at what percentage of consolidation, the surcharge load should be removed, in order to avoid further settlement in case of preloading techniques. Experiments have been performed as a model test of the preloading method, using this apparatus. One of the data is shown in Fig. 4, in which small white circles and triangles show settlement curves under constant stresses of different magnitude.

Starting from the curve of triangles, the surcharge is reduced to zero once, at a certain percentage of consolidation and again recharged to the stress, same as the one in the case of white circles in Fig. 4. These curves of consolidation-rebound-recompression process are plotted in black circles in Fig. 4. All the curves in these cases, fall in between the above-mentioned two curves, and naturally, the higher the degree of consolidation at the rebound stage, the smaller the residual settlement by the recompression.

Each of the curves in Fig. 4 is plotted as a total layer. However, in order to understand the consolidation process of these cases in detail, settlement curves in separate layers in the case of curve IV in Fig. 4, are shown in Fig. 5. Average degree of consolidation when the surcharge was removed is 34% in this case. As is seen in the figure, there are considerable differences of consolidation degree among each element, and as a result, there are also much difference of settlement caused by recompression.

In the case of No. 1 in Fig. 5, recompression is already an overconsolidation stage, and so the settlement is purely a creep nature. In contrast, that of No. 5 shows a hydraulic-lag type. Furthermore, it is interesting to see that the amount of total settlement, including surcharge stage, is reversed among Nos. 2, 3, 4 and 5. Needless to say, this is due to the effect of structural resistance developed during primary consolidation stage.

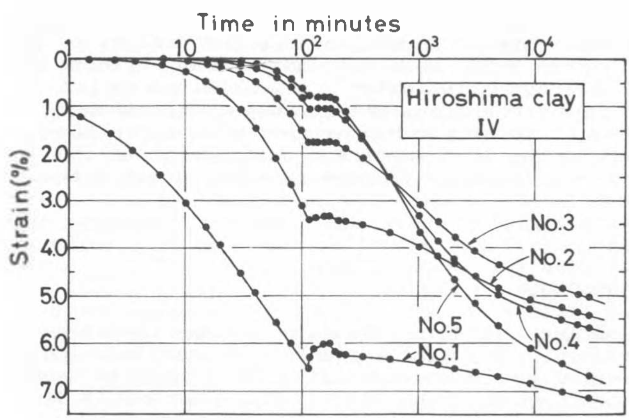


Fig. 5 Settlement in Rebound-Recompression Test, Separate Layers.

As for the change of pore pressure, it is shown in Fig. 6, from the initial surcharge until the end of recompression. During the surcharge, it is almost similar to the classical theory, with the exception that the dissipation is somewhat faster near the drainage boundary. However, by the removal of the surcharge at the average consolidation ratio of 34%, pore pressure at every part of the specimen falls down abruptly to a minus value, as shown in Fig. 6. From this value it recovers to zero rather soon during rebound stage. Pore pressure in the recompression stage is also shown in the figure.

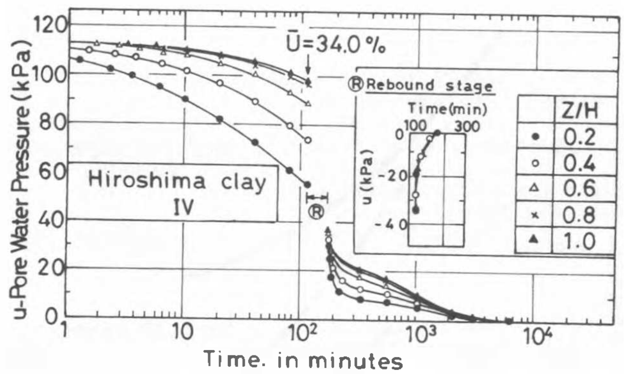


Fig. 6 Pore Pressure in Rebound-Recompression Test, Separate Layers.

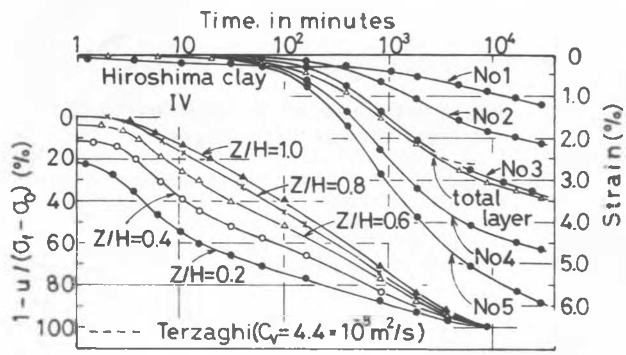


Fig. 7 Settlement and Pore Pressure Change during Recompression Stage.

Table II. Stress Path and Obtained Cv in Consolidation.

	σ_0 (kPa)	σ_P (kPa)	σ_0 (kPa)	σ_f (kPa)	C_{v1} (m^2/s)	C_{v2} (m^2/s)	$\bar{U}$ (%)
I	78.4	–	–	190.4	8.85×10^{-8}	–	–
II	78.4	190.4	78.4	117.6	–	2.83×10^{-7}	91.1
III	78.4	190.4	78.4	117.6	–	2.45×10^{-8}	56.8
IV	78.4	190.4	78.4	117.6	–	4.40×10^{-8}	34.0
V	78.4	–	–	117.6	3.78×10^{-8}	–	–

Symbol:

σ_0: Consolidation pressure at the initial or rebound stage.
σ_P: Consolidation pressure at the preloading stage.
σ_f: Final consolidation pressure.
C_{v1}: Value of Cv during consolidation without rebound.
C_{v2}: Value of Cv at the recompression stage.
$\bar{U}$: Average degree of consolidation for total layer at the time when surcharge load was removed.

The shape of curves in Figs. 5 and 6 at recompression stage seems to be rather unique. But this is due to its scale in logarithm. In Fig. 7, these curves are plotted, not from the beginning of the whole consolidation process, but from the start of recompression loading. These are typical for overconsolidated specimens. Especially the settlement curves are very interesting, because they are similar to the one shown by Leonards (1964), as the characteristic ones in case when the load increment ratio is small. In Table II, coefficients of consolidation obtained from Fig. 4 are shown. It shows

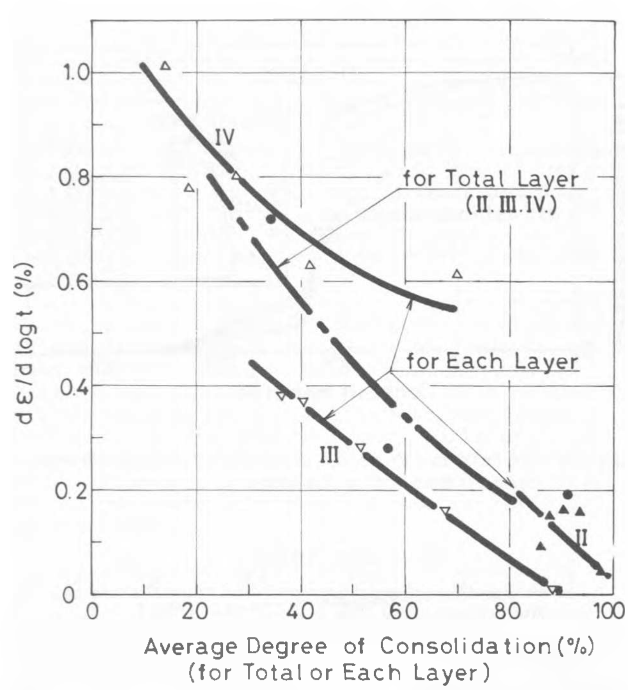


Fig. 8 Gradient of Creep Settlement.

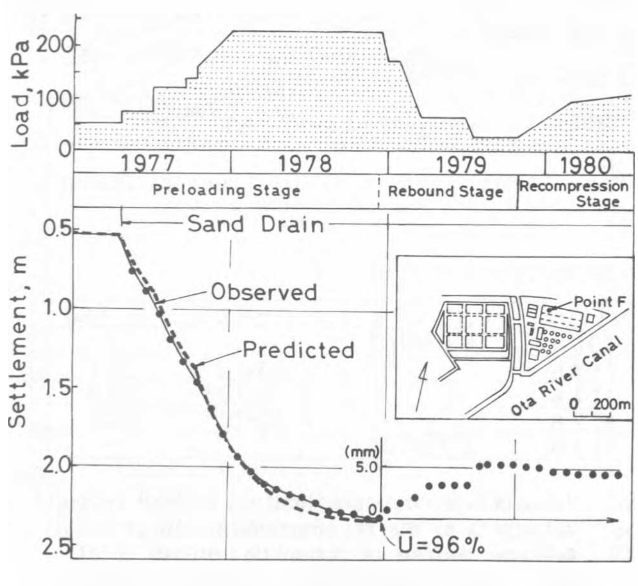


Fig. 9 Settlement by Preloading, West Hiroshima Sewerage Treatment Station.

the change of Cv with "consolidation stress path".

Finally, data on the gradient of creep settlement are summarized to the average degree of consolidation. The more the degree of consolidation proceeds, the less the residual settlement due to creep, as is shown in Fig. 8.

CONSTRUCTION OF A SEWERAGE TREATMENT STATION

Since 1975, Hiroshima Prefectural Government has begun to construct a new sewerage treatment station in the western part of the city. The construction site is situated in a newly reclaimed land on a river delta, 35 ha in area. Soil condition is so bad and there lies alluvial Hiroshima clay up to -30 m. The main structures to be constructed are, a large caisson of 81 m x 48 m with -27 m in depth for main building and pumping station, and water treatment building which consists of three long sewerage tanks of 230 m x 40 m with -14 m in depth.

Usually pile foundations are used in such a case, but it was decided to use preloading techniques with sand drains. Improvement of soft subsoils started in 1977 under the guidance of the author. Up to 95% preconsolidation by surcharge fill and lowering of water table, have successfully been performed, in order to keep the residual settlement by constructing structures, within a few cm.

CONCLUSION

Through careful investigations and design, it is convinced to be able to construct any structures on soft subsoils, which are stabilized by preloading techniques, without using pile foundations. To attain higher degree of consolidation is the most important check point in the method. It also reduces residual creep settlement.

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