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HORIZONTAL DRAIN METHOD FOR UTILIZING SLURRY WASTES AS GROUND MATERIALS

LA METHODE DE LA VIDANGE HORIZONTALE POUR L'UTILISATION DE DECHETS ECAILLES COMME MATERIAUX DE BASE

HORIZONTALES ABFLUSSVERFAHREN ZUR VERWENDUNG VON SCHLAMM ALS GRUNDMATERIAL

Development of effective system for disposing of slurry wastes or sludge, is a significant problem in Japan because of the difficulty for finding a waste pit near the field. This paper proposes a horizontal drain system for utilizing slurry wastes of high water content as ground materials. The method consists of the following procedures: Filter fabric is spread in a site properly bounded by banking ; On the filter fabric a sludge is dumped by 1 m depth, and subsequently the sludge layer follows the self-weight consolidation by the bottom drainage: The same performance continues repeatedly until the piled sludge reaches to a designated height; On the top surface of the piled sludge polymer grid is laid for reinforcing the bearing capacity , and then soil of about 2 m height is placed on it for accelerating the consolidation; After the degree of consolidation of sludge reaches to around 90 %, most part of the surcharge soil is removed, and the performance completes. By the above-mentioned works, the piled sludge becomes a stable state having the bearing capacity corresponded to the over-consolidation pressure, and thus it can be used as ground.

In diser Abhandlung wird ein horizontales Entwässerungssystem für schlammformige Abfalle mit einem extrem hohen Wasselgehalt von etwa 1000% für die Verwendung als Bodenmaterial. Diese Methode besteht aus den folgenden Verfahren: Filterstoff aus Faservlies wird auf einer durch Deiche begrenzten Fläche ausgebreitet. Schlammartiger Abfall wird mit einer Tiefe von 1 m auf den Filterstoff aufgebracht, und dann erfolgt Entwässerung nach unten hin und die Abfallschicht wird durch ihr eigenes Gewicht verdichtet.Dieses Verfahren wird wiederholt, bis die Ablagerungsschicht die Entwurfshöhe erreicht hat. Auf die Oberfläche des abgelagerten Abfalls wird ein Polymergitter gelegt, um die Lasttragekraft des Abfalls zu erhöhen, und dann wird eine gewisse Menge Oberflächenerde aufgetragen, um die Verdichtung zu beschleunigen. Wenn die Verdichtung etwa 90% erreicht hat, so wird der größte Teil der Oberflächenerde entfernt und die Arbeit ist beendet. Durch die obige Arbeit erreicht der aufgeschichtete Abfall einen stabilen extremverdichteten Zustand mit einer dem extremen Verdichtungsdruck entsprechenden Tragkraft und kann als Boden verwendet werden.

INTRODUCTION

Water purification plant of Ube City discharges the slurry waste,the sludge, of about 5000 m^3 per year, and it has been disposed by so-called storage method so far. However, the storage space has been gradually restricted, and the development of an effective system for disposing of sludge becomes a very significant problem. Among the some possible systems for disposing of sludge, the sun drying system is the least energy consuming one provided the space for spreading the sludge can be ensured. To overcome the difficult circumstances for the spreading space, Miura(2) proposed a geotechnical method. The principle of this method is very simple, i.e., the acceleration of consolidation of sludge by horizontal drainage with application of the well-known pre-loading method. This paper describes the principle of this method and the field test results. The obtained results may also apply to the disposing of other kinds of slurry wastes, such as red mud and white mud discharged from chemical plants.

HORIZONTAL DRAIN METHOD

The principle of the proposed method is illustrated in Fig. 1. In the process of disposing the sludge in a waste pit, filter fabric of non-woven synthetic fiber is placed in horizontally at a proper depth of sludge. By the function of horizontal drain, the consolidation of the sludge is expected to be finished in a relatively short period, and the lower layer will be compressed by the weight of the upper layer in order. On the top layer of sludge, a certain height of soil is placed as the preload for a period, and a part of the soil is removed after the sludge is consolidated by 90 % degree, thus each layer of sludge becomes a overconsolidated state. Hence the sludge layer may be used as a stable ground material. The merits of the proposed diposing method, which is called "horizontal drain method" hereafter, are: 1) Works are very simple, economical and of low energy consuming, 2) Space can be used effectively due to enough consolidation of sludge, 3) The piled sludge is easily taken out whenever the utilization method for sludge is developed.

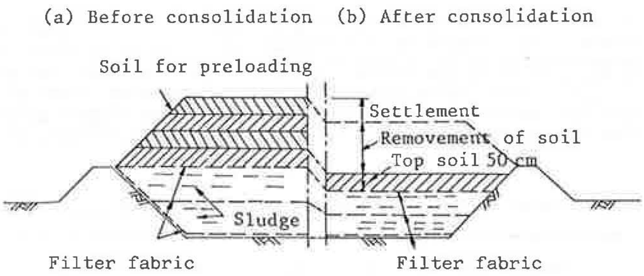

Fig. 1 Illustration of horizontal drain method for utilization of sludge as ground material

The horizontal drain method is a well known technique in the geotechnical field but application of this method for diposing of sludge has not been made , besides no basic

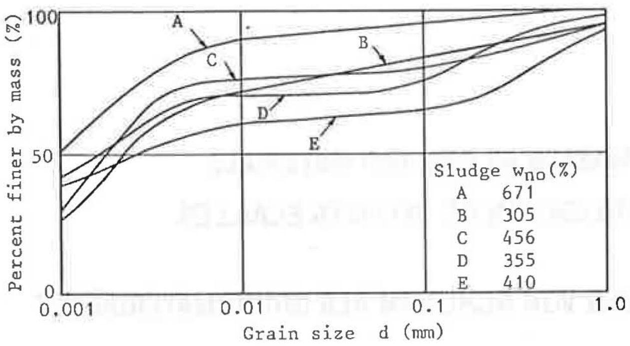

Fig. 2 Grain size distribution of tested sludges

geotechnical properties of sludge have investigated so far. This report describes the applicability of the horizontal drain method to a sludge discharged from a water purification plant, together with the geotechnical properties of the sludge.

PHISICAL PROPERTIES OF SLUDGE

The grading of the tested sludges which were discharged from the water purification plant of Ube City, are shown in Fig. 2, indicating that it contains as much as 60 to 85% of fine particles. The consistency properties of the sludges appear in Table 1. The liquid limit and the plasticity index of the samples are very high as shown in the table. The activity of the sludge, which is defined as the ratio of the plasticity index to the content of particles finer than 2 micron, is ranged between 3 to 4. This value indicates that the tested sludges are much higher activity than usual clays are. Such a high activity may be due to a high content of colloid particles and also due to containing of organic matter of 16 to 17 % as shown in Table 2.

In general, a soil containing a large amount of organic matter is sensitive to change of the consistency properties as being dried. For the present samples change of the consistency properties with drying were examined and the results were shown in Fig. 3. This figure shows that the sludges are very sensitive to drying action, and

Table 1 Physical properties of tested sludges

Properties	A	B	C	D	E
Natural water content w_n(%)	671	305	456	355	410
Natural volume ratio f (e+1)	19.0	8.9	12.9	10.5	11.6
Specific gravity G_s	2.68	2.59	2.61	2.68	2.59
Liquid limit w_L(%)	341	281	268	210	221
Plasticity index P.I.	258	208	203	160	168
Soil classification	CH	CH	CH	CH	CH

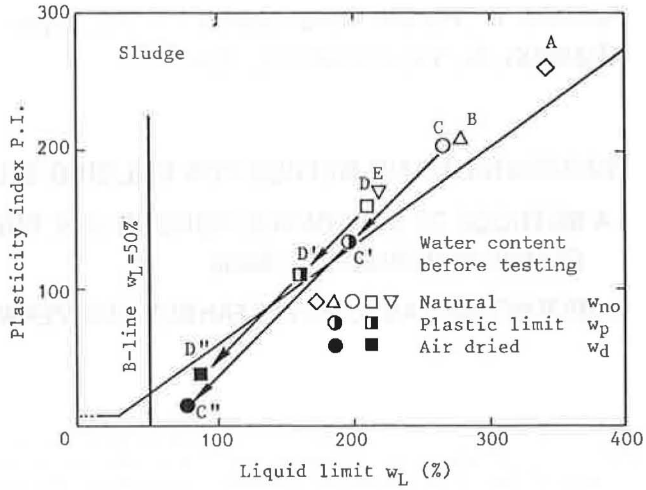

Fig. 3 Change of consistency properties of sludge with decreasing of water content

Table 2 Chemical components of tested sludges

Component	Weight percent
Ignition loss	16.6
SiO_2	43.0
Al_2O_3	31.5
Fe_2O_3	4.1
CaO	4.0
MgO	0.3
MnO_2	0.5
Total	100.0

their properties change toward preferable ones as ground materials. Therefore, if the sun drying process is introduced in the horizontal drain system, the combined system for disposing sludge would become an excellent system. It may be practical that the water content of a sludge is decreased lower than its plastic limit w_p under the sun drying process and subsequently subjected to the horizontal drain process.

CONSOLIDATION PROPERTIES

Compressibility Index

The compressibility of a material may be evaluated by the compressibility index C_c

$$C_c = \frac{f_1 - f_2}{\log(p_2/p_1)} \qquad (1)$$

where, f_1(= 1+e_1) and f_2(= 1+e_2) are volume ratios before and after the consolidation, p_1 and p_2 are the consolidation pressures. To determine the compressibility index of the sludges the standard consolidation tests were carried out and the results were obtained as shown in

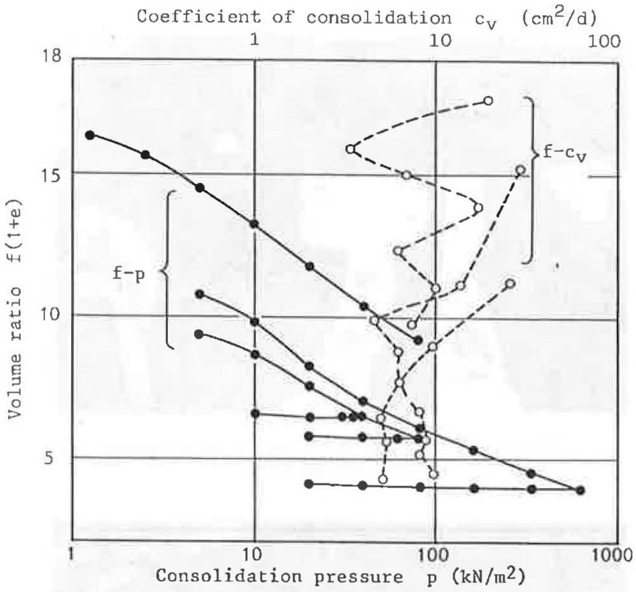

Fig. 4 Consolidation properties of tested sludges

Fig.4. The slope of f - p curve gives the value of compressibility index being 2 to 4 , which are several times of that of usual clays. It is well known there exsisting a relationship between compressibility index Cc and liquid limit w_L as,

$$C_c = 0.009 \ (\ w_L - 10 \ ) \tag{2}$$

The present samples seem to fit the above equation. Also there is a following relationship,

$$C_c = 0.40 \ (\ f_n - 1 \ ) \tag{3}$$

From these equations we are able to estimate the approximate value of compressibility index of a sludge.

Coefficient of Consolidation

The coefficient of consolidation of the tested samples are determined as indicated in Fig. 4, being approximately 10 m^2/d. This magnitude is about one-tenth of that of usual clays, suggesting that the consolidation of sludges are considerably difficult compared with soils.

Strength Increase Due To Consolidation

Undraind shear strength of clayey soil c_u increases with increasing of pressure p. It is necessary to determine the c_u - p relation for predicting the capacity of sludge ground after consolidation. Direct shear tests were performed for the sludge and obtained the results shown in Table 3, from which the value of c_u/p of the sludge is 0.80. This magnitude exceeds the twice those of usual clays, hence it is expected that the present sludge may be effectively improved by consolidation. Although the magnitude of the c_u/p is unexpectedly high, the c_u/p - P.I. relationship of the sludges fit the Skempton's equation,

$$\frac{c_u}{p} = 0.11 + 0.0037 \ P.I. \tag{4}$$

Instituting the values of P.I. in Table 1 into the above equation, and the average c_u/p of 0.88 is obtained which is approximately the same with the measured value 0.80.

Table 3 Strength increase due to consolidation

Consolidation pressure p (kPa)	10.0	20.0	40.0	c_u/p
Undrained shear strength c_u (kPa)	9.5	16.5	30.0	0.80

SPACING OF FABRIC FILTER

The values of coefficient of consolidation c_v and strength increase due to consolidation c_u/p were determined, then we may design the space of fabric filter for the horizontal drain.

First, we set the value of bearing capacity of the completed sludge ground to be 150 kPa. In order to attain this goal, the undrained shear strength of the sludge ground must be $c_u=q_u/5.7=26$ kPa, provided that we use the Terzaghi equation for the bearing capacity,

$$q_u = 5.7 \ c_u \tag{5}$$

Since the $c_u/p=0.80$ for the sludge, for resulting $c_u=26$ kPa of sludge state the necessary magnitude of consolidation pressure might be $p=c_u/0.80=33$ kPa. If we use a soil of density of 1.65 t/m^3 for the pre-loading weight the necessary height of the fill becomes 2.0 m.

If we apply the load of 33 kPa for consolidation of sludge, what decrease of the sludge depth will be? The answer is obtained from the f-log p curve. The sludge of the initial volume ratio $f_o(=1+e_o)$ of 17.1 becomes finally f=7.6 at the consolidation pressure of 33 kPa, hence, the ratio of the volume ratios before and after the consolidation is given by,

$$r = \frac{f_f}{f_o} \tag{6}$$

then, r=7.7/17.1=45%.

The spacing of filter fabric is determined as follows. The drain distance H for the horizontal drain method is a half of the spacing of fabric filter D, i.e.,D = 2H. Substitute this relation to the equation,

$$t = \frac{T_v \ H^2}{c_v} \tag{7}$$

where, t is time required for the consolidation and T_v is time factor. For the practical work, we consider the time required for the 90 % degree of consolidation t_{90} For estimating the t_{90} by consolidation theory, we should take into account of the considerable decrease of the sludge depth during consolidation. This effect can be properly evaluated by the Mikasa's consolidation theory (1) instead of the Terzaghi's. Then, the time factor for t_{90} becomes $T_v=0.35$ instead of 0.848 by Terzaghi. Substituting the above-stated figures together with c_v = 10 cm^2/d into equation (7), and we obtain,

$$t_{90} = 0.0088 \ D^2 \tag{8}$$

From the above relation, if we expect the sludge layer reaches 90 % degree of consolidation by 90 days, the necessary drain spacing distance is 101 cm. Thus, we decided the value of D being 1 m for the field test.

Before the field test on the horizontal drain method, we performed a self-weight consolidation test in actual scale

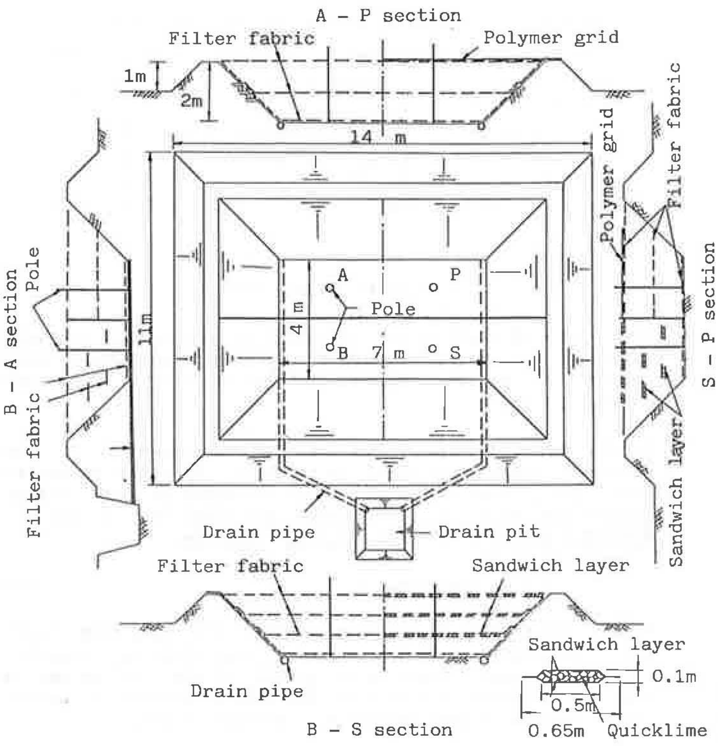

Fig. 5 Specification of the pit for field test

Photo. 1 Placing non-woven filter fabric for horizontal drainage

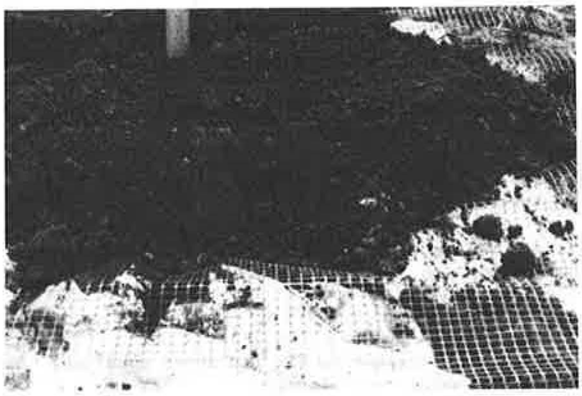

Photo. 2 Surface of P section reinforced wirh polymer grid

for the sludge of water content of 600%, using a container of 5 m diameter and 1 m height which was composed of polymer grid and filter fabric (3). It was confirmed by this test that the consolidation behaviors of sludge in self-weight can be well explained by Mikasa's theory. This result of full-scale preliminary test for the sludge encouraged us for confident of the success in the proposed system.

FIELD TEST

Outline of the Field Test

In the yard of the water purification plant of Ube City, a test pit was prepared in a size of 4m x 7m at bottom area. The specification of the test pit is shown in Fig. 5. The test pit was divided into four sections and the following different conditions were comparably investigated. They are:

- A section: Filter fabric is placed all over the surface of each sludge layer of 1m vertical spacing.
- P section: Same system with A section, except for placing a sheet of polymer grid on the top surface of sludge.
- B section: The same amount of filter fabric with section A is used but spacing geometry differs as illustrated in Fig. 5.
- S Section: Similar placing of filter fabric with section B but introducing sandwich layers (quicklime of 10 cm thick between two sheets of filter fabric).

The P section is for investigating the function of polymer grid for reinforcing the bearing capacity of sludge ground. The method adopted in S section has been proposed for banking with very soft clays(5). The used polymer grid and filter fabric are of such properties as shown in Table 4. The quicklime is the grading of finer than 30 mm.

Table 4 Properties of the used filter fabric and polymer grid

Materials		Nonwoven filter fabric	Polymer grid
Raw material		Polypro-pylene	Polypro-pylene
Unit weight (g/m^2)		400 + 40	203
Thickness (mm)		About 4	About 1
Width (m)		2.6	3.0
Strength (kN/m)	Longitudinal	13.7	11.8
	Transverse	7.8	16.7
Permear-bility (cm/s)	Longitudinal	1×10^{-1}	-
	Normal	1×10^{-2}	-

February 17, 1984, sludge of water content of about 650 % was poured into the pit of 2.0 m depth. Photo. 1 shows a view of the earth works. On the surface of the sludge, settlement plates were placed through the guiding poles. Twelve days after the pouring of sludge into the pit, the surface settlements of the four sections were 15 to 17 cm.

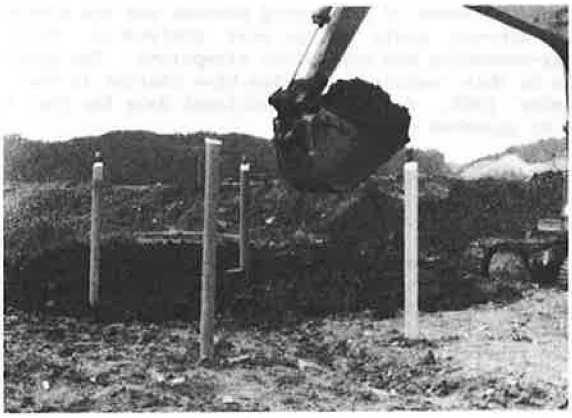

Photo. 3 Spreading of soil on sludge surface for 1st stage of pre-loading

Photo. 4 Completion of pre-loading soil of 2 m height for consolidation of sludges

On the surface of P section, a sheet of polymer grid(SS-1) was placed (Photo.2) and the first stage of fills of 30 cm(for A,B,S sections) and 50 cm (P section) were placed for the pre-loading as seen in Photo.3.

Three weeks after the first stage loading, the second stage works were performed to complete the whole fill of 2 m height (Photo.4). At this work, considerable deflections were observed in A and B sections, but little deflection were occurred in the P and S sections.

Consolidation Due To Pre-loading

The settlement curves for sludges of the four sections after pouring into the pit were as shown in Fig. 6. About 150 days elapsed after the final loading and the degree of consolidation seemed to be over 90 % until this time. In order to confirm the present degree of consolidation and also to estimate the final settlement, we used the hyperbolic curve method. Assuming that the time-settlement curve after the completion of loading may be approximated by the hyperbolic curve, we get the following relations;

$$s_t = s_o + \frac{t}{a + bt} \qquad (9)$$

$$s_f = s_o + \frac{1}{b} \qquad (10)$$

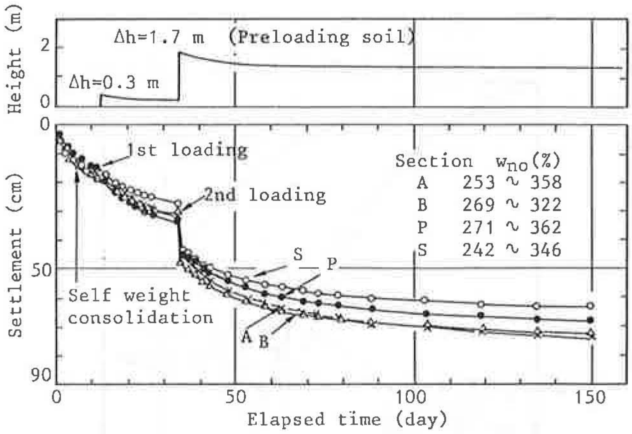

Fig. 6 Time - settlement curves of sludges in test pit

Table 5 Results of consolidation analysis

Section	a	b	s_o (cm)	s (cm)	s_f (cm)	U (%)
A	0.70	0.031	46.4	73.2	78.5	93.2
B	0.88	0.035	44.4	67.9	73.1	92.9
P	0.77	0.033	48.0	72.5	78.6	92.3
S	1.03	00.42	43.4	63.1	67.4	93.6

where, s_t (cm) is the settlement during t days, s_o (cm) is the settlement at the completion of the loading, s_f is final settlement and a and b are constants to be determined by observation. By approximating the plots of t and $t/(s_t - s_o)$ with a straight line, we can determine the constant a from the intercept of the ordinate and b from the slope of the line. The calculated results were as presented in Table 5, showing that the degree of consolidation had exceeded 90%. Thus, we removed the pre-loading soil of 1.5 m height.

Loading Test on the Consolidated Sludge Ground

To investigate the effect of the consolidation of sludge, loading tests were performed using a plate of 30 cm diameter. The test results were as shown in Fig. 7. The loading pressure - settlement curves for sections A and B are similar, then we considered that the geometry of placing of filter fabric does not affect the drainage effect after all. The numerals appear in Fig. 7 indicate the ultimate bearing capacities, which were estimated by assuming that the curves are approximated with hyperbolic curves. The values of the ultimate bearing capacity of the A and B sections are 110 - 130 kPa, which are somewhat lower than the expected value of 150 kPa. This difference may be caused from the reducing of the pre-loading weight due to side friction in the test pit. However, in a practical work in a wider space, the pre-load may be act more effectively and also we can choice a heavier pre-load. Therefore, an expected bearing capacity for the sludge ground will be obtained in practical works.

For the P section, on which the polymer grid was placed, the ultimate bearing capacity was 169 kPa. The difference of the values between P section and the A (or B) section, about 40 kPa, is due to the reinforcement effect of the polymer grid.

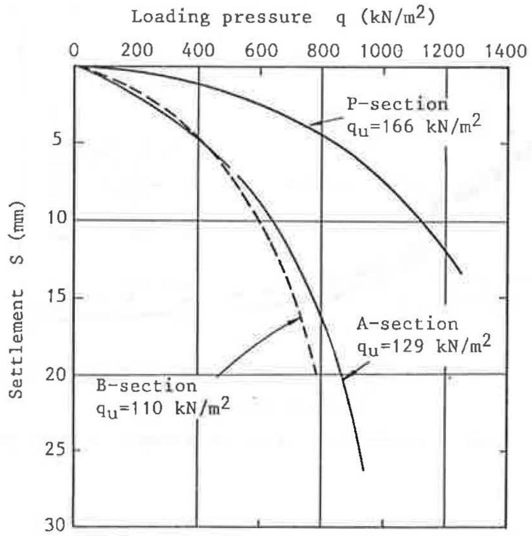

Fig. 7 Bearing capacity of sludge ground after consolidation

CONCLUDING REMARKS

A new technique for disposing sludges, the horizontal drain method was proposed and the experimental investigations performed in laboratory and field. The field tests was successfully performed thus the proposed method proved to be a useful and practical one. The physical properties of sludge is sensitively changed by drying process, as previously pointed out, then the combined system of sun-drying process and the horizontal drain process would be the most preferable from the energy-consuming and economical viewpoints. The practical works by this combined system have started in Ube City November 1985, and the observational data for the works will be appeared near future.

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