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ON THE ONE-DIMENSIONAL CONSOLIDATION DUE

TO THE TWO-DIMENSIONAL DEHYDRATION

WITH THE SECONDARY COMPRESSION

TAKEN INTO CONSIDERATION

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1. INTRODUCTION

The author proposed a method of analyzing the one-dimensional consolidation due to the three-di-mensional dehydration in the previous paper. The method can be applied to the case where a structure is loaded locally on the comparatively wide ground, but it is often unapplicable to the consolidation effect of the ground with the long-stretched structures such as ordinary roads or embankments. In such case, the dehydration accompanying with the con-solidation is thought to occur mainly in two direc-tions, namely in the transverse direction of the struc-ture and in the vertical direction of the consolidated layer, and the dehydration is practically observed as the synthetic flow of these two flows.
Therefore, it is necessarily required to regard the phenomena as the one-dimensional consolidation due to the two-dimensional dehydration in the analysis of such cases.
The method of analyzing of the consolidation effects with such cases and its application are mainly reported in the present paper.

2. DERIVATION OF THE BASIC EQUATION OF CONSOLIDATION

With a small element shown in Fig. 1, iA and iB may denote hydraulic gradients at faces A and B, u may denote pore water pressure, and 7- 0, unit weight of water. Then one may get,

Applying the Darcy's law to this element, amount
of water lost per unit time out of the minute ele-ment in the x-axis direction is expressed as,

where A, B : the surface area of faces A and B (A=B)
dV : the volume of the minute element
kh: the permeability coefficient in the x-

axis direction
In the same manner, the amount of water lost per unit time in the z-axis direction is

,where C, D: the surface area of faces C and D (C=D)
kv: the permeability coefficient in the z-
axis direction
Therefore, the total amount of dehydration out of
the minute element per unit time is

The amount of deformation of soil per unit time is, as shown in the previous paper,

Assuming that the amount of deformation equals
that of dehydration in the saturated soil, there is
obtained the equation

(2.1)

This equation is the basic equation of one-dimen-
sional consolidation due to two-dimensional dehydra
tion.

3. DEHYDRATION ONLY BY THE
VERTICAL FLOW

The basic equation of consolidation only by the
vertical flow is obtained by making •Ý u/•Ý x=-0 in the
above equation as

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Fig. 1 Mechanism of dehydration from a minute
element due to consolidation

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Next, this equation is analyzed to determine the
equation of the pore water pressure u.
Operating (p+77) on the both sides and arranging
the equation with respect to p, one gets

Assuming that u at any time t is expressed as the
product of (z), the function only of z, and cb (t) the function only of t, and writing

one obtains two equations independent of each other

(3.1)
(3 . 2)
,where Cv=kav T.•
The equation (3.1) is a linear differential equation of order 2 and degree 1, and the solution is

, where

(3.3)
The equation (3.2) is a linear differential equation of order 2 and degree 1, and the solution is

As u,--(z)0(t), the general integral of the basic equation becomes

The integration constants are determined by the use of the following boundary conditions.
(1) At 0 < t < 00 and z=0, u=0
From this condition,
C4=0

Accordingly,

(2) At 0 < t < 00 and H, u=0, where 2H denotes the thickness of the consolidated layer. From this condition,
sin 2 NH=0
Accordingly, 2 NH=--m 7r(m= 1, 2, 3...), then N= m r/2 H and

(3 . 4)

, where B,=C,C, and B2 = C2 C, •
(3) At 0 <z_<2H and t=0, u5=-K, where K denotes the load intensity.
Accordingly,

Multiplying the both sides by sin z and. inte-

grating the equation with respect to z, one finds

(3 . 5)

,where n=1, 3, 5...
(4) At t=0, ec=0.

εcis the permanent strain, and is shown by the following equation.

Application of f)=K-uz to the above equation gives

The coefficient of sin z is

Excluding the value at t=0 by regarding it as 0, and applying the condition that ec=0 at t=0 to the equation, one obtains

(3.6)

B1 and B2 are determined from the equations
(3 . 5) and (3 . 6) as

Applying these values to the equation (3.4) one finds

4. DEHYDRATION ONLY BY THE HORIZONTAL FLOW

The basic equation of consolidation only by the horizontal flow is obtained by applying a uia z=0 to the equation (2.1) as

(4.1)

The general integral of this equation is obtained
in the same manner as in the above-described Sec-tion 3 as

(4 . 2)
,where

(4.3)
The undetermined constants C1, C2, C3 and C4 in
the above equation (4.2) are determined by the use of boundary conditions.

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5. SURFACE CONDITIONS

The consolidation due to the two-dimensional de-hydration in the title means the case where dehydra-tion does not occur in the longitudinal direction, or the y-axis direction, of the long-stretched structures, but occurs mainly in its transverse, or the x-axis direction and in the vertical, or the z-axis, direction of the stratum.
The dehydration conditions due to consolidation in the x-axis direction are now examined.

In Fig. 2, the part surrounded by the lines I and II is the part suffering from consolidation, and those outside parts of these lines are those free from con-solidation. The x-axis coincides with the transverse direction of the structure on the ground. In other words, dehydration occurs through the boundary faces I and II of the consolidated region in the directions shown by the sign of arrows respectively, and the x-axis is made to point to the right direction.
The amount of water flowing out of the consoli-dated soil body toward the unconsolidated parts through the faces I and II of the area per time dt is

,where k denotes the permeability coefficient in the x-axis direction.
On the other hand, pore water is thought to flow out through the boundary faces of the consolidated soil body and the unconsolidated soil bodies at the rate proportional to the difference of their pore water pressure. Taking the pore water pressure of the consolidated soil body at the boundary faces I and IL shown in Fig. 2 to be u1 and till respectively, and that of the unconsolidated soil bodies to be 0, one gets h ets t_e amounts of water flowing out of the consolid-ated soil body into the unconsolidated soil bodies as

respectively, where a is a constant.
The amount of water flowing out of the consoli-dated soil body and those flowing into the uncon-solidated soil bodies can be made equal to each other at their boundary faces.
Accordingly, at the boundary face I

At the boundary face IL ,

Therefore, the equation of the surface condition at the boundary face I becomes

,and that at the boundary face II becomes

,where

Taking the origin of coordinates 0 of the consoli-dated part as shown in Fig. 3, one finds two equa-tions of surface conditions of the consolidated soil body at x=0 and x=b as

(5.1)

, respectively.

The value of is calculated from

the equation (4.2) as

Application of the equation (5.1) to the above equation gives

Accordingly, C4/9 C3M=0, then

Applying this to the equation (4.2), one finds

, where Bi= C, C3 and B,=C,C,
On the other hand,

Fig. 2 An explanatory figure of notation of surface conditions

Fig. 3 A figure showing the origin of coordinates
of the consolidated soil body

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Accordingly,

(5.2)
Letting mi stand for the values of M that satisfy
the above equation, one obtains

(5.3)

6. INITIAL CONDITION

The load on the saturated soil is thought to be supported by the pore water pressure immediately after the start of consolidation.
Therefore, at t=0, u=K.

(6.1)
The undetermined constant (B1 +B2) is determined
in the following manner.
If one writes the characteristec function as

then Di is the solution of the differential equation obtained by separation of variables in the basic equation of consolidation
(6.2)
and further satisfies the equations

(6.3)

(6 . 4)

Now an assumption is made that the characteristic values m1, m2, w3,...and the characteristic functions D1, D2, D3,.. are determined from these conditions, and any two values mp and mg, and Dp and Dg are taken from the series respectively, which naturally satisfy the equation (6 . 2) to give

Multiplying the both sides by Dg and Dp, respecti-vely, and subtraction one from the other, one obtains

Integration of the both sides from x=0 to x=b gives

(6 5)

On the other hand, from the equation of the

condition (6. 3) , one gets

From the above two equations, in the cace of ƒÀ•¬ 0, (6 . 6)
From the equation of the condition (6.4), one gets

From the above two equations, in the case of 9 0 (6 . 7)
Application of the equations (6.6) and (6.7) to the right side of the equation (6.5), with the condi-tion mh ma, gives

Whence, if multiplication of the both sides of the
equation (6.1) by Di and integration of them from 0 to b are made, then all the terms other than the i th one become 0, on the right side.
Accordingly,

In the same manner as in the case of dehydration only of the vertical flow, one gets, by letting ec=0 at t=0,

Applying the above values to the equation (5. 3), one obtains

7. ANALYSIS OF CONSOLIDATION DUE TO A TWO-DIMENSIONAL FLOW

The basic equation for this case is

, and its solution is obtained as a product of respective solutions of one-dimensional dehydration in the x-axis and z-axis directions. Namely,it is expressed as u=K(ux)K,i(uz)K.1
,where K is the external load, and(ux)K=, and(uz).K=1 are the values of lc, and uz when the soil supports the load K=1, respectively.
Furthermore, taking z7z, Fix and to be the mean value of u with respect to the x-axis and z-axis, that of ux with respect only to the x-axis, and that of u, with respect only to the z-axis respectively,

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one obtains the equation

,where

and

Accordingly, the mean pore water pressure due to the synthetic flow ii is obtained as

8. AMOUNT OF SETTLEMENT DUE TO CONSOLIDATION

The amount of settlement at time t due to the synthetic flow is
(8.1)

,where

(8.2)
and

(8.3)
Now examination is made with respect to ƒÉ1, ƒÉ2, ƒÉ1' and ƒÉ2'. Developing the ,/ part of the equations (3.3) and (4.3) by the use of the binomial theorem, one obtains ƒÉ1, ƒÉ2, ƒÉ1' and ƒÉ2' as

and

, where Ci, = and Ch=
Examination is further made for the case where the creep coefficient 71 is very small compared with the

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permeability coefficient k and creep lasts very long.

In this case, and

Accordingly,

and

In examining the coefficients in the equations (8.2) and (8.3) by the use of these values, one gets

and

Therefore, the amount of settlement S for this case becomes

The value of =Qi in the above equation is then calculated.

Concerning the numerator in the above expression, there is obtained

As to the denominator,

Accordingly,

(8.4)

Furthermore, the final amount of settlement S. is obtained, by applying .0 to the equation of the amount of settlement S, as S•å2 HK(v+r).
Therefore, the degree of consolidation for this case is

(8.5)

Next, examination is made for the case where the
creep coefficient is very large compared with the
permeability coefficient and creep finishes in such a
short time. In this case,

and and then and

Examination of the coefficients in the equation (8.2) and (8.3) by the use of these values gives

and

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Therefore, the amount of settlement S for this case is

Accordingly, the degree of consolidation U is expressed by the equation

This equation means that the delay of creep is
negligible in the case where creep coefficient is so
large that the permanent deformation occurs in a
moment, and so it becomes the same equation of the
degree of consolidation as in the case where only
the primary consolidation is taken into consideration.

9. RELATION BETWEEN THE DEGREE
OF CONSOLIDATION AND THE TIME FACTOR

An equation for calculating the degree of consoli-dation in the one-dimensional consolidation due to the two-dimensional dehydration with the secondary compression and creep taken into consideration was obtained in the preceding section. The relation bet-ween the degree of consolidation and the time factor is now to be obtained by the use of the equation.

Writing

in the equation (8.5), one gets

= Uv + Ur

,where and Ur mean the primary consolidation rate and the secondary compression rate respectively. Prior to obtaining the relation between U, and Ty, the characteristic values bmi corresponding to b fl= 0.1, 0 .5,......, 100, 500, co were determined by the use of the equation (5.2), and further the values of Qi were calculated by applying the values of b g and those of bmi corresponding to them to the equation (8.4).
The values of Qie- in the equation with
respect to Uv were calculated by using the values of bmi and Qi corresponding to various values of b g obtained in the above calculation and by taking a Tv to be 0.01, 0.02, 50, 60. The values were then summed up in the range of i=1-7 to obtain

Furthermore, the values of were
calculated by taking Tv=0.0001, 0.0002, 2.0.
The curves indicating the relation between Uv and Tv corresponding to various values of b g and a
obtained from the results of the above-described
calculations are shown in Fig. 4-13.
In these figures, the Uv- log Tv curves are shown with the case where =1.0.

Next, the relation between Ur and T' was obtained

by calculation by taking =0.025, 0.050, •c•c,

0.950, 0.975, 1.0, and the results are shown in Fig. 14.

Fig. 4 The Uv-log Tv curved-ruler by the value of b /9 of one-dimensional consolidation due to the two-dimensional dehydration (in the case of b 43=0.1)

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Fig. 5 The Uv-log Tv curved-ruler by the value of b p of one-dimensional consolidation due to the
two-dimensional dehydration (in the case of b P=0.5)

Fig. 6 The Uv-log Tv curved-ruler by the value of bƒÀ of one-dimensional consolidation due to the two-dimensional dehydration (in the case of b ƒÀ=1.o)

Fig. 7 The Uv-log Tv curved-ruler by the value of b /3 of one-dimensional consolidation due to the
two-dimensional dehydration (in the case of b ƒÀ=10)

Fig. 8 The Uv-log Tv curved-ruler by the value of b ƒÀ of one-dimensional consolidation due to the
two-dimensional dehydration (in the case of b ƒÀ=20)

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Fig. 9 The Uv-log Ti, curved-ruler by the value of b 43 of one-dimensional consolidation due to the
two-dimensional dehydration (in the case of b ƒÀ=30)

Fig. 10 The Uv-log Tv curved-ruler by the value of b ia of one-dimensional consolidation due to the
two-dimensional dehydration (in the case of b ƒÀ=50)

Fig. 11 The Uv-log Tv curved-ruler by the value of b p of one-dimensional consolidation due to the
two-dimensional dehydration (in the case of b ƒÀ=100)

Fig. 12 The Uv-log Tv curved-ruler by the value of b ig of one-dimensional consolidation due to the
two-dimensional dehydration (in the case of b ƒÀ=500)

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1 0 . METHOD OF USING THE FIGURES
OF DEGREE OF CONSOLIDATION--
TIME FACTOR RELATIONS

The method of obtaining the amount of consolida-
tion settlement in-situ by making use of the figures
of Uv - log T, curves (Fig. 4-13), results of the above analysis of consolidation due to the two-dimensional dehydration.
As the values of Cv, Ch and g of the consolidated soil layer in site are obtained by a consolidation test due to the three-dimensional dehydration, the value of b g is obtained by multiplying the loading width of the consolidated layer in site b by /9, and a is calculated by

,where H is a half of the thickness of the consoli-dated layer in the field.
The curve of the degree of consolidation of the primary consolidation part due to the two-dimensional dehydration in site is obtained by finding the Uv-log Tv curve corresponding to these values of b g and a in Fig. 4.-13.
The curve of the degree of consolidation of seco-ndary compression part is also found in Fig. 14. Making use of these curve of the degree of consoli-dation, one can obtain S, the amount of settlement of the consolidated layer in the field with any time t.

(10.1)
In the equation, K is the intensity of the consoli-dation load of the consolidated layer in site, and the values of the degree of consolidation U, and Ur are obtained by making use of the curve of the degree of consolidation of the primary consolidation part (the one found out from the curves in Fig. 4-13) and that of the secondary compression part (Fig. 14) for

Tv = .t and T' =2 77 t, respectively.

The consolidation constants V, r and 72 are also obtained by the consolidation test.
Therefore, one can get the time-settlement curve of the consolidated layer in site by calculating the amount of settlement corresponding to the time t from the equation (10.1).

11 . AN APPLICATION EXAMPLE

Application of the method of analyzing one-dimensional consolidation due to the two-dimensional dehydration to field cons-olidation settlement.

In this section, examination is made on the analy-sis and the test results of consolidation settlement in the Lake Hachiro test embankment, which is thou-ght to be the case of the one-dimensional consolida-
tion due to the two-dimensional dehydration.
(1) The state in site
A large-scale test embankment shown in Fig. 15

Fig. 13 The Uv-log Ty curved-ruler by the value of b 13 of one-dimensional consolidation due to the two-dimensional dehydration (in the case of b p=00)

Fig. 14 The Ur-log T' curved-ruler of one-dimensional consolidation due to the two-dimensional dehydration

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was constructed prior to banking of the Lake Hachi-ro cofferdam embankment for reclamation in order to estimate its amount of settlement and to examine its stability against slide.
This test embankment was planned and constructed in the 33 rd year of Showa (1958), and its settlement was observed for about 3 years. The base ground of the bank is shown in Fig. 16. As seen in the figure, the ground has an almost uniform weak clay layer 29 m thick, with a sand-mixed clay layer from the depth of 18 m to 25 m included. Physical properties of the weak clay were investigated, and the test results of the soil around the depth of 10 m,

which gives almost average values, are shown in Table 1.
Furthermore, the results of consolidation tests of the soil are shown in Table 2.
As a sand layer of 8 m in thicktiess lies under the weak layer, the consolidation condition of the ground is thought to be permeable through both face.
Now the method of analysis of the one-dimensional consolidation' due to the tw&dimensibnal dehydration, is applied to calculation of settlement of the test em-bankment, to obtain the time-settlement curve and to compare it with the results of observation of settlement for examining applicability of the method. The settlement curve observed at the center on the observation line S2 in the sand 'bed type (the point A in Fig. 15) showed a considerably good results and was used in discussion.
(2) Calculation of consolidation load
Unit' weight of soil in the ground is shown in Table 3.
As the groundwater level is at the ground level, the values are thought to coincide with those of the saturated unit weight, which were then used in calcu-lating the submerged unit weight, and the overburden intensity of load for each depth was estimated.' The soil profile and the overburden intensity of load observed are shown in Fig. 16.
The overburden intensity of load at the middle point of clay layer (at the depth of 14.5 m) po is 5.66 t/m2.
The values of intensity of preconsolidation load obtained by consolidation tests are plotted and shown in a dotted line in Fig. 16, which coincides compa-ratively well with the overburden intensity of load curve. As this 'suggests the fact that the clay in site may be regarded as normally consolidated, calculation of consolidation was made on the assumption that

Fig. 15 Explanatory figures of the test embankment

Table 1 Summarized results of laboratory tests of weak clay at the test embankment section.

Table 2 Summarized results of consolidation tests of the above-described soil

Table 3 Unit weight of soil of the ground in-situ

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consolidation of clay proceeds depending only on the
consolidation load.
Furthermore, examination of the observed settle-
ment curve made it clear that the secondary compre-
ssion was shown very little effect on the settlement
on those days, and therefore calculation of consoli-dation settlement was made only with the primary consolidation taken into consideration.
(3) Intensity of load due to banking
(i) The intensity of load due to the 1 st-step of banking
The intensity of load in the ground under the center line of the 1 st-step of embankment p, was calculated by regarding the banking as a trapezoid with the height of h=2.0 m, the top width of 92.2 m and the bottom width of 134.2 m, and using the unit weight of rt=2.0 t/m3.
The value of the dispersion coefficient At correspon-ding to trapezoid load was obtained by using twice the modified it-chart, by transposing the origin of this chart prepared according to the equation of the vertical stress under an infinite terrace,

, further we got the intensity of load in the ground by multiplying this value by the embankment load

γh.

(ii) Intensity of load due to the 2 nd-step of banking
The intensity of load in the ground p2 was obtained in the same manner as in the case of (i), by regar-ding the 2 nd-step of banking as a trapezoid with the height of 2.5 m, the top width of 52.2 m and the

bottom width of 92.2 m.
(iii) Intensity of load due to the 3 rd and 4 th-steps of bankings
The values of the intensity of load in the ground,
p3 and p4, were obtained ill the same manner as in the case of (i), by regarding the 3 rd and 4 th-steps of bankings as trapezoids with the height of 0.5 m, the top width of 47.7 m and the bottom width of 52.2 m, and with the height of 0.5 m, the top width of 43.2 m, and the bottom width of 47.7 m, respectively. The dispersion coefficients and the normal stress intensities in the ground corresponding to any bank-ings obtained in the above manner are shown in Fig. 18 and 19.

The values of the normal stress intensity due to the embankment load at the middle point of the clay layer (at the depth of 14.5 m) obtained from Fig. 19 are 3.97 t/m2, 4.97 t/m2, 0.97 t/m2 and 0.96 t/m2, res-pectively, corresponding to the 1 st-, the 2 nd-, the 3 rd- and the 4 th-steps of banking.
(4) Calculation of the final amount of settle-

ment

(i) The final amount of settlement . due to the every-step of banking
The final amout of settlement only caused by the

Fig. 16 Figure showing the overburden intensity of load of the original spot

Fig. 17 Explanatory figure of symbols in the equation of normal stress under an infinite terrace

Fig. 18 Figure of stress dispersion factor in the
ground

Fig. 19 Figure of normal stress in the ground due to embankment load

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primary consolidation is expressed as
S=2 v A pH
In this equation v denotes the rate of elastic def or-mation, and the v- log p curve obtained from con-solidation tests is shown in Fig. 20.
The final amount of settlement due to any banking calculated by the use of the above equation are shown in Table 4.
The values of the final amount of settlement shown
in Table 4 were calculated by neglecting the change of the stress in the ground due to the loads with the proceeding settlement of banking.
In the actual case, however, the stress intensity in the ground decreases as the banking part submerges. Especially, the correction of the final amount of settlement due to the 1 st-step of banking is needed. (ii) Correction of the final amount of settlement due to the 1 st-step of banking
The rate of decrease of the amount of settlement according to decrease of unit intensity of load caused by the 1 st-step of banking is

Taking the bulk density of a submerged emba-nkment to be rsub =1.0 t/m3 one obtains the amount of decrease of the stress in the ground according to the settlement of embankment of 1 m as

Therefore, the amount of settlement according to decrease of the unit intensity of load caused by the embankment Kb is

Taking the amount of settlement Sn to be balanced with the intensity of stress pn, one obtains the fo-llowing two equation.

The corrected final amount of settlement Sn is obtained from the above two equation as

(5) Calculation of the time of consolidation settlement
The time of consolidation settlement is calculated

by the use of the equation and the Uy—

log Ty curve obtained by application of the conso-lidation due to the two-dimensional dehydration.
As the values of the consolidation coefficient C, obtained from consolidation tests show variance co-rresponding to the range of depth, the average co-nsolidation coefficient Cy was calculated by using the Cv - log p curve and the following equation.

, where Hi and Cvi mean the thickness of the i th layer and the coefficient of compressibility of the i th layer.
The Cv - log p curve and the Cv- log p curve are shown in Fig. 21.
(i) Calculation of settlement due to the 1st-step of banking
The value of C corresponding to the stress inten-sity of 0.963 kg/cm2 in the ground at the time of loading of the 1 st-step of banking was obtained from

Fig. 20 The v-p curve

Table 4 Calculation table of the final amount of settlement

Fig. 21 Cy-log p figure

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Fig. 21 as C ,-=2.95 x 10-4cm2/sec.
Therefore the relation between the time of settle-
ment and the time factor for this case becomes

The amount of settlement corresponding to the
time needed of settlement in this case can be obta-
ined by the use of this equation and the above-described Up-log T, relationship as the final amount of settlement is 154.73 cm. As the slope of the banking in site is as gentle as about 1 : 10 and the difference between the bottom width of the banking of 134.2 m and the top width of the completed ba-nking of 43.2 m is large, the width of the consolidated soil body was assumed as 88.7 m, which is the mean value of the both.
Furthermore, thinking of the soil status in site, the designed section of the banking, the method of execution, and the amount of settlement of the ba-nking caused by those factors, one may assume, ChIG=1-10, whence

So the author used the values of c4=0, 0.2, 0.4,
0.6, 1.0 in calculation. Further the values of b fi=
10, 20, 50, 100, 500, co, were used for the respective
values of a and b g on the calculation for the time
needed of settlement.

In this connection, the value of c calculated by
the use of the Ch and Cv values obtained from the
test results of soil in site and the value of g obtained
by the use of the fl-value measuring apparatus are
to be used afterwards in examining the present theory
and its applicability.
(ii) Calculation of settlement due to the 2nd-step
of banking
The value of C, corresponding to the stress inte-
nsity of 1.46 kg/cm2 in the ground at the time of
loading of the 2nd-step of banking was obtained
from Fig. 21 as Cv=2.80 x 104cm2/sec.
As the 2nd-step of banking was constructed 34 days
(=4.90•~104min.) after the finish of the loading of
the lst-step of banking, the relation between the
time of settlement and the time factor for the case
becomes

Accordingly, t= 1.251 x 108Tv +4.90 x 104 (min)
The lapsed time to any settlement in this case, may be calculated as the final amount of settlement of 197.46 cm by the use of this equation and the above-described Up-log 7; relationship in the same manner as in the case of (i).

(iii) Calculation of settlement due to the 3 rd-step of banking
The value of CC corresponding to the intensity of 1.558 kg/cm2 in the ground at the time of loading of the 3rd-step of banking was obtained from Fig. 21. as2.80 x 10-4(cm2/sec). As the 3rd-step of ba-nking was filled 44 days (=-6.34x 104min.) after the finish of the 1st-step of banking, the relation between the time of settlement and the time factor for this case becomes

Accordingly, 1=-1.251 x 108 Tv+ 6 . 34 x 104 (min)
The lapsed time to any settlement in this case, may be calculated as the final amount of settlement of 35.53 cm by the use of this equation and the above-described Up-log T, relationship.
(iv) Calculation of settlement due to the 4th-step of banking
The value of C corresponding to the stress inte-nsity of 1.655 kg/cm2 in the ground at the time of loading of the 4th-step of banking was obtained from Fig. 21 as C=2.80 x 10-4(cm7sec) .
As the 4th-step banking was filled 379 days (= 5.46 x 105min.) after the finish of the 3rd-step ba-nking, the relation between the time of settlement and the time factor for the case becomes

Accordingly, t=1.251 x 108 Tv+ 5.46 x 105 (min) The lapsed time to any settlement in this case, may be calculated as the final amount of settlement of 32.91 cm by the use of this equation and the above-described Up- log 7; relationship.
The values of the consolidation constants used in the above calculation of settlement are those measured

by the technical staff of the Land Reclamation Office of the Lake Hachiro of those days.
(v) The total settlement due to all steps of the banking
The total settlements due to all steps of the bank-ing were obtained by summing up the amount of settlement due to the respective step of banking based on the results of calculation in the section (i)-(iv). They are shown in Fig. 22-a-Fig. 22-d. The actual settlement data in site are further shown by dotted lines.

According to Fig. 22-a-22-d, the amounts of sett-lement actually observed (shown by dotted lines) are 20-40 cm or so larger than the calculated values. This fact is attributed to the rapid increase of the amounts of settlement actually observed at the time of the banking. This is also proved by the fact that the amounts of settlement actually observed showed to be quite similar to that shown by the calculated

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values after some lapse of time in banking.
The rapid increase of the amount of settlement just after the banking is thought to be attributed to shear deformation due to shear stress in the ground added by the banking, and never be attributed to conso-lidation deformation due to the decrease of pore water among soil particles.
Accordingly, the amount of the rapid settlement just after the banking is to be studied separately from the consolidation settlement discussed in the

present paper.
The corrected actual settlement curve only due to consolidation deformation was therefore obtained by subtracting the amount of the rapid settlement from the amount of settlement actually observed, and is shown by the full lines in Fig. 22-a-22-d.
(vi) Examination of the corrected actual settle-

ment data with the calculated amounts of
settlement
First, the settlement curve in the case of a =0 in
Fig. 22-a-22-d, namely, in the case where dehydra-
tion occurs only in the vertical direction according
to Terzaghi's theory, shows such a slow advance of
settlement compared with the settlement curve by the
corrected actual data, and clearly its advance is not
coincident to the corrected actual data.
Next, examination is made by comparison of the
calculated values of consolidation settlement due to
the two-dimensional dehydration with the corrected
actual data.
The calculated values with a=0.2 in Fig. 22-a
show a slower. advance of consolidation even in the

case of bƒÀ=•‡ than that shown by the corrected
actual date. . This suggests that the ground in site

does not correspond to the case of ce =0, 2, but to the
case of a > 0.2.
Examining the case of a\=.0.4 in Fig. 22-b, one

Note : The curve with a=o in the figure shows the
values calculated according to Terzaghi's
theory of one-dimensional consolidation
Fig. 22-a The settlement curves due to the respective step of embankments and those actually
observed (the case of a=0.2)

Fig. 22-b The settlement curves due to the respective step of embankments and those actually
observed (the case of a=0.4)

Fig. 22-c The settlement curves due to the respective step of embankments and those actually
observed. (the case of a=0.6)

Fig. 22-d The settlement curves due to the respective step of embankments and those actually
observed. (the case of a=1.0)

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finds the settlement curve with b 9—loo coinciding
well that by the corrected actual data, which suggests
that consolidation occurs due to the two-dimensional
dehydration. In the same manner, the settlement
curves with a=0.6, b g =5o and a=1.0, b g =3o in
Fig. 22-c and 22-d are respectively found to coincide with the corrected actual data well.
The above three couples of the a and b g values of the cases where the settlement curves by calcula-
tion coincide well with the corrected actual data
were used for calculation with the horizontal conso-
lidation coefficient Ch and the relative dehydration
rate g in site.
The results are shown in Table 5.

The soil sample taken at the depth of 9.50-10.00
m in site (which shows almost the average value of Ci, in the layer to the depth of 18.50 m) was subjected to the three-dimensional dehydration conso-lidation test.
The obtained consolidation constants are shown in Table 6.
As shown in Table 6, the values of Cv=2.08x
10 (cm2/sec) Ch= . 90 x 10-4 (cm2/sec) and g = 1 . 33

×10-2(1/cm)were obtained with the intensity of

consolidation load of 1.6 kg/cm2.
The comparison of the experimental results with the actual data shown their good coincidence with the case of a=0.4 in Table 5.
Therefore, consolidation settlement in site is exp-ected to advance hereafter to the settlement curve of the case of a=0.4 and b g=100, which is thought to prove applicability of analysis of consolidation due to the two-dimensional dehydration.

12. CONCLUSION

In the present paper, the author showed a method of analysis of the one-dimensional consolidation due

to the two-dimensional consolidation with the seco-ndary compression taken into consideration, which is applied to analysis of consolidation of the soil layers under the structures comparatively long in the long-itudinal direction, such as banks or roads, constructed on the weak ground, where dehydration is expected to occur in the vertical and transverse direction.
To make an analysis more simply and conveniently,
the author showed on the U - log T, curves and the Ur - log T' curves and described the method of their application, for the calculation of settlements acco-rding to the present method mentioned above. Furthermore, comparison to the actual settlement data of the test embankment of the Lake Hachiro with the calculated values of settlements by the present method were made, in order to examine
applicability of the theory. As a results it was
noticed that the amount of settlement actually obse-rved is larger than that calculated by Terzaghi's theory of consolidation due to the one-dimensional
dehydration, and that the difference between them
becomes larger with the lapse of time of settlement. On the other hand, the above-described method of analysis based on the theory of the one-dimensional
consolidation due to the two-dimensional dehydration
was proved to almost satisfy the settlement data actually observed in the field.
And also the present method of analysis might solve some problems on the consolidation which are difficult to be solved by the former method.
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Table 5 Calculation table of Ch, and /3 of the case of good coincidence with the actual settlement
curve

Table 6 Calculation table of Ch and /3 by the three-dimensional dehydration consolidation test

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