GROUND SURFACE STRAIN OCCURRING AT THE TIME OF BASE FAILURE OF EMBANKMENT

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SUMMARY

This report deals with the results of the measurement of the ground surface displacement and strain by means of a ground surface strainmeter and a displacement pile. These experiments were made at two different sites, where the base failure of an embankment had been apprehended in the course of step by step construction on a very soft foundation. Through these observations, it was noticed that the measuring of strain is one of the useful predictive method of the failure.

MEASURING METHODS

Ground Surface Strainmeter

The landslide recorder shown in Fig. 1 is used as a means of measuring strain on a ground surface. This strainmeter continuously registers the variation of length of invar wire, which is tightened between two points on a ground surface. And end of the invar wire is connected to a drum of the instrument and a pointer is controlled by a clock. Its recording speed is changed into two steps of low and high, 0.5 mm/hr and 4 mm/hr respectively, and its magnification is five.

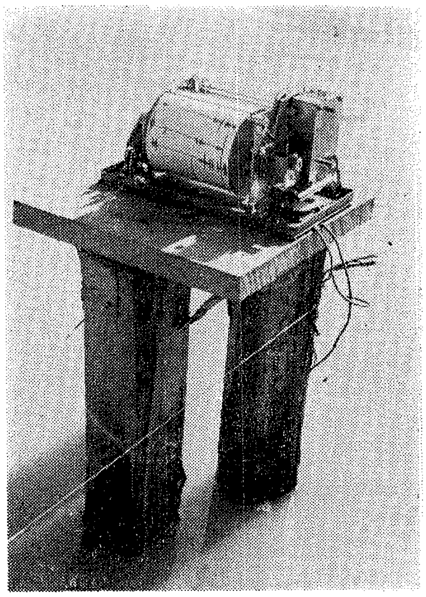

Fig. 1. Ground Surface Strainmeter Sre Type

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In case of setting up the instrument, a base line must be ins alled at a right angle to the center line of an embankment. Also a fixed point may be chosen on the toe line of an embankment, and a base line must be stretched from this point beyond the failure zone to the other fixed point, where the ins rument will be set up, as shown in Fig. 2. In general, this distance between the two fixed points may be decided in the range of 10 to 12 meters.

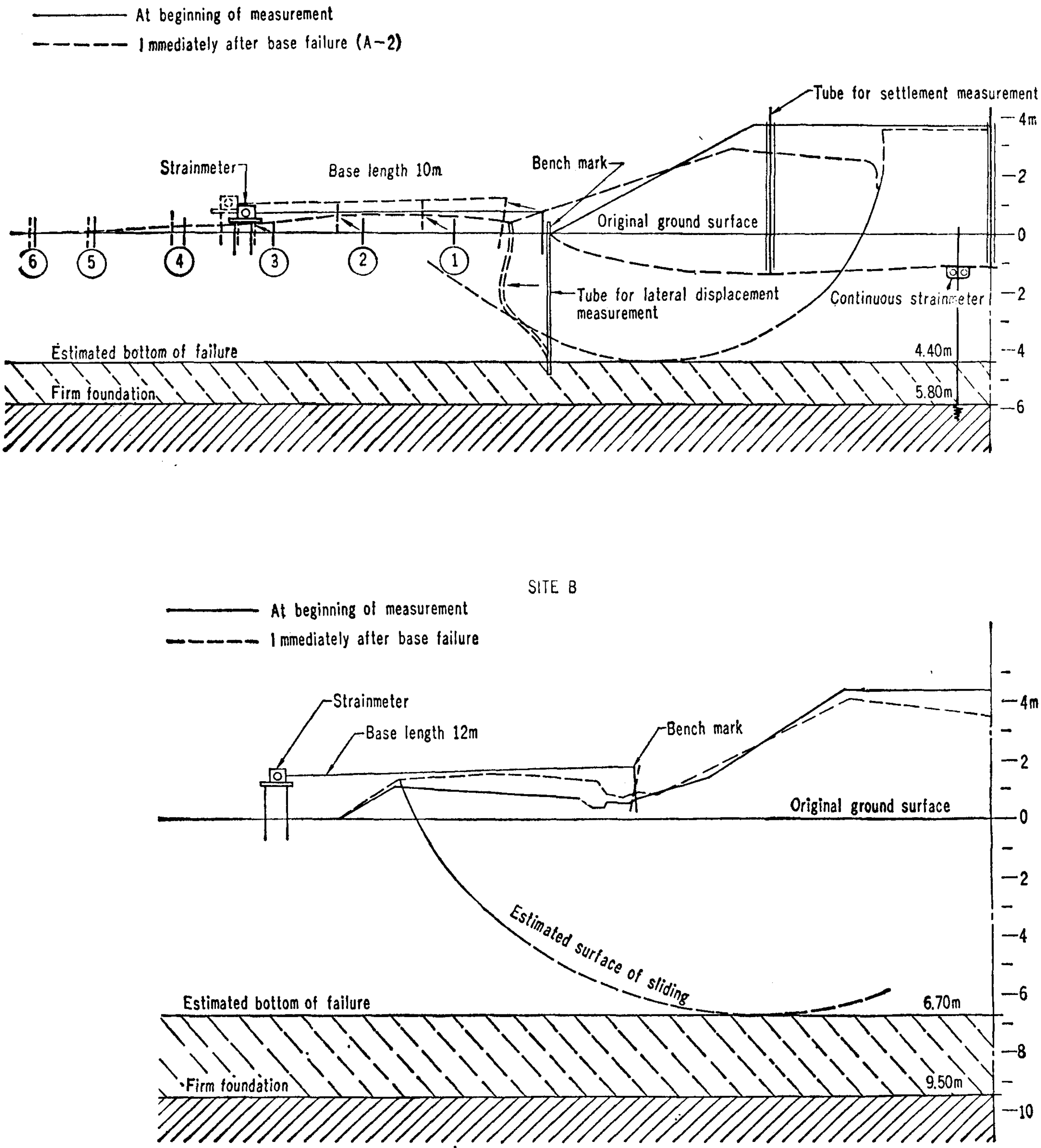

Fig. 2. Arrangement of Measuring Apparatus in Cross-Section

Displacement Pile

Small wooden piles, each one meter long, were driven into the ground to a depth of 60 cm as the bench mark. These were arranged at about 3 m intervals, parallel to the base line of the strainmeter, as shown in Figs. 2 and 10.

In observation, measuring of distance between each base point and the sixth one by steel tape and leveling of each bench mark were executed. Sometimes the absolute displacement of the sixth base point was checked by surveying.

SOIL PROFILES

The soil profiles of two sites *A* and *B* are shown in Figs. 3 and 4, respectively. On

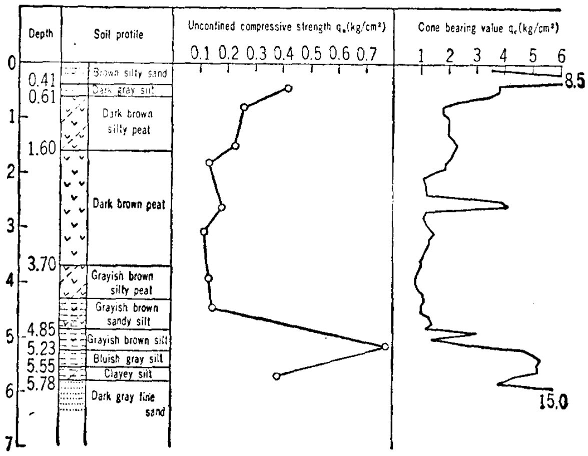

Fig. 3. Soil Profile on Site A

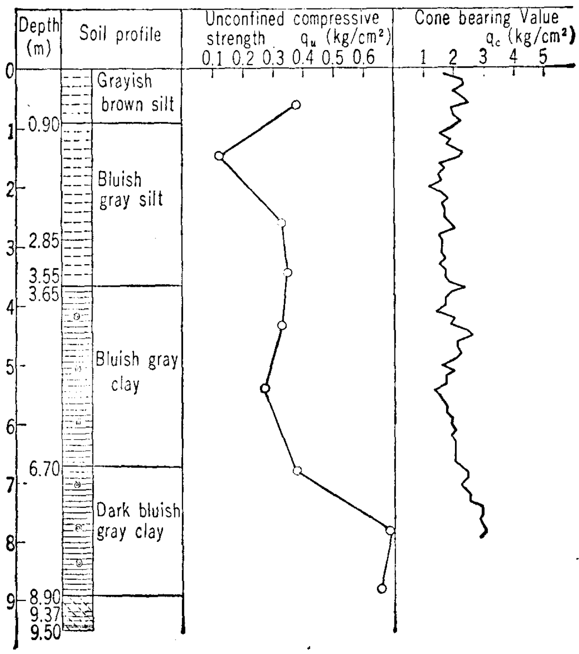

Fig. 4. Soil Profile on Site B

site A, the subsoil consists mainly of very soft peat layer, and it contains almost no soil grains, less integrated and may be classified into a fibrous peat at shallower depth. The average value of cohesion of soft peat layer is about 0.8 to 1.0 t/m².

On the other hand on site B, the subsoil consists of a homogeneous marine silt or clay and its average value of cohesion is higher than that of the site A, ranging from 1.45 to 1.60 t/m².

RESULTS OF OBSERVATION

Example for Peat Layer (Site A)

Surface displacement measured by displacement piles: The movements of all the displacement piles are shown in Fig. 5 as a vector starting from each origin. Immediately after the first step of filling, all the displacement piles begin the movements upward and outward. We can recognize the fact that the continuous movements of horizontal displacement and uplift are started from the initial stage of embankment construction on a very soft peaty layer.

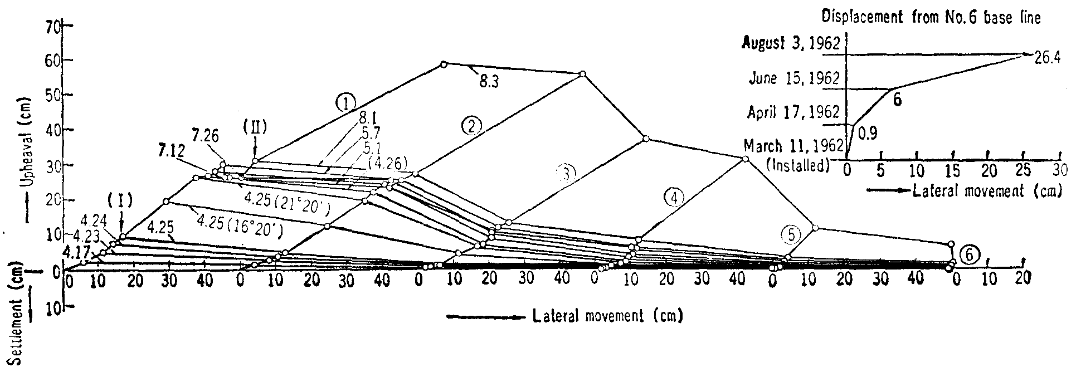

Fig. 5. Result of Observations with Displacement Pile on Site A

In this example, the base failures of embankment are recognized twice at the time denoted by the mark (↓) in Fig. 5. Though the incipient failure was seen at the first stage ↓ (I), it was fully developed at the second stage ↓ (II). In the latter case, no crevice is found in the toe area of sliding surface, only observed is a deformation shown in Fig. 5, but the compression strain is so large as to influence the outer boundary beyond the base point No. 6.

Movement of the surface strain: From the Fig. 3, we calculated the strains between the base points and plotted these values against time, as shown in Fig. 6. In Fig. 6, it is distinctly recognized that periods denoted by the mark ↓ (I) and ↓ (II) correspond to the periods of the sudden increase of the surface strain. It is obvious that the velocity of the surface strain attains an enormous value in the proximity of a base failure. After the failure, the strains between the base points slightly increase in the immediate neighbourhood to the embankment and somewhat decrease at the outer boundary. It seems that the former is in the state of plastic flow and the latter is somewhat in the elastic

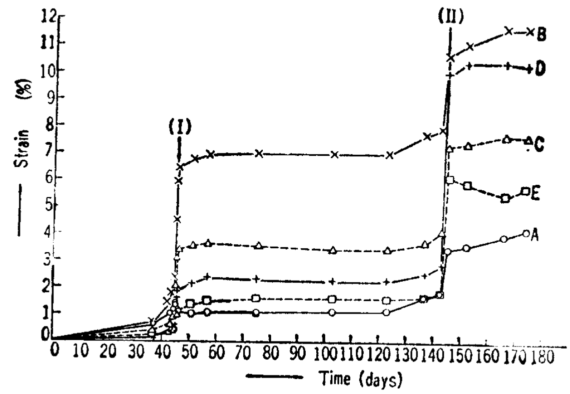

Fig. 6. Time-Strain Curves on Site A

state. Though the observation of displacement pile is the most primitive method, it seems from the test results that the velocity of strain is more important than the total amount of displacement to seek for the factors related to the phenomena of sliding. It may be quite natural to utilize the ground surface strainmeter, in which the surface strains are more easily recorded in detail than the method of the displacement piles, from the test results shown in Fig. 6.

Record of ground surface strainmeter and calculated velocity of strain: The relative displacement curves recorded by this strainmeter and the velocities of strain which are calculated from these records in the periods before and after the base failures of *A*–1 and *A*–2 are shown in Figs. 7 and 8 respectively. The relative displacements in both cases are shown as the curves downwards to the right hand in these figures. These curves also resemble the time-settlement curve in plate loading test, and the

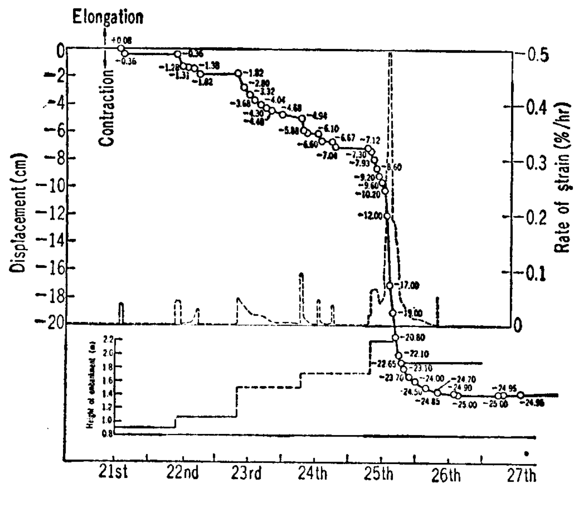

Fig. 7. Record of Ground Surface Strainmeter and Calculated Velocity of Strain in the Periods between before and after the Base Failure (Case A-1, Peat)

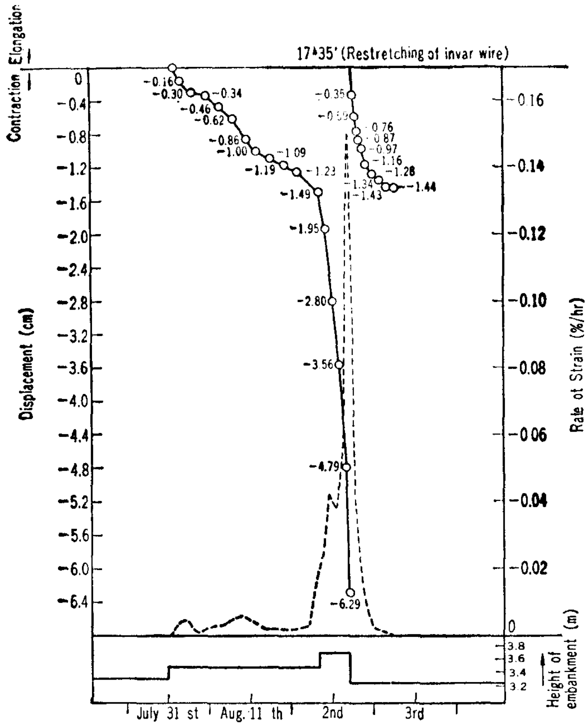

Fig. 8. Record of Ground Surface Strainmeter and Calculated Velocity of Strain in the Periods between before and after the Base Failure (Case A-2, Peat)

relative displacement may be stopped in course of time before coming into the stage of failure. On the contrary, these curves may become convex to upward to turn the state of sliding beyond the critical equilibrium.

It may be noticed from Fig. 8, which corresponds to the second failure (*A*–2) on the same location with *A*–1, that the critical strain velocity to sliding is decreased to one third as compared with the virgin sliding (*A*–1), owing to the potential sliding surface corresponding to the incipient failure. It may be estimated from these figures, that the critical strain velocity against the sliding is about −0.18%/hr and −0.06%/hr in Figs. 7 and 8 respectively.

Example for Clay and Skilt Laver (*Site B*)

As an observation of displacement pile requires a lot of labor, only a ground surface strainmeter was used on site *B*. There was once a base failure on this site, and the measurement was made about 45 days after that. The measured relative displacement curve (*B*–1) is shown in the right side of Fig. 9 as the strain. It has a conspicuous appearance as compared with the examples of *A*–1 and *A*–2. However, this curve may be explained as follows:

After the compression strain owing to the final step of filling ceases at a point (a), the tension strain (a) to (b) still continues. Then the curve turns suddenly with an acute compression strain (c) that corresponds to a state of sliding at the point (b),

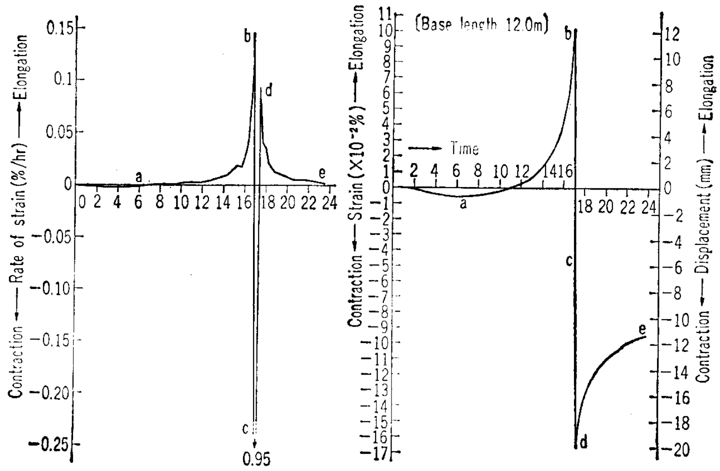

Fig. 9. Record of Ground Surface Strainmeter and Calculated Velocity of Strain in the Periods between before and after the Base Failure (Case B-1, Clay)

where the velocity of its strain becomes maximum. Again it follows after the former curve (a) to (b) at the point (d) and at last this tension strain (d) to (e) comes to an end at the point (e) in accordance with the cease of a failure movement.

The velocity of strain in this curve is shown in the lefthand side of Fig. 9. In this figure, the movement (a) to (b) seems to be already a part of a failure phenomenon, so that we cannot derive the critical velocity of strain from this figure only. If we consider the critical limit of strain was exceeded before this stage, the critical strain velocity in this case may be estimate about −0.002%/hr. However, this value is too small for a critical one, we presume that it may be caused from the difference in failure type rather than in soil type. As the failure of this site seems to belong not to the flow type sliding but to the rotational one, in this case it may be required to observe the inclination of the base pile and correct the test data.

STUDY ABOUT MEASURED DATA AND MEASURING METHOD

Measured Strain Compared with Elastic Strain

The distribution of the ground surface strain obtained by the displacement pile in the outer boundary of embankment is compared with the elastic strain calculated in the following way.

The strain in a cross-sectional direction of embankment ε_x is expressed as

$$\varepsilon_x = \frac{1}{E}\left\{\sigma_x - \mu(\sigma_y + \sigma_z)\right\} \quad \cdots\cdots (1)$$

where E to the Young's modulus of soil, μ: to Poisson's ratio of soil, and σ_x, σ_y, σ_z the σ: stresses in x, y, z axes respectively.

Assuming that no strain is induced in the direction parallel to the center line of embankment,

$$\varepsilon_y = \frac{1}{E}\left\{\sigma_y - \mu(\sigma_z+\sigma_x)\right\} = 0$$

then

$$\sigma_y = \mu(\sigma_z+\sigma_x) \quad \cdots\cdots\cdots\cdots \quad (2)$$

From (1) and (2)

$$\varepsilon_x = \frac{1}{E}\left[\sigma_x - \mu\left\{\sigma_z + \mu(\sigma_z+\sigma_x)\right\}\right]$$

$$= \frac{1}{E}\left\{(1-\mu^2)\sigma_z - \mu(1+\mu)\sigma_z\right\}$$

$$= \frac{1+\mu}{E}\,(1-\mu)\sigma_x - \mu\sigma_z \quad \cdots\cdots\cdots\cdots \quad (3)$$

substituting $\mu = 0.5$,

$$\varepsilon_x = \frac{1.5}{2E}(\sigma_x - \sigma_z) \quad \cdots\cdots\cdots\cdots \quad (4)$$

As distribution coefficient n_x and n_y of σ_x and σ_y are calcualted as shown in Fig. 10, we are able to calculate the ground surface strain, assuming the stress p under the embankment and the mean value of E on the fixed point of the displacemen piles.

(*Case A*–1)
Hight of embankment: $h=2.2$ m,
Settlement of embankment: $s=0.6$ m,
Unit weight of embankment: $\gamma=1.8$ t/m^3,
$\mu=0.5$,
$E=10$ kg/cm^2 (from the stress-strain curve of unconfined compression test result of silt layer at -0.5 m)

$$P = \gamma h + (\gamma - \gamma_w)s = 4.2 \text{ t/m}^2 \quad (= 0.42 \text{ kg/cm}^2)$$

Therefore

$$\varepsilon_x = \frac{1.5P}{2E}(n_x - n_z) = 3.15\times10^{-2}(n_x - n_z) \quad \cdots\cdots\cdots\cdots \quad (5)$$

The ground surface strains in the point A_0 to E in Fig. 10 will be calculated from the equation (5) as follows:

	A_0	A	B	C	D	E
$(n_x - n_z)$ *at* -1.0 m	0.167	0.087	0.061	0.048	0.039	0.035
ε_x (10^{-3}) *at* -1.0 m	5.26	2.74	1.92	1.51	1.23	1.10
ε_x (10^{-3}) *at* -0.5 m	2.63	1.37	0.96	0.76	0.62	0.55

Comparing the calculated elastic strain with the actual one in Fig. 4, the latter is far larger than the former in all points of A to E from the beginning of the measurement, so that the successive strain seems to be caused mainly by a flow movement. It will be noted from these test results that the critical value of strain against the failure may becomes 20 to 25 times of the elastic one.

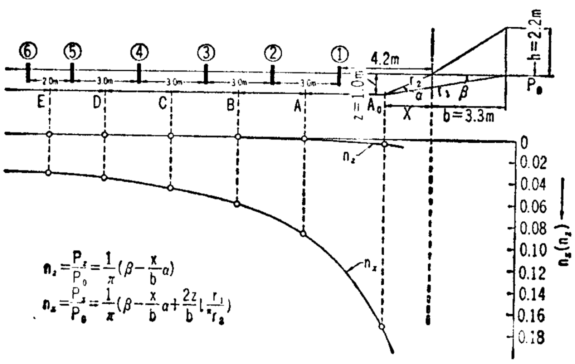

Fig. 10. Distribution of U_x and U_z

Load—Displacement Curves

The relations between the load of embankment and the sideward displacement on the two sites are obtained as shown in Fig. 11, so as to check the failure condition. In Fig. 11 the height of embankment is plotted against sideward displacement as a value proportional to a load of embankment. These curves bear the close resemblance to the load-settlement curves in plate loading test. As a consequence, it indicates a state of failure in acute breaking down of the curve, if it exceeds a certain critical value of load intensity.

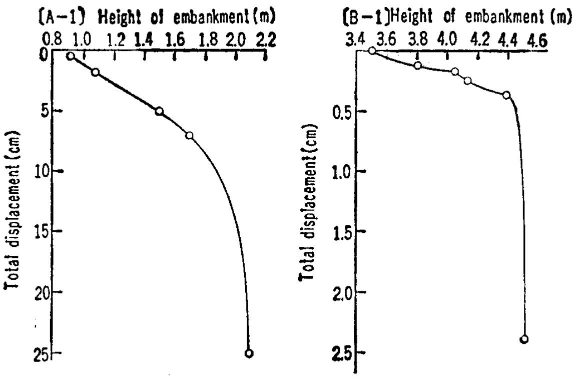

Fig. 11. Load-Displacement Curves

Similarly to the fact, that the slope of a time-settlement curve before breaking down depends mainly on the rigidity of an underground soil, the compressibilities of both grounds have an obvious influence upon the slope of these curves, *A*–1 and *B*–1 in Fig. 11. It seems to be necessary from the fact that the more accurate measurement is required in a ground similar to the site *B* than *A*, to predict an approach of failure from measured displacement.

Problems on Measuring Method

There are many problems to be discussed in a record with ground surface strain-meter as already stated about an example in site *B*. In order to obtain a precise record of relative displacement between two points on the ground surface, the fixed point of recorder and the other base point are required to be both on the ground surface strictly. But in practice, this requirement is very difficult to fulfill, as the base line may be disturbed with the slight swelling of intermediate ground surface or the apparatus cannot be defended against a rain or other obstacles. We use, for these reasons, generally the short piles to fix the base points on a ground surface, but this method may cause some trouble, as the movements of pile head and ground surface somewhat differ owing to the miscellaneous strains in the earth masses.

In case of using this strainmeter as a means of predicting the failure of an embankment under construction, it seems that the base point of strainmeter will be fixed better on a point farther from the embankment, where there is no influence of a sliding. However, this idea will be practically not so good, became the longer the base line, the less fidelity in transmission of displacement and the more vibration in invar wire that must be excluded.

The other pile of base point may be fixed on the toe line of embankment and this situation will appear near the center of sliding soil mass in the case of base failure, therefore the difference of the movements of a pile head and a ground surface will become larger on the occasion of a rotational sliding. It seems that there lies a considerable difference in respect to this point, between a peat foundation where the sideward flow movement is very large and a clay foundation where the rotational sliding is dominant. The curious strain curve shown in Fig. 9 may be explained from this standpoint, assuming the movement of pile head in case of the rotational sliding. An imaginary picture is given in Fig. 12 with respect to the invar wire movement. The marks in this figure are the same as those in Fig. 9. We hope to have a chance to prove these phenomena in field clearly.

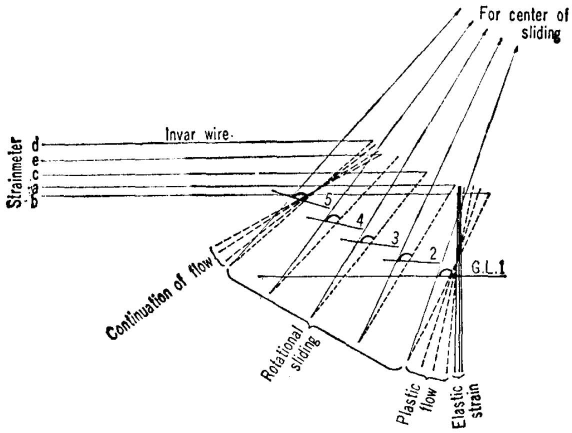

Fig. 12. Movement of Base Line in Case of Rotational Sliding