FORECASTING TIME OF SLOPE FAILURE BY TERTIARY CREEP
PREDICTION DU MOMENT DE RUPTURE D'UN TALUS PAR FLUAGE TERTIAIRE

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SYNOPSIS This paper describes the relationship between creep-rupture life left before failure and transient strain rate at optional time in the tertiary creep range. This relationship was found in field measurement at a site of landslide, and composed of modification of the relationship in the secondary creep range. It was proved to have good adaptability to the measurements in actual cases. The relation can be, therefore, utilize to estimate the rupture life of slope in the tertiary creep range.

INTRODUCTION

A method of forecasting the time of occurrence of slope failure by means of steady-state strain rate has been proposed by the author in the previous Proceedings. This method, however, is not applicable in the tertiary creep range, because of increasing strain rate of soil creep, and it should be a serious contradiction that the newest measured results cannot be used for prediction in spite of approaching failure. It is, therefore, urgently needed to find some possible method of forecasting applicable in the tertiary creep range.

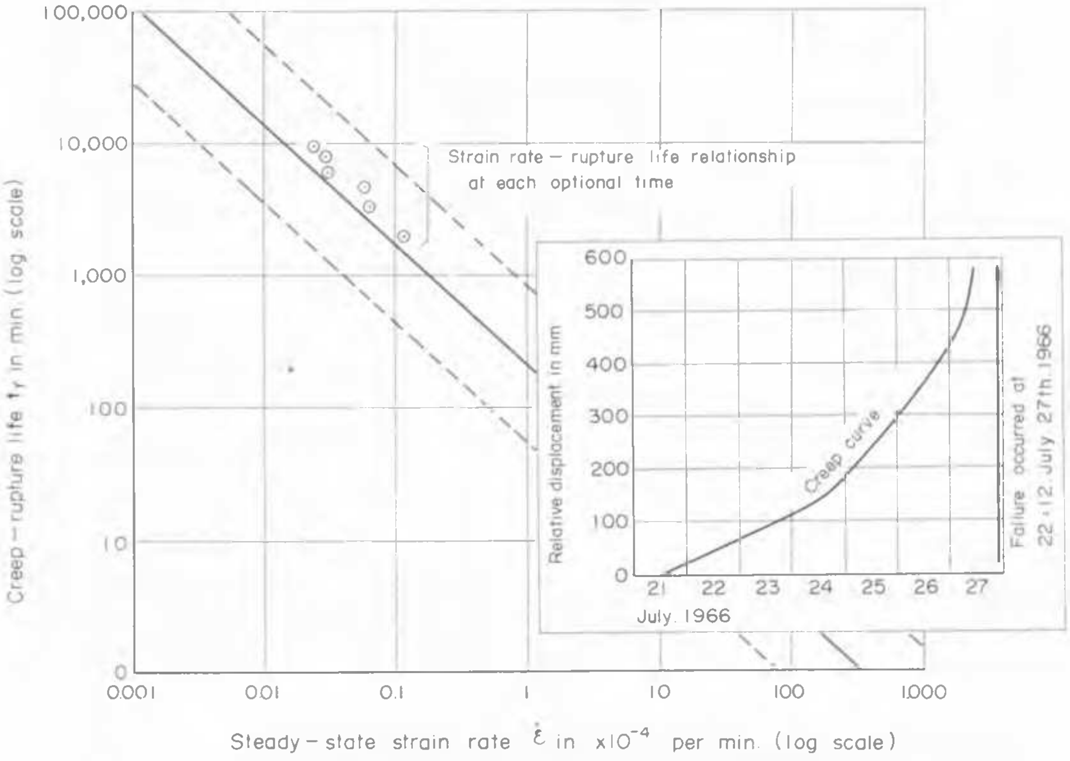

Fig. 1 Field measurement with an automatic strainmeter at Asamushi landslide

THE SHAPE OF CREEP CURVE IN THE TERTIARY CREEP RANGE

In case of Asamushi landslide, which occurred in July, 1966, an automatic recording device wrote down landslide movement only in the tertiary creep range because of late installation of the device to the site. But transient strain rate was also found to satisfy the relation as in the secondary creep range, paired with the rupture-life left before failure, as seen in Fig. 1. It is, therefore, considered possible to extend the previous relationship further to the tertiary creep range with some modification. The relationship between creep-rupture life t_r and steady state strain rate $\dot{\varepsilon}$ in the secondary creep range has been expressed as follows:

$$\log_{10} t_r = 2.33 - 0.916 \log_{10} \dot{\varepsilon} \pm 0.59 \quad .. \; .. \; .. \quad (1)$$

In the tertiary creep range t_r and $\dot{\varepsilon}$ may be substituted by the time length left before failure or creep-rupture life and transient strain rate at optional time, respectively, and numerical constants 2.33 and 0.916 may be expressed by log a and unity, respectively. Then, Eq. (1) will be reduced to the following form.

$$\log (t_r - t) = \log a - \log \dot{\varepsilon} \qquad (2)$$

or, by rearrangement,

$$\dot{\varepsilon} = \frac{a}{t_r - t} \qquad (3)$$

where t_r : time left before failure, or creep-rupture life,

t : optional time,

$\dot{\varepsilon}$: transient strain rate at optional time,

a : a constant.

Assume that $\dot{\varepsilon} = 0$ at $t = t_0$, and then we get

$$\varepsilon = a \log \frac{t_r - t_0}{t_r - t} \qquad (4)$$

or by putting

$$\varepsilon = \frac{\Delta l}{l_0}$$

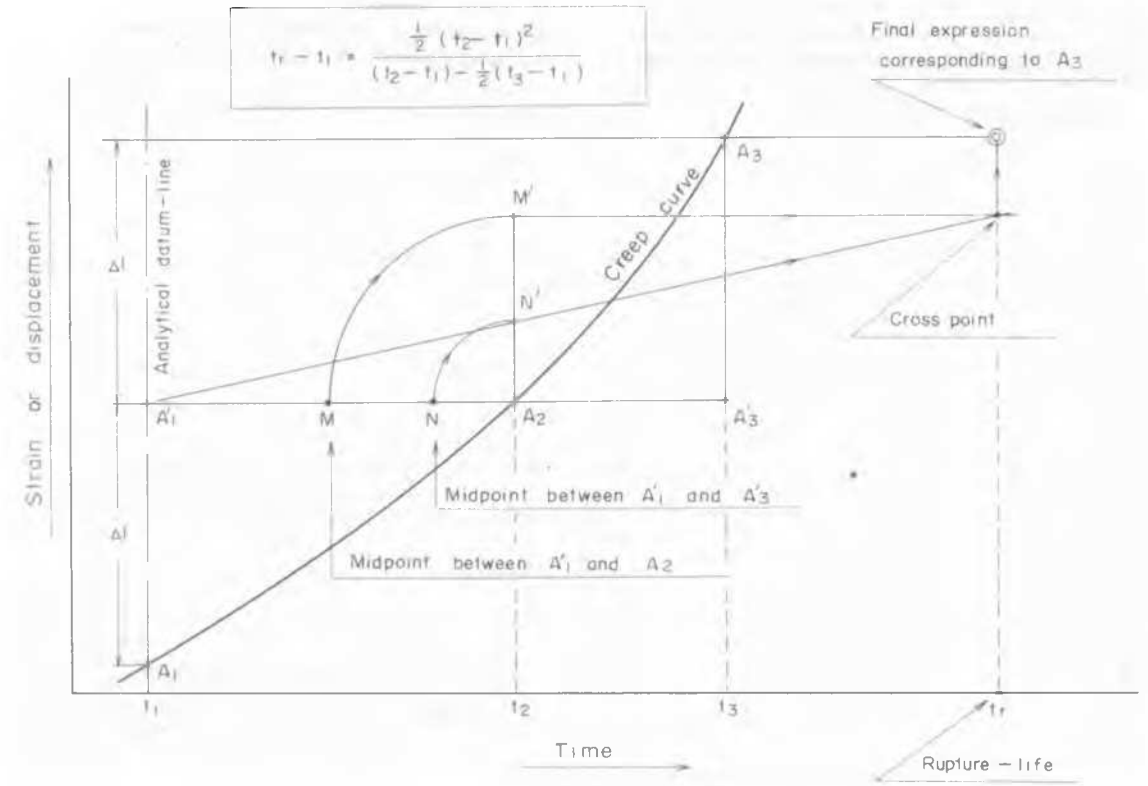

Fig. 2 Graphical analysis for rupture-life in the tertiary creep range

the equation is rewritten as follows.

$$\Delta l = l_0 a \log \frac{t_r - t_0}{t_r - t} \quad \text{.. .. ..} \quad (5)$$

where Δl : relative displacement between two measured points

l_0 : initial distance between two measured points

This equation shows applicability for deformation instead of strain as for Eq. (4).

Eq. (4) or Eq. (5) contains three unknown constants a or l_0 a, respectively, t_r and t_0; so creep-rupture life t_r or remaining life $(t_r - t)$ at optional time can be obtained with good reliability for practical use, if three or more points are properly selected on a creep curve.

GRAPHICAL SOLUTION FOR RUPTURE LIFE IN THE TERTIARY CREEP RANGE

Now, let us only use Eq. (5) for simplifying further explanation. Choose three successive points $(\Delta l_1, t_1)$, $(\Delta l_2, t_2)$ and $(\Delta l_3, t_3)$ on the tertiary creep curve, so as to have equal difference of displacement, that is to say,

$$\Delta l_2 - \Delta l_1 = \Delta l_3 - \Delta l_2.$$

Put the values of each points to Eq. (5), and we obtain three simultaneous equations. By eliminating two constants $l_0 a$ and $(t_r - t_0)$ from these equations we get the following relation.

$$\frac{\Delta l_2 - \Delta l_1}{\log \dfrac{t_r - t_1}{t_r - t_2}} = \frac{\Delta l_3 - \Delta l_2}{\log \dfrac{t_r - t_2}{t_r - t_3}}$$

From initial assumption for selecting points, this relation is reduced to the following form.

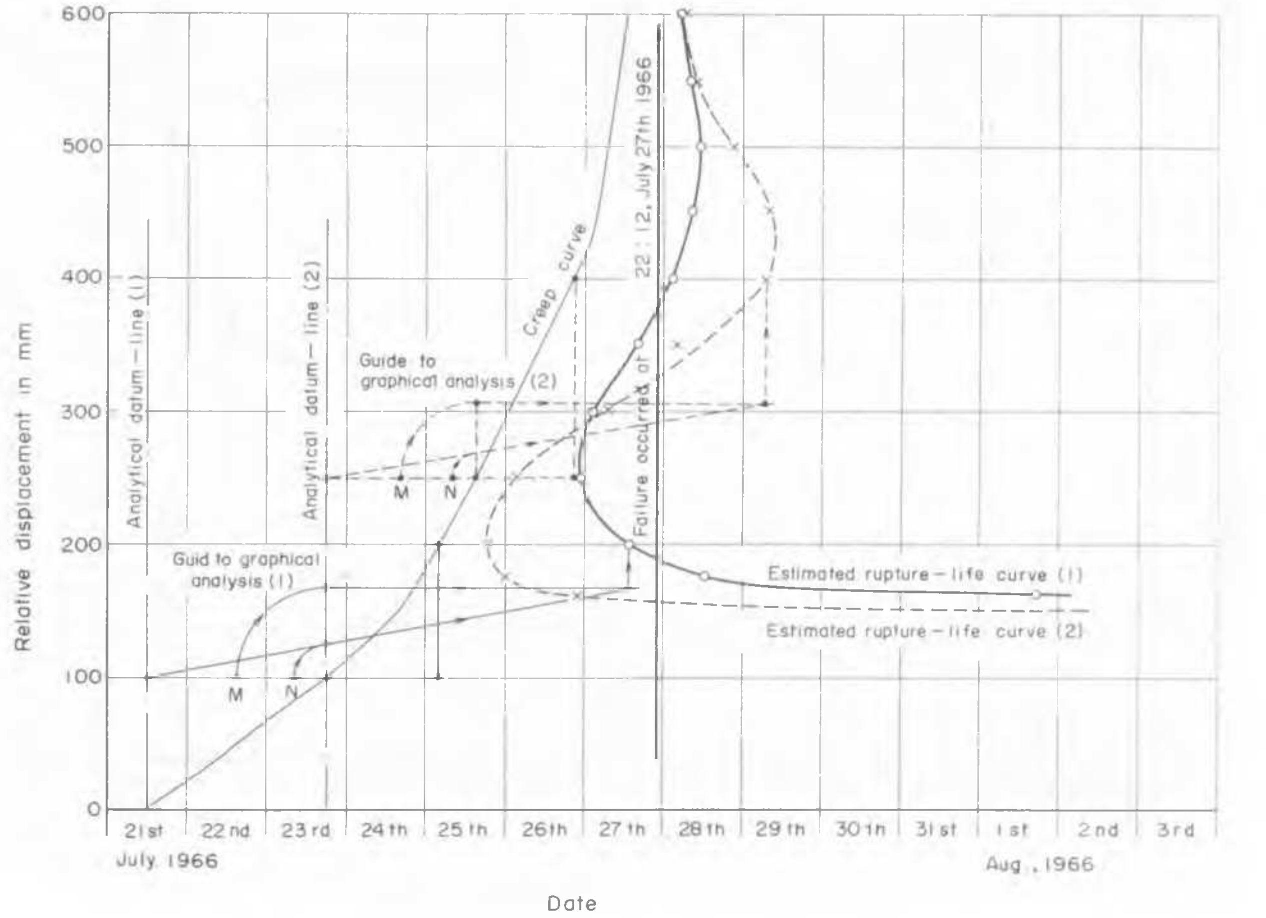

Fig. 3 Landslide at Asamushi on the Tōhoku Line

$$\frac{t_r - t_1}{t_r - t_2} = \frac{t_r - t_2}{t_r - t_3}$$

or, by rearrangement, we get the following equation for creep-rupture life t_r.

$$t_r = \frac{t_2^2 - t_1 \cdot t_3}{2t_2 - (t_1 + t_3)} \qquad (6)$$

As for the remaining life $(t_r - t_1)$, the next equation is obtained by transforming Eq. (6).

$$t_r - t_1 = \frac{1/2\,(t_2 - t_1)^2}{(t_2 - t_1) - 1/2\,(t_3 - t_1)} \quad \cdots\cdots\cdots\cdots \quad (7)$$

This relation makes it possible to solve the problem by graphical method.

In Fig. 2 three points $A_1(\Delta l_1, t_1)$, $A_2(\Delta l_2, t_2)$ and $A_3(\Delta l_3, t_3)$ are selected so as to have equal difference Δl of displacement. A_1' and A_3' are projects of A_1 and A_3, respectively, on a line passing A_2 and parallel to the time axis. M and N are midpoints of $A_1'A_2$ and $A_1'A_3'$, respectively. Choose M' and N' on a vertical line passing A_2 so that $M'A_2$ and $N'A_2$ are equal to MA_2 and NA_2, respectively. Then, the rupture-life can be obtained as abscissa of an intersection of a straight line passing through A_1' and N' with a straight line passing M' and parallel to the time axis.

The justification of this procedure is made with geometrical process. The result can be obtained easily and rapidly with this procedure; so it is recommended to use this graphical method also in the field under watching.

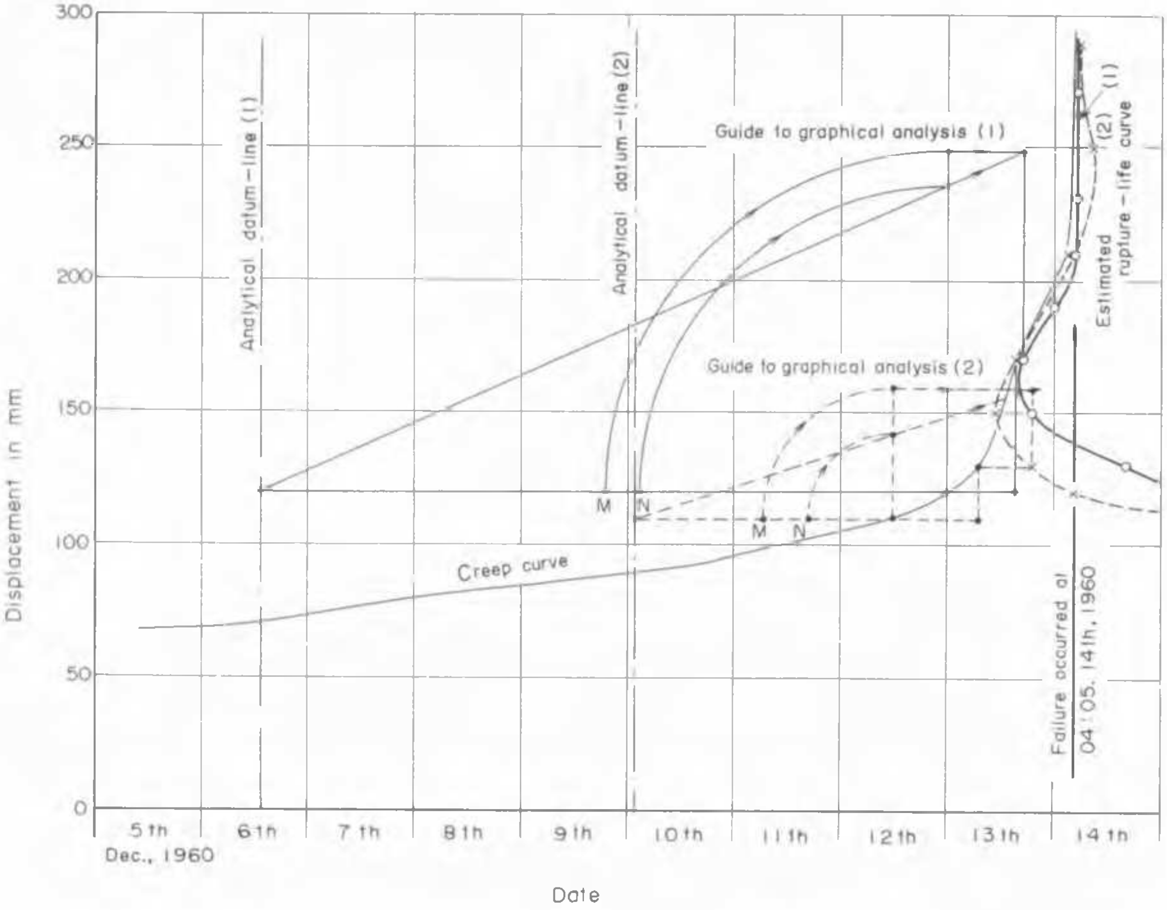

Fig. 4 Collapse of a large retaining wall on the Ooigawa Railroads

VERIFICATION OF APPLICABILITY OF THE METHOD COLLATED WITH ACTUAL FIELD MEASUREMENTS

There are several variations in actual operation according to initial time and displacement interval. Then, let us adopt, to begin with, a process with stationary initial time and variable displacement interval and then repeat the process with different initial time.

Landslide at Asamushi on Tōhoku Line

In July, 1966, a landslide occurred at Asamushi on the Tōhoku Line, one of main lines of Japanese National Railways, burying 80 m length of track, with 100,000 m^3 of earth movement, and interrupted railroad traffic for 26 days. Geologically the site consists of liparitic tuff, with well-developed joints near slope surface, partly affected by weathering and thermal metamorphosis.

It was on the 21st of July, just a week before failure, when a strainmeter of direct recording type was set on the slope. The record of movement of the slope and the results of graphical analysis are shown in Fig. 3. As for rupture-life curve, a full line (1) is for initial time of the 21st of July, and shows that estimation of rupture-life falls in the range of one day's deviation within 3 days before failure.

On the other hand, a broken line (2) is rupture-life curve for initial time of the 23rd of July, 2 days after beginning of observation. It shows 2 days deviation even within 3 days before failure. From this result, therefore, it can be said that the best way to have good estimation is to begin displacement measurement as earlier as possible, in order to utilize long duration record.

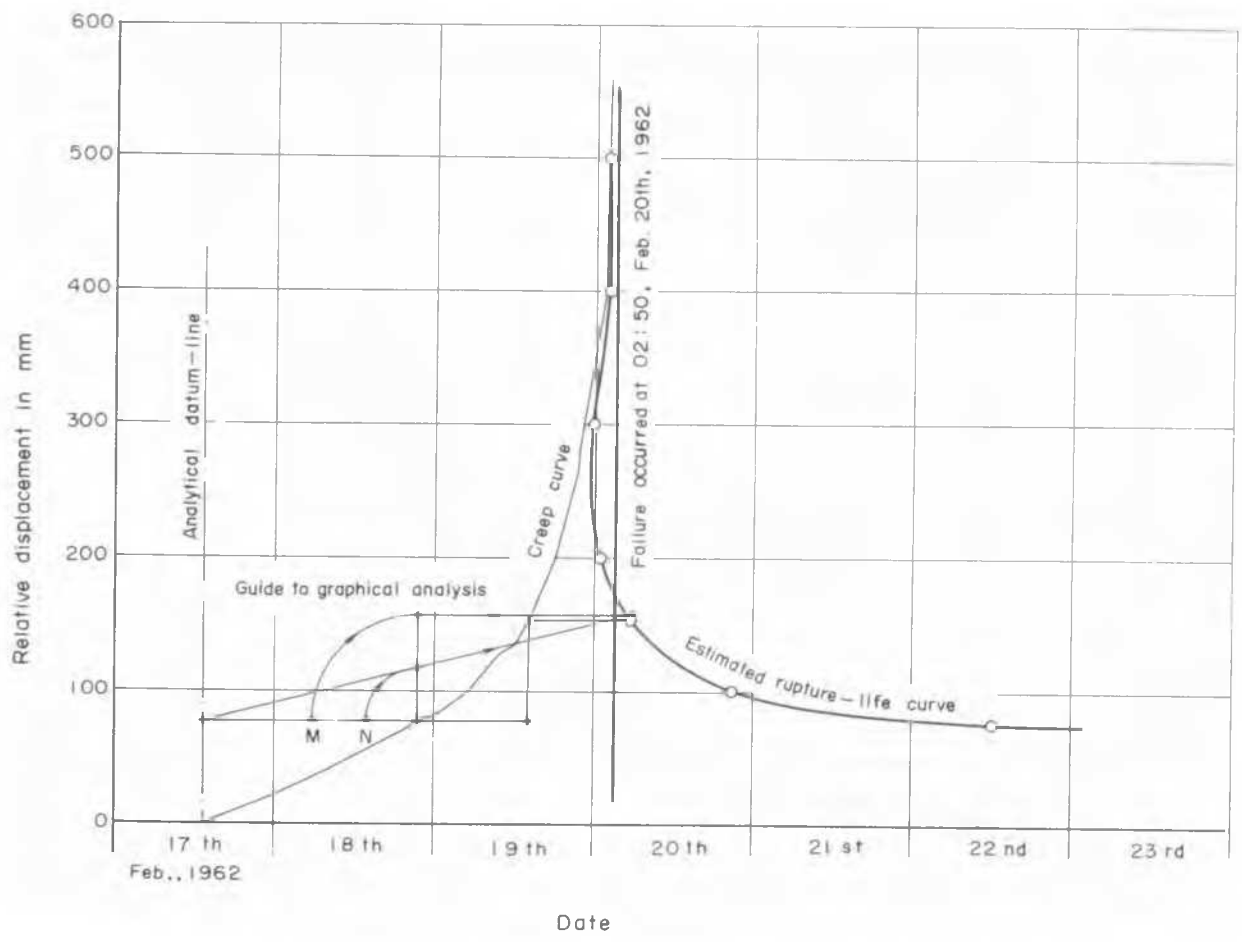

Fig. 5 Slope failure on the Dosan Line

Collapse of a Large Retaining Wall on the Ooigawa Railroads.

The detailed progress of collapse of a retaining wall was informed in the previous Proceedings. In this case 10 days' record before collapse was obtained besides the long-term records explained before. Fig. 4 is the results of graphical analysis for 10 days' record, and shows good approaching to the fatal line.

Slope Failure on the Dosan Line.

The detailed progress of slope failure on the Dosan Line was also informed in the previous Proceedings. Fig. 5 is the results of graphical analysis for the same record, and shows exceedingly good approaching to the fatal line, even for short duration of measurement.

Slide of a Slope on the Sōya Line.

This is an example of non-slipdown in spite of fairly rapid movement, and also reported in the previous Proceedings. Fig. 6 is the result of graphical analysis, and in this case rupture-life curve shows a tendency to proceed to one direction, without approaching asymptotically to the specific date-line. This characteristics may be utilized to identify unstable slope of non-slipdown.

CONCLUSION

On the basis of above-mentioned facts, the conclusion is deduced that reliable estimation for the time of occurrence of slope failure is expected by means of the substituted logarithmic curve, Eq. (5), in the tertiary creep range, and the nearer failure comes, the more reliable estimation is obtained.

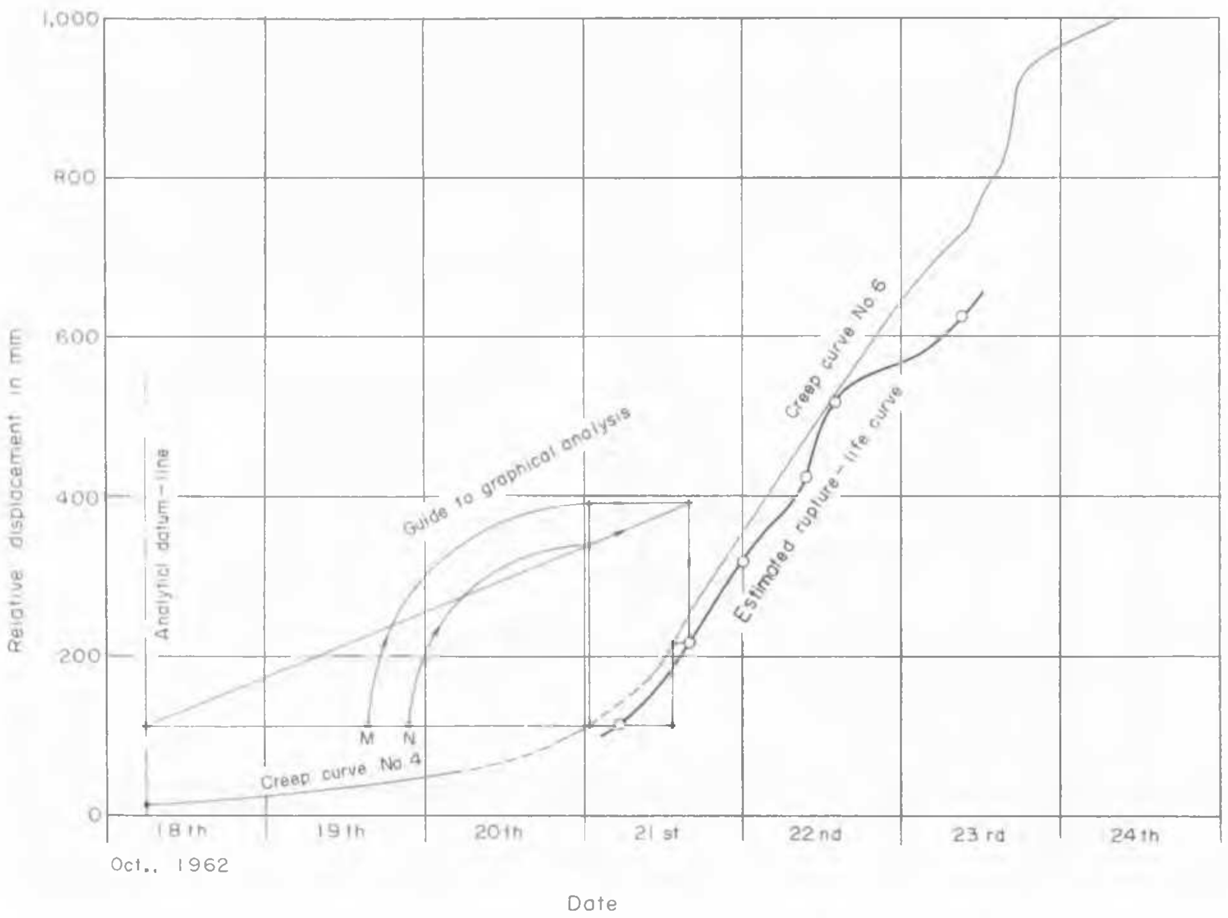

Fig. 6 Slide of a slope on the Sōya Line

The author does not mean that the proposed method will take the place of the former one estimated with steady-state strain rate. Each method has its own range of application according to the creep stage.

It is, therefore, advisable that the time of occurrence of slope failure is roughly estimated with steady-state strain rate in the secondary creep range, and precisely estimated with transient strain rate at optional time in the tertiary creep range.

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