Forecasting the Time of Occurrence of a Slope Failure

Prédiction du moment où se produira la rupture d'un talus

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SUMMARY

The author has examined the records of field measurements of slope failures and has confirmed that the relationship between strain rate and time of creep rupture life obtained in the laboratory is also applicable to actual slope failure. The author concludes, therefore, that forecasting the time of occurrence of slope failure is possible by measuring the surface strain of slopes.

SOMMAIRE

L'auteur a examiné les relevés des mesures sur place de la rupture des talus et a confirmé que la relation entre la vitesse de déformation et le moment de rupture par fluage obtenus au laboratoire est aussi appropriée à la rupture d'un talus réel. Donc il estime qu'il est possible de prédire le moment où se produira la rupture par la mesure des déformations de la surface des talus.

ANY INDICATION OF INSTABILITY of a slope close to a railway line will always cause some difficulties in train operation. It might be best if movement of the slope could be stopped soon, but this is rather difficult in most cases, especially when the area of the unstable slope is large. In such a case, a slowdown of train traffic is usually adopted in order to prevent accidents, but such restrictions cannot continue too long because of the necessity of transportation. It is, therefore, necessary to elucidate how and when sudden movement or failure of a slope will occur, in order to avoid unreasonable regulation of train operation.

OBSERVATION OF UNSTABLE SLOPES

It is only rarely that slope failure will occur suddenly, and without any previous indications. In most cases, several tension or shear cracks around the unstable area, or slight displacement and deformation of structures situated on the area will appear prior to failure. It may be fairly difficult to find such indications, however, or to continue watching them for a long period in cases of slight movement, or to have enough time to try possible means in case of rapid movement. In any of these cases, failure seems a sudden occurrence. It is, therefore, necessary to make an effort to find indications of unstable slopes, and to express them quantitatively through observation, in order to obtain measures of forecasting slope failure.

At the sites of unstable slopes, horizontal and vertical displacement, inclination, strain, and width of cracks on the surface of slopes are commonly measured, using proper devices, and sometimes observation on subsurface inclination, groundwater level, and quantity of drained water are added to the above measurements at the landslide area. It is very difficult, however, to obtain enough data to find a means of forecasting only through field observations, because there are so few chances to encounter such an occurrence at the site of observation.

PROCEDURES TO FIND FACTORS RELATED TO FORECASTING

An attempt was made, then, to find factors related to forecasting through full-scale experiments in the field, in which test slopes were made to fail by sprinkling water on them, and the behaviour of these slopes was measured with proper devices throughout the tests. An example of measured values is shown in Fig. 1. It can be seen that both strain and inclination on the surface of slopes show remarkable movement far before failure occurs; earth pressure in the slope, on the other hand, shows remarkable change only just before failure. The moisture content of the soil of the slope continues to change only gradually to the very end, although this is not shown in the figure. Therefore, strain and/or inclination can be adopted as forecasting factors. Strain is considered superior to inclination, because the change of inclination is gradual while that of strain is very sharp, and also because the strain characteristics of soils can be investigated with specimens in a laboratory.

Displacement itself is, of course, a hopeful factor in forecasting, but continuous recording of displacement at optimum points is very difficult if the unstable area is fairly large. For this reason, it was not adopted as a factor this time.

Based on the foregoing analysis, the creep-failure characteristics of soil were studied in the laboratory, and a relationship between strain rate and rupture life due to creep was found experimentally. This relationship seems to be independent of the type of soil or testing method and is also valid for test results carried out in other institutes, including those in foreign countries.

This result has been reported previously (Saito and Uezawa, 1961), and the relationship is expressed as follows:

$$\log_{10} t_r = 2.33 - 0.916 \log_{10} \dot{\epsilon} \pm 0.59$$

where t_r = creep rupture life in min. and $\dot{\epsilon}$ = constant strain rate in 10^{-4}/min. If this relationship is applicable to actual cases, it may be considered the most promising means of forecasting the time of slope failure at the present time.

EXAMINATION OF ACTUAL RECORDS

It is necessary to examine the field records of actual failures in order to verify the applicability of the creep rupture relationship to forecasting.

Collapse of a Large Retaining Wall on the Ooigawa Railroad

A retaining wall, 16 m high and 140 m long, on the Ooigawa Railroad had been surveyed for precautionary reasons several times a year, but no unusual indications of distress of the wall were found until September 30, 1960, when a narrow crack appeared on the roadbed across the track, although the wall showed no movement in any direction. From that time, the movement of the wall was

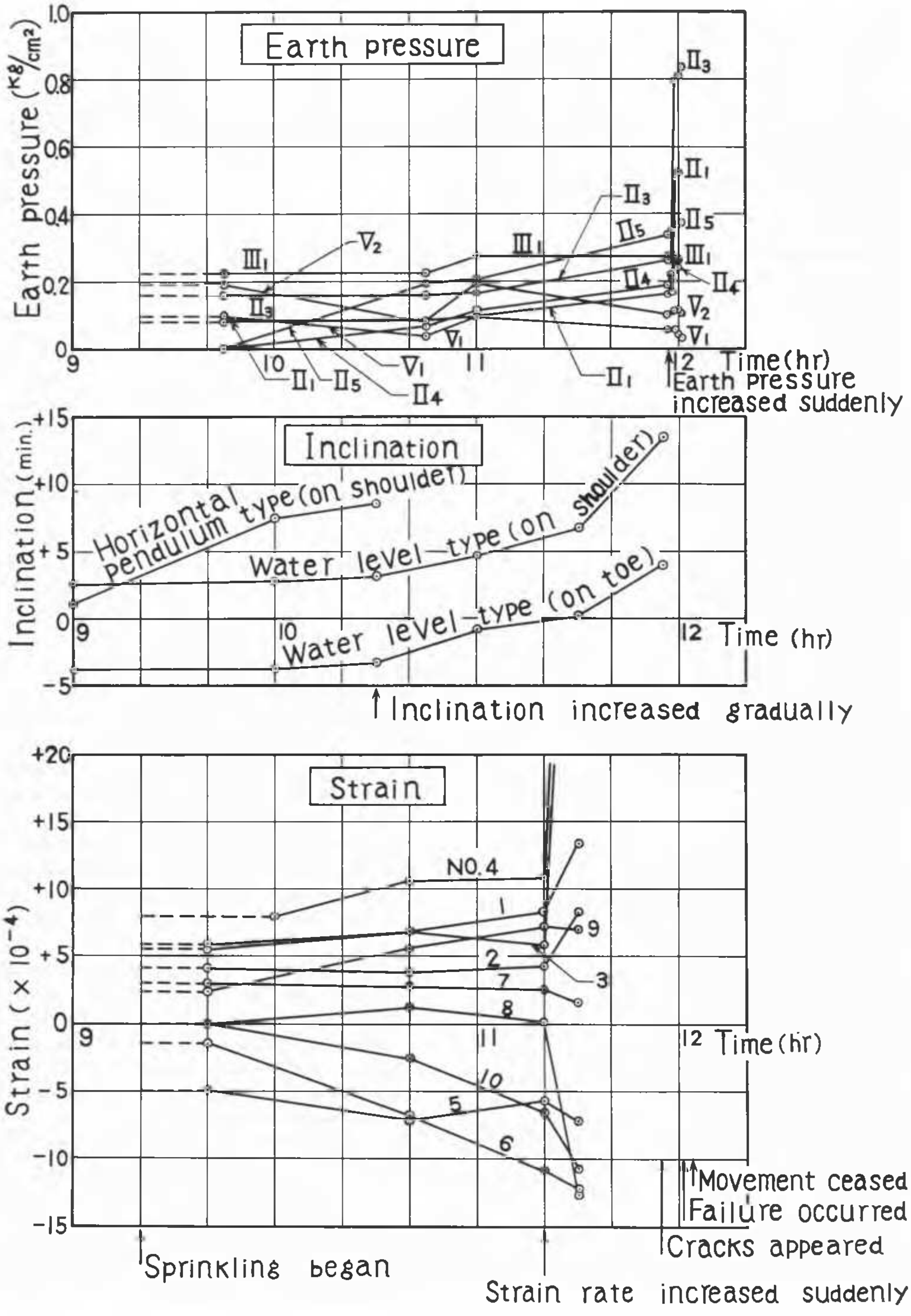

FIG. 1. An example of the results of full-scale experiments of slope failure in the field.

measured with surveying instruments every five days; the result of these observations is shown in Fig. 2. The displacement of the wall was small at first, but suddenly became large and maintained a constant rate at each point of the top of the wall. The rate increased still more after December 9, and the middle portion of the wall, 37 m long, fell down at 4:05 on December 14. In Fig. 2, Nos. 5, 6, 7, and 8 are located on the collapsed portion, while the others are on the remaining portion of the wall.

To convert displacement to strain, the distance between the retaining wall and the hillside, remaining after collapse and opposite to the wall in relation to the railroad track, was used as a basis. The values of calculated strain rate are shown in the figure. Creep rupture life was taken as the length of time from November 20 to December 14. The constant strain rate and the corresponding creep rupture life are plotted to a log-log scale on Fig. 5. The results show fairly good coincidence with the relation obtained in the laboratory tests.

In this case forecasting was successful and railroad traffic was interrupted at 10:30 on December 13, the day before the collapse.

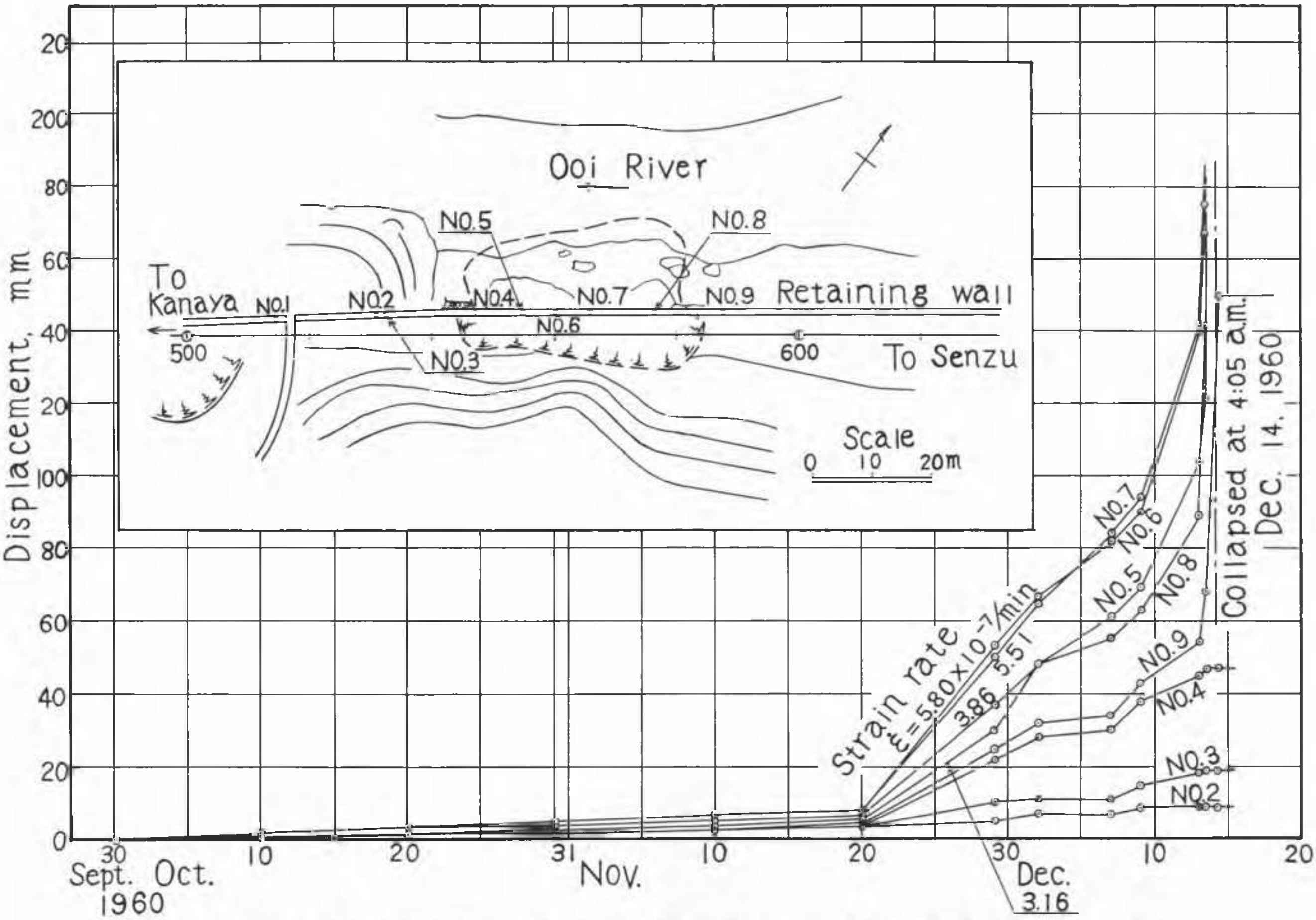

FIG. 2. Results of field measurement of collapse of a large retaining wall on the Ooigawa Railroad.

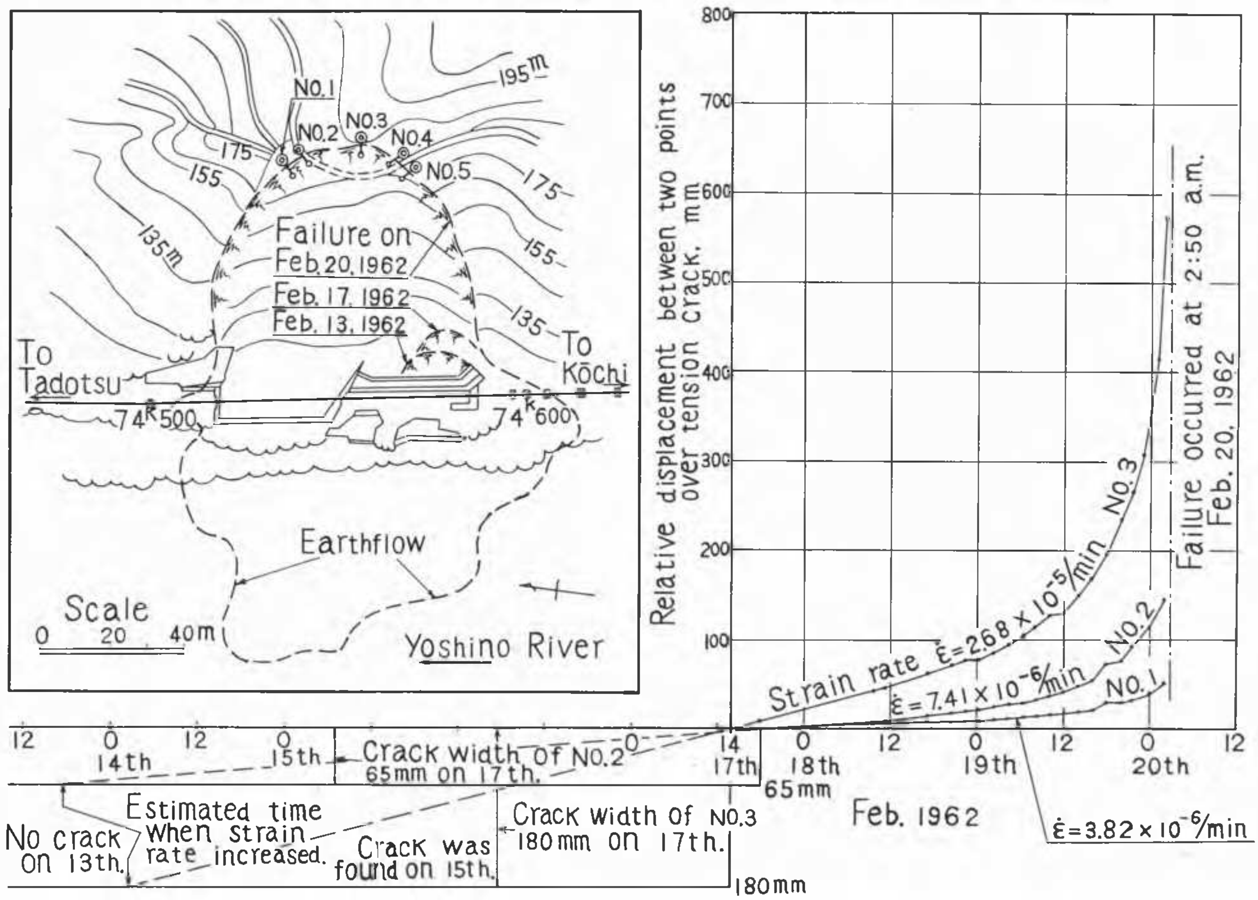

FIG. 3. Results of field measurement of a slope failure on the Dosan Line.

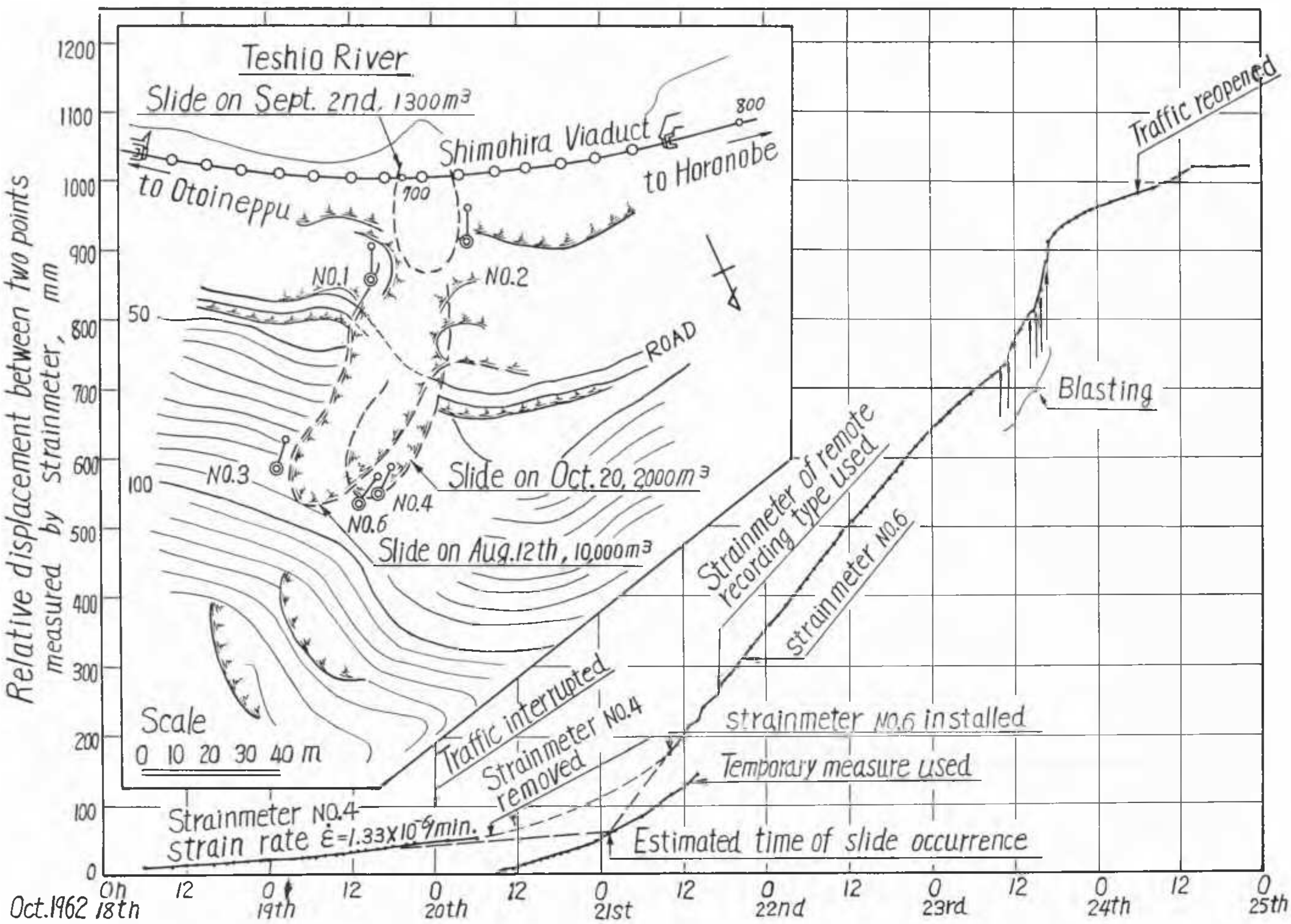

FIG. 4. Results of field measurement of a slide of a slope on the Sōya Line.

Slope Failure on the Dosan Line

The Dosan Line runs along a transversely eroded valley of crystalline schist, and consequently suffers frequently from slope failures and landslides. At the site in question, a slope failure occurred in 1948 and a train running onto the earthflow was derailed. After the disaster this portion of the railroad line was protected with a rockfall cover and retaining walls.

At the same site, a slope failure, covering a larger area but including the former site, occurred in February, 1962, and railway traffic was interrupted for 41 days. This time the failure occurred in three parts; the first on February 13, with an earth slide 600 cu.m. in volume, the second on February 17, with a volume of 200 cu.m., and the third before dawn on February 20, with an earthflow of 60,000 cu.m. which resulted in the destruction of the rockfall cover and the burial of 85 m of track.

No deformations or cracks were found on the slope by patrol around the site just after the first failure, but on the fifteenth tension cracks were found about 100 m above on the slope by a second patrol. Five sets of strain meters were then placed across the cracks on the seventeenth. Subsequent records of the strain meters are shown in Fig. 3 and these show that the strain rate was constant throughout the eighteenth, but the rate gradually increased on the nineteenth and failure occurred at 2:50 on the twentieth.

Supposing that the constant strain rate had been maintained from the beginning, the time of sudden increase of strain can be determined as the point of intersection between the straight line of constant strain rate and the line parallel to the abscissa having the distance equal to the width of the crack as shown in Fig. 3. Thus, it may be determined that the sudden increase of strain began at midnight of the thirteenth which is considered reasonable judging from the time of appearance of the cracks. Plotting the values of constant strain rate and the corresponding creep rupture life on Fig. 5, we can find the position fairly adequately. The discrepancy from the line of mean value is considered to result from too short a length of base line of the strain meter, as 1.0 to 1.5 m.

Slide of a Slope on the Sōya Line

A slope along the Sōya Line of Hokkaido caused a slide in August, 1962, after being struck by a typhoon. As the circumference of the site seemed unstable, observations were continued with strain meters after the slide. The remaining portion of the slope showed continuous slight movement, but the strain rate suddenly increased after October 18, reaching the value of 1.33×10^{-6}/min. Railway traffic was stopped at 0:00 on the twentieth, and after that the movement became larger. Strain meter No. 4 at the site was removed for fear of loss of data at the time of slide, but soon after was reset with strain meter No. 6. The interrupted record was filled with a temporary measure. Since lengthy interruption of traffic was not possible, removal of the sliding earth mass with explosives was tried. This was not successful, but the

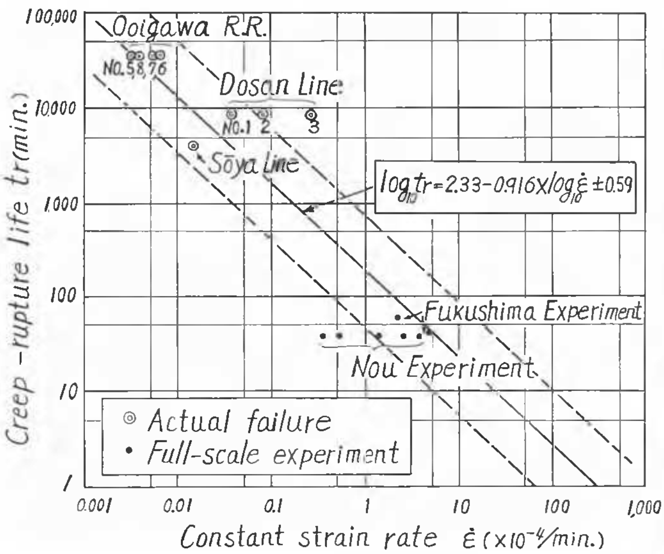

FIG. 5. Comparison of results of field measurement with the relationship between strain rate and creep rupture life.

movement decreased to zero and the railway was reopened on the twenty-fourth.

Referring to Fig. 4, the time of slide occurrence was estimated as that corresponding to the intersection of the extensions of the two straight parts of the displacement curve. In this case the measured value has good coincidence with the aforementioned relationship, as seen in Fig. 5.

In this connection, the results of full-scale experiments are shown again in Fig. 5, and it is well understood that long-term records can be obtained only through observation of actual slides.

Case of No Failure

There are many more examples in which no failure occurred in spite of long-term observation. During the construction of the New Tōkaidō Line, a potential failure condition was created by driving a tunnel just under the slope. Observation with strain meters was continued for 8 months, the whole period of construction, and the strain rate was usually less than 10^{-8}/min, though settlement of the ground surface attained a maximum of 8 cm just above the tunnel.

During a heavy rain, totalling 150 mm in 3 hours, the strain rate attained a value of 3×10^{-6}/min. If this heavy rain had continued, the slope might have failed in about one day. Fortunately, however, the strain rate decreased rapidly with the cessation of the heavy rain.

A PROPOSAL FOR FORECASTING SLOPE FAILURE

Each record shows the existence of constant strain rate of considerable duration before failure. No jump is seen on the occasion of the shift from the normal to the unstable state with constant strain rate, so the time of this shift can be easily found by extending the neighbouring straight parts of the relative displacement curve. On the other hand, the relationship obtained in the laboratory has shown fairly good coincidence with field observations. It may be said, therefore, that forecasting the time of slope failure is possible by the following procedures:

1. Measurement of the relative displacements of a slope across tension cracks or along the centre line, depending on field conditions.
2. Determination of the beginning of unstable state of the slope through the relative displacement curve.

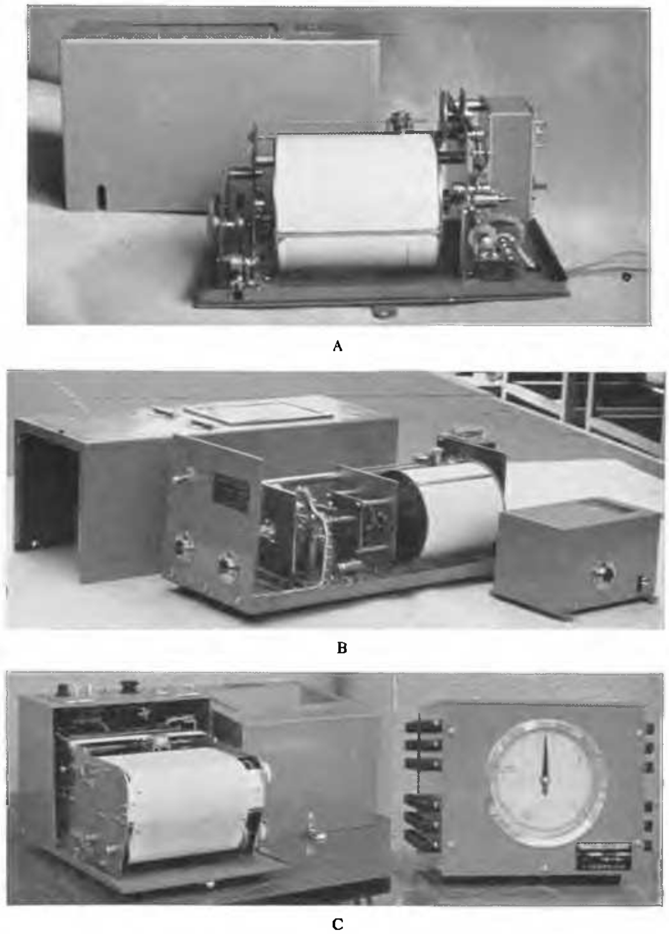

FIG. 6. Strain meters. A, Direct recorder; B, single remote recorder; C, multiple remote recorder.

3. Calculation of the constant strain rate from the relative displacement curve.
4. Estimation of creep rupture life corresponding to the strain rate, using the relationship between strain rate and creep rupture life.

It is necessary to measure the relative displacement continuously in order to use it for the purpose of forecasting. Several kinds of strain meters have been developed and are shown in Fig. 6, where A shows a direct recorder, used at a site which is easily accessible, B a single remote recorder, used at a site where access is difficult, and C a multiple remote recorder, for making concentrated observations.

The principle of these devices is that relative displacement is converted to revolution of a recording drum or a pointer or indicator through super-invar wire stretched between two stakes, and a recording pen or a dot-marker moves on recording paper by clockwork or by motor drive. Recorders of these types are now widely used in our country for various purposes.

CONCLUSIONS

The relationship obtained in the laboratory is also applicable to actual failures. It may be presumed therefore that forecasting of the time of slope failure is possible by measuring the surface strain of slopes.

REFERENCE

SAITO, M., and H. UEZAWA (1961). Failure of soil due to creep. *Proc. Fifth International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1, pp. 315–18.