

CREEP AND RELAXATION BEHAVIOR OF HIGHLY ORGANIC SOIL

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ABSTRACT: Because of the limited land area in Japan, many structures are built on peat and/or highly organic soft ground. These soils are well known for exhibiting large settlement and secondary compression during and after construction. Preloading is suitable for ground improvement of peat and highly organic soil, as well as clay.

The author has performed a series of laboratory loading and/or unloading creep tests that simulate actual preloading method for peat and silty clay which samples collected in Japan. Previously, the author reported that the characteristics of long-term creep settlement after unloading (rebound ratio, rate of secondary compression and re-settlement point) are affected by the over consolidation ratio, preloading time and plasticity index [1], [2]. In this paper, the experimental data from loading and/or unloading creep tests and stress relaxation tests are used to further explore the behavior of highly organic soil

Keywords: Peat, Highly organic soil, Preloading method, Creep Settlement, Stress Relaxation

1. INTRODUCTION

Recently, urban development has been brisk around large cities in Japan. Because of the limited land area, many structures are built on peat and/or highly organic soft ground, which used to be a marsh. Highly organic soil is known for its large compressibility during and after construction.

In addition, many areas along Pacific Ocean were damaged by tsunami at the time of the Great East Japan Earthquake in 2011. Therefore, developments of new revival residential land have been constructed inland and at higher places from the coastal line to prevent damage caused by tsunami. Many developments have been made inland and on higher ground that was formerly used for rice paddies or marsh. Due to the construction on highly organic soil, a geotechnical problem of large long-term settlement often occurs after construction. This paper focuses on improving the long-term settlement of soft soil by using the conventional preloading method. The effect of preloading was considered on the basis of the results of two types of experiments, i.e. the creep tests with loading and/or unloading, and the stress relaxation test that tolerates no settlement during secondary compression period by reducing the consolidation pressure.

The two tests are used to clarify the reduction of long-term settlement generated after unloading the preload.

The determination of OCR (over consolidation ratio) is often a difficult problem in the design of the

preloading method, because there are only a few studies related to design and construction preloading that consider large long-term settlement for highly organic soils (e.g. Kamao et-al. [1], [2] and Fukazawa et-al. [3], [4]).

2. USED SOIL

Table 1 shows the typical properties of the soil used in this study. The M soil is highly organic soil sampled in Chiba Prefecture near Tokyo. The S soil is silty clay sampled in Tokyo Bay area. The K soil is organic clay that is mixture of the M and S soils.

All specimens were used in remolded condition under reconsolidation pressure of 20 kPa. They were prepared as follows: the water content of the disturbed sample was adjusted to be twice the liquid limit (LL) and then consolidated under the reconsolidation pressure of 20 kPa for approximately two weeks.

Table 1 Soil properties

soil	Specific Gravity Gs	Water Content* w %	Liquid Limit LL %	Plasticity Index PI	Ignition Loss Lig %
M	1.83	431	349	147	35.2
K	2.38	148	155	67	14.5
S	2.60	52	50	18	5.2

* after reconsolidation

3. TEST PROGRAMS

This study considers the long-term settlement of the soft ground as a one-dimensional consolidation phenomena like embankment of a widely spread area without lateral movement. The Creep and the relaxation tests were conducted in the laboratory using a conventional consolidation apparatus using rigid consolidation ring ($\Phi=60\text{mm}$, $h=20\text{mm}$, JIS A 1217).

3.1 The Creep Test

Fig. 1 and Table 2 show the loading scheme and test conditions for the creep test. In the first step, reconsolidation pressure (p_0) of the remolded soil specimen was loaded for 24 h. In the second step, the preload (p_p) was loaded for preloading time t_p . In the last step, Δp load was removed.

The laboratory experiments correspond to the preloading method in the field, OCR, the rate of secondary compression (ϵ_a) and the rebound ratio (ϵ_R) were chosen as parameters for evaluating preloading effects defined in Equations (1), (2) and (3). Other details are shown in Kamao et al. 1995.

$$\text{OCR} = (p_0 + p_p) / (p_0 + p_p - \Delta p) = (p_0 + p_p) / p_f \quad (1)$$

$$\epsilon_a = \Delta \epsilon / \Delta \log t \times 100 (\%) \quad (2)$$

$$\epsilon_R = S_R / S \times 100 (\%) \quad (3)$$

where

p_0 : pre-consolidation pressure (kPa)

p_p : preloading pressure (kPa)

Δp : unloading pressure (kPa)

$\Delta \epsilon$: strain during long-term settlement

S : settlement before unloading (mm)

S_R : rebound due to unloading (mm)

t : elapsed time (min)

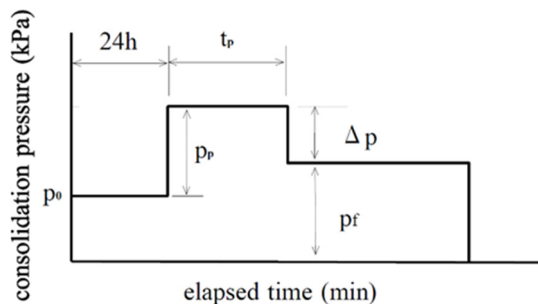


Fig. 1 Loading scheme of the creep test

Table 2 Test conditions for the creep test

p_0 kPa	p_p kPa	t_p min	Δp kPa	OCR -
20	60	60	0	1
			20	1.3
			30	1.6
			40	2
			50	2.7
			75	16

3.2 The Relaxation Test

The relaxation test was performed by reducing a load such that settlement generated in a specimen was eliminated completely when the load was reduced after loading the specimen with a preload of p_p for t_p . The relaxation tests were conducted as shown in Fig. 2 and Table 3. Each case had two relaxation phases (relaxation1 of t_1 and relaxation2 of t_2) at consolidation pressures of p_{p1} (80 kPa) and p_{p2} (160 kPa), respectively. In some cases, residual consolidation pressure was retained for a few weeks after the relaxation period (t_2) to measure the long-term resettlement.

By comparing the creep test and the relaxation test results, the author implemented to make basic data for preloading method considering the long-term settlement of highly organic soil. From the relaxation test, it is possible to get the absolute OCR number which has no long-term settlement.

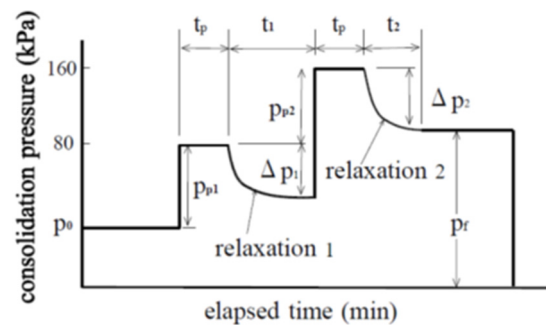


Fig. 2 Loading scheme of the relaxation test

Table 3 Test conditions for the relaxation test

cases	p_0 kPa	p_{p1} kPa	p_{p2} kPa	t_p min	t_1 min	t_2 min
1	20	60	80	120	1440	1440
2					120	720
3					360	360
4					720	120

4. EXPERIMENTAL RESULTS

4.1 Results of the Creep Test

Fig. 3 shows typical experimental results ($S - \log t$ curves) of the creep test. With removal of the preload at time t_p , rebound due to swelling occurred immediately for all OCRs except OCR = 1.0. Then, resettlement was observed after the rebound phase for all OCRs except the OCR = 16.0. Secondary long-term settlement seems linear relationship with logarithm of time.

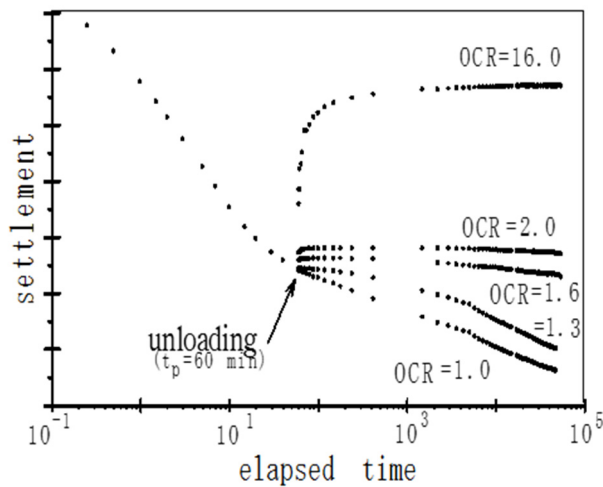


Fig. 3 Experimental results of the creep test

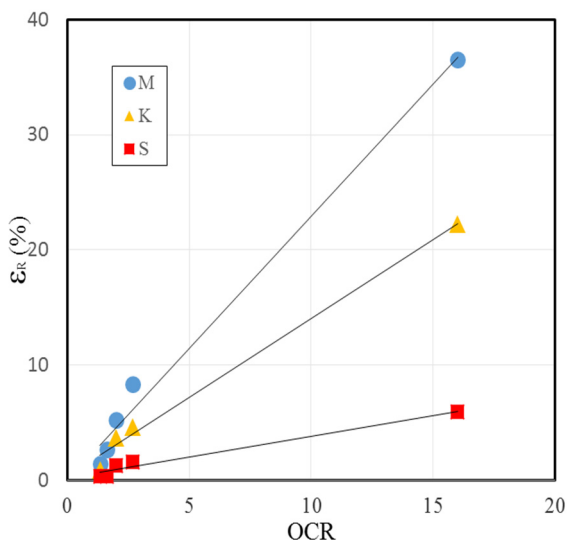


Fig. 4 Relationship between ϵ_R and OCR (1 < OCR < 16)

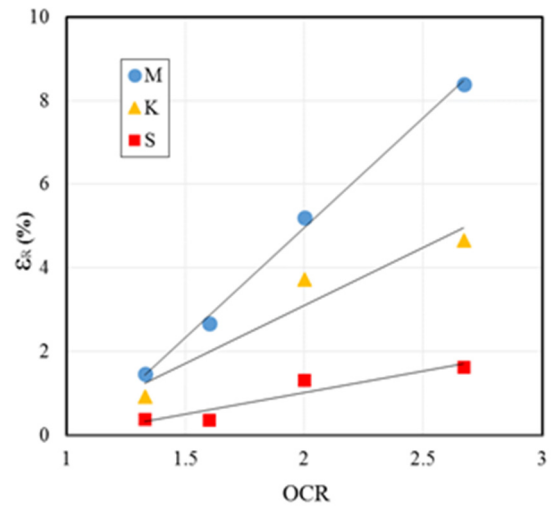


Fig. 5 Relationship between ϵ_R and OCR (1 < OCR < 3)

Relationships between the rebound ratio (ϵ_R) and OCR are shown in Figs. 4 and 5. Fig. 5 shows the details of Fig. 4.

From these figures, linear relationships between rebound ratio (ϵ_R) and OCR are obtained for each soil. The amount of rebound for soil M is 5 to 6 times larger than that for soil S and 1.6 to 1.8 times larger than that for soil K. The value of ϵ_R depends on the plasticity index (PI) of the soil.

The rate of secondary compression (ϵ_a) is defined by Equation (2). Fig. 6 shows the relationship between ϵ_a and OCR. The rate of secondary compression (ϵ_a) decreases with increase of OCR. The reduction ratio (R) of the rate of secondary compression, which is seen in Fig. 6, is defined as the ratio of ϵ_a and $\epsilon_{a, OCR=1.0}$, as indicated by Equation (4). These values can help evaluate the preloading effect.

The relationship between R and OCR is shown in Fig. 7. The optimum OCR (i.e., which minimizes resettlement) was approximately 2.0 to 2.5 for all types of soil. Fukazawa et-al. [3] reported the optimum OCR as approximately 1.3 to 1.5 in field measurement data. Laboratory data from the present study tended to a larger OCR number than the field data of Fukazawa et-al. [3]. The reason for this difference is considered to be the difference in the condition of the specimen. The disturbed specimen for this study has weaker soil structure than undisturbed field deposits (e. g., see Kamao [1]).

$$R = \{1 - (\epsilon_a / \epsilon_{a, OCR=1.0})\} \times 100 (\%) \quad (4)$$

where

ϵ_a : rate of secondary compression

$\epsilon_{a, OCR=1.0}$: rate of secondary compression at OCR = 1.0

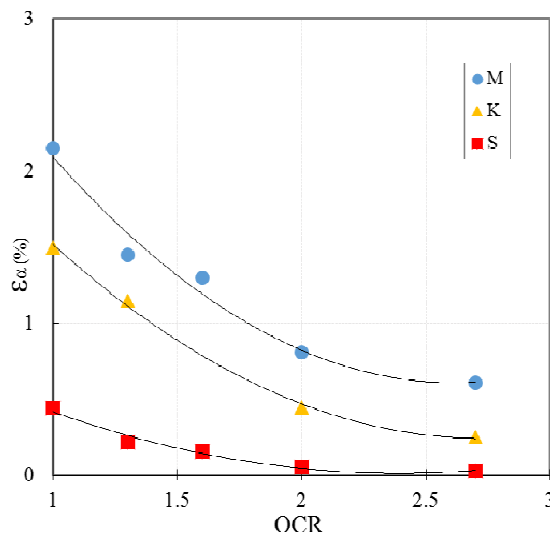


Fig. 6 Relationship between ε_a and OCR ($1 < OCR < 3$)

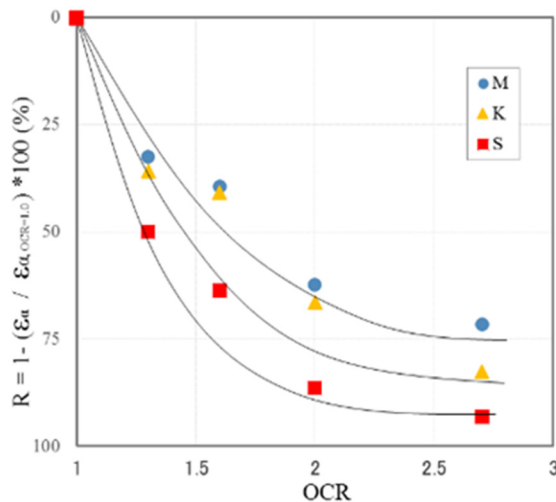


Fig. 7 Relationship between reduction ratio (R) and OCR

4.2 Results of the Relaxation Test

Figs. 8, and 9 show typical experimental results of the relaxation test. Fig. 8 shows the relationship between settlement and elapsed time before and after the relaxation phase (relaxation time is 120 min). Fig. 9 shows the relationship between consolidation pressure and relaxation time. From these figures, it can be seen that no settlement occurs after the start of relaxation time (Fig. 8), and significant reduction of the consolidation pressure was observed for all three types of soil, immediately

after shifting to the relaxation phase. Then consolidation pressure gradually decreased with relaxation time to keep settlement zero (Fig. 9). Reductions were achieved by stemming rapid settlement just before shifting to the relaxation phase, proving preferable and controlling operation.

It is difficult to estimate the final decreased consolidation pressure from Fig. 9, because the consolidation pressure decreases gradually with relaxation time. The relationship between consolidation pressure p and the logarithm of the relaxation time t_1 is linear at the latter part of the test, as shown in Fig. 10. The slopes of the latter p -log t curves (p/t) in Fig. 10 are similar to the secondary compression settlement in Fig. 3. The magnitude of the linear slope, seems to be proportional to the amount of secondary consolidation settlement. Fig. 11 shows the linear relationship between estimated residual consolidation pressure p_r and the Plasticity Index (PI) of the soil. The decreased consolidation pressure Δp_1 (Δp_2) in Fig. 2, which was defined as the consolidation pressure at $t=10^5$ min by extending the straight line of the latter part of the test, is shown in Table 4. This number ($t=10^5$ min) was determined in consideration of the elapsed time of the creep test. The final decreased consolidation pressure is similar to the unloading of the creep test shown in Fig. 1. Using residual consolidation pressure $p_r (= p_0 + p_{p1} - \Delta p_1)$, “the absolute OCR” (i.e., which means no long-term settlement ($\varepsilon_a = 0$) during the relaxation phase) was calculated for each soil using Equation (1). The calculated absolute OCRs are shown in Table 4, also. The relationships between the absolute OCR and PI for different soils are shown in Fig. 12. Regardless of the consolidation pressure p_p , number of the absolute OCR is well correlated with PI of soil.

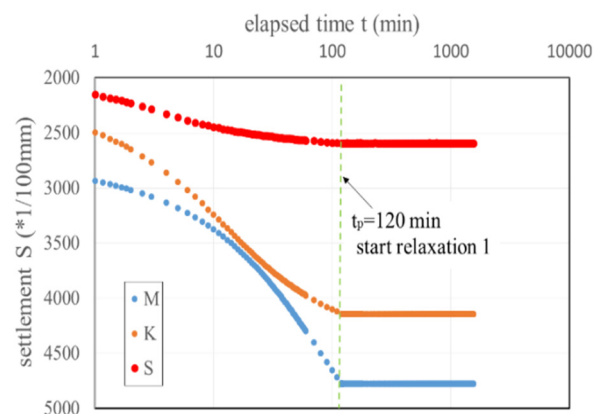


Fig. 8 Experimental result of the relaxation test ($s - \log t$ curves)

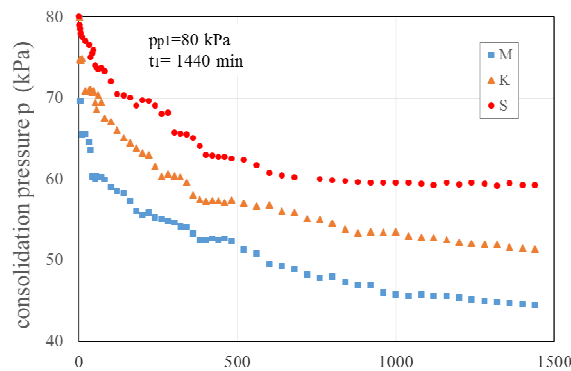


Fig. 9 Experimental result of the relaxation test (p - t curves)

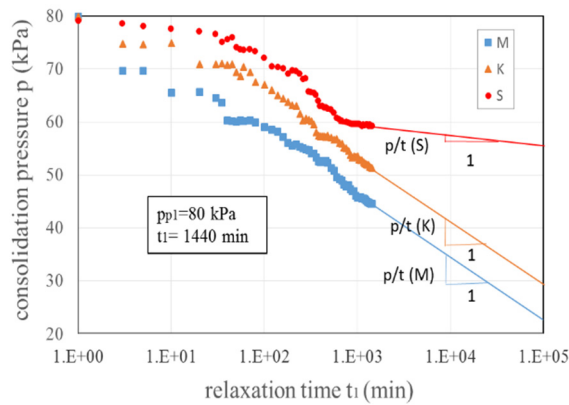


Fig. 10 Experimental result of the relaxation test (p - log t curves)

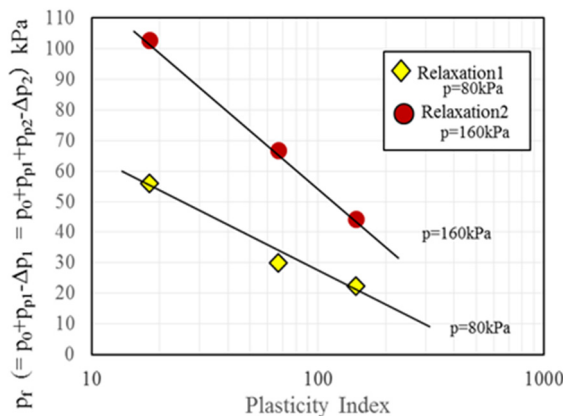


Fig. 11 Relationship between p/t and PI from the relaxation test

Table 4 Estimated residual consolidation pressure and calculated absolute OCR at the relaxation time of 10^4 - 10^5 min

$P_{p1} \cdot P_{p2}$	Types of soil		
	M	K	S
80	22.5 (3.56)	30 (2.67)	56 (1.42)
160	44.3(3.61)	67 (2.40)	102.9 (1.55)
average OCR	(3.59)	(2.54)	(1.49)

unit: kPa, ():OCR

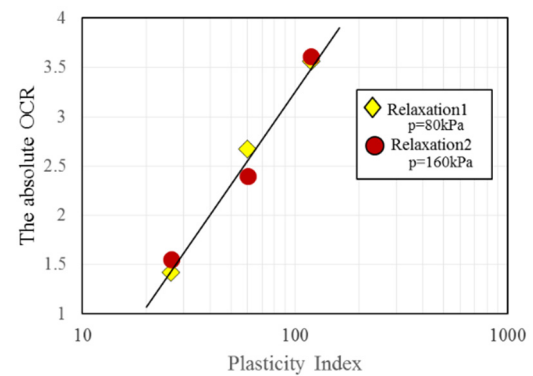


Fig. 12 Relationship between calculated absolute OCR and PI from relaxation test

5. DISCUSSION

The OCR of the preloading method is discussed by comparing the creep test with relaxation test. The absolute OCR (which has no long-term settlement ($\epsilon_a=0$)) is 3.5-3.7 for highly organic soil (M). For silty clay (S) and organic clay (K), absolute OCRs are 2.4-2.7 and 1.4-1.6, respectively.

These absolute OCRs were plotted on the creep test result (Fig. 7), as shown in Fig. 13. For $\epsilon_a=0$ (absolute OCR), the reduction ratio (R) become 100(%) from Equation (4). Black stars on the figure indicate the absolute OCR from the relaxation test. The tendency lines are re-described like dotted liens.

Fig. 13 shows the tendency lines of the relaxation test are steeper than the creep test data. The differences between the relaxation test and the creep test are caused by the speed of unloading (rapid or slow unloading) and duration of loading. The estimation method for the final reduced pressure (Δp_1) also seems to introduce differences.

Rapid unloading (as in the creep test) allowed the specimen to swell and rebound; however, slow

unloading (like relaxation test) did not allow either. Slow unloading took considerable time.

With rapid unloading, the soil structure was disturbed and changed due to the disruption of bonds between particles and aggregates (e. g., Den Haan et-al. [2]). Therefore rapid unloading made the reduction ratio (R) smaller than slow unloading. The difference between laboratory test data and field measurement data have to be considered another chance with additional loading test data.

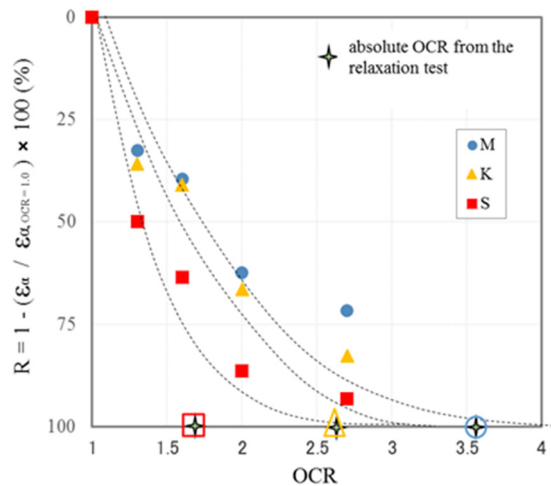


Fig. 13 Relationship between the reduction ratio (R) and OCR

6. COLCLUSIONS

Two series of laboratory model loading and unloading tests were performed against highly organic soil. The following conclusions were reached:

- (1)The creep test showed that the rebound ratio ε_R increases in accordance with increased OCR and the rate of secondary compression ε_α decreases in accordance with increased OCR.
- (2)The optimum OCR (i.e., that which minimize long-term settlement) is approximately 3.5-3.7 to 2.5 for all types of soil from the creep test results.
- (3)The relaxation test showed that reduction of consolidation pressure was well controlled, without settlement and rebound.

(4)The absolute OCR was obtained using estimated residual consolidation pressure.

(5) The absolute OCR was approximately 3.5-3.7 for highly organic soil (M). The tendency line is steeper than the creep test data for this kind of soil.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

- [1] Kamao, S., Yamada, K., Sato, F. and Aita, K. (1995)
Characteristics of long-term resettlement of soft ground after removal of the preload. International Symposium on Compression and Consolidation of Clayey Soils. (I.S. Hiroshima): 75-78
- [2] E. J. den Haan, Kamao S. (2003)
Obtaining Isotache parameters from a C. R. S. K0-oedometer. Soils and foundations, vol. 43, No. 4, pp203- 214
- [3] Fukazawa, E. and Monoi, Y. (1998)
Measurement of long-term settlement of highly organic soil improved by preloading. International Symposium on Problematic Soils. (I. S. Tohoku): 75-78
- [4] Fukazawa, E., Yamada, K. and Kurihara, H. (1994)
Predicting long term settlement of highly organic soil ground improved by preloading. Journal of Japanese society civil engineering, No.493, III-27, pp59-68 (in Japanese)

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