Settlement of Clay Subgrades of Low Bank Roads After Opening to Traffic

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SUMMARY. The so called "low bank road" is becoming usual in Japan for various reasons. However, when this type of road is built on a soft clay subgrade or ground, the road itself is apt to be unstable. Firstly this paper summarises the fundamental behaviour of clay under repeated loading in the laboratory, and in the second part reports a case history of a road built as a kind of low bank road on a typical soft alluvial clay ground and which has settled substantially after opening to traffic. As a result of comprehensive investigations, it was proved that the settlement arose mainly from the action of repeated loading by traffic. Finally some countermeasures against such a settlement are suggested depending on the concept of restraining a soft subgrade or ground of low bearing capacity.

1 INTRODUCTION

Bjerrum (Ref. 1) and the authors (Ref. 2 & 3) have indicated that soft saturated clay subjected to repeated loading shows a significantly different behaviour in its settlement from that under static loading. Especially, it is emphasised that the total settlement is increased under repeated loading due to secondary compression prevailing over primary consolidation.

Recently the low bank road has often been adopted in Japan for various reasons, and no concern arises about the road when it is built on firm ground. However, low bank roads have sometimes been built on soft clay ground also, without the above-indicated behaviour being taken into consideration in its design, only CBR.

This paper reports on an abnormally large settlement, as much as nearly 2 m over a length of 1700 m which has arisen in a national highway, Route No. 207, Saga Prefecture, Kyushu, built on a typical soft alluvial clay ground called "Ariake clay deposit" in a type of low bank road. The cause of the settlement was investigated by comparing the actually observed settlement in the field with the amount of settlement which was estimated by relating the test results on the samples taken from the field with the past traffic data on the road.

2 NOTATION

- p Consolidation load
- p_o Precompression load in distrubed sample
- p_{or} Precompression load given by repeated loading
- p_{os} Precompression load given by static loading
- p_r Repeated Load
- p_{ry} Yield stress in consolidation after repeated loading
- p_s Static consolidation load
- p_{sy} Yield stress in consolidation after statically consolidated
- p_y Yield stress in consolidation
- ε_e Resilient strain
- ε_p Unrecoverable strain
- ε_t Total strain

3 BEHAVIOUR OF CLAY UNDER REPEATED LOADING

Here the authors summarise the fundamental study that was carried out using a specially devised one-dimensional consolidated apparatus. Special new findings are reported in comparative detail even though these might not be directly applicable to a case history such as stated in the later section, inasmuch as this section aims at giving a concept of the effects of repeated loading.

The apparatus used in this study is not unlike the standard oedometer except for being capable of repeated-vertical loading of 5 sec to 60 sec a cycle.

(a) Behaviour During Repeated Loading

(i) Time-settlement relationship

When the settlement under repeated loading is compared with the one under static loading for the same magnitudes of load and duration, we find that repeated loading brings about a larger total settlement than the one under static loading, secondary compression prevailing over primary consolidation (Ref. 1, 2 & 3). However, in an alluvial organic clay containing about 10% organic matter total settlement was decreased, and hence primary consolidation is decreased. This may be accounted for as the result of a large swelling at every moment of unloading in each cycle.

(ii) Effect of initial soil structure

Using the coefficient of permeability in the equation by Kozeny-Carman, it was shown that structural change is decreased in initially oriented clays as opposed to that of clays with random structure which are largely changed in their structure under repeated loading (Ref. 2 & 3).

(iii) Relation between resilient deformation and irrecoverable deformation

Among resilent strain ε_e, irrecoverable strain ε_p and total strain ε_t, ε_e shows a tendency to become constant or to decrease, and ε_p is substantially increased with the number of cycles of repeated loading resulting in increase of ε_t, as shown by Fig. 1. Therefore, final settlement can approximately be determined using a point where $\varepsilon_e/\varepsilon_t \rightarrow 0$ or $\varepsilon_p/\varepsilon_t \rightarrow 1$

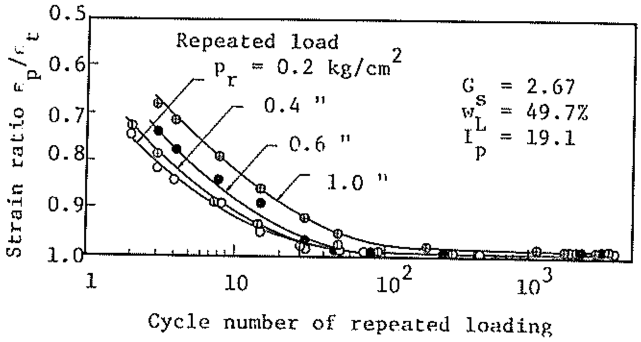


Fig. 1 Change of Strain Ratio During Repeated Loading

on the figure.

(b) Change of Consolidation Characteristics after Repeated Loading

Under repeated loading also as well as under static loading, such values as yield stress in consolidation p_y, coefficient of volume compressibility m_v and undrained shear strength c_u (or unconfined compressive strength q_u) are changed, accompanied by a change of soil structure.

(i) Yield stress in consolidation

According to the initial stress condition of the sample and the repeated load conditions as sketched in Fig. 2, the precompression load p_o is changed as a result of memorising the repeated load p_r. However there will be an error in determining the yield stress in consolidation p_y from derived e-log p curves obtained from the standard oedometer test.

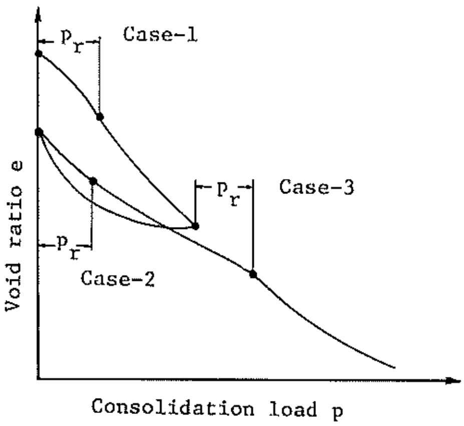


Fig. 2 Key Sketch of the Three Cases of Repeated Loading

Case-1 The case of a remoulded sample subjected to repeated loading. A relation $p_{ry} < p_{or}$ is found between the yield stress in consolidation after repeated loading p_{ry} and the repeated precompression load p_{or} (= 0.2 kg/cm^2). However, a relation $p_{ry} = p_{or}$ is expected to be obtained when the sample is subjected to repeated loading for a sufficiently long time.

Case 2 The case of a natural undisturbed overconsolidated sample subjected to repeated loading. A relation $p_{ry} > p_y$ is found between the yield stress in consolidation after repeated loading p_{ry} and the yield stress in consolidation p_y (= 1.2 kg/cm^2). When a repeated load p_r, relatively large compared with p_y is imposed as an overconsolidated load on the sample, the difference between these two values becomes large. Meantime, when the sample is subjected to a static load p_s as a precompression load, there is a relation $p_{sy} \leq p_y$ between the yield stress in consolidation after static consolidation p_{sy} and the yield stress in consolidation p_y.

Case-3 The case of an undisturbed normally-consolidated sample subjected to repeated loading. When the sample is subjected to a smaller repeated load p_r than the precompression load p_{os} after static consolidation of the undisturbed sample (p_r/p_{os} = 0.5), the following relation was obtained.

$$p_{ry} > (p_{os} + p_r)$$

And, the larger the repeated load period per cycle is, the larger the difference between these two values becomes.

(ii) Coefficient of volume compressibility

It was found that the longer the repeated loading duration is, the larger the coefficient of volume compressibility m_v becomes small under a static consolidation load p_s which is larger than a certain value, as shown in Fig. 3. This change is thought to result from a change of soil structure.

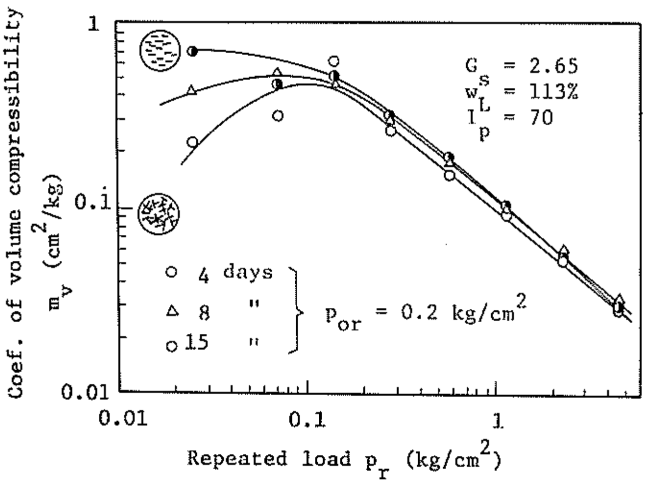


Fig. 3 Change of Coefficient of Volume Compressibility after Repeated Loading

(iii) Undrained shear strength

The ratio of the unconfined compressive strength q_u to the consolidation load p (repeated load p_r or static consolidation load p_s) after loading is shown in Fig. 4 for the cases of repeated loading and static consolidation, and it was shown that repeated loading results in a ratio which is larger than the ratio under static loading. This means that secondary compression also makes the undrained shear strength high.

The initial tangent modulus obtained from the stress-strain curve in an unconfined compressive strength test showed the same tendency as above stated.

4 ABNORMAL SETTLEMENT OF THE PAVEMENT IN A ROAD

The Shiroishi Town part of Route No. 207, National Highway, is located on a typical soft clay ground which is called the "Ariake clay deposit" as shown in Fig. 5(a). Banking of the road was constructed as a by-pass road with a structure as shown in Fig. 5(b) in 1964 and its banking was completed by the end of the year. Before the pavement was

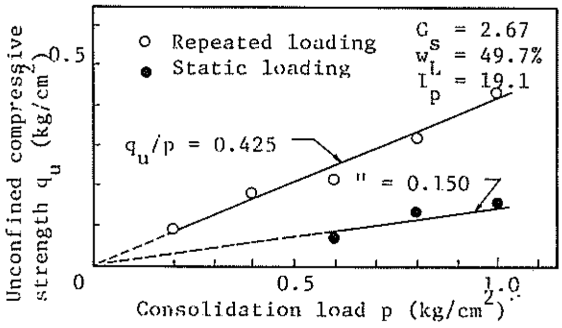
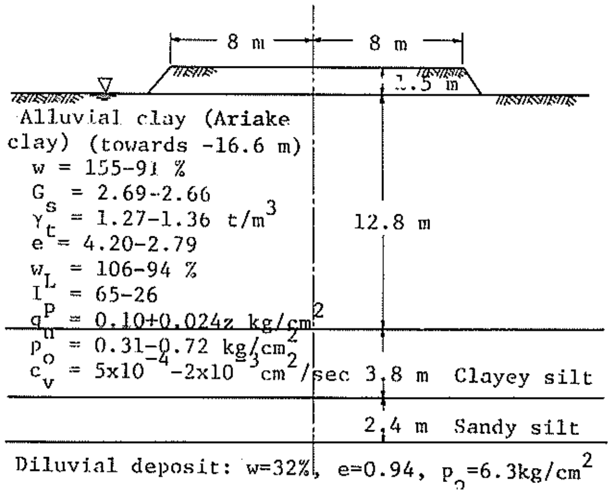
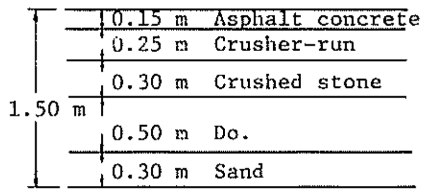


Fig. 4 Comparison of Undrained Shear Strength after Repeated Loading with that after Static Loading

opened to traffic the bank settled as much as 25 cm over the whole length of about 1700 m, and then after 2.5 years the pavement settlement attained 70 cm to 80 cm to the bench mark on an abutment which has been supported on a firm diluvial deposit (-20 m) by means of pile foundations. The successive settlement was shown in Fig. 6 as being finally



(a) Section of the ground.



(b) Section of the road-bank.

Fig. 5 Ground and Bank of the Low Bank Road

nearly as much as 2 m at the maximum. A local heaving as seen in the figure was ascertained to have been caused by over-laying work on the pavement. A scene which shows such a large settlement is shown in Fig. 7.

Such an abnormally large settlement was never anticipated prior to construction, and the administrative office of Saga Prefecture supposed that the settlement arose from a subsidence resulting from the pumping up of underground water for agricultural needs which is considered as one of the causes of subsidences in Japan. The authors considered the effect of repeated loading after opening to traffic as possibly another cause of the settlement.

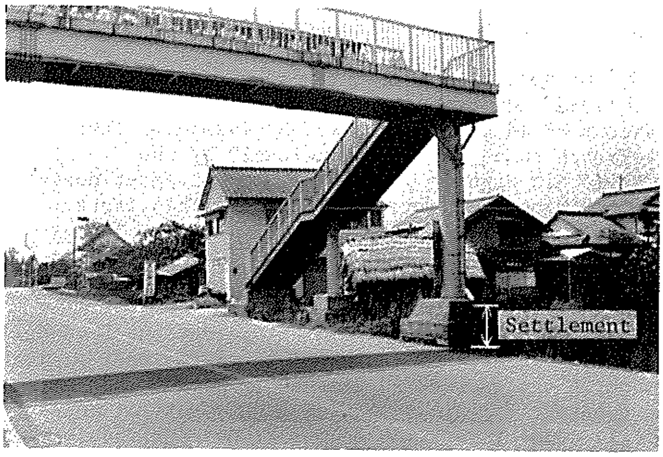


Fig. 7 Differential Settlement of the Pavement to the Foundation of a Pedestrian Bridge, after Over-laying Work

From the actual observations in the field, the following points were indicated by the authors.

(i) Before the over-laying work on the pavement, a rather uneven variation had appeared so that the smooth running of vehicles was bothered.

(ii) The pavement settlement does not reach parts far from the road despite the settlement being so large, but the old houses without foundations along the road are inclined towards the road.

(iii) No heaving occurs on the ground outside the road, and it was concluded that the settlement was a belt-like one.

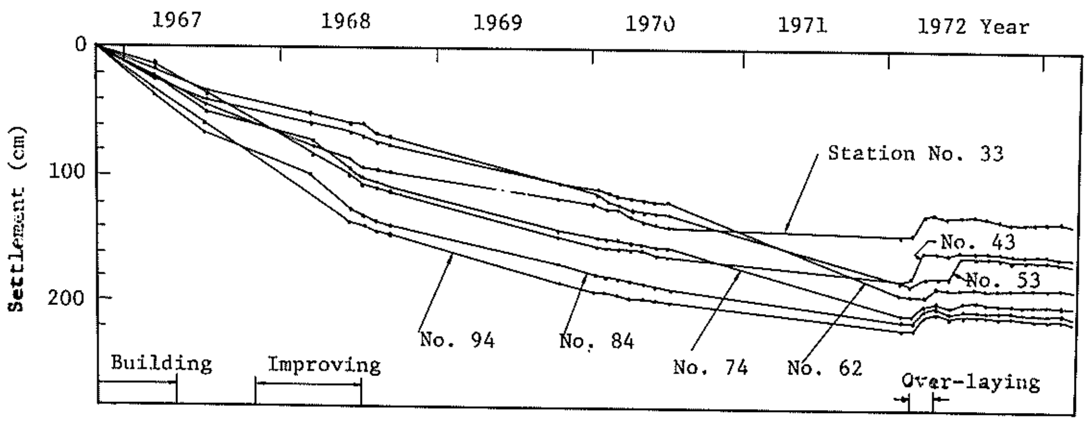


Fig. 6 Actually Observed Settlement of the Pavement

5 PROPERTIES OF THE FIELD CLAY AND THE TRAFFIC DATA

The clay in the ground at Shiroishi Town which is concerned in the present investigation may possibly be of random structure because salt has been leached out for a very long period. The authors carried out a repeated loading test on the samples taken from the ground outside the road using the repeated loading apparatus as beforestated under conditions of a cycle consisting of 20 sec loading and 40 sec unloading, and they obtained a relation between the number of repeated cycles and the irrecoverable settlement. Based on the figures, curves were drawn for the relation between number of cycles of repeated loading, repeated load and settlement, as shown in Fig. 8 in which the relation for a number of cycles so large as to be impossible to test was treated by the method stated in 3 (a) (iii).

Meanwhile, the actual past traffic data was acquired. Here the authors tentatively used a factor HK which was proposed by Takeshita (Ref. 4), referred to as the "traffic index" by the California Highway Department, for pavement design in treating the past traffic data. This factor is as follows:

$$HK = \sqrt{P} \log N$$

Where, HK : coefficient of failure action, P : wheel load, N : number of cycles of repeated loading. Inasmuch as the expression aims at relating P and N to a constant failure action of a pavement, it needs still to be investigated whether this expression can be applied to the settlement of a subgrade or foundation soil, as a sub-judice matter.

Assuming the traffic distribution on the pavement to be normal as shown in Fig. 9, the respective accumulative traffic number was converted to an equivalent number for 15t lorries at the centre of each lane, using equivalence coefficients for an N value of one million, as shown in Fig.10 (a). The load used in this conversion was not wheel load but total weight of the vehicle because for the present purpose the combined load of four wheel loads can approximately be represented by the total weight of a vehicle in computing stresses in the ground.

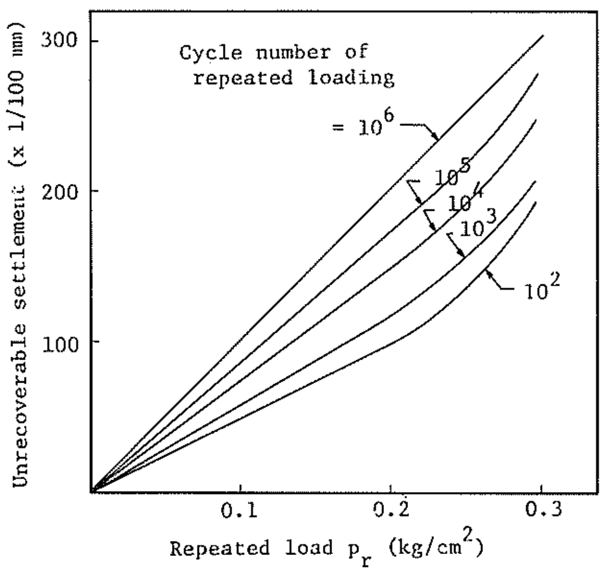


Fig. 8 Relation between Repeated Load, Cycle Number of Repeated Loading and Settlement

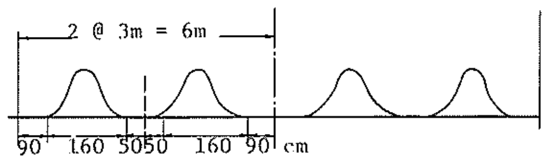


Fig. 9 Assumption of Traffic Distribution on the Pavement

6 ESTIMATION OF THE SETTLEMENT OF THE PAVEMENT DUE TO TRAFFIC LOADS

Letting the depth -12.8 m be a sufficient depth which is unaffected by ground settlement due to traffic load, and dividing this depth into four layers downwards, viz. 0.8 m, 1.5 m, 3.5 m and 7.0 m the total settlement of the ground was estimated by using Boussinesq's vertical stress at the centre of each respective layer and the relation shown in Fig. 8.

Fig. 10 (b) shows the result of comparison between the actual settlement and the computated settlements of the outer and inner lanes over the several years after opening to traffic, and it is seen that the final settlement is fairly similar to the actual settlement. But between these curves in an early stage after opening to traffic, there occurs a great discrepancy. The authors consider its cause to be the result of taking test results from thin samples as indicated by Suklje (Ref. 5) and others; this is, settlement progresses at an early stage after loading for a thin sample.

In the estimation of settlement by the authors, there still remain other factors to be discussed as follows.

(i) Consolidative settlement which is brought about by pumping up underground water.

(ii) Static consolidation and elastic settlement due to the self load of the bank.

(iii) Effect of vibration which arises from the transit of vehicles.

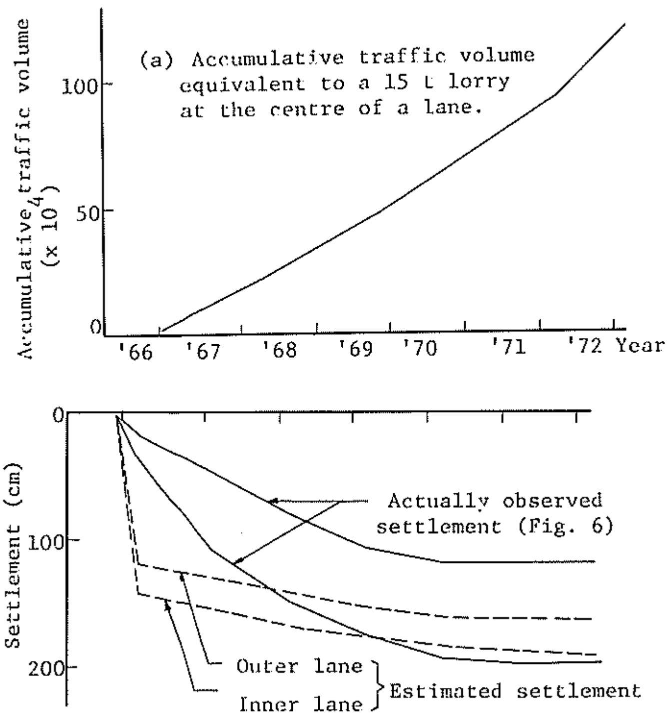
The settlement due to factor (i) may be a cause of subsidence over about 800 ha in the Shiroishi area, and it was found by Saga Prefecture that the settlement was about 20 cm over the last 6 years. Moreover, this subsidence has continued linearly unlike the fact that the actual settlement of the pavement has already stopped; although the amounts of these settlements cannot be separated.

Concerning factor (ii), static consolidation is too small to be a cause of the settlement whilst the amount of elastic settlement does not exceed 50 cm. Moreover, the elastic settlement should have finished before opening to traffic.

Factor (iii) should not be ignored as a cause of the settlement, but the vibrations are not so strong as to soften the clay, according to a study by one of the authors (Ref. 6).

7 COUNTERMEASURES AGAINST PAVEMENT SETTLEMENT

The counter measures for controlling such a settlement in a low bank road have not yet been established, and basically a bank of optimum height should be adopted as an orthodox road design on soft



(b) Comparison between the actually observed settlement and the estimated settlement.

Fig. 10 Accumulative Traffic Volume Equivalent to 15t Lorries and the Comparison between Observed Settlement and Estimated Settlement

ground. However, one of the authors has studied the effects of a restraining layer placed on soft clay ground of low bearing capacity as follows.

(i) Application of a semi-rigid course such as soil-cement on soft ground, to make a sandwich structure of the bank or pavement (Ref. 7).

(ii) Application of a resinous net which is placed on soft ground and anchored laterally (Ref. 8).

These methods have been proposed depending on a concept of restraining the soft subgrade or ground, and their effects have been proved experimentally especially as regards their settlements due to traffic, not only in the laboratory but also in the field. However, these methods can be applied only to a road which is newly built.

Recently, Saga Prefecture is going to test a prestressed-concrete slab as a surface course in the field, for a newly planned road. This method might give rise to problems at the joints even apart from the matter of high cost of construction.

8 CONCLUSIONS

It was proved that an abnormal settlement of the pavement in a low bank road built on soft clay ground has resulted mainly from the action of repeated loading after opening to traffic. This conclusion warns us that the action of repeated loading on soft clay ground or subgrades should be taken into more consideration in the design of other kinds of constructions also.

Some countermeasures against the settlement of soft clay ground are suggested for the case where it is essential to build such a road, but their effects need more investigation, especially in the field.

This paper not only leaves a problem of discrepancy between the actually observed settlement and the estimated settlement in the early stage after opening to traffic, but also a problem of incorporating the fundamental characteristics obtained from laboratory experiments into field investigation. The authors will contemplate these problems, since the behaviour of clay under repeated loading seems to be reasonably complex.

9 ACKNOWLEDGEMENTS

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