On the Effect of Remoulding Clay

Sur l'Effet du Remaniement de l'Argile

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Summary

In order to investigate the quantitative relations between the degree of remoulding given to undisturbed clay and its strength, the authors devised a remoulding apparatus which gave a simple shear deformation to a clay specimen under constant volume.

Experiments have been made with this apparatus on a sample of blue clay: the following results were obtained: (1) the more the clay was deformed, the more its strength decreased; (2) a linear relation existed between the ratio of the unconfined compression strength ($_nq_{u\theta}$) of the clay for repeated n-cycle shear deformation to that ($_1q_{u\theta}$) of single cycle deformation and the number of repetitions n, when both were plotted on logarithmic scale. In addition the trafficability of a crawler tractor over similar clayey ground was investigated.

Sommaire

En vue d'étudier la relation quantitative entre le degré de remaniement imposé à un échantillon d'argile intacte et sa résistance, les auteurs ont conçu un appareil de remaniement qui impose à l'échantillon une déformation de cisaillement simple sous volume constant.

Des essais ont été effectués sur un échantillon d'argile bleue à l'aide de cet appareil avec les résultats ci-après: (1) la résistance de l'argile diminue quand la déformation croît; (2) le rapport de la résistance à la compression simple d'une argile, après n cycles de cisaillement ($_nq_{u\theta}$) à la même résistance après 1 cycle, ($_1q_{u\theta}$) est en relation linéaire avec le nombre de cycles (n) lorsque ce rapport, ainsi que le nombre n, sont portés, l'un et l'autre sur des échelles logarithmiques.

On examine par ailleurs, la facilité de manoeuvre d'un tracteur à chenilles sur un sol de même nature.

Details of Apparatus and Soil Sample used in the Experiments

Mechanism of the remoulding apparatus—The authors have devised a remoulding apparatus (shown in Fig. 1) in which a simple shear deformation of constant volume could be applied to clay as a remoulding disturbance. In the illustration, A is the container for the clay specimen, and it is partitioned by two covers H and H' front and back, two side walls D and D', a bottom plate B fixed to the covers and an upper plate B' which

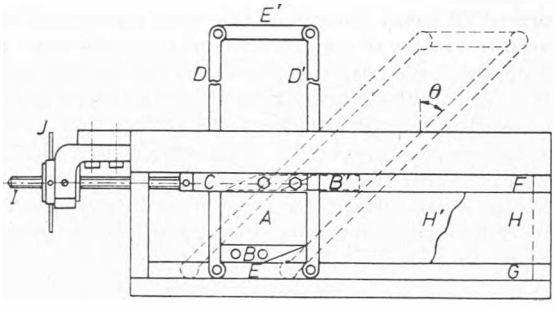

Fig. 1 Remoulding apparatus
Appareil de remaniement

can be moved along the guide grooves F made in the covers, being held horizontally in a fork C.

Side walls D and D' incline to form a parallelogram with two connecting links E and E'. When the fork C moves horizontally by means of the screw action of I and J there is an accompanying movement in the lower link E which moves along the lower guide grooves G made in the covers. In this manner a clay specimen receives a simple shear deformation under constant volume. To eliminate the influence of friction between the walls and the clay specimen the inner sides of the receptacle were smeared with sufficient grease as a lubricant. The volume of the receptacle was 50 × 50 × 80 mm.

The clay sample—The clay sample tested was an undisturbed blue clay carefully taken from a hill in the western part of Kyoto City. The grain size distribution curve is shown in Fig. 2. The water content of this clay was 39 to 43 per cent and its sensitivity ratio (according to Tschebotarioff's representation) was about 8.

Preliminary Examination

Distribution of the remoulding disturbance produced by the apparatus—In order to study the uniformity of the remoulding

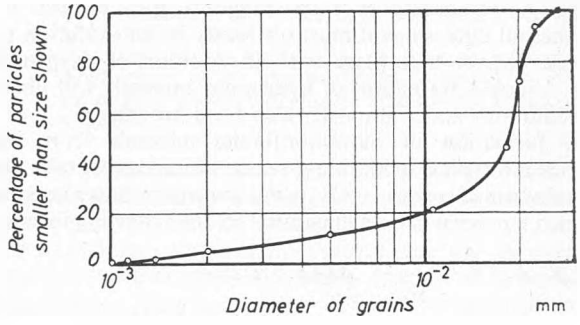

Fig. 2 Grain size distribution curve of the clay sample
Courbe granulométrique de l'échantillon

disturbance given to clay by this apparatus, a special clay specimen was remoulded by it in which several equally spaced seams of white clay were inserted. The patterns of the stripes after remoulding were examined in slices cut parallel to the plane of the covers. Fig. 3 shows one of the results, patterns on the left side and the right side correspond to a series of cut slices singly deformed to an angle $\theta = 30°$ and $\theta = 45°$ respectively, where θ is the angle of shear deformation as shown in Fig. 1. From these results it was clear that although the remoulding disturbance was not always uniform in every part of the container, it was uniform in the direction perpendicular to the paper in Fig. 3 and also uniform in any direction in the centre zone of the container. Therefore, the remoulded clay specimens for the following unconfined compression tests were taken only from material at the centre of the container and consisted of square columns with their long axes perpendicular

to the paper in Fig. 3. The dimensions of the specimens were 20 × 20 × 50 mm.

Effect of the remoulding speed—To examine the influence of the deformation speed, $d\theta/dt$, of the remoulding apparatus, experiments were performed with several speeds viz. $d\theta/dt$ = 80°/sec, 8°/sec and $\frac{1}{3}$°/sec. The influence of the difference in the deformation speed can hardly be recognized as shown in Fig. 4. It shows stress-strain relations of the unconfined compression tests for undisturbed clay, fully remoulded clay and clays remoulded to an angle $\theta = 40°$ with various speeds by the apparatus. The following tests were performed at a speed of about 10°/sec.

Test Results

To study the quantitative relations of the reduction in strength of clay by remoulding, the unconfined compression strength

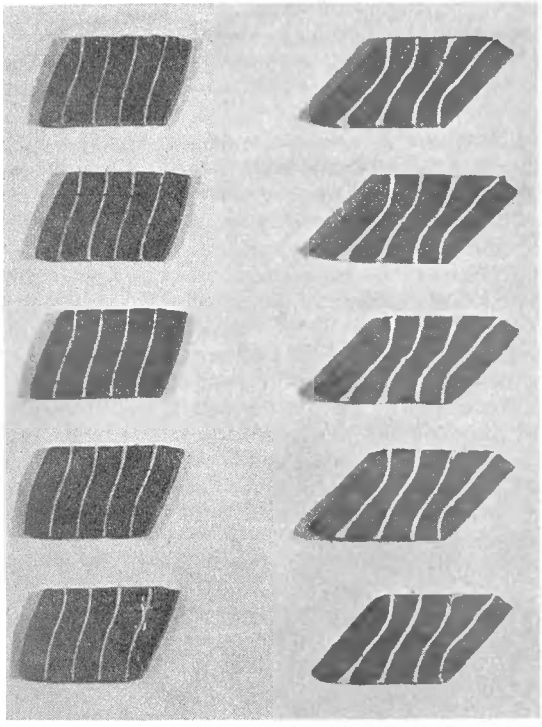

Fig. 3 Distribution of the disturbance in the specimen after single remoulding
Répartition des glissements dans l'échantillon, après un seul remaniement

was measured on undisturbed clay specimens carefully prepared using a fine wire saw in addition to specimens similarly prepared from clay remoulded by the apparatus. Every unconfined compression strength for the remoulded clay was measured at the same compressive strain at which the undisturbed clay failed.

Fig. 5 shows the relation between the angle of deformation singly given to the clay specimen and the degree of weakening in its strength. The ordinate represents the ratio of the unconfined compression strength $q_{u\theta}$ to that of the clay undisturbed q_u, and the abscissa the angle of deformation θ. The sensitivity ratio of this clay is about 8, and the illustration shows that the strength is weakened about half when deformed to an angle $\theta = 60°$.

Fig. 6 shows the relations between the weakening of the clay which is repeatedly deformed at a constant amplitude of the angle θ of deformation (i.e. repetition of the cycle of $0° \rightarrow \theta \rightarrow 0°$) and the number of repetitions. The ordinate represents the ratio of the unconfined compression strength of the clay deformed n cycles to an angle $\theta({}_nq_{u\theta})$, to that of the clay deformed with a single cycle to the same angle $({}_1q_{u\theta})$, and the abscissa the number of repetitions n. As the illustration shows, if both are plotted on logarithmic scale, a linear rela-

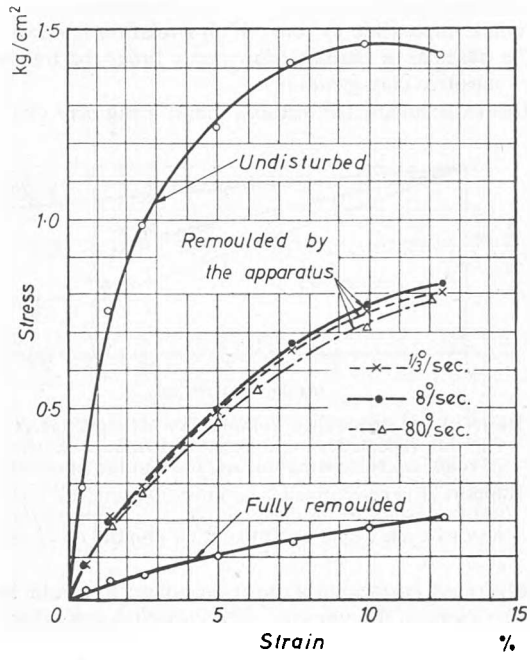

Fig. 4 Stress-strain curves of the unconfined compression tests for undisturbed clay, fully remoulded clay and clays remoulded with various speeds by the remoulding apparatus
Courbe contrainte-déformation sous compression simple, pour l'argile entièrement remaniée, et l'argile remaniée à diverses vitesses, par l'appareil de remaniement

tion exists between ${}_nq_{u\theta}/{}_1q_{u\theta})$ and n until a very high value of n is reached. It is clear from Fig. 6 that the greater the amplitude of the angle of deformation, the greater the effect of n; and if the number of repetitions becomes excessive, ${}_nq_{u\theta}$

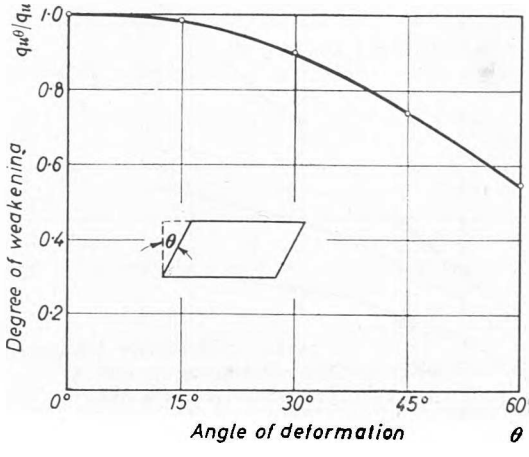

Fig. 5 Ratio of the unconfined compression strength of the clay deformed to an angle θ to that of undisturbed clay
Rapport de la résistance à la compression simple de l'argile remaniée, à celle de l'argile non remaniée en fonction de l'angle de remaniement

will approach a constant value equal to the ultimate strength of the fully remoulded clay ($q_u/8$) for any angle of θ.

An Example of Insufficient Remoulding for a Practical Application

As a practical example of insufficient remoulding, the trafficability of a crawler tractor over a sensitive cohesive soil was

investigated. As a crawler tractor gives a considerable deformation to the ground surface by its track shoes, if the ground is a sensitive clay its strength decreases with the increase of the number of passages of the tractor. Consequently, the tractive force decreases, slip of the track increases and finally the tractor may become impossible to run. If this relation is established, it may be possible to estimate how many times the tractor can run over sensitive clay ground.

For this experiment, the authors inlaid a big clay clod flush

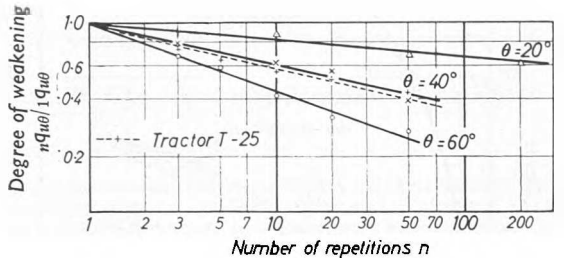

Fig. 6 Ratio of the unconfined compression strength ($_nq_{u\theta}$) of the clay for repeated n-cycle shear deformation to that ($_1q_{u\theta}$) of single cycle deformation and the number of repetitions n

Rapport de la résistance à la compression simple d'une argile, après n cycles de cisaillement ($_nq_{u\theta}$), à la même résistance après 1 cycle ($_1q_{u\theta}$), en fonction du nombre de cycles (n)

with the ground surface in a position where it would be run over by the shoes of the tractor. The clay clod was taken from a hill in the western part of Kyoto City, and the crawler tractor was a T-25 manufactured in Japan by the Komatsu Factory.

In this experiment weakening of the strength of the clay was measured by a vane-tester. The vane had a diameter of 20 mm and a height of 40 mm. Preliminary tests with this clay showed that the unconfined compression strength was just twice the cohesive strength obtained by vane test.

As illustrated in Fig. 6 by a dotted line, there still exists a linear relation between the degree of weakening of the clay and the number of passages of the tractor, when both are plotted on logarithmic scale. In this case, however, the abscissa n is defined by the number of passages of the tractor instead of the number of repetitions of the deformation cycle as in the case of the repeating remoulding test referred in the section on test results. It will be seen from this relation that the remoulding effect by this tractor agrees closely to that of the repeated remoulding test deformed to an angle $\theta = 40°$. This agreement may, however, be influenced by the dimensions of the tractor, i.e. the shape and the size of the tract shoe, weight of the tractor, etc. If these relations can be obtained, it will be possible to predict the trafficability of this type of ground for all variations in the tractor.

Conclusions

This report is an experimental study about the 'remoulding effect', i.e. the weakening in the strength of the sensitive clay due to a simple shear deformation given to it.

The results obtained are as follows:

(1) (a) The unconfined compression strength of the clay when it was subjected to simple shear deformation θ was 90, 73 and 55 per cent of the undisturbed strength for the values of θ of 30°, 45° and 60°, respectively (as in Fig. 5). (b) When the clay was remoulded repeatedly under a certain amplitude of the angle of shear deformation, there existed a linear relation between the degree of its weakening $_nq_{u\theta}/_1q_{u\theta}$ and the number of repetitions n, if both were plotted on logarithmic scale, until very high values of n were reached, i.e. $_nq_{u\theta}/_1q_{u\theta} = n^{-a}$ where, a is a function of the angle of deformation θ.

(2) As a practical example of insufficient remoulding of clay, the decrease in strength of the clay caused by the passage of a crawler tractor T-25 over it was investigated. The results conformed very closely to the above equation, and the remoulding effect by the track shoe corresponded to that of the repeated deformation by an amplitude of $\theta = 40°$ with the remoulding apparatus, if n was expressed by the number of passages of the tractor. In this way the trafficability of this type of clay may be calculated for the tractor.