Dynamic Properties of Compacted Soil

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Abstract

In order to investigate the changes in the dynamic properties of soil structures and foundation soils under a finite number of repetitive loading cycles, compacted soil specimens were subjected to repetitive loads of sine wave pattern by means of a triaxial compression equipment.

By this series of tests, it has been verified that the mode of changes in properties of soil subjected to repetitive dynamic loads is to a large extent affected by the moisture content of the soil and also by the amplitude of the load.

It has also been found that considerable change of soil properties takes place in the first 10 cycles or so of loading and this change decreases thereafter exponentially.

1. Introduction

Both in design and in construction of earth structures and foundation for buildings and other structures, it is essential that possible changes in the dynamic properties of soil which may occur under a finite number of repetitive loading as may occur during earthquakes be predicted and such changes be duly taken into consideration in design and construction of the engineered structures. In this view, the authors carried out a series of tests by continuously subjecting compacted soil specimens to repetitive loads generated by compressed air produced by a modified triaxial compression test apparatus.

At present, a number of research reports are available which discuss the changes in the properties of soil specimeans subjected to repetitive loading of rectangular wave pattern. Unlike these, this present paper deals with the case where compacted soil specimens are subjected continuously to the repetitive loading of sine wave pattern, and describes the changes in dynamic properties of soil under such loading with respect to different cell pressures and variant moisture contents of specimens.

2. Samples and Test Specimens

Soil to be used for preparation of test specimens was sampled from Tokiwadai area in city of Ube and is a type of clayey soil.

The physical properties of the sampled soil are shown in Fig. 1.

For preparation of soil specimens, the sample soil as described above was airdried in the laboratory to such an extent that the soil could be crumbled with fingers, and then it was made to pass through a 2000 μ mesh sieve.

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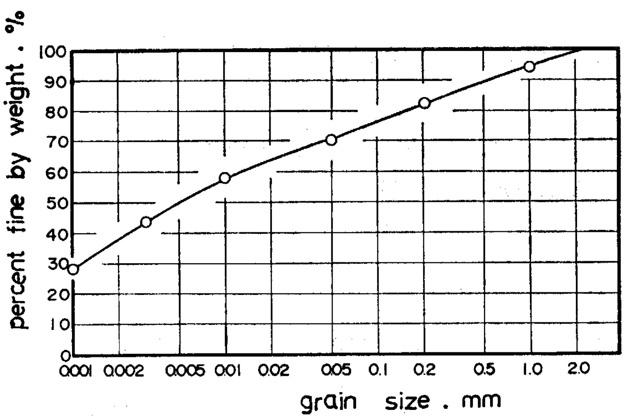


Specific gravity of soil; 2.70
Liquid limit; 50.84%
Plastic limit; 15.35%

Fig. 1 Grain-size distribution curve.

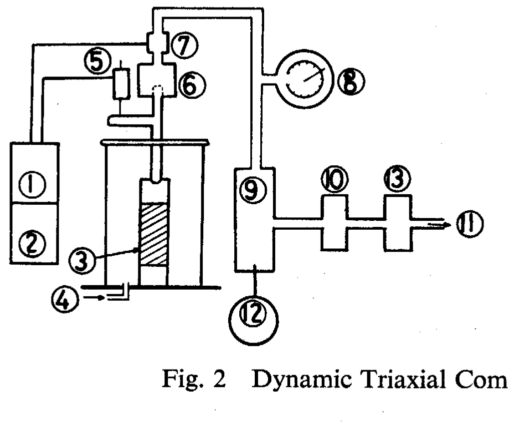
The part of soil which had passed the 2000 μ sieve was thoroughly mixed, the soil being wetted by spray of water to a predetermined moisture content. Then, the soil was left for a few hours in a manner that precluded the evaporation of moisture content.

After a lapse of time, the sample soil was remixed, and a number of cylindrical specimens, each 3.5 cm in diameter and 9.6 cm in height, were prepared by placing the soil in moulds and tamping it statically.

These specimens were further curved for 24 hours, attention being exercised to prevent the moisture content from changing, and then they were subjected to test loading.

3. Test Apparatus and Teasting Method

Fig. 2 show the principal parts of the apparatus used for the testing.



1) Amplifier
2) x-y recorder
3) Specimen
4) Cell pressure
5) Differential Displacement gauge
6) Air cylinder
7) Load cell
8) Pressure gauge
9) Secondary compressor
10) Air regulator
11) to Compressor
12) Motor
13) Filter

Fig. 2 Dynamic Triaxial Compression Test Apparatus.

This apparatus is featured by its loading mechanism which is capable of imposing pressure of sine wave pattern on the test specimens. For loading, compressed air stored in a pressure tank of the air compressor is delivered through a filter and an air regulator into the secondary air compressor. This secondary air compressor has a piston which is connected with a disc on one end, and the piston is reciprocated by causing this disc to be rotated with a motor. It is the action of this piston that pressure of sine wave pattern is generated within the secondary compressor.

Sine wave pressure thus generated is then transmitted to the ram of the triaxial compression test apparatus which in turn applies the pressure to the specimen.

It is possible to vary the amplitude of pressure by changing the eccentricity of the disc attached to the end of the piston.

In applying repetitive loads continuously in the form of sine wave pressure to soil specimens by the use of the above-mentioned test apparatus, the loading frequency was set at 0.7 c.p.s. and the loading intensity was set four levels, i.e., maximum, medium, small and minimum. The amplitude of deviate stress at respective load levels are as given in Table 1.

Displacements and amplitudes of deviate stress were measured with a differential displacement gauge and a 500 Kg load cell respectively, and the measurements were transmitted to the X–Y recorder.

Table 1. Values of $\sigma_{1\,\mathrm{max}}$ (Kg/cm^2).

Strokes / σ_1	Maximum	Medium	Small	Minimum
0.2	0.97	0.90	0.55	0.32
0.3	1.80	1.00	0.59	0.42
0.4	1.26	1.20	0.73	0.51

In taking measurement, axial displacement and deviate stress were plotted on the X-axis and the Y-axis respectively.

4. Test Results and Consideration

On the basis of the curves recorded by the X–Y recorder (Fig. 3), the measured results were processed by the use of the following formula:

$$\sigma=\frac{\Delta y\cdot S_p}{A_0/(1-x\cdot S_d/H_0)} \qquad \varepsilon=\frac{\Delta x\cdot S_d}{H_0}$$

$$\sin\delta=c/a=d/b \qquad \frac{\Delta A_H}{A_H}=\frac{\mathit{Area\ of\ ABCDEA}}{\mathit{Area\ of\ \Delta ACD}}$$

where, s_d and s_p : Displacement sensitivities of the X-axis and Y-axis respectively

A_0 and H_0: Cross sectional area and height, respectively of the specimen

x, Δx, Δy, a, b, c, d, A, B, C and D: As shown and defined in Fig. 3 below.

Fig. 4 below shows the relationship between moisture content ($w\%$) and dry density (γ_d g/cm^3) of compacted soil specimens before and after tests.

Since it was known by the preliminary experiment that dynamic properties of soil would show pronounced changes at the 10th cycle or so of the repetitive loading,

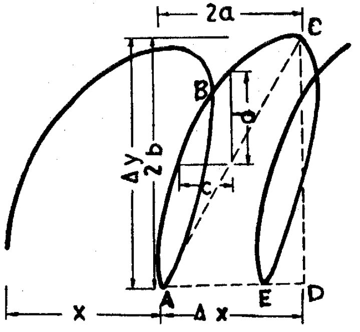
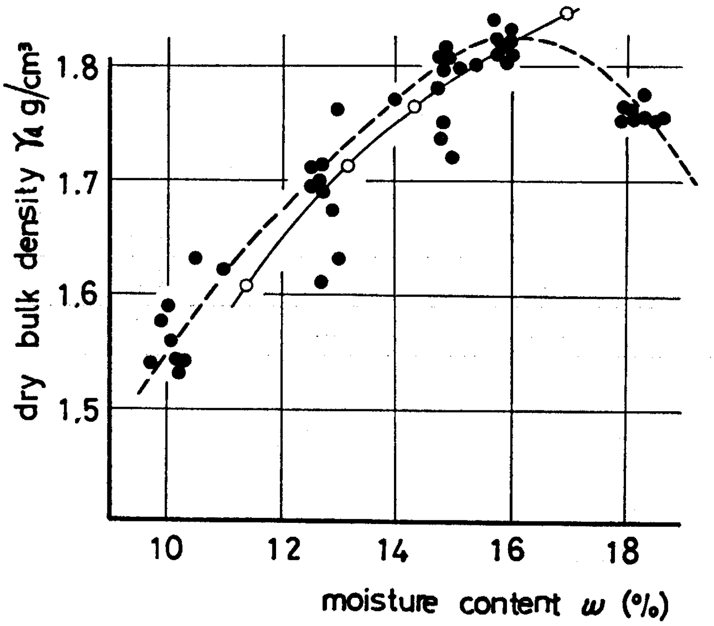


Fig. 3 Curves plotted by the X-Y recorder.



—○— values before test —●— values after test

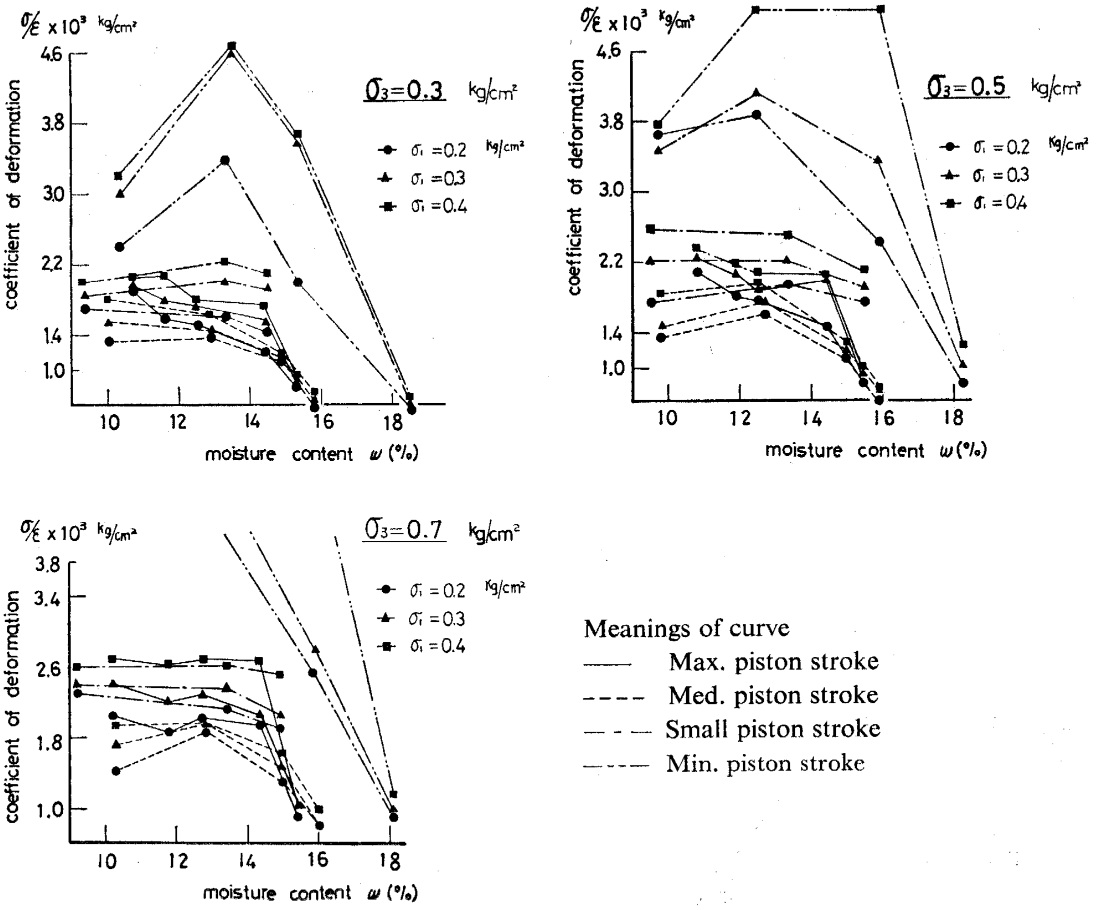
Fig. 4 Moisture Content vs Dry Density Relationship.

the relationships between deformation coefficient, (σ/ε), and sine wave load intensity was studied in connection with each load level at the 10th cycle of repetitive loading by using moisture content (w) as a parameter. These relationships are shown in Fig. 5, 6 and 7.

Since soil is not a perfect elastic body, slight changes in stress and strain should cause changes in the values of deformation factor (σ/ε).

As can be known from Figs. 5, 6 and 7, the valves of σ/ε did not change significantly at the maximum, medium and small piston strokes until the moisture content (w) reached 14.5%; however, at the minimum piston stroke, σ/ε ratio increased in direct proportion to the moisture content, and σ/ε reached its peak at $w = 13.5\%$ and decreased sharply when becomes more than 13.5%.

This value of $w = 13.5\%$ is smaller the value of optimum moisture content obtained by the compaction test.



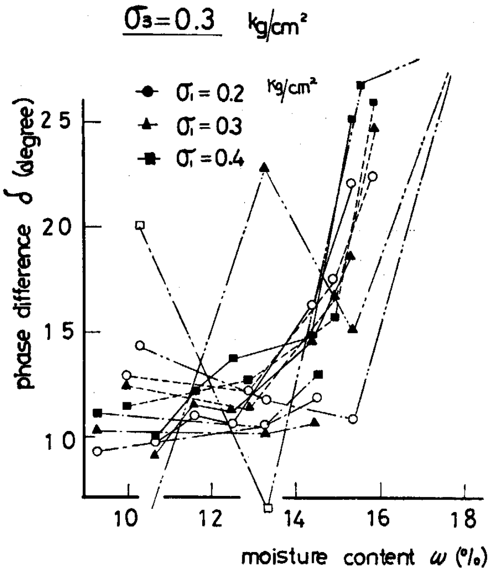
Figs. 5, 6 and 7 Relationship between Coefficient of deformation and Moisture Content.

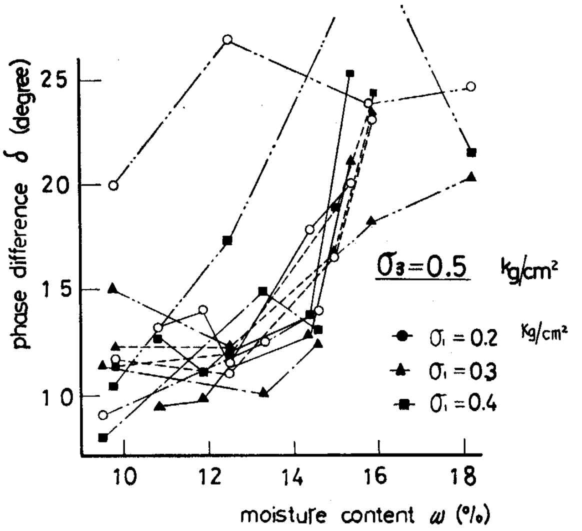
Generally speaking, the largest value of σ/ε was reached at a moisture content somewhat smaller than the optimum moisture content, and it was observed that σ/ε values decreased as the moisture content of the soil being tested reached or exceeded the optimum moisture content. This phenomenon is considered attributable to the fact that the maximum values of unconfined compressive strength and bearing ratio of soils are reached at a moisture content somewhat lower than the optimum moisture content. It is also presumed that water content existent in the voids of soil acts like ball bearing, and thus causes soil grains to slide, there by resulting in high σ/ε values.

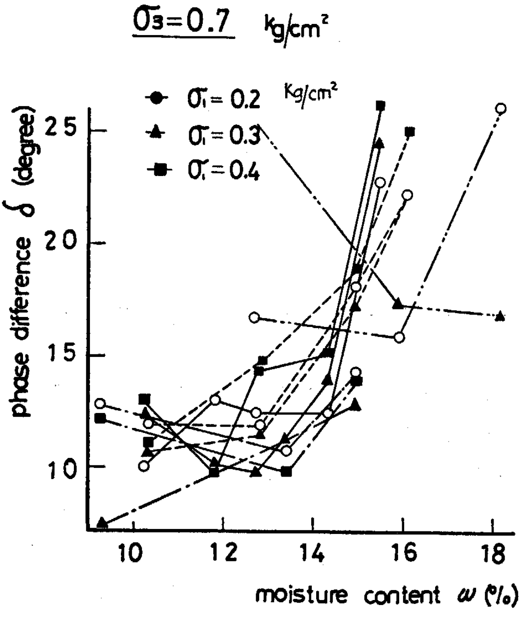
Shown in Figs. 8, 9 and 10, the changes in the phase difference of strain caused by the variation of moisture content for varying levels of cell pressure at the 10th cycle of the repetitive loading.

The variation in the pysteresis residual ratios $(\Delta A_H/A_H)$ as related to the moisture content at respective cell pressure levels at the same cycle are as shown graphically in Figs. 11, 12 and 13. The hysteresis residual ratios $(\Delta A_H/A_H)$ as given in these figures are expressed by the ratio of energy given to the specimen to energy residual in the specimen, its value being proportional to the damping coefficient during the vibration.

As can be known from the curves, representing changes in values of the phase difference (δ) and hysteresis residual ratio $(\Delta A_H/A_H)$, these values, too, inflected when



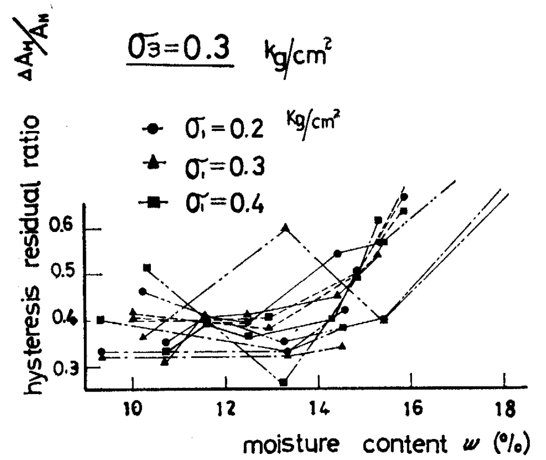


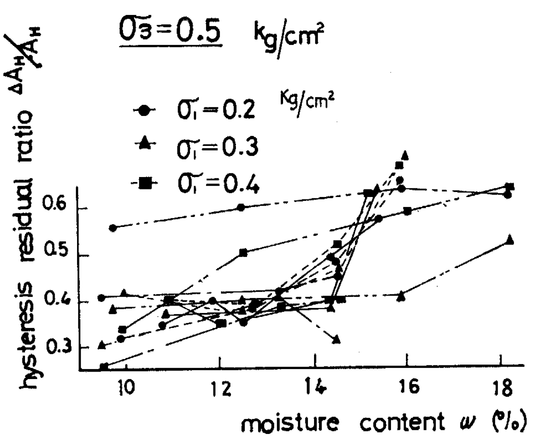


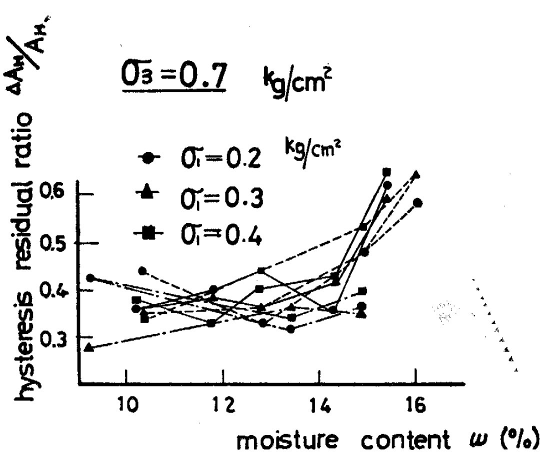
Figs. 8, 9 and 10

Relationship between phase difference of strain (σ) and moisture content (ω)

the moisture content of the soil specimens reached a range of 13.0% to 14.5%, both δ and $\Delta A_H/A_H$ increasing sharply above the foregoing range of the moisture content. From the fact that δ and $\Delta A_H/A_H$ being to change drastically at a moisture content which was somewhat lower than the optimum moisture content of the specimens, it may apparently be stated that pronounced structural changes of soil grains take place at the 10th cycle or so of repetitive loading if soils have a moisture content which exceeds a boarder line moisture content which is somewhat lower than the moisture content of the soil in question.







Figs. 11, 12 and 13

Relationship between Hysteresis Residual Ratio and Moisture Content.

5. Conclusions

The experiment herein described was conducted with the objective to investigate the changes in the properties of soil structures are subjected to a finite number of repetitive loading cycles as in the case of earthquakes. For this experiment, a number of conditions, such as sine wave pressure for repetitive loading. Short time intervals of repetitive loading and low degree of saturation of soil were specified.

All these conditions were prescribed in order to prevent thixotropic effects from influencing the results of the tests in which cohesive soil was used as specimens.

The findings derived from the experiment are as follows:

(1) Changes in the properties of soil under repetitive dynamic loading are affected by the moisture content of soil and the amplitude of repetitive loading.

(2) Among the soil property changes related with the amplitude of repetitive loading, the deformation coefficient, rather than the phase difference and hysteresis residual ratio, is most remarkably affected.

(3) Although this is the finding during the preliminary experiment, it has been verified that soil properties change very remarkably in the first ten or so cycles of the repetitive loading and thereafter the changes become less noticeable expornentially.