The Behaviour of Soil during Vibration

Comportement de certains sols pendant la vibration

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Summary

Some experiments on the behaviour of sand and loam when subjected to vertical harmonic vibration are described and the results are given. The shearing strength of the tested materials diminishes considerably with increasing acceleration of vibration. This effect, called "liquefaction" by the authors, may explain the behaviour of weak soil as observed during earthquakes. Further the change in density of the materials during vibration is considered.

Sommaire

Nous présentons les résultats de quelques expériences sur le comportement des sables et des limons soumis à une vibration (harmonique et verticale). La résistance au cisaillement de ces milieux diminue sensiblement en fonction de l'accélération croissante. Cet effet, réputé «liquéfaction» par les auteurs, semble expliquer certains phénomènes observés dans les sols meubles au cour des tremblements de terre. La variation de la densité des milieux en état de vibration est également considérée.

Introduction

During experiments with model embankments made of sand with a thin layer of paraffin which were subjected to vertical vibration it became apparent that at a definite amplitude and frequency the sand began to move turbulently; sometimes the sand flushed out through cracks appearing in the thin paraffin layer in other cases a hollow space appeared below the paraffin layer which collapsed, and there also appeared cracks along the shoulders of the embankment. In both cases the behaviour of the sand was like that of soft soil during earthquakes (small heavings of sand were observed e.g. at Amagasaki during the earthquake in 1951, see Fig. 1). It seems that, when vibrated, sand acts in the same way as a liquid. The following paper presents some results of a more systematic investigation on this "liquefaction" effect in soil materials as a result of the influence of vibration.

Fig. 1 One of Small Heavings of Sand Found at Amagasaki, after an Earthquake
Une des petites élévations de sable découvertes à Amagasaki après un tremblement de terre

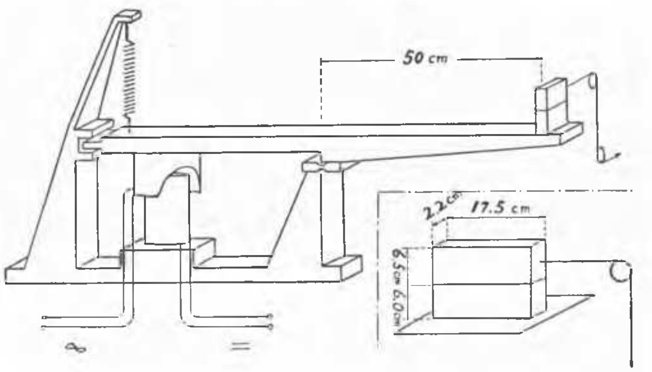


Fig. 2 Apparatus Used
Appareil employé

Apparatus

The test material was filled into a metal box fixed on a electrical vibration table which was able to move vertically and sinusoidally. The maximum vibration amplitude obtain-

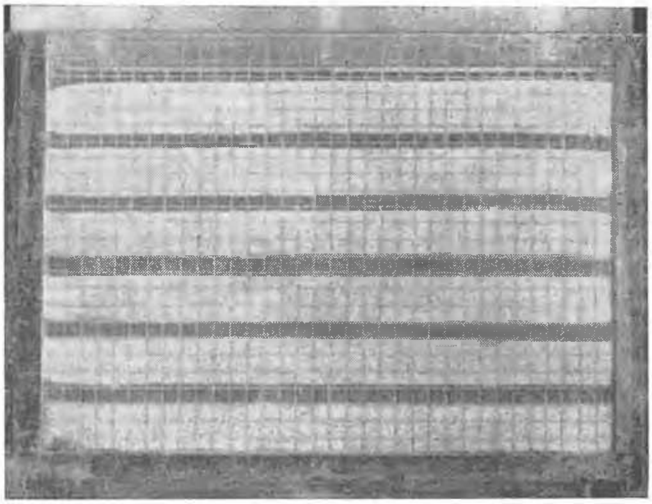
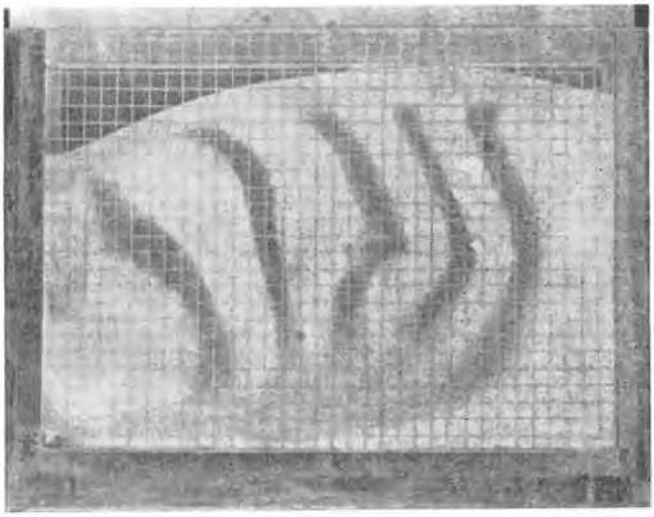


Fig. 3a Patterns in the Sand at Rest
Schèmes sur le sable au repos



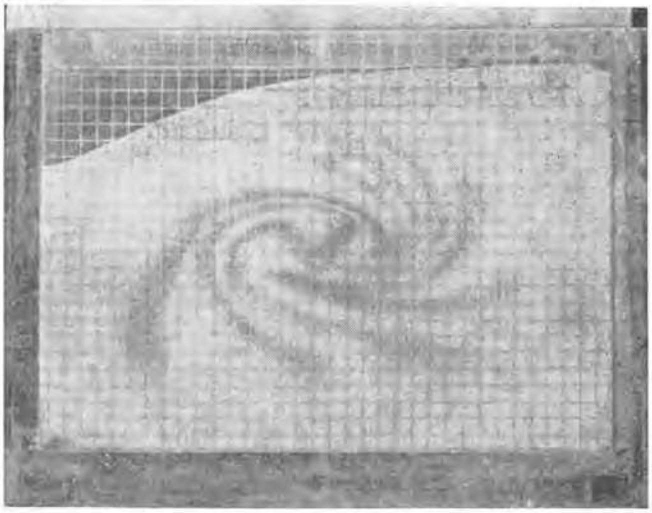


Fig. 3b, 3c Disturbance of Patterns in the Sand when Vibrated
Distorsion des schèmes sur le sable pendant la vibration

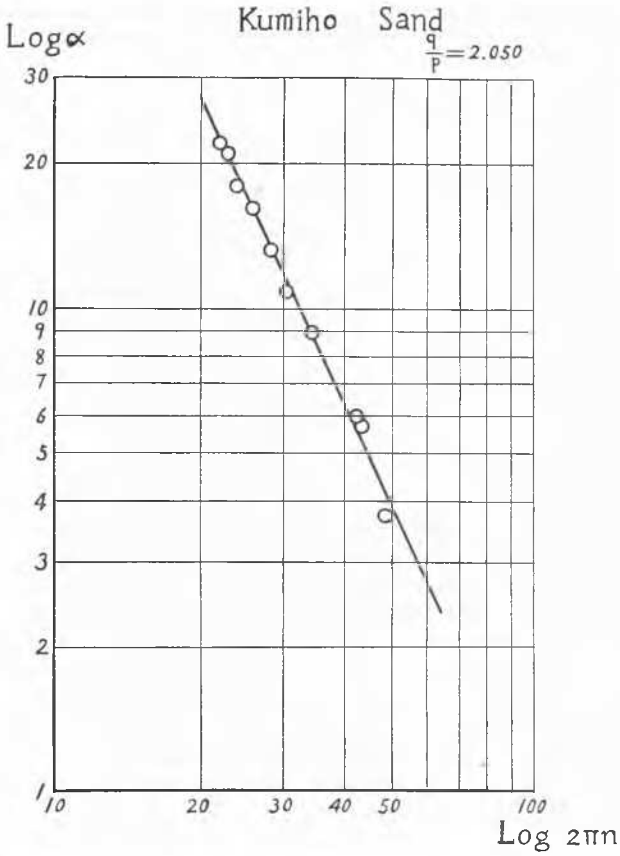


Fig. 4 Relation between Acceleration and Frequency in Case of Kumiho Sand
Relation entre accélération et fréquence dans le cas du sable de Kumiho

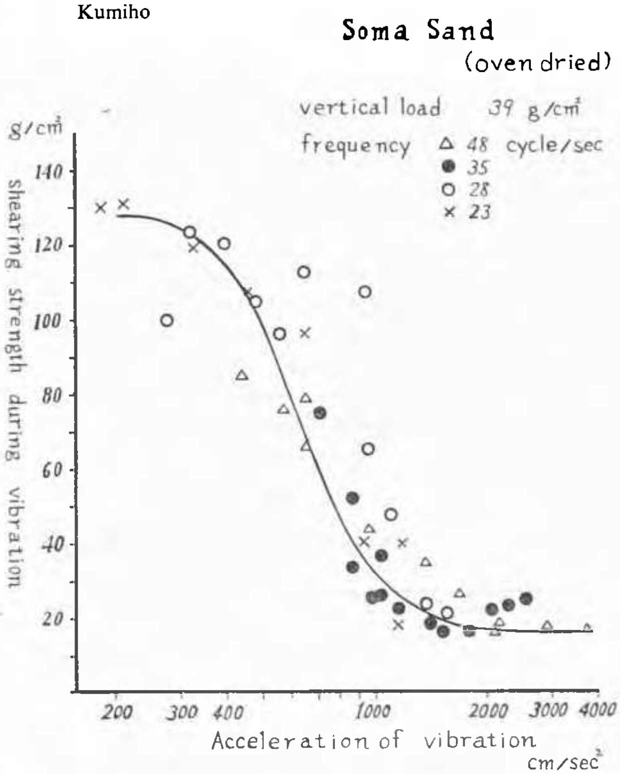


Fig. 5 Relation between the Shearing Strength of Soma Sand and Acceleration of Vibration with Constant Load and Variatons of Frequency
Variation de la résistance au cisaillement du sable de Soma en fonction de l'accélération et des changements de fréquence

Table 1 The q/p in the formula $a^p n^q$ = a constant obtained by three methods for several materials
q/p dans la formule, $a^p n^q$ = constante obtenue par trois méthodes pour plusieurs matériaux

Method a			*Method b*			*Method c*		
Materials		$\frac{q}{p}$	*Materials*		$\frac{q}{p}$	*Materials*		$\frac{q}{p}$
Kumiho sand		2.050	Slime		1.907	Carborundum	1	1.894
Alundum	1	1.680	Carborundum	1	1.780	Carborundum	2	1.977
Alundum	2	1.715	Carborundum	2	2.081	Carborundum	3	1.970
Green Carborundum	1	2.475	Corborundum	3	2.097	Carborundum	4	1.894
Green Carborundum	2	2.097	Potter's Clay	1	2.020	Kanto-Loam	1	2.020
Green Carborundum	3	2.035	Potter's Clay	2	2.050	Kanto-Loam	2	2.434
Millet	1	1.921	Rouge		2.050	Kanto-Loam	3	2.097
Millet	2	1.842				Kanto-Loam	4	2.145

able was 2 mm within a frequency range of 10 to 50 c.p.s. (corresponding maximum accelerations: 800 to 20,000 cm/sec²). The apparatus is illustrated in Fig. 2. Fig. 3 (a, b, c) demonstrates the very irregular motion of the sand particles subjected to vibration.

The Experiments

The following problems were treated:

(1) Criteria for the "liquefaction" of soil-material;

(2) Vibration properties necessary to cause the "liquefaction" effect;

(3) Variation of shearing strength of the tested materials during vibration;

(4) Changes in density as a function of vibration.

(1) As criteria (or definitions) for the desired degree of liquefaction the following tests were adopted:—

(*a*) A ditch of known measurement dug in the surface of the sand, was to be destroyed through the influence of vibration within 10 sec;

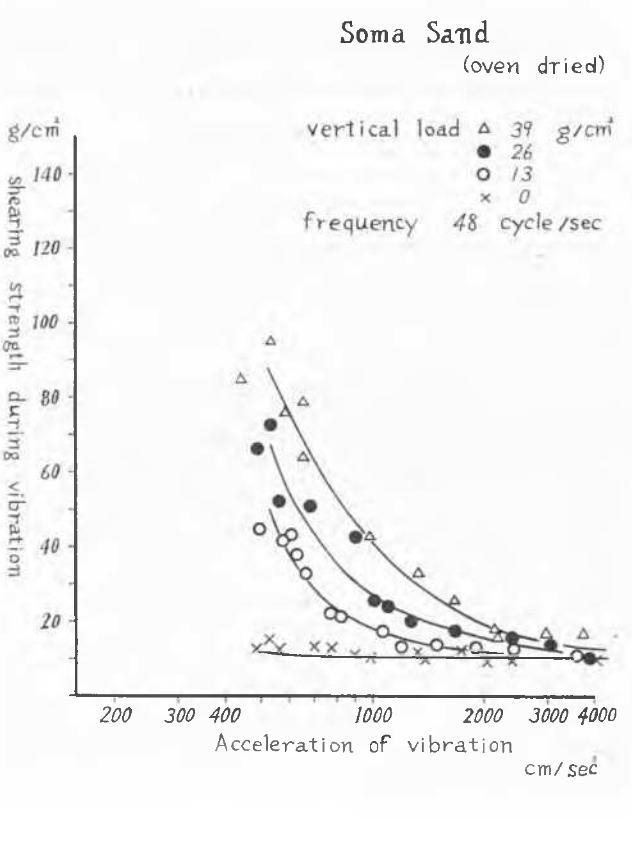


Fig. 6 Relation between the Shearing Strength of Soma Sand and the Acceleration of Vibration with Constant Frequency and Variations of Frequency
Relation entre la résistance au cisaillement du sable de Soma et l'accélération de la vibration; en cas de fréquence constante et de changements de charge

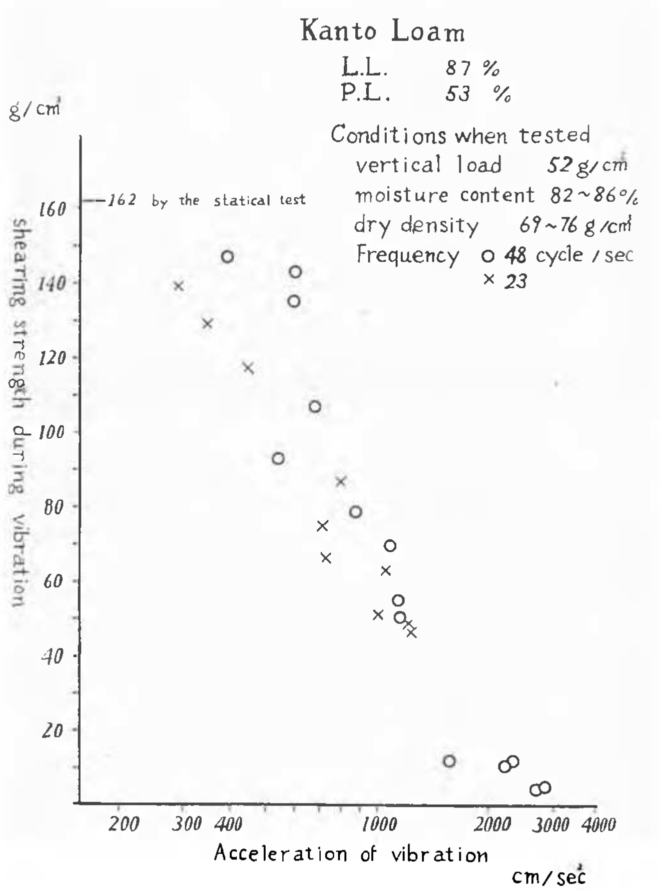


Fig. 7 Decrease in Shearing Strength when vibrated in Case of Kanto Loam
Diminution de la résistance au cisaillement pendant la vibration pour glaise de Kanto

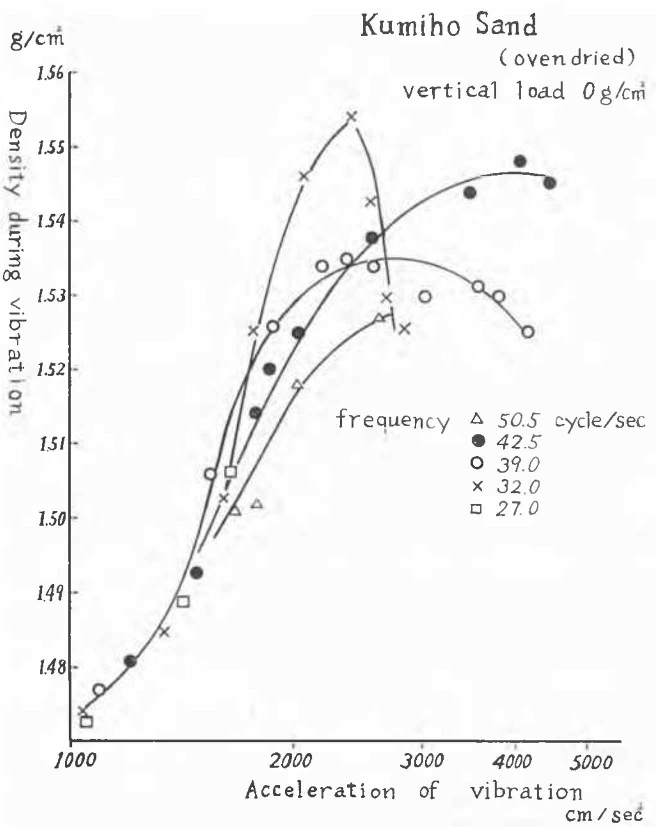


Fig. 8 Densities of Kumiho Sand during Vibration
Densités du sable de Kumiho pendant la vibration

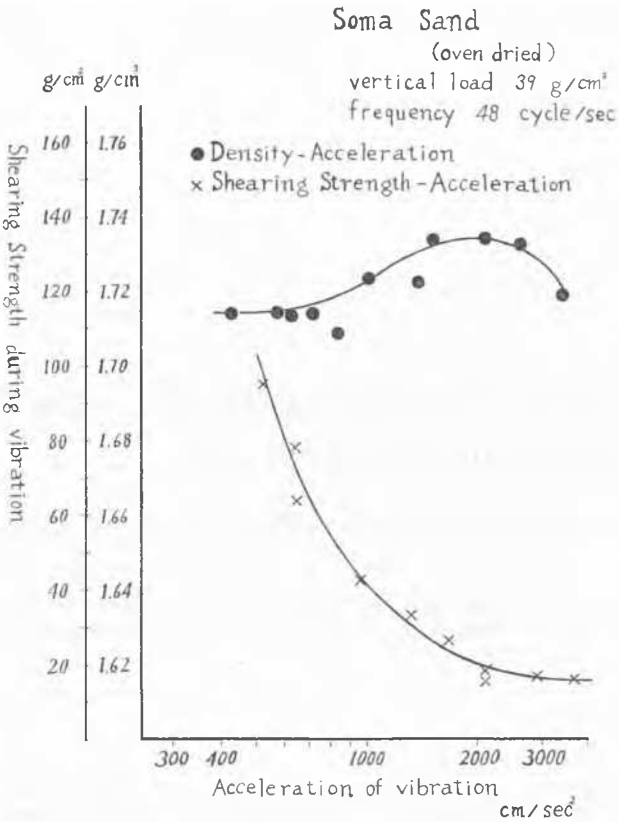


Fig. 9 Figure Showing that the Shearing Strength Decreases during Vibration whereas Density Increases
Diminution de résistance au cisaillement pendant vibration et augmentation de densité

(*b*) A cone of sand of a predetermined shape was to be transformed into another cone less high and with a larger base after being vibrated for 5 sec;

(*c*) A metal bar (see Fig. 2) was set vertically in the sand; this bar had to penetrate the sand down to a certain depth during 5 sec of vibration.

(2) We plotted the amplitudes of the vibrations which had just caused this "liquid" behaviour against the corresponding frequencies; on log. paper these diagrams show straight lines (see Fig. 4), i.e. of the form $a^p n^q$ = constant (a = amplitude, n = frequency, p, q = constants). Table 1 above gives the quotients q/p obtained in accordance with the three methods mentioned above and shows that this quotient is very close to 2.0, corresponding to the relation an^2 = constant. That means that the acceleration of the vibration is the decisive factor of the "liquefaction" effects.

(3) The method we applied to get to the bottom of this "liquefaction" behaviour in terms of physics was to examine the change in the shearing strength of the materials during vibration, again as a function of the acceleration of vibration. Figs. 5, 6 and 7 show some typical results: the shearing strength decreases as a function of increasing acceleration in a very striking manner: in fact it decreases almost to zero, which could justify the expression "liquefaction".

(4) Further we examined the change in density of the materials during vibration. Figs. 8 and 9 give results for two typical sands of our country. As yet no general law could be deduced. The effect is strikingly altered by an even slight loading.