JOURNAL OF THEORETICAL
AND APPLIED MECHANICS
2, 36, 1998

BEHAVIOUR OF ANTHROPOGENIC SOILS SUBJECTED TO VIBRATION LOADINGS

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The paper presents the results of experimental investigations into the influence of dynamic loadings on the shear strength in two chosen soils: coal ash and dump soil. The authors suggest description of the change of shear strength due to dynamic loading in terms of the W_Z ratio. It shows a quantitative change of strength due to vibrations related to the initial value of strength. The functional relations have been established between the W_Z ratio and frequency of the dynamic loading. The authors indicate that the tested soils respond more intensively to vibrations in the horizontal plane, as well as to distinct quantitative and qualitative changes in the soil microstructure.

Key words: anthropogenic soil, vibration, strength, laboratory test

1. Introduction

Anthropogenic (artificial) soils often create foundations of various engineering objects including slope and escarpments in open-pits, landfills, dump ponds, etc. In the course of producing them it is necessary to consider the influence of dynamic loadings causing changes in the microstructure and degradation-liquefaction. The two soils were chosen for testing: coal ashes and dump soils. The influence of dynamic loadings on the shear strength was detected by means of the vane test equipment. In result, the relations between shear strength, frequency of vibrations and their direction were determined.

2. Characteristics of the tested soils

Coal ashes result from the process of burning the coal in heat and power plants from which they are transported by means of hydraulic systems and deposited in a water environment in dump ponds. They are composed of aggregates, grains and conglomerates, respectively, each one of them having its own porosity. The conglomerates are composed of various elements: unburned coal, rocks, quartz, etc. Their granulometric composition classifies them as sand-silts. They are characterised by: low level of consolidation, high water content, porosity (macroporosity), instability of the microstructure, sensitivity to water content and water leaking – sometimes leading to liquefaction. Main chemical components of the tested ashes were: SiO_2 – 40%, Al_2O_3 – 20%, Fe_2O_3+MgO+CaO – 15%, and the rest – 25% ignition losses. They can be classified as silicate-aluminium ashes of basic mineral components: quartz and mullit, occasionally, magnetite or hematite. Basic properties of the tested ashes are presented in Table 1.

Table 1. Properties of soils

Parameter	Coal ashes	Dump soils
specific density [Mg/m^3]	2.22	2.69
clay fraction content $< 2\mu$m [%]	–	39
silt fraction content $2 \div 50\mu$m [%]	6.5	43
sand fraction content $> 50\mu$m [%]	93.5	18
maximal volume density [Mg/m^3]	1.22	1.73
optimal water content [%]	30.5	20.5
liquid limit [%]	–	65
plastic limit [%]	–	35
porosity [%]	65	35.7
cohesion total/efective [kPa]	$27 \pm 4/10 \pm 9$	$31.5 \pm 6/7 \pm 7$
angle of internal friction total/effective [°]	$10.5 \pm 2/34 \pm 4$	$9 \pm 2/24.5 \pm 2.5$

The processes of exploitation, transportation, deposition and compaction have a decisive effect on the properties of dump soils, which differ considerably from those of the original soil. The tested soil was sampled from the internal dumpsite in a sulphur mine in Machów. The original soil was Tertiary clay building the blanket deposits of sulphur. The dump soil is a two-level structure, therefore it is the so called second-type medium. The first level is its internal structure of pebbles, while the second – its composition. The tested soil is a clay of illite-montmorillonite mineral composition. In a chemical composition the following components prevail: SiO_2 – 53%, Al_2O_3 – 15%, FeO – 6%, CaO 7Na_2O – 1%, ignition losses – 13%. Other basic properties are presented in Table 1.

3. Equipment and experimental methods

Mechanical instruments are the sources of vibrations appearing in transportation equipment, pile and wall constructions, or vibrations transmitted by foundations of mining machines. Laboratory vibrators of vertical and horizontal planes of vibrations generated such dynamic loadings in our experimental tests. The frequency varied within the range $0 \div 100$ Hz while the amplitude values from the range $0 \div 10$ mm were taken. The tests were made in plexiglass containers (10×15 cm), therefore no water outlet was possible. Soils of different water contents and disturbed structure were tested. The container was attached to vibrators. The tests of shear strength were performed for two depths before and after vibrations at a given frequency, using the vane test equipment WF-23500, Wykeham Farrance. Totally, four series of tests were performed:

1. Vibrations in the horizontal plane
   (a) constant amplitude $2H = 2$ mm, variable frequency;
   (b) constant frequency $f = 10$ Hz, variable amplitude.
2. Vibrations in the vertical plane
   (a) constant amplitude $2H = 1$ mm, variable frequency;
   (b) constant frequency $f = 50$ Hz, variable amplitude.

4. Results of the tests

The results of investigations having been conducted till now (cf Ishihara and Kasuda, 1984; Kaczyński et al., 1994; Tatsuoka and Shibuya, 1992; Whitman, 1985) indicate that the dynamic loadings increase the water pressure in pores, which results in a decrease in the effective shear strength.

In the paper the change of shear strength in the tested soil was determined as the W_Z ratio

$$W_Z = \frac{\tau_{av} - \tau_f}{\tau_{av}}$$

where

τ_{av} – mean shear strength before the test

τ_f – shear strength after the test.

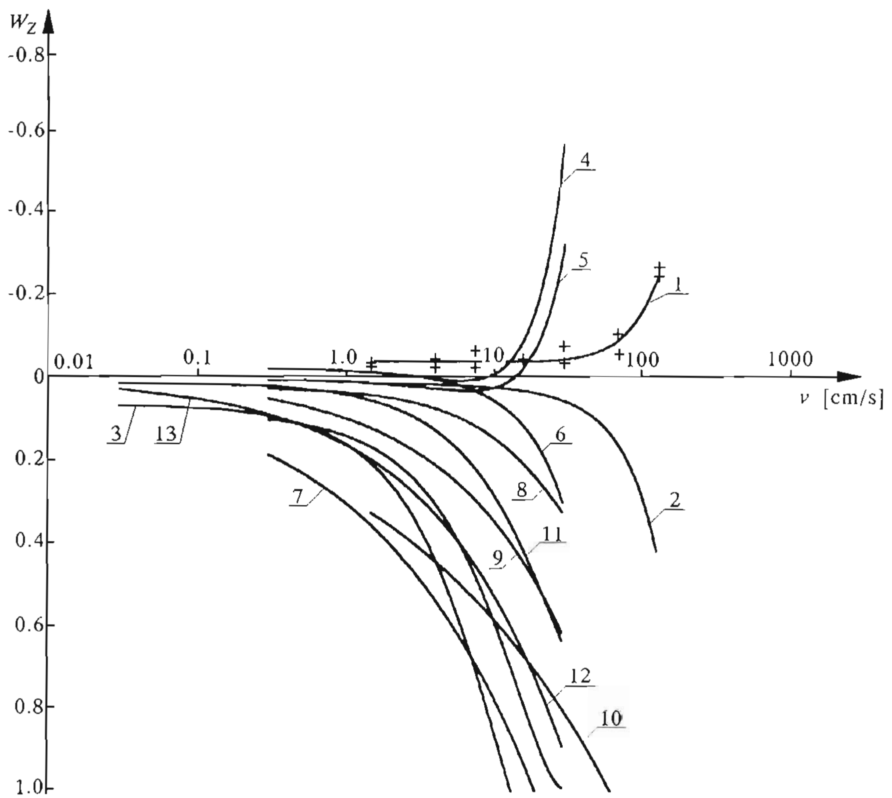

Fig. 1. Relationship between W_Z and v for different water contents of dump soils; w – water content, f – frequency, A – amplitude.
Vertical vibrations: $W_Z = f(2A)$: 1 – $w = 10\%$, 2 – $w = 21\%$, 3 – $w = 35\%$, $W_Z = f(f)$: 4 – $w = 10\%$, 5 – $w = 21\%$, 6 – $w = 28\%$, 7 – $w = 35\%$.
Horizontal vibrations: $W_Z = f(2A)$: 8 – $w = 10\%$, 9 – $w = 21\%$, 10 – $w = 35\%$ $W_Z = f(f)$: 11 – $w = 10\%$, 12 – $w = 21\%$, 13 – $w = 35\%$

The W_Z ratio can take both positive and negative values. If the soil after the dynamic test reveals a decrease in the shear strength the value of W_Z is positive, while if the soil increases its strength the values of W_Z becomes negative. The obtained values of W_Z versus the intensity (velocity) of vibrations are presented in Fig.1.

The velocity of vibrations has been calculated from the measured values of frequency and amplitude of vibrations.

All coal ashes with the water content 30% have decreased their strength to 0, and therefore the liquefaction followed, while the ashes with the water contents 12 and 20% behaved in a different way. Vibrations in the horizontal plane of the ashes with the water content 12 have decreased the strength, the same refers to the vertical vibrations but only those caused by changes of the amplitude. In the course of vertical vibrations caused by changes of the frequency the ashes with the 12% and 20% water contents have increased their strength. The W ratio values above 0.1 were obtained, generally, when the velocity of vibrations exceeded 0.3 cm/s. Only for the ashes with the 30% water content this took place already at the velocity of 0.1 cm/s.

13 series of experimental tests were made on the dump soil. In three of them it has undergone compaction, while in the remaining ten – decompaction. The compaction has appeared for soils with the 10 and 21% water contents for vertical vibrations. The horizontal vibrations have caused destructive results independently of the water content. The influence of vibrations on the shear strength within the range of W_Z $(0.1 \div 0.2)$ was observed for this soil at velocities above $0.3 \div 1.0$ cm/s. It should be mentioned that dynamic loadings influence both quantitatively and qualitatively the microstructure of soil. First quantitative analyses of microstructure (QAM) test of the scanning electron microscope (SEM) images indicate, that a new, split microstructure is created under vibrations. This structure reveals clear turbulent elements: changing parameters of porous space, shapes of pores become isometric. First images indicating such changes are presented in Fig.2.

5. Conclusions

The tested anthropogenic soils decrease their shear strength and become more deformable when subjected to dynamic loadings after exceeding a certain velocity of vibrations.

The W_Z ratio describing changes of shear strength depends upon: water content, volume density, velocity and direction of vibrations and the ways of generating them as well as their duration.

The tested soils at low volume densities and water contents up to 10% (coal ashes) or 20% (dump soils) undergo compaction within the range of the

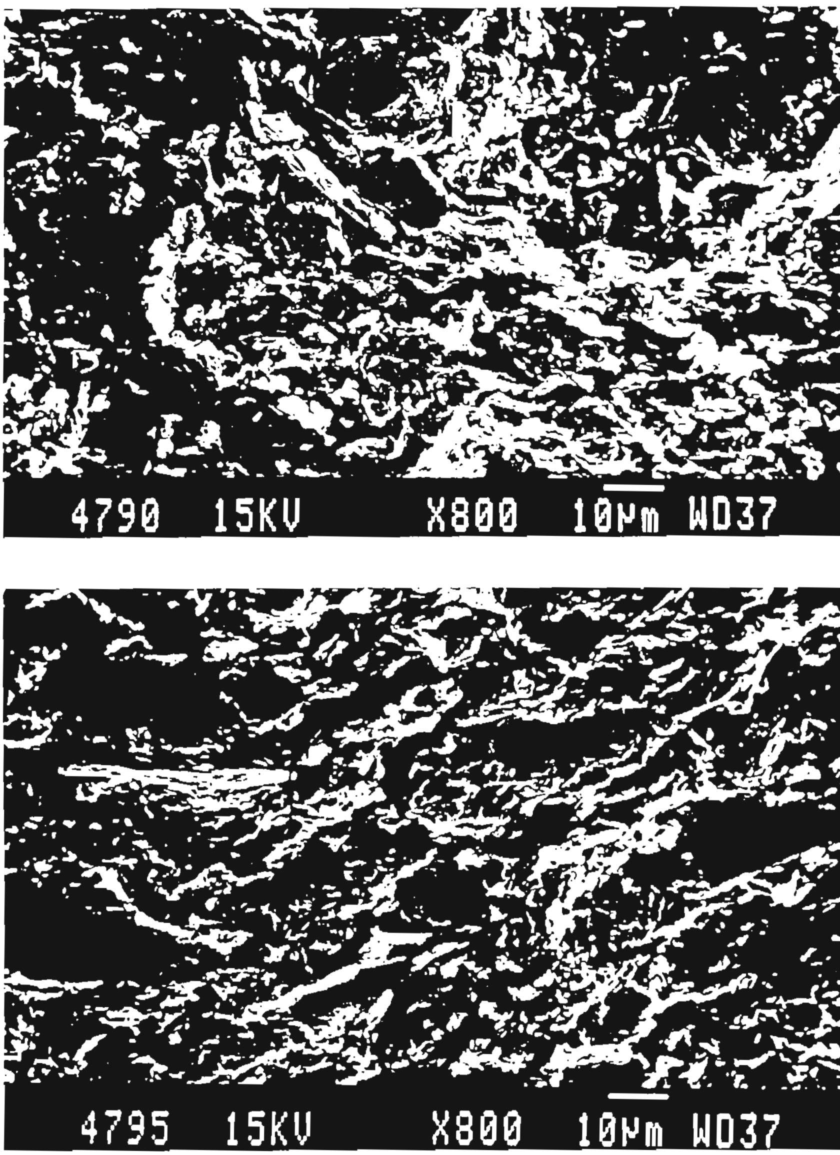

Fig. 2. Sample SEM photos of dump soils and before and after the vibration test, respectively, magnification ×800

applied loadings. At higher water contents and velocities 0.1 ÷ 0.3 cm/s the shear strength decreases. The soils with a water content above 30% and at velocities of loadings 7 ÷ 10 cm/s entirely loose their shear strength.

The influence of dynamic loading on the shear strength in the tested soils is described by a polynomial regression function.

The tested soils respond more intensively to dynamic loadings in the horizontal plane. Under the influence of dynamic loadings the microstructure is split and becomes a turbulent microstructure.

Acknowledgements

The research was financially supported by the State Committee for Scientific Research (KBN) under grant No. 3 P403 008 06.

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Zachowanie się gruntów antropogenicznych poddanych obciążeniom wibracyjnym

Streszczenie

W pracy zostały przedstawione wyniki badań laboratoryjnych wpływu obciążeń dynamicznych typu wibracji na wytrzymałość na ścinanie dwóch wybranych gruntów antropogenicznych: popiołu węglowego i gruntu zwałowanego. Zmianę wytrzymałości na ścinanie wskutek działania drgań proponuje się określać za pomocą wskaźnika W_Z. Przedstawia on ilościową zmianę wytrzymałości pod wpływem drgań w stosunku do pierwotnej wytrzymałości. Ustalono zależności funkcyjne pomiędzy wskaźnikiem W_Z a prędkością obciążeń dynamicznych. Przedstawiono, że badane grunty reagują intensywniej na drgania w płaszczyźnie poziomej oraz wykazują wyraźne zmiany jakościowe i ilościowe mikrostruktury gruntów poddanych obciążeniom dynamicznym.

Manuscript received December 9, 1997; accepted for print January 6, 1998