SEISMIC BEHAVIOUR OF UNDERGROUND STRUCTURES IN SOFT GROUND

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ABSTRACT

For the investigation of the earthquake response of engineered underground structures such as tunnels, pipelines and conduits in soft ground, within current research work shaking model tests are being carried out. During these tests accelerations and bending strains in the investigated structures, earth pressures acting on the investigated structures and accelerations and displacements of the adjacent soil are being measured. This research work aims at the improvement of the seismic design methods for underground structures such as tunnels, pipelines and conduits in soft ground.

Key words: dynamic soil-structure interaction, earth pressure, shaking model test, underground structure, tunnel, pipeline, conduit (**IGC:** E08 / H05)

INTRODUCTION

In urban areas underground structures are generally constructed in soft ground and are vulnerable to seismic disturbance (Iida et al., 1996). Even though an underground structure usually does not come into resonance with the surrounding ground, it responds in accordance with the seismic response of the surrounding ground (Kawashima, 1994). With increasing size of an underground structure the flexural deformation of the underground structure due to seismic loading increases. Since the seismic loading of an underground structure depends on the seismic ground deformation, the characteristics of the ground deformation induced by near-field ground motions need to be clarified before the seismic design of underground structures is being carried out.

EXPERIMENTAL INVESTIGATIONS

For the experimental investigation of the seismic behaviour of underground structures such as tunnels, pipelines and conduits in soft ground two types of structure with different stiffness and geometry are embedded in soil, installed in a laminar box. The laminar box has horizontal dimensions of 996 mm x 496 mm. The height of the soil specimen amounts to about 900 mm. The type of soil used within these experiments is Toyoura sand (Table 1).

Table 1. Characteristic parameters of the rigid phase of the used type of soil

Soil		Toyoura Sand
Maximum Grain Diameter D_{max}	[mm]	0.420
Mean Grain Diameter D_{50}	[mm]	0.190
Fines Content (less than 0.074 mm)	[%]	0
Specific Gravity G_S	[1]	2.653
Maximum Void Ratio e_{max}	[1]	0.977
Minimum Void Ratio e_{min}	[1]	0.597

The investigated flexible structure is an acrylic pipe with an external diameter of 200 mm and with a wall thickness of 3 mm. The Young's modulus of the acrylic material amounts to 3140 MN/m^2. The investigated rigid structure is a rectangular double boxed aluminium structure having a total width of 300 mm and a height of 200 mm. The wall thickness amounts likewise to 3 mm. The Young's modulus of the aluminium material amounts to 75000 MN/m^2. The length of both investigated structures amounts to 496 mm. The soil overburden above the roof amounts to 300 mm for each structure.

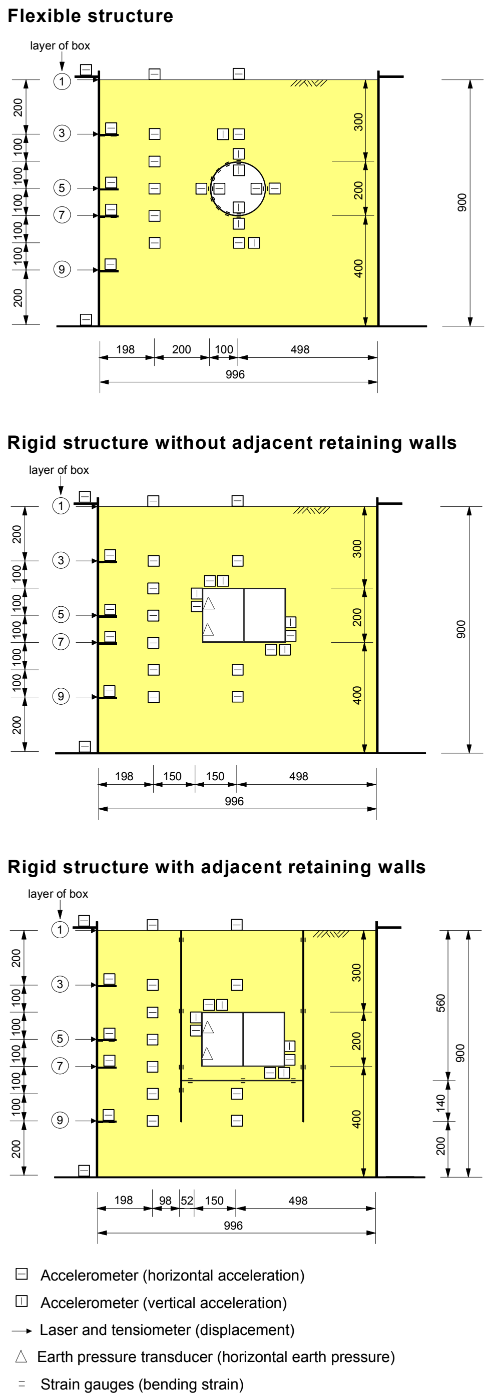

Fig. 1. Setup of the laboratory tests

Additionally, at the stiffer structure is being investigated the influence of adjacent 4 mm thick retaining walls of aluminium, connected by a horizontal 4 mm thick slab of aluminium. The connecting slab is located 60 mm beneath the structure. The setup of the laboratory tests is shown in Fig. 1.
For the reduction of the influence of a possible edge disturbance the investigated structures are divided into three parts. The measuring devices are installed on the central part of each structure, subjected to the least disturbance.
The characteristic parameters of the used type of soil in the installed dry state are shown in Table 2.

Table 2. Characteristic parameters of the used type of soil in the installed dry state

Soil State		Toyoura Sand Dry
Dry Density of the Soil ρ_d	[g/cm³]	1.50 ÷ 1.57
Relative Density of the Soil D_r	[1]	0.54 ÷ 0.76
Void Ratio e	[1]	0.69 ÷ 0.77

On the shaking table of the Geotechnical Engineering Laboratory, Department of Civil Engineering, University of Tokyo, the laminar box with the installed soil and with each structure installed separately is being subjected to shakes with input frequencies of 1 Hz, 3 Hz, 5 Hz and 10 Hz and input accelerations of 300 gal and 500 gal.

DISCUSSION OF TEST RESULTS

In Fig. 2 are shown shaking model test results of the dynamic bending strain measured on the surface of the invert of the investigated flexible structure embedded in dry soil at an input frequency of 3 Hz and an input acceleration of 300 gal.

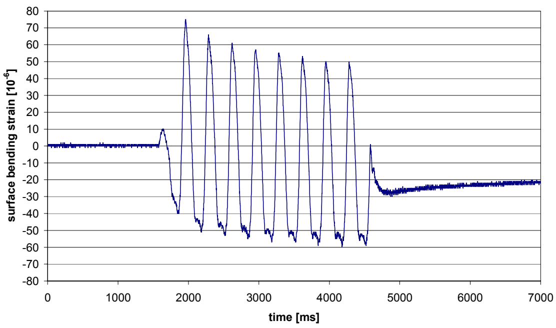

Fig. 2. Dynamic bending strain in the invert of the investigated flexible structure

At the investigated flexible structure, a surface bending strain of $\varepsilon = 100 \times 10^{-6}$ corresponds to a bending moment of M = 0.47 Nm/m. In Fig. 2 the average peak value of the bending strain amounts to about $\varepsilon = \pm 60 \times 10^{-6}$, corresponding to a bending moment of M = ± 0.28 Nm/m. In comparison to this value the bending strain in the invert of the flexible structure due to static load of the overburden soil, measured right after installation of the specimen, amounts to $\varepsilon = 170 \times 10^{-6}$, corresponding to a bending moment of M = 0.80 Nm/m.

In Fig. 3 and Fig. 4 are shown shaking model test results of the horizontal dynamic earth pressure acting on the upper part of the investigated rigid structure embedded in dry soil at an input frequency of 3 Hz and an input acceleration of 300 gal.

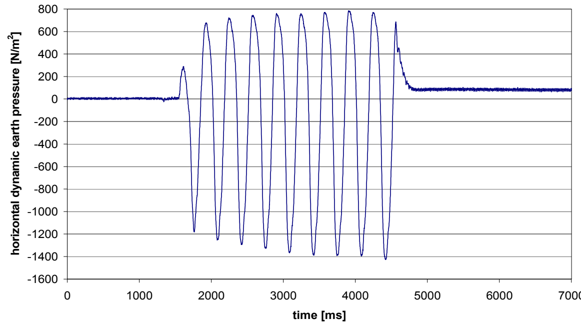

Fig. 3. Horizontal dynamic earth pressure acting on the upper part of the wall of the rigid structure without adjacent retaining walls

In Fig. 3 the average peak values of the horizontal dynamic earth pressure amount to about p = +700 N/m^2 and p = –1300 N/m^2. In comparison to these values the horizontal earth pressure acting on the upper part of the wall of the investigated rigid structure without adjacent retaining walls due to static load of the overburden soil, measured right after installation of the specimen, amounts to p = 1490 N/m^2.

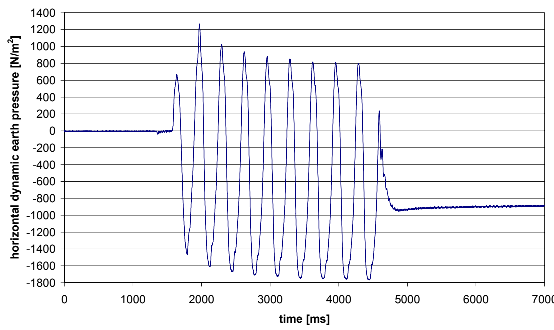

Fig. 4. Horizontal dynamic earth pressure acting on the upper part of the wall of the rigid structure with adjacent retaining walls

In Fig. 4 the average peak values of the horizontal dynamic earth pressure amount to about p = +900 N/m^2 and p = –1700 N/m^2. In comparison to these values the horizontal earth pressure acting on the upper part of the wall of the investigated rigid structure with adjacent retaining walls due to static load of the overburden soil, measured right after installation of the specimen, amounts to p = 2180 N/m^2.

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