Energy-based characterization of an embankment centrifugal model with respect to compaction water contents

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To study the stress-strain relation in an embankment affected by the compaction water content, dynamic centrifuge model tests were conducted. This study focuses on the energy-based characterization during dynamic loading. The results showed that the ratio between dissipated energy and strain energy has the same tendency in different cases, depending on the stress-strain condition and the water content. The maximum energy ratio appeared in the case with water content most close to the optimum water content.

Experimental conditions

In this study, Hiroshima sand with an optimum water content ratio w_{opt}=11.2% was used to conduct the comparative study for which the compaction water contents of five cases were changed from 6% to 14% by 2% increments. The test model subjected to 50G centrifuge acceleration was shown in Fig. 1. In all cases, the prototype scale was shown in this study.

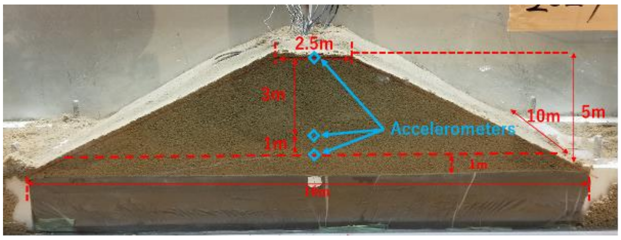

Fig. 1 Photo of a centrifugal model

The ramped sine wave of 1 Hz was applied to the model with the maximum amplitude of 300gal. Among the total number of 30 cycles, the amplitudes of the first 5 cycles are gradually increased from 0 to 300gal, and those in the last 5 cycles are gradually decreased from 300 to 0gal.

In this study, the embankment is treated two-dimensionally, and the data is processed on the assumption that there is no difference in the transversal direction.

Determination of shear stress and shear strain

As shown in Fig.1, 3 accelerometers were installed in locations A, B, and C, and both the shear stress and shear strain can be obtained from the acceleration.

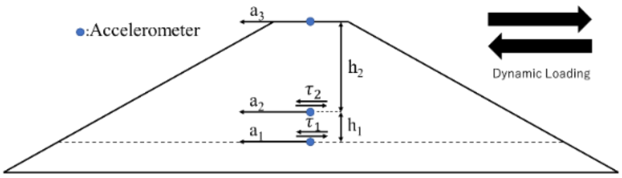

Fig. 2 Shear stress and horizontal acceleration

The horizontal displacement in each point can be calculated by double integration of acceleration with time as expressed below:

$$\int \left(\int \boldsymbol{a_n(t)\, dt} \right) \boldsymbol{dt} = \boldsymbol{d_n} \qquad (1)$$

The shear strain can be calculated from the differential displacement between two accelerometers, given by equation (2), where Δd=differential displacement between two accelerometers, and Δh=distance between two accelerometers.

$$\boldsymbol{\gamma_n = \Delta d_n / \Delta h_n} \qquad (2)$$

. Like shown in Fig. 2, the shear stress can be obtained by using the wet density (ρ_t), the installation distance (h_1 *and* h_2), and the acceleration (a) by the following equations:

$$\tau_1 = \sum ma = \rho_t \cdot \left(\frac{h_2}{2} \cdot a_3 + \frac{h_1 + h_2}{2} \cdot a_2 + \frac{h_1}{2} \cdot a_1 \right) \qquad (3)$$

$$\tau_2 = \sum ma = \rho_t \cdot \frac{h_2}{2} \cdot (a_3 + a_2) \qquad (4)$$

Energy-based method

In this study, the soil was considered as a viscoelastic material so when it was loaded cyclically, the induced strain has a phase lag from applied stress, and the strain-stress relationship will show a close area, as shown in Fig.3. The area enclosed by the elliptical loop ΔW represents the energy dissipated during one cycle of loading, on the other hand, the elastic strain energy stored during cyclic loading takes a maximum value W at the peak of stress or strain, corresponding to the area of the triangle OAB or OA'B'.

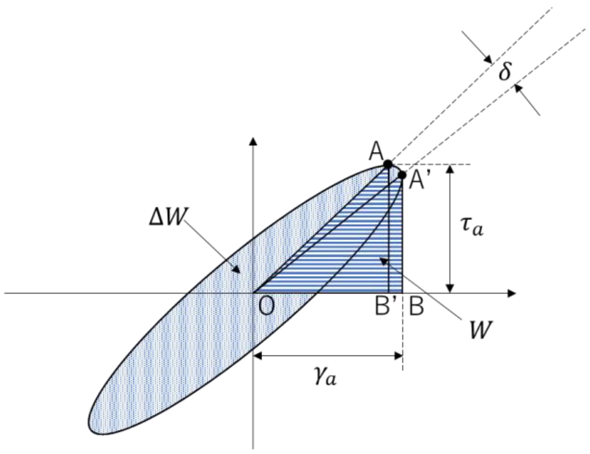

Fig. 3 General stress-strain relationship of viscoelastic material

Experiment results

In this study, the stress and strain were separated into cycles by which the dissipated energy ΔW and the strain energy W in each cycle were obtained and normalized by the initial effective consolidation stress σ'_c. Figure 4 shows a ratio of the dissipated energy to the maximum elastic strain energy per cycle characterizes a potential of energy dissipation in the material. The slope between any two adjacent points represents the energy ratio in one cycle, so the energy dissipation potential can be observed by the slope change of the curve.

From the results, a similar tendency of the energy relationship was observed in all cases, indicating that the energy ratio is high at the initial condition and decrease with the increase of cycle number. At the end of the dynamic load, the energy ratio slightly increases again because the magnitude of the input ramped sine wave gradually decreases at the end of dynamic loading. When the water content is low, the change in energy ratio is significant, but when the water content is high, the energy ratio is almost unchanged during dynamic loading because the corresponding stress-strain relationship exhibits a straight line.

The obvious differences can be observed when comparing the energy ratio between different cases. The energy ratio is small in low water content and is increased with the increase of water content. The maximum energy ratio appeared in the water content of 12% is close to the optimum water content (11.2%). Moreover, , the energy ratio decreases again when the water content exceeds the optimum water content.

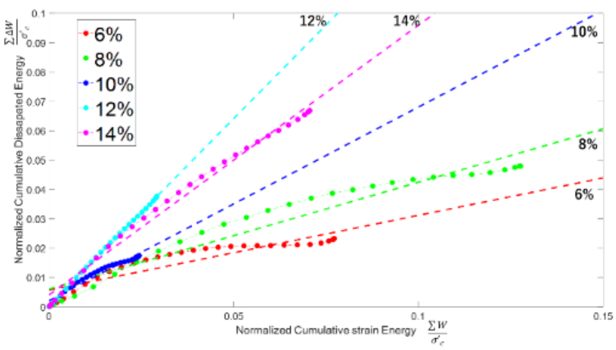

Fig. 4 Energy condition with different water content

Conclusion

The energy ratio of embankment under the same dynamic loading process in centrifuge tests obviously varies with the construction water content and when the water content is close to the optimum water content, the energy ratio shows the maximum value. Moreover, the energy ratio for the ramped portion of input sine wave seems to be slightly higher than other parts due to lower magnitudes of the initial and the final sinusoidal motions.

Reference

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