Seismic Stability of Earthen Embankment Subjected to Steady State Seepage and Rapid Drawdown

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Introduction

Earthen embankments, which act as a barrier to water in small reservoirs have numerous kind of uses for human kind, are distributed all over the world. These were mostly constructed in large numbers in the period when technology was not as advanced as now. These embankments are subjected to various kinds of conditions annually depending on the season and climatic conditions prevailing at the location of embankment. But, the centrifuge tests targeting the seepage and the dynamic analysis of the earthen embankment at different stages was not done in earlier studies but only considering half the embankment for seepage and shaking[1)]. So, in this study we have made an embankment which was subjected to centrifugal acceleration and we have observed the pore water pressure at different points in embankment when it is in steady seepage state or rapid drawdown state and also observed dynamic accelerations when subjected to shaking.

Material used for Embankment

We have used Masado soil as the material for the embankment as it is the most found material in Japan which is used for construction of earthen embankments. Properties of the soil are shown in table. 1.

Table 1. Material properties of Masado soil used in this study.

Sand (%)	90.23
Silt (%)	9.77
Maximum particle diameter (mm)	4.75
Average particle diameter (mm)	0.38
Solid particle density ρ_s (gm/cc)	2.6
Void ratio at maximum density *e*	0.465
Optimum moisture content w_{opt} (%)	14.3
Maximum dry density ρ_{dmax} (gm/cc)	1.72
Permeability of soil at 95% DOC *k* (cm/sec)	1.6×10^{-5}

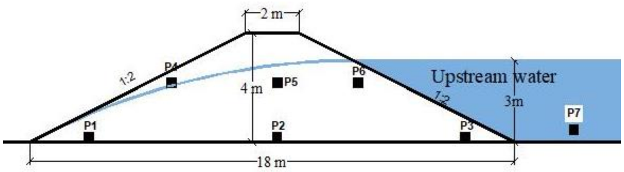

Fig. 2. Cross-section view of embankment with notation of PWP sensors in this study.

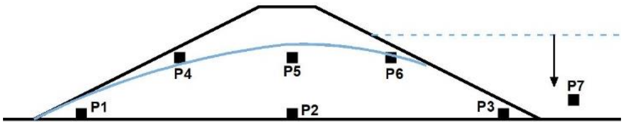

Fig. 3. Embankment during rapid drawdown.

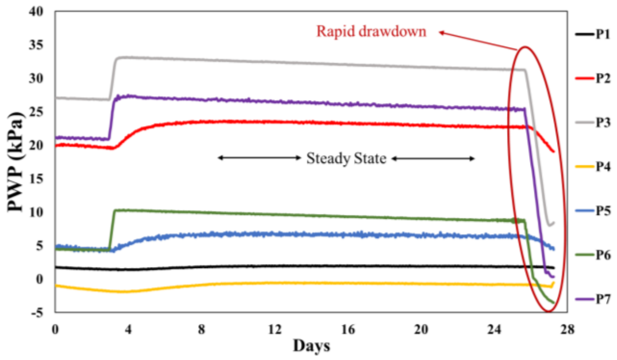

Fig. 4. Pore water pressure values in the model

Steady state flow

Steady state flow in embankment is the state in which the outlet flow is equal to inlet flow. This is achieved in centrifuge experiment by allowing the flow through seepage from upstream to downstream of embankment and wait till the readings in PWP sensors become constant. As shown in fig. 2, in which P1 is placed at downstream toe of embankment, P1 would be the last one to become constant for steady state.

Rapid drawdown

Rapid drawdown is one of the state in which embankment is at its least strength. So, we have tried to replicate this phenomenon in centrifuge. Once the steady state flow is achieved in the embankment we would drain the upstream water as shown in fig.3 which makes the water level in embankment to slowly reduce in its level. Fig. 4 shows the values of pore water pressure when the water level in upstream is reduced where we can observe that rate of change in P1, P2, P4 and P5 is not same as sensors P1, P3, P6 and P7 which are on upstream side.

Shaking tests in centrifuge

In this study we have given two input motions to the model after we have achieved a steady state and rapid drawdown in the embankment. First motion is given after we have achieved steady state or rapid drawdown and the second motion is given after a 5-10 minutes' interval in model scale. Details of the shaking tests are shown in Table.2.

Table 2. Shaking tests conducted in this study.

1st experiment	2nd experiment	3rd experiment
Seepage		
Steady state flow		Rapid drawdown
Two consecutive shakings are given after the phenomenon		

Results of shaking test

Fig.6 shows the acceleration time histories at different points of embankment after steady state and rapid drawdown as shown in fig.5. We can observe from the results that acceleration of point A4 have higher peak value than other points in rapid drawdown during shaking 2, but in shaking 1 it has less value which is because of damage shown in fig.7 after shaking 1. But in case of steady state the point with higher amplification is the top of embankment (A5) and is consistent in its response in both the shakings.

Conclusion

Earthen embankment which is made in centrifuge using Masado soil was subjected to seepage conditions and also two shakings were given consequently. When the embankment was given shaking after achieving steady state and rapid drawdown, there is a significant change in its strength on upstream slope after rapid drawdown phenomenon but not after achieving steady state.

References

1) Higo, Y., Lee, C., Doi, T., Kinugawa, T., Kimura, M., Kimoto, S., Oka, F., 2015. Study of dynamic stability of unsaturated embankments with different water contents by centrifugal model tests. Soils and Foundations 55 (1), 112-126.

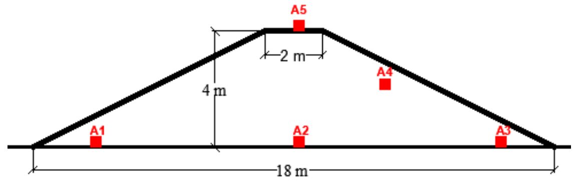

Fig. 5. Notation of accelerometers used in this study.

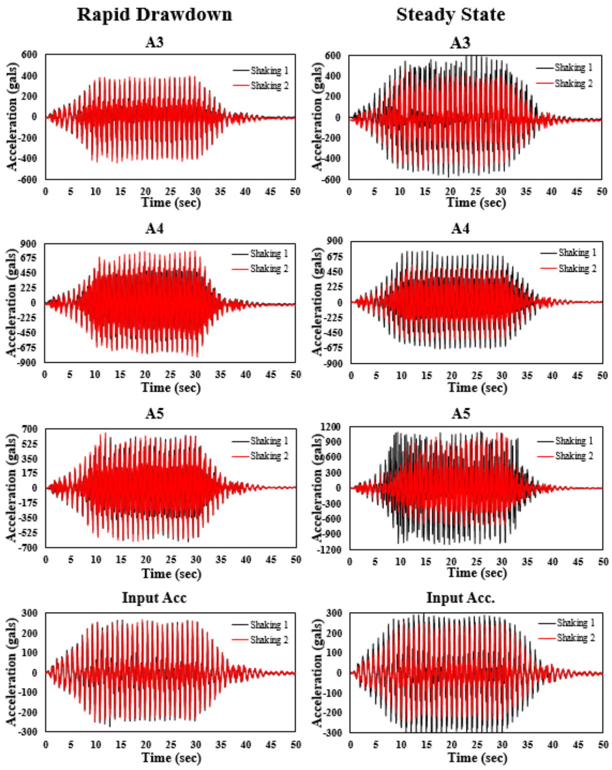

Fig. 6. Acceleration time histories in embankment.

Fig. 7. Damage to embankment after rapid drawdown