IG SHAKING TABLE TESTS ON ROCKING PHENOMENON OF SHALLOW FOUNDATION

University of Tokyo, Student Member. ○1. Catherine Kariuki
Railway Technical Research Institute, Regular Member. 2. Takaki Matsumaru
University of Tokyo, Fellow Member. 3. Junichi Koseki

INTRODUCTION AND OBJECTIVE OF STUDY

Non-linear behaviour at the soil-foundation interface is likely to occur especially during earthquakes of high acceleration. This non-linear behaviour is characterised by foundation uplift and/or soil yielding. Due to the cyclic nature of earthquake load, the mechanism of foundation uplift and accompanying soil yielding, takes place in an oscillating motion with a re-centering effect. The oscillating motion of foundation causes relative motion between soil and foundation resulting in energy dissipation by radiation of energy away from foundation and hysteric damping within the soil. Some researchers have used the term rocking foundation to refer to foundations that dissipate energy using this mechanism of plastic hinging in the soil-foundation interface.

To promote plastic hinging in the soil (rocking phenomenon), it has been suggested that foundations should be under designed, as there is an indirect relation between the likelihood of non-linear behaviour at the soil-foundation interface to vertical static factor of safety of foundation, Gazetas et al. (2013) and Algie et al. (2015). This would imply the surface area of foundation is reduced or structures are built on less stiff soils. Another phenomenon that accompanies earthquake with high acceleration, especially on non-plastic loose soils is: liquefaction. Liquefaction occurs when a saturated and loose mass of non-plastic soil is subjected to a strong cyclic shear force. Hence, in an attempt to provide for dissipation of energy by rocking, one may render a structure at risk of liquefaction. This study reproduces rocking phenomenon of a model typical box shaped RC wall structure, in a 1-G shaking table by varying the input motion parameters. Additionally it aims at predicting the extent of applicability of rocking phenomenon by observing its performance on liquefiable soils.

METHODOLOGY OF STUDY

The research was conducted by undertaking a series of 1-g shaking table test as summarized in *Table 1*, on a model structure for both dry soil and liquefiable soils. The model structure was developed by scaling down a typical 7 storey midrise box shaped Reinforced Concrete Building on a raft foundation by a factor of 40. The structure is assumed to be designed using AIJ standard for structural design of RC box-shaped wall structures, for purposes of scaling vertical static load for dynamic analysis.

Table 1 Summary of the experiment schedule

Case	Parameter Studied	Experiment Series	Soil Condition
Case 1	Input motion Frequency & Amplitude	A. 2Hz (2-6m/s^2) B. 5Hz (2-6m/s^2) C. 8Hz (2-6m/s^2) D. 10Hz (2-6m/s^2) E. 15Hz (2-6m/s^2) F. 20Hz (2-6m/s^2)	Dry Soil
Case 2	Effect of Liquefaction	A. 5Hz (2-5m/s^2) B. 10Hz (4-5m/s^2)	Saturated Soil

The tests are classified into 2 cases, dry soil tests and liquefaction tests. The ground is modelled using Silica sand No. 7 for both cases. Sand is poured through sieves in a soil box of 20cm width, 260cm long and 60cm depth. The first layer is formed to relative density of 86% and subsequent layers are formed of loose soil with relative density of 36%. The same is repeated, in the liquefaction study, with the soil layers formed by water pluviation, to form saturated soil ground of similar relative density. Accelerometer sensors, laser displacement sensors and pore water pressure transducers are used and positioned as illustrated in *Fig.1*, for data collection. Sinusoidal input waves of 40cycles are used for this study.

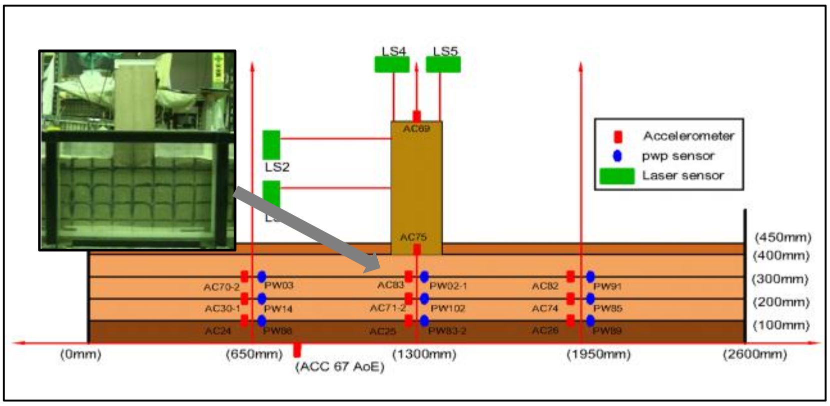

Fig. 1 Position of sensors

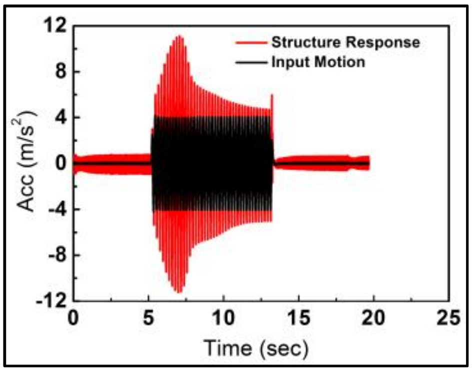

Fig. 2 Sample input & response motion (5Hz, 4m/s^2)

RESULTS AND DISCUSSIONS

a) Dry Tests

Keywords: 1-G Shaking table, Shallow Foundation, Rocking Phenomenon.
Contact Address:113-8656 Tokyo-to, Bunkyo-ku, Hongo 7-3-1

In the dry soil test, the input frequency is varied from 2 to 20Hz as summarized in *Table 1* and at each frequency the amplitude is increased from 2m/s^2 to 6m/s^2 at an increment of 1 m/s^2. *Fig. 2* shows typical input and response motions.

In this set of experiments, the goal was to establish the limits for occurrence of rocking phenomenon on the model structure, in relation to variations in input motion. Apart from 2Hz frequency at all accelerations and 5Hz frequency for the lower accelerations (2m/s^2~3m/s^2), the response of the structure is independent of that of the surrounding soil, due to the non-linearities causing rocking. By standardizing the maximum response acceleration of the structure with the base motion (denoted herein as AoE), amplification is compared in *Fig. 3*. The rocking is observed to be frequency dependent, with a decrease in amplification occurring with increase in input motion apart from 2Hz case, where no rocking is observed. The resonance frequency is also observed to shift down and to the left with increase in input motion. This can be attributed to the dissipation of energy due to the rocking motion of the model structure. *Fig. 4* shows a typical rocking response of the model structure. By considering the maximum rocking cycle, dissipated energy can be calculated and for each frequency it is observed to increase with increase in input motion more rapidly for 5,8,10Hz than in 2,15 and 20Hz as illustrated in *Fig. 5* as these frequencies are close to the natural frequency of the structure.

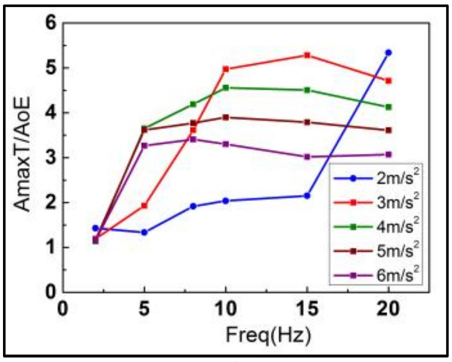

Fig.3: Summary of AmaxS/AoE

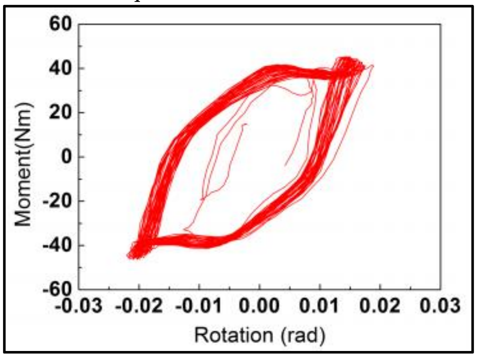

Fig.4: Typical Moment-Rotation relation

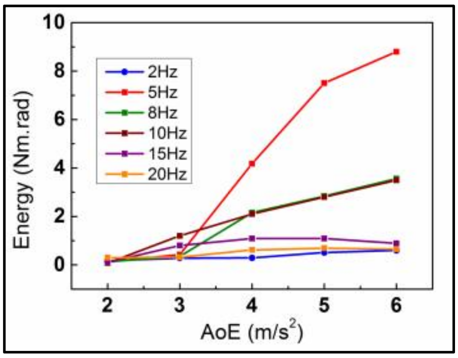

Fig.5: Summary of Energy variation

b) Liquefaction Tests

In the liquefaction case, base isolation is observed after the first cycle: see *Fig. 6*.But the base isolation cannot be attributed to rocking motion as the dominant deformation behaviour observed is rapid subsidence: see F*ig. 7* and the energy dissipation from limited rocking is minimal compared to that observed in dry soil test. Some rocking is observed but to a limited extent as can be seen in F*ig. 8*. In the 5m/s^2 case, excessive tilting is observed. For a structure on liquefiable soils, the superstructure may not undergo structural failure but risk of excessive subsidence or even overturning is likely to occur due to soil failure. All figures for Case 4m/s^2-5Hz.

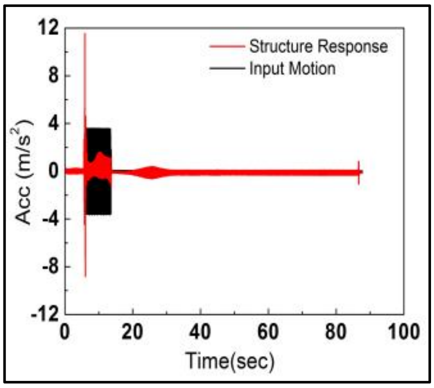

Fig.6: Sample input & response motions

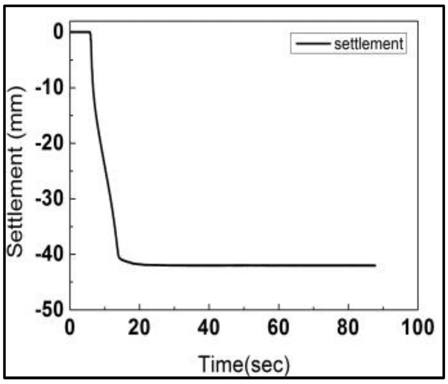

Fig.7: Settlement of structure

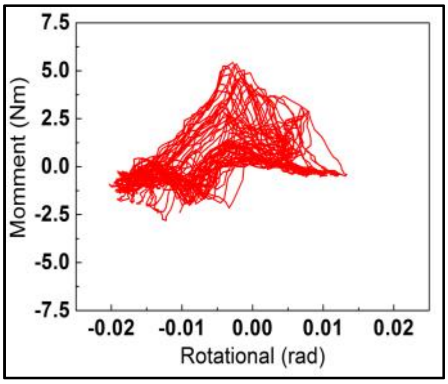

Fig.8: Typical Moment-Rotation relation

CONCLUSION

Rocking could be reproduced for the model structure in 1-g shaking table, and was observed to occur at high amplitude and is frequency dependent. It occurs at frequencies close to the natural frequency of the model structure. In liquefiable soils, although base isolation takes place, the dominant deformation behaviour is subsidence with limited rocking occurring. Liquefaction risk, limits the applicability of rocking phenomenon as it also introduces risk of structure overturning and excessive subsidence.

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Contact Address:113-8656 Tokyo-to, Bunkyo-ku, Hongo 7-3-1