Rocking shallow foundations in earthquake zone: field snap-back testing in cohesive soil

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INTRODUCTION

Rocking shallow foundation is an innovative foundation design concept that allows the footing to rock during strong earthquake motions, as opposed to conventional "fixed-base" footing concept. A snap-back testing is a comparatively short dynamic test approach, which allows the structure to rock at its natural vibration frequency. Previous studies showed that snap-back testing is an effective and a simple tool to investigate the nonlinear behavior of shallow foundation (Algie 2011, Salimath et al. 2017). The challenge is to understand the nonlinear soil-foundation-structure-interaction (SFSI) and incorporate this into existing earthquake resistant design solutions. Algie (2011) and Phipps et al. (2012) performed a series of snap-back tests to study the moment vs. rotation response of shallow foundations on natural soil deposits. However, there is still a lack of field tests data under different conditions such as rocking direction, initial amplitude, and the static factor of safety. A series of snap-back tests was carried out on shallow foundations standing on the surface of cohesive soils in Edmonton, Alberta. High initial displacements were applied (a maximum drift ratio of 8%) to the structure from its initial position, held still, then suddenly released by using a quick release mechanism to rock the structure about its shallow footing. The objective was to investigate the nonlinear behaviour of the structures supported on rocking shallow foundation.

EXPERIMENTAL PROGRAM

A cohesive soil site was selected for the snap back field tests of rocking footing system. The natural water content of the soil was about 30%, and plastic and liquid limit were about 35 % and 75 % respectively. The soil at the site can be classified as elastic silt according to Unified Soil Classification System (USCS). The rocking foundation system consisted of a rectangular reinforced-concrete spread footing of 1.5 m by 1.0 m size, a steel tubular column, and RC slabs on the top of column used as the superstructure weight as show in Figure 1. The rectangular footing stood on the ground surface representing an isolated footing supporting a structural assembly. To achieve various factors of safety (FS) against the bearing failure, additional vertical loads from concrete slabs (2 m by 2 m by 0.3 m) were added on the top of the deck. The displacement of the foundation and column was measured. An accelerometer was placed on the top of structure to measure the acceleration at the top of structure. Strain gauges were mounted at bottom of the column to measure the moment during the rocking. The snap-back tests were conducted by pulling the structure to a designated drift ratio, using chains attached to a quick release mechanism. Chain was secured around the top of each column on the north side of the structure and fastened to an excavator through a quick release mechanism. The excavator was used as an anchor point for the chains. At the desired rotation the device was released and the structure would rock under free vibration.

RESULTS AND DISCUSSION

Figure 2a shows the typical static moment-rotation curves also called pushover curve obtained during the application of the pullback forces. The moment vs. rotation curve is highly nonlinear and also that the stiffness is degraded from one test to the next. However, as in cyclic test moment capacity was not observed to decrease with respect to number snap-back test. This type of backbone curve is very important for calibrating the numerical modeling of both rocking foundation and structural response to near field ground motion.

Figure 2b shows the relationship between fixed base period and measure rocking period. The natural period of fixed base structure increased significantly when the structure rocked about its footing. The rocking foundations reduce the seismic force on the structure by lengthening its natural period. Continuous settlement of the foundations during rocking and a progressive rounding of the soil interface with large amplitudes of footing rotation and loss of the contact area due to the softening of the system led to lengthening the natural period of the rocking structure. Large amount of energy dissipation through the soil was noted. Additional, during the experiment it is found that the natural periods increase monotonically with increasing vertical load (i.e. decrease FS against bearing) on the footing.

It was observed that the rocking foundation, once released, only rocked for 2 to 5 oscillations before it came to rest which indicates a high level of damping. Damping values were calculated from all snap-back tests using the logarithmic decrement method. Significant amount of damping, ranging from around 8% to 30% was obtained after analysis both deck acceleration and displacement time histories. Although there is a significant scatter in data, it is observed that when the yielding is significant (i.e., rotations are greater than 2 millirad), the damping ratio is insensitive to the amplitude of rotation for snap-back tests.

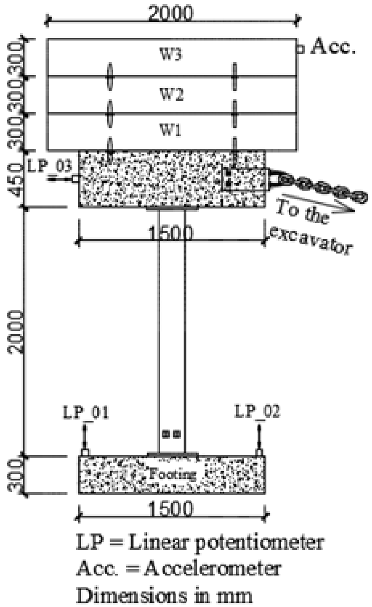

Figure 1. Schematic diagram of the model in the field

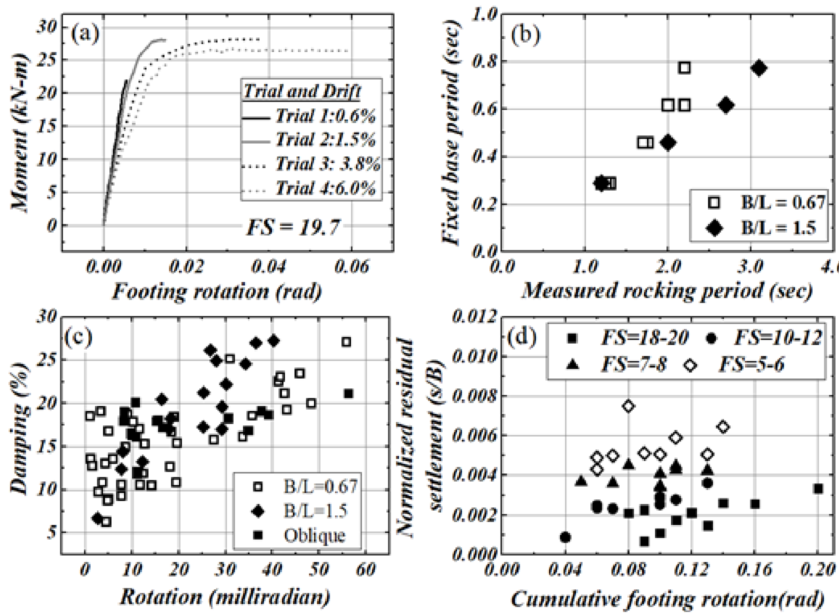

Figure 2. Typical results (a) Moment vs. rotation, (b) measure rocking period vs. fixed base period, (c) damping vs. rotation, and (d) normalized residual settlement vs. cumulative footing rotation

The cumulative footing rotation and the residual footing settlement normalized by the footing length in rocking direction were obtained using the method of Deng et al. (2012). As footing rocks, the contact area between the soil and footing reduces and lead to limited localized bearing failure at the edge of footing that in turn leads to progressive settlement due to cyclic nature of load. Based on the snap-back tests, settlements are significant if FS is small i.e. less than 10 in our case. If FS is greater than 10, the settlements tend to be very small as shown in Figure 2d.

CONCLUSIONS

A series of snap-back tests was carried out on shallow foundations resting on the surface of cohesive soil in Edmonton, Alberta to examine dynamic behaviour of rocking shallow foundation. The following observations are made.

1) The pushover curves from the snap-back tests displayed nonlinear moment-rotation behaviour. The curves displayed a degradation of initial rotation stiffness throughout the tests. This was from soil damage and rounding that occurred during the slow pullback part of snap-back test.
2) Significant period elongations ranges from 200-300% were observed. With increasing vertical load, the fundamental mode periods increase approximately linearly.
3) The experiments showed that rocking foundations demonstrate significant damping; snap-back experiments revealed the damping ratio ranges from 8-30 %.
4) Excessive settlement did not occur during snap-back tests. This is evident by the cumulative footing rotation vs. normalized residual settlement relationship.

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