I - 460

A STUDY OF SOIL-STRUCTURE INTERACTION OF A MODEL REINFORCED CONCRETE TOWER

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INTRODUCTION: To provide verification data of soil-structure interaction, a model reinforced concrete tower has been constructed in the Chiba Experiment Station of the University of Tokyo. More than 200 earthquakes have been recorded since August 1983, the largest being the Chibaken-Toho-Oki Earthquake of December 17, 1987. Its peak ground acceleration (PGA) of the North-South (NS) component recorded at ground level -1 m at borehole P5 is 393 cm/s^2. The objective of this paper is to present results of analysis of earthquake and microtremor data as well as values of parameters of the soil-structure system, determined by observation and numerical modeling.

OBSERVATION OF SOIL-STRUCTURE INTERACTION EFFECTS: As it was shown in previous publications by the same authors [1], depending on the amplitude of the dynamic excitation, there is a shift of the dominant frequency (Figure 3) from about 4.0 Hz for the microtremor through 3.5 Hz for a moderate earthquake (IEQK 8519, PGA=70 cm/s^2) to 2.5 Hz for the considerably larger Chibaken-Toho-Oki Earthquake (IEQK 8722, PGA = 393 cm/s^2). This is explained with the influence of two factors: the nonlinear behavior of the soil and the separation of the soil from the structure. Separation has been observed by other researchers, too [2]. Investigation of the absolute soil pressure on the walls and floor of foundation at different earthquakes was used to assess quantitatively the separation of the soil from the structure. The points at which non-positive values of the absolute soil pressure were detected are hatched in the perspective plot in Figure 1. Simultaneous separation at all those points during the Chibaken-Toho-Oki Earthquake were observed, which means that at least about 12% of the area of the walls (2 of 12 gauges plus the area between them) and 20% of the area of the bottom of the foundation (3 of 13 gauges) did not participate in the support of the structure.

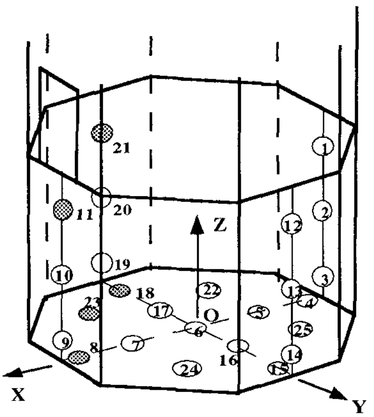

Figure 1. Locations of separation of the structure from the soil

NUMERICAL MODELING OF THE TOWER: The observation tower was modeled numerically with a sway-rocking model in which the soil support was represented by two springs and two dashpots with their respective coefficients: a rocking spring (K_R), a sway spring (K_H), a rocking dashpot (C_R) and a sway dashpot (C_H)[1]. Initially these coefficients were obtained as functions of the frequency (f) according to the methodology, presented in [3]. The static values of K_R and K_H (at f = 0 Hz) produced a good agreement with regard to the frequency contents of the real and calculated response for small events (e.g. IEQK 8717, PGA = 24 cm/s^2). Appropriate values of the spring coefficients for larger earthquakes were found by trial and error. The squared sum of differences between the Fourier spectra of the real and calculated response in the range 2-6 Hz was used as a criterion for the best-fitting values of K_R and K_H. During this step of the analysis we were concerned with fitting the real response only in terms of its frequency contents, so the values of C_R and C_H were kept constant. Once the values of the stiffness coefficients were determined in this way, the damping coefficients were adjusted by a similar procedure to fit the amplitude of the real response. A very good agreement was achieved for all the analyzed events using the thus evaluated sets of constants. Figure 2 shows an example of comparison in the frequency domain between the real and

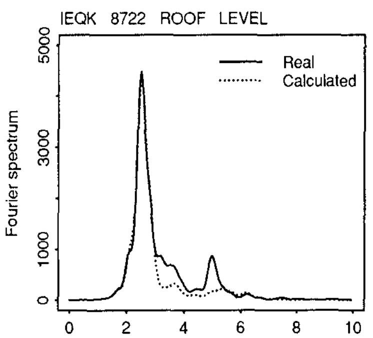

Figure 2. Comparison of real and calculated response of the tower

calculated acceleration at the roof level for the OX-component of the Chibaken-Toho-Oki Earthquake. It is interesting from practical point of view how much of the decrease of the coefficients is due to non-linearity and how much to separation. The effect of nonlinearity was investigated with the program SHAKE on the basis of one-dimensional wave propagation theory. Using the earthquake record at P5, the changes of the shear modulus and damping ratio were obtained and the stiffness and damping coefficients were recalculated on that basis. Figure 3 shows an example of discrimination between the effect of soil nonlinearity and effect of separation on the sway spring constant for the Chibaken-Toho-Oki Earthquake. The line labeled "Overall Change" shows the value of the constant, obtained by numerical analysis. The separation has a much stronger influence on the weakening of the soil support than the soil nonlinearity. Figure 4 presents graphically empirical relations between the peak ground velocity (PGV) and the soil constants for 16 earthquake components and corresponding linear curve fits. It can be seen, that all the coefficients except the sway dashpot coefficient decrease with the increase of the peak ground velocity. Analysis of two weak aftershocks of the Chibaken-Toho-Oki Earthquake showed values of the soil constants, which were closer to those, calculated for the preceding strong motion, than for other small earthquakes. This signifies that the soil support remained weaker for a certain period of time after the large event.

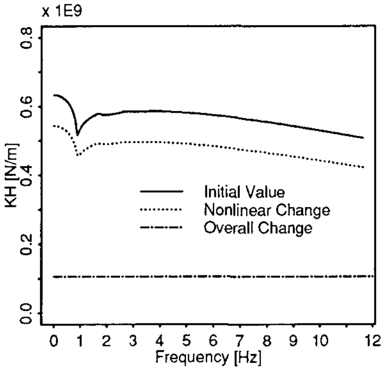

Figure 3. Influence of nonlinearity and separation on the sway spring constant

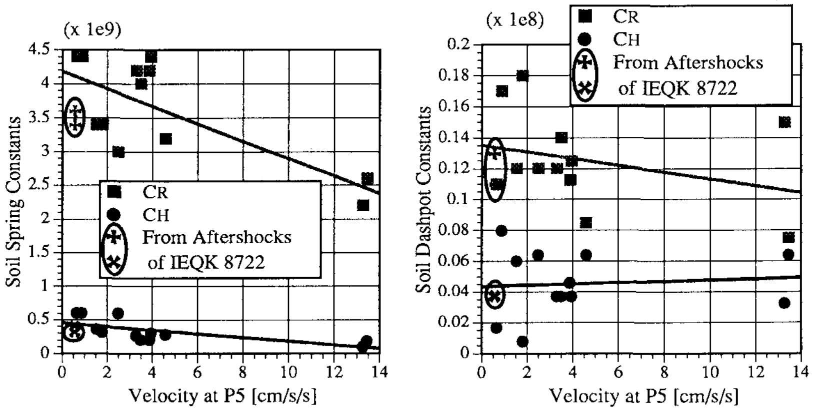

Figure 4. Empirical relations between the PGV and the soil constants

CONCLUSIONS: Using a linear sway-rocking model with constant values of the stiffness and damping coefficients, the behavior of the observation tower was simulated successfully. The influence of the interaction phenomena on the soil parameters was determined by a comprehensive comparative study of real and calculated structural response. For each analyzed event, a set of best-fitting values of the soil coefficients was determined. A distinct assessment of the effect of soil-nonlinearity and the effect of separation on the soil parameters was made. It was found that separation weakens the soil support much more than the soil nonlinearity. Simple empirical relationships between the peak ground velocity and the soil spring and dashpot constants for earthquake excitation of different magnitude were found. All the constants decrease with the increase of the peak ground velocity, with the exception of the sway dashpot constant.

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