I-499 NONLINEAR SEISMIC PILE-SOIL-PILE INTERACTION

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Using single, 2-, 3-(row) and 9-(3x3)pile group soil-structure systems, we have been studying on nonlinear seismic behavior of pile-soil-pile systems. In our Hybrid Experiments on Nonlinear earthquake induced Soil-Structure Interaction, (HENESSI), we started with lumped parameter discretization of large scale models through them we established systems of second order ordinary differential equations to be used later in static and dynamic experiments. Next based on results from forced vibration tests, Fig.(1), complex frequency dependent stiffness matrix of the systems were constructed in frequency domain. Satisfying conditions of causality and introducing a complex pseudo-stiffness whose imaginary term is the Hilbert transformation of its real static stiffness of the system and then through inverse fourier transformation, we developed a time-history dependent stiffness in time-domain numerical scheme which accounts for nonlinearity as well as frequency dependency characteristics of dynamic systems[5]. The deformation state of lumped parameter systems were determined by sway and rocking modes chosen as two degrees of freedom measured at their gravity centers. Equations of dynamic equilibrium deduced through these degrees were later used in forced vibration tests in them we determined frequency dependent characteristics for the systems through phase delay study of dynamic developed restoring forces in the systems in response to harmonic displacement input excitations[4]. Fig.(2) illustrates established dynamic characteristics by lines whereas those obtained through forced vibration tests are shown by small circles. Studying on frequency dependent behavior of the systems we used a constant, a virtual mass and the above mentioned frequency dependent stiffnesses for soil-pile interaction models that were located at the lower part of foundations. In our study we utilized Pseudo-Dynamic Testing method which combines conventional time-domain dynamic analysis procedure with experimentally measured information to provide realistic dynamic responses[1]. For the step-by-step numerical integration algorithm we have used Central Scheme of Finite Difference Method which is thought to be most widely used in Japan[3] and reliable and accurate enough if the time increment is set to less than or equal to twice the inverse of system's natural frequency[2]. System response to 30 to 400 gal maximum acceleration amplitude-scaling technique on TAFT, HACHINOHE and IBARAKI(observed at the field) are normalized and shown in Fig.(3) and (4) respectively for 1-pile and 2-pile foundation systems. Effects of application of seismic inputs with different wave-patterns and frequency components were studied through Fig.(5). Different frequency dependendent stiffness modelings have shown different effects on the system seismic response. Results are shown in Fig.(6). Fig.(7) shows restoring force characteristics of 1-pile and 2-pile systems.

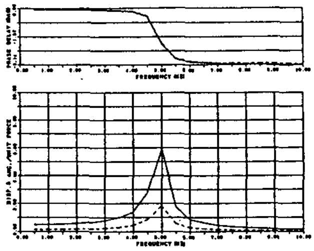

Fig.(1)
Forced Vibration test results for 2-pile.

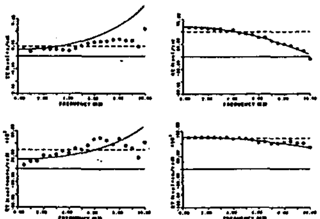

Fig.(2)
Dynamic frequency dependent stiffness and damping of 2-pile for sway and rocking.

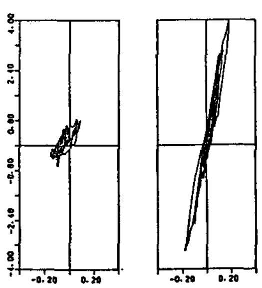

Fig.(7)
Dynamic restoring force characteristics of 1-pile-CNV and 2-pile-CNV.(shown at left and right respectively)

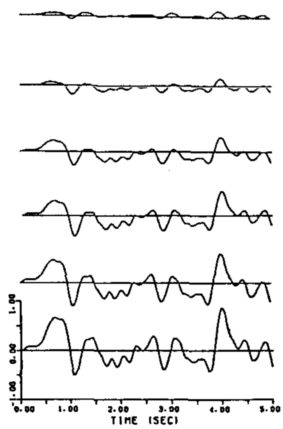

Fig.(3)
Response of 1-pile-CNV to TAFT(S69E) with 30, 60, 120, 180, 240 and 300 gal max. input.

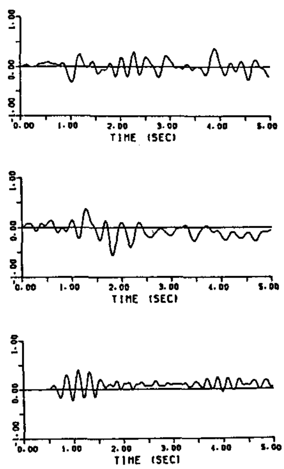

Fig.(5)
Response of 2-pile-CNV to TAFT, *HACHINOHE* and *IBARAKI* with *180 gal* maximum input. (downwards respectively)

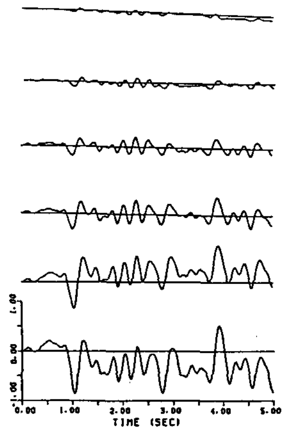

Fig.(4)
Response of 2-pile-CNV to TAFT(S69E) with 30, 60, 120, 180, 240 and 300 gal max. input.

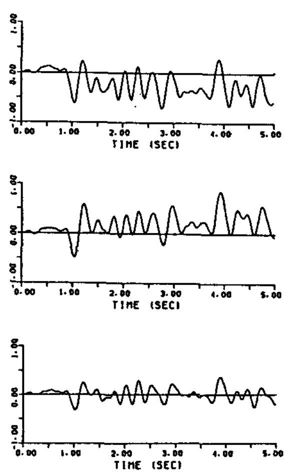

Fig.(6)
Response of 2-pile-CNS, 2-pile-VRL and 2-pile-CNV to TAFT with 180 gal maximum input. (downwards respectively)

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