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Real-time dynamic hybrid testing for soil–structure interaction analysis

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ABSTRACT

Simulating dynamic soil–structure interaction (SSI) problems is a challenge when using a shaking table because of the semi-infinity of soil foundations. This paper develops real-time dynamic hybrid testing (RTDHT) for SSI problems in order to consider the radiation damping effect of the semi-infinite soil foundation using a shaking table. Based on the substructure concept, the superstructure is physically tested and the semi-infinite foundation is numerically simulated. Thus, the response of the entire system considering the dynamic SSI is obtained by coupling the numerical calculation of the soil and the physical test of the superstructure. A two-story shear frame on a rigid foundation was first tested to verify the developed RTDHT system, in which the top story was modeled as the physical substructure and the bottom story was the numerical substructure. The RTDHT for a two-story structure mounted on soil foundation was then carried out on a shaking table while the foundation was numerically simulated using a lumped parameter model. The dynamic responses, including acceleration and shear force, were obtained under soft and hard soil conditions. The results show that the soil–structure interaction should be reasonably taken into account in the shaking table testing for structures.

1. Introduction

In the 1930s, researchers began realizing that structure and its underlying soil foundation should be considered as an entire system in dynamic analysis. Since then, tremendous efforts have been made by researchers to obtain an accurate and effective numerical calculation method for soil–structure interaction (SSI) analysis. Generally, SSI analysis can be grouped under the direct and substructure methods [1]. In the direct method, the structure and soil are treated as an entire system. The region of the soil adjacent to the structure–soil interface is explicitly modeled. Artificial boundaries must be introduced to cover the semi-infinite soil domain. In the substructure method, the structure and soil are treated as two different substructures. Each substructure can be analyzed using a best-suited computational technique. Combining the force–displacement relationship at the interface between the soil and the superstructure results in the integral motion equations of the entire system.

Although many theoretical SSI analysis procedures have been developed, considering the SSI effect in shaking table tests is still problematic because of the semi-infinity of soil foundation. Laboratory-based SSI studies generally employ a purpose-designed soil container, such as rigid container with sufficiently large size [2], rigid container packed with foam at the sides of the container [3], laminated soil container [4], and so on, to model foundations. However, the boundary effect of the finite soil container is not yet well solved. In addition, limited by the bearing capacity of the shaking table, the structures are commonly simulated by a small-scale model in these tests. It is hard for a small-scale model to reasonably represent the dynamic properties of dimension-sensitive prototype structures.

Alternatively, SSI in shaking table tests is considered by combining the numerical calculation of the semi-infinite soil together with the physical test of the superstructure in this paper. This idea comes from the concept of real-time dynamic hybrid testing (RTDHT), a recently developed testing method [5–9]. The fundamental idea of RTDHT is to split the entire system under consideration into two parts: numerical substructure and physical substructure. The former will be simulated in the computer by developed numerical models. The latter, or the remainder, which may be nonlinear, rate-dependent, or generally have a complicated dynamic behavior, is built as a physical model and tested using dynamic testing equipment (e.g., dynamic actuators or shaking tables) [10–13]. The RTHDT has been applied to simple structural systems where the numerical substructure was developed on the basis of over-simplified modeling techniques and few degrees of freedom [10–13]. Very recent studies reported the large-scale RTHDTs using detailed nonlinear analytical models (similar to those used in state-of-the-art numerical dynamic analysis) with a large number of degrees of freedom [14,15].

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