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Use of global ductility for design of structure–foundation systems

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ABSTRACT

This paper investigates the applicability of global ductility in the conventional design procedure of structure–foundation systems under earthquake excitation. For a bilinear elastoplastic model, an equivalent ductility factor for the combined structure and foundation is derived, which can be used in conjunction with the enlarged period and increased damping due to soil–structure interaction (SSI) to determine the design strength. A geometric transformation rule for predicting the ductility demand developed in the structure alone from that experienced by the interacting system is also derived, without the need of computing the rigid-body motion of the foundation. To validate this practical approach for assessing both inelastic strengths as well as ductility demands, a number of numerical results for different system parameters and earthquake excitations are provided. The effects of principal parameters involved are also examined.

1. Introduction

The current SSI design provisions are usually based on elastic response studies [1–3], ignoring that the SSI effects in inelastic systems are less important than in elastic systems [4]. The reason for this is that the structural yielding increases the relative flexibility between the structure and soil and hence decreases the effects of SSI. Investigations on this subject are scarce as compared with the elastic case. A recent study [5] has shown that, for soft/deep soil deposits, the SSI effects in yielding structures may result in either increase or decrease of the fixed-base strengths and displacements, depending primarily on the period ratio of the structure and site. The higher the structural ductility, the smaller becomes these effects.

The displacement ductility is a widely used response parameter for evaluating the seismic performance of structures. For SSI systems, however, the global ductility is not an appropriate performance index as it encompasses a rigid-body motion of the foundation that is not associated with strains in the structure. This observation was noted by Ciampoli and Pinto [6] and Mylonakis and Gazetas [7] while studying the inelastic response of bridge piers supported on soft soils. According to the former authors, if this rigid-body motion is removed from the total displacement of the structure, the pier ductility demands are consistently decreased by the effects of SSI. On the contrary, the latter authors have found that the SSI effects may cause significant increases in the pier ductility demands depending on the characteristics of the SSI system and the earthquake excitation.

As has been pointed out by Mylonakis and Gazetas [7], the indiscriminate use of global ductility obscures the beneficial or detrimental role of SSI in the inelastic response of structures and this may lead to erroneous conclusions. These authors purify the total displacement of the structure by subtracting the rigid-body displacements induced by the translation and rocking of the foundation. As an alternative, we propose here a more direct formulation based on the derivation of a geometric transformation relation between the structure and system responses. This avoids the need for computing the foundation-induced motions, which is required by other previous approaches [6,7].

In this work, the replacement oscillator approach [1–3] earlier developed to account for the SSI effects in elastic systems is extended to inelastic systems, for the important special case of bilinear elastoplastic behavior. To do this, an equivalent ductility factor for a replacement fixed-base oscillator with the same yield strength and total displacement as the original flexible-base structure is deduced. The concepts presented are derived with reference to the model of Priestley and Park [8] for bridge structures. The adequacy of the proposed approach for evaluating both inelastic strength spectra as well as ductility demand spectra is proved for different system parameters and earthquake excitations. The results are given in terms of dimensionless parameters for their general application, using a set of appropriate soft-soil ground motions for ensuring generality of conclusions.

2. SSI system and its solution

To account for the foundation flexibility resulting from the interaction between a bridge pier and the soil, practitioners have

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