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Footings under seismic loading: Analysis and design issues with emphasis on bridge foundations

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Abstract

The paper provides state-of-the-art information on the following aspects of seismic analysis and design of spread footings supporting bridge piers: (1) obtaining the dynamic stiffness (''springs'' and ''dashpots'') of the foundation; (2) computing the kinematic response; (3) determining the conditions under which foundation–soil compliance must be incorporated in dynamic structural analysis; (4) assessing the importance of properly modeling the effect of embedment; (5) elucidating the conditions under which the effect of radiation damping is significant; (6) comparing the relative importance between kinematic and inertial response. The paper compiles an extensive set of graphs and tables for stiffness and damping in all modes of vibration (swaying, rocking, torsion), for a variety of soil conditions and foundation geometries. Simplified expressions for computing kinematic response (both in translation and rotation) are provided. Special issues such as presence of rock at shallow depths, the contribution of foundation sidewalls, soil inhomogeneity and inelasticity, are also discussed. The paper concludes with parametric studies on the seismic response of bridge bents on embedded footings in layered soil. Results are presented (in frequency and time domains) for accelerations and displacements of bridge and footing, while potential errors from some frequently employed simplifications are illustrated.

Keywords: Dynamics; Footings; Impedance; Kinematic response; Soil–structure interaction; Numerical methods

1. Introduction

During earthquake shaking, soil deforms under the influence of the incident seismic waves and ''carries'' dynamically with it the foundation and the supported structure. In turn, the induced motion of the superstructure generates inertial forces which result in dynamic stresses at the foundation that are transmitted into the supporting soil. Thus, superstructure-induced deformations develop in the soil while additional waves emanate from the soil–foundation interface. In response, foundation and superstructure undergo further dynamic displacements, which generate further inertial forces and so on.

The above phenomena occur simultaneously. However, it is convenient (both conceptually and computationally) to separate them into two successive phenomena referred to as ''kinematic interaction'' and ''inertial interaction'' [1–4], and obtain the response of the soil–foundation–structure system as a superposition of these two interaction effects:

(a) ''Kinematic interaction'' (KI) refers to the effects of the incident seismic waves to the system shown in Fig. 1b, which consists essentially of the foundation and the supporting soil, with the mass of the superstructure set equal to zero (in contrast to the complete system of Fig. 1a). The main consequence of KI is that it leads to a ''foundation input motion'' (FIM) which is different (usually smaller) than the motion of the free-field soil and, in addition, contains a rotational component. As will be shown later on, this difference could be significant for embedded foundations.

(b) ''Inertial interaction'' (II) refers to the response of the complete soil–foundation–structure system to the

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