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Dynamic soil-structure interaction of bridge-pier caisson foundations

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Abstract

This paper presents the main results of 3D FE dynamic analyses carried out in the time domain to assess the seismic performance of rigid and massive circular caisson foundations supporting bridge piers. Various foundations systems are subjected to a real acceleration time history. Soil behaviour is described by an elastic-plastic model capable to provide a fair estimate of nonlinear soil behaviour and hysteretic damping under cyclic loading conditions. The coupled dynamic analyses are carried out in terms of effective stresses, thus evaluating the excess pore water pressures induced by earthquake loadings. Caisson construction stages are reproduced in a simplified way. The influence of pier height and caisson slenderness on maximum and permanent displacement and rotation attained during and at the end of the seismic shaking is considered. The equivalent seismic coefficient to be adopted in a pseudo-static analysis to check the safety of the foundation against geotechnical limit states is also evaluated.
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Keywords: bridges; caisson foundations; dynamic anayses; earthquakes; seismic coefficient

1. Introduction

In the framework of the performance-based design, the seismic performance of a structure can be evaluated by comparing specific threshold values of earthquake-induced displacements or rotations to those attained during and at the end of the seismic event. Typically, the performance of bridge-pier caisson foundation systems is evaluated via

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direct or substructure approaches. In the direct approach, the whole system is included in a unique model and the analyses are carried out in the time domain: it is then possible to perform nonlinear 3D analyses, referring to numerical methods [1]. Conversely, in the substructure method the soil-structure interaction problem is solved separately evaluating the kinematic and inertial effects in the frequency domain: it is then possible to perform only linear analyses, and permanent displacements cannot be evaluated [2,3].

In this paper, the seismic behaviour of various caisson foundation – bridge pier systems, differing in pier height and caisson slenderness, is studied. All systems are characterised by the same static and seismic factors of safety, F_{Sv} and F_{Se}, following the procedure proposed by Zafeirakos and Gerolymos [1], in order to analyse systems with similar degrees of mobilisation of soil shear strength before and during the seismic event. Soil behaviour is described using the *Hardening Soil with Small Strain Stiffness* (*HS small*) model [4], an elastic-plastic hysteretic model available in the library of the 3D FE code Plaxis. Systems are subjected to a real acceleration time history. Results are expressed in terms of maximum and permanent pier displacements and caisson rotations, highlighting the influence of geometric and dynamic properties of the system on them. The maximum value of the horizontal seismic coefficient to be used in the pseudo-static approach to design the caisson against geotechnical ultimate limit states is also evaluated.

2. Problem definition

In Figure 1 the problem layout is shown. The behaviour of the different systems considered in the analyses is studied in the transverse direction. A linear elastic reinforced concrete circular caisson of height H and diameter D = 12 m, supporting a bridge pier of height h_s, is embedded in a 5 m thick layer of gravelly sand and a 55 m thick layer of silty clay. The water table is located at the interface between the gravelly sand and the silty clay, z_w = 5 m, and the pore water pressure regime is hydrostatic. The pier is modelled as a linear viscous-elastic single degree of freedom, with a lumped mass $m_s = m_{deck}+0.5\cdot m_{pier}$ applied at the top; the remaining half mass of the pier is applied at the head of the caisson through a distribution of vertical pressures $\sigma_{z(0.5\ pier)}$. The pier cross section is a hollow rectangle with sides $L > B$ and thickness s.

The mechanical properties of the foundation soils are reported in Table 1, in which I_P is the plasticity index, γ is the unit weight, c' and φ' are the effective cohesion and the angle of shearing resistance, and k_0 is the coefficient of earth pressure at rest.

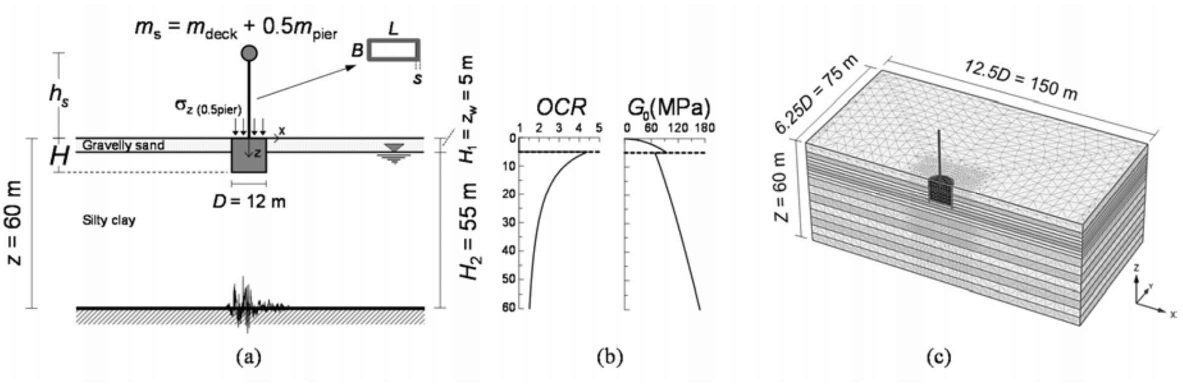

Fig. 1. Problem definition: (a) schematic layout; (b) *OCR* and G_0 profiles; (c) 3D view of the model as implemented in Plaxis 3D.

Table 1. Mechanical properties of foundation soils

Soil	I_P (%)	γ (kN/m^3)	c' (kPa)	φ' (°)	*OCR*	k_0
gravelly sand	-	20	0	30	1.0	0.5
silty clay	25	20	20	23	4.4 – 1.5	1.1 – 0.7

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