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1D seismic response analysis of soil-building systems including failure shear mechanisms

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Abstract

Modelling of soil shear rupture due to an earthquake is not generally implemented in the common codes for 1D seismic response analysis. It requires the use of advanced plasticity-based constitutive models of soil, that are often neglected in practice. A good balance between simplicity and reliability can be achieved with methods based on simplified formulations of the mathematical equations and of the constitutive models. The paper presents a computer code based on this philosophy conceived, addressed and optimised to reliably model both the 'transient' seismic response ('stick' mode) and the permanent deformation mechanisms accounting for the coupled effects of deformability and strength ('slip' mode). The code can be adopted to evaluate the seismic performance of different geotechnical systems that can be reasonably approximated to a 1D problem. In the paper, the code is applied to model a soft-storey failure occurred in a framed structure heavily damaged during a strong-motion earthquake.

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Keywords: seismic response analysis; soil-building system; shear failure; stick-slip model

1. Introduction

The 1D seismic site response can be performed using different numerical methods for the solution of the ground motion equations, depending on the subsoil discretization approach (i.e. continuous layers vs. finite elements) and on the adopted cyclic soil-behaviour model (i.e. linear equivalent vs. non-linear methods) [1]. The most widespread

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computer codes describe partially dynamic soil behaviour and do not guarantee a reasonable solution of the ground motion equations when large strains and failure conditions are reached. These aspects can be modelled by advanced computer codes implementing plasticity-based constitutive models for the dynamic soil behaviour. In practice, these are not widespread, because these models often require cumbersome calibration through detailed laboratory cyclic tests and their effectiveness can be significantly reduced if they are not implemented with an appropriate numerical formulation. In addition, the achievement of failure conditions is a singularity of the system that cannot be evaluated with numerical methods which assume the continuity and the differentiability of the stress and strain variables.

A good-working compromise is adopting a simplified description of both the mathematical equations and of the constitutive soil model. To this aim, the procedure proposed by [2] based on stick-slip dynamics, was extended with more general assumptions and implemented in the SCOSSA (Seismic COde for Stick-Slip Analysis) code [3]. The paper summarizes the model formulation and describes its application to simulate the damage occurred in a framed structure during l'Aquila Earthquake in 2009.

2. The stick-slip model

The adopted dynamics of the stick-slip model refers to a lumped mass system, reproducing the seismic response of a vertical soil column either horizontally layered (Fig. 1) or sloped. Two stages of dynamic analysis can be identified: in the first ('stick') phase, the potentially unstable mass cumulates vibrational kinetic energy, that is converted into a frictional sliding mechanism during the second ('slip') stage.

In the stick phase, the seismic response in terms of absolute displacements, $\mathbf{u}_\mathbf{a}$, to a base ground motion, $\ddot{u}_g$, can be computed by integrating the MDOF system equation:

$$\mathbf{M}\ddot{\mathbf{u}}_\mathbf{a} + \mathbf{C}\dot{\mathbf{u}}_\mathbf{a} + \mathbf{K}\mathbf{u}_\mathbf{a} = \mathbf{f} \qquad (1)$$

where **M**, **C** and **K** are the mass, damping and stiffness matrices, **f** is the vector of applied forces.

The forces, T, acting on a generic s layer are:

$$T = -m_T \ddot{u}_s - \mathbf{1}^\mathrm{T} \mathbf{M}_\mathrm{s} \ddot{\mathbf{u}} \qquad (2)$$

where the first term is the inertial force induced by the absolute acceleration at the s-th layer, $\ddot{u}_s$, while the second results from the non-uniform relative acceleration profile, $\ddot{\mathbf{u}}$, within the sliding mass, referred to $\ddot{u}_s$.

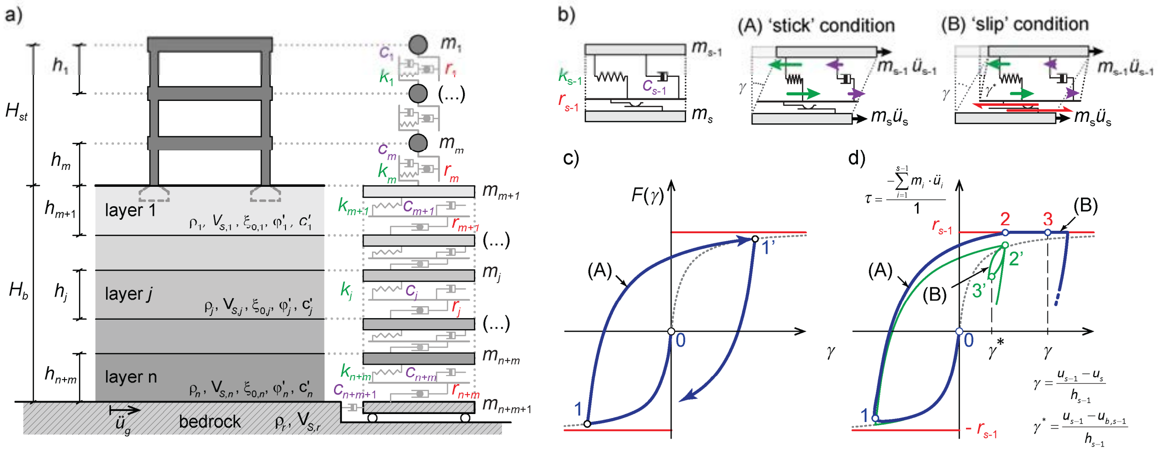

Fig. 1. (a) The MDOF system adopted in this study. (b) 'Stick' and 'slip' conditions in a two-mass system; (c) purely hysteretic behaviour; (d) dynamic response of the system.