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Effect of ground-motion asynchronism on the equivalent acceleration of earth dams

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ABSTRACT

Under seismic loads the deformability of an earth dam may induce several effects, including ground-motion amplification and asynchronism between different points of the dam embankment. The paper analyses the asynchronous effects occurring in two existing earth dams, representing well-documented case histories: the El Infiernillo Dam (Mexico) and the Camastra Dam (Italy). Asynchronous effects are analysed by theoretical predictions of the dam seismic response by adopting an advanced dynamic approach, which takes into account the main features that dam soils exhibit under cyclic loading conditions. For different potentially unstable masses within the dam embankment, equivalent accelerations were computed as the ratio between the resultant of the inertial forces and the weight of the volume V associated to the unstable mass. With the exception of very cortical sliding surfaces – not significant for dam stability – in most of the analysed cases the equivalent seismic coefficients do not exceed the peak acceleration at the dam base.

1. Introduction

Under seismic loading conditions the safety of an earth dam with respect to global instability depends on the maximum values of acceleration attained inside the dam body and, moreover, on the spatial distribution of instantaneous accelerations, that is to say, of inertial forces.

The development of asynchronous (i.e. out-of-phase) motions in earth dams can be related to the features of the input motion (frequency content, amplitude and duration) and to the features of the dam embankment (mainly: geometry, stiffness and damping of the construction soils). In general, asynchronism tends to increase when the higher vibration modes of the dam embankment are excited. This is likely to occur when the seismic signal is rich in high frequencies or the natural frequencies of the dam are relatively low. This is the case of very high dams or embankments made of very deformable materials.

As well known, under seismic loading conditions soil stiffness and damping depend on the mobilized level of shear strain. The severity of the input motion, hence, may strongly influence the development of asynchronism in earth dams. Stronger earthquakes actually induce significant decrease in dam stiffness (with respect to the initial value), thus promoting the onset of asynchronism.

Starting from the pioneering work of Seed and Martin [1], different simplified methods have been developed to take into account asynchronous motions arising in embankments and slopes during earthquakes. To such a purpose, the restrictive hypothesis of rigid soil mass has to be removed and coupling between the dynamic response of the earth dam and the characteristics of the input motion has to be considered. Most of literature studies on asynchronism were primarily focused on finding the proper "equivalent acceleration" to evaluate the inertial forces in pseudo-static approaches or to carry out displacement-based analyses by the Newmark's sliding block model (e.g. [2,3]). In recent years in Italy many efforts have been carried out on such a topic, under the auspicious of the ReLUIS project. Reference could be made, among others, to the works of Ausilio et al. [4,5], Rampello et al. [6,7], Bilotta et al. [8], and Sica et al. [9].

In the present paper, ground-motion asynchronism has been analysed both experimentally, by interpreting the acceleration signals recorded at several points of an earth dam, and theoretically, by numerical predictions of the dam seismic response.

The experimental approach, although extremely valuable in highlighting the asynchronous motions, does not allow an accurate computation of the inertia forces in the whole domain of interest because of the reduced number of measurement points. Usually, only a few seismic stations are installed on an earth dam. Recording data, hence, provide information with very low spatial resolution, usually inadequate to describe the phenomenon at hand. It should be further added that a seismic

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network frequently records seismic events of weak intensity and in a few cases stronger ones. From a practical viewpoint, in earth dams it is important analysing asynchronism effects when strong earthquakes occur: in this case the issue of dam safety with respect to global instability becomes meaningful. For such additional reason, studying the phenomenon by a theoretical approach is almost unavoidable. Sophisticated models, nowadays available, assure reliable predictions of dam seismic response even to intense earthquakes.

The paper first shows the asynchronous motions observed in the Camastra Dam (Italy), by comparing both the displacement and the acceleration time histories recorded at three different locations of the dam body, where accelerometric stations are active. Since the recordings were acquired during very weak earthquakes (the only ones recorded at the dam site since July, 2002 when the seismic network started to work), such measurements are scarcely useful from a practical viewpoint, but they are valuable to highlight the occurrence of asynchronism in earth dams.

The paper later illustrates the results of a theoretical study aimed at characterizing ground-motion asynchronism in two earth dams under various seismic conditions and its influence on the "equivalent seismic coefficient". The results of extensive and refined finite element modelling of the seismic response of the selected case-histories [10,11] have been imported to such a purpose.

2. Brief description of the two dams

For both the Camastra and the El Infiernillo Dam, a large amount of data has been collected on the construction process, the static and dynamic properties of the materials, the monitoring activities daily carried out. Detailed interpretation of such data has been provided in different papers the reader could refer to [10–17]. This section briefly describes only the main features of the two selected dams.

2.1. Camastra Dam

The Camastra Dam (Fig. 1) was built from July 1963 to November 1964, at about 20 km from the town of Potenza in Southern Italy. It is a zoned dam 57 m high. The vertical core is made of sand with clayey silt (PI=17%, w_L=37%, permeability $k=10^{-10}$ m/s) and the shells of sandy gravel. The dam is founded on two chaotic calcareous-clayey and calcareous-arenaceous formations, which can be considered rigid bedrock.

In 2002 the dam was instrumented with a network of 5 accelerometer stations. Two stations were placed on the dam abutments and three along the boundary of the main cross-section in correspondence of the top, the mid-height bank and the base of the downstream shell. The recordings at the three stations

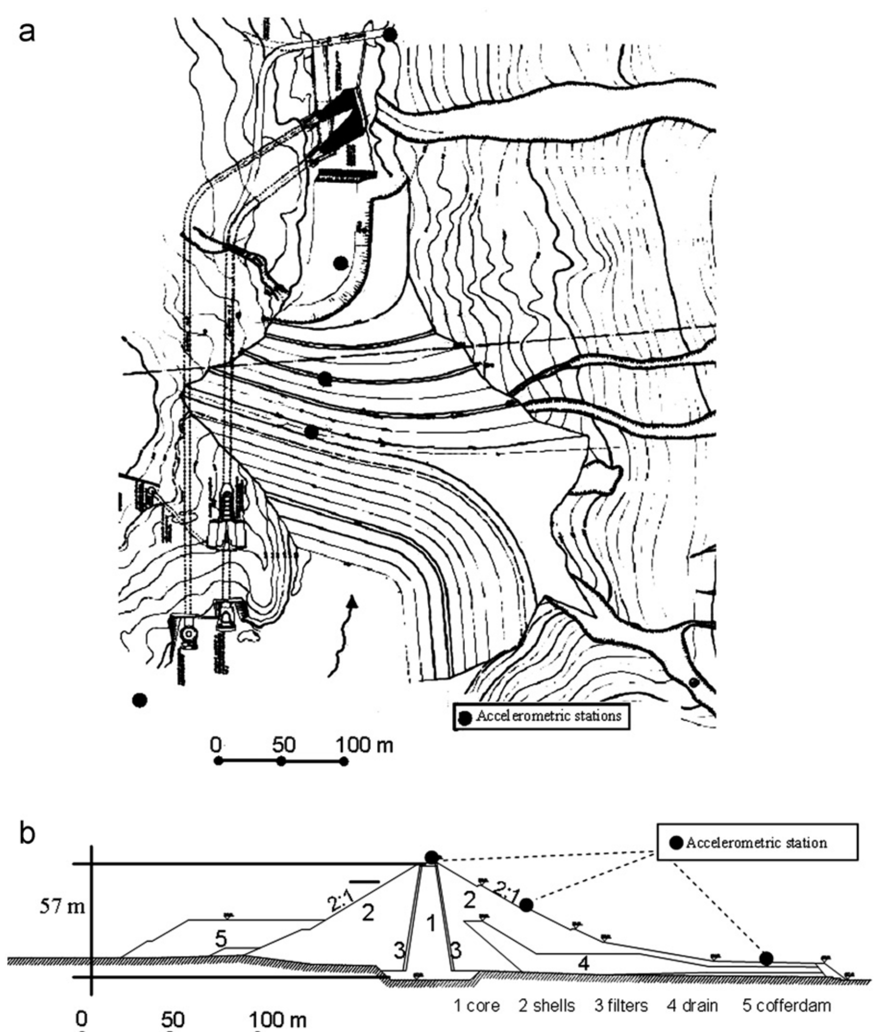

Fig. 1. Camastra Dam: plan view (a) and maximum cross-section (b).