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Calibration of finite element models of concrete arch-gravity dams using dynamical measures: the case of Ridracoli

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Abstract

Accurate and reliable predictions of the dynamic behaviour of dams is essential to ensure their correct management and the safety of the downstream population. In this context, structural monitoring and testing procedures for their dynamic characterization are essential tools for the calibration of numerical models of dams. This paper presents some results of an ongoing research program aimed at an accurate definition of the geometric and structural properties of a large arch-gravity dam: the Ridracoli dam in the Emilia-Romagna region, Italy. In the first part of the research, a detailed survey carried out by an Unmanned Aerial Vehicle has allowed the detailed reconstruction of the three-dimensional geometry of the structure. The dense point cloud, as provided by the aerial survey, has been the base for the definition of a high-fidelity finite element model, including the dam, the surrounding rock mass, with a detailed reconstruction of the site topography, and the reservoir water, whose dynamic interaction with the structure is modelled by means of acoustic elements. A large program of structural monitoring, including a number of vibration tests, has been performed on the Ridracoli dam during the last thirty years. The dynamic monitoring system includes accelerometers, located in the structure and in the foundation rock mass, strain gauges and hydrodynamic pressure cells. The forced vibration tests were carried out in correspondence to the maximum water level, in order to identify the dynamic characteristics of the dam. The mechanical properties of the dam material and of the foundation rock are calibrated by comparing model predictions with the results obtained from vibration tests and from acceleration recordings acquired under recent seismic events, considering the actual water levels registered during the tests. The finite element model obtained will allow the simulation of the seismic performance of the dam under different design earthquakes. The assessment of the effects of the reservoir level and of the vertical joints on the dynamic response of the structure will be analysed.

Ke Keywords: dam; UAV; FE model; dynamic analysis

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1. Introduction

Primary aspects in dam management are the safety of downstream population and the efficient maintenance of the structure [1]. In fact, dam break events for large dams can have far-reaching catastrophic consequences, as demonstrated by documented case-histories and numerical studies [2]. Non-invasive techniques for the evaluation of the conservation state of the dam structure have been thoroughly investigated [3]. Under the assumption of linear behavior of the structure, modal analysis can be performed on dams by means of 2D or 3D Finite Element (FE) models to identify the natural frequencies and the corresponding mode shapes of the structure [4]. This information can then be used to identify the occurrence of a local degradation process [5], since a variation of the material properties over some portion of the structure can determine a corresponding change in the natural frequencies under the same dynamic input. For structures such as segmented arch dams built on valleys with complex topography, the detailed definition of the structure geometry – including the joints between the different segments – and of the foundation rock mass is of primary importance in defining the natural frequencies of the system. Moreover, specific attention must be paid to the mechanical response of expansion joints, as their stiffness affects significantly the overall response of the structure and the occurrence of inelastic sliding can cause internal forces redistribution under strong seismic events [6,7]. Therefore, a detailed geometrical reconstruction of the dam system can be very helpful in the definition of the dynamic properties of the dam and in the detection of their spatial variations. In this respect, the limited accessibility of large dams does not allow the use of traditional survey techniques, while the use of Unmanned Aerial Vehicles (UAV) is well suited for this purpose [8]. In particular, the "Structure from Motion" (SfM) technique can be used for the reconstruction of 3D objects from 2D images. However, the applications of such methodologies on large dams are still relatively scarce, and a reliable terrestrial survey is still necessary [9]. The present work aims at describing the preliminary calibration of a masonry dam FE model. Its geometry was derived from a UAV survey. The paper is organized as follows. Firstly, the case study of the Ridracoli dam is presented, the monitoring system of the dam and the UAV survey are illustrated. Secondly, the FE model construction is presented, paying attention to the joint, rock foundation and fluid-structure interaction modeling. Then the comparison of the 3D model with the vibration tests and with a seismic response is presented. Finally, the first results and conclusions are illustrated.

Nomenclature

E'	Drained Young's modulus	E_d	Dynamic elastic modulus	T	Period
G'	Drained shear modulus	N	Poisson's coefficient	H	Dam high
E_u	Undrained Young's modulus	ρ	Bulk density	*p*	Prescribed pressure
G_u	Undrained shear modulus	B	Bulk modulus		
E_s	Static elastic modulus	f	Frequency		

2. The Ridracoli dam: monitoring system and UAV survey

The Ridracoli dam is an arch-gravity dam in simple concrete (height 101 m and crest 432 m long) that closes a wide U-shaped valley in the center of Italy. The dam was completed in 1982 and it was completely filled for the first time in 1986. The dam body has a double curvature shape, symmetric with respect to the key section. It rests on a foundation saddle, which extends along the entire perimeter of the excavation. The body of the dam is not continuous, but divided in 27 vertical sections, which work as independent static elements in order to reduce the deformations within the dam body, during reservoir level changes, temperature variations or other actions, and to avoid cracking of the structure. The ashlars are connected by the insertion of neoprene elements that are disposed around the entire outer perimeter of the transverse section and of the tunnels that cross longitudinally the dam and the foundation.

2.1 Monitoring Systems

The control of the behaviour of the structure, the foundation rock, the reservoir banks and the downstream rocky slopes is achieved through a complex monitoring system activated since the construction phase. Most of the instruments and measuring points are located in five radial sections of the structure: the key section, the two external lateral ones and the two intermediate lateral ones [10]. Hydrostatic level, concrete, water and air temperatures, displacements, uplift pressures, deformations of concrete and rocks, and stresses in the dam body are periodically acquired and analysed by a dual control system, on-line and off-line. They verify independently the effective behaviour