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Seismic Hazard and Structural Analysis of the Concrete Arch Dam (Rules Dam on Guadalfeo River)

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Abstract

The aim of this paper is to describe the seismic hazard performance on the site of Rules Dam, in Granada province (southern Spain), and the seismic influence on this body's dam, as well as on its critical elements, the reservoir and the interaction fluid-structure. The seismic hazard defines the Deterministic Seismic Hazard Assessment (DSHA) and the Probabilistic Seismic Hazard Assessment (PSHA), which are important to calculate the Safety Evaluation Earthquake (SEE) and the Operating Basis Earthquake (OBE), respectively. This recent seismogenic zone provides important data to do the analysis, such as regional geologic setting, seismic history and seismology. In the Spanish code the Peak Ground Acceleration (PGA) for this area is 0.17 g, however in the current analysis the greatest soil acceleration registered is 0.35 g, which is about twice the value. Three accelerograms (controlling earthquakes), by using the Engineering Strong-Motion database, have been chosen to identify the seism's main characteristics. The dam analysis using different software needs to be done to calculate the vibration periods, the hydrodynamic pressure and the maximal vertical stresses. Time-history analyses have been made to analyze the consequences of a dam failure and to estimate minor damage acceptance. The analyses show that the stresses exceed the tensile maximum allowed creating plastic hinges. There are other factors which can affect the dam's behavior such as the vertical component of the earthquake and the silt in the reservoir bottom. The concrete arch gravity dam needs to be modeled in two- and three-dimensions, in accordance to classic theoretical method and current codes, considering its big dimensions (length of the crest: 620 m; radius: 500 m; area of the reservoir whit a operating level: 308 Ha). A dam is an extremely strategic work which needs to be carefully designed to avoid environmental damage to water reservoirs and nearby facilities and for human security. Given that the recent sources of hazard in Spain are from 2015, it would be advisable to reassess the seismic hazard particularly related to existing dams of category A (Spanish code) in areas of high seismicity.

Keywords: Seismic hazard; concrete arch gravity dam; dynamic analysis.

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1. Introduction

The focus of this paper is to describe the seismic risk on Rules dam site and its influence in relation to the interpretation of the fluid-structure's dynamical problems. The seismic hazard of a new seismogenic zone is useful to recalculate the actions on the dam. In particular, deterministic and probabilistic analysis will be made to define the SEE and OBE, respectively, using four different attenuation equations. In the Engineering Strong-Motion database three accelerograms have been chosen to do a time-history analysis and to identify the main characteristics of the controlling earthquakes. The dam is modeled by two- and three-dimensions to account for the interaction of the rock foundation and water. The dam analysis in three dimensions defines the modal analysis and the fundamental dam period (0.284 s). In two dimensions, considering a triangular dam shape, the vertical compressive stresses of the element in the bottom of the upstream face have been calculated. It is useful to do the dynamic analysis to know the cyclic behavior of the material subjected to stresses. During the seism, the water in front of the structure exerts a cyclic dynamic load on the wall and the critical mode occurs during the phase when pressure goes in direction to the wall. This phenomenon added to the inertia dam can reach intense stresses. The study of tensional states is necessary to analyze the consequences of a dam failure and to estimate minor damage acceptance.

2. Seismic hazard of a new seismogenic zone

The seismic hazard assessment has been made on basic criteria, as the Cornell method [10], which is based on (i) earthquake recurrence time following a Poisson process and on (ii) event magnitude that is exponentially distributed by Gutenberg and Richter. The model used includes a total of 11 zones and considers a radius of 150 km from the dam site. The coordinates of the dam are: 36.51° (latitude), - 3.29° (longitude). The mean annual rate of exceedance and the b-values have been taken from the new Spanish seismogenic source model but they have been opportunely recalculated taking in to account the many uncertainties of the procedure [13]. The dam is situated in a rocky stratigraphic profile with an average shear wave velocity over 750 m/s.

2.1. SEE and OBE definition

From the disaggregation analysis – which is made to separate the magnitude and distance contribution that has generated acceleration –, for a dam fundamental period (T_d), the following numbers are obtained: Mw = 5.9 (magnitude moment) and $R_{epi.}$ = 7.5 km (epicentral distance). In Fig. 1 (right) the Pseudo-Spectra Accelerations (PSA) with these values are shown (T is the structural period). The four attenuation relations do not use the same parameters, therefore the values have been adapted (see [6,7,8,9] for the attenuation relations). In Fig. 1 (left) annual probability of exceedance is shown – expressed in terms of return period – in function of PGA. The differences between the curves depend mainly on attenuation equations used and on their standard deviations: when standard deviation decreases the return period increases. The standard deviation values used range from ± 0.19 to ± 0.29 (for the analytic analysis zero has been used). The green curve values, in Fig. 1 (left), are higher because the equation has not been well-constrained for low magnitudes; therefore the curve overestimates higher T_r. This analysis, through a probabilistic approach, has been made only for the seismogenic zone where the dam is: ZS35 [11].

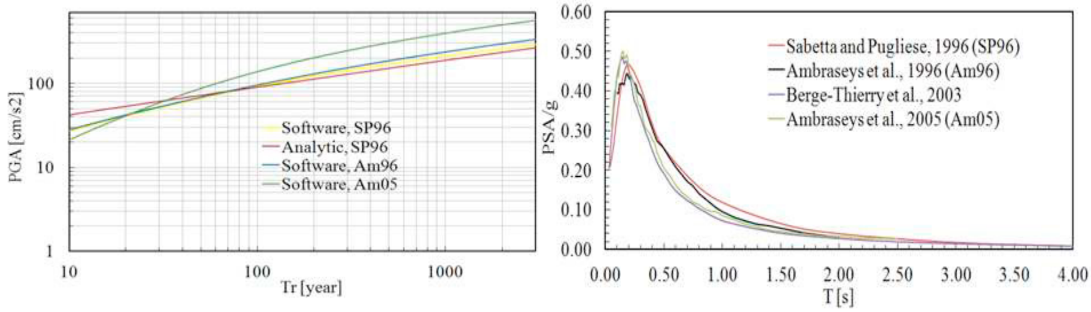

Fig. 1. (left) PGA vs. T_r (used CRISIS2007©software); (right) synthetic spectra.