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Sensitivity analysis of the seismic response of gravity quay walls to perturbations of input parameters

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ABSTRACT

Gravity quay walls are extremely common geotechnical systems in many ports. In earthquake-prone regions it is important to assess the seismic behavior of such berths, and to determine which input parameters have the largest effect on the response. This study presents a seismic sensitivity analysis of a blockwork wharf, wherein the effects of inherent variations of ground motions and geotechnical quantities are investigated. An advanced finite difference model is used to propagate the uncertainties, and several nonlinear dynamic analyses are performed for this purpose. Two methodologies are also adopted: Tornado and First Order Second Moment (FOSM). Results from both approaches are found to be in fair agreement, and throw light on the relative importance of input parameters for the considered case. It is showed that the uncertainties associated with the seismic input, i.e. intensity level and ground motion definition, are the most relevant ones. Then there are the effects of the geotechnical parameters, the largest of which is given by the friction angle of the backfill.

1. Introduction

In Performance Based Earthquake Engineering (PBEE), a fundamental step is the probabilistic evaluation of systems and components under seismic loading. The seismic response of structures and geotechnical works is measured by assessing some Engineering Demand Parameters (EDPs), whose definition is based on commonly accepted engineering considerations. A detailed illustration of PBEE can be found in many references (e.g. [1–4]).

Several studies have also addressed the seismic sensitivity of different systems. In these researches, the unknown variability in the predicted output (i.e. the seismic response), is estimated and quantified based on the known variability in the considered input. Amongst these investigations, Lee and Mosalam [5] presented a seismic demand sensitivity analysis for a reinforced concrete shear-wall building, while Na et al. [6] investigated the effects of input perturbations on the seismic response of a caisson-type quay wall as the ones damaged during the Kobe earthquake, 1995.

In the current work a sensitivity analysis is performed for a blockwork wharf, which is the oldest configuration for gravity quay walls, and one of the most common in the whole Mediterranean region [7]. It is noted that the same configuration has also been used by the authors to derive fragility curves using a novel approach [8].

2. Prototype model

The prototype configuration analyzed in this study, depicted in Fig. 1, is a blockwork wall realized with a pile of five blocks, each 2.5 m tall, for a total height of 12.5 m. The width is 8 m at the base, and 4 m on top, with a decrease of 1 m for each level.

Soil characteristics are assigned based on real stratigraphies found for the Port of Gioia Tauro, Southern Italy [9], as reported in Table 1.

2.1. Finite difference model

A numerical model of the system is obtained using the software FLAC 2D [10], a two-dimensional explicit finite difference software widely used for nonlinear geotechnical analyses. Total model dimensions are 90 m × 42.5 m, with a fine grid definition. The largest zone is 1 m × 2.5 m (far field conditions), while the

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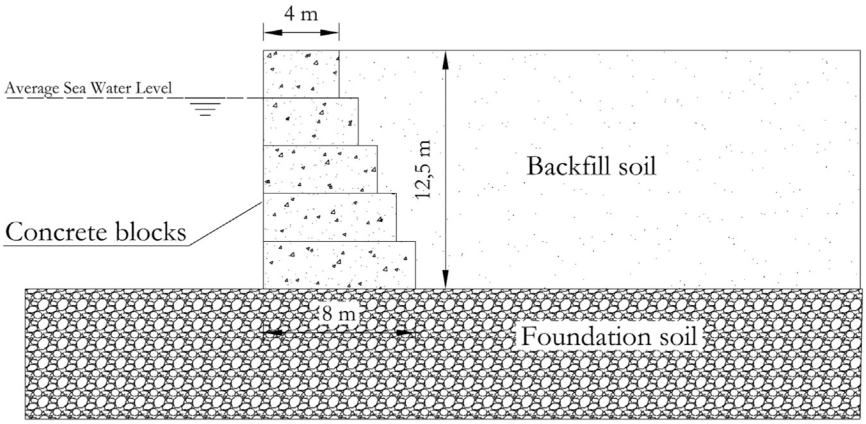

Fig. 1. General model of the blockwork wharf analyzed in this study.

Table 1
Soil properties assumed for the different strata.

Layer	Lithological unit	γ [kN/m^3]	c' [N/m^2]	ϕ' [°]	E' [kN/m^2]
Upper backfill soil	Sand with gravel (U1)	17	0	30	30,000
Lower backfill soil	Silty sand (U2)	19	0	30	50,000
Upper foundation soil	Coarse sand (U3)	18	0	36	50,000
Lower foundation soil	Fine sand (U4)	19	0	36	80,000

minimum dimension is 0.75 m × 0.75 m (below the wall). The soil is modeled with an elastic soil model, together with the Mohr–Coulomb yielding criterion, and some modifications to include the damping active at small-medium strain. Seed et al. [11] curves for sand are used for the modulus reduction curve. It is recognized that more advanced constitutive models are currently available to simulate soil response. However these formulations also require a refined geotechnical characterization and an *ad hoc* calibration of their parameters. Lysmer and Kuhlemeyer [12] viscous boundaries are used at the bottom of the model, while the lateral boundaries are modeled with the formulation by Cundall et al. [13].

The geotechnical parameters used in the model are the friction angles and the shear moduli of backfill and foundation soils, as well as the friction angles at the interfaces block-backfill, and block-foundation. Therefore, six geotechnical variables are considered. Further information about modelling assumptions, as well as validation tests, can be found in Calabrese and Lai [14].

2.2. Seismic input

Analogously to the prototype model, the reference hazard levels used in this study are also based on the seismicity of the site where the Port of Gioia Tauro is located. Uniform Hazard Spectra (UHS) and deaggregation at the site are taken from the Probabilistic Seismic Hazard Analysis (PSHA) performed by the Italian Institute of Geophysics and Volcanology (INGV). The Uniform Hazard Spectra (UHS) (5% damping) for several probabilities of exceedance in 50 years at the selected location are reported in Fig. 2, while a summary of site seismicity is reported in Table 2. The Peak Ground Acceleration (PGA) values for the considered hazard levels range from 0.07 to 0.5 g.

Based on the deaggregation, nine sets of seven spectrum-compatible accelerograms have been selected for the return

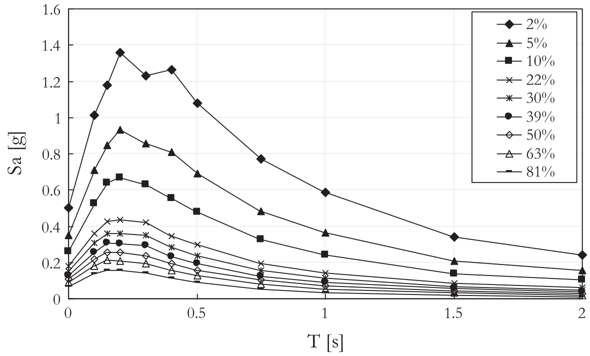

Fig. 2. Uniform hazard response spectra in terms of pseudo-accelerations used in this study. The spectra refer to 5% damping, and to different probabilities of exceedance (from 2% to 81%) in 50 years at the reference site.

Table 2
Probabilities of exceedance, return periods, and PGA of the UHS.

Prob. of exceedance in 50 years	81%	63%	50%	39%	30%	22%	10%	5%	2%
Return period (years)	30	50	75	101	140	201	475	975	2475
PGA (g)	0.07	0.09	0.11	0.13	0.15	0.18	0.26	0.35	0.50

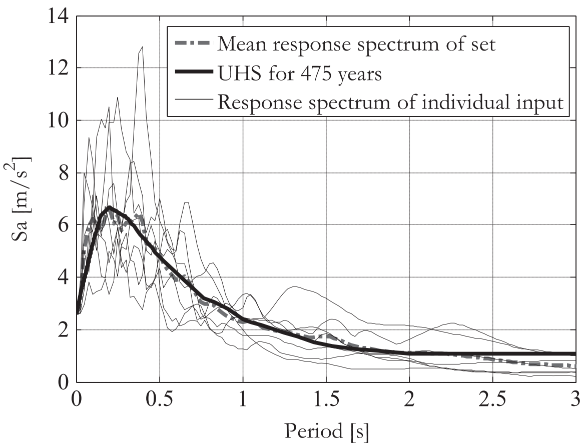

Fig. 3. Mean response spectrum, UHS and response spectra of all accelerograms of the 475 years return period's set.