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The role of source and site effects on structural failures due to Azores earthquakes

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ABSTRACT

The existing building stock in Azores islands (Portugal) was severely damaged during 1980 and 1998 earthquakes. Structural failure was probably caused by a combination of factors that are not yet well understood. Earthquake source characteristics, site effects and structural vulnerability may be some of those factors. However, it is very difficult to assess the influence of each factor on structural failure, mainly because recorded accelerograms used in nonlinear structural analysis are influenced by both source characteristics and site conditions. The only way to overcome this problem is to control each factor individually which can be done by using simulated accelerograms. In our previous work, stochastic ground motion simulations results were compared with earthquake records. Results seem to indicate that simulated accelerograms can match recorded accelerograms if proper source characteristics and geological site conditions are selected. In this work, simulated accelerograms were used for seismic nonlinear structural analysis. Simulations were carried out considering several 1980 Azores earthquake possible sources and for different geological site conditions. Simulated accelerograms were then used to evaluate the structural nonlinear behaviour of a reinforced concrete structure and of two masonry structures. The results of this work highlight the importance of site conditions and earthquake source characteristics to the determination of the design seismic actions of Azores islands. This work was performed in the scope of "Strong ground motion for Azores – SiGMA" project, financed by the Portuguese Science and Technology Foundation (PTDC/CTE-GIX/121957/2010).

1. Introduction

The Portuguese Azores Islands are located in the middle of the North Atlantic Ocean, near the triple junction of the Euro-Asiatic, African and North American plate boundary. This region is capable of producing large magnitude events and has high seismic activity, related mainly with volcanic activity. The 1 January 1980 earthquake and the 9 July 1998 earthquake were the last two destructive events that affected Portugal.

The 1980 Azores earthquake was felt with an anomalous Mercalli modified intensity (MMI) distribution throughout the Terceira Island, with values varying between V and IX [1]. Studies using ambient vibrations have shown a good correlation

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between surface geology and observed structural damage [2]. Damage studies using basic nonlinear structural models also pointed out some correlation between soil characteristics and structural damage [3].

The 1998 Azores earthquake was strongly felt throughout Faial Island, where it reached maximum MMI intensities of VIII/IX. Site amplification of ground motions was also observed causing extensive damage [4].

Unfortunately, there are not many strong ground motion records of Azores earthquakes. The 1980 Azores earthquake was only recorded at Faial Island and the ground motion record exhibits a peak value of 53.51 cm/s^2, but it is not complete [5]. The 1998 Azores earthquake was also recorded at Faial Island, at the same station, with an observed peak ground motion acceleration of 399 cm/s^2 [6]. This value is higher than the peak value prescribed for the Azores in the Eurocode 8 (EC8) Portuguese National Annex [7], which is 250 cm/s^2 for rock sites and 375 cm/s^2 for soft soils. This is one of the reasons why it is so important to carry out more studies to better understand the Azores seismic action. The use of earthquake simulation can be very useful, in this context.

The historical Angra do Heroísmo city centre was severely damaged during the 1980 Azores earthquake. This city area was composed essentially by masonry buildings. The existent reinforced concrete buildings performed quite well. However, some peculiarities have been observed and some questions need answers: why did a more vulnerable reinforced concrete structure have less damage than other designed to withstand an earthquake? Is this difference related to the earthquake characteristics? Or is related to site effects, because one was sited on a rock outcropping formation and the other on a soft soil?

Trying to answer this kind of questions, a multidisciplinary study was carried out. Some factors that have influence on seismic structural failure were studied, namely source characteristics, site effects and structural vulnerability.

To better control earthquake characteristics, stochastic earthquake simulations of the 1980 Azores earthquake were carried out for different site conditions and source characteristics. Several seismic nonlinear analyses of a reinforced concrete structure that sustained no damage during the 1980 Azores earthquake were performed using the simulated response spectra to evaluate the causes for this happening. Seismic nonlinear analyses of typical Azores masonry structures were also carried out to evaluate possible structural failures due to earthquake effects.

2. Stochastic ground motion simulations

Stochastic earthquake simulations considering geological site effects have been already carried out for Portugal [8,9]. The program SIMULSIS was used to carry out earthquake simulations for Azores. It is a user friendly freeware computer software for stochastic ground motion simulation, capable to reproduce earthquake accelerograms when proper source characteristics and site conditions are adopted [9,10].

It assumes that the fault plane is divided in N_F subfaults, each one considered as a point source event. A small earthquake is randomly generated for each subfault. In SIMULSIS the rupture spreads radially from the hypocenter, with a constant or a variable rupture velocity V_{ri} on each subfault i (Fig. 1).

Simulated time series results from a superposition of sinusoidal waves which are summed with a proper delay (Δt_i) and can be written as follows:

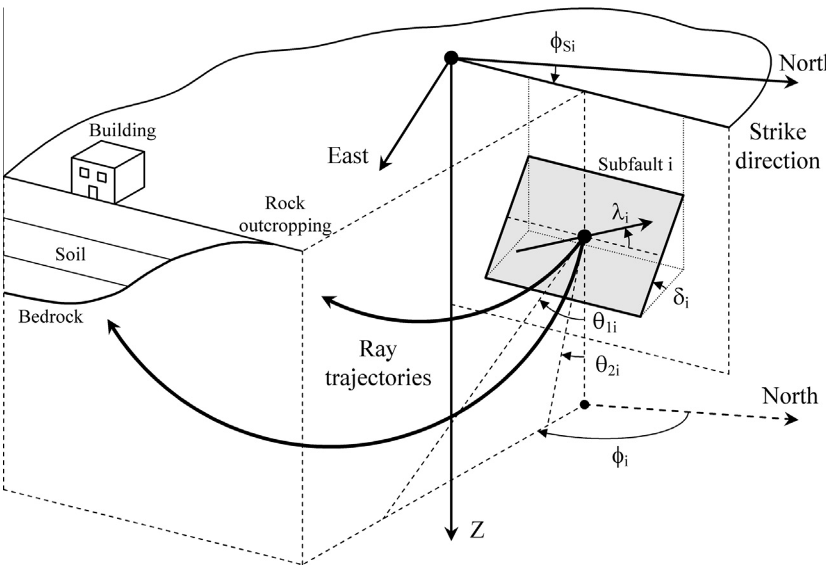

Fig. 1. Global SIMULSIS ground motion generation procedure.