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Local ground effects in near-field and far-field areas on seismically protected buildings

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ABSTRACT

This paper presents a 2-D numerical study on the nonlinear seismic response of buildings equipped with two types of energy dissipators, which dissipate energy activating two different mechanisms. Three types of reinforced concrete buildings with 3, 7 and 15 stories, respectively representative of short, medium and long period ranges, are considered. Dissipators are placed on steel diagonal braces at all the floors; their sliding threshold (or yielding) forces are taken as 100% of those generated by the equivalent static lateral forces recommended by EC8 for a ductile moment resisting frame. The input consists of six recorded earthquakes, 3 representatives of near-field earthquakes and 3 representatives of far-field earthquakes. Each input is considered once from the bedrock and once filtered by a common ground with several layers of different thicknesses. The responses of the buildings are discussed and compared emphasizing the filtering effects produced by the ground.

1. Introduction

In the last years the influence of local ground conditions on the superficial seismic acceleration has stimulated several studies and observations thanks to a lot of recordings taken during seismic events that have been gathered and saved. Only in the last 25 years, in fact, strong motion instrumental records have been obtained at a number of locations in the same general area to show the major effects of variations in local soil conditions on the characteristics of strong ground surface motions. It has been observed that, during the same earthquake, recordings taken in close areas show significant differences due to different ground characteristics. The same signal, in fact, shows different frequency contents depending on the site soil. The properties of the most superficial ground layers generally create a local amplification with respect to the bedrock, while the structural interaction causes a variation of the foundation accelerogram with respect to the free ground surface accelerogram. When the soil is considered without the presence of a structure on it, its effect on the characteristics of the vibratory waves propagated from the basement rock to the surface can be evaluated. The resulting soil-surface accelerations without the structure are known as "free-field motions". In this case the foundation medium is to be considered merely as a "filter", which simply modifies the characteristics of the free-field motions and must be represented in the analysis by an appropriate mathematical model. Additionally, like the energy dissipation on the outer layers, the ground dissipative capacity depends on the radiation damping. The latter is not very important and is due to an elastic behavior of the ground. On the contrary, the radiation damping has high importance for the seismic energy dissipation and increases with the relative stiffness between the structure and the ground.

The effects of softer ground layers have been considered in this paper in the analysis of building structures seismically protected with Energy Dissipating Devices (EDDs). More in detail, the main objective of this paper is to investigate the seismic efficacy of EDDs when the structure is founded on the bedrock or on common ground. The study consists of assessing the 2-D seismic dynamic response of three types of reinforced concrete buildings with 3, 7 and 15 floors representative of short, medium and long period ranges built on rock or on common ground better specified below. In addition the buildings have been designed as ductile moment resisting frames and have been subjected to six earthquake recordings representative of far-field and near-field ground motions. Each input has been filtered by the same ground and the response of the buildings in the two cases of stiff ground and common ground have been compared and discussed. The results obtained are very interesting also because different parameters affecting the seismic response of the buildings in near-field areas have been considered.

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2. Local ground conditions

The damage resulting from earthquakes may be influenced in a number of ways by local soil. For example, if the damage is related to soil instability, it results in permanent movements of the ground surface; in this case, the relationship between the structural damage and the local soil conditions is readily apparent. A less obvious effect of soil conditions on building damage is the influence that they exert on the characteristics of the seismic inputs and thereby on the structural damage that may develop even though the soils underlying a building remain stable during an earthquake. The influence of the soil conditions is very high on the intensity of ground shaking during earthquakes, while, on the contrary, there is no significant influence on peak acceleration values [1]. If the earthquake motions in the bedrock underlying the soil are known, the free-field motions can be determined by treating the soil layer exactly like any other structural system for which the support motions are known. To this aim a discretized model suited to the geometric form of the soil deposit is used and the earthquake input is assumed to be a rigid-base translation. In the present paper this analysis is numerically performed by a computer code, SHAKE-91 [2].

In the present study the ground, which filters the signal, is composed by seven clay and sand layers with different thickness. The total depth of the ground above the bedrock is about 17.15 m and its stratigraphy is shown in Fig. 1. The parameter ϕ is the plasticity index (difference between the humidity indices corresponding to liquid and plastic limits), which characterizes the dynamic properties of every clay layer. The seismic behavior of sand layers is mainly influenced by their contour pressure (CP). This ground has been selected as representative of soft soil or "common soil". Ground parameters have been obtained from laboratory tests on different layers of soil at the "Laboratori de Geotècnia", Universitat Politecnica de Catalunya (Barcelona, Spain).

The amplification spectrum of the seismic wave through the common ground is plotted in Fig. 2 (from SHAKE-91code). The amplification spectrum is the ratio of the amplitude acceleration motion at the top of the 7th sub-layer divided by the one at the top of the 1st sub-layer at 5% damping.

Fig. 3a shows the modulus reduction curves (G/G_{max}) for the types of ground considered in the analysis. G is the secant shear modulus (from the ground hysteresis loop) and G_{max} is the maximum shear modulus (corresponding to small shear strains). The physical meaning of the ratio G/G_{max} is the decrease of ground stiffness for large strains (non-linearity coefficient). Plots from Fig. 3a show that the decrease is higher for clay than for sand.

Fig. 3b shows the ground damping factor vs. the shear strain ratio. Conversely to Fig. 3a, plots from Fig. 3b show that damping increases for bigger strains (both for sand and clay). This points out that the ground energy dissipation capacity of each layer is important in large inputs.

The purpose of the analysis of the ground layers is to establish the time history of the surface motions. Such analysis is very useful also when the surface motions are known for a type of soil system, which significantly differs from the soil at the proposed building site. The basement-rock motions are first determined by an inverse analysis from the given ground-motion record, and then the free-field motions at the surface of the design-site soil deposit are computed by a direct analysis.

In the last case of direct analysis it is possible to determine the desired free-field motion as the total surface acceleration $\tilde{\ddot{u}}_g(t)$, which is the sum of the relative acceleration $\bar{\ddot{u}}_g(t)$ and the pseudo-static contribution:

$$\tilde{\ddot{u}}_g(t) = \bar{\ddot{u}}_g(t) + r_g\, \ddot{u}_b(t) \tag{1}$$

In Eq. (1) r_g is the displacement at the surface due to a unit static displacement of the bedrock and $\ddot{u}_b$ is the bedrock acceleration history. After some computation the final expression of the total surface acceleration is:

$$\tilde{\ddot{u}}_g(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} \left[Q(\varpi) + r_g\right] \exp(i\varpi t)\, d\varpi \tag{2}$$

In Eq. (2) $Q(\varpi)$ is the transfer function expressing the amplitude of a harmonic motion at the soil surface due to a harmonic-acceleration input from the basement rock. The evaluation of the transfer function $Q(\varpi)$ can be performed very easily by wave-propagation methods if the soil layer can be idealized as a one-dimensional system.

In the inverse procedure it is possible to determine the basement-rock motions in terms of the Fourier Transform $G(\varpi)$ of the free-field motions. From the deconvolution of the signal performed according to the methods expressed also in [3] it is possible to obtain:

$$\ddot{u}_b(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} \left[Q(\varpi) + r_g\right]^{-1} G(\varpi) \exp(i\varpi t)\, d\varpi \tag{3}$$

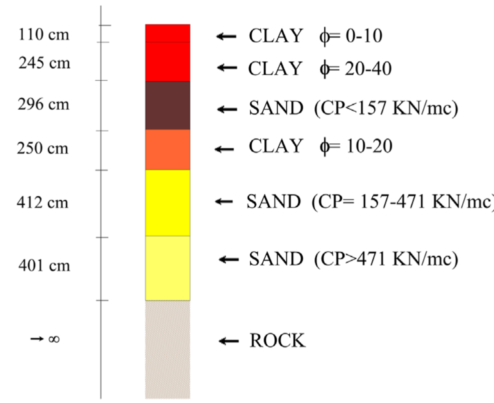

Fig. 1. Stratigraphy and composition of the common ground considered in the analysis.

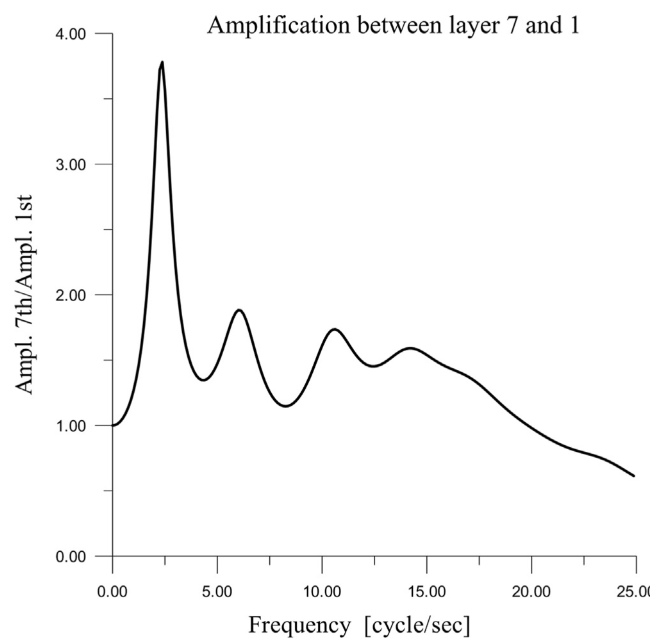

Fig. 2. Amplification of the ground.