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Bounding surface models in site response analysis: comparison with the equivalent linear approach

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A reliable prediction of the response of a soil column subjected to earthquake excitation is a basic although challenging achievement in geotechnical earthquake engineering problems.

A critical step is the analysis type selection. Nowadays, the equivalent linear approach is extremely widespread, mainly for its low computational demand and for its suitability to simulate soil behaviour up to the medium-strain level. However, this approach approximates the hysteresis loop exhibited by soils during a load cycle through an average shear modulus and damping ratio. Consequently, the nonlinear approach would more adequately describe the real soil behaviour, but it requires a large amount of data to be correctly calibrated that is not always available.

To address the differences by using these approaches, a comparison between the surficial acceleration response spectra of a single-layered 20 m-thick soil column of Messina Gravels (gravel and sand with occasionally silty levels) underlain by a rigid bedrock, subjected to strong-motion recordings, is presented.

The software STRATA was used for the equivalent linear analyses. The nonlinear site response analyses were performed with the OpenSees framework, while the bounding surface-based SANISAND constitutive model was selected to reproduce the soil nonlinear behaviour.

A single column in 3D space with periodic boundaries to simulate 1D conditions was considered. The input excitation was applied at the base nodes of the column and the parameters to be assigned to the model were obtained from Gorini (2019).

For both analysis methods, linear elastic analyses were performed by applying a 0.3g sine sweep with frequencies up to 30 Hz. The obtained results were interpreted in terms of acceleration transfer function and a satisfactory congruence was achieved.

The non-linear behaviour of the soil was triggered by applying three accelerograms from strong-motion events (Kobe, Kocaeli and Chi-Chi), downloaded from the PEER database. As results, for periods higher than 1.5 s neglectable amplification effects are observed, so a good accordance is highlighted between equivalent linear and nonlinear analyses. For the period range 0.3-1.5 s, amplification occurs but it is still correctly caught by both the approaches. Strong differences are, instead, observed in the lower periods range, up to 0.3 s, where the equivalent linear approach returns essentially similar spectral accelerations as those of the input motions, while nonlinear

analysis highlights amplification and eventually deamplification effects.

In conclusion, it appears that the soil non-linearity should be carefully evaluated for high-seismicity areas because the equivalent linear method tends to underestimate the response, assuming a stiffer behaviour. This was clear for a single-layered soil column and it becomes certainly more complex for stratified soil deposits. To this end, the non-linear approach appears more appropriate to avoid underpredictions of the input motion to be applied for design purposes, but a high effort should be made to properly characterize the soil for the calibration of the selected nonlinear model as well.