

## Numerical analyses on the subsurface seismic damage induced by the complex interference between body waves and surface waves

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In the past earthquakes, the damages were often localized to specific regions and enlarged due to irregularly shaped bedrock. It is said that the localized and extensive damage can be attributed to interference and amplification at a specific position between the surface wave generated at the irregularly shaped bedrock and the body wave transmitted/reflected through the sedimentary layer (so called as “edge effect”<sup>1)</sup>). However, in the most current prediction/evaluation methods for earthquake damage based on vertical one-dimensional body wave, multi-dimensional effects such as generation of surface waves due to ground irregularity and complicated interference between surface waves and body waves is not taken into consideration. Therefore, there is concern that underestimation and overlooking of earthquake damage are caused. This study tries to reproduce the surface waves (Rayleigh waves and Love waves) and assess their influences on subsurface ground damage using 2D and 3D seismic response analyses which can consider the effect of irregularly shaped bedrock. The analysis code employed was the soil-water coupled finite deformation analysis<sup>3)</sup>, which incorporates an elasto-plastic constitutive model that allows description of soils ranging from sand through intermediate soils to clay within the same theoretical framework<sup>2)</sup>.

First, seismic response analysis of elastic ground considering ground irregularity was carried out to numerically reproduce the surface waves (Rayleigh and Love waves) and confirm whether the waves satisfy the characteristics of elastic theoretical solutions. As a result, when seismic ground motion was input in the horizontal direction (x direction) with respect to the bedrock inclination, waves are propagating from the inclined base end section. Also the following characteristics of elastic theoretical solutions are confirmed. 1) In the infinite one-layer ground, the propagating wave is a regular wave of a single period, 2) Displacement is largest at the ground surface and becomes smaller as the depth increases, 3) It draws a counterclockwise trajectory on the surface, but it turns clockwise in the deeper part, 4) In the multilayered ground, dispersion of waves is observed.

Next, in order to evaluate the influence of surface waves on subsurface seismic damage, finite deformation analysis of two-phase elasto-plastic material was conducted assuming a basin-shaped ground with soft clay deposited on the hard bedrock. Fig.1 shows the shear strain distributions with elapsed time. Shear strain progresses towards the central ground from the both left and right base end sections, which indicates the propagation of surface waves. Moreover, shear strain exhibits a non-uniformity due to the refraction of body waves at the irregular boundary, and the complex interference of the surface waves and the body waves. Consequently, the followings are concluded. 1) Shear strain is non-uniformly distributed and locally concentrates, 2) Because the surface waves stays in the basin and continues to oscillate for a long time, the mean effective stress reduction ratio is larger than that in the one-dimensional analysis, and also continues to increase even after the earthquake, 3) Settlement after the earthquake non-uniformly occurs and is locally enlarged, 4) Mean effective stress reduces higher due to Rayleigh wave than Love wave in this case. These analytical results indicate that the multi-dimensional effect represented by the generation and propagation of the surface waves is not negligible, and it is rather a matter of considering for precise damage prediction.

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