Nonlinear site amplification for high intensity ground motions during the 2018 Mw 6.6 Hokkaido eastern Iburi earthquake

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Large peak ground accelerations (PGAs) exceeding 1g on both the horizontal and vertical components were recorded at a fault distance of about 25 km during the September 6, 2018, Mw 6.6 Hokkaido eastern Iburi earthquake. Explaining the large PGAs at the distance for the magnitude of the event requires detailed investigation of the site response and source radiations. At several sedimentary sites, peak ground velocities (PGVs) exceeding 100 cm/s were recorded. Comparison of the observed PGAs and PGVs with the ground motion prediction equations (GMPEs) by Si and Midorikawa (1999) revealed that the observed data, especially the PGVs, were substantially larger at fault distances smaller than about 40-50 km, while the data at longer distances showed little or no trend different from the GMPEs. This motivated us to examine the site response during the earthquake. We processed many small amplitude (PGAs between 5 and 20 cm/s/s) accelerograms from earthquakes that occurred prior to the mainshock (the Mw 6.6 event) at sixteen KiK-net sites, and compared the surface-to-borehole spectral ratios between the small-amplitude ground motions from prior earthquakes and large-amplitude ground motions recorded during the mainshock. The comparison suggested that the sites at short distances where PGVs were underestimated, sustained various degrees of nonlinear site response, and the recovery is still undergoing at some of the sites based on similar analysis of aftershock recordings. Nonlinear site amplification has been known for a long time for the reduction of short-period ground motion amplitudes at a soil site during strong input motions compared with the weak input motions. Another commonly reported effect of nonlinear site response is the shift of predominant frequency to lower one. This second effect was found to be very prominent during the mainshock at soil sites and smaller distances, which caused stronger amplification at relatively longer-periods resulting into large PGVs and large JMA intensities. At the site of largest PGA, the ground motions were amplified by an order of magnitude at the new predominant frequency during the mainshock. We also analyzed the horizontal-to-vertical (H-to-V) spectral ratios at K-NET sites where PGAs were larger than 200 cm/s/s. We found that the K-NET sites also experienced larger degree of nonlinear site response at sites of larger PGAs. Based on the above analysis, the nonlinear site amplification could be one of the major reasons for the high intensity ground motions that were underestimated at the smaller distances by the GMPEs. Moreover, two sites (IBUH01: KiK-net; HKD127: K-NET), which were closely located, recorded vertical PGAs exceeding 1g for the up going motions at the surface, and the recordings showed asymmetric waveforms and amplitudes characteristics to the nonlinear site response reported during a few earthquakes in the past. A few sites having lower vertical PGAs were also suspected of being experienced nonlinear site response on vertical motions. Finally, we derived an ad-hoc equation to correct for the nonlinear site amplification in the prediction of horizontal PGVs with respect to the GMPE by Si and Midorikawa (1999). The results indicated that the stronger input motions may induce larger changes in PGVs at the surface than that for a proportional change in the shallow S-wave velocities (Dhakal et al. 2019).

Reference:

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Keywords: Soil nonlinearity, 2018 Iburi earthquake, PGA, PGV, Spectral ratios