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SITE EFFECTS AT SITES WITH PRONOUNCED TOPOGRAPHY: OVERVIEW & RECOMMENDATIONS

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We overview our recent results on site effects at sites with pronounced topography (Burjanek et al., 2014) and sketch recommendations for practical applications. A number of instrumented sites with complex topography were identified in Switzerland and Japan based on quantitative DEM analysis. A detailed site characterization, including measured S-wave velocity profiles down to 30-200 m, is available for these sites, as well as empirical amplification functions relative to a derived reference rock profile (Edwards et al., 2013). Observed amplifications can differ up to a factor of 20 for similar sites with comparable surface topography (see Figure 1), which is a too large difference with respect to expected ground motion variability due to surface geometry only (Maximum factor of 2, e.g. Assimaki et al., 2005). Thus, the large systematic amplifications at topographic sites cannot be explained by surface geometry only.

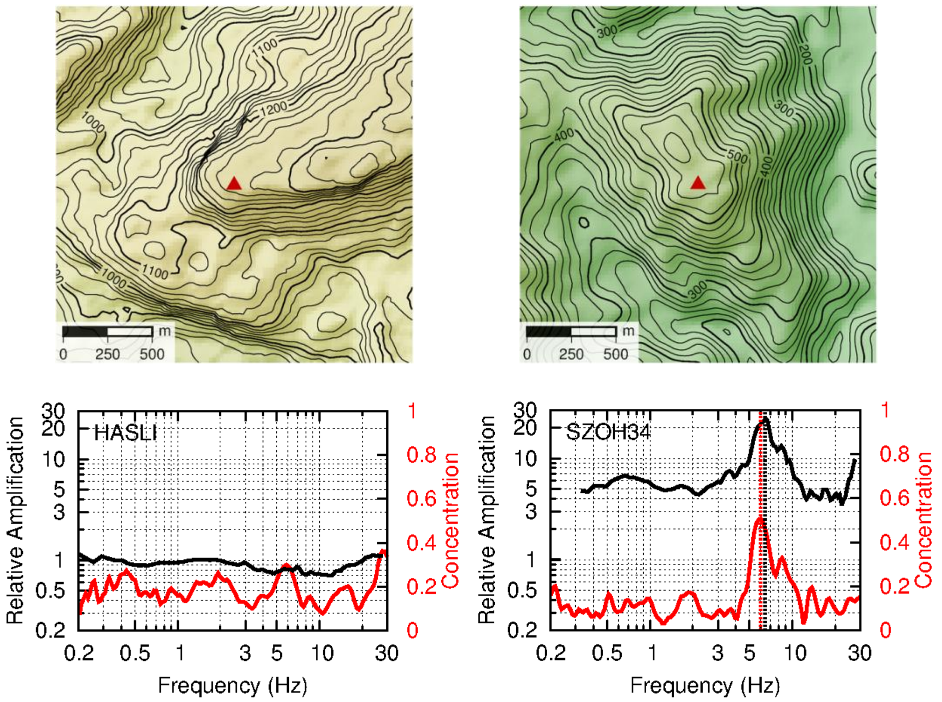

Figure 1. Examples of sites with relatively weak (on left) and strong site effect (on right). Geometry of the terrain (based on ASTER GDEM, contour lines placed for every 20 m) and location of the station (red triangle). Directionality (expressed as *concentration* of the particle motion azimuth, see Burjanek et al., 2014) and amplification curves are presented in the bottom row. The vertical line in the amplification and concentration plots represent the corresponding picks of the fundamental frequencies.

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Subsurface velocity structure was found to be variable even under sites with complex topography. (EC8 soil classes ranging from A to D). Some of the sites can be identified as outcropping rock sites by only looking at the borehole lithology log, but the Vs30 values correspond to velocity ranges of sediment sites. The rock sites (EC8 class A) with pronounced topography studied here do not, on average, exhibit any systematic amplification. On the other hand, the rest of the sites (non EC8 class A) present systematic frequency dependent amplifications (up to a factor of 20 in particular frequency bands) with respect to reference rock condition. So, the amplification is controlled in first place by the sub-surface velocity structure.

The amplified ground motion at non EC8 class A is found to be polarized and directional, i.e., ground motion vibrates in specific directions. The frequency of the fundamental peaks in the amplification curves correlates with the frequencies where the ground motion becomes polarized and directional. The directionality and polarization of ground motion originate likely from the structure near the surface (<100 m, in most of the cases). This was demonstrated by polarization analysis of corresponding borehole recordings of the Japanese sites, which present neither directionality nor polarization.

Based on our findings, we can propose the following recommendations for local seismic effect evaluation at sites with pronounced topography: (i) Seismic response can be hardly anticipated just from the terrain geometry. Standalone analysis of a digital elevation model will not reduce uncertainty in hazard estimation at sites with pronounced topography. It could lead to severe underestimation of potential amplifications. (ii) Significance of amplification at a given site can be predicted at low-cost through non-invasive polarization analysis of the ambient noise wave-field. Strong polarization of the horizontal component and high directionality of ambient vibrations are signatures of potentially strong site effect. (iii) Efforts should be concentrated on retrieving subsurface velocity structure. If a potential site-effect was identified from single station polarization analysis, it might be justified to measure the velocity structure. This should be obtained by direct measurements and not from the lithology of observed outcropping rock unit. (iv) Detailed numerical modeling can reveal the joint effect of surface geometry and subsurface velocity structure. A successful prediction of the local response of sites with pronounced topography needs a reliable shear wave velocity model representative of the site (i.e., a measured one). Detailed numerical modeling can subsequently reveal the joint effect of surface geometry and subsurface structure.

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