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We analyze the variations of subsurface seismic properties associated to the successive shaking of the 2016 Mw 7.3 Kumamoto foreshocks, mainshock and aftershocks. We use autocorrelation functions and interferometery methods as suggested recently by Bonilla et al. (2019). The used data was recorded by surface and borehole sensors at the KiK-net stations over a period of 8 years. The seismic velocity of subsurface exhibits clear changes during the earthquake followed by a recovery phase. We observe a decrease of about 30% of seismic velocity during the mainshock, showing average changes of shallow material properties between borehole and surface stations by using the interferometry method. Using autocorrelation technique, we detect about 60% decrease of seismic velocity during the mainshock ground motion, showing the velocity changes of material properties just below the surface sensor. In a further analysis, we analyze the memory properties of material by using the velocity changes during the peak ground acceleration. It shows a gradual decrease in velocity changes after the mainshock. In addition, we analyze the variation of shear modules based on shear strain and also Vs30, which show degradation of shear modulus in the mainshock and healing process of shear modulus. Such observation can be used to improve estimate of seismic shaking hazard, site effect, and healing process of material.

Development of a New Methodology for Evaluation of Site Fundamental Frequency and Its Associated Uncertainty Based on H/V Spectral Ratio Using an NGA-West2 Dataset

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A new automated methodology is developed for estimating the site fundamental frequency (f_0), its corresponding amplitude (A_0), and their associated uncertainty using Horizontal-to-Vertical Spectral Ratio (HVSR) of ground motion records. Over the last decades, many studies have been carried out for developing ground motion prediction equations (GMPEs). In the GMPE, the local site effect is mainly addressed by V_{S30}. However, recent studies show that site fundamental frequency (f_0) is another useful proxy in reducing the uncertainties associated with the GMPEs. Using HVSR is an efficient and inexpensive measure to estimate f_0 as it does not require a reference rock site. It has been found that the peak in the HVSR curve is associated with f_0. In general, there are more than one peak in the site's HVSR curve. Therefore, peak selection relies on the analysts' decisions while they are only using the average HVSR curve of the site, so a single number for the f_0 is estimated. In other words, f_0 might be estimated subjectively, and it does not incorporate uncertainty. This study uses selected sites in the NGA-West2 dataset to evaluate the performance of a new fully automated method in estimating the site characteristics (i.e., f_0 and A_0). In addition to using the site's average HVSR curve, individual HVSR curves from the recorded events are also considered for estimating the site proxies. In this methodology, the average HVSR curve is used to find a rough estimation of the site fundamental frequency ($f_{0,m}$), which is assumed to be the lowest frequency peak in the average HVSR curve. Then, the peaks in individual events that are more consistent with $f_{0,m}$ are selected as flagged peaks. In the next step, the statistical parameters (i.e., mean, standard deviation) are calculated using the flagged peaks. The whole process is programmed in a way to be completely automated, hence unbiased. Overall, this study presents this new automated methodology for estimating the site fundamental frequency, its corresponding amplitude, and their associated uncertainty using HVSR.

High-Resolution Site Response Study of the Los Angeles Basin From the 2019 Ridgecrest Earthquake Sequence

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We study site response in urban Los Angeles during the two largest events of the 2019 Ridgecrest earthquake sequence, using recordings from multiple regional seismic networks as well as a subset of 350 stations from the much denser Community Seismic Network (www.csn.caltech.edu). We calculate response spectral amplitudes for a selection of periods of engineering significance (1,3,6, and 8 s) and compute site amplification factors relative to three bedrock sites. The site effects present in urban Los Angeles are significant and reproducible between the M7.1 and M6.4 events. Coherent longer-period amplification patterns are present in the Los Angeles basin with the maximum amplifications found in the central and western Los Angeles basin regions for both events (amplification factors of up to 7, for 6-s period). We observe the largest amplification factors for the shorter periods in the south-eastern Los Angeles basin region (amplification factors of up to 6 for 1-s period); however the amplifications are less spatially coherent. The high network density provides an increase in the spatial resolution of the observations and an opportunity to capture these smaller scale variations. We observe high amplifications in the south-eastern quadrant of the San Fernando Valley basin at all periods up to factors of 9 at 6-s period. We examine possible correlations of the site amplifications with geophysical parameters such as the depth-to-basement and the uppermost 30-m average shear-wave velocity (VS30). We found no significant correlation for the 1-s period, while a weak correlation appears for the 3-s period and gets stronger for the longer periods, which likely reflects the correlation of Vs30 with sedimentary basins.

Passive Site Response Characterization Using Teleseismic Receiver Functions From Wideband Optical Accelerometers

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Since 2018, the Bureau of Reclamation Strong Motion Monitoring Program (SMMP) has deployed 23 ultra-low-noise optical accelerometers at 7 dams across the western US, replacing traditional Force-Balance Accelerometers (FBAs) used in our legacy systems. In contrast to standard FBA sensors, which usually exhibit self-noise exceeding the NHNM at frequencies below ~1Hz, the noise floor of our optical sensors is comparable to a broadband seismometer.

Because the optical sensor is capable of measuring both strong and weak motion accurately, it unlocks new potential for teleseismic imaging techniques which were never before possible on FBA systems. We utilize several such methods in this study to estimate site response and constrain basin properties beneath three SMMP stations at Jackson Lake Dam, WY.

In 1986, crosshole Vp and Vs tomography was performed in the vicinity of SMMP's Jackson Dam toe station (JKLK1). While Vp and Vs were measured to a depth of 465 feet by the study, boreholes did not penetrate basement, therefore basin depth underlying JKLK1 remains poorly-constrained.

Here, we combine the crosshole velocity model with analysis of teleseismic receiver functions (RFs), body-wave H/V spectral ratios (HVSR) and P-SV polarization to estimate basin depth using a suite of distant earthquakes recorded by the optical sensors.

Comparison of HVSR between freefield and toe stations indicate fundamental basin resonance of ~0.8Hz, corresponding to a basin depth of 500-600ft beneath JKLK1, in general agreement with prior seismic studies conducted in the area.

The first 5s of RFs from JKLK1 closely agree with synthetic data generated using the crosshole model, while fitting subsequent reverberations using a basin model based on HVSR data yields mixed results. Azimuthal variation of RFs suggests the influence of horizontal scattering at basin boundaries. However, the stability of near-surface impulse responses shown here implies that inversion of teleseismic RFs can potentially characterize site responses at other upgraded SMMP stations where shallow shear structure is unknown.

Primary Linear Site Response Parameters From Transfer Functions and Ratios of Response Spectra

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Site response is determined by the velocity structure and other dynamic parameters and input ground motion at a site and measured by the soil-to-rock spectral ratio (SSR) or borehole transfer function (TF) in seismology and ratio of response spectra (RRS) in earthquake engineering. Thus, quantification of site response is nonergodic, or site-specific. A response spectrum is a plot of the peak response of a series of a single-degree-of-freedom system with a natural period and damping to an input ground motion; it is fundamentally different from the Fourier spectrum of the input ground motion. In other words, site response is quantified differently in seismology and earthquake engineering. The site response parameters (i.e. base-mode and peak frequencies or periods and corresponding amplifications) are of primary importance and are the subject of this investigation. We used weak ground-motion record-