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Coseismic Dynamic Soil Behavior of the 2024 M7.6 Noto Peninsula Earthquake Based on Strong Motion Data Analysis

〇Miroslav HALLO, Kimiyuki ASANO, Tomotaka IWATA

1. Introduction

The M_J7.6 earthquake that struck the Noto Peninsula on January 1, 2024 had devastating consequences, including the loss of many lives and widespread damage to civil infrastructure. Studying strong motion waveforms of such a destructive event may provide valuable insights into the coseismic dynamic behavior of soil and rock layers. During such earthquakes, near-surface layers can undergo some structural changes that are driven by flow liquefaction, cyclic mobility, or elastic softening phenomena. These changes affect the site response and near-surface seismic velocities, altering the predominant resonance frequency (e.g. Sawazaki et al. 2006, Bonilla et al. 2019) both during the shaking (coseismic behavior) and even after it (postseismic behavior). This study focuses on the dynamic soil behavior observed during the 2024 M_J7.6 Noto Peninsula earthquake, analyzing how the predominant resonance frequency shifts in response to strong ground shaking.

2. Data and Processing

We perform an analysis of Horizontal-to-Vertical Spectral Ratios (HVSR, Lermo and Chávez-García 1993) derived from earthquake waveforms recorded at 160 sites across the Noto Peninsula and surrounding areas. The selected sites are continuously monitored by using three-component accelerometers from:

- K-NET and KiK-net strong motion networks operated by the National Research Institute for Earth Science and Disaster Resilience (NIED 2019, Aoi et al. 2020),
- Shindo-kei networks operated by prefectural governments (Ishikawa-ken, Toyama-ken) and the Japan Meteorological Agency (JMA),
- seismic stations operated by the Port and Airport Research Institute (PARI),
- stations around the Morimoto-Togashi Fault Zone managed by the Disaster Prevention Research Institute (DPRI) of Kyoto University.

We processed waveform data for the M_J7.6 event as well as moderate earthquakes recorded within the period from 1996 to January 4, 2024. By examining HVSR over various time windows (before, during, and after the M_J7.6 earthquake), we assess the temporal variations in the site-specific predominant resonance frequency, which is related to changes in seismic velocities of near-surface soil layers.

3. Results

The analysis reveals significant changes in the site response during the coseismic phase of the M_J7.6 earthquake, marked by a notable drop in the predominant resonance frequency identified in HVSR curves (see the drop between 30 and 60 s in Figure 1). The resonance frequency declines simultaneously and omnidirectionally during the strong ground shaking and recovers logarithmically after the shaking ceases for a duration of days-to-years. Extreme coseismic predominant resonance frequency drops δf_l^* in the HVSR exceed a relative difference of -70% (i.e. 30% of the initial frequency value) at some sites located close to the fault plane (see Table 1). The postseismic predominant resonance frequency shifts are correlated with the peak ground acceleration (PGA) and peak ground velocity (PGV) recorded during the M_J7.6 earthquake. The observed coseismic and postseismic frequency shifts reflect alterations in the shear-wave velocity and shear modulus of the near-surface layers, highlighting the dynamic, nonlinear, and nonstationary behavior of the soil under strong shaking.

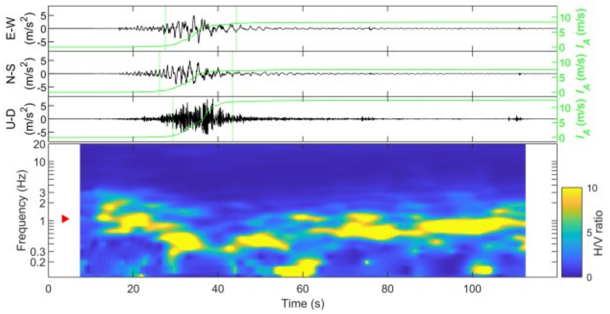

Figure 1. *Coseismic site-response change at the ISKP38 site (Monzenmachi of the Wajima City) during the 2024 M_J7.6 Noto Peninsula earthquake. Upper panels show measured acceleration waveforms (black curves). The bottom panel shows short-time HVSR determined from E–W horizontal component (values shown by color scale). All panels have a joint time axis.*

Table 1. *Extreme coseismic drop of the predominant resonance frequency during the M_J7.6 earthquake.*

Station Code	Site Location	Horiz. PGA (m/s^2)	Horiz. PGV (m/s)	δf_i^* (%)
ISKP38	Monzen (Wajima)	6.95	1.54	-70
ISK005	Anamizu Town	11.5	1.47	-79
JMAE10	Wajima City	5.8	1.13	-79
ISKH03	Noto Municipality	7.8	1.08	-74
ISK015	Anamizu Town	9.8	1.02	-93
ISKP35	Noto Island	6.1	0.86	-71

4. Conclusions

The 2024 M_J7.6 Noto Peninsula earthquake provides valuable insights into the coseismic dynamic behavior of near-surface soils (Hallo et al. 2025). The observed changes in the predominant frequency highlight the nonlinear, time-dependent nature of the soil response to strong ground shaking. These findings have important implications for earthquake engineering, particularly in the design of resilient structures that must account for the dynamic and nonstationary behavior of the underlying soil during large seismic events.

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