Preliminary analysis of S-wave site amplification factors at the S-net sites

Yadab P. Dhakal[1], Atsushi Wakai[1], Hiroaki Yamanaka[2], Takashi Kunugi[1], Shin Aoi[1]
[1]National Research Institute for Earth Science and Disaster Resilience
[2]Tokyo Institute of Technology

Introduction

S-net is a large-scale permanent type seafloor observation network of 150 seismograph and tsunami-meter stations for earthquakes and tsunamis along the Japan Trench (Aoi et al. 2020). The network started operation in 2016, and all the stations record and send the waveform data in real-time at the designated data management centers. One of the main objectives of the establishment of the S-net was to enhance the Japan Meteorological Agency (JMA) earthquake early warning (EEW) and tsunami early warning. The EEW can be enhanced by faster detection of earthquakes and estimation of source parameters compared to the land-based observation network. For the reliable estimation of the earthquake source parameters such as hypocenter and magnitudes, it is important to understand the site amplification effect on the recorded motions. In the present study, we examined the strong-motion data from moderate earthquakes of magnitudes ~ Mw 3.5-6.0, recorded by S-net, and performed spectral inversion to separate the source, path, and site terms from S-wave parts of the records. Below, we report the methodology, data processing, and results briefly. Finally, we conclude with some discussions and plans for the future study.

Methodology

Spectral inversion method is a simple yet powerful technique for separation of site amplifications and source parameters from earthquake records (e.g., Andrews 1986, Iwata and Irikura 1988). The following equation may be used to express the far-field observed S-wave Fourier spectra in terms of source, site and path terms.

$$O_{ij}(f) = S_i(f)G_j(f)R_{ij}^{-1}exp\left\{\frac{-\pi R_{ij} f}{Q_s(f)V_s}\right\}$$

where $O_{ij}(f)$ denotes the observed S-wave Fourier amplitude spectrum of i^{th} event at j^{th} station; f denotes frequency in cycles per second; $S_i(f)$ denotes source amplitude spectrum of i^{th} event; $G_j(f)$ denotes site amplification factors at j^{th} station; R_{ij} denotes hypocentral distance between i^{th} event and j^{th} station; Q_s denotes average quality factor for S wave along the wave propagation path; V_s denotes average S-wave velocity along the wave propagation path. In this study, the value of V_s is taken to be 3.5 km/s. The above equation was linearized taking logarithms on both sides and terms were arranged for a reference distance of 1 km for inversion. To minimize the tradeoff between the source and site terms, the site amplifications at two sites on land were constrained by the theoretical site amplifications estimated for the sites using the structures obtained by inversion of surface-to-borehole spectral ratios of the records at the sites (e.g., Yamanaka et al. 1998). The obtained source spectra were fitted assuming a simple omega square model, and the obtained moment magnitudes were compared with the catalog magnitudes of F-net. The path factors were also compared with the previous study results.

Data processing

We started with a large data set consisting of records from more than 1000 earthquakes of Mj > 4 and focal depths < 70 km, recorded by S-net between 2016 and 2019. We also used strong-motion records from three stations on land, two stations of which were used as reference sites and the third one was used as a validation site, where the site amplifications were estimated priorly. We used the records with vector PGA between 5 and 50 gals, and with hypocentral distance between 30 and 200 km. The records at S-net stations were corrected for their orientations for computing the Fourier spectra. The S-onset times were obtained manually, and the records were used if the absolute time differences between the manual S-onsets and JMA travel time table were smaller than 5 s. Magnitude dependent S-wave time windows ranging between 8 and 20 s were selected, 1 s cosine tapering applied at both ends, and the Fourier spectra were computed for a time length of 40.96 s, by padding zeroes. The spectra were smoothed using Parzen window of 0.2 Hz. The mean of two horizontal-component spectra was used in the spectral inversion. Our final data set contains at least three records at each site and for each event. The results presented in the next section are from about 550 events and about 5000 records. The left panel in Fig. 1 shows the locations of the final events and sites used in the derivation of the results presented below.

Results

The obtained site amplifications at the periods of 0.5 s and 2 s are depicted in the middle and right panels of Fig. 1. The amplification factors ranged between about 3 and 30 at the S-net sites. Even though the values ranged widely and varied spatially, the figure suggests the general distribution of the site amplification values in the following ways. The values are relatively small for sites near the coast, while the values are larger for sites in the landward slope areas of the trench axis. The values on the outer-rise segment stations range widely, but are generally milder than those at the immediate sites landward of the trench axis.

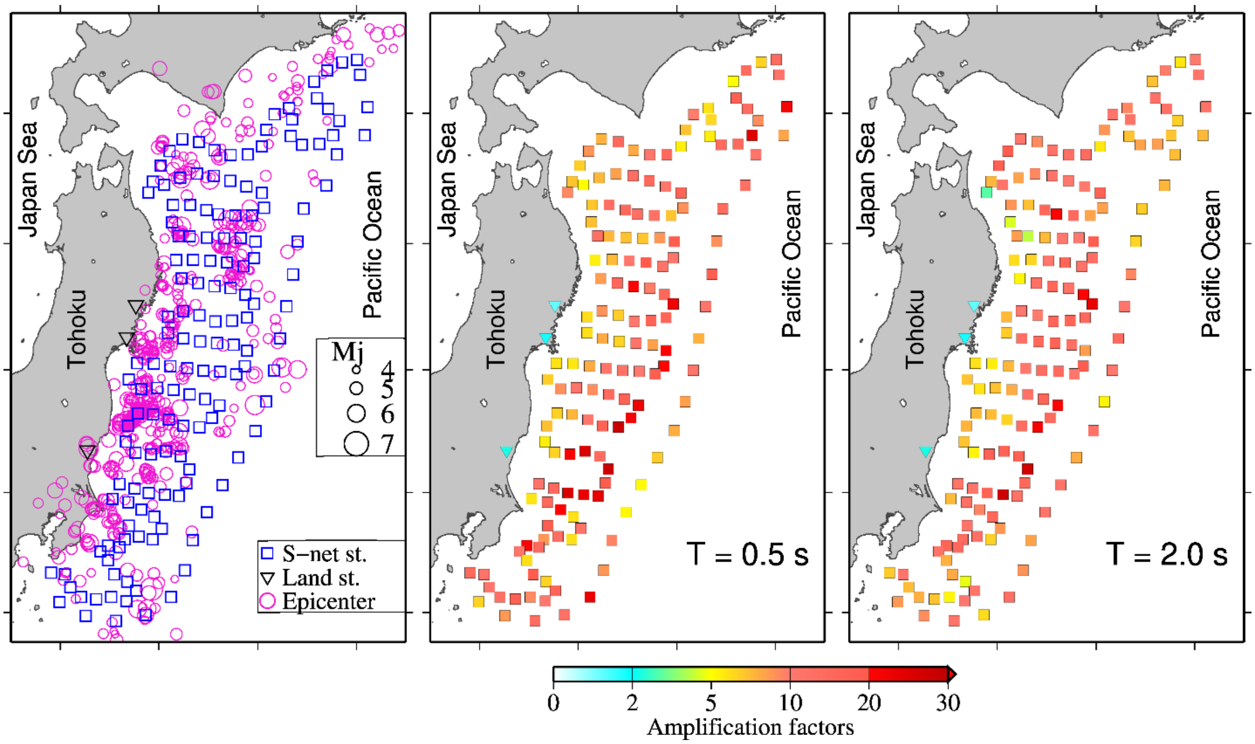

Fig. 1: Left panel: location of the events (circle), land stations (triangles), and S-net stations (squares), used in the study. Middle and right panels show the amplification factors at the periods of the 0.5 s and 2 s, respectively.

Figure 2 shows the Mw values estimated in this study after fitting the source spectra with omega-square model (Aki 1967, Brune 1970). The figure shows that the values generally agree well with somewhat larger discrepancies at small and large magnitude values. Figure 3 shows a comparison of the Qs values between this study and those in Nakamura (2009). Nakamura (2009) obtained the Qs values by dividing the Japan islands into multiple zones comprising of two layers of depths 0-30 km, and 30-60 km, respectively. Their region numbers 4 for 0-30 km and 13 for 30-60 km correspond closely to the region in the present study. The analysis in Nakamura (2009) was between 1 and 10 Hz. Our results at lower frequencies, especially < 0.5 Hz, may not be reliable due to lower S/N values. The values between 1 and 10 Hz in Nakamura (2009) for the depth range of 30-60 km are nearly similar with the values in this study.

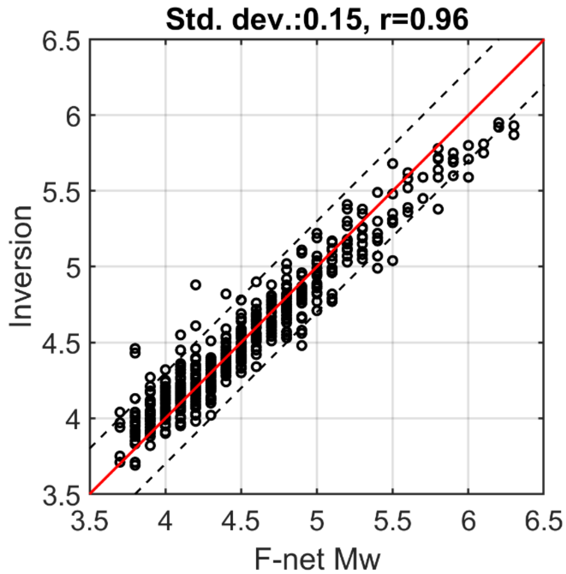

Fig. 2: Comparison of the catalog Mw values of F-net and Mw values obtained from this study

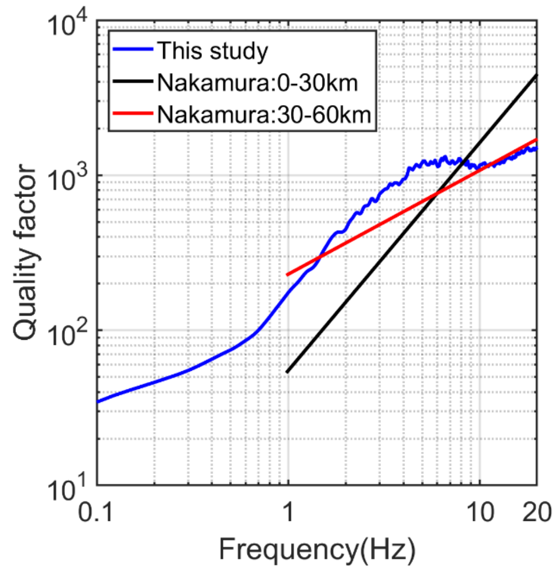

Fig. 3: Comparison of the Q values obtained in this study (blue line) with those for the shallow-depth (0-30 km) and deep (30-60 km) regions (regions 4 and 13, respectively) in the forearc of the northeast Japan in Nakamura (2009). See the results section for details.

Discussions and conclusions

We obtained site amplifications at the S-net sites using the spectral inversion technique. The site amplification values depend on frequencies and differ hugely among the sites. The values ranged between about 3 and 50 at the periods of about 0.5 and 2 s. Slight regionalization of the amplification factors was seen: relatively smaller values at the sites close to the coast and outer-rise region and larger values in between. The peak amplification was mostly at frequencies higher than 1 Hz, but amplification factor greater than 10 was found at many sites in the landward of the Japan Trench. It was found that the amplification factors are lower than 1 at higher frequencies than about 10 Hz at many sites, which may suggest stronger attenuation of higher frequencies by the shallow unconsolidated sediments. The estimated Mw values and path-averaged quality factor for S wave were reasonable, suggesting that the site amplifications were estimated generally well. However, the catalog Mw values were somewhat larger than those estimated here for magnitudes greater than about 5.5. We found that the source spectra were depth dependent, giving larger amplitudes for deeper event at frequencies higher than about 1 Hz. We report the detail results including the tectonic and mechanism classifications in the future paper.

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