Site characteristics of DONET1 seafloor observation network, Japan, evaluated by HVSR of coda waves and ambient noise

H. Kubo(1), T. Nakamura(2), W. Suzuki(3), T. Kunugi(4), N. Takahashi(5), S. Aoi(6)

(1) *Researcher, National Research Institute for Earth Science and Disaster Resilience, hkubo@bosai.go.jp*
(2) *Senior Research Fellow, National Research Institute for Earth Science and Disaster Resilience, t_nakamura@bosai.go.jp*
(3) *Chief Researcher, National Research Institute for Earth Science and Disaster Resilience, wsuzuki@bosai.go.jp*
(4) *Chief Researcher, National Research Institute for Earth Science and Disaster Resilience, kunugi@bosai.go.jp*
(5) *Deputy Director-General Researcher, National Research Institute for Earth Science and Disaster Resilience, narumi@bosai.go.jp*
(6) *Director-General, National Research Institute for Earth Science and Disaster Resilience, aoi@bosai.go.jp*

Abstract

To improve an understanding of the site characteristics at seafloor observation network DONET1, which has been employed in the Nankai subduction zone in southwestern Japan, we investigate horizontal-to-vertical spectral ratio (HVSR) of coda waves and ambient noise in the 0.1–10 Hz frequency band. The feature of HVSR is different between near-coast stations and near-trench stations. The HVSRs at the near-coast stations have a significant peak in the frequency of 2–5 Hz, while the HVSRs at the near-trench stations have a flat shape without a significant peak. This variation is considered to reflect the underground structure complexity of the accretionary wedge. Moreover, the HVSRs of coda waves are larger than those of ambient noise at the near-coast stations, although the HVSRs of coda waves are almost identical to those of ambient noise at the near-trench stations. The obtained HVSRs are inconsistent with the site amplification factors derived by the spectral inversion except for the HVRSs of coda waves at the near-coast stations, which suggests that it is difficult to use HVSR of coda waves and ambient noise directly as site amplification factors at DONET1.

Keywords: Site characteristics, DONET1, Seafloor observation network, HVSR, coda waves, ambient noise

1. Introduction

Recently, strong-motion observation networks have been implemented offshore in Japan. In the Nankai subduction zone in southwestern Japan, the Dense Oceanfloor Network system for Earthquakes and Tsunamis (DONET) was deployed with broadband seismometers, strong-motion accelerometers, and pressure gauges by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and is now jointly managed by the National Research Institute for Earth Science and Disaster Resilience (NIED) and JAMSTEC [1, 2, 3]. Along the Nankai subduction zone, M8-class large interplate earthquakes, which are associated with the subduction of the Philippine Sea plate, have repeatedly occurred at intervals of 100–200 years [4]. DONET consists of two networks that cover the source area of the Tonankai and Nankai seismogenic zones; DONET1 and DONET2 are located in the eastern and western areas off the Kii Peninsula in southwestern Japan, respectively (Fig. 1). The DONET1 stations can be divided into five groups: KMA, KMB, KMC, KMD, and KME.

Ground-motion observations with seafloor networks such as DONET1 are expected to be useful in earthquake early warning [e.g., 5, 6] and real-time forecast of ground motions directly based on current ground motions [e.g., 7, 8, 9]. For further using seafloor ground-motion data, it is necessary to understand the site characteristics of seafloor observation network. Nakamura et al. [6, 10] demonstrated through observations and waveform simulations that seafloor ground motions at DONET1 stations in the 0.05–0.2 Hz frequency band are significantly amplified and prolonged because of the effect of offshore sediment structure. Kubo et al. [11] revealed through the spectral inversion that S-wave amplification factors at DONET1 stations are much large in the 0.5–10Hz frequency band. This large amplification is attributable to the subsurface structure beneath DONET1 stations that includes a thick accretionary wedge and shallow soft sediments.

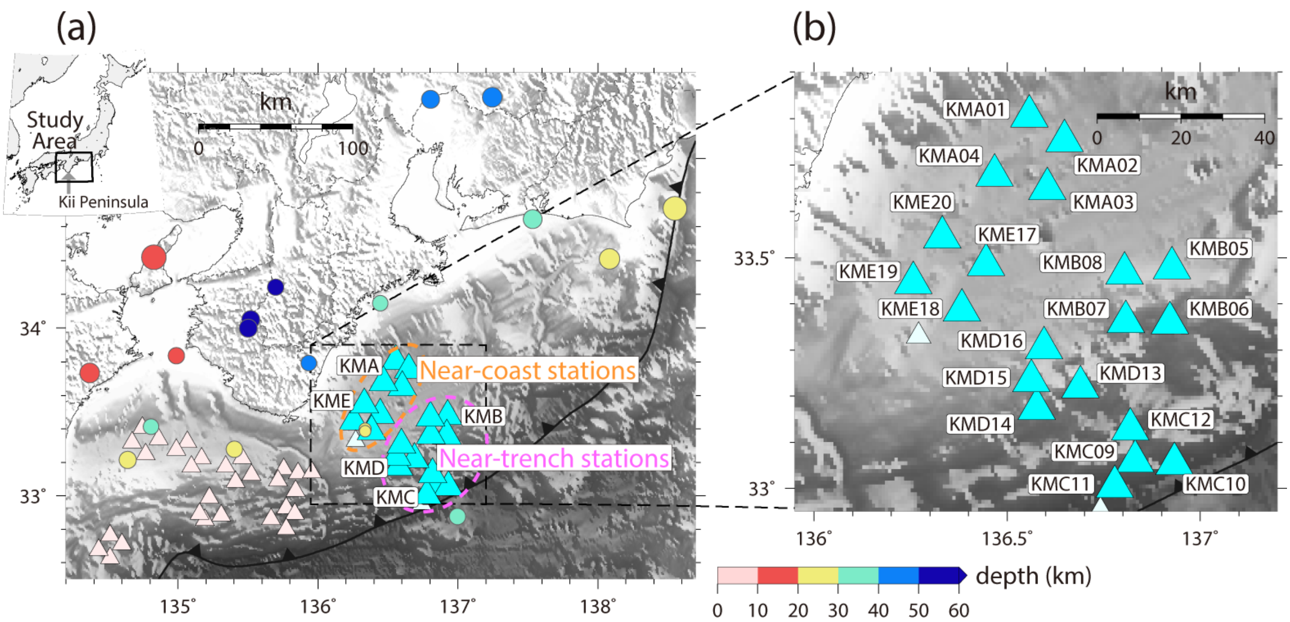

Fig. 1 (a) Distributions of stations used in this study. Dark cyan triangles denote DONET1 stations installed before 2011, which are used in this study. Green triangles denote F-net stations, also used in this study. Small light-cyan triangles denote DONET1 stations installed after 2012. Small light-pink triangles denote DONET2 stations. Circles denote the earthquakes used in coda-wave analysis and its color indicates the depth of the earthquakes. (b) Enlarged views of Figure 1a around DONET1.

Table 1 – List of earthquakes of which records used in the coda-wave analysis

Date	M_{JMA}	Depth (km)
Aug 1st, 2011, 23:58	6.2	23.03
Aug. 10th, 2011, 08:13	4.7	61.23
Aug. 12th, 2011, 04:37	5.2	27.0
Oct. 8th, 2011, 06:11	4.2	12.7
Oct. 25th, 2011, 22:37	4.0	38.5
Dec. 14th, 2011, 13:01	5.1	48.8
Jan. 9th, 2012, 00:37	4.7	56.2
Mar. 13th, 2013, 05:33	6.3	14.9
Aug. 3rd, 2013, 09:56	4.9	33.5
Sep. 13th, 2013, 09:38	4.0	31.4
Feb. 19th, 2014, 01:49	4.0	46.6
Nov. 12th, 2014, 10:13	4.3	61.3
Nov. 30th, 2014, 08:00	4.2	33.8
Feb. 6th, 2105, 10:25	5.1	11.2
Mar. 4th, 2015, 00:04	4.6	40.2
Aug. 10th,2015, 13:15	4.2	28.6
Sep. 2nd, 2015, 16:07	4.5	29.7
Apr. 1st, 2016, 14:13	3.1	21.8
Apr. 19th, 2016, 13:10	3.0	1.9

In this study, we investigate the horizontal-to-vertical spectral ratio (HVSR) of coda waves and ambient noise in the 0.1–10 Hz frequency band at DONET1. Because opinions vary as to whether the HVSR of coda waves or ambient noise can be regarded as site amplification factors [e.g., 12, 13, 14], it is important to investigate this issue with actual observation records.

2. Method & Data

To obtain the HVSR of coda waves at DONET1 stations, we collected records of strong-motion accelerometers with a good signal-to-noise ratio for 19 earthquakes (Fig. 1 and Table 1). From the acceleration waveforms, Fourier amplitude spectra were obtained by the fast Fourier transformation from records of 40.96 s (starting from twice the S-wave travel time after the origin), with a cosine tapered window (10% at the head and tail of the waveforms), and smoothed using the filter of Konno and Ohmachi [15].

Horizontal spectra were obtained by vector summation of two horizontal components of the amplitude spectra. From the horizontal and vertical spectra, the HVSR of ambient noise in the frequency band of 0.1–

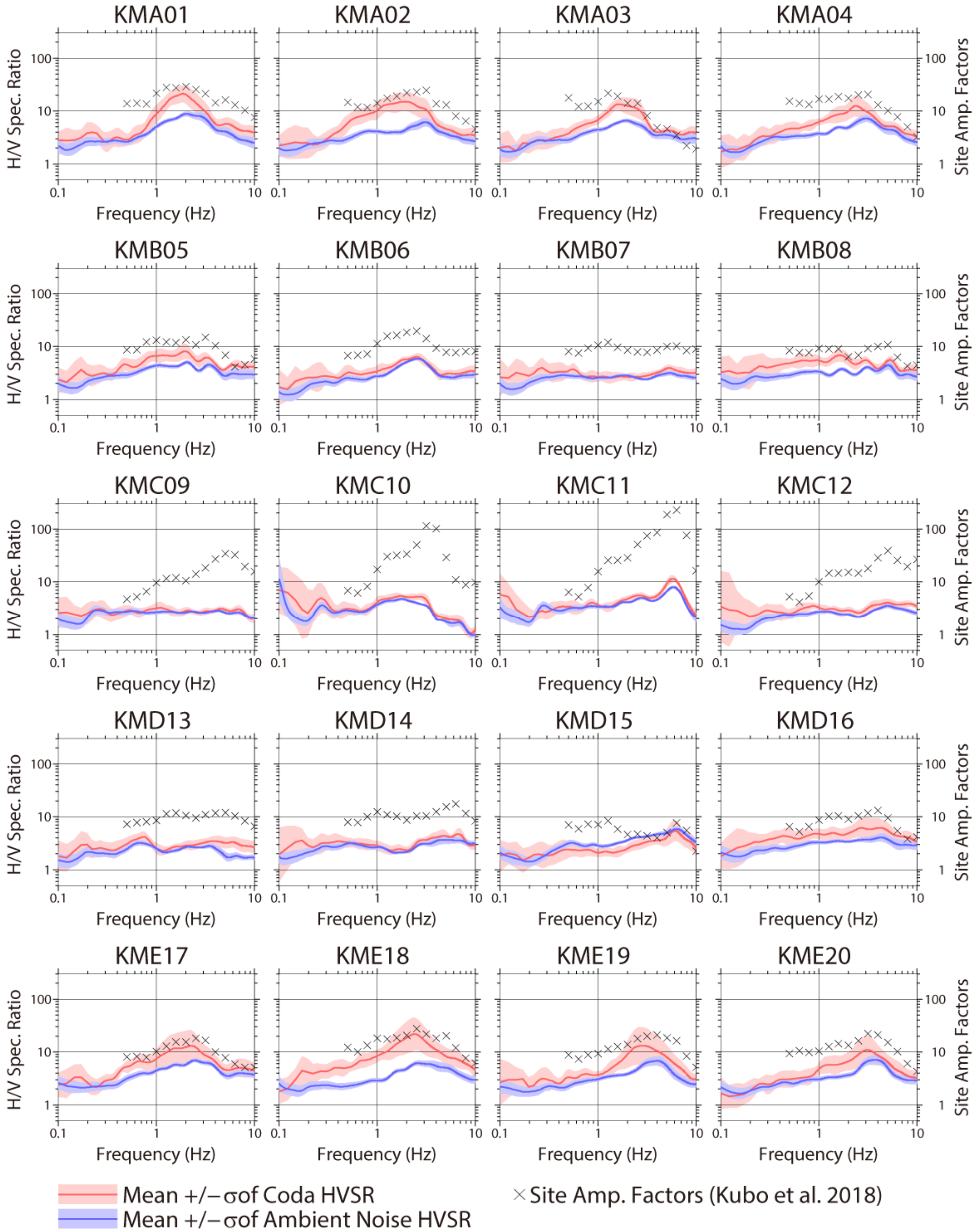

Fig. 2 HVSRs at DONET1 derived from coda waves (red) and ambient noise (blue). Crosses denote the site amplification factors [11].

10 Hz was obtained.

To obtain the HVSR of ambient noise, we used continuous velocity records of broadband seismometers of 690 minutes on April 1, 2016, 00:00–11:30. We subdivided the whole records to record sections of 163.84 s by overlapping 50% and select sections where there is no instrumental noise. From velocity records of the selected windows, the HVSR of ambient noise were obtained in the same way as the HVSR of coda waves.

3. Results & Discussions

Fig. 2 shows the HVSRs of coda waves and ambient noise at DONET1 stations. The site amplification factors estimated by the spectral inversion [11] are also shown. The HVSR values of both data are larger than 2 in the broadband frequency range at all stations. The feature of HVSR is different between near-coast stations (KMA and KME) and near-trench stations (KMB, KMC, and KMD).

At KMA and KME stations, the HVSRs of both data have a significant peak in the frequency of 2–5 Hz. The HVSRs of coda waves are larger than those of ambient noise. Moreover, the peak frequency of the HVSRs of coda waves is slightly lower than that of ambient noise. The HVSRs of coda waves are close to the site amplification factors, although the HVSRs of ambient noise are inconsistent with the site amplification factors.

At KMB, KMC, and KMD stations, the HVSRs of coda waves are almost identical close to those of ambient noise. The HVSRs at most stations have no significant peak and their shapes seem to be flat compared to those at KMA and KME stations. The HVSRs of both data are inconsistent with the site amplification factors, especially at KMC stations that have significant large site amplification.

The variation of HVSR among station groups is considered to reflect the underground structure complexity of the accretionary wedge [e.g., 11, 16, 17]. The KMA and KME stations are located in the Kumano basin with thick sediments. The KMB and KMD stations are installed on the seaward edge of the Kumano basin or the landward region of the lower slope of the accretionary wedge. The KMC stations are located at the tip of the accretionary wedge.

The previous studies demonstrated the incoincidence between HVSRs of ambient noise and S waves at land strong-motion observation [e.g., 13, 14], which is consistent with our results. They consider that this incoincidence is likely to be caused by the different nature of wavefield for ambient noise and earthquake. Thus, we may say that it is difficult to use HVSR of coda waves or ambient noise directly as site amplification factors at DONET1. On the other hand, it is important for earth science to reveal what causes a notable difference between site amplification factors and HVSRs of coda waves and ambient noise at DONET1 stations, and further investigations are needed.

There are several studies investigating ambient noises at DONET [e.g, 18, 19]. Tonegawa et al. [19] used seismograms and pressure records around 0.1 Hz to obtain one-dimensional Vs profiles below DONET stations. However, the previous studies mainly focused on ambient noises at low frequency (< 1 Hz), and further studies focusing on ambient noises at high frequency (> 1 Hz), at which DONET stations have significant site amplification, are required including a discussion on self-noises of seismometers [20, 21].

4. Conclusion

We investigated the HVSR of coda waves and ambient noise at DONET1. The features of HVSR is different between the near-coast stations (KMA and KME) and the near-trench stations (KMB, KMC, and KMD). At the near-coast stations, the HVSRs have a significant peak in the frequency of 2–5 Hz. The HVSRs of coda waves at the near-coast stations are larger than those of ambient noise and are consistent with the S-wave site amplification factors derived by the spectral inversion. At the near-trench stations, the HVSRs of coda waves are almost identical close to those of ambient noise and they have no distinct peak. The HVSRs of both data at the near-trench stations are different from the site amplification factors, especially at KMC stations. Our result suggests that it is difficult to use HVSR of coda waves or ambient noise directly as S-wave amplification factors at DONET1, as pointed out by previous studies in land observation.

5. Acknowledgements

We used Generic Mapping Tools [22] to draw the figures.

6. Copyrights

7. References

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