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Long-period ground motion characterization by cross wavelet transform

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ABSTRACT

The 2011 Tohoku Earthquake is occurred 11 March 2011 and caused strong ground shaking in the Tohoku region of the north-eastern Japan. Sendai city is one of the cities with over million populations and situated near the rupture zone. Site specific ground motion characteristics are studied and observed dominant period at sites are compared with those site amplification estimated from deep underground geology model. Previous studies suggested that it needs to investigate the observed wave propagation characteristics within the basin. The authors evaluate the wavelet basis method for ground motion study while taking into account the future applications, such as ground motion prediction for earthquake early warning.

1. INTRODUCTION

In seismic countermeasures for building and urban safety, it is important to evaluate site specific ground motion taking into account geological structure. Seismic wave propagation characteristics in basin structure and site amplification at local area were studied based on observed strong motion database in Sendai basin, during the 2011 Tohoku earthquake. Long period ground motion amplification have observed in the city, therefore the investigation focused to characterize the long-period ground motion using various techniques such as, to examine the site amplification based on deep underground geology model to estimate wave propagation velocity based on array techniques and cross wavelet transform. The investigation is important to further considerations regarding local geological structure study and wave propagation characterization to various engineering applications such as ground motion prediction.

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2. GENERAL CHARACTERISTICS OF OBSERVED GROUND MOTION

Strong motion records in Sendai during the 2011 Tohoku earthquake are used for the study, and database is recorded by local strong motion networks, namely Small Titan (Kamiyama et al, 2012), DCRC network (Ohno et all, 2012) and nationwide networks. Fig. 1 shows the geological map (Japan Geological Survey, 2010) and distribution of strong motion sites, which used in the study.

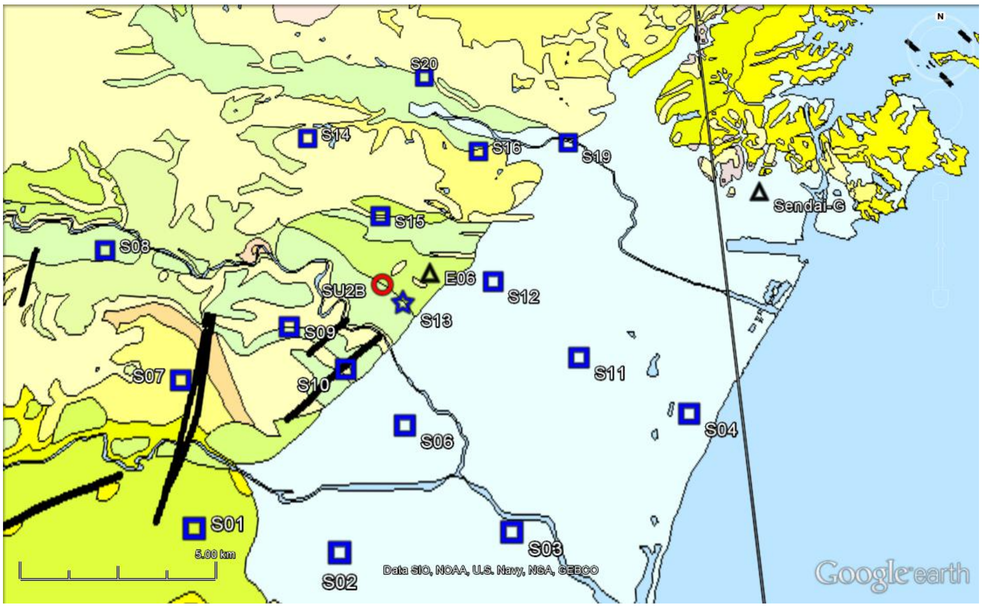

Fig.1Geological map and strong motion sites

2.1 Site Amplification Characteristics

Deep underground geological model (Miyagi Prefecture, 2005; Motosaka et all, 2006)is used for comparison of observed strong motion characteristics with those theoretical amplification in divided zones within basin has investigated (Tsamba et al, 2012), and among those the central zone, its sites' soil profile are shown together with calculated amplification in Fig.2.

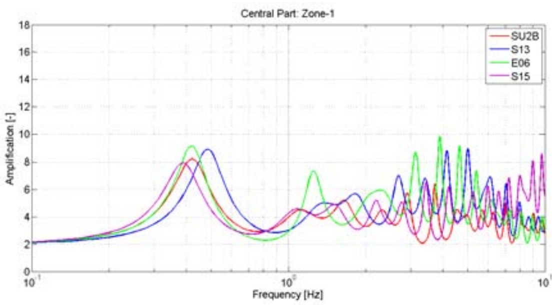

Fig.2Soil profile and theoretical amplification in central zone

Site amplification at the sites due to specific earthquake is important issue to seismic hazard, where geological layers have effect on seismic motion. In the analysis, it is assumed that the direction of the incident wave is vertical, and a one-dimensional analysis is performed. In this study, the input motion is adopted as outcrop motion, which the Sendai-G site has chosen. The site is located at the basin edge of the Sendai city, and acceleration records of borehole at depth of 10 meters below the ground surface are used. The site is maintained by PARI (Port and Airport Research Institute, 2011). Description of the soil layer, and observed acceleration waveform together with response spectra have shown in Fig. 3. Site amplification due to the 2011 Tohoku earthquake in central zone of Sendai, has calculated based on an existing geological model by Miyagi Prefecture, deep underground structure model. Calculated results were compared with observed ground motion at the sites in Fig. 4. Since the geology model is deep structure, therefore analysis results focused on the longer period range of ground motion spectra. Observed response spectra is shown by solid line and calculated response spectra is shown by dashed line. In the central zone calculated amplified period is 2.5 sec but observed is 3 sec.

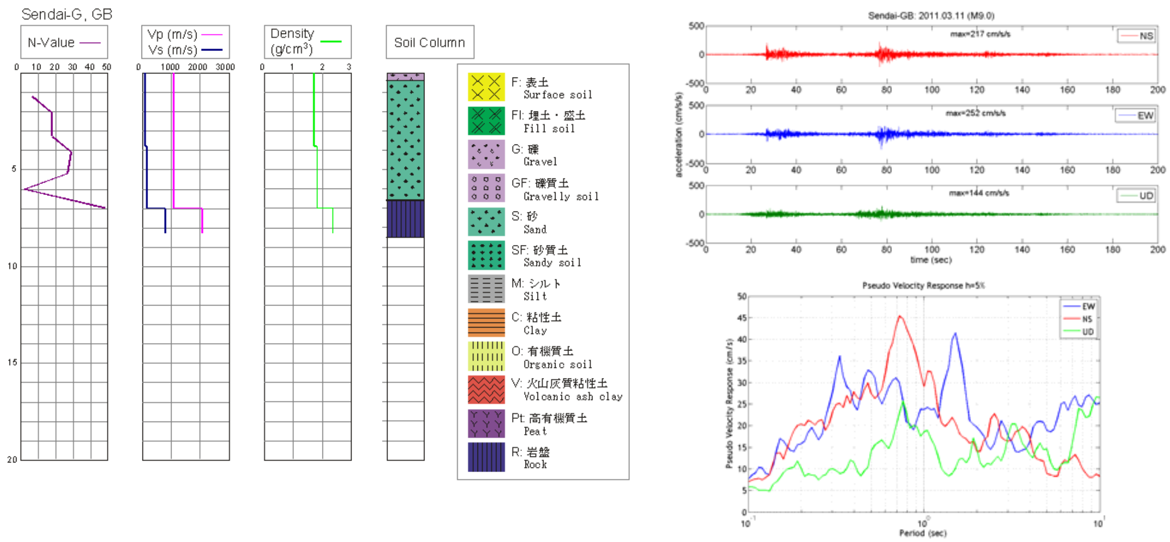

Fig.3Soil profile of the site and observed acceleration records

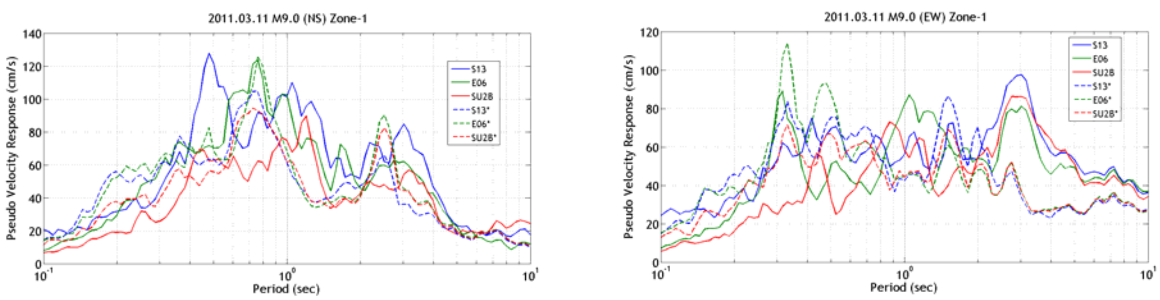

Fig.4Site amplification in central zone

2.2Frequency-Wavenumber Analysis

Array configuration was arranged by using the sites of Small Titan network. A reference site is chosen in the center of the city, which correspond the site S13 (Renbou). The network is maintained by Tohoku Institute of Technology. Strong motion records obtained during the 2011 Tohoku earthquakes were calculated for frequency wavenumber analysis and results are shown in Fig. 5. Acceleration waveform of NS direction at S13 is shown in Fig. 5 (a). For 2011 earthquake, acceleration records are used for calculation in frequency band from 0.25 Hz to 0.5 Hz and the apparent velocity within the array is 3.3 km/s for back azimuth ~93 degree (Fig.5 (b)). The beam power is expressed by isolines in db. Furthermore, since the 2011 Tohoku earthquake is multi shock event, the analysis is done by dividing in time sections of the largest amplitude level. In time section from 80 sec to 120 sec, the apparent velocity is 3.6 km/s/s for back azimuth ~94 degree (Fig. 5 (c)), respectively.

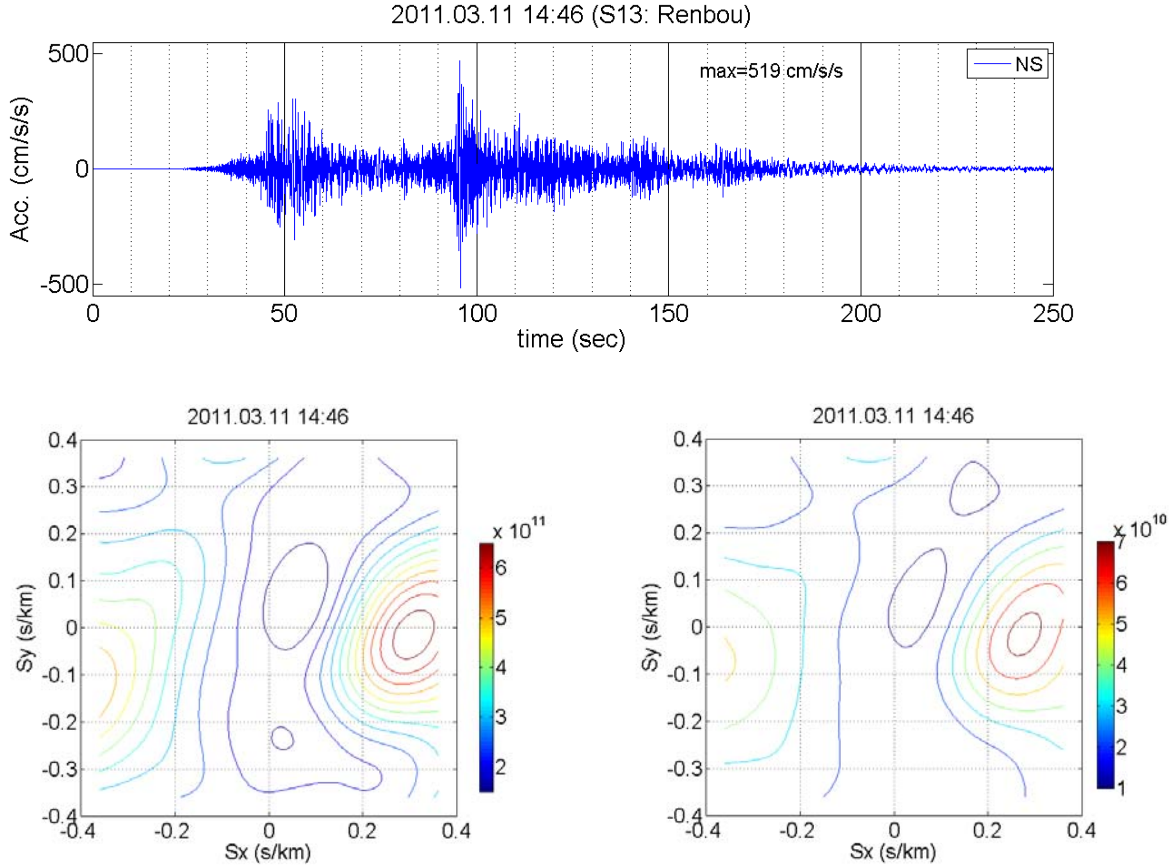

Fig.5Frequency wavenumber analysis

3. LONG-PERIOD GROUND MOTION CHARACTERIZATION BY CROSS WAVELET TRANSFORM

Cross wavelet transform has estimated from two acceleration waveforms between neighboring sites. Since the long period ground motion with 3 second has observed by amplifying in basin. Raw data of acceleration waveform is filtered by band limited range of interested amplified frequency band from 0.25 Hz to 0.5 Hz. The acceleration data in largest amplitude level of earthquake of 2011 Tohoku were used. From Fig. 6, for 2011 Tohoku earthquake, there are wave groups are traveling is clearly visible. Analysis is as follows. The cross correlation is examined between fair sites. Based on correlation between sites, it could find the travel time and, if constantly phase delay it confirms the waves are coherent. The wave group with center-frequency 0.33Hz in time section from 80 sec to 120sec, is traveling with clear shape from coast site S11through S12 and cross wavelet transform is calculated between sites of fair (Fig. 6).

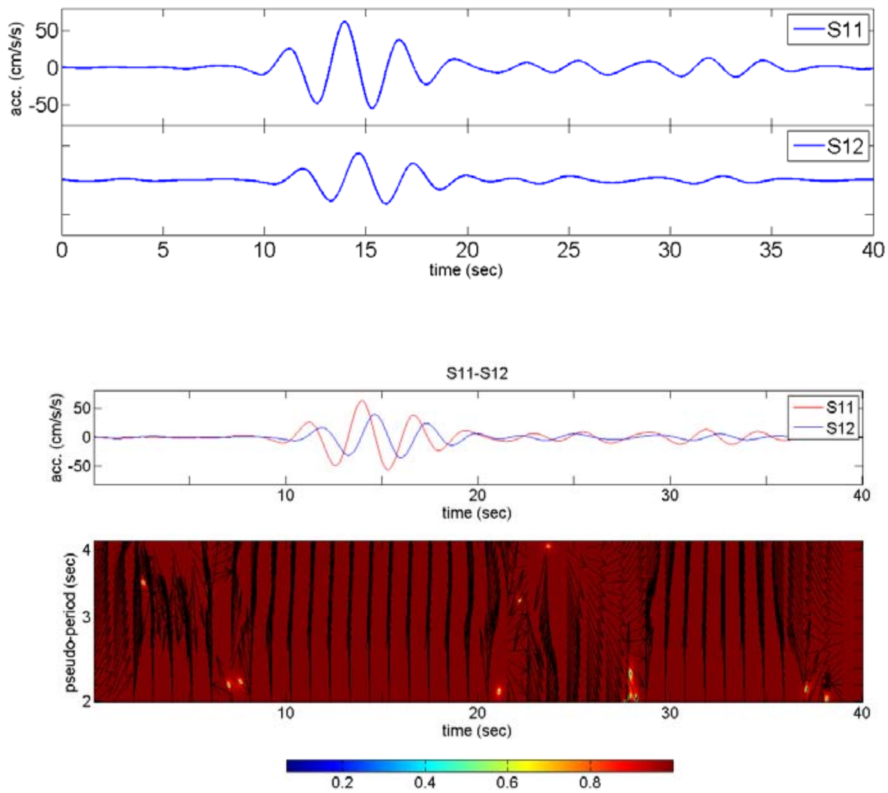

Fig.6Long-period acceleration records and cross wavelet transform

Results are as follows. Assuming that, the planer waves are traveling from back azimuth ~94 degree. The relative distance along ray path is 2.6km for S11 versus S12.Travel time difference of central wavelet power spectrum is approximately 0.7 sec, and relative phase delay is constantly varying in time section from 10 sec to 20 sec.

Therefore, it could be concluded that relative velocity of the wave group is ~3.7 km/s between the recorded stations.

3. CONCLUDING REMARKS

It is important to discuss the observed ground motion characteristics in relation the existing geological model. During the 2011 Tohoku earthquake, long-period ground motion, the period of 3 sec range is amplified the basin of Sendai. Investigation has done using various techniques such as:site amplification during the earthquake has examined using the deep underground geological model; wave propagation characteristics focusing on long period are studied using the frequency-wavenumber analysis. Furthermore, cross wavelet transform is evaluated between fair sites to characterize the long period ground motion. The obtained results are useful in both directions: in geophysics, the inverse problems to improve the regional geology model; and in earthquake countermeasures, the warning purposes to develop the forward prediction method of ground motion.

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