Damage during the 2013 Awaji Island Earthquake in Sumoto Plain and Its Ground Motion Characteristics

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At 5:33 a.m. on April 13, 2013, an earthquake of magnitude 6.3 occurred near Awaji Island in the western Japan. This paper describes the results of damage assessment survey conducted immediately after the earthquake event on Sumoto City focusing on the extend and characteristics of damage to the wooden houses. The major damage was broken of roof tiles of one and two story wooden houses and damage to wooden houses were concentrated at Takenokuchi area (alluvial soil deposit area in northern Sumoto plain) and reclaimed areas. Similarly, microtremor measurement was also conducted at Sumoto plain and its result showed that the longer predominant period was observed around reclaimed areas and at bank of Sumoto River. The abrupt change in predominant frequency was also observed within the small distance at northern portion of Sumoto plain which might have affected on the ground vibration during strong ground motion causing concentrated damage of wooden houses.

Key Words : *2013 Awaji Island Earthquake, Earthquake damage, Microtremor*

1. INTRODUCTION

A moderate earthquake of magnitude 6.3 on the JMA (Japan Meteorological Agency) scale occurred near Awaji Island in western Japan on 13 April 2013 at 5:33 a.m. According to JMA, its epicenter was located at latitude 34.42°N and longitude 134.83°E, at a depth of 15 km. Cabinet office report showed that 34 people were injured and 8072 houses were damaged due to strong motion of this earthquake[1)]. The earthquake damage was reported in Hyogo, Osaka and Okayama Prefectures and damage was comparatively higher in Sumoto City of Awaji Island.

A field survey for an assessment of earthquake damage was carried out by authors soon after the earthquake event. Our study area was mainly focused on Sumoto City which is developed around the mouth of Sumoto River. Some areas are newly developed by reclaiming the old Sumoto River which transformed the orientation of the river. Till Meiji Era, old Sumoto River used to flow over the reclaimed area such as Shioya 1-chome as shown in **Fig.1**. Similarly, authors also conducted the microtremor measurement of Sumoto plain to understand its ground characteristics.

2. EARTHQUAKE DAMAGE IN SUMOTO CITY

In Sumoto City, the maximum ground acceleration was 455 gal recorded by MLIT station (strong motion observation station) and the peak ground acceleration at K-NET Sumoto and Sumoto Gas stations were also higher than 300 gal[2)]. Due to this strong ground motion, damage to the wooden houses, liquefaction of reclaimed areas and damage to the infrastructures (bridge) were observed during our

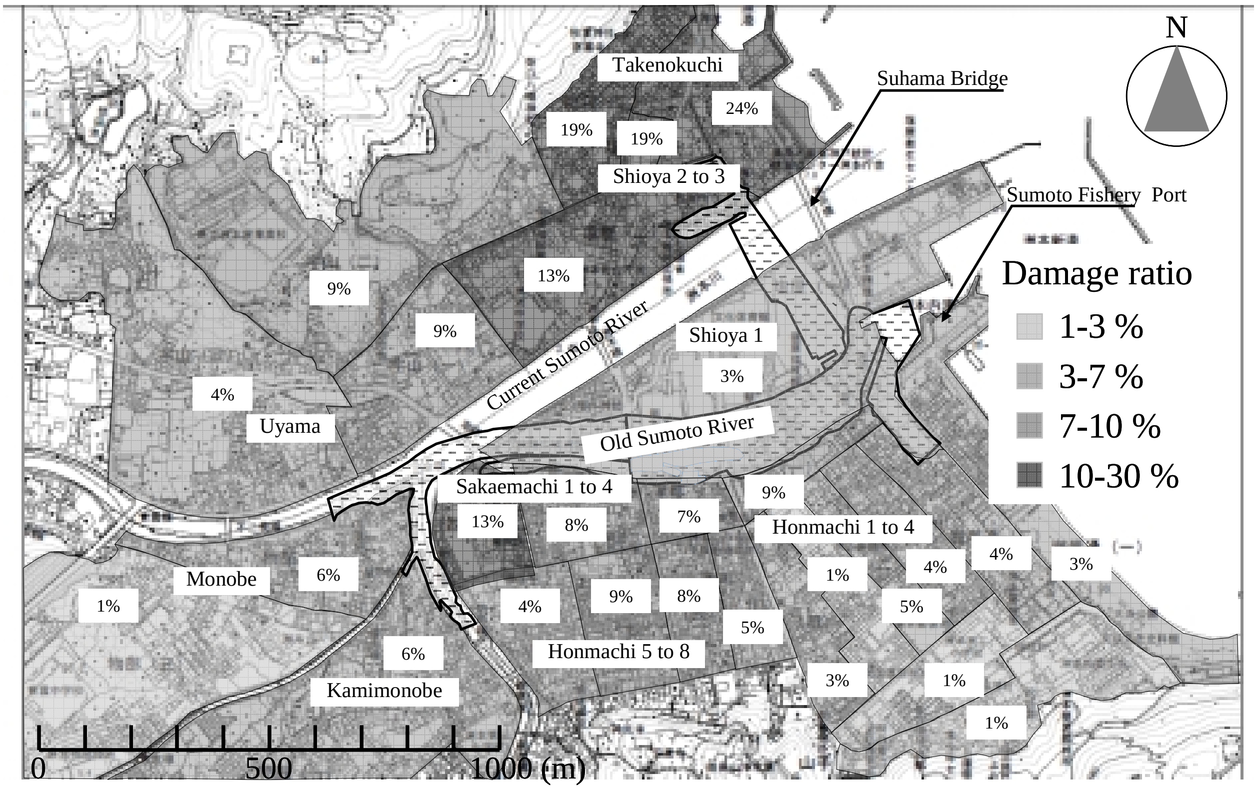

Fig.1 Damage distribution of wooden houses damaged by 2013 Awaji Island Earthquake in Sumoto City. Hatched portion indicates the flow direction of old Sumoto River until Meiji Era. The value in a box represents the damage ratio (in percentage) of damaged wooden houses at specific site.

survey. Earthquake damage and its distribution is briefly explained in the following sub-headings.

(1) Damage to wooden houses and buildings

Most of houses in Sumoto city are of one and two story wooden houses with typical Japanese style roof. Due to tremor of earthquake, many one and two story old wooden houses were suffered from roofs damage. The roof tiles were broken and even fell down to the ground. However, no structural damage to the timber beam and column was noticed. Moreover, it is worth mentioning that no breakage of window glass was observed even in the house with damaged roof.

The distribution of damaged houses in Sumoto City is shown in **Fig.1**. This map was prepared based on the damaged ratio of wooden houses at specific site. Damge ratio is the ratio of number of total number of damaged houses to the total number of houses at specific site. In this case, damage ratio was calculated for every town (known as chome in Japan) and damaged town were divided into four zones. Damage ratio with 1-3%, 3-7%, 7-10% and 10-30% were termed as highly sparsed damage zone, sparsely damage zone , moderately densed damage zone and densly damage zone respectively. At Takenokuchi town, the roofs of wooden houses were heavily damaged and number of damaged houses were concentrated within small area. The damage ratio of Takenokuchi town was highest among our surveyed area. The typical damage to the roofs of wooden houses in Takenokuchi 2-chome are shown in **Fig.2(a)** to **Fig.2(c)**. It is supposed that Dabutsugawa River used to flow around the Takenokuchi area. The soft sediment of this river might have amplified the ground motion causing concentrated damages. During our survey, some minor damage to reinforced concrete (RC) building (**Fig.2 (d)**) were also observed in Takenokuchi 1-chome. A 1.4 mm width vertical cracks were noticed on the wall of two story RC building. Sakaemachi and Monobe towns were moderately densed damage zone where the number of damaged houses was in the range of 10-20. The old Sumoto River, till Meiji period, used to flow in between Shioya 1-chome and Sakaemachi town as indicated in Fig.1. Thus it can be assumed that Sakaemachi town might be the flooding area of this river during raining seasons at ancient Meiji period. Thus layer of soft sediment deposits may be thick in this town and this might be major parameter for more damage in this zone. However, the damage ratio at Shioya 1-chome was low (only 3%) although

Fig.2 (a) Damage to the roofs and broken tiles of two story wooden house at Takenokuchi 2-chome.

Fig.2 (b) sliding of roof tiles of one story wooden house with no breakage of window glass.

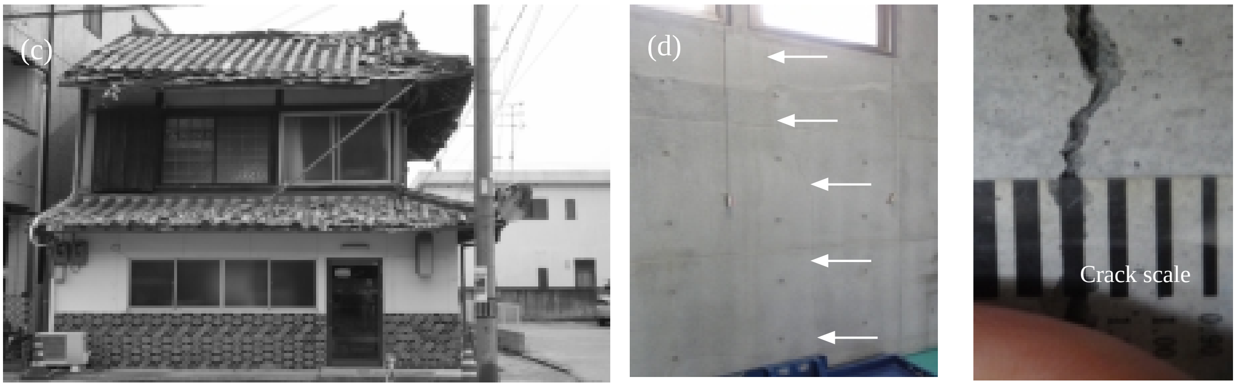

Fig.2 (c) large deformation of the roofs and second story frame of a two story wooden house at Takenokuchi 2-chome.

Fig.2 (d) Vertical cracks (1.4 mm width) on the wall of reinforced concrete building at Takenokuchi 1-chome.

Fig.2 Earthquake damage to wooden houses and reinforced concrete building at Takenokuchi area.

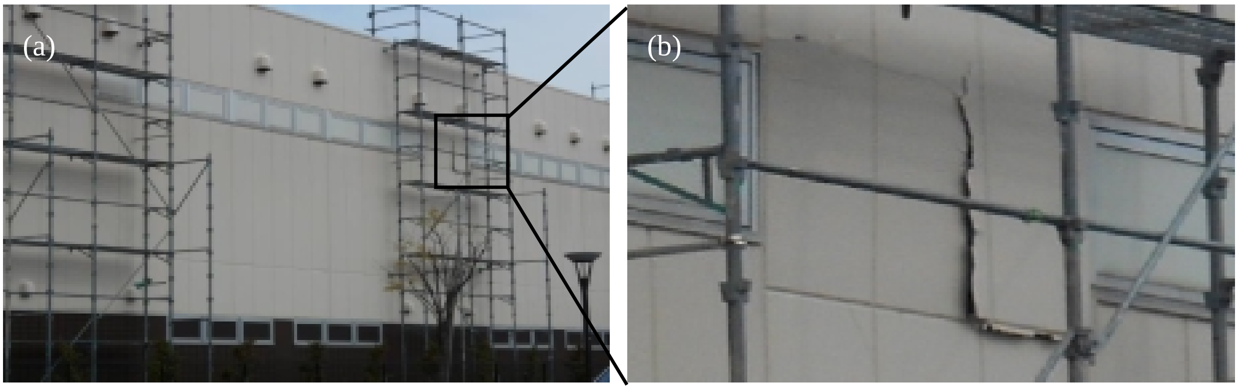

Fig.3 Slight damage to the exterior wall of a shopping center at Shioya 1-chome; (a) View of damaged exterior wall made of ALC panel; (b) out-of-plane deformation of ALC panel.

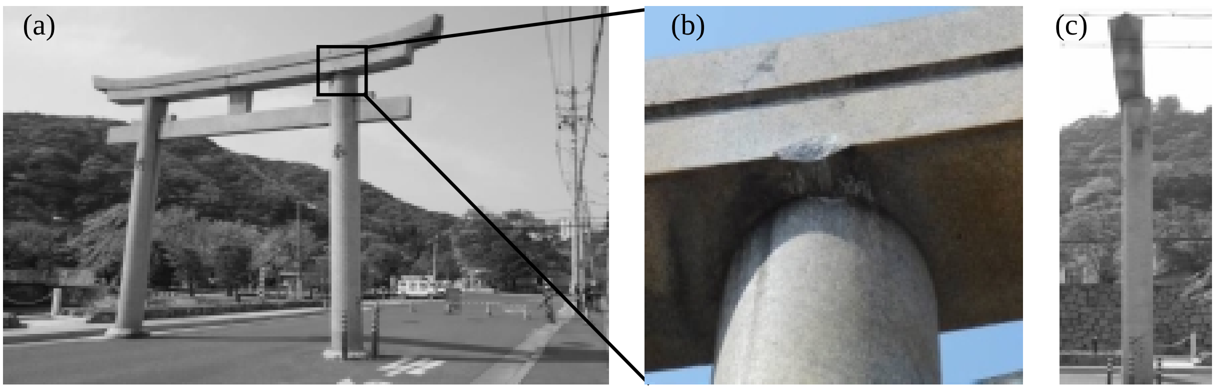

Fig.4 Earthquake damage to the first gate of Sumoto Hachiman Shrine; (a) Front view of gate; (b) Foused damaged portion; (c) Side view of gate showing sliding of Horizontal member.

this area is reclaimed area. In this town, wooden houses were less and newly constructed reinforced concrete building were made earthquake resistant which resulted in less damage. A shopping center constructed over the reclaimed land on the old Sumoto River was slightly damaged as shown in **Fig.3**. The exterior wall made of ALC panels (autoclaved lightweight aerated concrete panel) deformed out-of-plane due to earthquake motion.

Similarly, the damage ratio at Honmachi town , consisting of 8 sub towns (chome), was 5% in average, however inside this town, the damage ratio varies from 1% to 9% depending upon its sub-town. The damage ratio at Honmachi 3-chome was least

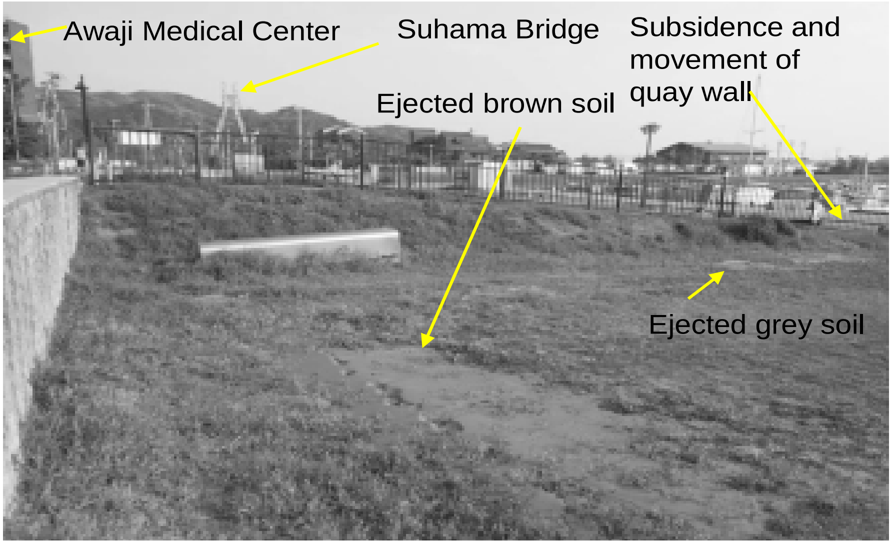

Fig.5 Liquefaction and liquefaction induced damage observed at Sumoto Fishery Port.

Fig.6 Liquefied grey soil creating fissures parallel to the quay wall.

Fig.7 Subsidance of ground behind the quay wall and movement of quay wall toward sea

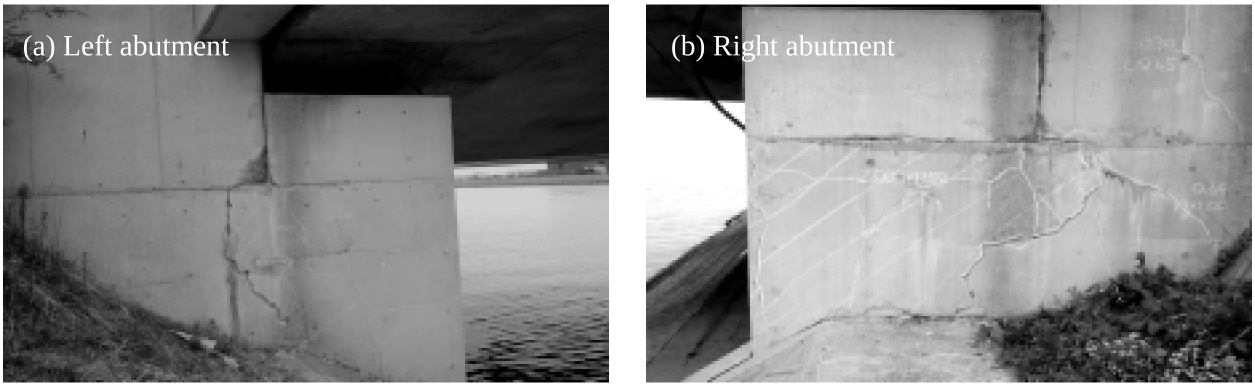

Fig.8 Earthquake damage to the abutments of Suhama Bridge; (a) Cracks on the left abutment; (b) Cracks on the right abutment.

where only two wooden houses were damaged while this ratio was around 9% at Honmachi 7-chome and 8-chome. The first gate of Sumoto Hachiman shrine was damaged due to sliding and rocking of upper horizontal members supported by two columns during main shock as shown in **Fig.4**. In general, it can be said that area at the left bank side of current Sumoto River and areas where old Sumoto River used to flow were highly damaged. The soft sediment deposits might have amplified the ground motion during earthquake causing concentrated damage in these areas.

(2) Damage due to liquefaction

Liquefaction is considered as a common damage of an earthquake in the reclaimed areas when the intensity of the earthquake exceed 5. Some areas around Sumoto Fishery Port near to Awaji Medical Center were liquefied as indicated in **Fig.5.** Brown and grey soils were ejected, creating fissures in the ground parallel to the quay wall (**Fig.6**). Subsidence of ground behind quay wall was 13 cm due to liquefied soil eruption (**Fig.7**). Cracks due to differential settlement on an asphalt pavement were also noticed at the parking area of Sumoto pumping building.

(3) Earthquake damage to Suhama Bridge

Most of the infrastructures especially bridges in this city performed well during this earthquake. However, the damage to the abutments of Suhama Bridge, a 149 m long two span cable-stayed bridge across Sumoto River, was quite remarkable. Shear cracks on both abutments of this bridge was observed (**Fig.8**). The cracks were concentrated on abutments and no major crack and damage was observed in the bridge girder. The coupled interaction between bridge girder, stopper and abutment due to earthquake motion could be possible cause of shear cracks in the abutments. The failure mechanism of this bridge was discussed by Mori et al[3].

3. Microtremor measurement at Sumoto plain

Microtremor measurement is considered as very useful method for obtaining the dynamic characteristics of ground including predominant period and site amplification factor. The large damage in the Takenokuchi could be due to effects of surface geology on the ground motion (local site effects). In this study, horizontal to vertical (H/V ratio) spectrum method originally proposed by Nakamura[4] was used to evaluate the predominant period of ground.

The microtremor measurements were carried out along the line joining the south edge to the north edge of Sumoto plain which approximately 2 kilometers. The start point of this line is Sumoto JMA station (JMA), extreme point of south part of Sumoto plain, while its end point is Akiba shrine, extreme point north part of Sumoto plain. The microtremor measurement points at Sumoto plain are shown in **Fig.9**. Each point is denoted by three alphabets representing the specific location. For example, JMA refers to

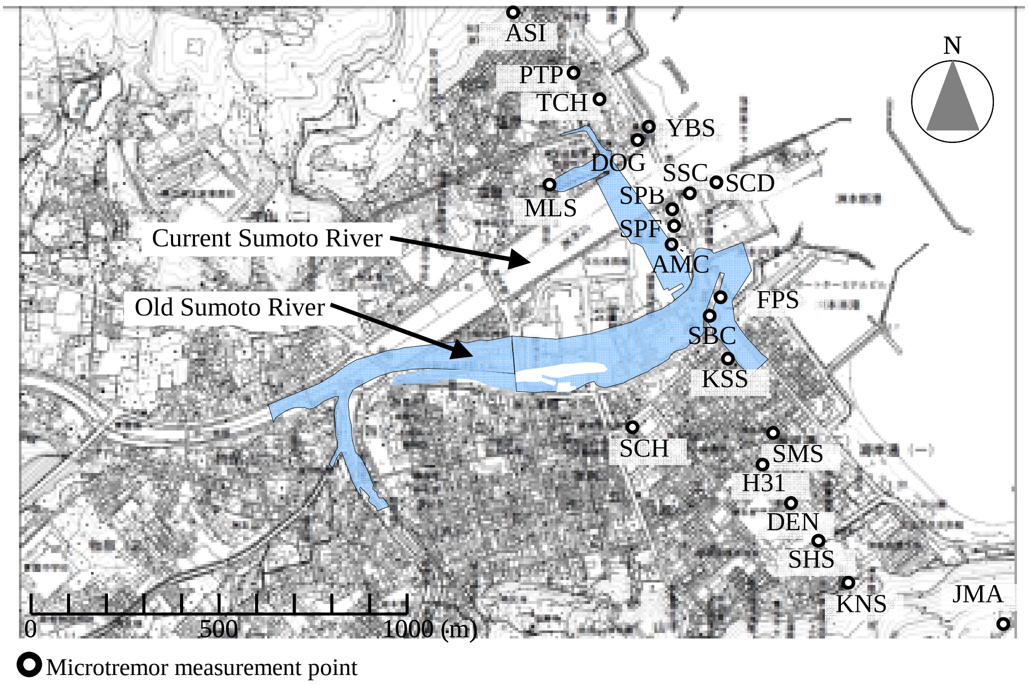

Fig. 9 Microtremor measurement points along North-South cross-section of Sumoto plain.

Japan Meteorological Agency Sumoto, SHS refers Sumoto Hachiman Shrine, SBC refers to Sumoto Bus Center and so on.

(1) Microtremor data acquisition method

Microtremor measurements were carried out using a GEODAQS sensor, GPS and a laptop computer. GEODAQS is a three components (one vertical and two horizontal) moving-coil type velocimeter consisting of a spring type pendulum having natural frequency of 0.5 Hz. During microtremor measurements, a sensor was set on the ground so that two horizontal directions were oriented toward north-south (NS) and east-west (EW) direction of the site. Measurements were recorded for 180 seconds with the sampling frequency of 200 Hz. While taking measurements, cares were taken to avoid the effect of heavy traffic, manholes and underground structures.

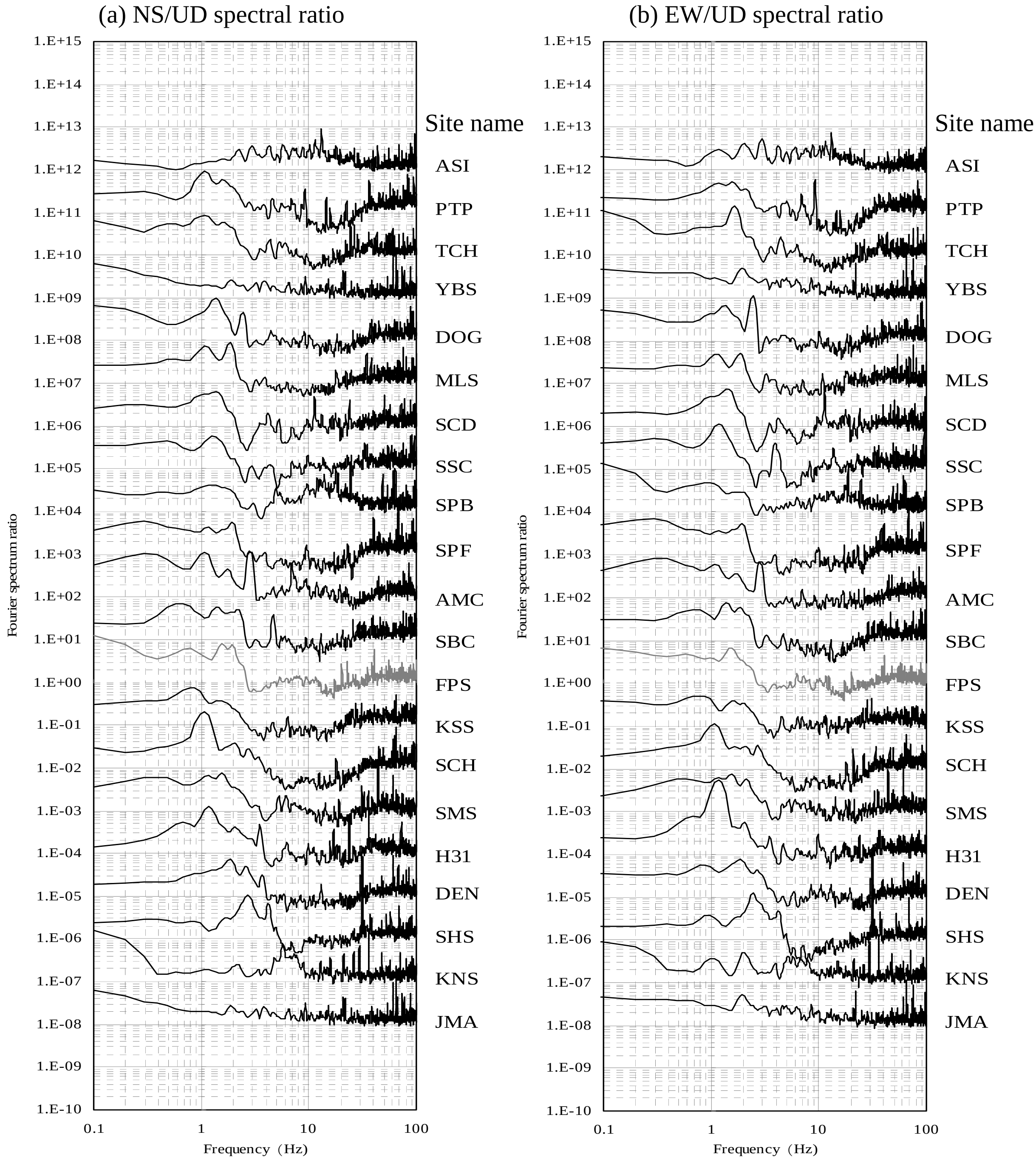

Fig.10 Fourier spectral ratio of microtremor measurement points along the Sumoto plain; (a) NS/UD spectral ratio; (b) EW/UD spectral ratio.

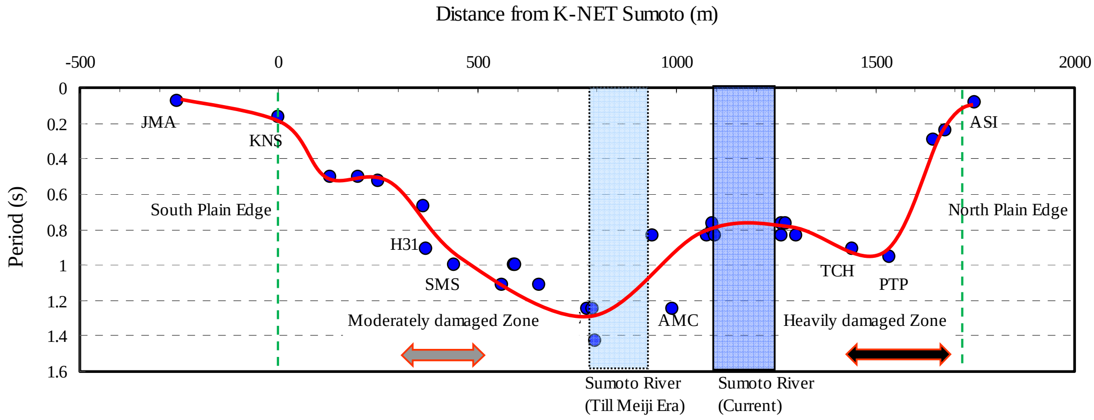

Fig.11 Distribution of predominant period at North-South profile of Sumoto plain.

Multiple measurements were taken where the noises due to running vehicles were high.

For each microtremor measurement point, entire velocity time histories of each component were drawn after doing drift correction (removal of mean of entire signal from each sample). Then 8 segments of 1024 data were extracted and transformed into frequency domain by using Fast Fourier Transformation. Then Fourier spectra were smoothed using 0.4 Hz Parzen's window. Finally predominant period of each site was determined using H/V spectral ratio peak. The detail observation on the Fourier spectra of electrical noise indicated that the microtremor signals in the range of 0.45 Hz to 25 Hz are useful signals. In this range, ratio of signal to noise (S/N ratio) is greater than two. Thus we considered this fact while determining the predominant period of the measurement points.

(2) Results and discussion

The Fourier spectral ratio of representative 21 sites was shown in Fig.10. For an easy understanding about predominant frequency of sites, the Fourier spectral ratio were arranged in single vertical column from JMA Sumoto Station (JMA) to Akiba Shrine (ASI). As stated earlier, the JMA site is starting point,a south edge of Sumoto plain and ASI site is ending point, a north edge of Sumoto plain. Thus spectral ratios from south edge to north edge of sumoto plain were arranged from bottom to top (**Fig.10**). The Fourier amplitude were multiplied by the integer of 10 to avoid the overlapping of spectral ratio. Thus the amplitude shown in **Fig.10** has no any physical meaning. It should be noted that multiplication factor for FPS site (grey) is 1. Two sites JMA (south edge) and ASI (north edge) sites were over hard rocks. Thus spectral ratio of these sites shows the smaller peaks at higher frequencies. In contrast to these two sites, other sites are located on the sediment deposits. **Fig.11** shows the variation of predominant periods along the cross-section of Sumoto plain, where abscissa represents orthogonal distance projected on the line joining the JMA (south edge) and ASI (north edge) sites and the ordinate represents the predominant periods obtained from Fourier spectral ratio. The predominant period become longer as sites are close to Sumoto River. There is increase of predominant periods from south edge to south bank of Sumoto river from 0.5 seconds to 1.25 seconds. The longer period on SBC and AMC sites was observed. These sites are located over old Sumoto river where thickness of soft sediment deposits may be high. The predominant period at Honmachi town was around 0.5 s-1.0 s. The predominant period around Sakaemachi was around 1.0 s-1.25 s. The old Sumoto river used to flow around Sakaemachi and it can be assumed that this town might be the flooding area of old Sumoto River. Thus thickness of soft sediment may be high causing longer period around this area. The Predominant period of ground adjacent to both abutment of Suhama bridge was around 0.8 s-0.9 s while the predominant periods at Takenokuchi town was around 0.2 s-0.3 s. Takenokuchi town represents the heavily damaged zones. The abrupt change in predominant period from 0.8 s to 0.3 s might influence on the concentrated damages in northern side of Sumoto Plain (around Takenokuchi area).

4. CONCLUSIONS

1. The major damage caused by 2013 Awaji Island Earthquake was concentrated to the roofs of one storey and two storey wooden houses. Damaged houses was higher in northern part of Sumoto plain

(Takenokuchi area). This area is considered as the flooding area of old Dabutsu River around Meiji period. Thus it can be assumed that the soft sediments deposits on this area might caused dense damage in this zone.

2. The predominant period along the Sumoto plain varies from 0.5 s to 1.25 s. The longer period around old Sumoto River was observed. Thus it can be said that the thickness of soft sediment deposits around old Sumoto River is high which amplified the ground motion during earthquake causing more damage and liquefaction in areas around old Sumoto River. The predominant period of ground adjacent to left and right abutment of Suhama Bridge was around 0.8 s which showed that the ground vibration around abutments of this bridge was almost same. However, the predominant period of highly damage area was around 0.2-0.3 s. The change in predominant period from 0.8 s to 0.3 s within relatively small distance might have affected on the ground vibration causing more damage in northern part of Sumoto plain.

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