第16回性能に基づく橋梁等の耐震設計に関する
シンポジウム講演論文集（2013年7月）

# Damage Distribution in the 2013 Awaji Island Earthquake and Ground Motion Characteristics in Sumoto plain

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## 1. Introduction

At 5:33 AM on April 13, 2013, a earthquake of magnitude 6.3 occurred near Awajishima Island in western Japan. The epicenter of this earthquake was Awajishima Island at latitude 34°25.1'N and 134°49.7'E and its depth was 15 km according to Japan Meteorological Agency (JMA). Offical records showed that about 34 people were injured and about 8072 houses were damaged due to this earthquake[1)]. The damages were in Hyogo, Osaka and Okayama Prefectures. The damages were concentrated in Sumoto city of Awaji Island.

Immediately after the earthquake event, the second author visited the affected areas to collect information about the damages and its distribution. Our study area was mainly focused on Sumoto City which is approximately 6 km away from the epicenter. Sumoto city was developed around the mouth of Sumoto River. Some areas are newly developed by reclaiming the Sumoto River which transformed the orientation of river. Till Meiji Era (period), old Sumoto River used to flow over the reclaimed area such as Shioya 1-chome (Fig.1). This information helped us to decide the area to be investigated for liquefaction damges as reclaimed areas are susceptible to liquefaction during earthquake.

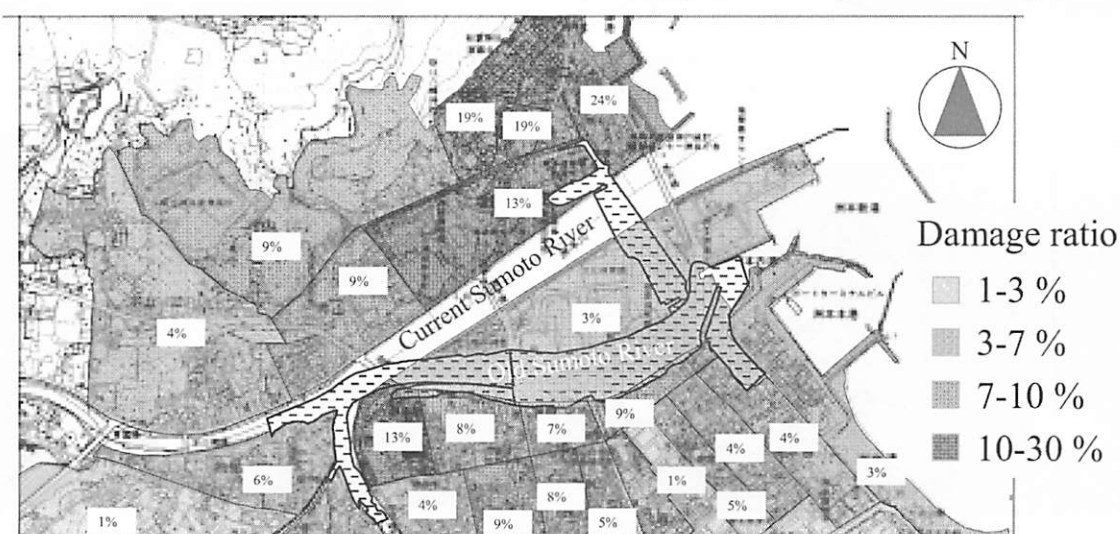



Fig.1 Damage distribution of wooden houses damaged by 2013 Awaji Island Earthquake in Sumoto City.

Similarly the authors also conducted the microtremor measurement to understand the ground behaviour of Sumoto plain.

## 2. Earthquake damages in Sumoto City

Sumoto K-NET station records showed that the peak ground acceleraton (PGA) in this station was about 349 $cm/s^2$(gal) and The peak ground acceleration at MLIT Sumoto, Sumoto Gas and JMA Sumoto were also higher than 300 gal[2)]. Due to this strong ground motion, damages to the old wooden houses, liquefaction of reclaim areas and damages to infrastructures (bridge) were observed during our survey. Damages and its causes are briefly explained in the following sub-headings.

### 2.1 Damages to wooden houses and buildings

In Sumoto city, most of houses are of one and two storey wooden houses with typical Japanese style roof. Due to tremor of earthquake, many one storey and two storey old wooden houses were suffered from roof damages. The roof tiles were broken and even fell down to the ground. However, no structural damages to the timber beams and columns were noticed. Moreover, it is interesting to state that no breakage of window glass was observed even in the house with damaged roof. The distribution of damaged houses in the Sumoto city is shown in Fig.1. This map was prepared based on the damaged ratio of wooden houses in specific site. Damage ratio is the ratio of number of total damged houses to the total number of houses in specific site. In this case, damage ratio was calculated for every town (known as chome in Japan) and damaged towns were divided into four zones. Damage ratio 1-3 %, 3-7 %, 7-10 % and 10-30% were termed as highly sparsed damage zone, sparsely damaged zone, moderately densed damaged zone and densely damaged zone respectively. At Takenokuchi town, locating at left bank side of current Sumoto River, the roofs of wooden houses were heavily damaged and number of damaged

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

Fig.2 (b) Sliding of roof tiles of one storey wooden house with no breakage of window glasses.

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

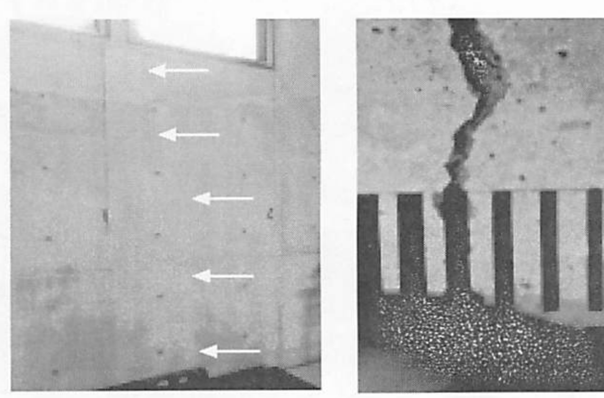


Fig.2 (d) vertical cracks (1.4 mm width) on the walls of reinforced concrete building at Takenokuchi 1-chome.

Fig.2 Earthquake damages to wooden houses and reinforced concrete building in Takenokuchi area

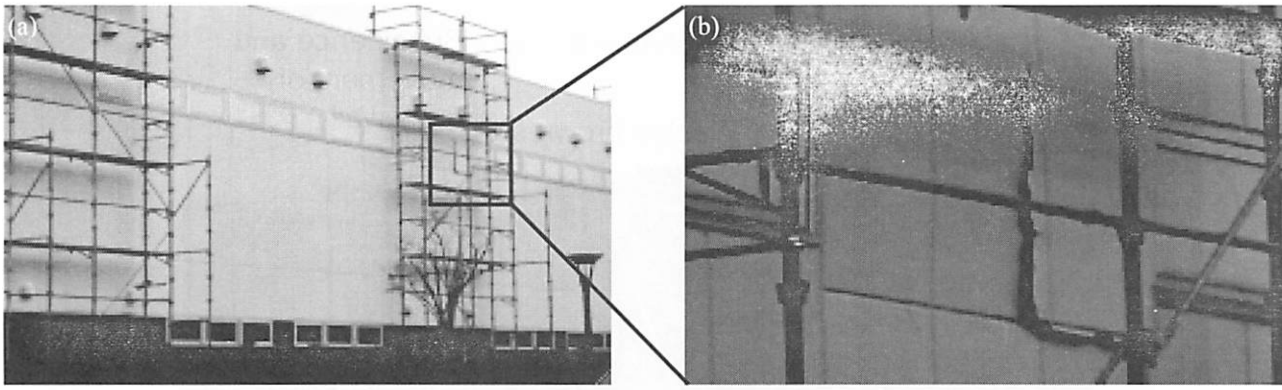



Fig.3 Slight damages to the exterior wall of a shopping center at Shioya 1-chome; (a)View of damaged exterior wall made of ALC panel (autoclaved lightweight aerated concrete panel); (b) Out –of plane deformation of ALC panel.

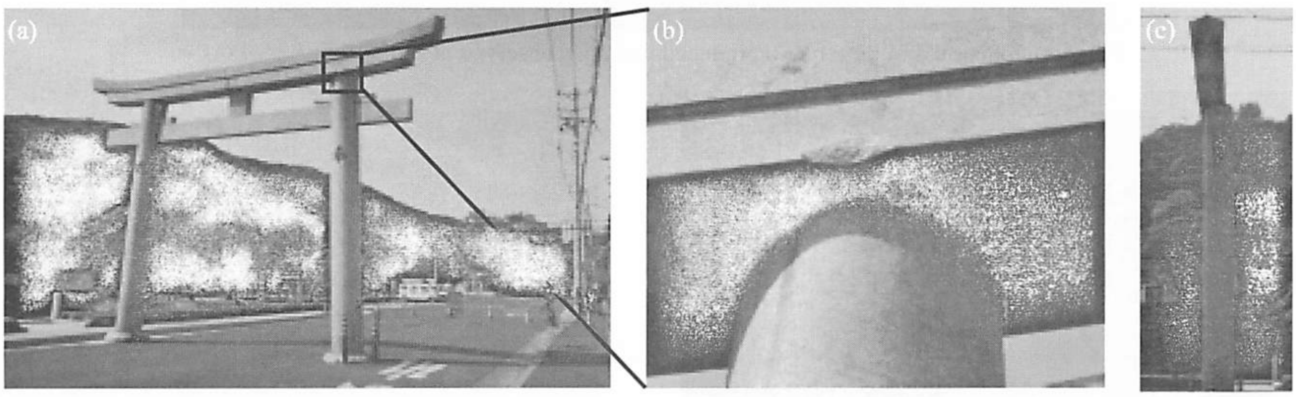



Fig.4 Earthquake damages to the first gate of Sumoto Hachiman Shrine; (a) Front view of gate; (b)Focused damaged; (c) Side view of gate showing sliding of horizontal member.

houses were concentrated within small area. The damages ratio of Takenokuchi town was highest among our surveyed area. The typical damages to the roofs of wooden houses in Takenokuchi 2-chome are in 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 damages to the 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 walls of two storey RC building. Sakaemachi and Monobe towns were moderately densed damaged 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 Sakamachi 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 damages in this zone. However, the damage ratio at Shioya was low ( only 3% ) although this area is reclaimed area. In this town, wooden houses were less and newly constructed reinforced concrete building were made earthquake resistance which resulted in less damages. 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. Similary, the damage ratio at Hommachi town, consisting of 8 sub- towns (chome), was 5 % in average however inside this town, the ratio varies from 1 % to 9 % depending upon its sub-town (chome). The damage ratio of Honmachi 3-chome was least where only two wooden houses were damaged while this ratio was around 9 % in Honmachi 7-chome and 8-chome. In these sub-towns, the damages houses were concentrated. 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. Some houses in Honmachi 1-chome were also suffered from roof damage even though these housese were survived in 1995 Hyogoken-Nambu earthquake. In

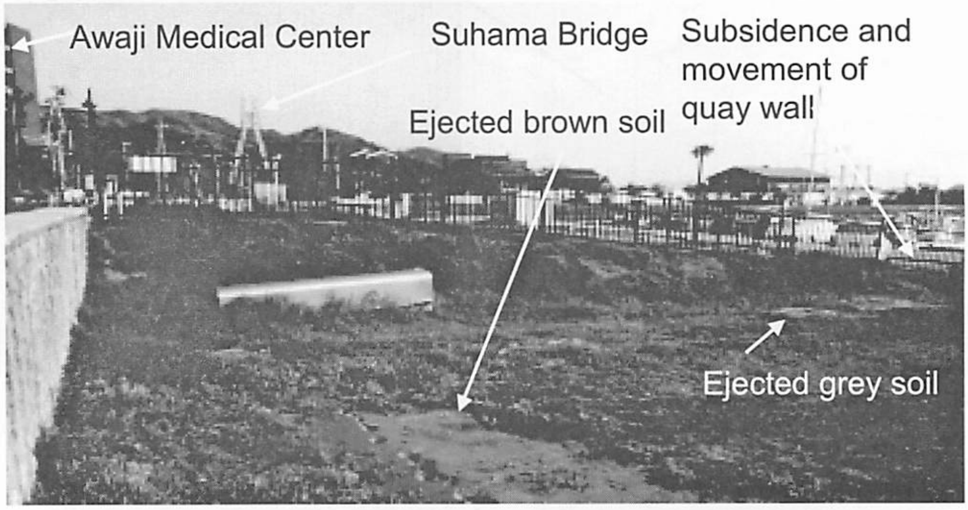



Fig.5 liquefaction and liquefaction induced damages observed at Sumoto Fishery Port.

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

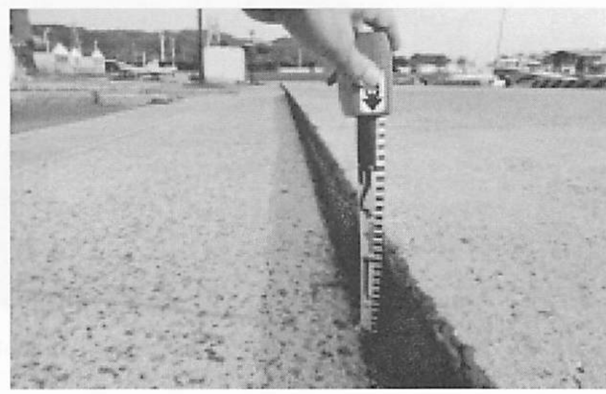


Fig.7 Subsidance of ground behind the quay wall and movement of quay wall toward sea.

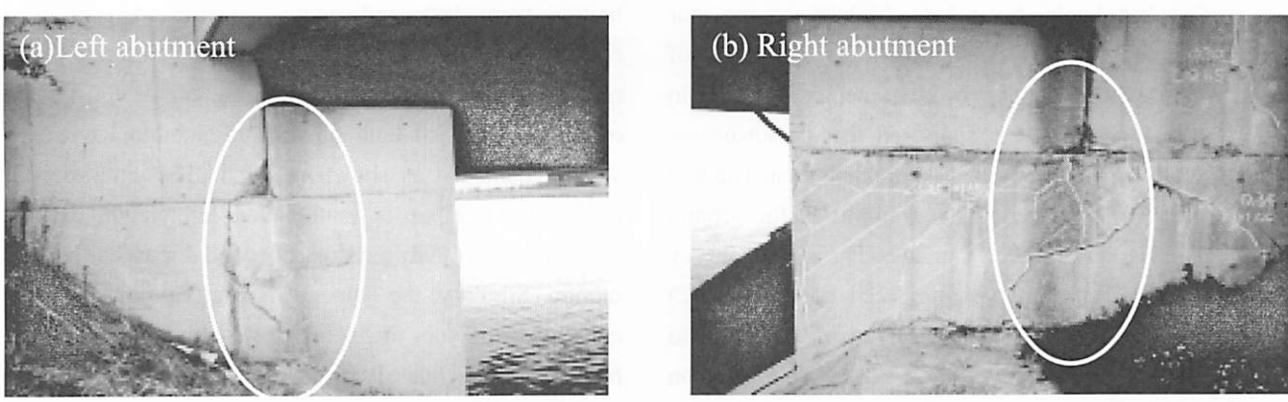



Fig.8 Earthquake damages to the abutments of Suhama Bridge; (a) Cracks on the left abutment; (b) Cracks on the right abutment.

general, it can be said that the areas 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 damages in these area.

## 2.2 Damages due to liquefaction

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

### 2.3 Earthquake damages to Suhama Bridge

All the infrastrucutures especially bridges located in this city performed well during this earthquake. However the damages to the abutments of Suhama bridge, a 149 m long two span cable-stayed bridge, was quite noticeable. Shear cracks on both abutments (left and right) of this bridge were observed (Fig.8). The cracks were concentrated on abutments and no major cracks and damages were 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 mechanisms of this bridge was discussed by Mori et.al.[3]

## 3. Microtremor measurement at Sumoto plain

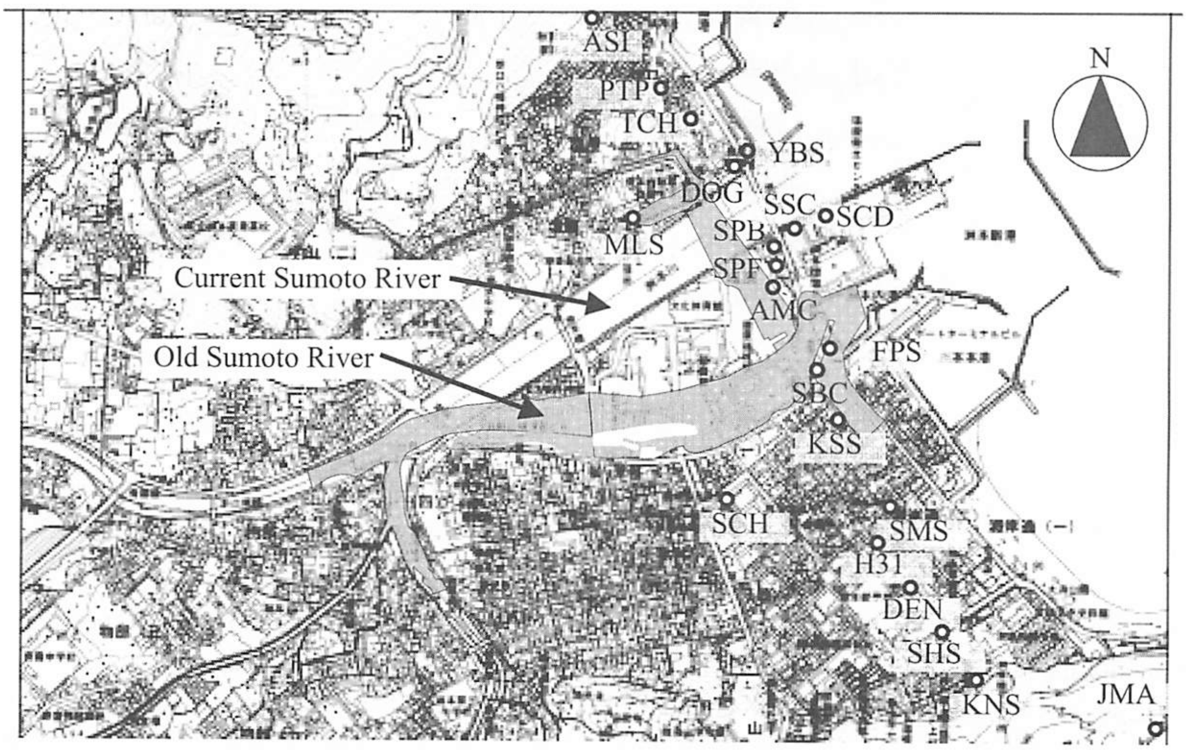
### 3.1 Micortremor measurements sites

Microtremor measurement is considered as very useful method for obtaining the dynamic characteristics of ground including predominant period and site amplification factor. The large damages in the Takenokuchi could be due to effects of surface geology on ground motion (local site effects). In this study, horizontal to vertical (H/V ratio) spectrum method originally proposed by Nakamura[4] was used to evaluated 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 is 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 (ASI), extreme point of north part of Sumoto plain. The microtremor measurements points at Sumoto plain is shown in Fig. 9. Each point is denoted by three alphabets representing the specific location. For example, JMA refers to Japan Meteorological Agency Sumoto, SHS refers to Sumoto Hachiman Shrine, SBC refers to Sumoto Bus Center and so on.

### 3.2 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 direction were oriented




O Microtremor measurement point

Fig.9 Microtremor measurement points along North-South cross section of Sumoto plain and flow direction of old and current Sumoto River.

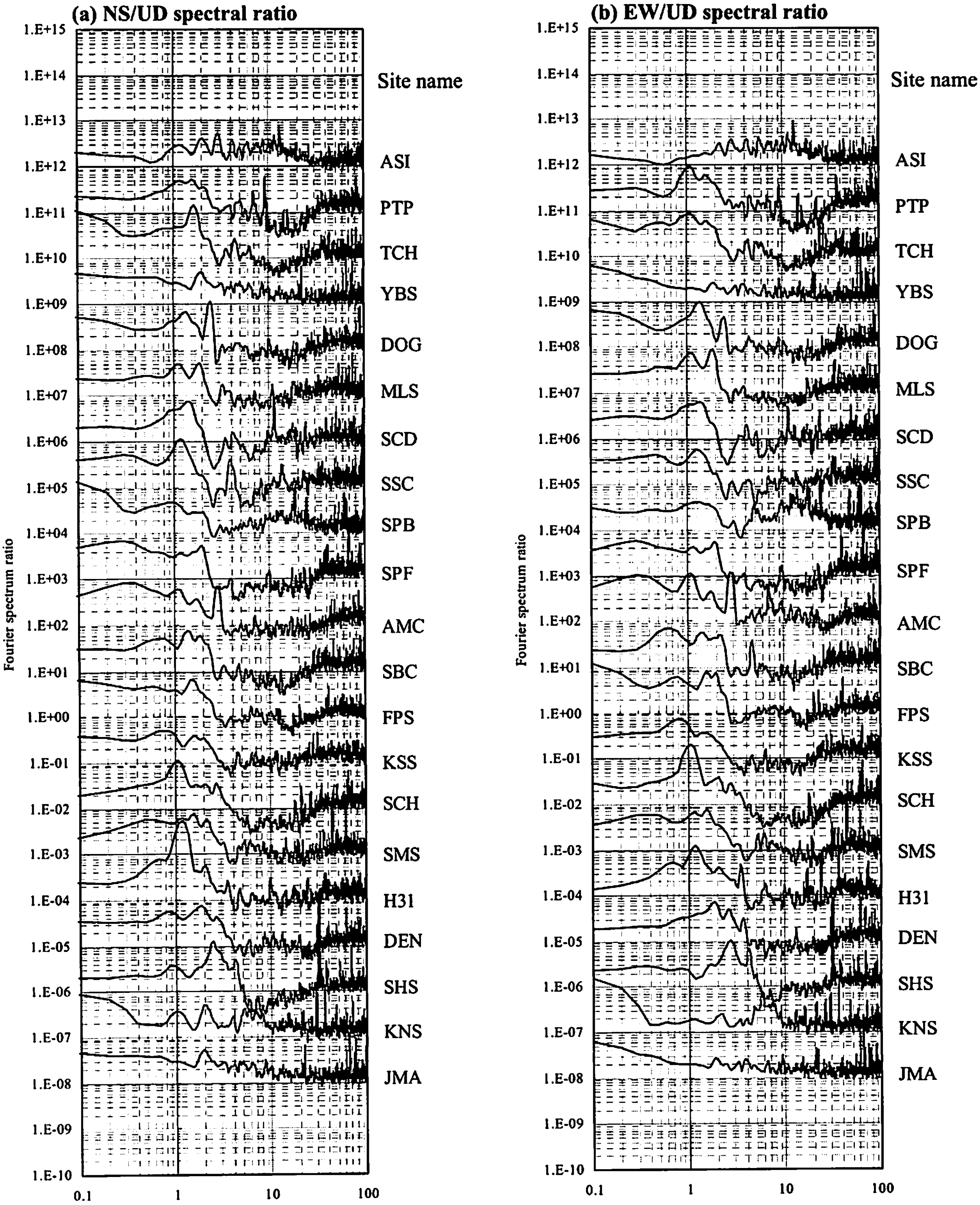



Fig.10 Fourier spectral ratio of microtremor measurement points along the Sumoto plain; (a) NS/UD spectral ratio; (b) EW/UD spectral ratio

toward the north-south (NS) and east-west (EW) of the specifice 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. 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 driff 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. The 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

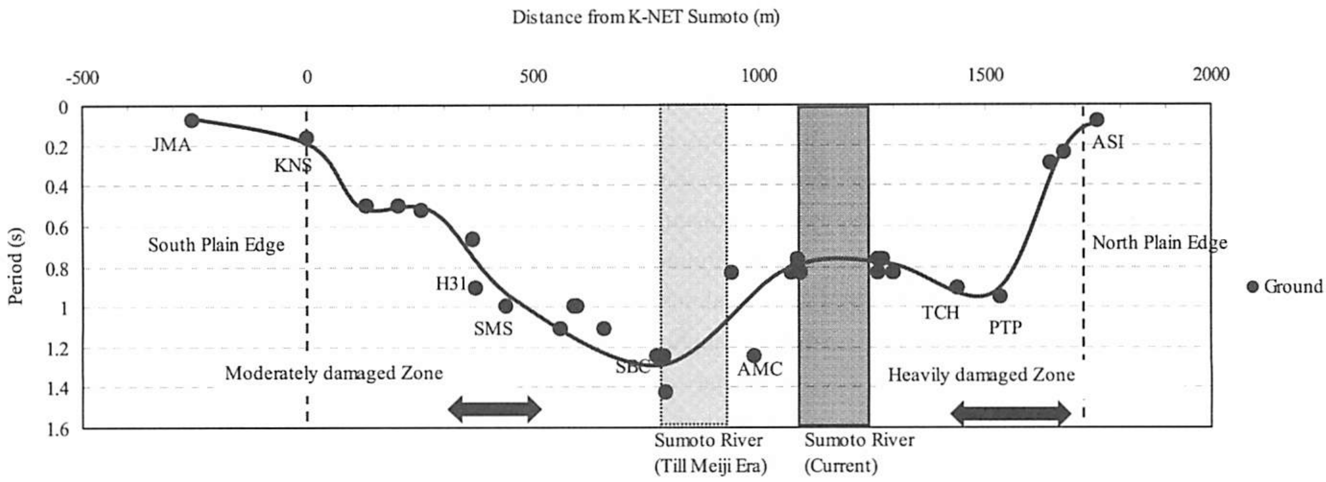



Fig.11 Distribution of predominant period at North-South profile of Sumoto plain.

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, the 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.

### 3.3 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 damages caused by 2013 Awaji Island Earthquake were 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 damges 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 damages 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 damages in northern part of Sumoto plain.

## 5. Acknowledgement

The authors would like to thank the Sumoto City Office and its staffs for providing various information and their assistance during our investigation.

## 6. References

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