Investigation Report on Earthquake near Awajishima on April 13, 2013

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Key Facts

- Hazard Type: Earthquake
- Date of the disaster: April 13, 2013
- Location of the survey (Lat. Lon., name or address): Awajishima-Island, Japan
- Date of the field survey (if any): April 13 – April 23, 2013
- Survey tools (if any): Portable GPS receivers
- Key findings
  1) Strong motions on rocks were successfully recorded at both Naruto and Awaji sides of Onaruto-Bridge, a 1629m long suspension bridge across the Naruto Strait. There was about half a second time delay recognized in the record at Naruto side about 2km southwest of Awaji site.
  2) Although the observed peak ground acceleration of about 600 gal was reached near the epicenter, overall damage to structures was insignificant.
  3) Comparing velocity response spectra of both April 13th earthquake and the Hyogoken-Nanbu earthquake of 1995, it was found that long-period components of the Hyogoken-Nanbu earthquake surpassed those of the April 13th earthquake indicating that the April 13th earthquake was less significant than the overwhelming Hyogoken-Nanbu earthquake.
  4) Damaged structures were confined at some locations such as reclaimed lands and estuary regions on alluvial soil deposits developed along rivers.

Key Words : *Earthquake near Awajishima, strong ground motion, damage to houses, soil liquefaction*

1. INTRODUCTION

An earthquake of Magnitude 6.3 on the JMA scale (M_w=5.8) occurred on April 13, 2013, at 5:33 JST with its epicenter near Awajishima Island, which is located to the south of Kobe city as shown in **Fig 1**. Large values of seismic intensity 6 minus on the JMA (Japan Meteorological Association) scale, which varies from 0 to 7 with 7 being the strongest, were reached at two stations (Gunge and Shizuki in Awaji-city, shown by blue donut)[1)]. It is worh mentioning that the epicenter of this earthquake was just south of the 1995 Hyogoken-Nanbu earthquake (M=7.3 on JMA scale) that caused serious devastation to this area.

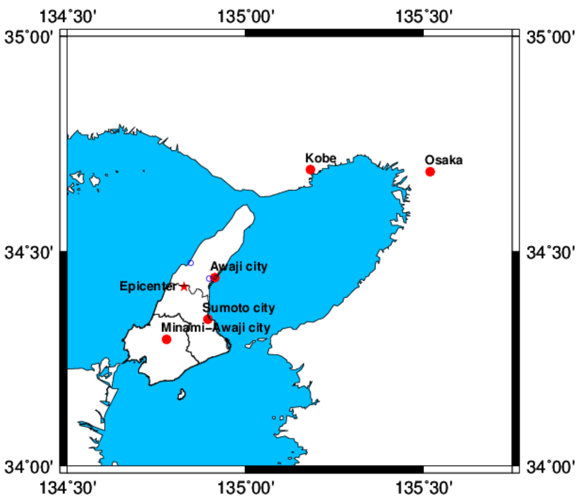


Fig.1 Location of Awajishima-Island

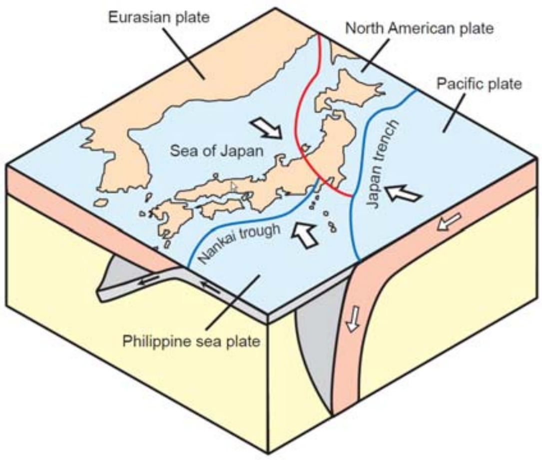


Fig.2 Tectonic setting of Japan

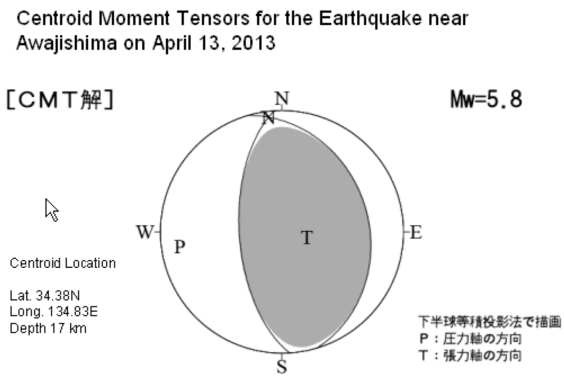


Fig.3 Focal Mechanism of Earthquake near Awajishima on April 13, 2013 (The Headquarters for Earthquake Research Promotion, 2013) http://www.jishin.go.jp/main/chousa/13apr_awaji/p04.htm

Awajishima-Island consists of 3 cities of similar size; Awaji-city (184.28km^2, population=47,095), Sumoto-city (182.48km^2, population=47,320), and Minamiawaji-city (229.23km^2, population=50,545 as of May 31). Fortunately there were no faitalities in the affected areas, but 34 people were reportedly injured. Major damage to a total of 6 houses and minor damage to approximately 8,000 houses were reported (Fire and Disaster Management Agency, FDMA)[2].

According to JMA, the hypocenter was at 34.4183N, 134.8283E and 15 km deep[1]. This location is almost on a close extension of the rupture trace of the Nojima-Fault that appeared in the 1995 Hyogoken-Nanbu earthquake. However, the Headquaters for Earthquake Research Promotion (HERP)[3] has concluded it not to be an extension of the Nojima Fault but an unidentified fault.

This report outlines findings obtained through a quick survey carried out by the authors. Though some of the descriptions in this report require further validations yet, the authors have put them herein as a basis for further discussion among readers. Chapter 2 describes the geologic and tectonic setting. Chapter 3 shows strong ground motions of the main shock recorded by a digital instrument array previously installed on the island. In Chapter 4, local site effects are inferred from the observed failure patterns, and Chapter 5 summarizes all our findings.

2. GEOLOGICAL AND TECTONIC SETTING

(1) Geological and techtonic setting

The Japan consists of the Northeast Japan arc and the Southwest Japan arc as shown in **Fig.2**. The island affected by the earthquake of April 13, 2013 is located within the Southwest Japan arcs. The Southwest arc was formed as a result of the Philipine plate subduction beneath the continental plate (Eurasia plate).

Bedrock of the island is comprised of granite of the Cretaceus period (north central region) and marine sedimentary rock composed of sandstone, mudstone and conglomerate of the Cretaceus period (southen region). The area straddling Naruto straits, which will be shown later, spreads over the latter formation.

(2) Fault setting

Fig. 3 shows the moment tensor solution of April 13, 2013 earthquake on the so-called beachball diagram. This figure shows that the event was of a re-

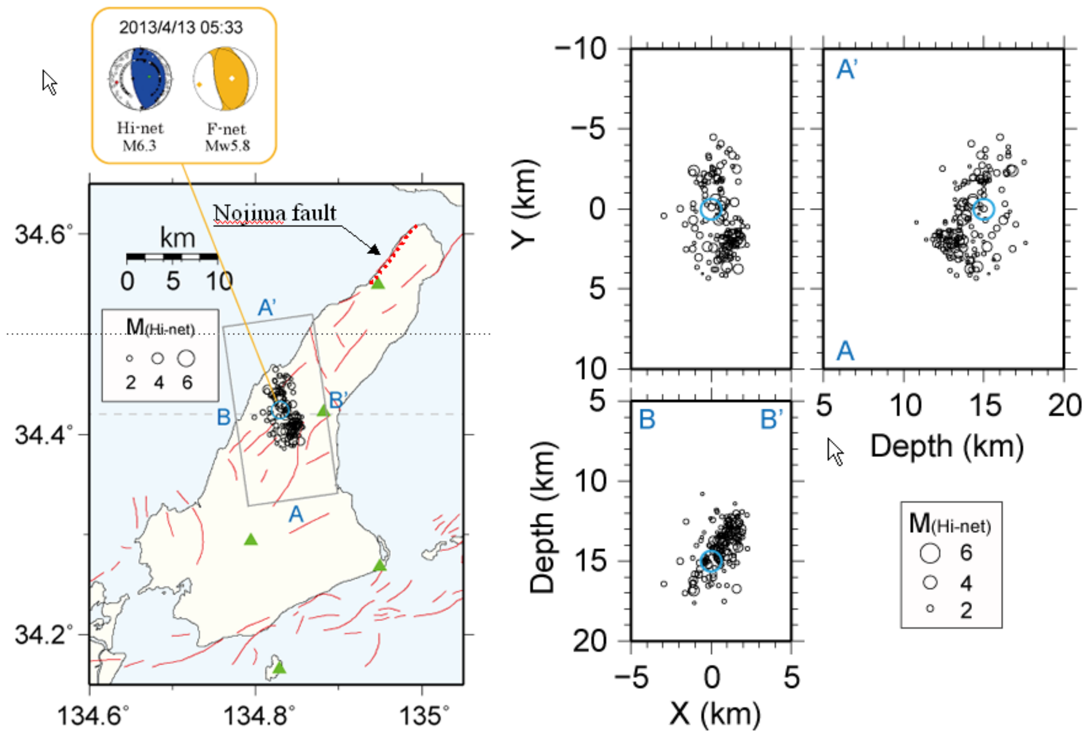


Fig.4 Source distribution
(National Research Institute for Earth Science and Disaster Prevention, 2013)
http://www.hinet.bosai.go.jp/topics/awaji130413/

verse fault type with its compression axis trending in the E-W direction, and the event occurred within the crust (HERP)[3].

(3) Main shock and aftershocks

Spatial distribution of the main shock and its aftershocks provided by NIED is shown in **Fig.4**. The location of the main shock was 34.4183N, 134.8283 and 15 km deep. The source faults, as inferred from the aftershock distribution and the focal mechanism, was a reverse fault striking in the NNW-SSE direction and dipping to the west, according to HERP[3]. The strike and dip angles are evaluated by JMA to be 175 and 60 degrees, respectively[4].

(4) Relation to Nojima fault and other nearby faults

Also shown in **Fig.4** near the northern end the Awaji island is about a 10km long stretch of the Nojima-Fault. JMA has announced its negative judgment on the cause-and-effect link between these earthquakes.

There are some other faults with similar strikes clustered together near the fault activated on April 13. They include Shizuki and Ikuha faults. However, they dip to the east, while the fault of the April 13 earthquake dips to the west.

3. SEISMOGRAPHS

Ground motions were successfully captured by seismometer arrays of various organizations. Locations and peak ground accelerations are summarized in **Fig.5** and **Table 1**.

(1) K-NET, KiK-net, JMA recordings

There are four K-NET observtion sites and one KiK-net site on the island operated by the National Research Institute for Earth Science and Disaster Prevention (NIED). Also there are four observation sites operated by JMA. Locations and peak ground accelerations (resultant values of X,Y,Z components) are shown in **Table 1**.

(2) Ground motions observed at Onaruto bridge site

In addtion to the NIED and JMA sites, the authors have successfully obtained records of the main shock at tips of rock capes on both sides of Onaruto Bridge .

The Onaruto Bridge is a suspension bridge connecting Awajishima island and Shikoku across the Naruto Straits. Its center span and the total length are 876 meters and 1629 meters, respectively. Construction of the bridge began in 1976 and was completed in 1985 according to the report by Hon-

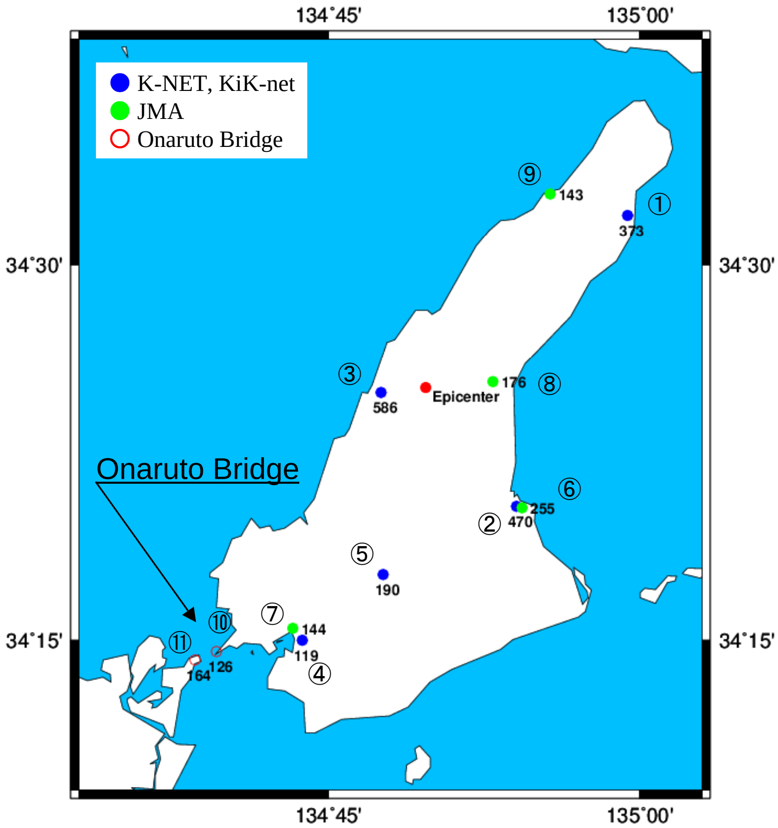


Fig.5 Strong-Motion observation network in Awajishima

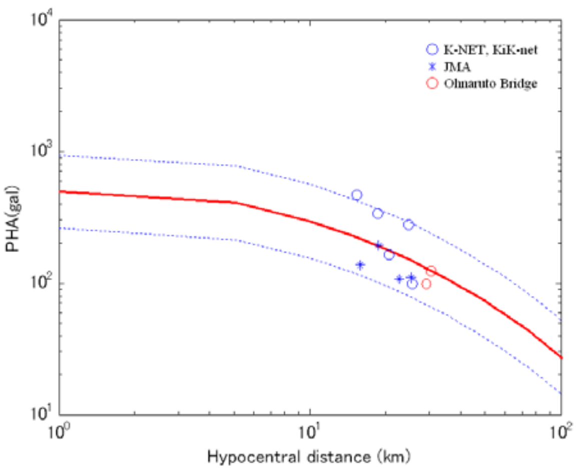


Fig.6 Plot of observed peak ground acceleration

shu-Shikoku Bridge Authority[5].

Tokushima Prefecture started seismic observation at Naruto Straits from 1963 before the bridge was constructed until when the observation system was transferred to the Institute of Industrial Science (IIS), University of Tokyo in 1973. The IIS had been conducting observations since then with the objective of clarifying features of outcrop input motions to the bridge[6]. In 2003, the equipments for the observation system were replaced with new sets of servo-type accelerometers (Tokyo Sokushin, SV-355T) and data loggers equippted with microprocessors, internal memories for data storage and GPS internal receivers (Tokyo Sokushin, SAMTAC-500). The catalog describing specifications of the renewed system ensures the time measuring error within 1/200 seconds. Since April, 2013, the seismic observation system was transferred to the University of Tokushima.

(3) Attenuation relationship

Fig. 6 shows a double logarithmic plot of observed peak ground accelerations (PGAs) with increasing distance from the seismic source together with the empirical attenuation model developed by Fukushima and Tanaka[7), 8)]. The thick red line shows the mean values of the model while the broken lines show the fluctuation extent of standard deviation (+-1 sigma). The PGAs of recorded motions of the April 13 earthquake fall within the +- 1 sigma range of fluctuation. Note that averaged value of two horizontal acceleration peaks was used in the Fukushima and Tanaka's model. Both Onaruto Bridge sites (two sites) rest on rocks, hence, the attenuation relationship should be modified by a factor of 0.6 as suggested by Fukushima and Tanaka (The plots here are as they were observed.).

Table 1 Summary of Strong Motion Stations

	Category	Site Code City Name	Site Name	Latitude	Longitude	Eleva-tion	PGA** (gal)	Seismic Inten-sity	Epicen-tral Dist.(km)
①	K-NET	HYG024	Higa-shiura	34.5330	134.9904	2.0	373.2	5.3	23
②	K-NET	HYG025	Sumoto	34.3405	134.9014*	10.0	470.3	4.8	11
③	K-NET	HYG026	Goshiki	34.4149	134.7925	70.0	586.1	4.8	2
④	K-NET	HYG027	Nandan	34.2499	134.7292	115.0	119.1	3.8	18
⑤	KiK-net	HYGH01	Mihara	34.2937	134.7941	65	190.0	4.8	12
⑥	JMA	Sumoto	Orodani	34.3383	134.9055	-	254.6	4.8	12.3
⑦	JMA	Minami-Awaji	Fukura	34.2579	134.7217	-	143.9	4.7	17.6
⑧	JMA	Awaji	Nakada	34.4223	134.8822	-	176.2	4.5	8.1
⑨	JMA	Awaji	Toshima	34.5472	134.9281	-	142.6	4.5	20.0
⑩	Tokushima Univ.	Onaruto Bridge	Awaji side	34.2424	134.6604	-	126.0	-	-
⑪	Tokushima Univ.	Onaruto Bridge	Naruto side	34.2367	134.6430	-	163.7	-	-

* Location of K-NET Sumoto is 34.3391N, 134.9010E based on authors' GPS positioning device.

** Resultant values of X,Y,Z components

(4) Ground motions as input to the long suspension bridge

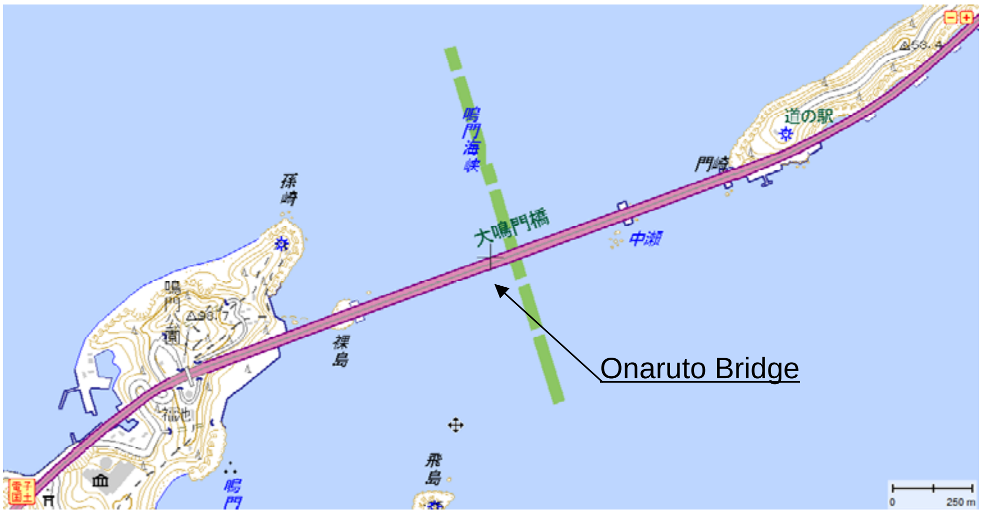
As the seismometers on the Onaruto bridge sites were installed on rock outcrops only 50 to 100 m away from the bridge abutments on Awaji and Naruto sides of the strait as shown in **Fig.7**, the obtained seismometer records (**Figs 8(a)** and **8(b)**) are considered to clearly reflect the basic features of the input ground motions to the bridge abutments. Given GPS signals as a very accurate time reference for both the seismometers, it is noted the that record on Awaji side started about half a second earlier than that on Naruto side indicating that the primary wave took about half a second to cross the 2 km wide Naruto Strait.

Fig.9(a) and 9(b) show power spectra of the records on the Awaji and Naruto sides, respectively. Blue and red lines in this figure show respectively the original and smoothed power spectra with a smoothing window (0.4Hz Parzen window). It is noted that the Naruto side has some remarkable peaks over the frequency range of 5 to 8 Hz while the other peaks for both sides do not exhibit any marked difference.

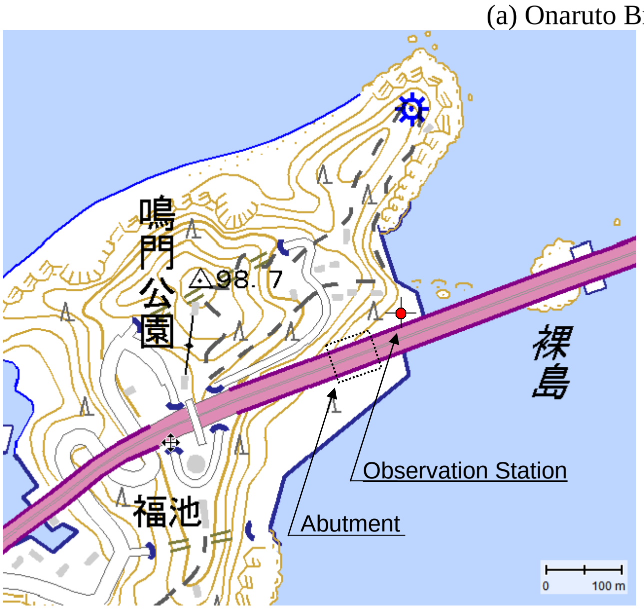
Fig.10(a) shows displacement time histories in the direction of bridge axis obtained by double-integrating the corresponding accelerograms. Though displacements of both sides of strait are almost in-phase over the 10 to 25 seconds duration of time, there is a short delay recognized in the displacement response on the Naruto side as shown in **Fig.10(b)**. This fact is consistent with the delay in the arrival time shown in **Fig.8**. A frequency domain analysis for dispersive nature of the observed waves will be necessary.

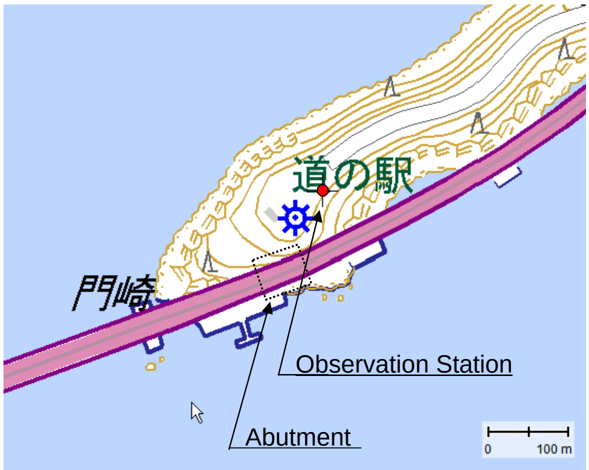
(5) Comparison of velocity response spectrum

Fig.11 compares velocity response spectra observed from this earthquake and those from the 1995 Hyogoken-Nanbu Earthquake (JR Takatori). PGA observed at K-NET Goshiki during this earthquake and the one observed at JR Takatori during the 1995 Hyogoken-Nanbu Earthquake are nearly the same. However, long-period components of JR Takatori record surpass those of the April 13 earthquake suggesting the overwhelmingly destructive power of the Hyogo-ken Nanbu Earthquake.



(a) Onaruto Bridge Site





(b) Naruto Side (c) Awaji Side

Fig.7 Observation station at the Onaruto Bridge site
(Topographical maps issued by the Geospatial Information Authority of Japan (GSI) were used.)

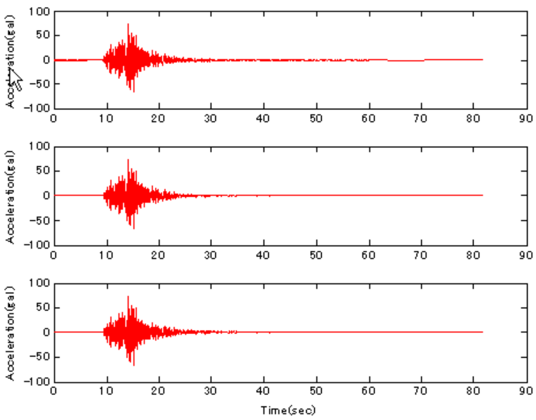
4. DAMAGE TO STRUCTURES

(1) Damage to houses

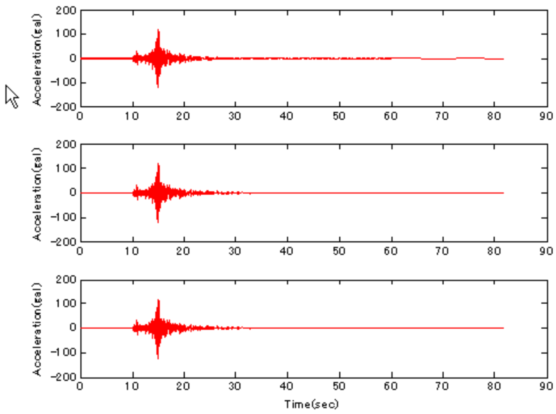
The extent of damage to houses appeared to be more srious in estuary regions and/or reclaimed lands along the eastern coast of the island rather than the west coast where alluvial plains are less developed. According to a press release by Hyogo prefecture on May 13[9], 8 houses were completely destroyed (5 in Sumoto, 2 in Minami Awaji, and 1 in Awaji) and 72 houses were partially destroyed (45 in Sumoto, 26 in Awaji, and 1 in Minami Awaji).

One of the common and typical features of damage to Japanese traditional houses was that roof tiles arranged over fine mud were shaken off in the intense shake. In Sumoto city, damage to houses was concentrated in the Takenokuchi area which spreads over an alluvial soil deposit of the estuary delta of Sumoto river (**Fig.12, Photo.1**). No clear trace of liquefaction was found by the first author during his first survey. In a nearby cemetery of a Buddist temple, approximately 150 tombstones toppled over in the earthquake, according to the chief priest of the temple. The total number of the tombstones in this cemetery is roughly estimated to be about 500.

Moderate liquefaction traces were found at some areas on a reclaimed land in Awaji city (**Fig.13**). **Photo.2** shows one of the liquefied sites (Tsuna seaside sports park). Different features of damage to houses from those of Takenokuchi area were observed in a residential area near the park (**Photo.3**). There were liquefied soils from place to place. Ac-

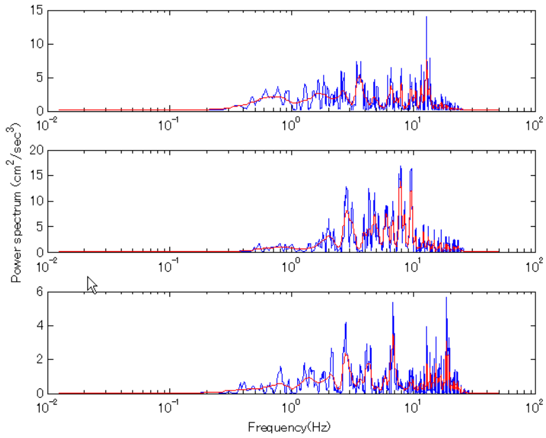


(a) Awaji side

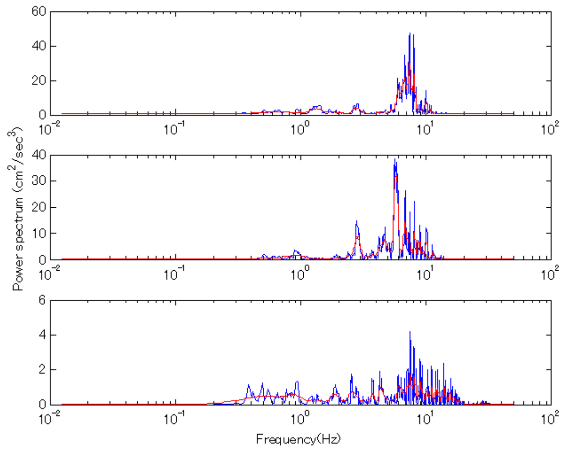


(b) Naruto side

Fig.8 Obtained seismometer records at Onaruto Bridge site



(a) Awaji side



(b) Naruto side

Fig.9 Power spectra obtained at Onaruto Bridge site

cording to a person who was clearing sand-covered roads, his house has slightly-tilted in the earthquake. No roof tile seems to have been damaged in this area probably because the liquefied subsoil reduced ground acceleration remarkably.

(2) Damage to bridges

Only Suhama Bridge, the lowermost cable-stayed bridge across Sumoto River, suffered some marked damage to its abutments (**Photo.4**). Both abutments were cracked probably due to collision(s) with the bridge girders. Permanent deformation of its rubber bearing remained on the south side of the river (**Photo.4**). More details can be found in the report by Mori[10].

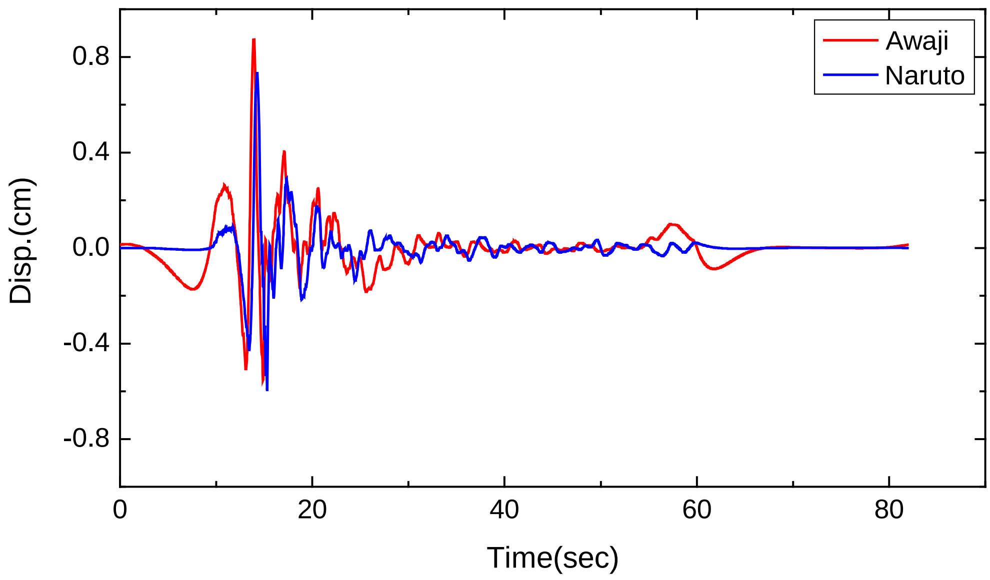
(3) Damage to port facilities

Most significant failures of port and harbor facilities were reported at Ikuho fishing port of Awaji city (**Photo.5**). Quay walls have thrusted forward by approximately 20 - 30 cm. Ground fissures appeared about 10 m inland parallel to the coast line. No clear trace of liquefaction was seen when the authors visited the site.

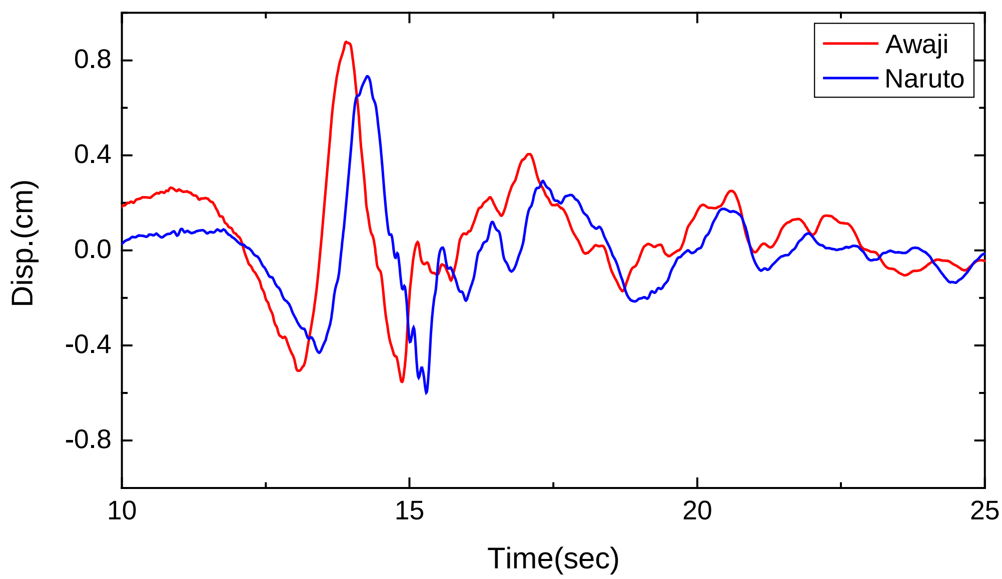
5. SUMMARY

An intense earthquake occurred near Awajishima-island on April 13, 2013. The source area of this earthquake was on the southwest extension of the Nojima-fault that caused devastating damage to this area in 1995. This report outlined the findings through the quick survey. Results and findings obtained through the survey are as follows :

(1) Strong motions on rocks were successfully recorded at both Naruto and Awaji sides of Onaruto-Bridge, a 1629m long suspension bridge across the Naruto Strait. There was about half a second time delay recognized in the record at Naruto side about 2km southwest of Awaji site.
(2) Although the observed peak ground acceleration of about 600 gal was reached near the epicenter, overall damage to structures was insignificant.



(a) Full length of time histories



(b) Time histories from 10 to 25 seconds

Fig.10 Displacement time histories in the direction of Onaruto Bridge axis

(3) Comparing velocity response spectra of both April 13th earthquake and the Hyogoken-Nanbu earthquake of 1995, it was found that long-period components of the Hyogoken-Nanbu earthquake surpassed those of the April 13 earthquake indicating that the April 13th Earthquake was less significant than the overwhelming Hyogo-ken Nanbu Earthquake.
(4) Damaged structures were found confined at some locations such as reclaimed lands and estuary regions on alluvial soil deposits developed along rivers.

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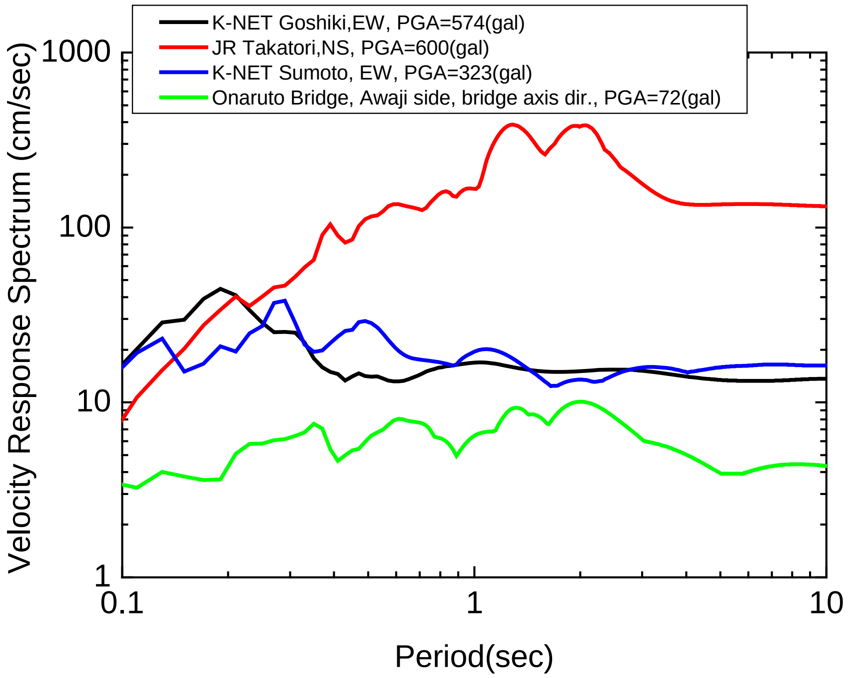

Fig.11 Comparison of velocity response spectra obtained from this earthquake and 1995 Hyogoken-Nanbu earthquake

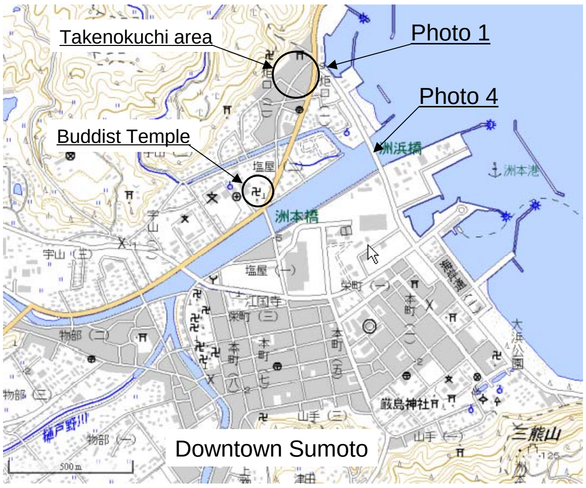

Fig.12 Investigated area in Sumoto City
(Topographical map issued by GSI was used.)

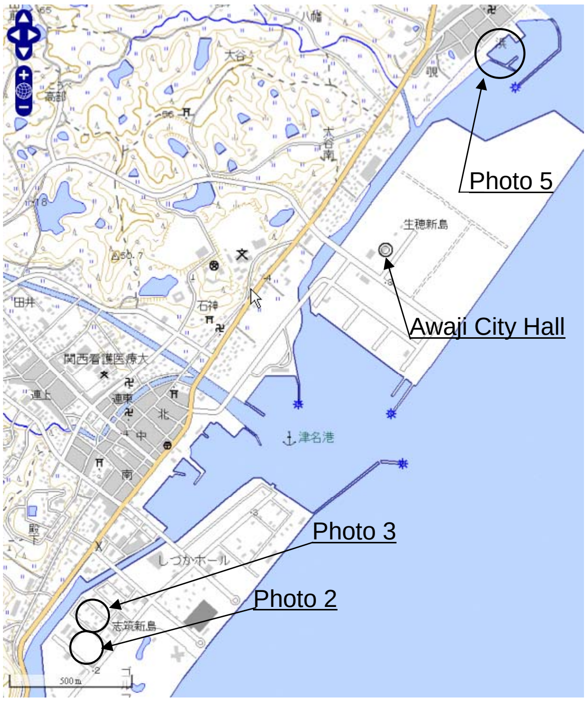

Fig.13 Investigated area in Awaji City
(Topographical map issued by GSI was used.)

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(a) N34.351105, E 134.891905, April 16, 2013

(b) N34.352003, E 134.892645, April 16, 2013

Photo 1 Damage to houses in Takenokuchi area, Sumoto city

Photo 2 Liquefaction seen at Tsuna seaside sports park (N34.424707, E134.900878, April 14, 2013)

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Photo 3 Liquefied residential area

(N34.425987, E134.901113, April 14, 2013)

Photo 4 Damage to Suhama Bridge

(N34.347940, E134.896113, April 23, 2013)

Photo 5 Damage to Ikuho fishing port in Awaji city (N34.446263, E134.918498)