Borehole Strong Motion Observation along the Itoigawa-Shizuoka Tectonic Line

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SUMMARY:
We have carried out borehole strong motion observation along the Itoigawa-Shizuoka Tectonic Line since late 2005 to understand ground motion characteristics along the tectonic line and in the neighboring basin. Two sites were selected in Matsumoto, one is the Kanda station near the Gofukuji fault, and the other is the Shimadachi station located in the Matsumoto basin. The borehole depths are 100 and 200 m for the Kanada and Shimadachi stations, respectively. We performed velocity measurements of the boreholes and confirmed that both the boreholes reached the geological rock with V_s = 1,000 m/s. Acceleration seismometers were installed at the ground surface and borehole depth. The information of the velocity measurements, reflection profiling, and geomagnetic profiling were used for integration of the velocity structure model in the Matsumoto basin, where the seismic basement inclines from west to east. The stations succeeded to record the 2007 Noto Hanto, 2007 Chuetsu-oki, 2009 Suruga-bay, 2011 Tohoku earthquakes. The records are released on the website: http://smsd.eri.u-tokyo.ac.jp/smad/.

Keywords: Strong motion observation, borehole observation, temporary observation, Itoigawa-Shizuoka Tectonic Line, Matsumoto

1. INTRODUCTION

The Itoigawa-Shizuoka Tectonic Line is one of the fault zones with large earthquake potential in Japan. The Headquarters for Earthquake Research Promotion evaluated a M8-class earthquake potential of 14% for the central part of the Itoigawa-Shizuoka Tectonic Line with the Gofukuji fault in the next 30 years (e.g., Earthquake Research Committee, 2002). The Gofukuji fault in Matsumoto is considered to be a master fault of the Itoigawa-Shizuoka Tectonic Line. Ikeda *et al*. (2004) pointed out slip partitioning between the Gofukuji fault with strike-slip components and the Matsumoto east boundary fault with east-dipping reverse faulting beneath the Gofukuji fault. Matsumoto city is located above the complex tectonic setting, and it is important to observe geophysical signals. Based on the long-term evaluation of the earthquake potential for the Itoigawa-Shizuoka Tectonic Line, several ground motion predictions have been performed. Earthquake Research Committee (2009) assumed an earthquake scenario for the northern and central parts of the tectonic line with M_w 7.4. Ishise *et al*. (2009) proposed four earthquake scenarios for the northern, central, and southern parts of the tectonic line ranging M_w 7.1 to 7.7. For most cases, the cities of Matsumoto and Suwa are suffered from strong ground motions.

After the 1995 Kobe earthquake, in addition to the strong motion network by the Japan Meteorological Agency, nationwide strong motion networks such as K-NET and KiK-net have been equipped, and waveform data are open to the public (e.g., Kinoshita, 1998; Aoi *et al*., 2000). Also each local government installed seismic intensity sensors, and some of them provide waveform data (e.g., SK-net; Takano *et al.*, 2002). Nagano prefecture joined SK-net, and those seismic intensity records are used for research (e.g., Izutani and Kaneko, 2002). When we consider seismic hazard assessment for forthcoming earthquakes along the Itoigawa-Shizuoka Tectonic Line, focused strong motion stations are required near the Gofukuji fault and in the Matsumoto basin. In this paper, we describe two

borehole strong motion stations installed in 2005 and five temporary strong motion stations for 2011-2012 in Matsumoto.

2. BOREHOLE STRONG MOTION OBSERVATION

Borehole strong motion observations in small-to-moderate sized basins have succeeded for understanding site effects (e.g., Kudo *et al*., 1988). We have started borehole strong motion observation along the Itoigawa-Shizuoka Tectonic Line since late 2005 to understand ground motion characteristics along the tectonic line and in the neighboring basin. Two sites were selected in Matsumoto, one is the Kanda station near the Gofukuji fault, and the other is the Shimadachi station located in the Matsumoto basin (Table 1 and Figure 1). The borehole depths of the stations are 100 and 200 m for the Kanada and Shimadachi stations, respectively. Acceleration seismometers were installed at both the ground surface and borehole depth. Those are composed of SMAC-MDU and JEP-4B3. Foundations of the seismometers were constructed following Sakaue and Takahashi (1997). We performed velocity measurements of the boreholes by the downhole and suspension methods as shown in Figure 2. Both the boreholes reached the geological rock with V_s = 1,000 m/s. The information of the velocity measurements, reflection profiling, and geomagnetic profiling were used for integration of the velocity structure model in the Matsumoto basin. The stations succeeded to record the 2007 Noto Hanto, 2007 Chuetsu-oki, 2009 Suruga-bay, 2011 Tohoku earthquakes (Figure 3).

2.1. KND: Kanda Station

KND is located near the reflection profile of Line-II in Ikeda *et al*. (2004). This station is selected to be near the Gofukuji fault and above the Matsumoto east boundary fault. The borehole depth is 100 m, and reached the mudstone at a depth of 73 m. The velocity profiles in Figure 2 show the similarity of *P*- and *S*-wave speeds between KND and NGNH32.

2.2. SMD: Shimadachi Station

SMD is located near the reflection profile of Line-I in Ikeda *et al*. (2004). Because there were no strong motion stations in the central part of the Matsumoto basin, this station is expected to be a unique station to measure the basin response. To reach the geological rock, we decided the borehole depth of 200 m. From the logging data, the borehole reached the sandstone at a depth of 175 m. *P*- and *S*-wave speeds were available up to 178 m.

Table 1. Locations of Borehole Strong Motion Stations

Station code	Latitude (deg)	Longitude (deg)	Altitude (m)	Observation period
KND (Kanda)	36.216 N	137.988 E	600	Dec 2005 – present
SMD (Shimadachi)	36.221 N	137.941 E	592	Dec 2005 – present

Figure 1. KND (left) and SMD (right) borehole strong motion stations.

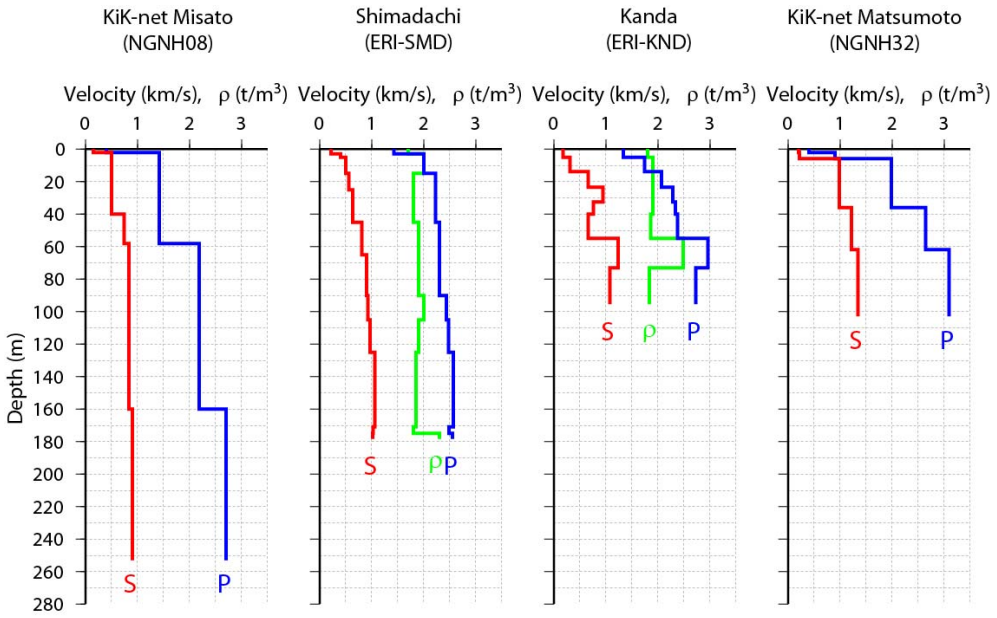

Figure 2. Velocity profiles for the KiK-net Misato (NGNH08), SMD, KND, and KiK-net Matsumoto (NGN012) strong motion stations from west to east in the Matsumoto basin.

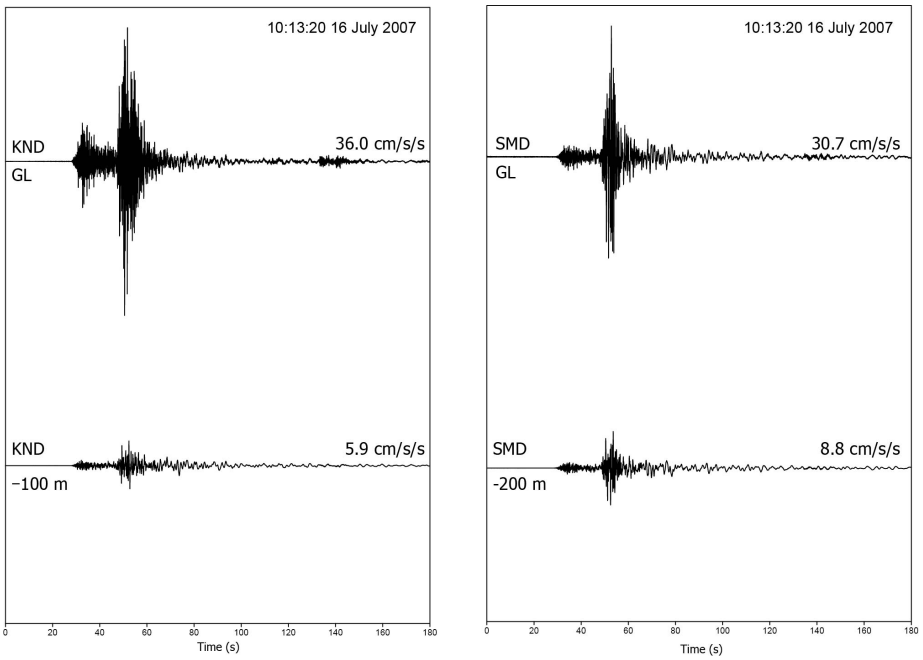

Figure 3. Observed waveforms at KND and SMD for the 2007 Chuetsu-oki earthquake.

2.3. Seismic Basement in the Matsumoto Basin

There are two seismic profiles in the Matsumoto basin. One is Ikeda *et al.* (2004) using *P*-wave refraction surveys to focus on the Gofukji and Matsumoto east boundary faults. The other is Koketsu *et al.* (2007) using *P*- and *S*-waves refraction surveys to focus on the western part of the Matsumoto basin. From the surveys, east-declined basin shape was clearly identified. This declination was also confirmed by microtremor array exploration and seismic interferometry by Yamanaka and Uchiyama (2008). As shown in Figure 4, KND (= KIS) is located near the complex structure of the Gofukuji and Matsumoto east boundary faults. SMD is located in the central part of the Matsumoto basin, and the depth of the seismic basement beneath the station is around 1,000 m.

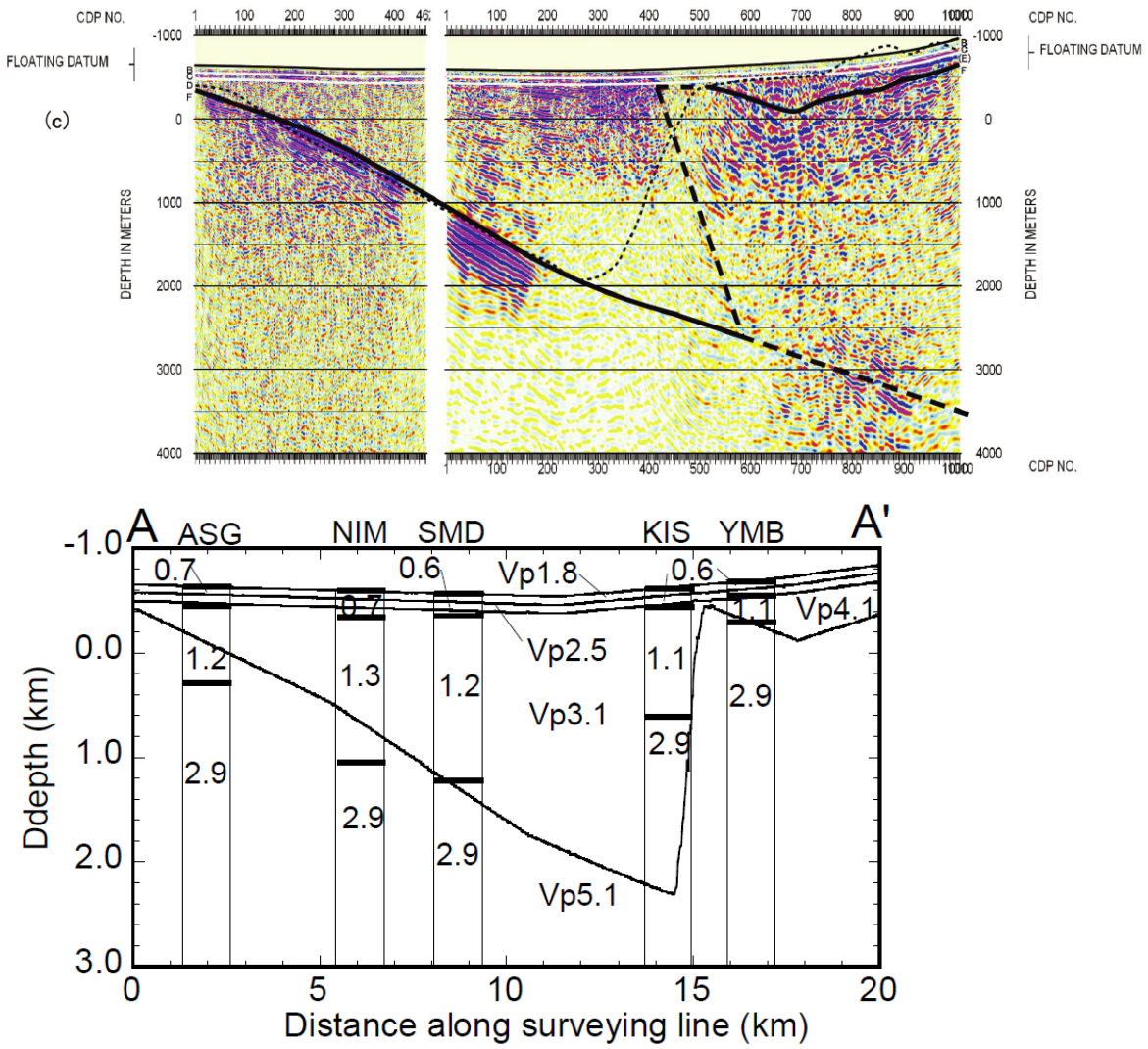

Figure 4. Upper: Seismic profiling in the Matsumoto basin (Ikeda *et al*., 2004; Koketsu *et al*., 2007). Lower: Estimation of *S*-wave velocity profiles in the Matsumoto basin from microtremor array exploration and seismic interferometry (Yamanaka and Uchiyama, 2008). KIS means KND.

3. TEMPORARY STRONG MOTION OBSERVATION

Since 29 June 2011, earthquake swarm following the 2011 Tohoku earthquake had occurred in Matsumoto. A few M5-class earthquakes and significant aftershocks were recorded. At 8:16 on 30 June 2011, a strike-slip event of M_{JMA} 5.4 with a focal depth of 4 km occurred around 3 km west of the Gofukuji fault. The peak ground accelerations at SMD were 552 and 365 cm/s^2 at the ground surface and borehole depth, respectively. Those at KND were 300 and 99 cm/s^2. Because of large variations of the seismic damage in Matsumoto, we installed five temporary strong motion stations as shown in Table 2 and Figure 5 near SMD and KND for microzonation of the seismic hazard assessment. The acceleration sensors were the same type of K-NET95 (Kinoshita, 1998). The locations of the earthquake swarm triggering the strong motion stations were categorized into near SMD and near the Gofukuji fault. Due to the shallow focal depths, we recorded strong motion records with various incident angles. Some records provided peak ground accelerations by *P*-wave vertical motions. Especially, reflection/reflaction waves were observed at SMD. Further investigation is required to understand the relation of the records and the velocity structure model in the Matsumoto basin, where the seismic basement inclines from west to east (e.g., Koketsu *et al*., 2007, 2008, 2012; Yamanaka and Uchiyama, 2008). The records are summarized in Table 3. Relative large site amplifications were found at the KND, KMT, NYG, and Matsumoto city (Marunouchi) stations.

Table 2. Locations of Temporal Strong Motion Stations

Station code	Latitude (deg)	Longitude (deg)	Observation period
YSK (Yoshikawa)	36.187 N	137.956 E	4 July 2011 – 25 Apr 2012
NYG (Namiyanagi)	36.207 N	137.980 E	5 July 2011 – 24 Apr 2012
KMT (Kamata)	36.223 N	137.961 E	5 July 2011 – 25 Apr 2012
SBZ (Shibazawa)	36.211 N	137.916 E	6 July 2011 – 25 Apr 2012
SMU (Shimauchi)	36.249 N	137.941 E	6 July 2011 – 25 Apr 2012

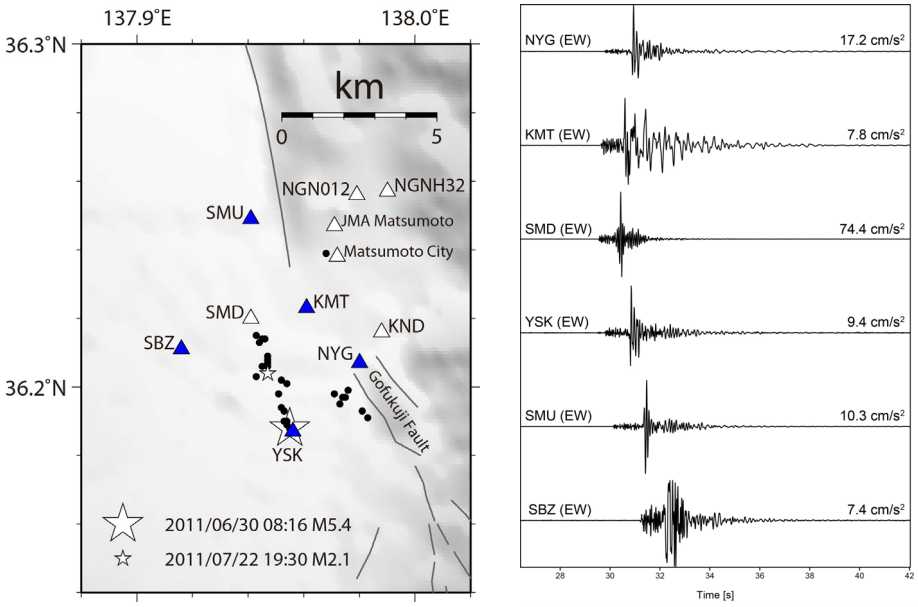

Figure 5. Left: Station map and earthquake swarm triggering the strong motion stations. The blue and white triangles show the temporary and permanent strong motion observations, respectively. Right: Accelerations recorded for the earthquake with M_{JMA} 2.1 at 19:30 22 on July 2011.

Table 3. Triggered Earthquake Lists with the JMA Seismic Intensities (Japanese Version is Available at the Website of the Matsumoto City Office:http://www.city.matsumoto.nagano.jp/kurasi/bosai/saigai/shindokei.html)

Event	KND	SMD	YSK	KMT	NYG	SMU	SBZ	Matsumoto City	JMA Matsumoto	K-NET NGN012
19:32 29 Jun M3.4	3	4						3	2	2
20:04 29 Jun M2.8	3	3						3	2	1
20:58 29 Jun M2.3	2	3						2	1	1
04:45 30 Jun M2.4	2	2						2	1	1
08:16 30 Jun M5.4	5+	5+						5+	5-	4
08:21 30 Jun M5.1	5-	5-						4	4	4
08:30 30 Jun M2.5	2	3						2	1	1
08:45 30 Jun M2.1	2	2						1		
09:20 30 Jun M2.4	3	2						2	1	1
13:53 30 Jun M3.1	3	4						3	2	2
14:11 30 Jun M3.4	4	3						4	3	3
07:28 02 Jul M3.9	4	3						3	3	3
11:52 02 Jul M2.3	2	2						2	1	1
06:23 05 Jul M2.6	3	2	2					2	1	1
14:38 15 Jul M2.7	3	2	2	3	2	1		2	1	1
19:30 22 Jul M2.1		2	1	2	1	1	2	1		
23:58 01 Aug M6.2*	3	3	3	4	4	3	3	4	3	3
18:06 05 Aug M2.2		2	1	2	2	1	2	1		
19:01 01 Sep M2.4			1	2	2			1		
18:59 05 Oct M5.4*				2	2			2	1	1
19:06 05 Oct M5.2*	2	1		2	2	1		2	1	1
19:37 06 Oct M4.7*				2						
07:53 19 Nov M2.9	2			2		1		1	1	1
22:23 01 Dec M4.6*				2				1	1	1
13:23 06 Dec M3.1	2	1	1	2	2	1		1		1
13:01 14 Dec M5.1*	2	2		2	3			2		1
07:39 28 Jan M4.9*	1			2	2			1		
07:43 28 Jan M5.4*	2			2	2			1		1

4. CONCLUSIONS

We have performed borehole strong motion observation along the Itoigawa-Shizuoka Tectonic Line since late 2005. The stations succeeded to record the 2007 Noto Hanto, 2007 Chuetsu-oki, 2009 Suruga-bay, 2011 Tohoku earthquakes, and the records are released on the website: http://smsd.eri.u-tokyo.ac.jp/smad/. Due to the earthquake swarm following the 2011 Tohoku earthquake, we installed temporary strong motion stations in Matsumoto from July 2011 to April 2012. Variations of the site effects were estimated using both nearby (no mark in Table 3) and far away (with asterisks in Table 3) earthquake records. Strong ground motions reported in the damaging area near YSK during the earthquake swarm are considered to be responsible for the source effect rather than the site effect.

AKCNOWLEDGEMENT

We are greatly indebted to K-NET, KiK-net, and SK-net for the strong ground motion data and JMA for the earthquake catalog. We thank the Matsumoto city office for their cooperation. This study was partly supported by the Integrated Research Project for Active Fault System along the Itoigawa-Shizuoka Tectonic Line.

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