EVALUATION OF SURFACE LAYER CHARACTERISITCS IN KOIWAGAWA WHICH CAUSED A LOT OF TILE ROOF DAMAGE IN THE 2019 OFF THE YAMAGATA PREFECTURE EARTHQUAKE

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Maximum instrumental seismic intensity of 6+ was observed at near source area during the 2019 off the Yamagata Prefecture earthquake, *M*j6.7. However, most of the earthquake damage was to tile roofs, so earthquake damage was minor compared to past earthquakes of the same scale. A lot of roof tile damage occurred in Koiwagawa which is located in near source area. Damage situation was different even within a narrow area by aerial photography survey and site investigation. In the Koiwagawa, it was assumed that the distribution of ground motion was different by place. In this study, surface wave surveys and micro-tremor surveys were conducted to clarify the surface layer characteristics in Koiwagawa.

Key Words : *Surface wave survey, Microtremor, Ground motion, Koiwagawa, the 2019 off the Yamagata Prefecture earthquake*

1. INTRODUCTION

The *M*j6.7 (magnitude determined by Japan Meteorological Agency, JMA) earthquake was occurred on June 18th 2019 in the offshore of the boundary between Yamagata prefecture and Niigata prefecture (Hereafter, Yamagata earthquake). The epicenter of this earthquake was located in a strain concentration zone along the Eastern Japan Sea margin. Some of major earthquakes have been occurred in this area in the past. Maximum instrumental seismic intensity 6+ (JMA scale) was observed in Fuya, Murakami city, Niigata prefecture[1)]. Peak ground acceleration reached to 1,190 cm/s^2 in this station. YMT006 of Atsumi[2)], NIG006 of Kangawa[2)] and JMA Atsumigawa[1)] which are seismic stations located in near source area, has observed also strong ground motion. PGA of each stations reached to 653 cm/s^2, 244 cm/s^2 and 742 cm/s^2. Figure 1 shows epicenter of the mainshock and location of seismic stations. Star symbol means epicenter and filled triangle symbols means seismic stations. According to these observation results, it was thought that strong ground motions generated in near source area. However, earthquake damage in near source area was minor compared to same scale past earthquakes[3)]. There was no significant damage to infrastructure system and service. Some damage occurred in a wooden residential house. Although, a total of 28 houses were half collapsed and 1,580 were partially destroyed, there were no fully collapse[4)]. Most of partially damaged houses were damaged to roof tiles. Slope failures and landslides occurred in the 2007 off the Niigata prefecture earthquake which occurred in coastal area as same as the Yamagata earthquake, but there was no major damage in this earthquake.

As mentioned above, main earthquake damage in this earthquake was tile roof damage of wooden houses. Koiwagawa which is research target area in this study, is located along the Japan Sea and near epicenter. It is a small area which has a narrow shape. Distance is about 8.9 km from NNE direction from Fuya, Murakami city. Figure 1 shows location of Koiwagawa. Ground motion in Koiwagawa was considered to be equal to or greater than Fuya station because of the epicentral distance is about the same as Fuya.

The damage situation of Koiwagawa was also minor. However, damage situation was different from other areas. Roof tiles damage rate was the highest in near source area[3)]. Furthermore, although Koiwagawa is a narrow area stretching along the Japan Sea with 650m length, it was clarified that damage rates were different by place. So, it is considered that the distribution of ground motion was different in this area. Therefore, conditions and characteristics of surface layer are different in this site. In this study, we try to clarify surface layer condition in Koiwagawa using surface wave survey method and microtremor survey method.

2. THE 2019 OFF THE YAMAGATA PREFECTURE EARTHQUAKE

Yamagata earthquake occurred in offshore the boundary between Yamagata prefecture and Niigata prefecture. This area is included the seismic zone of eastern margin of the Japan Sea and it has been occurred many major earthquakes in the past.

Table 1 shows source parameters of the Yamagata earthquake. These parameters were referred from the JMA and F-net[5)]. Figure 1 shows aftershocks distribution which were occurred within 24 hours[6)] and focal mechanism of main shock by F-net. Aftershocks distribution was stretched along the NNW-SSE direction. That direction is consistent with the STR of focal mechanism. Color of each aftershock symbol means depth. The aftershocks occurred in the western side have shallower depth than eastern side. According to that, the fault plane is considered to be east-dipping. Figure 2 shows ground motion observed at Fuya station, Murakami city[1)]. The Koiwagawa may have been generated to the same level of ground motion as the Fuya station because epicentral distance is about the same.

3. DAMAGE IN KOIWAGAWA

Koiwagawa is located in along the Japan Sea with

Table 1 Source parameters of the 2019 off the Yamagata prefecture earthquake.

Origin time	2019/06/18 22:22:19.9
Epicenter	38°36.4' N 139°28.7' E
Depth	14km
Magnitude	Mj6.7 Mw6.42[5)]
Seismic moment[5)]	5.41×10^{18} N·m
STR/DIP/RAK[5)]	26 / 27 / 86

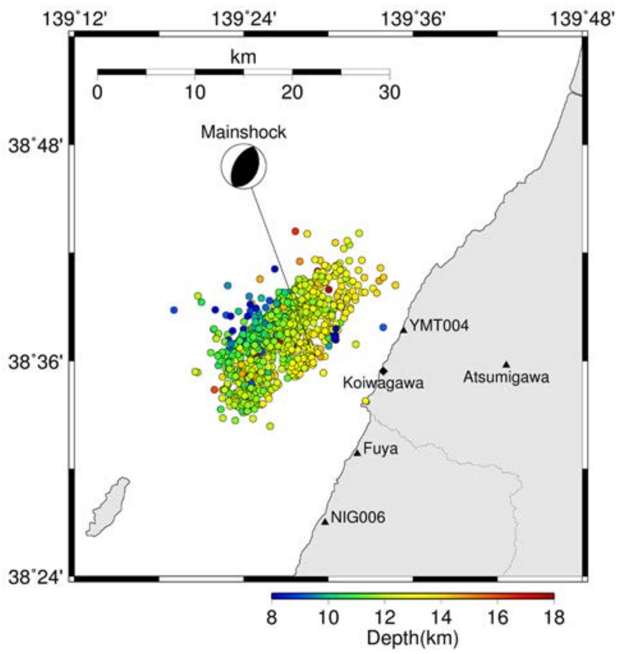

Fig.1 Location of epicenter and aftershocks distribution of the 2019 off the Yamagata prefecture earthquake. Filled triangle symbols means seismic stations. Filled square diamond symbol indicate Koiwagawa.

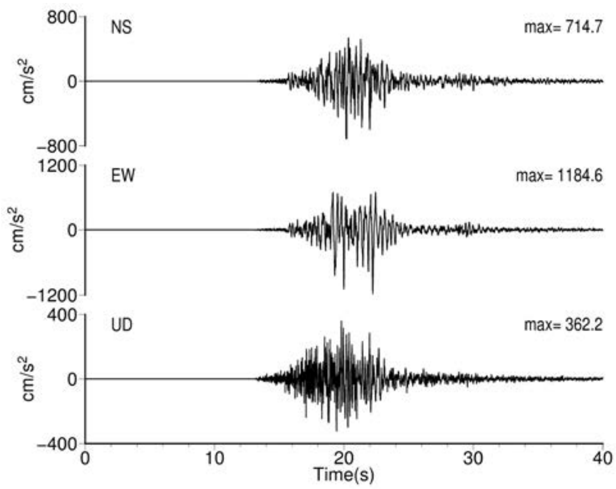

Fig.2 Ground motion observed at Fuya station, Murakami city, Niigata prefecture[1)]. Instrumental seismic intensity based on this record was 6+.

elongated shape. Figure 3 shows a plain view of Koiwagawa[7]. Length and width are about 650 m and about 200 m respectively. 2 small rivers of Iwaosawa-gawa river and Deguchisawa-gawa running at northern part and southern part. The area is surrounded by mountains on three sides. According to site conditions it seems that surface layer is mainly consisted of sand deposit form the sea.

Figure 4 shows aerial photograph taken by 8 days after the earthquake (June 26th 2019)[8]. Figure 5 shows tile roof damage in Koiwagawa taken by 20th June. This photograph was taken from point *P* in Figure 4. There were many houses covered with blue sheets. These houses can be considered a roof damaged house. Some damaged houses had already begun to be repaired. Damaged houses are mostly found on the center of the area. On the other hand, there are small number of damaged houses in northern side and southern side. It was known that damage situation of houses was varies along the longitudinal direction of Koiwagawa. Figure 3 shows the damage classification into three areas based on aerial photographs and field investigations. Category A was the highest damage rate area. Category C is mostly no damaged area. Category B is medium damage rate area.

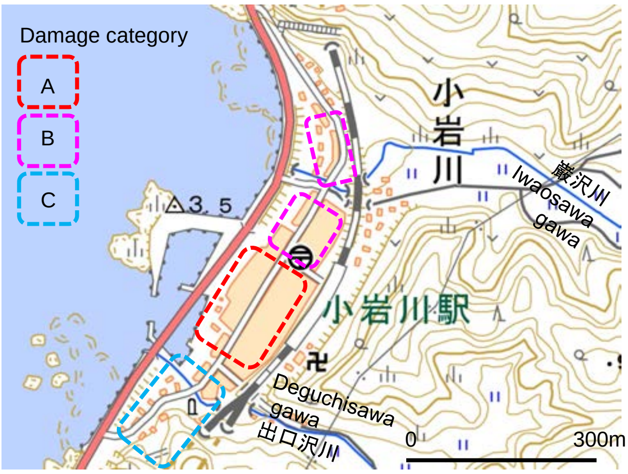

Fig.3 Map of Koiwagawa and damage classification. Category A which indicate red colored broken area, has a lot of roof damaged houses and category C has a small number of roof damaged houses. The base map is a reproduction of the Digital Topographical Map 25000 published by Geospatial Information Authority of Japan[7].

Fig.4 Aerial photograph in Koiwagawa on June 26th, 2019[8]. There are many houses covered with blue sheet. In this study, houses covered with blue sheets were considered as damaged houses.

Fig.5 Damage situation of roof tile in Koiwagawa on June 20th. Some houses have begun to have repaired.

4. SURFACE WAVES SURVEY METHOD

(1) Methodology

It was known that multi-channel analysis of surface waves analysis (MASW)[9),10)] was a very useful method for evaluating characteristics of surface layer. In this method, artificially generated surface waves by a hammer hitting on the ground, are observed by multiple receivers in a row, and the 2-dimensional S-wave velocity structure can be obtained. Hayashi and Suzuki proposed CMP analysis[11)] which was able to estimate the S-wave velocity structure with higher accuracy even for complicated ground. In this study, we used MASW analysis and CMP analysis for evaluation the 2-dimensional S-wave velocity (Vs) structure in target area.

(2) Measurement

It was pointed out that the ground motion may be different in the longitudinal direction of the Koiwagawa based on the damage situations. Input ground motions to engineering base in Koiwagawa should be considered constant considering from hypocentral distance and size of the Koiwagawa. Therefore, it can be considered that the characteristics of surface layer was different despite the narrow area in Koiwagawa.

So, we try to clarify 2-dimensional S wave velocity structures in surface layer along the longitudinal direction using surface wave survey (SWS) method.

The SWS was conducted along the former national highway running through the center of the area. As mention above, the road crosses two rivers, so we divided measuring line to 3 which are Line A, Line B and Line C from south side. Line A was measured from A1 to A2 direction. Similarly, Line B was measured from B1 to B2, and line C was measured from C1 to C2. Length of each lines were 61 m, 345 m and 60 m respectively. Figure 6 shows location of SWS measurement lines.

We have used McSEIS-SW system (OYO Corporation) and 24 Geophones which were vertical velocity sensors with 4.5Hz predominant frequency. There were deployed at 1 m intervals. To keep the interval between each receiver, we used Land Streamer with a belt system[12)]. The massive sledgehammer was used as a source. The nearest source to receiver offset was 5 m. The source interval to use for moving source measurement was 2 m. Starting point of each measuring line (A1, B1 and C1) and the end of line B (B2) are facing the river. So, we applied a fixed source measurement in this range. Figure 7 shows SWS measurement situation at Line B (moving source measurement).

(3) Analysis

We calculated 2-dimensional S-wave velocity structure by MASW analysis and CMP analysis using multi-channel and multi shot surface wave data. In this method, it was known that the analysis accuracy can be improved by constraining the layer boundaries of the surface layer using boring data which obtained in near measuring line. In this analysis, we couldn't get any borehole data in the survey area. Therefore, the analysis was performed under the condition that the Vs structure is continuous at Line A (A1) to Line B (B1) and Line B (B2) to Line C (C1).

Figure 8 shows calculated 2-dimensional S-wave velocity structure in Koiwagawa. At the boundary between Line A and Line B, both Vs values are slightly different. However, the shape of the Vs structure is continuous in boundary between Line A and Line B. At the boundary between Line B and Line C, we can find that the Vs values and structures are continuous. Because of these results, calculated Vs structure are considered to reproduce the current situation.

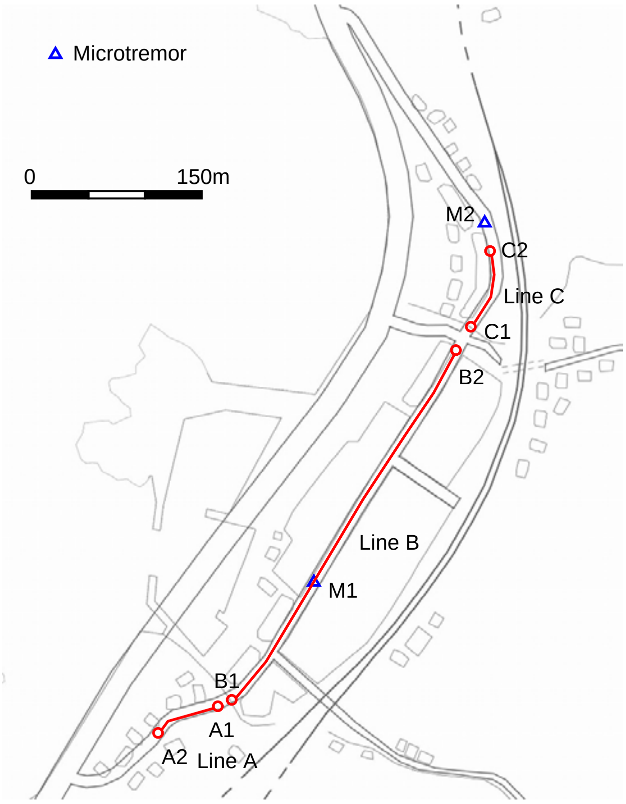

Fig.6 Location of SWS measurement lines (Line A, Line B and Line C) and microtremor measurement sites (M1 and M2). The base map is a reproduction of the Digital Topographical Map 25000 published by Geospatial Information Authority of Japan[7)].

Fig.7 SWS measurement situation at Line B (moving source measurement)

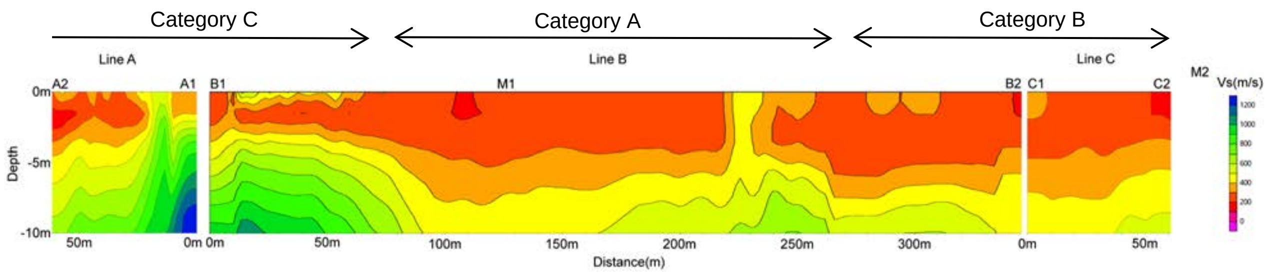

Fig.8 S-wave velocity structure of the Koiwagawa evaluated by SWS method. Thickness of surface layer is different by sites. The surface layer thickness of the damaged area is thicker than undamaged area.

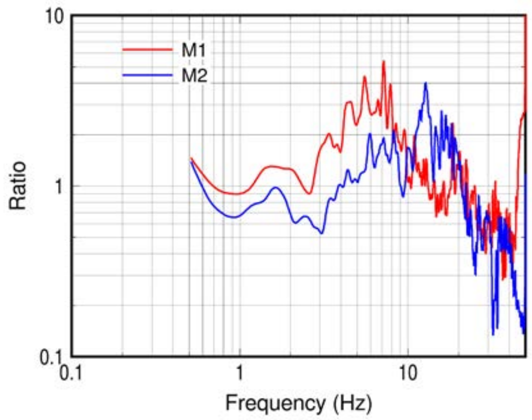

Fig.9 H/V spectral ratio at M1 and M2. Peak frequency of H/V spectral ratio at M1 and M2 were 7.0 Hz and 12.0 Hz respectively.

Vs value near the ground surface is about 200 m/s. However, there is a difference in the layer thickness which has Vs = 200 m/s. The layer thickness of the area classified as category C is thinner than another categories area. If the layer of Vs less than 400 is defined as the surface layer, thickness of surface layer at category C is clearly thinner than other categories.

The thickness of surface layer is qualitatively consistent with the roof damage situation. The surface layer thickness of the areas classified as category A and B are about 7-8 m. On the other hand, the surface layer thickness in category C is about 3-4 m.

We can find high Vs area near ground surface at range of 220-230m from B1 on Line B. During the field survey, we could not find the cause of the high Vs in this range. It is possible that the accuracy of the analysis result in this area is not enough.

5. MICROTREMOR MEASUREMENT

Microtremor measurements were carried out at two sites of M1 and M2, to evaluate the surface layer properties. M1 is located along the Line B, about 130 meters away from the point B1. A lot of roof tiles damage has been confirmed around the M1. M2 is located about 20 meters north out of the Line C. There are few houses damage around M2.

CV-374AV of 3 components velocity seismometer with high sensitivity (Tokyo Sokushin Co., LTD.) was used for microtremor measurement. Sampling frequency of measurement was 100 Hz. The measurement time was 5 minutes, and multiple measurements were taken at both sites.

Figure 9 shows H/V spectral ratio at M1 and M2. H/V spectral ratio can be calculated by dividing the horizontal microtremor spectrum by the vertical one. It was smoothed by Parzen window with 0.2 Hz width. The peak frequency of the H/V spectral ratio meaning the natural frequency of the site[13),14)]. Peak frequency of H/V spectral ratio at M1 and M2 can be found at 7.0 Hz and 12.0 Hz respectively. Therefor surface layer properties were different between M1 and M2. Estimating the thickness of the surface layer using the 1/4 wavelength method from the natural frequency, were 7.1 m and 4.1 m. These results are consistent with the SWS results.

6. CONCLUSIONS

The 2019 off the Yamagata Prefecture earthquake caused many damages of tile roofs in Koiwakawa which located in near source area. Damage ratio of tile roofs were different by place in this area, so it was assumed that the ground motions were different. We conduct surface wave survey to evaluate S wave structures which are highly related with ground amplification characteristics in this site. The validity of the S-wave velocity structure was evaluated by the continuity of the S-wave velocity structure and the single point H/V spectrum of microtremors. The S-wave velocity structure in the Koiwagawa area is different between the central part and the edge part. The thickness of the surface layer and the damage situation were found to be quantitatively consistent. Some parts of the SWS results are not accurate enough, so we need to re-calculate of SWS data.

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