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The dynamic response of Horonobe Underground Research Center during the 2018 June 20 earthquake

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ABSTRACT: The Horonobe Underground Research Laboratory (URL) is assumed to be located in an aseismic region and earthquakes are rarely occur. An earthquake with a moment magnitude of 4 occurred in at 5:28 (JST) in early morning of June 20, 2018. The strong motions induced by this earthquake were recorded by the accelerometers installed in the URL as well as the Kik-Net and K-Net strong motions networks operated by the National Research Institute for Earth Science and Disaster Prevention of Japan (NIED). The authors explain the results of analyses carried out on the ground amplification and frequency characteristics of the acceleration records at the URL and those of the Kik-net strong motion station and the structural effect of the URL on the ground amplification and frequency characteristics. Furthermore, the implications of the results obtained from this study in practice and the safety of the nuclear waste disposal at depth are discussed.

1 INTRODUCTION

In order to cover the general geological environment in Japan, two URLs, one for sedimentary rock and another for crystalline rock have been planned, one is the Horonobe Underground Research Laboratory the other is the Mizunami Underground Research Laboratory (JNC, 2001; 2002). One purpose of this plan is to confirm the technical reliability of the geo-logical disposal methods for high-level radioactive waste, as indicated by the Second Progress Report (JNC, 2000).

The site of the URL project for sedimentary rock is located at Horonobe, in the northern part of Hokkaido, north of Japan. The geology consists of Tertiary and Quaternary sedimentary rocks. Conceptual design for the Horonobe URL at present is as follow:

- Two 500 m access shafts and one Ventilation Shaft; and
- Experiment levels, at 140 m, 250 m, 350 m and 500 m depths.

In 2012, excavation of the Ventilation Shaft and East Access Shaft reached 350 m depth, and the ex-periment gallery at 350 m depth was excavated be-tween 2012 and 2014. In 2012, excavation of the West Access Shaft started, and reached 350 m depth in 2013. Countermeasures against rock bursts and large volume/high-pressure inflows of water or inflammable gas are important issues to be addressed during excavation of shafts and research galleries. Figure 1 shows the layout of the Horonobe URL.

The shafts and galleries have been excavated through overlying Neogene sedimentary rocks named Koetoi formation (diatomaceous mudstones with opal-A) and into the Wakkanai formation (sili-ceous mudstones with opal-CT). The Koetoi formation and upper part of Wakkanai formation have been faulted and have undergone sever-al episodes of uplift and subsidence from the Miocene to the Pliocene, indicated by the presence of lacustrine and marine sedimentary formations unconformably overlying the basement. Table 1 shows properties of the formations and groundwater.

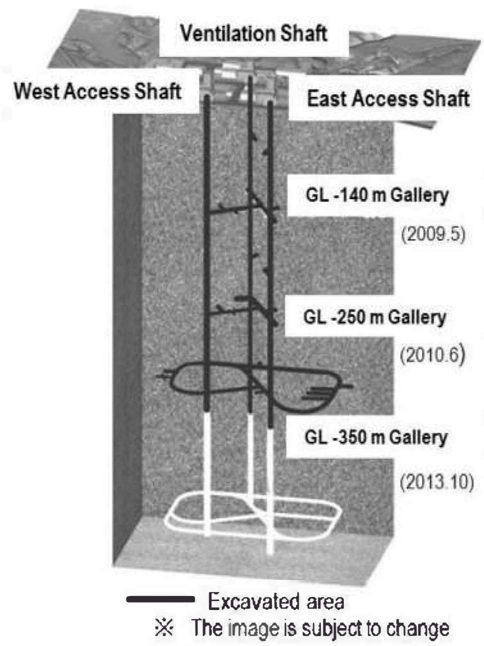


Figure 1. Layout of Horonobe URL.

It will be necessary to evaluate direct and/or indirect influence of large earthquakes to design and construction of repository, and safety of geological disposal system during long period in safety assessment. The Horonobe URL is assumed to be located in an aseismic region and earthquakes are rarely occur. But, an earthquake with a moment magnitude of 4.1 occurred in at 5:28 (JST) in early morning of June 20, 2018, which is also named as the 2018 June 20 Soya Region earthquake. The seismic intensity at Horonobe town was 3 on the Japan Meteorological Scale.

This paper shows the results of the analyses carried out on the ground amplification and frequency characteristics of the acceleration records at the Horonobe URL and those of the Kik-net strong motion station for the 2018 June 20 Soya Region earthquake and the structural effect of the URL on the ground amplification and frequency characteristics. Furthermore, the authors discuss the implications of the results obtained from this study in practice and the safety of the nuclear waste disposal at depth.

2 THE 2018 JUNE 20 SOYA REGION EARTHQUAKE

2.1 *Characteristics of Soya Region Earthquake*

The Soya Region Earthquake occurred on 2018 June 20 at 5:28 AM. The moment magnitude of the earthquake was 4.0 according to F-NET of NIED. The focal mechanism of the earthquake was estimated to be thrust fault (Figure 2), which is a consistent mechanism in view of tectonics of the Soya region. Figure 3 shows the inferred stress state for the earthquake. The maximum horizontal stress acts in almost in East-West (EW) direction.

2.2 *Characteristics of Iburi Earthquake*

Another major earthquake with a moment magnitude of 6.6 (Mj 6.7) occurred on September 6, 2018 at 3:08 in Iburi Region of Hokkaido Island, which is about 260 km away from Horonobe. The focal mechanism of this earthquake was due to the blind steeply dipping thrust fault. The earthquake was felt in Horonobe as recorded by Kik-Net network. However, the maximum ground acceleration was 3.3 gals.

Table 1. Properties of rock and groundwater.

Property	Koetoi F.	Wakkanai F.
UCS* (MPa)	1.44 - 9.80	8.90 - 34.9
Young's modulus (GPa)	0.38 - 1.03	1.41 - 6.35
Poison's ratio	0.22 - 0.47	0.17 - 0.34
Effective porosity (%)	60 - 65	40 - 50
Unit weight (kN/mm^3)	14 - 16	15 - 19
Hydraulic conductivity	10^{-8} - 10^{-9}	10^{-6} - 10^{-11}
Swelling factor	<0.04	<0.03
Durability factor (Id^2) (%)	>90	>95
Dissolved gas	Methane dominant	
Groundwater	Saline water	

*Unconfined Compressive Strength

2.3 *Acceleration records at Horonobe URL*

Accelerometers are set at the ground surface, GL.-250 m and GL.-350 m galleries in Horonobe URL (Figure 4). Figure 5 shows the Seismic records of the 2018 June 20 Soya Region earthquake. Table 2 compares the maximum acceleration at each strong motion station installed at various depths. The ground motions are amplified towards the ground surface. The data even in the same level is scattered, which may imply some local effects such as the geological

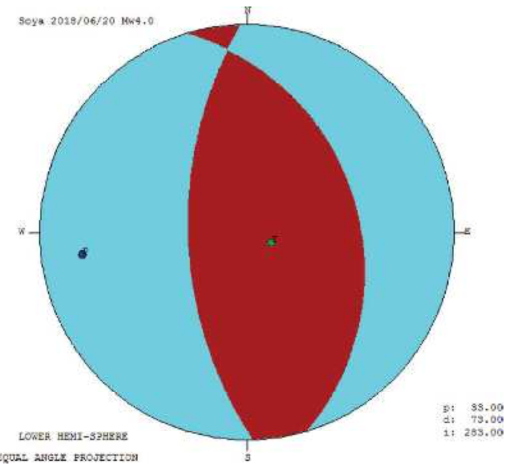


Figure 2. Re-drawn focal mechanism obtained by F-NET

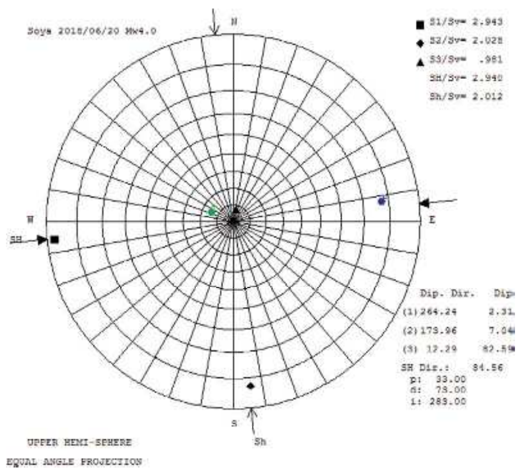


Figure 3. Inferred stress state for the focal mechanism obtained by F-NET by Aydan's method (2000).

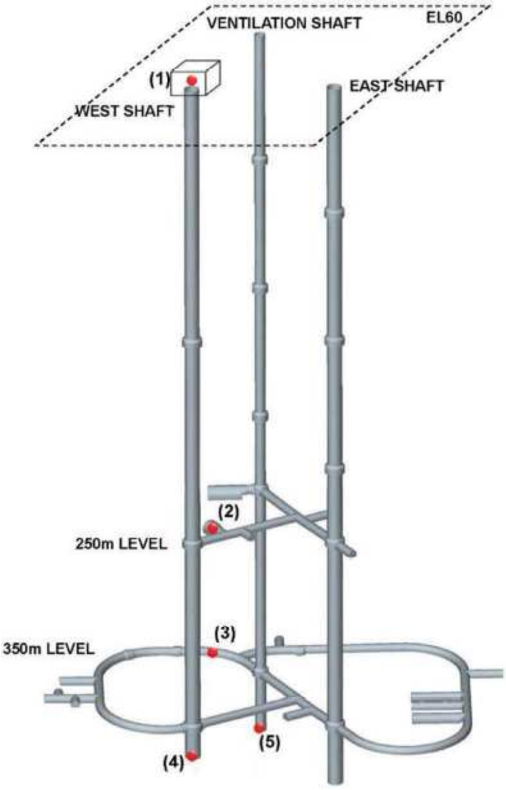


Figure 4. Locations of strong motion observation stations.

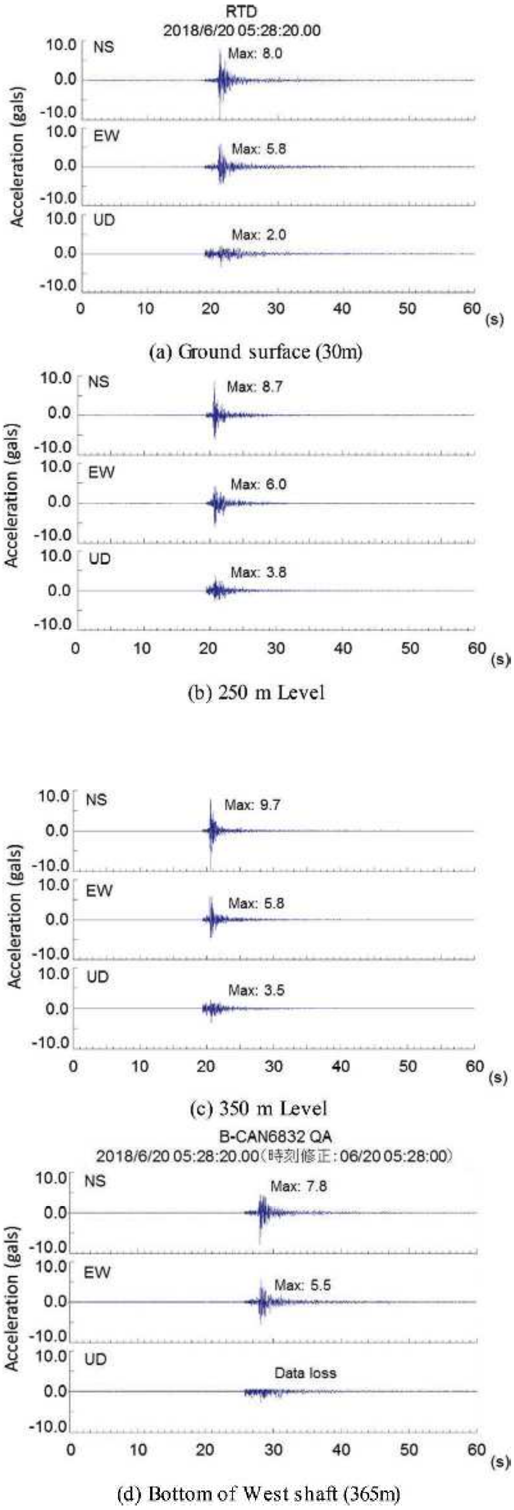


Figure 5. Seismic records of the 2018 June 20 Soya Region earthquake (20 Jun. 2018, M=4.8) observed in Horonobe URL. There is a possibility that the recorder set at the bottom of West shaft has a problem.

conditions, the geometry of the opening where the devices are installed.

2.4 *Kik-Net and K-Net data*

National Research Institute for Earth Science and Disaster Prevention of Japan (NIED) has been operating the Kik-Net and K-Net strong motions networks. There is a strong motion station of the Kik-net in Horonobe town and the accelerations recorded at the ground surface and at a depth of 100 m from the ground surface (-70 m). Figure 6 shows the acceleration records taken at the ground surface and at the base (100 m below the ground). Table 1 gives the maximum ground accelerations and their amplifications. Theoretically, the amplification is expected to be greater than 2 for an elastic ground (Nasu 1931). The comparison indicates that the amplification is more than 3 times. Compared to data from the Kik-Net, the measurements at the Horonobe URL are somewhat scattered.

3 FOURIER AND ACCELERATION RESPONSE SPECTRA ANALYSES

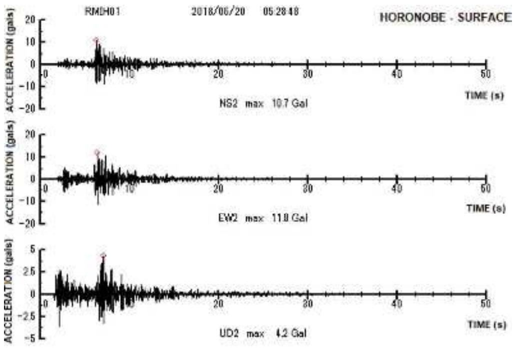
The Fourier and accelerations response spectra analyses have been carried out for each strong motion stations. We report some of them herein.

Table 2. Maximum acceleration

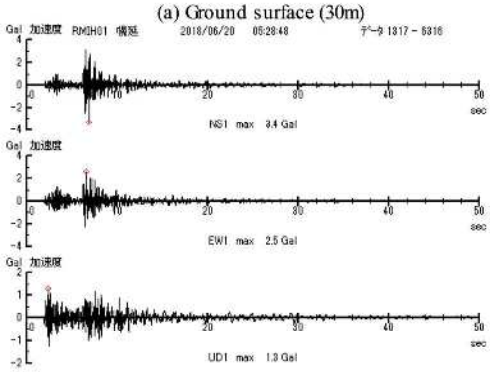
Locations	NS (gals)	EW (gals)	UD (gals)
Surface (+60 m)	8.0	5.8	2.0*
250 m Level	8.7	6.0	3.8
350 m Level	9.7	5.8	3.5
West shaft (365 m)**	7.8	5.5	Data loss

*Data having low quality are possible.

**There is a possibility that the recorder set at the bottom of West shaft has a problem.



(a) Ground surface (30m)



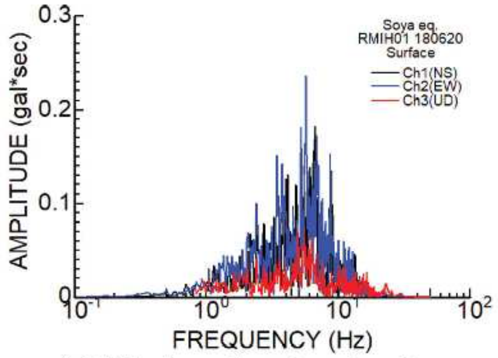
(b) Base (100 m below the ground surface)

Figure 6. The acceleration records taken at the ground surface and at the base of Kik-net.

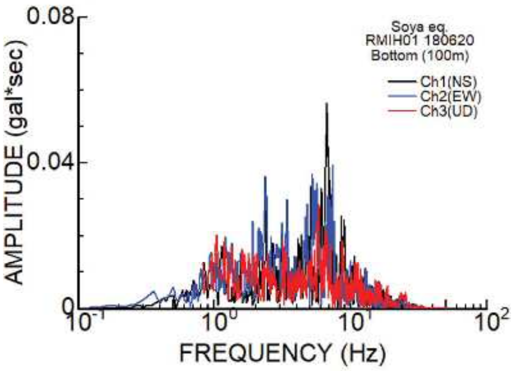
3.1 *Fourier spectra analyses*

The Fourier spectra analyses of acceleration records measured by the Kik-Net (RMIH01) at the ground surface and base are shown in Figure 7. As noted from the figure, the dominant frequency ranges between 4-8 Hz and the Fourier Spectra characteristics do not change with depth, although the amplitude of the ground surface is at least 3 times that at the base.

Figure 8 shows the FFT of records taken at ground surface and at a depth of 365 m at the West Shaft bottom (No.4) in Horonobe URL. The FFT amplitude of the shaft bottom records are almost the same as that of the ground surface. The frequency characteristics are also quite similar and they resemble to those of the Kik-Net records.



(a) FFT of records at Ground surface



(b) FFT of records at the base

Figure 7. FFT of records at the ground surface and base.

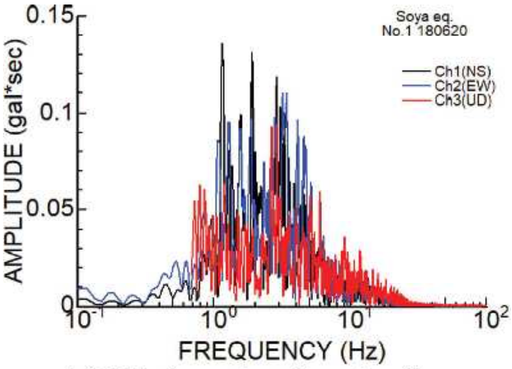
Figure 9. shows the FFT spectra of the record taken at the bottom of Vent. Shaft (No.5) observation station during the 2018 Iburi Earthquake. Except UD component, the other components are quite similar to those of the Soya Region Earthquake shown in Figure 7, except amplitude. The normalized amplitude may be useful for comparison purposes.

3.2 *Acceleration response spectra analyses*

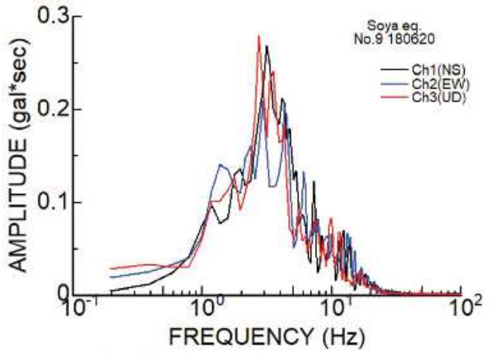
A series of acceleration response analyses are carried out. Figure 10 shows the acceleration response spectra for RHIM01 and Horonobe URL Surface (+60 m) strong ground motion stations (No.1). The amplitude and frequency characteristics are somewhat different. The ground conditions at the RHIM01 may be softer than those at the Horonobe URL site.

4 MODAL ANALYSES

A series of 3D finite element modal analyses were carried out for four conditions, which are namely, no shafts, single shaft, double shafts and triple shafts. The software used was 3D MIDAS-FEA. Table 4 gives the material properties used in numerical analyses while Table 5 compares the Eigen values for four different conditions and Figure 11 shows



(a) FFT of records at Ground surface



(b) FFT of records at the base

Figure 8. FFT of records at the ground surface and base.

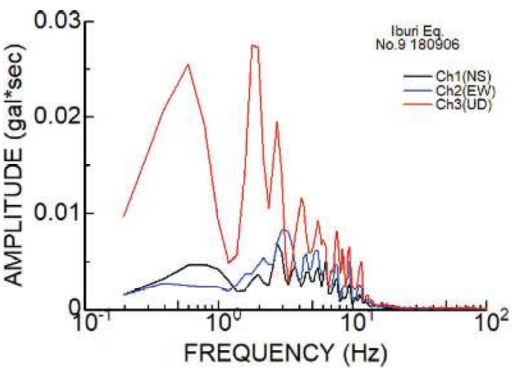
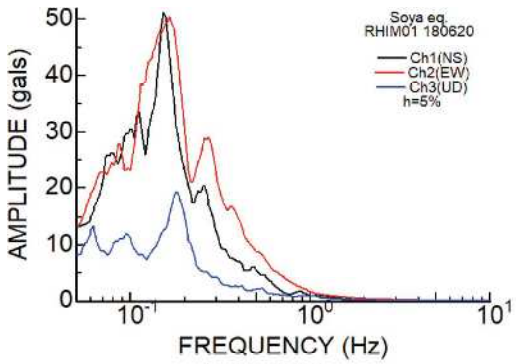


Figure 9. FFT of records at the ground surface for the records due to 2018 Iburi earthquake of 2018 Sep. 06.

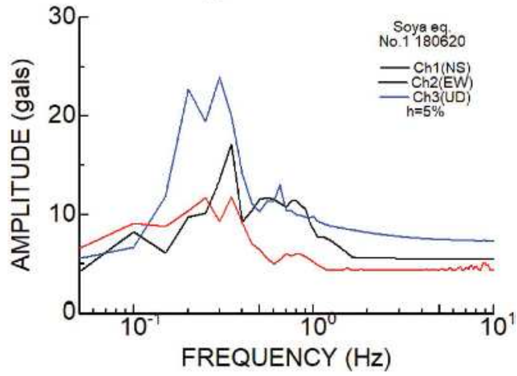
displacement response for Mode 1. Detailed comparison of actual response and analyzed results is necessary for future work.

5 CONCLUSIONS

An earthquake with a moment magnitude of 4 occurred on June 20, 2018 in Soya Region and the strong motions induced by this earthquake were recorded by the accelerometers installed in the Horonobe URL



(a) RHIM01



(b) Horonobe URL

Figure 10. Comparison of acceleration response spectra for RHIM01 and Horonobe URL site.

Table 3. Maximum acceleration and amplification

	NS (gals)	EW (gals)	UD (gals)
Surface (+30 m)	10.7	11.8	4.2
Base (-70 m)	3.4	2.5	1.3
Amplification	3.15	4.72	3.23

Table 4. Material Properties

Material	UW (kN/m^3)	E (GPa)	Poisson's ratio
Rock mass	26.5	0.600	0.37
Concrete	23.5	11.042	0.20

Table 5. Eigen values for Mode 1

	No shaft	Single	Double	Triple
Mode 1(s)	1.763	1.752	1.203	1.199
Mode 2(s)	1.645	1.635	1.889	1.172
Mode 3(s)	1.564	1.554	1.117	1.111

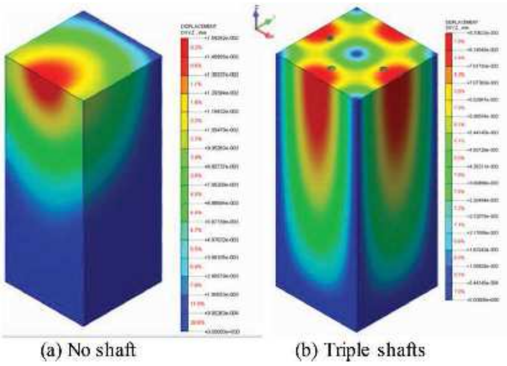


Figure 11. Displacement response for Mode 1.

as well as the Kik-Net and K-Net strong motions networks. The authors analyzed strong ground motions with an emphasis on the ground amplification and frequency characteristics of the acceleration records at the Horonobe URL and those of the Kik-net strong motion station and the structural effect of the URL on the ground amplification and frequency characteristics. Although the results show similar tendencies regarding the ground amplification and frequency characteristics, the structural effect of the Horonobe URL does exist on the recorded data. The results are probably affected by the geological and rock mass characteristics of the site. As the amplitude of the motions were less than 10 gals, the non-linear features could not observed. It is needless to say that the large amplitude records may reveal better insights on the dynamic responses of the URL. Nevertheless, these result clearly show that there is a ground amplification as the depth become shallower, which may have some important implications on the dynamic safety of the nuclear waste disposal at depth.

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