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Attempt of lignite pit exploration by seismic tomography using directional drilling borehole

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ABSTRACT: The occurrence of depression on the ground surface due to lignite pit has been observed at central southern area of Gifu prefecture, Central Japan. In order to prevent the ground surface depression caused by collapse of the tunnel due to the shaking of the Tokai and Tonankai earthquakes, which is expected to occur near future, the work on filling fluent earth materials to the underground cavity is proceeding. To clarify the distribution of lignite pits and to monitor the filling condition of fluent earth materials in the cavity, the seismic tomography is planned between ground surface and the borehole several meters below and parallel to the lignite layer, which is drilled by the directional drilling technology. We report the current status of the site, drilling and survey plan, and outline of the 3D simulation results of seismic tomography.

1 INTRODUCTION

1.1 *Background*

Since 2000, CRIEPI (Central Research Institute of Electric Power Industry) has been conducting the project on the directional drilling and logging/measurement technologies in its boreholes (Kiho et al. 2009). This project was implemented as part of the development of an effective investigation method at the site selection stage of geological disposal in Japan. This project is almost completed in 2013 as planned and was scheduled to contribute to the site selection afterwards, but the geological disposal project has not started yet.

Until starting the geological disposal project, we have established a CD (Controlled Drilling) workshop consisting of members including authors in order to inherit this technology and started searching for the application of this technology, in order to apply this drilling method to civil engineering investigation and civil engineering construction.

On the other hands, currently, there are many artificial underground cavities such as abandoned mines and shelters and natural underground cavities such as limestone caves, nationwide. The ground surface depression and the ground facility disasters such as settlement and inclination are frequently occurring due to the modification of the ground surface such as the reduction of the soil covering thickness by excavation, the increase of the load by the embankment, the degradation and aging of the rock, the external forces such as the earthquake. In particular, cases where the abandonment of the lignite mine causing depression due to rock deterioration and earthquakes has become conspicuous. In Mitake Town, Gifu Prefecture, surveys and countermeasures are being carried out in order to suppress the risks of abandoned lignite mines ahead of the whole country, but a fixed method has not been established for the method of investigation and the evaluation of countermeasure effect.

1.2 *Objectives*

In order to confirm the distribution of abandoned lignite mines and to monitor the filling condition of the fluent earth-material to the cavity, we propose the seismic tomography between the borehole drilled by the directional drilling method and the ground surface. We also confirm the effectiveness of seismic tomography by three dimensional simulation..

2 LIGNITE MINE IN MITAKE TOWN

2.1 *Geography and Geology*

Mitake Town is located in the southeastern part of Gifu prefecture (Fig. 1), facing the Kiso River in the northeastern part and the western part of the town. The urban area spreads to the flat area between the hills of the north and the hills of the south side, roughly extending in the east-west direction and between the altitudes of 100 to 150 m.

The Mizunami group is one of the miocene strata deposited in the sea called "Koseto Inland Sea" in southwestern Japan, distributes from the central and southeastern part of Gifu prefecture. The Mizunami group is classified into the Hachiya Formation, the Nakamura Formation and the Hiramaki Formation from the lower level in the Mitake Town. The Nakamura Formation is about 120 m thick, divided into a lower layer composed of conglomerate or tuffaceous sandstone and siltstone and an upper layer consisting of tuffaceous sandstone and siltstone sandwiching the brown coal (lignite) layer. It is confirmed that at least three lignite layers belonging to the upper layer of Nakamura Formation are distributed in shallow underground around Mitake Town (Fig. 2).

These layers have east-west strike and gentle south dip, so the lower lignite layer distributes in the northern part and the upper lignite layer distributes in the southern part of the town.

Figure 1. Locality map

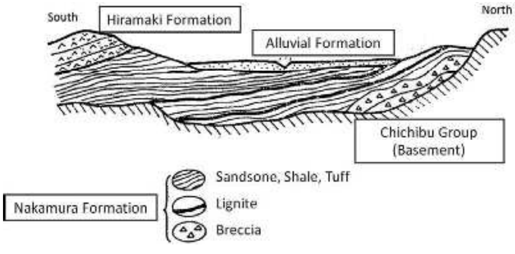

Figure 2. Geological section in Mitake Town (modified from Mitake Town history)

2.2 *Lignite mine*

Since the discovery of the coal vein in 1869, the surroundings of Mitake Town became a major production area of the lignite, supporting important energy of Japan. Mining of the lignite was energetically carried out from the World War II to the postwar period and mining was done about 40 m in depth in the early stage and after the blasting was adopted in 1952, the mining was operated about 100 m deep. In the lignite mine in Mitake Town, the mining was carried out by a method of expanding the mining space from the tunnel while leaving lignite column at regular intervals. In 1956, the mining peaked, production volume rose nearly a quarter to 410,000 tons out of 1.55 million tons nationwide, Mitake Town prospered as a coal mine town. Since then, with the rise of better quality energy sources, in 1968 all the lignite mines closed.

3 SURFACE DEPRESSION AND FILLING

3.1 *Depression on the ground surface*

Lignite was mined by a method called "residual column method" (Fig. 3) that supports the stability of the gallery by leaving a part of the lignite layer in a columnar shape. The remaining column part gradually deteriorate and collapse, so the ground surface depression has come to occur (Fig.4).

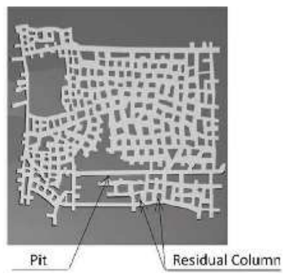

Figure 3. Lignite pit excavation (Hama, 2017)

Figure 4. Case example of Surface depression (Hama, 2017)

In Mitake Town, at least 246 surface depressions caused by abandoned mine were confirmed between 1959 and 2001, and 19 cases were confirmed in only 4 years from 2011 to 2014.

3.2 *Filling to abandoned lignite mine*

Even now, there are surface depressions caused by lignite galleries, but many and large scale surface depressions caused by shaking of the Tokai and Tonankai earthquakes that are expected to occur near future are concerned. In Mitake Town, from the viewpoint of "disaster prevention bases, places where evacuation facilities concentrate and depression frequently occurred in the past", two filling work areas of total 60,270 m2 were selected among the vast area where the lignite abandoned mine is supposed to exist underground. In these selected areas, filling work to the abandoned mine is in progress. In the filling work, a method of stabilizing the ground is adopted by injecting slurry kneaded fixation agent from the ground through the borehole into the underground cavity and closing it.

In the filling work, it is necessary to grasp the three dimensional distribution of the target lignite gallery. There is a location map of the lignite mine at that time in Mitake-Town, but it is difficult to grasp the detailed distribution. Geophysical exploration from the ground surface, for example, radar exploration, electric exploration, etc. are being carried out, but it has not yet been confirmed accurately the cavities existing at several tens of meters underground. For this reason, currently borehole is drilled according to a specific arrangement from the ground surface, and filling work is carried out by using the borehole which reached the cavity at the assumed depth. Also, after completion of filling work, check borehole is drilled, and filling into the cavity is judged according to the state of filling material amount in the borehole.

4 LIGNITE PIT EXPLORATION

The borehole is drilled parallel to the lignite layer at the lower level (about 10 m separation depth) of the target mining site (Fig. 5). By carrying out seismic (Vp and Vs) tomography between the borehole and several survey lines parallel to the borehole at the surface, three dimensional distribution of the lignite gallery can be detected and this can contribute to the decision for selecting the area and arranging borehole location. Also, tomography is performed before, during and after filling, and the filling situation (filling place and filling rate) is monitored by cross section analysis.

In addition, the seismic tomography will be performed between one borehole and multi-survey lines parallel to the borehole on the ground surface, so that the survey range becomes linear. For this reason, as a structure to be surveyed, it is assumed to be a road (national highway) which is a linear important structure.

In this chapter, we introduce the outline and actual results of directional drilling which is the key technology of the survey for lignite gallery which we plan to propose in the future. In addition, we introduce a part of simulation results using geological model of Mitake Town that was conducted to confirm the effectiveness of the seismic tomography.

4.1 *Outline of directional drilling system*

The directional drilling system is based on the wire line drilling principle, but conventional wire line tools can't insert the drilling and measurement assembly in a gently sloping or horizontal drill hole. The water pressure inserting apparatus (so called pump-in system) which can insert the downhole tools by using pressure of drilling fluid was selected.

This drilling system comprised downhole tools, casing pipe following the downhole tools in order to case the borehole wall protecting borehole wall collapse, and the armored cable with inserting apparatus which can push down and pull up the downhole tools easily and can transmit the data of the downhole tools by telemetric line installed inside the armored cable (Fig. 6).

The mud fluid flows down inside the casing pipe and also inside LWD and MWD, and provides the hydraulic pressure to rotate the DHM. Most of the fluid then flows up to the surface through the

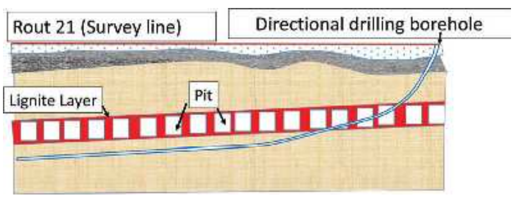

Figure 5. Layout of lignite pit exploration

annulus, which is the aperture between the borehole wall and outside diameter of the casing pipe.

The tools for drilling can be pulled up to the surface by using a wire-line cable in each 3m core runs; to collect core sample, and if a test is deemed necessary, the drilling tools will be exchanged for the testing tools.

4.2 *Drilling results at Kami-Horonobe site*

In 2005, the seismic reflection method was used at Kami-Horonobe site where the outcrop of the Omagari fault is located, and the fault lineament is well defined. Taking into consideration the fault profile deduced from the results of seismic reflection, a borehole trace was proposed to intersect the fault. In 2006, directional drilling was started to verify the applicability of the drilling and measuring system. The borehole was drilled on a bearing of S40W, with a stable inclination of 35° from 0 m to a length of 200 m. From 200 m onward, the directional drilling was relaxed to a shallower inclination of 3° per 30 m, and the borehole reached a horizontal attitude at a length of 720 m. Drilling was terminated at a length of 1000 m after horizontal drilling for 280 m, as of 2011 (Fig. 7). From 0 m to 200 m, drilling was conducted without coring, and from 200 m, cored drilling was performed, and the core recovery was almost 98% as of 2011, even in the fractured zone (Kiho et al. 2016).

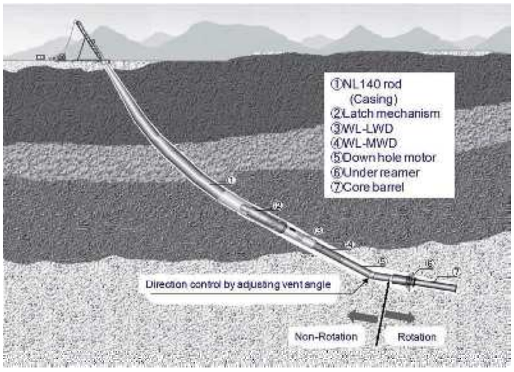

Figure 6. Outline of directional drilling system (Kiho, et al., 2016)

4.3 *Waveform modeling and prestack imaging for the distribution of lignite pit*

We investigated capability of imaging the small-scale subsurface structure of abandoned lignite mines at shallow depth using synthetic seismogram calculated by 2D finite-difference acoustic modeling. The size of our model was 500 meters horizontally by 100 meters vertically, with the ground surface at the top (Fig. 8). The model consisted mainly of shale, with a thin layer of abandoned lignite mines at the depth of approximately 20 to 30 meters as the imaging target. Thickness of the target layer was set to 3 meters. It was configured with alternating pillars of lignite and water, whose horizontal widths are both 3 meters, to simulate the possible conditions of the abandoned mine. The synthetic seismic data was created by deploying the surface receivers at 1 meter intervals. While multiple sources were to be used for the survey in practice, calculated shot gathers from a single source at the center of the model was firstly investigated using Ricker wavelet as the source wavelet, to check the imaging capability of the target layer.

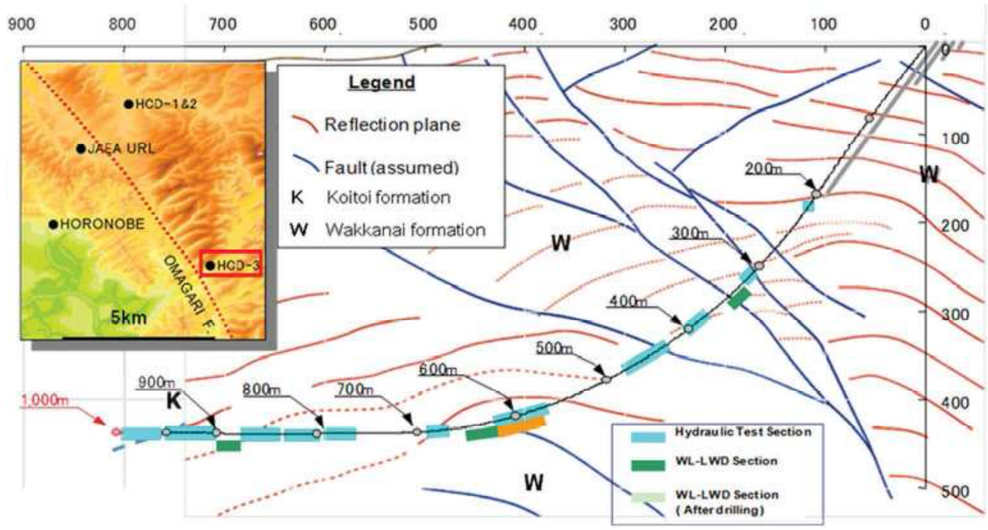

Figure 7. Drilling results at Kami-horonobe site in Hokkaido (Kiho, et al., 2016)

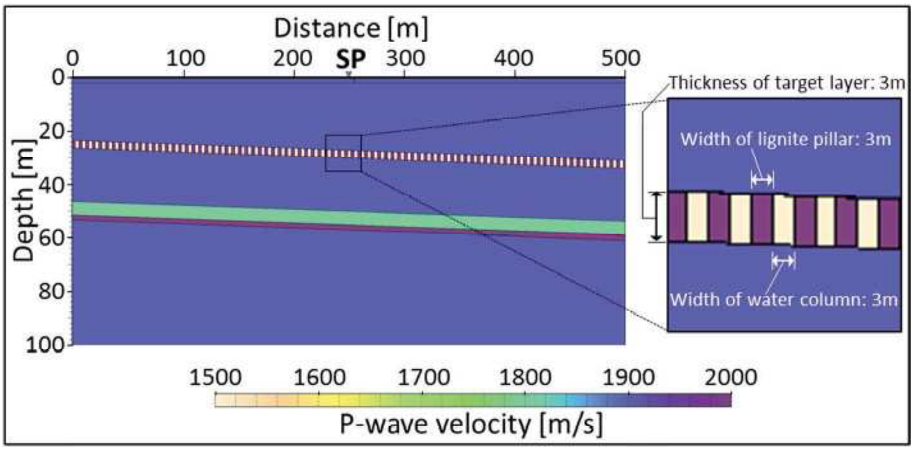

Figure 8. Two dimensional model for P-wave velocity, with an enlarged view of the target layer (Twice vertical exaggeration)

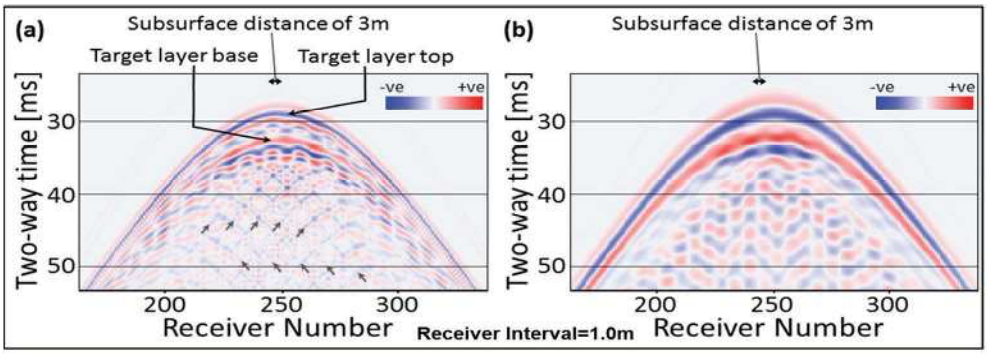

Figure 9. Shot gather created using Ricker wavelet with peak frequency of (a) 500Hz, (b) 250Hz for comparison. Diffracted waves from the target layer are indicated by gray arrows

We analyzed the shot gathers calculated with a range of peak frequency from 65Hz up to 1000Hz to determine how high the frequency should be to image the alternating pillars of lignite and water at the target layer. Diffracted waves from the target layer were observed on the shot gathers (Fig. 9). Individual pillars of lignite and water was delineated by applying Kirchhoff pre-stack time migration in common shot domain, when the dominant frequency of the source wavelet was increased to above 500Hz (Fig. 10).

5 CONCLUSION

– In Mitake Town, Gifu Prefecture, the lignite was mined until 1960's, the ground surface depressions caused by the abandoned lignite mines have been occurring, which is a social problem. Furthermore, there is concern that large-scale depressions may occur due to the shake of the Tokai and Tonankai earthquakes that are expected to occur near future.
– Currently, filling work of the fluent slag to the abandoned mines just beneath important structures is keenly underway, but since it is not possible to grasp the three dimensional distribution of underground cavity, multi boreholes are drilled and filling work is carried out from boreholes hit on underground cavity. Also, the method to confirm the filling situation in the cavity has not been established.
– Synthetic experiments indicate that effective high-frequency component above 500Hz is a prerequisite to detect the small-scale subsurface structure of abandoned lignite mines.

6 ACKNOWLEDGEMENT

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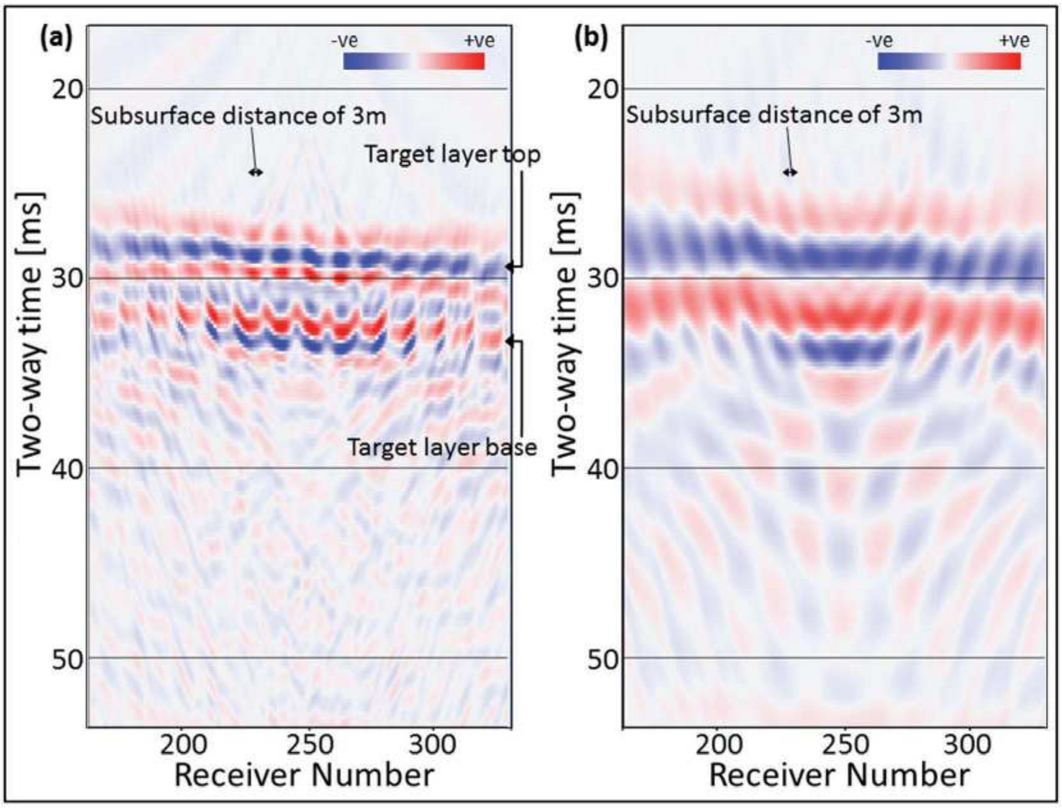

Figure 10. Shot gather after pre-stack time migration in common shot domain, created using Ricker wavelet with peak frequency of (a) 500Hz, (b) 250Hz for comparison.

Research Center of JAEA (Japan Atomic Energy Agency, formerly JNC).

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