

地熱フィールドで発生する有感地震の特性 Characteristics of felt earthquakes occurred from geothermal field

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The authors have reviewed three significant cases of the felt earthquakes occurred from geothermal field, Cooper Basin, Australia, Basel, Switzerland, and Yanaizu-Nishiyama, Japan. Recently, the occurrence of felt earthquake from the geothermal reservoir has become critical issue in geothermal development. Microseismic activity is observed in many of hydrothermal reservoirs. It is also common that the microseismic events occurred at hydraulic stimulation of EGS/HDR reservoirs. However, some of the micro earthquakes have unexpectedly so large magnitude and they were felt on the surface. The physics behind such felt earthquakes were not well understood so far.

1. Cooper Basin, Australia

Geodynamics Ltd. developed HFR system at Cooper Basin. During the hydraulic stimulation and initial hydraulic test in 2003, several felt earthquakes occurred. The magnitude of the largest seismic events was estimated as $M_w = 3.0$ by Geoscience Australia. The felt earthquakes occurred over initial hydraulic test and after shut-in. Hypocenters of the felt earthquake were located widely in the seismic cloud, although, geological structures where the felt earthquakes occurred were not observed. The source mechanism of the felt earthquakes may be common to other smaller events because of identical first motion of the P-wave at monitoring station. Spatio-temporal analysis revealed that the felt earthquakes occurred at the edge of the seismic cloud and then, the seismic cloud extended to the aseismic zone. Many small events were observed within the fault area of the felt earthquake as after shocks. So, it is concluded that the felt earthquake occurred from the asperity which play a role of the hydraulic barrier.

2. Basel, Switzerland

GEL (Geothermal Explorer Ltd.), an operating company of the Basel Project, conducted hydraulic stimulation in 2006 at Basel urban area. First felt earthquake with $M_w = 2.0$ occurred at 5th day of the hydraulic stimulation. Then, following felt earthquakes including largest one with $M_w = 2.68$ took place just after the shut in from the deep and middle part of the seismic cloud. After one month of the stimulation or later, three large events still occurred and their hypocenters were located in the middle or shallow part of the seismic cloud. Three felt earthquakes from deep part of the seismic cloud were likely occur from common fault plane and showed high similarity in waveforms to the smaller events. However, no apparent extension of the seismic area was observed. In contrast, the similarity in waveform between the felt earthquakes from shallow part of the reservoir was low, suggesting that mechanism was not identical to that of smaller events. In fact, hypocenters of felt earthquakes from shallow part of the reservoir were located outside of the seismic cloud.

3. Yanaizu-Nishiyama, Japan

Geothermal power plant at Yanaizu-Nishiyama, Fukushima, Japan has a 65,000 kW of the capacity and has been operated by Okuaizu Geothermal Co. Ltd. (OAG) since 1995. The hydrothermal reservoir is consisted by caldera-related fracture system and the reservoir is steam-dominant at around 2 km depth. There has been seismic activity for long years in this area and micro earthquakes were surely observed before the operation of the power plant. The hot water is re-injected by gravity feed. Large earthquake were sometimes observed in this area. Largest earthquake with JMA magnitude 4.9 occurred on October, 2009. There was no clear correlation between the operations of production/injection and the occurrence of the felt earthquakes. These felt earthquakes had hypocenters within the cloud of micro earthquakes. FPSs estimated by JMA for four felt earthquakes showed same normal fault plane of NW-SW strike and around 45 deg. of inclination. However, seismic structure where the many of the smaller events occurred had more different orientations. It is interpreted that the felt earthquakes were likely to occur from fracture plane in particular nature.

Keywords: Microseismicity, Felt earthquake, Magnitude, Cooper Basin, Basel, Yanaizu-Nishiyama