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Initiation of time lapse measurement to monitor the change of water table in water pumping at Al Wasee field, Saudi Arabia using a seismic ACROSS source and multi-receivers (Preliminary report)

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SUMMARY

We are developing a seismic technology for CCS, CO2-EOR and permanent reservoir monitoring using ultra-stable and long duration seismic source. We use seismic-ACROSS (Accurately controlled and Rousingly Operated Signal System) developed in Japan and multi-seismometers for the above purpose. We carried out synthetic evaluations of reservoir change imaging assuming single seismic sources and field experiment of time-lapse related to underground air injection in Japan in 2011.

We are applying a seismic ACROSS in the context of carbonate rocks in Saudi Arabia. The Al Wasee water pumping site approximately 120 km east of Riyadh has been selected as a test-site. The intention is to observe the changes in aquifers induced by pumping operations. One ACROSS unit was installed at the Al Wasee site this December 2011. The instrument has been operated from 10 to 50 Hz with 40 ton-f at 50Hz. We use a device with a horizontal rotational axis. Using alternatively clockwise and counter clockwise rotations we can synthesize vertical and horizontal forces, respectively. 31 three-components and 8 nearby geophones have been used to monitor the seismic changes from pumping the water.

Comparing the data during one and half month, we identified waveform changes and clear daily variations. These waveform changes might be caused by the change of water table. In this report, we will show the preliminary results obtained in this field. This experiment is conducted in the cooperation by Japan and KACST funded by JCCP (Japan Cooperation Center, Petroleum) and KACST.

Key words: Time lapse, EOR, ACROSS, CCS, Seismic method

INTRODUCTION

The active monitoring using seismic ACROSS (Accurately Controlled and Routinely Operated Signal System) is one instance of these time-lapse approach technologies (Kasahara *et al*., 2010a).
The ACROSS has been developed in Japan from 1994, before the 1995 Hanshin-Awaji Earthquake which caused many deaths. Prof. Kumazawa and his colleagues devoted their efforts toward the completion of the system at JAEA's Tono Geoscience Centre (Kumazawa *et al*., 2000, Kunitomo and Kumazawa, 2004).
Kasahara et al. (2010b, 2011a-d, 2012) has indicated the ACROSS system for the time-lapse researches in CO_2-EOR, CCS and oil-gas exploration. Imaging simulations assuming changing zones at various depths were carried out and proved that one seismic ACROSS source along with a multi-geophone array can give nice images of time-lapse zones (Hasada et al, 2011, Kasahara *et al.*, 2011a).
In addition to the simulation, a first trail of field test was carried out in Awaji Island, Japan, in 2011, with this system (Kasahara *et al.*, 2011b-d, 2012). During this field test 80 tons of air was injected into the sedimentary layer, 100 m below the ground surface. 31 surface geophones and one 800 m borehole geophone were used to monitor the change in underground. The results show very large changes on the waveforms several hours after the air injection started (Kasahara et al., 2011b-d). The imaging of the spreading of the air-water phase was also carried out (Kasahara *et al*., 2012). The results suggest that the method developed by Kasahara *et al*., (2010b, 2011a-d, 2012) is very useful to image the time-lapse underground.

In the Kingdom of Saudi Arabia, time-lapse studies for such all fields might have strong demands. The joint research project between Japanese researchers and KACST in the Kingdom of Saudi Arabia, aiming at studying time-lapse using seismic ACROSS in Al Wasee water pumping field, was initiated in 2009 with the financial support from both JCCP (Japan Cooperation Centre, Petroleum) and KACST.

The Main objectives of the above approach is to test the feasibility of the seismic ACROSS in the Al Wasee water pumping field, which is approximately 120 km east from Riyadh, in Saudi Arabia, and to continuously monitor the physical state of aquifers in the Al Wasee area. However, as an aquifer is relatively more diffused when compared to a CO_2 injection well, this behaviour may affect the quality of image re-construction.

If we can demonstrate the high potential in the active and continuous monitoring of physical state underground, this technology can then be used in CO_2-EOR, CCS, hydro-fracturing of shale gas and the enhancement of oil and gas production.

ACROSS OPERATIONAL CHARACTERISTICS AND DESCRIPTION OF THE TEST FIELD

Although seismic ACROSS radiating frequency bands vary from one to another device in Japan, our system uses a wider frequency band ranging from 10 to 50 Hz. The rotation of an eccentric mass by means of a servo motor generates a force expressed as

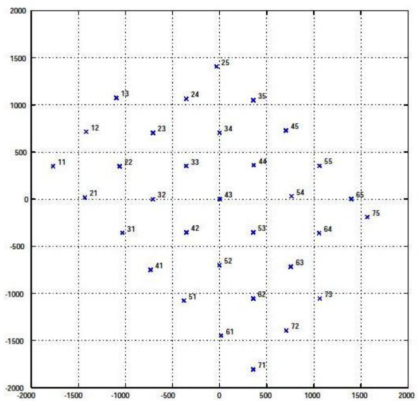
$$F = MR\omega^2, \quad (1)$$

where M is the eccentric mass, R the radius and ω the angular frequency. At 50 Hz, the instrument in Al Wasee can generate a 40 ton-f centrifugal force.

The Al Wasee test field is set in approximately 120 km east of Riyadh. The water extracted in Al Wasee supplies Riyadh. The ACROSS source is placed at the centre of an array of geophones and 32 three-components surface seismic stations were deployed in 3 km x 2 km area with 500 m distance grids (Fig. 1).

The basement of the test field is composed of limestone-dolomite locally covered with sand-dunes. The seismic ACROSS source (Fig. 2), was mounted in a concrete block approximately 10m wide x 10m large x 5m deep. The geophones were installed in 1m deep concrete casing, on average.

Figure 3 shows an example of frequency sweep. The system in Saudi Arabia uses a frequency band ranging from 10 to 50 Hz. In this frequency band, one up-down sweep lasts 200 seconds, the sweep is repeated 16 times, and quiescent time is taken for 400 seconds. Normal and reverse rotation are switched every hour. By adding and subtracting normal and reverse seismic records, we generate vertical and horizontal vibrations (see Kasahara *et al.*, 2011c).



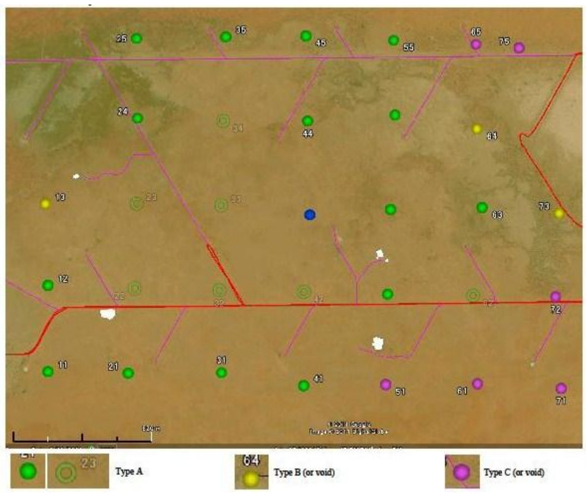


Fig. 1 (Upper) location map of seismic ACROSS source (#43) and seismometers. (Lower) ACROSS (centre) and seismometers for the Al Wasee water pumping field. The scale of the upper is m. The heading of upper figure is north. The heading of the lower one is N45W.

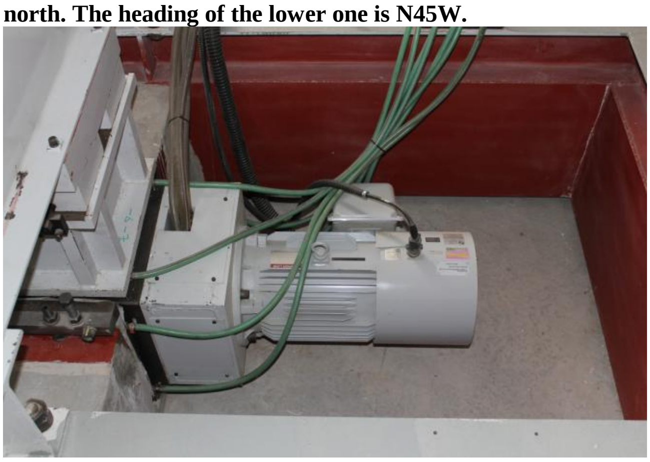


Fig. 2 Picture of the Seismic ACROSS vibrating unit showing the servo-motor.

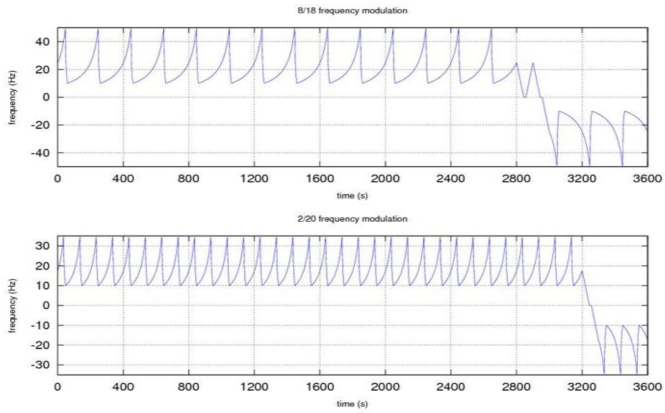


Fig. 3 Examples of sweep pattern during one hour from the seismic ACROSS. Upper and lower are 10-50Hz sweep with 200 second time window and 10-35Hz sweep with 100 second time window, respectively. At every hour the rotational direction switches from normal to reverse, and vice versa.

PRELIMINARY RESULTS

We obtained preliminary results shown in Figs. 4 and 5 at #42, 44, 52, 53, 54, and 63 (see Fig. 1). The distances between the ACROSS and each station is approximately 500-1,000 m. The rotational axis is parallel to #42-source-#44 line and perpendicular to #53 and #63. Three component transfer functions for vertical and horizontal forces were obtained by addition and subtraction of clock-wise and counter-clockwise rotations, respectively (Fig. 4) (Kasahara *et al*. 2011c). Large amplitudes of surface waves were identified. There seems S-wave anisotropy from H2-H3.

The S/N ratio of one hour data is distributing from 10-100 depending on frequencies (Fig. 6). For #63 at 1 km offset, the S/N ratio is approximately 5-10 even during daytime. The S/N does not show large change between 06 h and16 h because the test sites is a few km from the main highway. Because the longest distance is 1,700 m, we can obtain enough S/N ratios to discuss the time lapse using two hour time spacing.

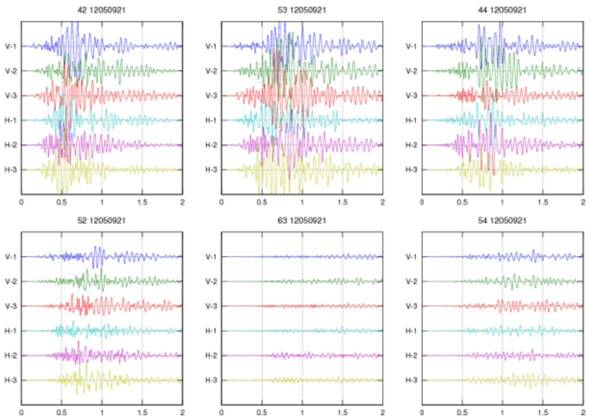


Fig. 4 Example of transfer functions for the vertical force (V1-V3) and horizontal force (H1-H3) at six sites obtained by two hours data between 21 hr and 22 hr in 2012/05/09. The offset distances for #42, 44 and 53 are 500 m. The one for #63 is 1,000 m. V1-H1, V2-H2, and V3-H3 are transfer functions for vertical, N-S and E-W components, respectively.

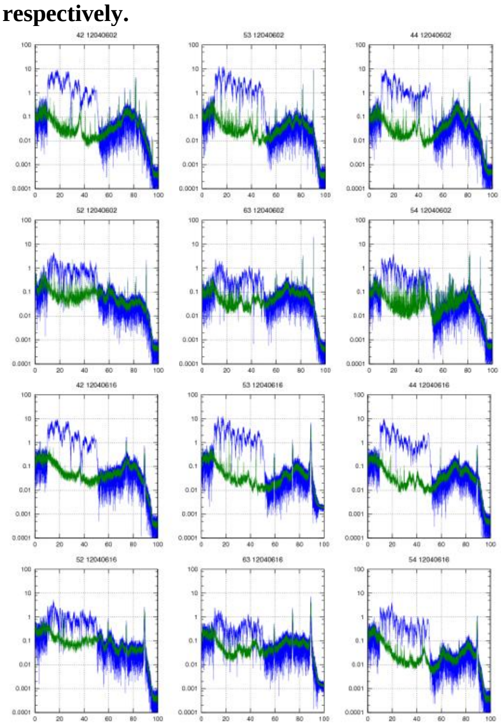


Fig. 5 Example of observed spectra at six stations in the morning (2012/04/06/02-03h) and in the evening (2012/04/06/04/12/16). Spectra between 10 Hz and 50 Hz are designed spectra.

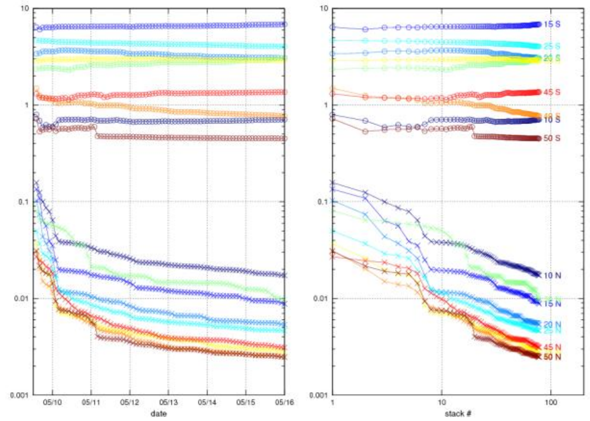


Fig. 6 Effect of stacking for several frequencies. Noise level for each frequency decreases with stacking duration (left) and their details (right).

DISCUSSIONS AND CONCLUSIONS

The field experiment has started in spring 2012. However, there are many unexpected troubles in frequent power shutdown caused by the water supply system, sand-storm affecting to air conditioners and the high temperature as high as 45℃ affecting the lead battery lives. We are going to solve these problems and will start the continuous test observation.

The preliminary results show promising data to discuss the time lapse problem. We are confident that the field test in Al Wasee will have a great impact in the time-lapse studies in the world.

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