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Development of Seismic Sources for Coastal CCS/CCUS Projects with Considering Underwater Noise Issues

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Abstract

While coastal areas can be suitable sites for CCS due to the proximity of CO2 emission sources and geological storage, they also have a thriving fishing industry, and building a good relationship with fishermen is essential for the stable implementation of the project. Here, the sound pressure level of the artificial seismic source "air gun array", which is used for structural surveys to select suitable sites for the CCS project and for seismic surveys to monitor the spread of the injected plumes, is high and is known to be one of the causes of marine noise problems. Environmentally friendly next-generation marine seismic sources with low sound pressure or vibration levels are essential for CCS operators operating in coastal areas with joint fishery rights to proceed smoothly with their projects, and the demand for such sources is expected to increase in the future. The first is a stationary small seismic source used for long-term monitoring by DAS-VSP. It is isolated from benthic animals by installing it in a shallow borehole below the seafloor. The second is a towed marine seismic vibrator used for time-laps seismic surveys, where the sound pressure is reduced to a level that does not affect marine organisms. This presentation will discuss the concept and current status of their development.

Introduction

According to the International Energy Agency (IEA), when net-zero emissions are reached in 2070 in the Sustainable Development Scenario, 9.5 Gt CO2 is captured and stored and another 0.9 Gt is captured and used (IEA, 2020) [1]. As of September 2022, the total number of CCS projects, including those in planning, was 197, with a storage capacity of 244 million tons per year, an increase of 44% over the past 12 months (GCCSI, 2022) [2]. The United States, which accounts for 50% of these projects, is promoting aggressive climate change policies by stimulating investment in domestic clean energy development through the introduction of incentive-based tax-credit programs.

Japan is about to enter a period of full-scale deployment. In March 2023, the Japanese government formulated a roadmap defining a path for CCS utilization (METI, 2023) [3], targeting storage of 120 to 240 million tons by 2050, and selected seven leading projects for priority support (METI, 2023) [4]. In parallel with the government's efforts to establish a legal system that defines the right to long-term geological storage of CO2 and the responsibility for its management and monitoring, each of the groups implementing the projects will demonstrate business models for advanced CCS projects. First, suitable sites for underground storage must be selected through site surveys, and then a value chain must be established to connect the CO2 emitted from factories, etc. to technologies that capture the CO2, transport it by ship or pipeline, and then store it underground.

If this plan goes smoothly, demand for seismic surveys for site selection and monitoring to understand the behavior of plumes is expected. On the other hand, many of these sites are located in coastal areas of Japan, and there are numerous stakeholders. In particular, CCS operators operating in joint fishery rights areas must demonstrate to fishermen that their catch and aquaculture production will not be affected and establish friendly relations with them.

The issue of underwater noise from seismic sources used in seismic surveys is a point of controversy. The sound pressure level (SPL) of a 3,000 cu-in airgun array in a typical seismic reflection survey can be as high as 260 dB re 1μP@1m. This is a level that is damaging to marine organisms' organs, and there is concern that it may encourage alarm and avoidance behavior and affect the migration routes of fishing targets and aquaculture growth (NOAA, 2018) [5]. The effort involved in negotiating with fishermen is also increasing. Underwater noise issue is as big a risk as CO2 leakage in CCS projects in Japan.

Environmentally friendly next-generation offshore seismic sources with low sound pressure or vibration levels that utilize only the necessary frequency bandwidth are essential for the smooth operation of CCS projects, and demand for such sources is expected to increase in the future. The authors believe that it is necessary to introduce two types of seismic sources that can be used in shallow water and coastal areas: the first is a stationary small seismic source (Tsuji et al., 2021[6]; Tsuji et al., 2023[7]; Tsuji et al., 2023[8]) for use in CO2 injection control systems; the second is a marine seismic vibrator, intended for time-lapse surveys, with a sound pressure level of 180-190 dB and a quality equivalent to a 480 cu-in air gun. (Ozasa et al., 2015 [9] ; Ozasa et al., 2019[10]). We are currently working on optimizing these seismic sources for CCS in shallow and coastal waters, and this talk will discuss the concept and current status of its development.

Portable Active Seismic Source

The risk of rapid plume migration and leakage to the surface due to poor completion of the injection well or the presence of unknown faults is considered to be highest during this period. Continuous or high frequency monitoring during this period is desirable. However, from an environmental perspective, there is concern about the impact of stationary seismic sources on benthic organisms inhabiting the surrounding marine area.

A study on the effects of vibratory pile driving equipment and other offshore construction activities on benthic organisms would be helpful. Takeyama and Isogai (2011)[11] found that bivalves are sensitive to low-frequency vibrations. An alarm behavior is generally observed above 60 dB for seafloor vibration levels in the 10-60 Hz frequency range, and above 100 dB, the bottom sediment liquefies, causing benthic organisms that had been hiding in the sand to be pushed up onto the bottom sediment and unable to dive into the sand. When stationary seismic sources are used on the seafloor in a joint fishing right area, the use of a single device with a high excitation force may cause a decrease in the activity level of benthic organisms and a slowing of their growth, making it difficult to reach a consensus with fishermen. It is believed that the installation of several units vibrating synchronously and in unison, at a reasonable distance from each other, will have less impact on benthic organisms in the vicinity of each seismic source.

To achieve continuous monitoring, a portable active seismic source (PASS) and distributed acoustic sensing (DAS), a type of fiber-optic sensor that can measure vibrations along the entire fiber-optic cable, will be used. The PASS will be installed in a borehole, preferably below the seafloor, to generate a stable and repeatable seismic signal, while the DAS will be installed along a monitoring well or injection well to monitor changes in the seismic signal as it passes through the CO2 reservoir. The combination of PASS and DAS should minimize 4D noise caused by changing environmental conditions and allow for rapid detection of anomalies (Tsuji et al, 2021[6]).

Tsuji et al. (2023)[8] reported DAS-VSP recordings using a borehole DAS and a PASS. The use of small seismic sources offers several advantages, including reduced power consumption, reduced deployment space, easy redeployment, and minimized acoustic/vibration noise. The PASS used in the report utilizes the force generated by rotating an eccentric weight to continuously generate signals such as chirp signal (Figure 1). The on-board servomotor enables stable oscillation of the same signal by improving controllability, and the signal-to-noise ratio can be improved by adding multiple-oscillated signals or by synchronous oscillation of multiple units. In the experimental system, a motor is connected to two eccentric weights via bevel gears, and each is rotated in opposite directions to generate a vertical excitation force (Figure 1, right). The eccentric weights have a 0.16 kg eccentric mass attached to a disc with a radius of 4 cm and generate a force of 632 N at 50 Hz rotation. It is housed in a cylindrical metal container and can be mounted inside the housing using a separately supplied clamping device.

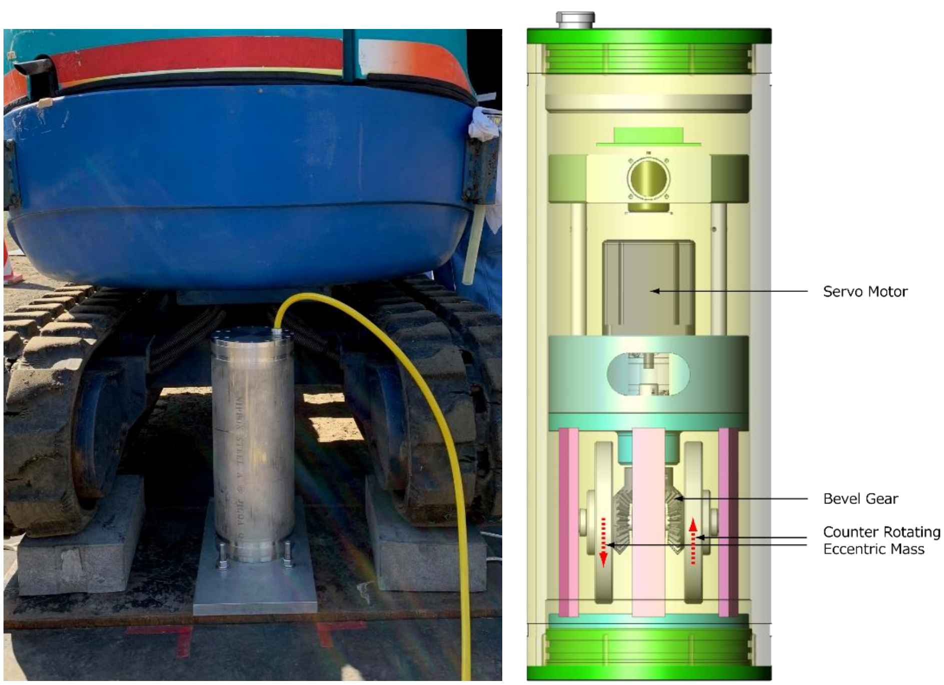


Figure 1. Photograph (left) and schematic diagram (right) of a borehole PASS.

Figure 2 shows a prototype PASS designed for low-frequency excitation of 200 N @ 10 Hz and 3,000 N @ 60 Hz for the purpose of monitoring CO2 reservoirs at depths of 800 m or greater. This model aims to enhance the seismic force by synchronizing multiple units through precise phase control. In the performance test, the two units (black boxes) were placed facing each other and coupled to the ground by means of a vibrator base plate, while vertical excitation was performed by synchronous vibration. A shot record measured by DAS using a FIMT (fiber in metal tube) cable lowered into the well to a depth of 1,000 m is shown in Figure 3. A 30-second Chirp signal with a bandwidth of 10-40 Hz was repeatedly swept and summed 120 times, revealing a clear direct wave to the bottom of the well and multiple reflected waves. The combination of PASS and borehole DAS suggests that it could be an effective tool for monitoring CO2 distribution around boreholes. The next step in the development of this model is to accommodate it within a cylindrical vessel installed in a borehole.

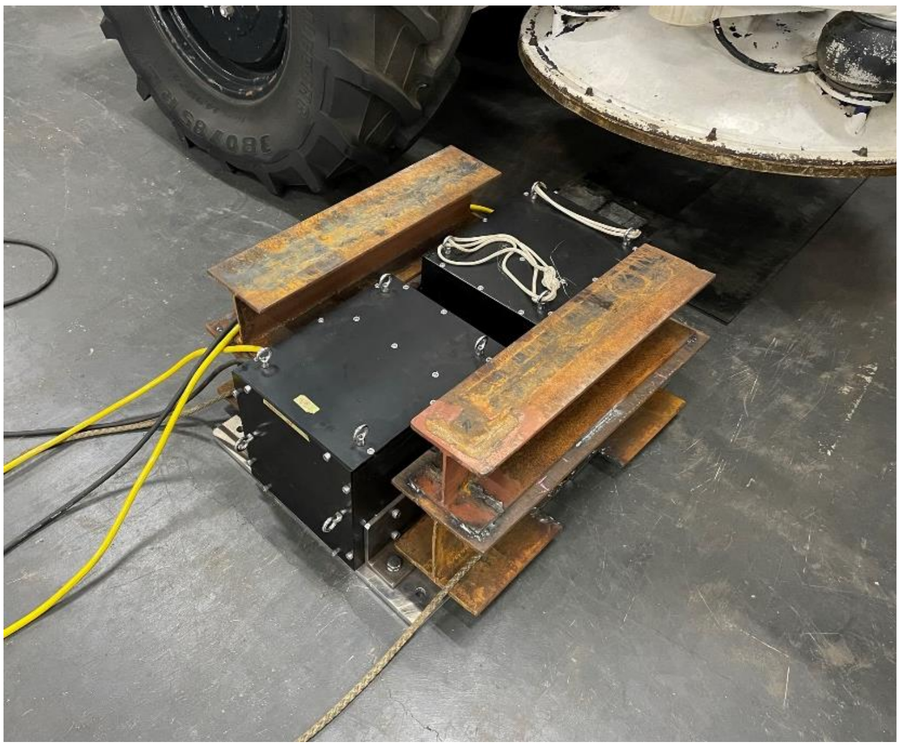


Figure 2. Photograph of the equipment used to test synchronized sweeps of two seismic source units. The base plate of the vibrator used to obtain the coupling between the source device and the ground is shown in the upper right.

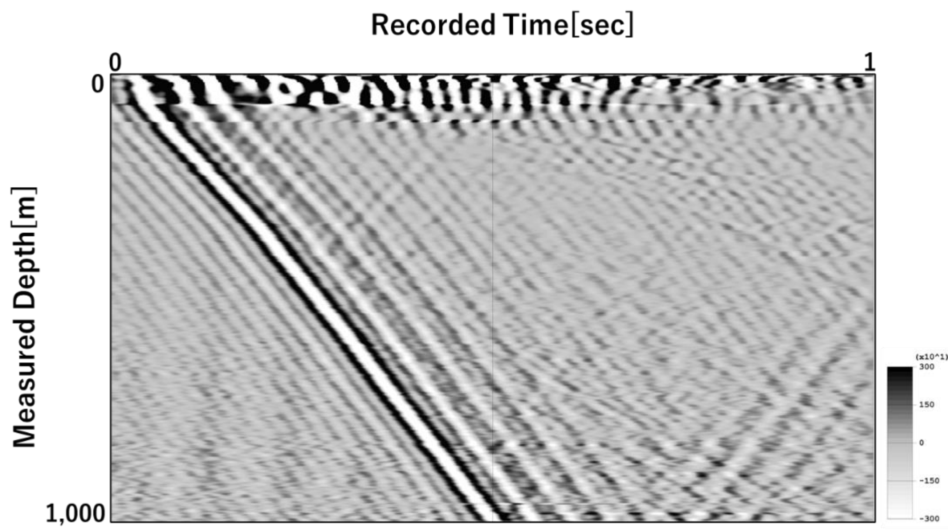


Figure 3. Example of DAS-VSP recordings with synchronous seismic with two units (black boxes) shown in Figure 2.

Marine Seismic Vibrator

The Marine Seismic Vibrator (MSV) (Figure 4), manufactured by IHI, is a servo-controlled, hydraulically driven marine seismic source developed in the 1990s for research by the Japanese Defense Agency (now the Japanese Ministry of Defense). It is a device that contains a control unit, vibration unit, and hydraulic unit in a compact body, and is characterized by its ability to arbitrarily control the volume, frequency, and phase of the seismic sound. By controlling the pressure inside the device so that it balances with the water pressure, it is possible to eject and vibrate at high depths, and to generate oscillations of 3 to 300 Hz, which contribute to the acquisition of reflection records (Figure 5).

Figure 6 shows the results of a comparison test with a 480-cu-inch air gun array by Ozasa et al. (2019)[10]; the MSV was towed at a depth of 50 m and oscillated with a 4-second sweep. The seismic frequency range is 10 to 100 Hz. While the sound pressure was 232 dB for the airgun array, the MSV was 180 dB to 186 dB, about 40 dB (100 times lower). However, the MSV also provided a reflected section to a depth of more than 1 second below the seafloor, indicating that the recordings were comparable to those of the airgun array.

Here, with regard to the effects of artificial underwater noise on marine organisms, studies have been conducted for marine mammals, and it is well known that sound pressure levels below 150 dB can be considered safe, with sound pressure levels of 230 dB having serious effects on hearing (NOAA, 2018)[5]. Behavioral and physiological responses to noise in fish, crustaceans, and mollusks are not yet well known, but several reports are available.

Hatakeyama et al. (1997) [12] investigated the effects of sound pressure on the sea bream and found that 180 dB could damage the auditory organs and 220 dB could cause internal bleeding death or decompression sickness associated with a sudden increase. McCauley et al. (2017) [13] reported an example where plankton populations were halved in the vicinity of the oscillation measurement line of a small 480-cu-inch airgun array. The authors are currently in the process of building an MSV for coastal areas, which will be used to facilitate streamer surveys and 3D DAS-VSP in CCS projects in communal fishing rights areas.

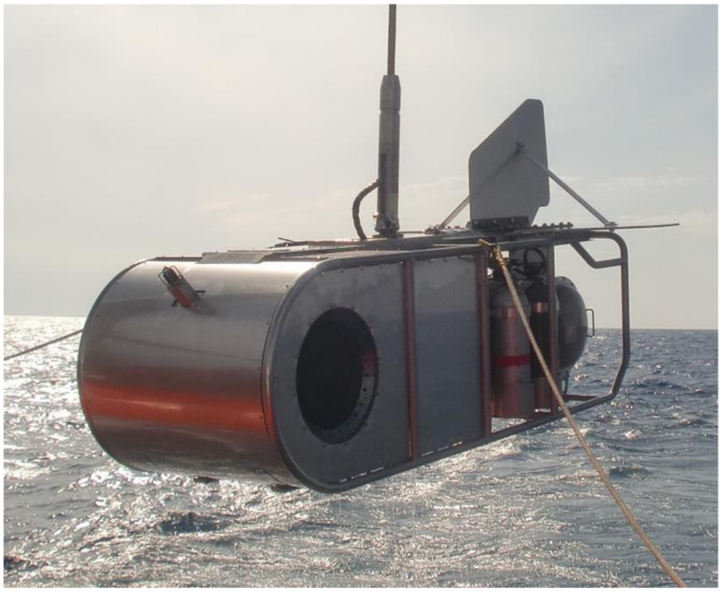


Figure 4 Appearance of Marine Seismic Vibrator photographed during Sea trial 2017 (courtesy of IHI).

Main Specs	Type		Hydraulic Driven, Non-resonant
	Required Power		22 kW (30kVA), 440V, 60Hz
	Frequency Range		to 300 Hz
	Output Waveform		Sine, Sweep, Random, etc.
	Tow Depth		to 250 m
	Size	Length	Approx. 2,800 mm
		Width	Approx. 1,000 mm (without wing)
		Height	Approx. 1,200 mm (without wing)
	Weight (dry / wet)		Approx. 2,000 kg / 1,000 kg
Note	The original technology has been developed in 1990's by IHI. The commercialized type has been delivered from 2000's for the oceanographic research.		

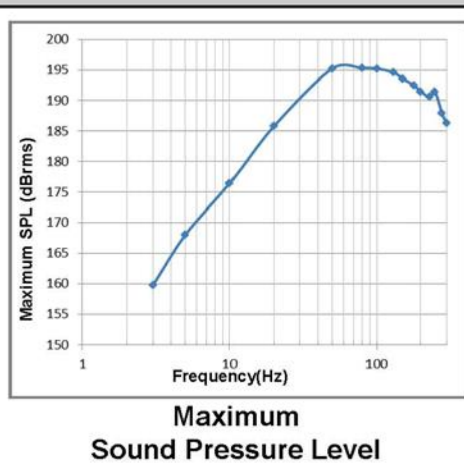


Figure 5. The seismic source used in the sea trial (top) and sound pressure levels at different frequencies (courtesy of IHI).

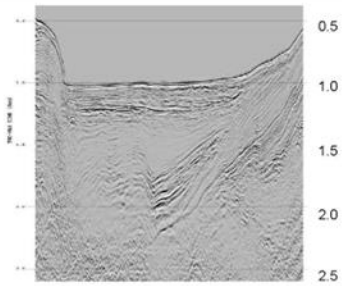
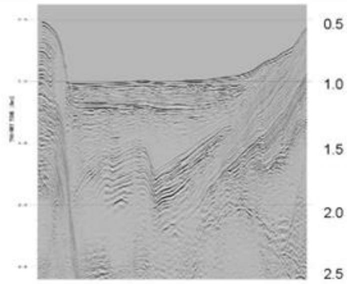
Source	MSV (Source towing depth = 50 m)	480 cu-inch Airgun (reference)
SPL / Waveform	180 to 190 dB / Non-linear 4s-sweep (10 to 100 Hz)	Approx. 232 dB / Impulse
Result		

Figure 6. Comparison of reflection cross sections (courtesy of IHI)

Conclusions

To facilitate CCS projects in coastal areas, the authors are developing an environmentally friendly small stationary source PASS and introducing marine vibrators, which will contribute to reducing marine noise problems. Synchronized oscillation of multiple PASSs is considered effective in dispersing oscillation energy and optimizing excitation force. The borehole type can be installed in shallow wells to reduce the effects of vibration and sound pressure on benthic organisms, and when installed on land, it is expected to be less susceptible to the effects of heterogeneity near the surface. We are currently working with the manufacturer to optimize the design of the MSV to meet the needs of CCS operators.

Acknowledgments

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