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Underwater noise from geotechnical drilling and standard penetration testing

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Abstract: Geotechnical site investigations prior to marine construction typically involve shallow, small-core drilling and standard penetration testing (SPT), during which a small tube is hammered into the ground at the bottom of the borehole. Drilling (120 kW, 83 mm diameter drill-bit, 1500 rpm, 16–17 m drill depth in sand and mudstone) and SPT (50 mm diameter test tube, 15 mm wall thickness, 100 kg hammer, 1 m drop height) by a jack-up rig in 7–13 m of water were recorded with a drifting hydrophone at 10–50 m range. Source levels were 142–145 dB re 1 μPa rms @ 1 m (30–2000 Hz) for drilling and 151–160 dB re 1 μPa^2s @ 1 m (20–24 000 Hz) for SPT.

[DRD]
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1. Introduction

Concerns about anthropogenic noise in the ocean and its potential impacts on marine life have grown over recent decades leading to an increase in research on noise emission and its effects and to the development of underwater noise regulations in many countries.[1] Research and regulation have focussed on "large" operations (large in terms of the generated noise footprint), such as wind farm construction, geophysical exploration, or hydrocarbon production. Smaller operations have been ignored, such as geotechnical site investigations that are undertaken by industry or developers prior to marine construction.

One method of investigating the upper seafloor at a potential construction site is geotechnical drilling. A small, solid core is drilled and extracted from the seafloor for examination on the surface. Geotechnical drilling is commonly carried out from jack-up rigs, which are essentially barges that are driven or towed into position with the legs jacked up into the air. Once in position, the legs are jacked down until they reach the seafloor; and the barge is jacked up above the highest wave level. Only the legs and drill string penetrate the sea surface during operation.

Geotechnical investigation may also include standard penetration testing (SPT), during which a sample tube is hammered into the ground at the bottom of the borehole in a way similar to pile driving. The number of blows needed for the tube to penetrate a fixed depth relates to the hardness of the ground and is termed the "standard penetration resistance."

We recorded the underwater noise of the jack-up rig *Sideson II* of Sides Drilling Contractors Pty. Ltd. during geotechnical drilling and SPT. Documenting the noise output of these activities is the first step in assessing their potential impacts on marine fauna.

2. Methods

The jack-up rig *Sideson II* was recorded at two locations, at the Port of Geraldton (28.77° S, 114.60° E), Western Australia, on 20–21 May 2010, and at James Price Point (17.50° S, 122.12° E), Western Australia, on 5 September 2010. Once in location and operation, only the three legs and the drill string penetrated the water surface (Fig. 1). The *Sideson II* (dimensions 17 m × 16.5 m) had a 160 hp engine and used a PQ3 drill bit (83 mm diameter) with an average rotational speed of 1500–1600 rpm. At Geraldton, the drill went from 4 to 20 m below the seafloor encountering sand, mudstone and limestone. It drilled at 16–17 m below the seafloor into sand at James Price Point.

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Fig. 1. (Color online) Photo of the *Sideson II*.

All measurements were conducted in ideal weather, with a light 5–10 kn breeze and minimal swell. Sound was recorded for 10 min at various ranges and azimuths from the drill string. Locations and distances to the drill string were measured with a GPS and a laser range finder. The recording system was calibrated prior to deployment with a G.R.A.S. pistonphone. At Geraldton, recordings were obtained by deploying a High Tech Inc. HTI-96 hydrophone with a built-in pre-amplifier (-164 ± 2 dB re 1 V/μPa sensitivity; 2 Hz–30 kHz bandwidth) over the side of a 7 m boat. Recordings were digitized by a Sound Devices SD722 digital audio recorder, sampling at 48 kHz, 24 bits. The hydrophone was clipped to a weight bearing line, lowered over the side of the boat, and attached to a float via a catenary system 5 m from the boat to separate it from vessel and wave motion. The water depth at the different recording locations varied between 7 and 13 m; the hydrophone depth was also variable, 6–11 m below the sea surface, intended to be 1–2 m above the seafloor. At James Price Point, a JASCO Autonomous Multichannel Acoustic Recorder (AMAR) was used. This was configured with a Geospectrum Technologies Inc. M8E hydrophone (-165 ± 5 dB re 1 V/μPa sensitivity). Data were recorded on the 24–bit channel sampling at 48 kHz, with an effective bandwidth of 2 Hz–22 kHz. The AMAR was deployed off the side of a boat, suspended from a float in a catenary system, and drifted to 5 m from the boat. The water depth was 12 m and the hydrophone depth 10 m.

Ambient noise measurements were taken at 150 m from the *Sideson II* inside Geraldton harbor. There were two large grain carriers, the *POS Knight* and the *AS Venetia*, being loaded about 450 m from the *Sideson II*. Both vessels ran auxiliary engines. In terms of land-based activity on the edge of the water, construction was occurring on one side, about 500 m from the *Sideson II*, and trains were entering the port, unloading and departing. Ambient noise at James Price Point was measured at 2 km range from the rig in the absence of any other activities.

Analysis was conducted using JASCO's PAMlab and custom MATLAB scripts. In the case of drilling, mean power spectrum density levels were computed over the 10–min durations at each site. In the case of SPT, spectra were computed over the T_{90} duration of each pulse, defined as the time between the 5% and 95% points on the cumulative energy versus time curve.[2] Peak-peak levels (*PK-PK*) and zero-peak levels (*PK*), root-mean-square (rms) sound pressure levels (*SPL*) in both the T_{90} window (SPL_{90}) and a fixed 125 ms window, and sound exposure levels (*SEL*) were calculated for all of the recorded SPT pulses at each site. Source levels were computed by applying a spherical spreading term, 20 $\log_{10}$ (range, m) to the levels recorded at the shortest ranges.

3. Results

Spectra of the sound received at various ranges from the drill string are shown for the case of drilling (Fig. 2) and SPT (Fig. 3). Ambient noise was higher inside Geraldton harbor than off James Price Point. The spectra recorded of drilling surpassed ambient levels within a 30 Hz–2 kHz band at Geraldton and within a 20 Hz–20 kHz band at James Price Point. Recorded SPT levels surpassed ambient levels within a 20 Hz–24 kHz band at both locations. The means of the measurements of the SPT pulse waveforms are summarized in Table 1. The broadband (30 Hz–2 kHz) drilling source levels were 145 dB re 1 μPa @ 1 m for the *Sideson II* at Geraldton and 142 dB re 1 μPa @ 1 m at James

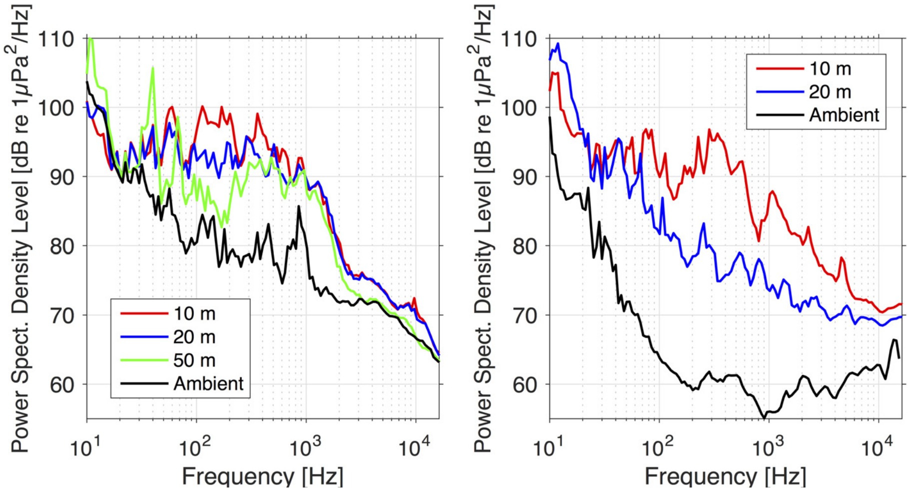

Fig. 2. (Color online) Power spectral density levels of drilling received at various ranges from the drill string at Geraldton (left) and James Price Point (right), compared to ambient noise at both sites—averaged over 10 min.

Price Point. The broadband (20 Hz–24 kHz) SPT source levels were 160 and 151 dB re 1 μPa^{2}s @ 1 m at Geraldton and James Price Point, respectively.

4. Discussion

We measured geotechnical investigations by a jack-up drill rig (*Sideson II*) at short ranges (10–50 m from the drill string) in two different locations: at the Port of Geraldton and off James Price Point, Western Australia. Recorded spectral levels varied by up to 15 dB at some frequencies between the two locations and different recorder ranges. This variability in the spectral shape has been noted by others recording at such short ranges from drilling[3] and pile driving.[4] The underwater sound field is a superposition of sound from simultaneously operating sources travelling along different propagation paths. In the case of legged platforms like jack-up rigs or oil rigs, the main engine, generators and machinery on the platform generate noise that travels through the legs into the water and seafloor. Noise generated on the platform in air may also reach a receiver underwater via direct air-to-water transmission that is effective for incidence angles of less than 13° from the vertical. Noise also originates at the drill bit under ground and at the vibrating drill string and casing in the water. In the case of pile driving, a waterborne acoustic wave is generated from the small mechanical deformation of the pile that travels from the hammer, down the pile, into the ground and reflects back upward. Because of the number of sound generating mechanisms and propagation paths involved, the sound field in the water critically depends on the recorder location and depth, in particular below and near the rig.

On the basis of the recordings at 10 m range from the drill string and a geometric spreading model, broadband source levels of drilling were similar in both

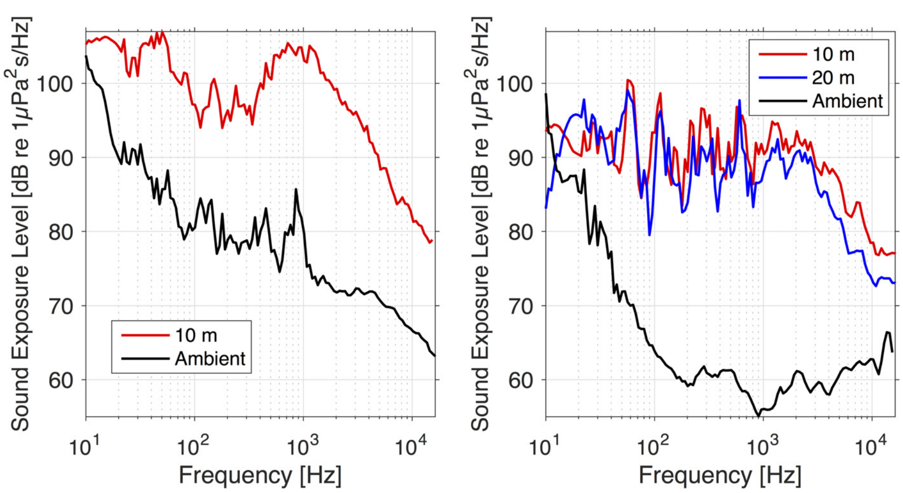

Fig. 3. (Color online) Sound exposure levels of SPT received at various ranges from the drill string at Geraldton (left) and James Price Point (right), compared to ambient noise at both sites.

Table 1. Received zero-peak level (*PK*), peak-peak level (*PK-PK*), pulse duration (T_{90}), root-mean-square sound pressure level over T_{90} (SPL_{90}), *SPL* over a 125 ms window, and sound exposure level (*SEL*) measured from *n* SPT pulses recorded at Geraldton and James Price Point at 10 and 20 m range.

	n	PK [dB re 1 μPa]	PK-PK [dB re 1 μPa]	T_{90} [ms]	SPL_{90} [dB re 1 μPa]	125 ms SPL [dB re 1 μPa]	SEL [dB re 1 μPa^2s]
Geraldton 10 m	40	167 ± 1	172 ± 1	35 ± 12	154 ± 1	151 ± 4	140 ± 1
James Price Point 10 m	10	158 ± 2	164 ± 2	50 ± 7	144 ± 1	147 ± 5	131 ± 1
James Price Point 20 m	13	155 ± 2	161 ± 2	48 ± 5	141 ± 2	144 ± 6	128 ± 1

locations: 145 and 142 dB re 1 μPa @ 1 m (30 Hz–2 kHz). These levels compare well with those recorded of a diamond coring rig in an ice-covered lake in Canada:[3] 142 dB re 1 μPa @ 1 m (1 Hz–22 kHz). [Note that we computed this broadband source level from the reported received level at 5 m by applying a geometric spreading term.] The diamond coring rig operated in 15 m of water (compared to 7–13 m at the Western Australian sites), used a 64 mm drill bit (compared to the 83 mm drill bit used by the *Sideson II*), and was recorded at 6 m depth and 5 m range (compared to 6–11 m depth and 10–20 m range in Western Australia). In all three datasets, the drilling spectra peaked between 40 and 400 Hz and exhibited tonal components.

Levels of geotechnical drilling were less than from oil production drilling,[5,6] which is done from larger platforms. In particular in the case of drillships, noise from deck couples well into the water directly through the hull. Furthermore, production drilling is accompanied by greater and more powerful support operations involving support vessels and helicopters, resulting in a composite underwater noise field. Noise around a Floating Production, Storage and Offloading (FPSO) vessel varied by 40 dB depending on operations.[7] Even small support boats with outboard engines can have broadband levels exceeding those of geotechnical drilling operations reported here.[8] Noise from the actual drill bit under ground and the vibrating drill string and casing in the water can be lower than from accompanying machinery and operations, resulting in little increase in noise when the rig is actively drilling.[9] Summaries of underwater noise from oil and gas production can be found elsewhere.[10–13]

SPT, which is also part of geotechnical investigations, involves hammering a small tube into the ground by actions of a dropping weight (hammer), and so the resulting noise underwater is pulsed and can be likened to that from pile driving. However, pile driving for construction purposes involves much larger piles and hammers. For example, in another shallow-water Australian environment, bridge pillars of 75–150 cm diameter were driven into the ground by a 12–14 t hammer, resulting in an *SEL* of 179–183 dB re 1 μPa^2s at 14 m range.[2] By comparison, SPT generally uses tubes of 50 mm diameter and hammers of <100 kg, and received levels are lower, 131–140 dB re 1 μPa^2s at 10 m range.

Altogether, underwater noise from geotechnical site investigations was up to 35 dB above ambient levels at certain frequencies and hence likely detectable by various taxa of marine fauna. Levels were tens of dB less than those from production or construction operations and below levels commonly considered in marine noise regulations.[14]

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