Review of Down-the-Hole Rock Socket Drilling Acoustic Data Measured for White Pass & Yukon Route (WP&YR) Mooring Dolphins

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May 28, 2020

Illingworth & Rodkin, Inc. (I&R) measured sound levels associated with the installation of 42-inch diameter steel piles that were constructed as mooring dolphins for the White Pass & Yukon Route (WP&YR) railroad dock in March 2019. The pile installation included down-the-hole (DTH) drilling of the pile sockets and rock anchors. According to the pile log sheets, piles were driven in 35 to 37-meter (m) deep water. The piles were installed about 15 to 17m into the bottom substrate with a vibratory and impact hammer. The piles were then advanced about 3 m into the "hard competent rock using DTH drilling techniques to drill rock sockets. Finally, 8-inch diameter rock anchor tensions were installed using DTH drilling techniques. Hydrophones were deployed at various positions from the pile, ranging from 12m to 1.4 kilometers (km) from rock sockets and 19 to 700m for rock tension anchors. Hydrophone depths were either 5 or 20m within 120m of the pile and 5 and 30 m deep in the deeper waters at distances up to 1.4 km.

At the time sound levels were measured in Skagway for WP&YR, the activity was assumed to produce continuous sounds and the measurement approach was designed to capture continuous sounds in fixed 1-second time intervals during the activity (Reyff and Heyvaert 2019). National Marine Fisheries Services (NMFS) now classifies the types of sounds based on Southall *et al*. (2007) suggested criteria of using a 3-dB difference in measurements between the continuous and impulse settings of a sound level meter (SLM). Specifically, if the SLM root-mean-square (rms) sound pressure level measurement from the impulse setting (a 35-msec window) is 3-dB or greater than the continuous setting (a 1-sec window, defined as slow response in a SLM), the sound is classified as impulsive. In the case of the sounds measured in Skagway, the difference between impulse and slow-response sound pressure level was 5 dB. The WP&YR report reported DTH sounds as continuous and did not include sound level pressure measurements for pulses. This paper computes the SEL per pulse and provides an estimate of RMS over the pulses.

DTH drilling uses a combination of percussive and drilling mechanisms with the hammer acting directly on the sediment to advance the pile. Therefore, the drilling and hammering of the sediment below the pile is the source of the sound, not the pile. I&R referenced measurements for this activity based on the distance from the drill tip rather than the pile. Other studies reported for DTH sounds have referenced sound levels based on distance to the pile (Dennes *et al.* 2016 and 2019, Guan and Miner 2020). To be consistent with other studies and acoustic thresholds that rely on two-dimensional propagation, this paper provides an adjustment of the reported sound levels to be referenced to the pile, as if the pile were the source of sound.

Sound levels for rock socket DTH drilling normalized to 10 m from the source (not pile) were summarized in the WP&YR 2019 report in Table 1. Note that these sounds were comprised of percussive hammering that was consistent throughout much of the measured driving period.

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Table 1 42-inch diameter pile rock socket DTH sound levels, 10 meters from sound source

Metric	Transmission Loss Coefficient	Unweighted Median Level	Weighted LF Cetacean Level	Weighted MF Cetacean Level	Weighted HF Cetacean Level	Weighted Phocid Pinnipeds Level	Weighted Otariid Pinnipeds level
Peak	16.7	203 dB					
$RMS_{impluse}$	~15.9	184 dB					
RMS	~15.9	179 dB (1 sec)					
SEL	16.2	212 dB	210 dB	180 dB	175 dB	199 dB	199 dB

It should be noted that the maximum measured peak was 199 dB and that the pulse results were not measured, but rather computed from SEL using 0.035sec and measured using RMS impulse detector. The distance to unweighted 120 dB criterion based on continuous RMS was computed to be 43 kilometers. The approximate distance to the 160 dB (pulse) based on $RMS_{impulse}$ was 330 meters.

The same type of data for rock tension anchors were summarized in the same report are shown in Table 2. Unlike rock socket drilling using DTH techniques, the rock anchor impulsive DTH drilling was intermittent.

Table 2. 10-inch diameter rock anchor drilling/DTH sound levels, at 10 meters from sound source.

Metric	Transmission Loss Coefficient	Unweighted Median Level	Weighted LF Cetacean Level	Weighted MF Cetacean Level	Weighted HF Cetacean Level	Weighted Phocid Pinnipeds Level	Weighted Otariid Pinnipeds level
RMS	28	157 dB (1 sec)					
SEL	28	193 dB (4265 sec)	191 dB	173 dB	171 dB	184 dB	184 dB

It should be noted that the maximum peak was 170 dB at 36 meters. The distance to the unweighted 120 dB criterion was 205 meters.

Reanalysis of 42-inch Diameter DTH Rock Socket Data

Adjustment for Distance

The sound levels were adjusted to the hydrophone distances from the pile. The distances to the source and pile, as shown in Table 3, were used to adjust sound levels.

Table 3. Distance from hydrophone to sound source and pile

Distance from DTH source	Distance from Pile
32m (20-m depth)	12m
47m (5-m depth)	12m
104m (20-m depth)	100m
1.4km (30-m depth)	1.4km
1.4km (5-m depth)	1.4km

This adjustment lowered the reported near-source (10-meter) levels but also resulted in a decreased transmission loss (TL) coefficient, as shown in Table 4.

Table 4. Relationship of median sound level and distance from sound source and pile.

Descriptor	Distance from DTH source	Distance from Pile	Computed 10m Level
Peak	RLpeak=219-16.7*Log(Distance)	RLpeak=210-13.8*Log(Distance)	196 dB
SEL	RLSELs=195-16.2*Log(Distance)	RLSELs=187-13.3*Log(Distance)	174 dB
RMSimp	Not reported	RLimp=191-13.1*Log(Distance)	178 dB

The median 1/3rd octave band frequency spectra, based on 1-second energy-average (or $Leq_{[1\ sec.]}$) sound levels, are shown in Figure 1 for the various distances from the pile.

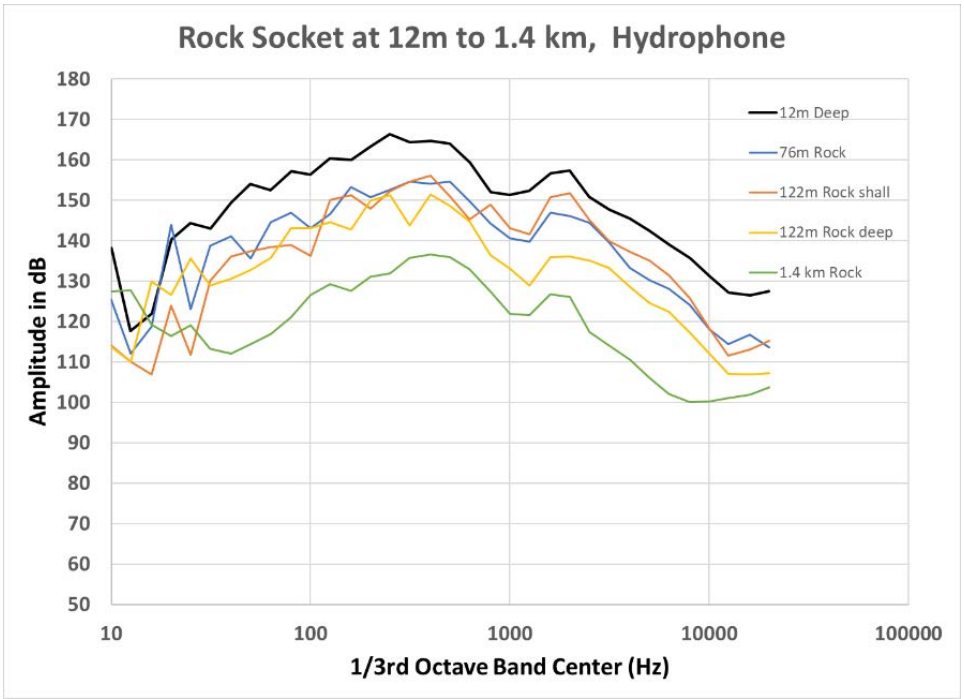

Figure 1. 1/3rd octave band frequency spectra for rock socket DTH sounds

Weighted frequency adjustments (WFAs) for marine mammal hearing groups were computed from Median SEL for Rock Socket levels, based on the data shown in Figure 1. These are presented in Table 5.

Table 5. Marine Mammal WFAs Computed from Median SEL for Rock Socket Drilling

Position / Pile Event	LF	MF	HF	Otariid	Phocid
12m Average	-2.1	-31.6	-37.5	-13.5	-12.8

Treating DTH Sounds as Impulsive

Treating DTH sounds as impulsive has two effects: (1) the SEL criteria for PTS injury is greater for impulsive sounds and (2) the RMS sound pressure level is computed only over the shorter portion of individual pulses that contain 90 percent of the sound pressure.

The measured sounds from DTH drilling for WP&YK were dominated by the percussive hammering as shown below in the time history plot of sound pressure. Sound pressure levels were 40 dB above background and consistent throughout much of the event shown in Figure 2 that lasted approximately 10 minutes[2]. Therefore, SEL can be measured over the duration of the activity rather than over each pulse. Accumulated SEL was measured based on the accumulated SEL measured over the duration of activity.

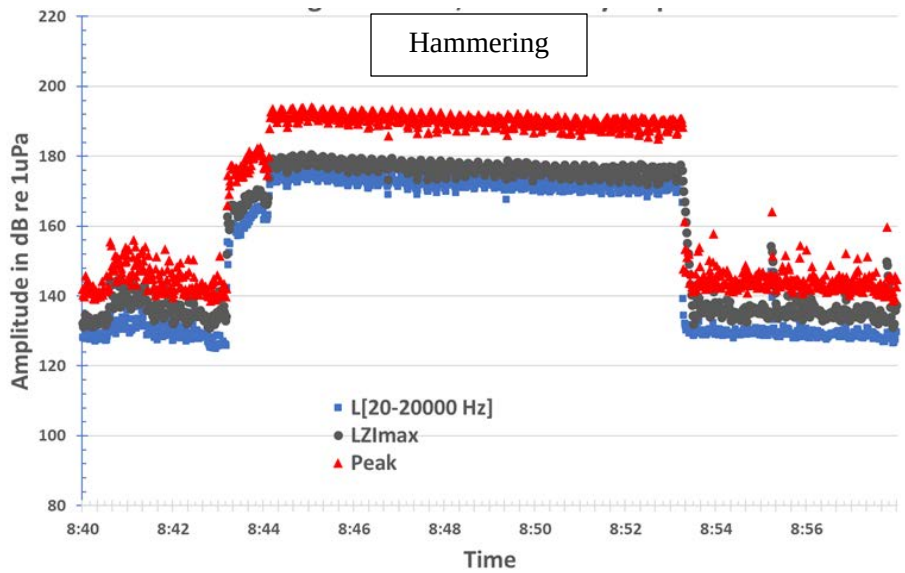

Figure 2. Time history of DTH drilling event at 12 meters form pile.

A short selection of the driving period at the deeper hydrophone that was 12 m from the pile was examined to measure the pulse levels. The time history of sound pressure over one second, shown in Figure 3, reveals the duty cycle of DTH drilling with the percussive hammer to be 10 Hz. For this 1 second time period, the SEL measured and reported with a SLM was 175 dB[3]. Individual pulses would have a SEL that has one-tenth the acoustic energy or 165 dB. A sample analyzed found the pulse SEL levels to be 165 to 166 dB with a time duration of about 0.032 seconds. The pulse RMS sound pressure level was computed at 180 to 181 dB over this duration. The SLM measurement for that same sample with the impulse RMS detector was 180 dB.

[2] Note this was just a portion of the DTH drilling required to complete the rock socket for this pile as the activity was suspended that day. Another pile required a total of 34 minutes DTH drilling.

[3] Note that this chosen selection of data examined had a higher sound level than the median level of the entire driving period for both deep and shallower positions (175 dB vs 173 dB overall).

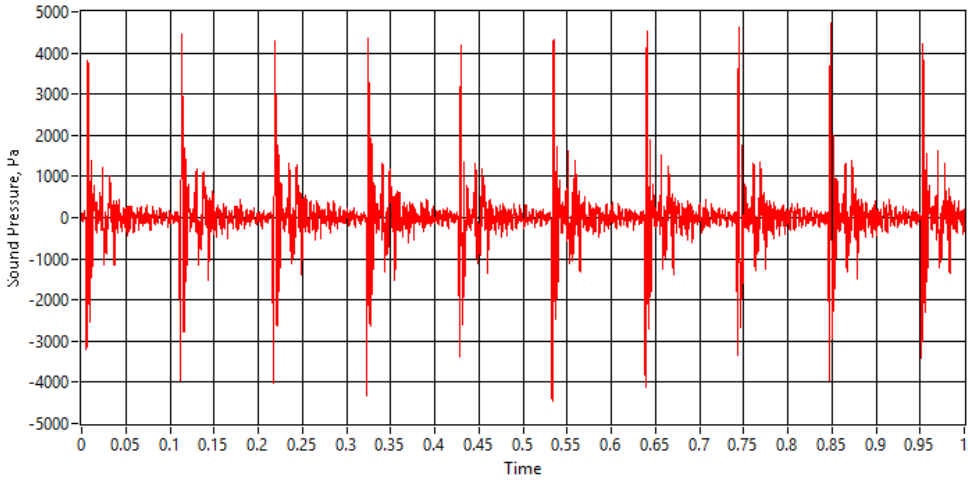

Figure 3. Time History – One Second of DTH Pulses at 12m from Pile

There were two different DTH drilling events measured. The first event was the entire drilling period that lasted 2,036 seconds. The second event lasted only 604 seconds and drilling could not be completed that day. The cumulative SEL at 10 meters from the pile for the complete drilling event is computed as 174dB + 10*Log(2036sec) = 207dB, where 174 dB is the median SEL for one second of DTH at 10 meters from the pile.

Reanalysis of 8-incha Diameter Rock Tension Anchor Data

Rock tension anchor drilling included sounds from drilling/clean-out and rock hammering. Hammering occurred intermittently. The installation of three casings were measured with the first and third events being the loudest and most representative. The distances to the source and pile, as shown in Table 6, were used to adjust sound levels.

Table 6. Distance from hydrophone to sound source and pile

Distance from DTH source	Distance from Pile
1st Event	
37m (20-m depth)	22m
40m (20-m depth)	27m
88m (20-m depth)	85m
3rd Event	
36m (20-m depth)	19m
91m (20-m depth)	85m
116m (20-m depth)	110m
120m (5-m depth	110m

This adjustment lowered the reported near-source (10-meter) levels but also resulted in a decreased transmission loss (TL) coefficient, as shown in Table 7.

Table 6. Relationship of sound level and distance from sound source and pile.

Descriptor	Distance from DTH source	Distance from Pile	Computed 10m Level
SEL	RLSELs=203-35.4Log(Distance)	RLSELs=180-24.2Log(Distance)	156 dB

Since the impulsive sounds from this activity were intermittent, additional analysis were conducted to identify levels during percussive hammering (see Figure 4). The third event captured provided the cleanest sounds from the hammering. Note that these sounds also included other construction related sound; therefore, the hammering sounds had to be isolated. This was done by only analyzing the sounds above the background when hammering was not occurring. The median $Leq_{[1\ sec]}$ levels measured at 22 and 19 meters from the pile were used to characterize the impulsive sounds during this activity. The computed transmission loss of 23.5* Log of the distance was used to adjust these sound levels to a distance of 10 meters from the pile.

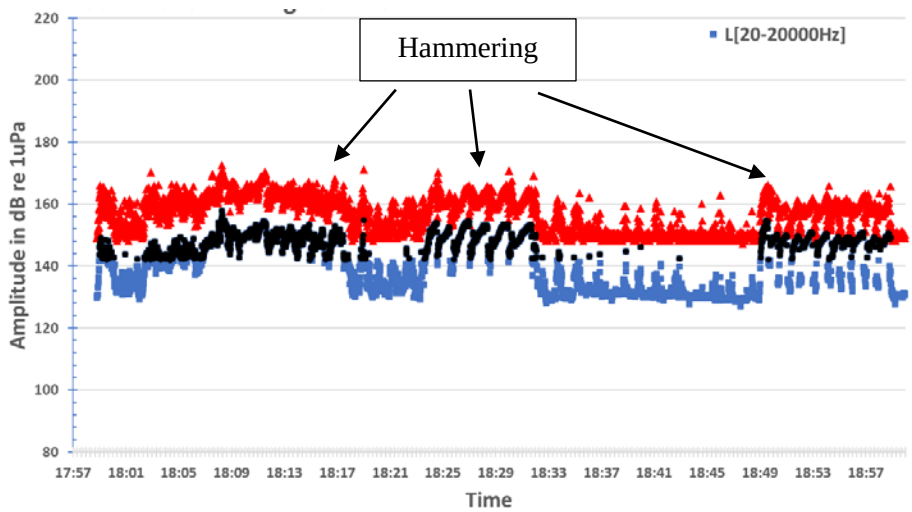

Figure 4. Time history of rock anchor DTH sound levels (red is peak and blue/black is $Leq_{[1\ sec]}$)

The computed median one-second $Leq_{[1\ sec]}$ for hammering sounds was 149 dB at 19 m. The near source level was 154 dB when using a 15* Log (distance from pile) regression equation. The maximum peak sound pressure level at 10 meters from the pile was computed as 174 dB. Pulses from the rock anchor drilling are shown in Figure 5. The hammering rate was about 15 Hz.

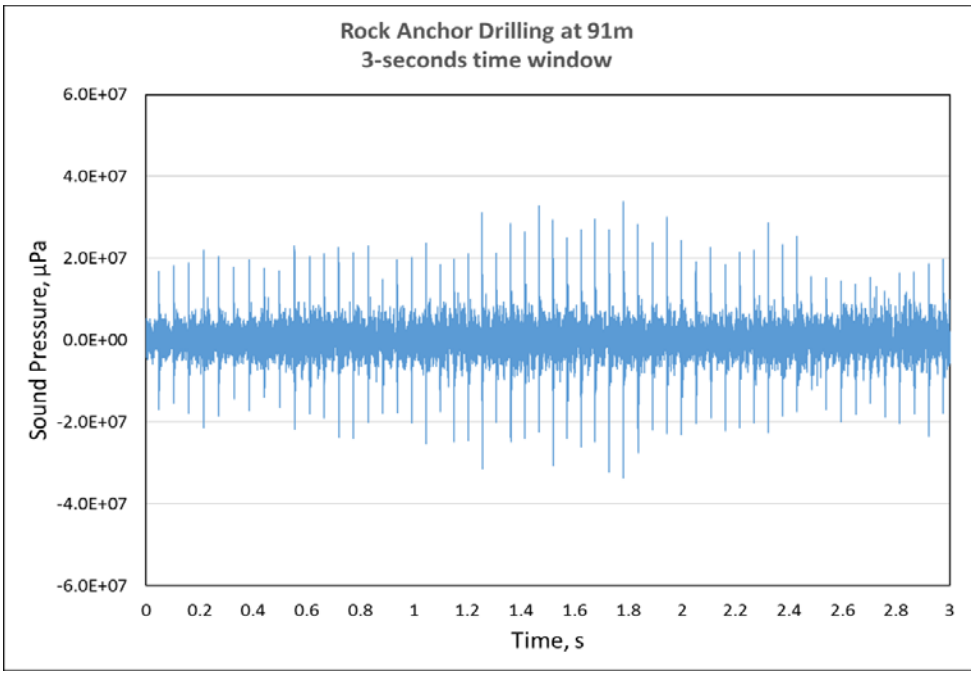

Figure 5. Time History – Three seconds of DTH pulses at 85 m from pile.

The median 1/3rd octave band frequency spectra, based on 1-second energy-average (or $Leq_{[1\ sec.]}$) sound levels, are shown in Figure 6 for the various distances measured from the pile.

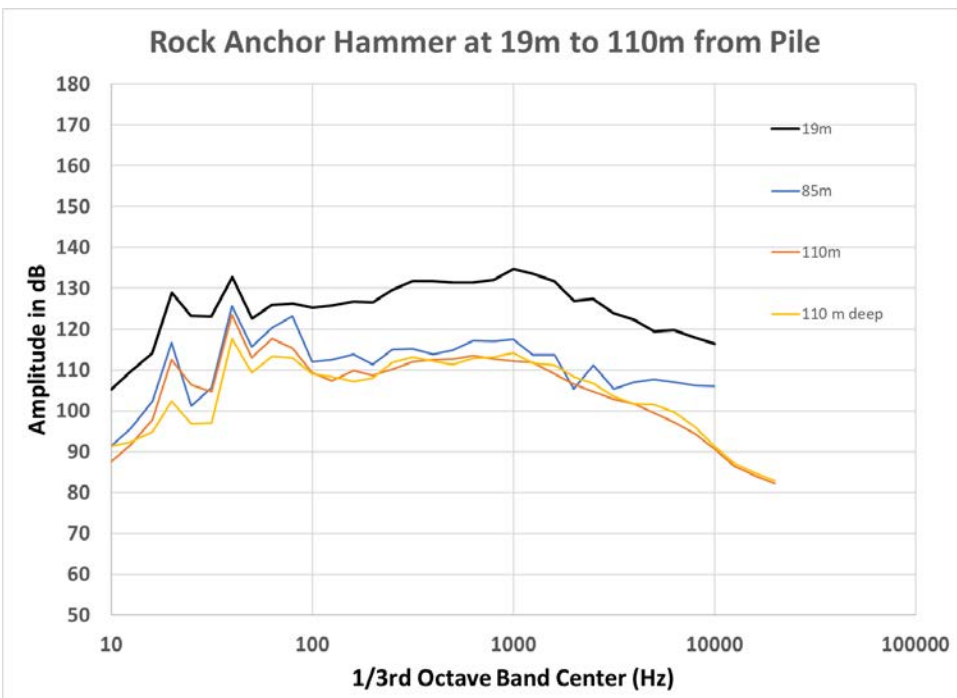

Figure 5. 1/3rd octave band frequency spectra for rock socket DTH sounds

Weighted frequency adjustments (WFAs) for marine mammal hearing groups were computed from Median SEL for Rock Socket levels, based on the data shown in Figure 1. These are presented in Table 5.

Table 7. WFAs Computed from Median SEL for Rock Anchor Drilling

Position / Pile Event	LF	MF	HF	Otariid	Phocid
19-22m Average	-3.8	-21.1	-23.6	-10.5	-10.8

Summary of WP&YR DTH Data and Comparison to Others

The WP&YR data are summarized and compared with other data based on measured sound levels at 10 meters from the pile.

Project	Pile Size (diameter in inches)	Hammer Rate	SEL (pulse)	SEL (sec or cont.)	RMS (pulse)	Peak
Skagway WP&YR Rock Socket	42-in	10Hz	164dB*	174dB	178dB 0.03sec	194dB
CTJV Thimble Shoals	42-in	7.5Hz	164dB	172dB*	180dB 0.02sec	190dB
AKDOT&PF Kodiak	24-in	15.5Hz	154dB*	166dB	NR	NR
Biorka Island	18-in	13Hz	146dB	157dB*	162dB 0.03sec	172dB
Skagway WP&YR Rock Tension Anchor	8-in	15 Hz	144 dB*	156 dB	NR	<170 dB

*Computed level from data set using hammering rate
NR = not reported

References

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