California Department of Transportation
Division of Environmental Analysis
Environmental Engineering
Hazardous Waste, Air, Noise, Paleontology Office

CALTRANS Engineering Technical Brief

OVERVIEW OF THE EVALUTION OF PILE DRIVING IMPACTS

ON FISH FOR THE PERMITTING PROCESS

Technical Advisory, Hydroacoustic Analysis

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NOTE: This technical advisory only applies to fish and should not be used to address pile driving impacts on other species such as marine mammal or turtles. Vibratory pile driving is considered to be a mitigation approach for reducing effects from impact pile driving on fish and is not assessed for potential injury to fish. Vibratory driving however may affect marine mammals so vibratory driving must be considered when marine mammals are present. Metric distance units are used in this advisory because of Caltrans' metrification legacy. When research on this topic began in the early 2000's, typical pile driving reference measurements were taken at 10 meters from the pile.

Introduction

Impact pile driving that is conducted in or near waterways can generate high levels of underwater sound pressure that have the potential to injure or kill fish. If fish that are protected by state or federal laws are expected to be present when pile driving will occur, an evaluation of the effects of pile driving sound on the fish must be conducted as part of the permitting process. The purpose of this advisory is to provide a brief overview of the impact evaluation procedure and data that are needed to complete the assessment process. Refer to the Caltrans document entitled "Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish" for a detailed discussion of this topic.

Fundamental Concepts

When a pile is struck with an impact hammer the pile vibrates and radiates sound energy into the water. Figure 1 below shows the pressure modulations associated with a single pile strike. The peak sound pressure occurs immediately after the pile is struck. The pile will then continue to ring for a few hundred milliseconds. One way to characterize the sound produced by the pile strike is to measure the peak sound pressure expressed in decibels relative to 1 micro-pascal. This is called the Peak Sound Pressure Level or L_{PEAK}.
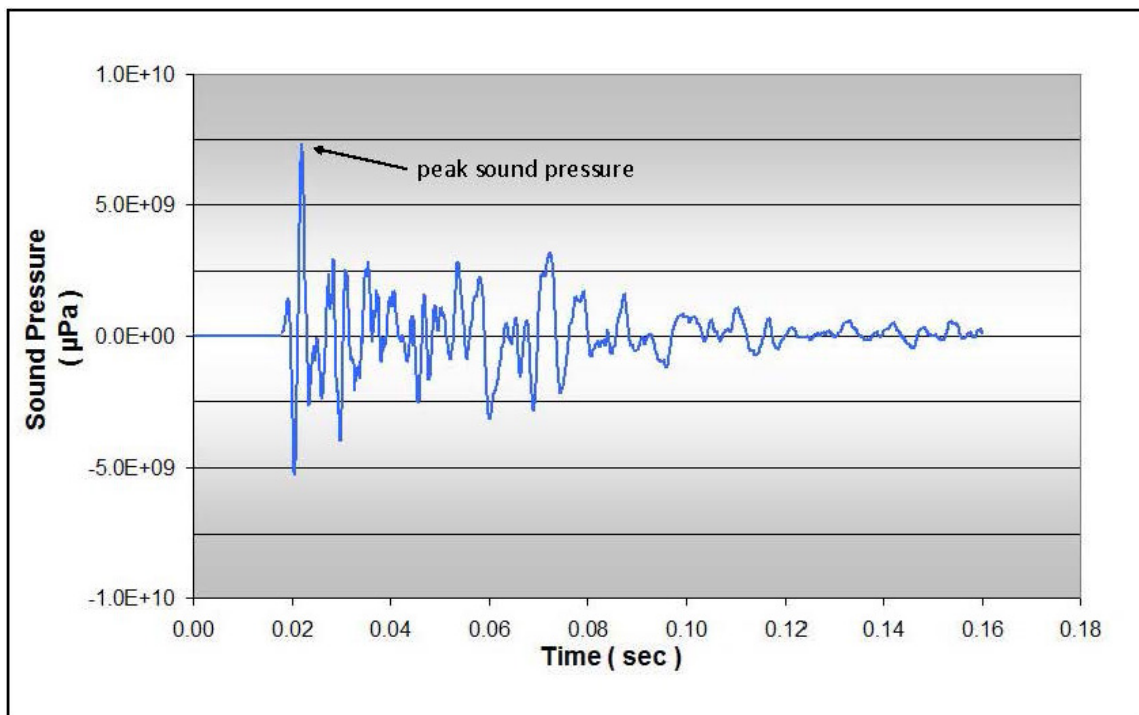

Figure 1. Sound Pressure Resulting from Pile Strike

Another way to quantify the sound associated with a pile strike is to measure the total energy associated with the pile strike. This is commonly expressed as the Sound Exposure Level or SEL. The total sound energy associated with the pile strike is summed and normalized to 1 second. The figure below shows how sound energy from a single strike accumulates over time to reach a maximum value. For a given pile and pile strike the SEL value is typically 25 dB less than the peak level.
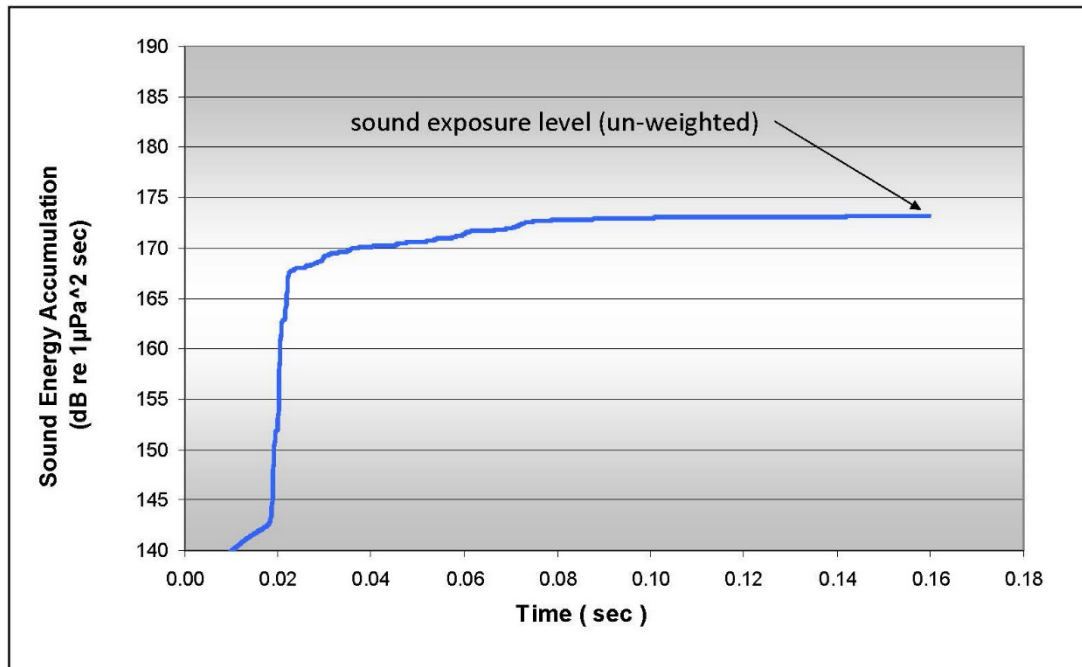

Figure 1. Sound Energy Accumulation Resulting from Pile Strike
Note: This is an 'un-weighted' sound energy scale and does not use the A-weighting scale normally applied to human hearing.

Because pile driving involves a series of pile strikes throughout the day the cumulative sound energy associated with the pile strikes that occur in one day is also used. The cumulative SEL or SEL$_{CUMULATIVE}$ is determined by adding up the sound energy associated with all pile strikes that occur over a given day. If the single strikes SEL and the number of daily strikes is known the cumulative SEL can be calculated with the following equation:

$$SEL_{CUMULATIVE} = SEL_{SINGLESTRIKE} + 10Log \text{ (number of strikes)}$$ eq. 1

A final metric that is sometimes used to characterize pile driving sound is the Root-Mean-Square or RMS level. This is essentially an average of the sound energy associated with a single strike.

Sound levels diminish over distance as a result of many complex factors. For the purposes of this type of analysis a simplified approach is taken. Sound is assumed to diminish at a rate of 4.5 dB per doubling of distance. This is generally a conservative approach and should be used unless there is site-specific

information indicating that a different attenuation rate is appropriate. Attenuation is calculated with the following equation:

$$dB_2 = dB_1 - F*\log (D_2/D_1) \qquad\qquad\qquad eq.\ 2$$

where: dB_1 is the sound level at a distance of D_1 from the pile

dB_2 is the sound level at a distance of D_2 from the pile

F = attenuation factor (attenuation is 4.5 dB per doubling of distance where F = 15)

EXAMPLE: If pile driving produces a sound level of 206 dB_{PEAK} at a distance of 10 meters, the sound level at a distance of 200 meters can be calculated as follows:

$$dB_{200} = dB_{10} - 15\log(200/10) = 206 - 19.5 = 186.5 \sim 187\ dB$$

If it is desired to know how much distance is needed for a pile driving sound level to diminish to a specific sound level, the following equation can be used:

$$D_2 = D_1 * 10^{((dB2-dB1)/15)} \qquad\qquad\qquad eq.\ 3.$$

EXAMPLE: If pile driving produces a cumulative sound level of 214 dB at 10 meters the distance at which the sound level diminishes to 187 dB can be calculated as follows:

$$D_{187dB} = 10 * 10^{((214-187)/15)} = 10 * 631 = 631\ meters$$

Interim Injury Criteria

Acoustic criteria intended to protect fish from harm and mortality from pile driving activities were adopted by Caltrans, FHWA, the California Department of Fish and Wildlife, the U.S. Fish and Wildlife Service, and the NOAA Fisheries Northwest and Southwest Regions in 2008. These "interim injury criteria" are now routinely used to evaluate the effects of impact pile driving sound on fish. **These criteria do not apply to vibratory pile driving. Vibratory pile driving is considered to be a mitigation approach for reducing effects to fish from impact pile driving and is not assessed for potential injury to fish. Vibratory driving however may affect marine mammals so vibratory driving must be considered when marine mammals are present.** Table 1 summarizes the adopted interim criteria.

Table 1. Interim Injury Criteria for Fish

Interim Injury Criteria	Agreement in Principal
Peak	206 dB
Cumulative SEL	187 dB – for fish size of two grams or greater
	183 dB – for fish size of less than two grams

An additional assessment threshold that has been identified by NMFS is that a level of 150 dB_{RMS} should be used to assess if a pile driving project will have behavioral effects on fish.

Impact Assessment Process

The pile driving impact assessment process has two components: an acoustic calculation component and a biological component. Typically an experienced noise analyst will work with a fish biologist to complete the assessment. The analyst will collect technical engineering information on the proposed pile driving activity and prepare a summary of pile driving underwater sound predictions. These predictions are expressed in the form of distances within which an applicable threshold is predicted to be exceeded. For example, calculations may indicate that the 187 dB$_{SEL}$ threshold would be exceeded within 350 meters of a pile driving site. The assumption from a biological perspective is that any fish present within that distance would be injured. The biologist then uses these predictions to evaluate pile driving effects on fish in the context of the biological and regulatory setting of the project.

Effective Quiet

An important concept in the prediction process is the concept of "effective quiet." When the received SEL from an individual pile strike is below a certain level, then the accumulated energy from multiple strikes would not contribute to injury, regardless of how many pile strikes occur. This SEL is referred to as "effective quiet" and is assumed to be 150 dB. **Effective quiet establishes a limit on the maximum distance from the pile where injury to fishes is expected. This distance is the distance at which the single-strike SEL diminishes to 150 dB. Beyond this distance, no physical injury is expected, regardless of the number of pile strikes.** However, the severity of the injury can increase within this zone as the number of strikes increases.

For each cumulative SEL criterion (187 dB and 183 dB) there is a maximum number of daily strikes associated with effective quiet. Once the number of daily strikes exceeds this maximum number the distance within which the injury criterion would be exceeded does not increase. The number of strikes associated with effective quiet is as follows:

> 187 dB – 5,012 strikes

> 183 dB – 1,995 strikes

Key Data Needed

The following is key information needed by the acoustic analyst to complete the underwater sound level predictions:

- Layout map showing the location of all impact driven piles
- A description of all piles to be installed (i.e. 24-inch steel pipe, 16-inch round concrete, 16-inch H pile)
- The number of pile strikes needed to install each type of pile (this should be a high, conservative estimate)
- The number of piles that can be installed in one day (this should be a high, conservative number as well).

The depth to the tip elevation of the pile may also be useful. Although this information is not used directly in the hydroacoustic analysis, it can be used in the field to monitor project progress and assist in determining if the project can remain on schedule.

Typically project engineers do not have this level of detail at the point in time that the hydroacoustic assessment needs to be done. It is however very important that the project engineer and not the noise analyst develop reasonable worst case pile strike estimates because the estimates drive the analysis results which are typically part of the permit conditions. **During the construction phase, Caltrans will typically be held to the results of the hydroacoustic analysis results in the permit conditions so it is important to be conservative with the pile strikes estimates.**

Calculations

The following are key steps in the underwater noise prediction process:

Step 1. Source levels for the pile being analyzed are developed. The Caltrans document entitled "Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish" contains Appendix I Compendium of Pile Driving Sound Data with a database of measured pile driving sound levels for a wide variety of pile sizes and types in various environmental conditions. From Appendix I, the noise analyst should select a similar pile driven in similar conditions as the pile being evaluated for the project. These sources levels typically include a single strikes peak level, SEL, and RMS level at a reference distance of 10 meters.

Step 2. This distances within which each injury criteria for small and large fish and the behavioral criteria are exceeded are calculated using equation 3. As discussed above, the distances to the injury criteria thresholds cannot exceed the distances to effective quiet. A spreadsheet developed by the NMFS will do this calculation automatically based on source levels provided by the user.

Step 3. If it is anticipated that an attenuation system such as a bubble curtain, dewatered cofferdam, or dewatered (or bubbled) isolation casing will be used, reference levels are typically reduced by 5 dB.

Table 2 on the following page shows the results from a typical hydroacoustic analysis.

Table 2. Sample Hydroacoustic Analysis

	Data provided by Project Design Engineer								Data from Appendix I Compendium of Pile Driving Sound Data					Calculation by Noise Analyst					
									Underwater Sound Level Assumptions							Distance (m) to Threshold			
																Onset of Physical Injury			Behavior
														Cumulative SEL at Reference Distance	Transmission Loss Constant	Peak	Cumulative SEL dB		RMS
Pile Location	Pile Diameter & Type	Driver or Extractor	Total Number of Piles	Piles per Day	Engineer's Estimate of Strikes Per Day	Total Strikes or Vibratory Minutes per day	Total Driving Period[1]	Attenuation (dB)[2]	Peak	SEL	RMS	Reference Distance (m)	Source for Sound Level Assumptions			dB	Fish ≥ 2 g	Fish < 2 g	dB
																206 dB	187 dB	183 dB	150 dB
In-Water Piers	60-Inch Pipe Piles in water	Impact	14	2	1000	2000	24 days	NA	210	185	195	10	Caltrans 2012. Table I.2-1. 60-inch steel CISS pile in water.	218	15	18	1,168	2,154	10,000
In-Water Piers with attenuation from bubble curtain or fully dewatered cofferdam.	60-Inch Pipe Piles in water	Impact	14	2	1000	2000	24 days	5	205	180	190	10	Caltrans 2012. Table I.2-1. 60-inch steel CISS pile in water.	213	15	<10	542	1,000	4,642
Abutment on Land	60-Inch Pipe Piles on land	Impact	4	2	770	1540	24 days	NA	197	173	185	17	Caltrans 2012. Table I.2-3A. 66-inch steel pipe pile on land. Russian River.	205	15	<10	264	488	3,663
Abutment on Land (using 72-Inch Pipe Pile option)	72-Inch Pipe Piles on land	Impact	4	2	530	1060	8 days	NA	204	175	185	10	Caltrans 2012. Table I.2-1. 72-inch steel pipe pile on land. RMS estimated as 10 dB above SEL.	205	15	<10	165	304	2,154
Temporary Casing Installation	8☐ 10☐Diameter Temp. Pile	Vibratory	1 temp pile used at 14 diff. locations	2 pile installations per day	NA	Total 10 minutes of vibration	24 days	NA											
Temporary Casing Extraction	8☐ 10☐Diameter Temp. Pile	Vibratory	1 temp pile extracted at 14 diff. locations	2 pile extractions per day	NA	Extraction might require vibration (<10min if required)	24 days	NA					Not applicable to vibratory driving.						
Cofferdam Installation	Assumed Cofferdam Size 10☐10☐	Vibratory	16 sheet piles per cofferdam for 14 cofferdams = 224 sheet piles	16	NA	Total 80 minutes of vibration	14 days	NA											
Cofferdam Extraction	Assumed Cofferdam Size 10☐10☐	Vibratory	16 sheet piles per cofferdam for 14 cofferdams = 224 sheet piles	16	NA	Extraction might require vibration (<20min if required)	6 days	NA											

[1] Total driving period is typically need for project permits.
[2] Attenuation of 5 dBA is typically assumed if an attenuation systems such as a bubble curtain, dewatered cofferdam, or dewaterered (or bubbled) isolation casing will be used.