Jones & Stokes

# Memorandum

Date: December 21, 2007

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Subject: **Application of Revised Interim Pile Driving Impact Criteria**

## Background

On December 21, 2007 Dr. Mardi Hastings, Dr. Arthur Popper, and Dr. Thomas Carlson issued an expert memorandum which describes their current recommendations regarding interim criteria for pile driving sound exposure to fish. The purpose of this application memo is to provide some general guidance as to what the criteria in the expert memo mean in practical applications commonly experienced by Caltrans. Information in this application memo is based on the opinions of the authors (Buehler, Oestman, Reyff) only and is not Caltrans policy.

## Revised Interim Criteria

In summary the updated interim criteria are expressed in terms of peak sound level and cumulative SEL and are separated by the three major effects associated with pile driving:

- Non-auditory tissue damage
- Auditory tissue damage (hair cell damage)
- Temporary threshold shift (TTS)

The criteria are further segregated by fish type (hearing specialist or hearing generalist) and fish weight (mass). In California virtually all fish of concern are hearing generalists so the criteria for hearing specialists are generally not applied in California. This discussion focuses on hearing generalist fish only.

Juvenile fish most commonly evaluated in California, e.g. listed species (salmon, steelhead, green sturgeon, etc) during in water work windows have a mass in the range of 2 to 8 grams (g). Migrating smolts would typically have a mass in the range of 8 to 12g. Accordingly, this discussion assumes that juvenile fish have a mass in the range of 2 to 12 g. For most projects

Caltrans pile driving projects, 2 g fish is the smallest fish that would likely be encountered. The most stringent peak criterion for all hearing generalist fish at all types of effects is 206 dB-peak. 206 dB-peak is therefore considered to be the only peak criterion level to be applied.

In summary the cumulative SEL criteria for hearing generalists are as follows:

Non-auditory tissue damage: 183 to 213 dB-SEL sliding scale corresponding to fish mass between 0.5 g and 200 g.

Auditory tissue damage: 189 to 213 dB-SEL

Temporary threshold shift: 185 dB-SEL

Practical Evaluation of Interim Criteria

Tables 1 and 2 have been prepared which indicate what these criteria generally mean in practical application for a range of typical pile types. The data reported in these tables were collected by Illingworth & Rodkin as reported in Appendix A of the unpublished document entitled "Guidance Manual on the Effects of Sound on Fish-Draft" (Jones & Stokes 2007). Data on the number of pile strikes per day are from a presentation to the Fisheries Hydroacoustic Working Group by James Reyff of Illingworth & Rodkin on December 6, 2006.

Unattenuated Impact Pile Driving

Table 1 shows an analysis for unattenuated impact pile driving for four types of typical piles. Single strike peak and SEL source levels are provided along with the number of typical strikes per day. Cumulative SEL values are then calculated from these daily numbers of strikes using the following equation:

Cumulative SEL = 10log(# of strikes) + single strike SEL

For the purposes of this discussion we assume that a fish would not be exposed to more than 1 day of pile driving sound. The exposure model used to evaluate impacts will be a critical aspect of project specific analyses and will need to be a primary point of discussion between Caltrans and the resource agencies.

Underwater sound from pile driving attenuates over distance. Underwater sound attenuation is highly complex and is a function of factors including water depth and substrate type. Illingworth & Rodkin have conducted underwater sound level measurements as far as 1,000 meters from pile driving. Within this distance attenuation rates in the range 2 to 10 dB per doubling of distance have been observed.

For the purposes of this discussion an attenuation rate of 4.5 dB per doubling of distance (15 log function) is assumed. This attenuation rate is used to estimate the distance needed for underwater sound level to attenuate to criterion levels and is considered typical for open water conditions. Because there are no data on underwater pile driving sound levels beyond 1,000 m, no attempt is made to estimate sound levels beyond 1,000 m.

In order to effectively evaluate the results "injury" must be defined. It is understood that the experts who prepared the criteria agree that TTS is not "injury" since it is an effect from which a fish recovers. This will likely be a point of discussion with the resource agencies. For the purposes of this discussion TTS is not considered to be injury. Clearly, tissue damage of any type is injury. The results in Table 1 indicate the distances to which the potential for injury extends beyond 10 m. For the cumulative SEL distances several representative fish masses have been selected. The mass of 0.75 g corresponds to the 185 dB-SEL TTS criterion. The mass of 1.7 g corresponds to the 189 dB-SEL auditory tissue damage criterion and is generally representative of the smallest listed fish likely to be encountered on a Caltrans project (about 2 g).

Figure 1 provides some additional perspective on the non-auditory tissue damage criteria that are a function of fish mass. Accumulated SEL values at reference distances of 10-20 meters are shown for a range of pile types and pile driving strike numbers. Given that most pile installations will require more than 1,000 pile strikes per day, this figure shows that the non-auditory impact criteria will likely be exceeded at 10-20 meters for almost any non-attenuated pile type that is likely to be driven on a Caltrans project.

Attenuated Impact Pile Driving

Caltrans has applied effective methods for attenuating underwater sound from pile driving. These attenuation methods include:

Unconfined air bubble curtains
Air bubble curtain confined in fabric
De-watered isolation casings
Bubbled isolation casings
De-watered coffer dams

Nominal attenuation values that can generally be expected for each type of pile have been estimated from data collected by Illingworth & Rodkin as presented in Jones & Stokes 2007. These are nominal values and will vary depending on site specific conditions. Table 2 repeats the analysis from Table 1 but includes the nominal attenuation that can be expected with the use of an attenuation method. As can be seen the distances within which the criteria would be exceeded can be substantially reduced with the application of effective attenuation measures.

Vibratory Pile Driving

The criteria do not directly address sound from vibratory pile installation which can produce 1-second SELs up to about 155 to 160 dB at 10 meters from sheet piles. With that type of sound level, about 10 minutes of pile installation would generate an accumulated SEL of up to 188 dB. It could be that the non-impulsive type of sound generated by vibratory pile installation could be less injurious. However, sounds from vibratory pile installation could now be an issue.

Background Levels

Since there is no lower limit on the level at which injury or effects to the auditory systems could occur, the contribution of background sound could be significant. This would especially be the case at positions that are quite distant from the pile. For instance, background levels in San Francisco Bay have been measured at 120 to 140 dB RMS. This would equate to an accumulated SEL of 165 to 185 dB over the course of a 10-hour workday or 170 to 190 dB for an entire day. As a result, a lower threshold at which injurious or auditory effects occur is necessary to provide an appropriate evaluation from pile installation activities. Measurements at any position distant from pile driving could result in an accumulated SEL that exceeds the criteria, regardless of the level generated by pile driving. Practical methods for measuring cumulative SEL in the field will need to be developed.

Conclusions

As a practical matter, the analysis indicates that the peak criterion of 206 dB-peak will only come into play for very large piles. This value is comparable to but slightly more stringent than the single strike criterion of 208 dB-peak recommended in Popper et al 2006.

The cumulative SEL criteria will likely govern impact conclusions and mitigation requirements for all pile driving situations. The recommended cumulative SEL criteria in the range of 183 dB-SEL to 189 dB-SEL are substantially more stringent than the single strike 187 dB-SEL criterion recommended in Popper et al 2006. The auditory tissue damage threshold of 189 dB-SEL will govern applications where all fish are greater than 2 g. Where very small fish (<0.5 g) are present the cumulative 183 dB-SEL criterion will govern all impacts conclusions. As a practical matter, Caltrans is unlikely to encounter listed fish smaller than 2 g on any projects. The non-auditory tissue damage threshold for a 2 g fish is 190 dB-SEL. Accordingly, the 189 dB-SEL criteria for auditory tissue damage will likely govern in almost all cases.

Although every project will need to be evaluated on a case-by-case basis, the applicable impact criteria will be 206 dB-peak and cumulative 189 dB-SEL for almost all projects that Caltrans is likely to encounter. On recent projects NOAA has applied 208 dB-peak and cumulative 187 dB-SEL impact criteria. The new recommended peak criterion is 2 dB more stringent than this and the SEL criterion is 2 dB less stringent. Since the cumulative SEL criterion will govern in

almost all cases, the new recommended criteria can, as a practical matter, be considered to be about 2 dB less stringent than the criteria currently applied by NOAA.

Citations

Jones & Stokes 2007. Guidance manual on the effects of sound on fish-draft – Appendix A. Unpublished. Sacramento, CA.

Popper et al. 2006. Interim criteria for injury to fish exposed to pile driving operations. College Park, Maryland.

Table 1. Sample Calculations for Impacts on Hearing Genearlist Fish for Unattenuated Pile Driving

| Pile Type | Size or Diameter | Project | Location | Hammer Type | Water Depth (m) | Measurement Distance (m) | Single Strike Peak | Single Strike SEL | Distance (m) to 206 dB Peak[1] | Typical Number of Strikes Per Day | Accumulated SEL at 10 m For Total Strikes Per Day | Non-auditory Tissue Damage<br>Auditory Tissue Damage<br>TTS | Distance (m) to Cumulative SEL Criterion Level[1 2]<br>, 0.5g Fish<br>-<br>-<br>183 dB SEL | 0.75g Fish<br>-<br>All Fish<br>185 dB SEL | 1.7g Fish<br>All Fish<br>-<br>189 dB SEL | 12g Fish<br>-<br>-<br>199 dB SEL | > 200g Fish<br>-<br>-<br>213 dB SEL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Steel H Pile** | 15-inch thin, battered | Ballena Isle Marina | Alameda, CA - San Francisco Bay | Diesel Impact | 2 to 3 | 10m | 190 | 155 | <10m | 1,300 | 186 | | 16 | 12 | < 10 | < 10 | < 10 |
| **Concrete** | 24-inch Octagonal | Berth 22 Reconstruction, Port of Oakland | Oakland, CA - San Francisco Bay | Diesel Impact | 10 to 15 | 10 m | 188 | 166 | < 10 m | 2,900 | 201 | | 158 | 117 | 63 | < 10 | < 10 |
| **Steel Pipe** | 40-inch | Alameda Bay Ship & Yacht | Alameda | Diesel Impact | 13 | 10m | 208 | 180 | 14 m | 3,000 | 215 | | >1,000 | 1,000 | 541 | 117 | 14 |
| **CISS Steel Pipe** | 96-inch | Benicia-Martinez Bridge, CALTRANS | Benicia, CA - Carquinez Straits | Hydraulic Impact | NA | 10m | 220 | 194 | 86 m | 7,000 | 232 | | >1,000 | >1,000 | >1,000 | >1,000 | 185 |

[1] **15log attenuation (4.5 dB per doubling of distance) assumed**

[2] **Typical juvenile fish generally weigh 2 to 12 g**

Table 2. Sample Calculations for Impacts on Hearing Generalist Fish for Attenuated Pile Driving

| Pile Type | Size or Diameter | Project | Location | Hammer Type | Water Depth | Distance to Pile (m) | Single Strike Peak | Single Strike SEL | Nominal Attenuation [3] | Single Strike Peak Attenuated | Single Strike SEL Attenuated | Distance to 206 dB Peak (m)[1] | Typical Number of Strikes Per Day | Accumulated SEL at 10 m | Non-auditory Tissue Damage<br>Auditory Tissue Damage<br>TTS | Distance to Cumulative SEL Criterion Level[1,2] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | , 0.5g Fish<br>-<br>- | 0.75g Fish<br>-<br>All Fish | 1.7g Fish<br>All Fish<br>- | 12g Fish<br>-<br>- | > 200g Fish<br>-<br>- |
| | | | | | | | | | | | | | | | | 183 dB SEL | 185 dB SEL | 189 dB SEL | 199 dB SEL | 213 dB SEL |
| **Steel H Pile** | 15-inch thin, battered | Ballena Isle Marina | Alameda, CA - San Francisco Bay | Diesel Impact | 2-3m | 10 | 190 | 155 | -5 dB | 185 | 150 | <10 | 1,300 | 181 | | < 10 | < 10 | < 10 | < 10 | < 10 |
| | 14-inch 14x89 HP | Various | Various | Diesel Impact | various | 10 | 197 | 165 | -5 | 192 | 160 | < 10 | 1,300 | 191 | | 34 | 25 | 14 | < 10 | < 10 |
| **Concrete** | 24-inch Octagonal | Berth 32 Reconstruction, Port of Oakland | Oakland, CA - San Francisco Bay | Diesel Impact | 8m | 10 | 184 | 165 | -5 dB | 179 | 160 | < 10 | 2,900 | 195 | | 63 | 46 | 25 | < 10 | < 10 |
| **Steel Pipe** | 40-inch | Alameda Bay Ship & Yacht | Alameda | Diesel Impact | 13m | 10 | 208 | 180 | -10 dB | 198 | 170 | < 10 | 3,000 | 205 | | 293 | 215 | 117 | 25 | < 10 |
| **CISS Steel Pipe** | 96-inch | Benicia-Martinez Bridge, CALTRANS | Benicia, CA - Carquinez Straits | Hydraulic Impact | NA | 10 | 220 | 194 | -20 dB | 200 | 174 | <1 0 | 7,000 | 212 | | 858 | 631 | 341 | 74 | < 10 |

**[1] 15log attenuation (4.5 dB per doubling of distance) assumed**

**[2] Typical juvenile fish generally weigh 2 to 12 g**

## Figure 1. Accumulation of SEL Based on SEL per Strike