Hydroacoustics and Biological Evaluation of Bridge Foundations

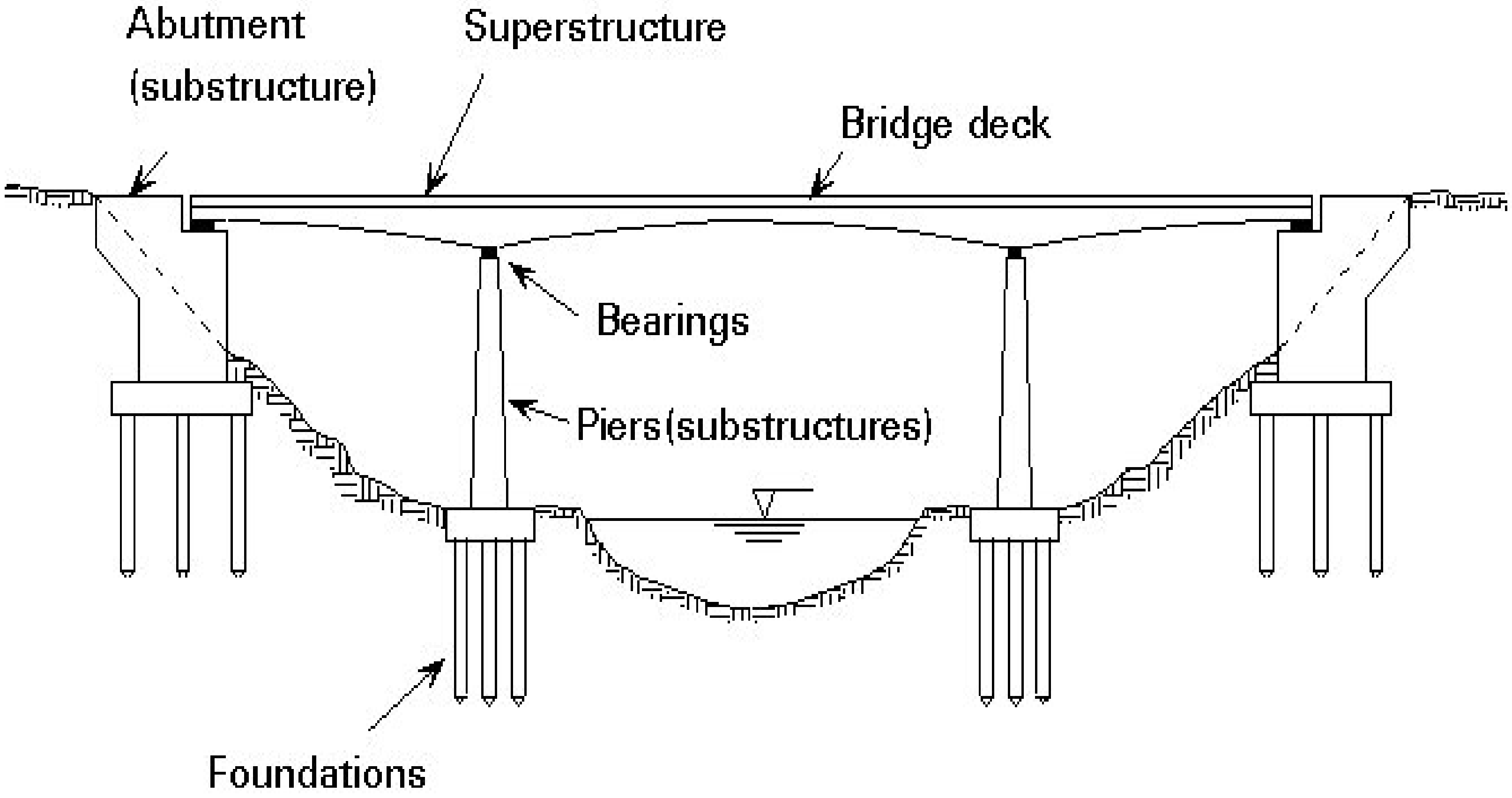
Smaller Bridges

Larger Bridges

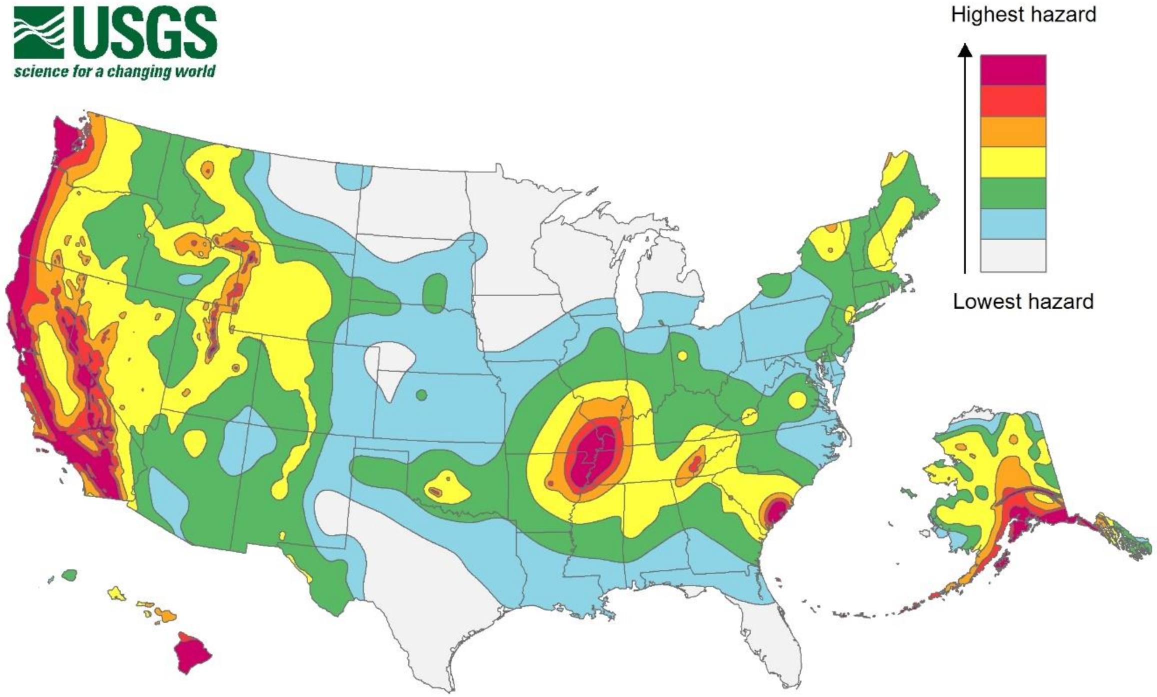
Summary of Topics

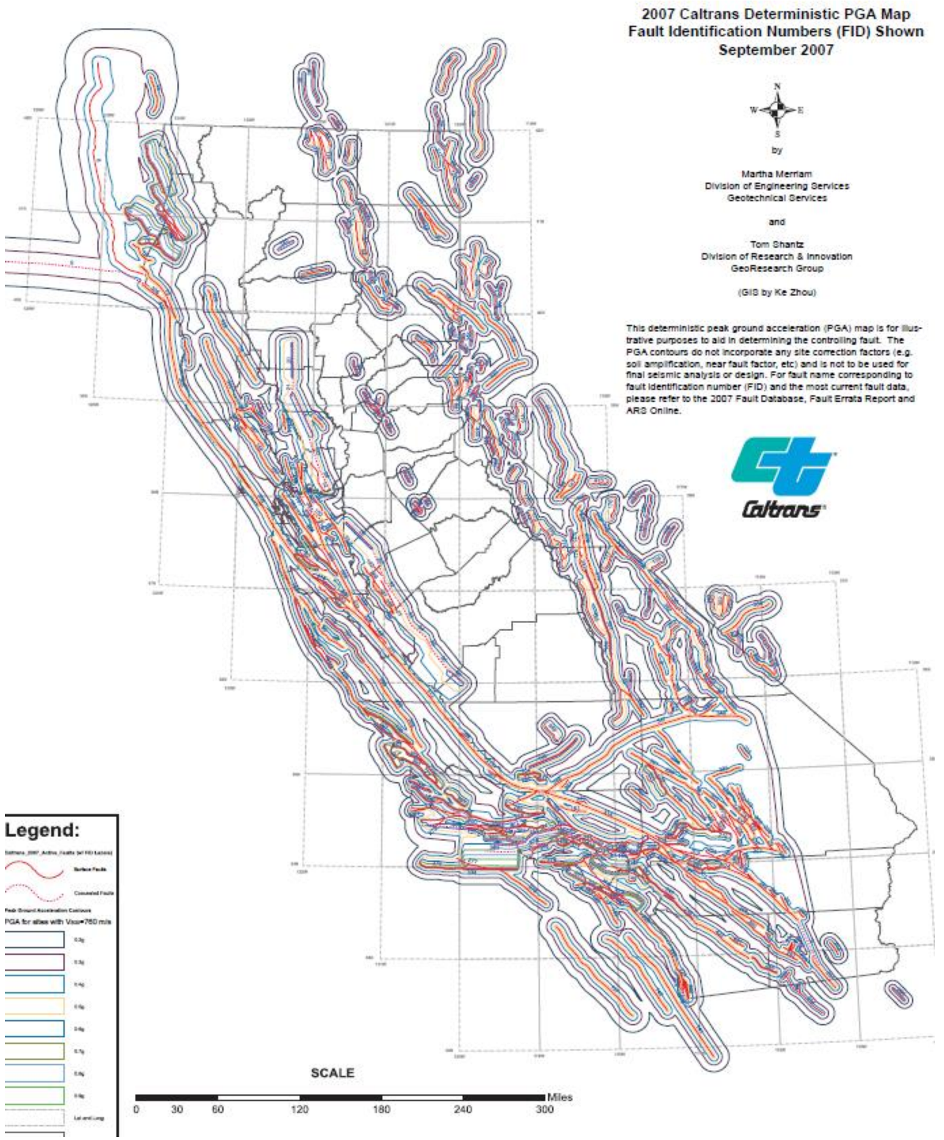
- Bridge components, foundation types and application
- Construction methods, biological pros and cons
- Principles of hydroacoustic impacts to fish
- Avoidance and attenuation
- Analysis
- Monitoring and reporting
- Research

- **Superstructure**: Bridge components that span end-to-end
- **Substructure**: Columns and Bent Caps, Abutments
- **Foundation:** Piles and footings



Seismic Hazard





2007 Caltrans Deterministic PGA Map
Fault Identification Numbers (FID) Shown
September 2007

by

Martha Merriam
Division of Engineering Services
Geotechnical Services

and

Tom Shantz
Division of Research & Innovation
GeoResearch Group

(GIS by Ke Zhou)

This deterministic peak ground acceleration (PGA) map is for illustrative purposes to aid in determining the controlling fault. The PGA contours do not incorporate any site correction factors (e.g. soil amplification, near fault factor, etc) and is not to be used for final seismic analysis or design. For fault name corresponding to fault identification number (FID) and the most current fault data, please refer to the 2007 Fault Database, Fault Errata Report and ARS Online.

Seismic Event Collapse

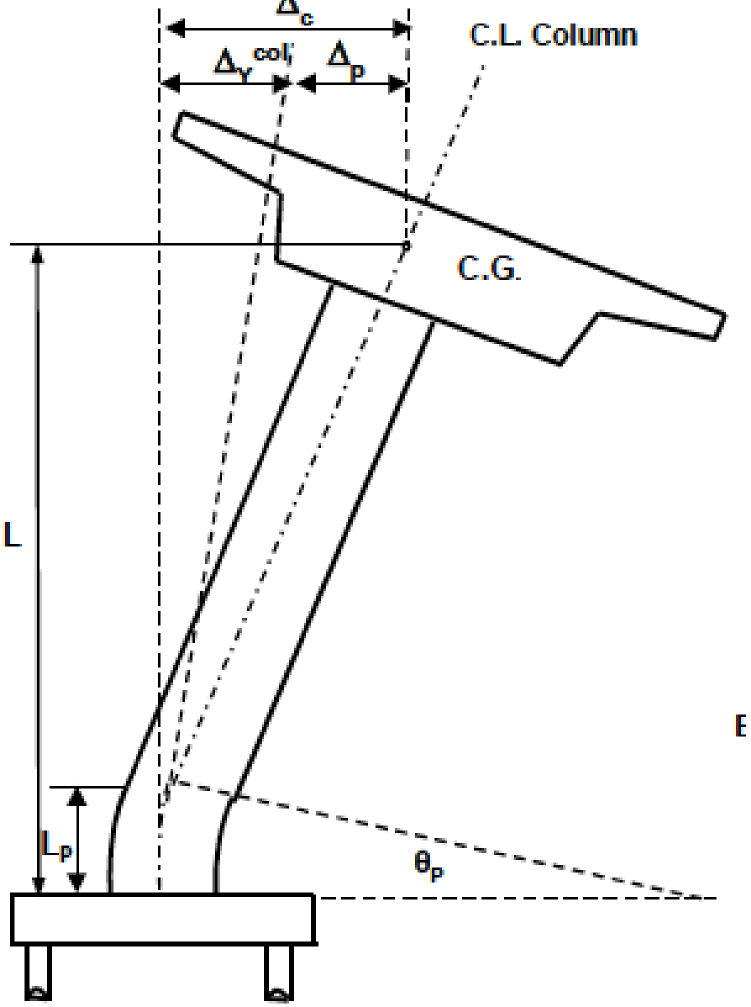
1989 Loma Prieta Earthquake, Magnitude = 6.9

1971 San Fernando Earthquake, Magnitude = 6.5

Caltrans Seismic Design Philosophy

- Bridges may suffer damage but are expected to remain standing.
- Columns are designed to deform.
- Footings (foundations) are to remain undamaged.

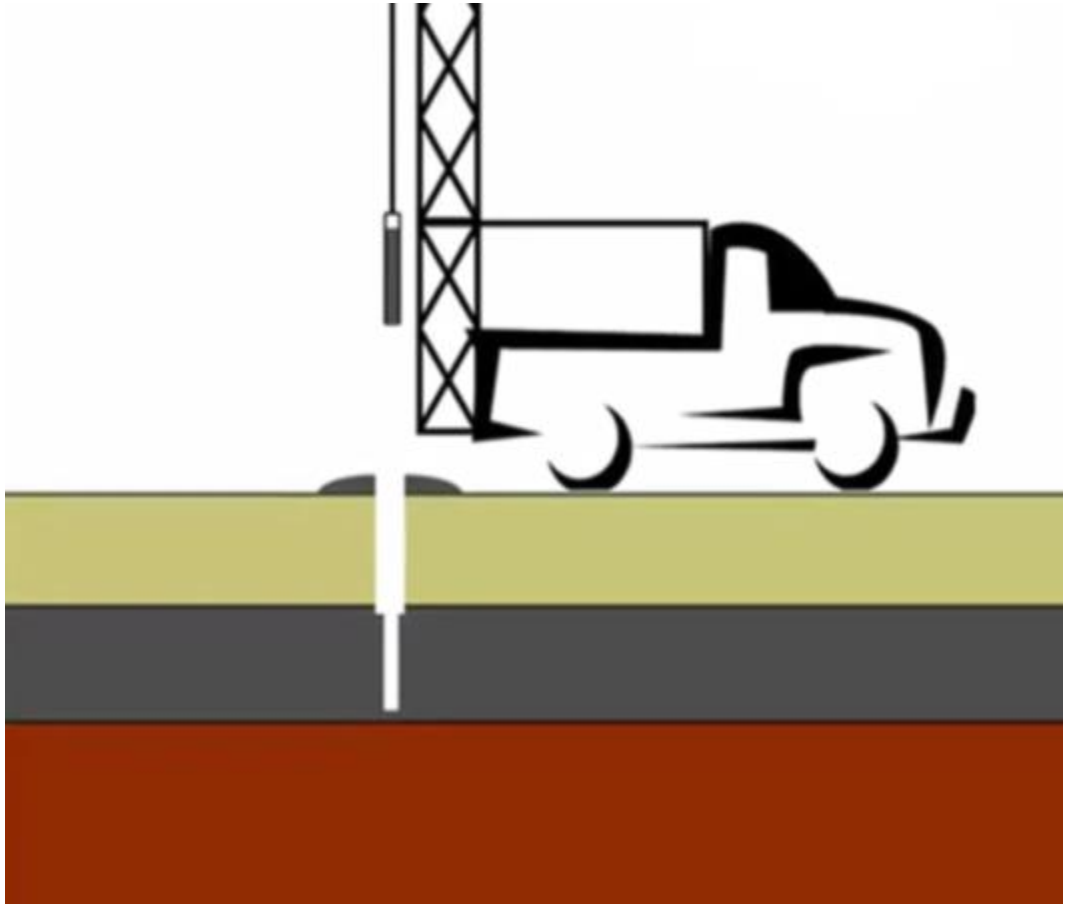
Seismic Design Criteria Manual

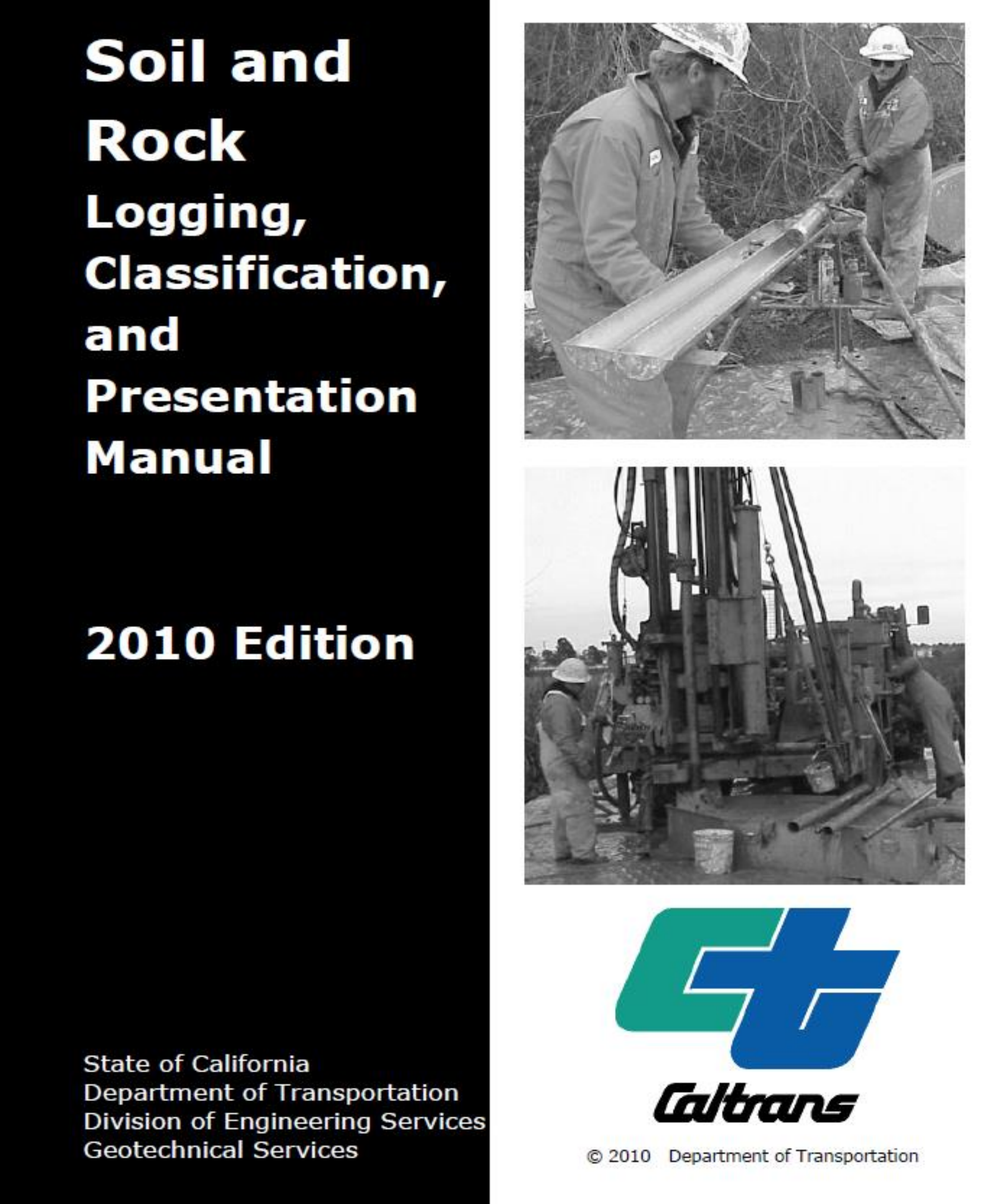


Sampling – Geotechnical Drilling

Substrate Sampling - Drilling

- Informs foundations design and construction methods
- Reduces the potential for unforeseen construction issues and environmental impacts
- Improves outcome of long-term bridge, foundation, and watershed performance





Soil and Rock
Logging, Classification, and Presentation Manual

2010 Edition

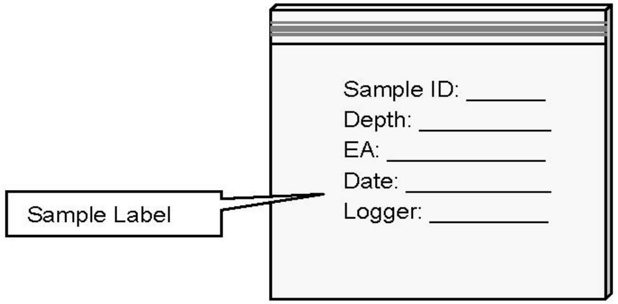
State of California
Department of Transportation
Division of Engineering Services
Geotechnical Services

Caltrans

Logging, Classification and Presentation

1. Field Sampling (geotechnical investigations),
2. Quality Check (field observations),
3. Laboratory Testing (refined description of sample), and
4. Preparing Boring Logs

Geotechnical Sampling



Sample Label

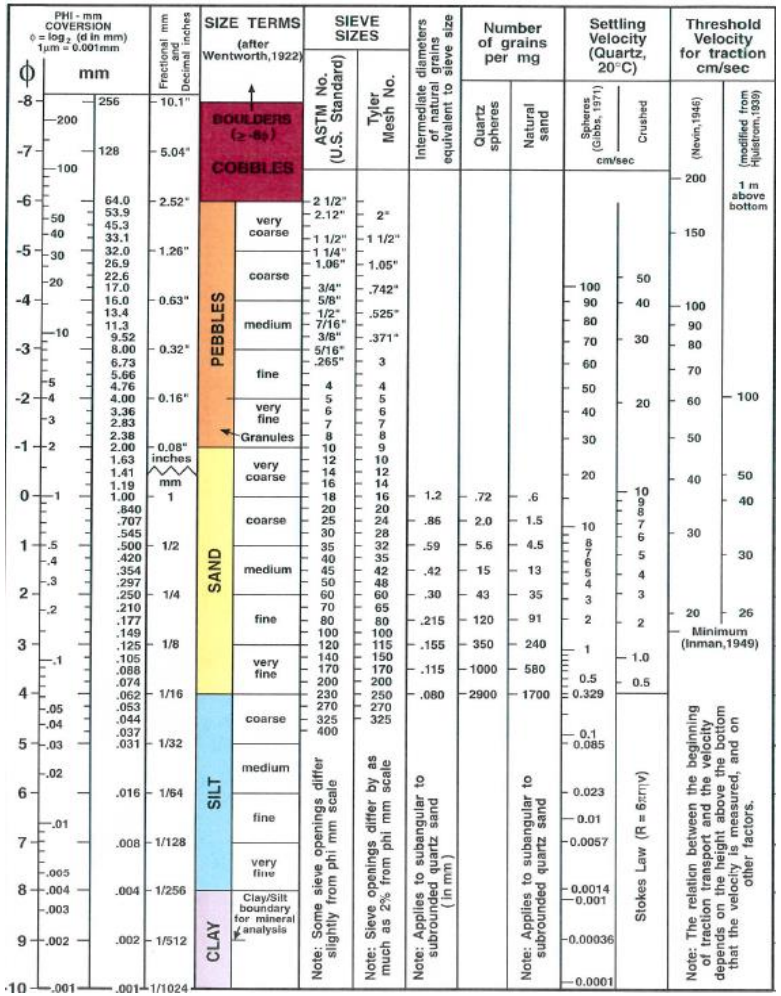
Sample ID: ______
Depth: __________
EA: ___________
Date: __________
Logger: _________

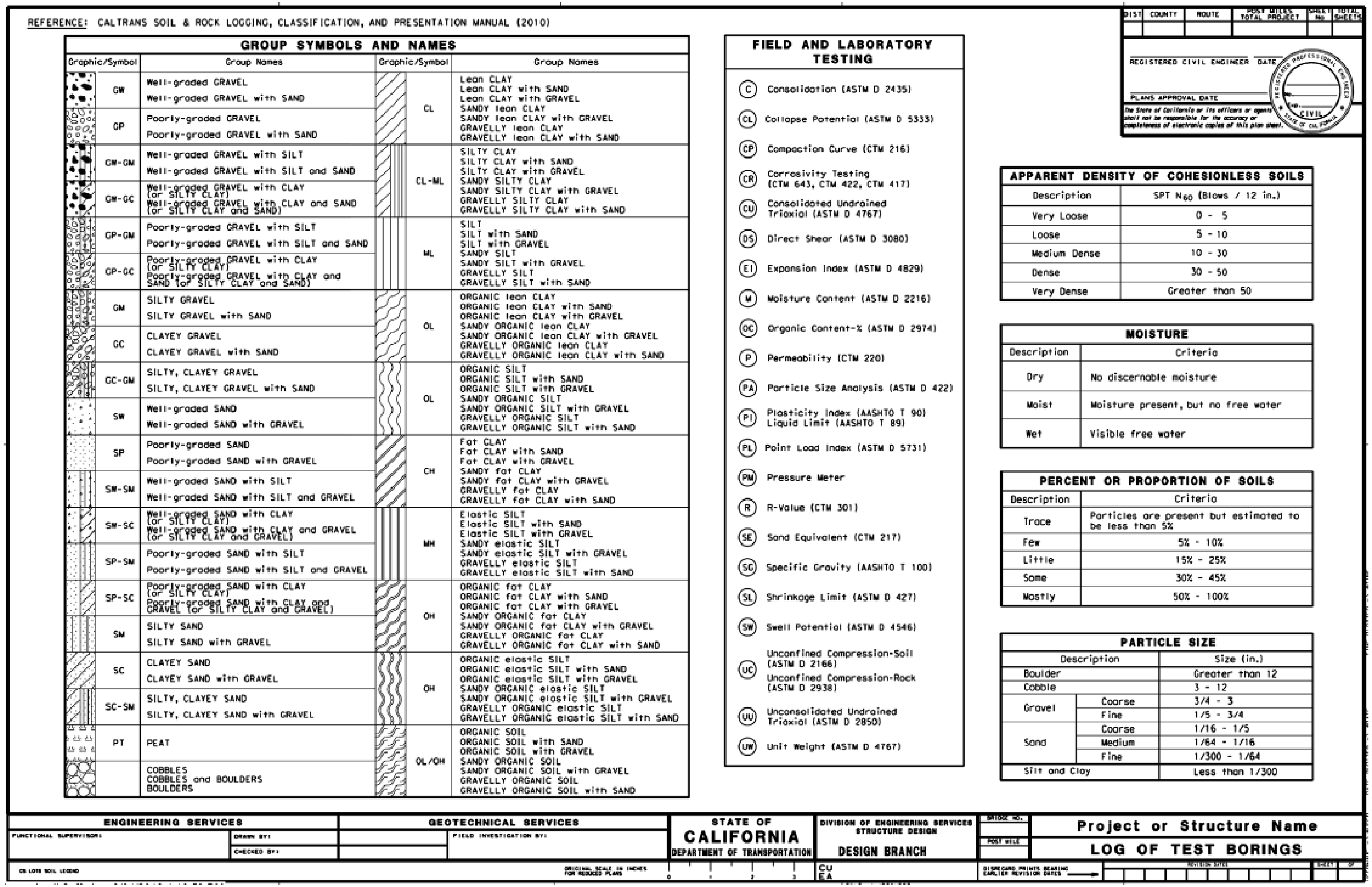
Caltrans Design Engineering Services, Structures – Transportation Laboratory ‘Translab’ (Sacramento)

- Innovative analysis and research laboratory for geology and materials engineering.
- Analysis and research expertise includes geology, materials engineering, geotechnical engineering, specialized testing, and field investigations.

Geotechnical Layer Analysis

- **Boulders and Cobbles**
- **Pebbles:** Very coarse, coarse, medium, fine, and very fine
- **Sand:** Very coarse, coarse, medium fine, and very fine,
- **Silt:** Coarse, medium, fine, and very fine, and
- **Clay:** Clay/silt boundary for mineral analysis





<u>REFERENCE:</u> CALTRANS SOIL & ROCK LOGGING, CLASSIFICATION, AND PRESENTATION MANUAL (2010)

GROUP SYMBOLS AND NAMES

Graphic/Symbol	Group Names
GW	Well-graded GRAVEL Well-graded GRAVEL with SAND
GP	Poorly-graded GRAVEL Poorly-graded GRAVEL with SAND
GW-GM	Well-graded GRAVEL with SILT Well-graded GRAVEL with SILT and SAND
GW-GC	Well-graded GRAVEL with CLAY (or SILTY CLAY) Well-graded GRAVEL with CLAY and SAND (or SILTY CLAY and SAND)
GP-GM	Poorly-graded GRAVEL with SILT Poorly-graded GRAVEL with SILT and SAND
GP-GC	Poorly-graded GRAVEL with CLAY (or SILTY CLAY) Poorly-graded GRAVEL with CLAY and SAND (or SILTY CLAY and SAND)
GM	SILTY GRAVEL SILTY GRAVEL with SAND
GC	CLAYEY GRAVEL CLAYEY GRAVEL with SAND
GC-GM	SILTY, CLAYEY GRAVEL SILTY, CLAYEY GRAVEL with SAND
SW	Well-graded SAND Well-graded SAND with GRAVEL
SP	Poorly-graded SAND Poorly-graded SAND with GRAVEL
SW-SM	Well-graded SAND with SILT Well-graded SAND with SILT and GRAVEL
SW-SC	Well-graded SAND with CLAY (or SILTY CLAY) Well-graded SAND with CLAY and GRAVEL (or SILTY CLAY and GRAVEL)
SP-SM	Poorly-graded SAND with SILT Poorly-graded SAND with SILT and GRAVEL
SP-SC	Poorly-graded SAND with CLAY (or SILTY CLAY) Poorly-graded SAND with CLAY and GRAVEL (or SILTY CLAY and GRAVEL)
SM	SILTY SAND SILTY SAND with GRAVEL
SC	CLAYEY SAND CLAYEY SAND with GRAVEL
SC-SM	SILTY, CLAYEY SAND SILTY, CLAYEY SAND with GRAVEL
PT	PEAT
	COBBLES COBBLES and BOULDERS BOULDERS

Graphic/Symbol	Group Names
CL	Lean CLAY Lean CLAY with SAND Lean CLAY with GRAVEL SANDY lean CLAY SANDY lean CLAY with GRAVEL GRAVELLY lean CLAY GRAVELLY lean CLAY with SAND
CL-ML	SILTY CLAY SILTY CLAY with SAND SILTY CLAY with GRAVEL SANDY SILTY CLAY SANDY SILTY CLAY with GRAVEL GRAVELLY SILTY CLAY GRAVELLY SILTY CLAY with SAND
ML	SILT SILT with SAND SILT with GRAVEL SANDY SILT SANDY SILT with GRAVEL GRAVELLY SILT GRAVELLY SILT with SAND
OL	ORGANIC lean CLAY ORGANIC lean CLAY with SAND ORGANIC lean CLAY with GRAVEL SANDY ORGANIC lean CLAY SANDY ORGANIC lean CLAY with GRAVEL GRAVELLY ORGANIC lean CLAY GRAVELLY ORGANIC lean CLAY with SAND
OL	ORGANIC SILT ORGANIC SILT with SAND ORGANIC SILT with GRAVEL SANDY ORGANIC SILT SANDY ORGANIC SILT with GRAVEL GRAVELLY ORGANIC SILT GRAVELLY ORGANIC SILT with SAND
CH	Fat CLAY Fat CLAY with SAND Fat CLAY with GRAVEL SANDY fat CLAY SANDY fat CLAY with GRAVEL GRAVELLY fat CLAY GRAVELLY fat CLAY with SAND
MH	Elastic SILT Elastic SILT with SAND Elastic SILT with GRAVEL SANDY elastic SILT SANDY elastic SILT with GRAVEL GRAVELLY elastic SILT GRAVELLY elastic SILT with SAND
OH	ORGANIC fat CLAY ORGANIC fat CLAY with SAND ORGANIC fat CLAY with GRAVEL SANDY ORGANIC fat CLAY SANDY ORGANIC fat CLAY with GRAVEL GRAVELLY ORGANIC fat CLAY GRAVELLY ORGANIC fat CLAY with SAND
OH	ORGANIC elastic SILT ORGANIC elastic SILT with SAND ORGANIC elastic SILT with GRAVEL SANDY ORGANIC elastic SILT SANDY ORGANIC elastic SILT with GRAVEL GRAVELLY ORGANIC elastic SILT GRAVELLY ORGANIC elastic SILT with SAND
OL/OH	ORGANIC SOIL ORGANIC SOIL with SAND ORGANIC SOIL with GRAVEL SANDY ORGANIC SOIL SANDY ORGANIC SOIL with GRAVEL GRAVELLY ORGANIC SOIL GRAVELLY ORGANIC SOIL with SAND

FIELD AND LABORATORY TESTING

(C)	Consolidation (ASTM D 2435)
(CL)	Collapse Potential (ASTM D 5333)
(CP)	Compaction Curve (CTM 216)
(CR)	Corrosivity Testing (CTM 643, CTM 422, CTM 417)
(CU)	Consolidated Undrained Triaxial (ASTM D 4767)
(DS)	Direct Shear (ASTM D 3080)
(EI)	Expansion Index (ASTM D 4829)
(M)	Moisture Content (ASTM D 2216)
(OC)	Organic Content-% (ASTM D 2974)
(P)	Permeability (CTM 220)
(PA)	Particle Size Analysis (ASTM D 422)
(PI)	Plasticity Index (AASHTO T 90) Liquid Limit (AASHTO T 89)
(PL)	Point Load Index (ASTM D 5731)
(PM)	Pressure Meter
(R)	R-Value (CTM 301)
(SE)	Sand Equivalent (CTM 217)
(SG)	Specific Gravity (AASHTO T 100)
(SL)	Shrinkage Limit (ASTM D 427)
(SW)	Swell Potential (ASTM D 4546)
(UC)	Unconfined Compression-Soil (ASTM D 2166) Unconfined Compression-Rock (ASTM D 2938)
(UU)	Unconsolidated Undrained Triaxial (ASTM D 2850)
(UW)	Unit Weight (ASTM D 4767)

DIST	COUNTY	ROUTE	POST MILES TOTAL PROJECT	SHEET No	TOTAL SHEETS

REGISTERED CIVIL ENGINEER DATE

PLANS APPROVAL DATE

The State of California or its officers or agents shall not be responsible for the accuracy or completeness of electronic copies of this plan sheet.

REGISTERED PROFESSIONAL ENGINEER
No.
Exp.
CIVIL
STATE OF CALIFORNIA

APPARENT DENSITY OF COHESIONLESS SOILS

Description	SPT N_{60} (Blows / 12 in.)
Very Loose	0 - 5
Loose	5 - 10
Medium Dense	10 - 30
Dense	30 - 50
Very Dense	Greater than 50

MOISTURE

Description	Criteria
Dry	No discernable moisture
Moist	Moisture present, but no free water
Wet	Visible free water

PERCENT OR PROPORTION OF SOILS

Description	Criteria
Trace	Particles are present but estimated to be less than 5%
Few	5% - 10%
Little	15% - 25%
Some	30% - 45%
Mostly	50% - 100%

PARTICLE SIZE

Description		Size (in.)
Boulder		Greater than 12
Cobble		3 - 12
Gravel	Coarse	3/4 - 3
	Fine	1/5 - 3/4
Sand	Coarse	1/16 - 1/5
	Medium	1/64 - 1/16
	Fine	1/300 - 1/64
Silt and Clay		Less than 1/300

ENGINEERING SERVICES
FUNCTIONAL SUPERVISOR:
DRAWN BY:
CHECKED BY:

GEOTECHNICAL SERVICES
FIELD INVESTIGATION BY:

STATE OF
CALIFORNIA
DEPARTMENT OF TRANSPORTATION

DIVISION OF ENGINEERING SERVICES
STRUCTURE DESIGN
DESIGN BRANCH

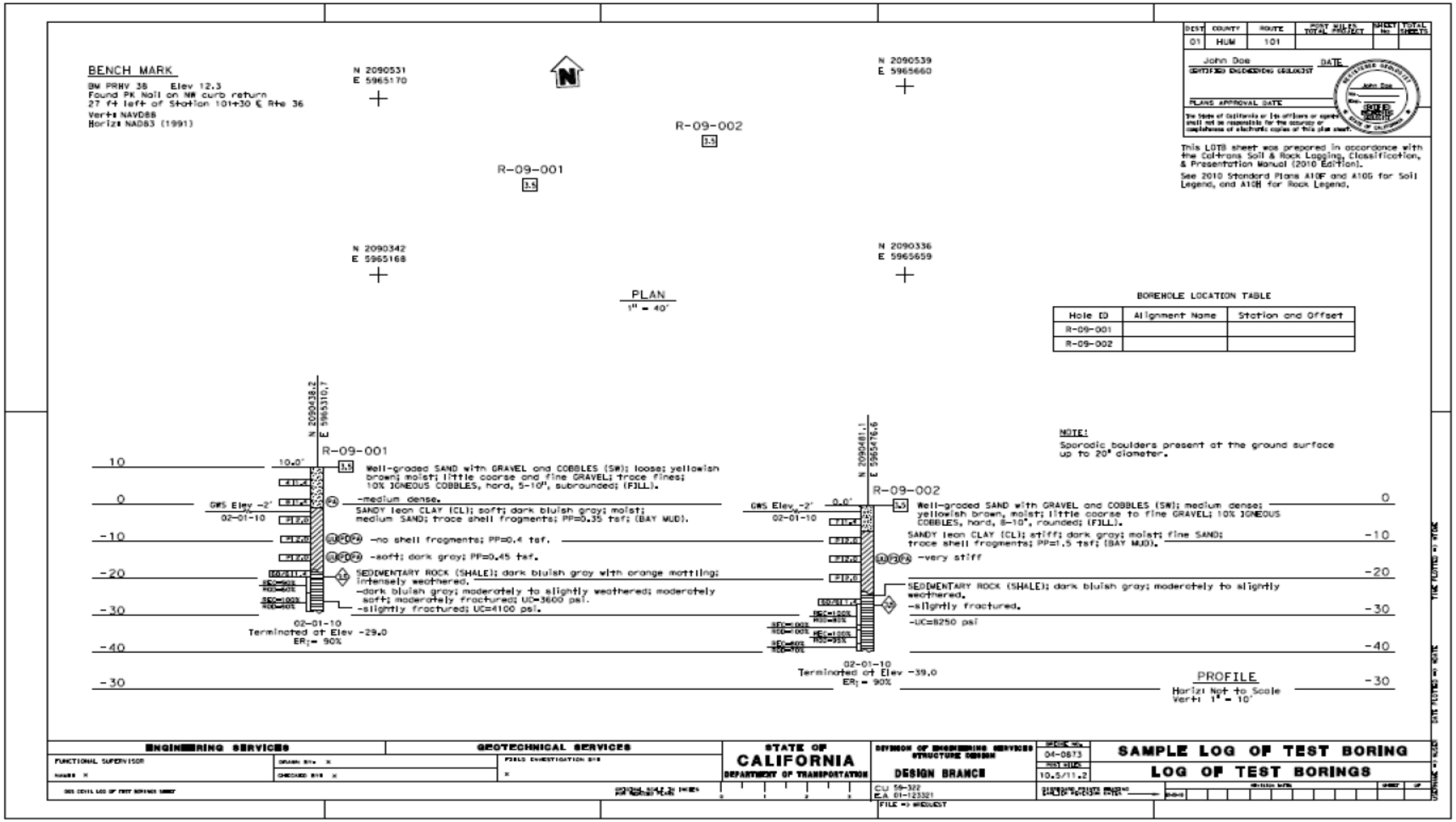
BRIDGE NO.
POST MILE

Project or Structure Name
LOG OF TEST BORINGS

CS LOTB SOIL LEGEND
ORIGINAL SCALE IN INCHES FOR REDUCED PLANS
0 1 2 3
CU
EA
DISREGARD PRINTS BEARING EARLIER REVISION DATES
REVISION DATES
SHEET OF

Caltrans

Soil and Rock Logging, Classification, and Presentation Manual (2010)
Erratum Sheet



BENCH MARK

BM PRHV 36 Elev 12.3
Found PK Nail on NW curb return
27 ft left of Station 101+30 ℄ Rte 36
Vert: NAVD88
Horiz: NAD83 (1991)

DIST	COUNTY	ROUTE	POST MILES TOTAL PROJECT	SHEET No	TOTAL SHEETS
01	HUM	101			

John Doe
CERTIFIED ENGINEERING GEOLOGIST
DATE

PLANS APPROVAL DATE

The State of California or its officers or agents shall not be responsible for the accuracy or completeness of electronic copies of this plan sheet.

This LOTB sheet was prepared in accordance with the Caltrans Soil & Rock Logging, Classification, & Presentation Manual (2010 Edition).

See 2010 Standard Plans A10F and A10G for Soil Legend, and A10H for Rock Legend.

BOREHOLE LOCATION TABLE

Hole ID	Alignment Name	Station and Offset
R-09-001		
R-09-002		

NOTE:
Sporadic boulders present at the ground surface up to 20" diameter.

Well-graded SAND with GRAVEL and COBBLES (SW); loose; yellowish brown; moist; little coarse and fine GRAVEL; trace fines; 10% IGNEOUS COBBLES, hard, 5-10", subrounded; (FILL).
-medium dense.
SANDY lean CLAY (CL); soft; dark bluish gray; moist; medium SAND; trace shell fragments; PP=0.35 tsf; (BAY MUD).
-no shell fragments; PP=0.4 tsf.
-soft; dark gray; PP=0.45 tsf.
SEDIMENTARY ROCK (SHALE); dark bluish gray with orange mottling; intensely weathered.
-dark bluish gray; moderately to slightly weathered; moderately soft; moderately fractured; UC=3600 psi.
-slightly fractured; UC=4100 psi.

02-01-10
Terminated at Elev -29.0
ER_i = 90%

Well-graded SAND with GRAVEL and COBBLES (SW); medium dense; yellowish brown, moist; little coarse to fine GRAVEL; 10% IGNEOUS COBBLES, hard, 8-10", rounded; (FILL).
SANDY lean CLAY (CL); stiff; dark gray; moist; fine SAND; trace shell fragments; PP=1.5 tsf; (BAY MUD).
-very stiff
SEDIMENTARY ROCK (SHALE); dark bluish gray; moderately to slightly weathered.
-slightly fractured.
-UC=8250 psi

02-01-10
Terminated at Elev -39.0
ER_i = 90%

ENGINEERING SERVICES
FUNCTIONAL SUPERVISOR
NAME: X
DRAWN BY: X
CHECKED BY: X

GEOTECHNICAL SERVICES
FIELD INVESTIGATION BY:
X

STATE OF
CALIFORNIA
DEPARTMENT OF TRANSPORTATION

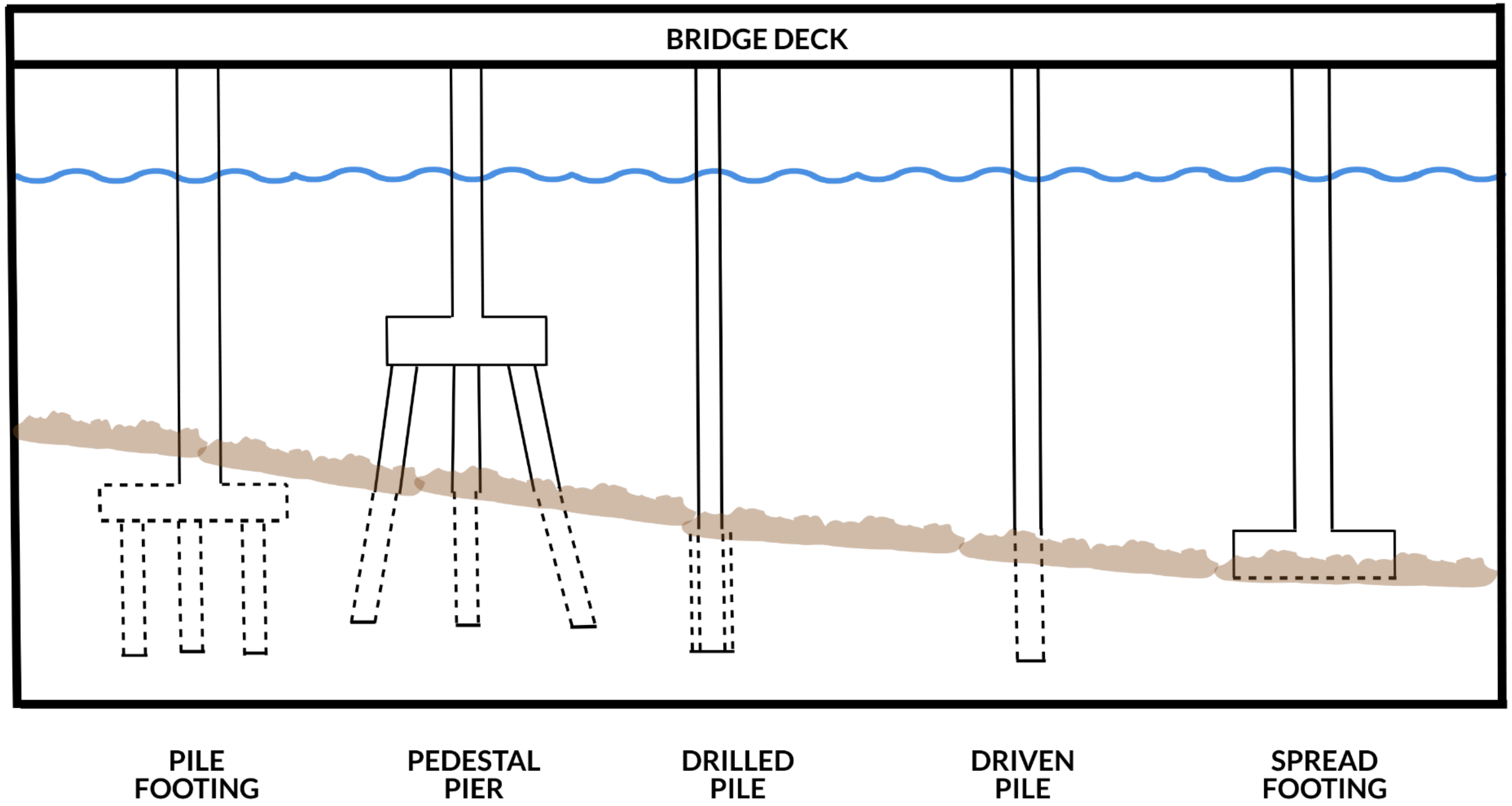
DIVISION OF ENGINEERING SERVICES
STRUCTURE DESIGN
DESIGN BRANCH

BRIDGE No.
04-0873
POST MILES
10.5/11.2

SAMPLE LOG OF TEST BORING
LOG OF TEST BORINGS

CU 59-322
EA 01-123321
FILE => $REQUEST

Common Bridge Foundation Types

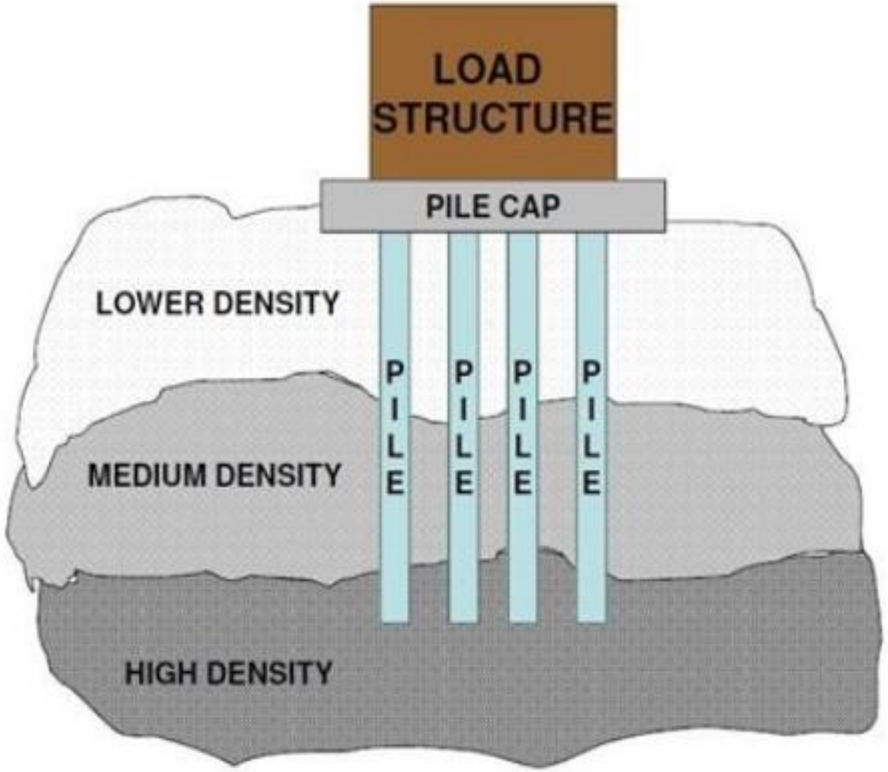


Shallow Foundations – Spread or Slab

Shallow Foundations and bent walls have a Greater Scour and Flanking Risk, often requiring Countermeasures such as Rock Slope Protection (RSP)

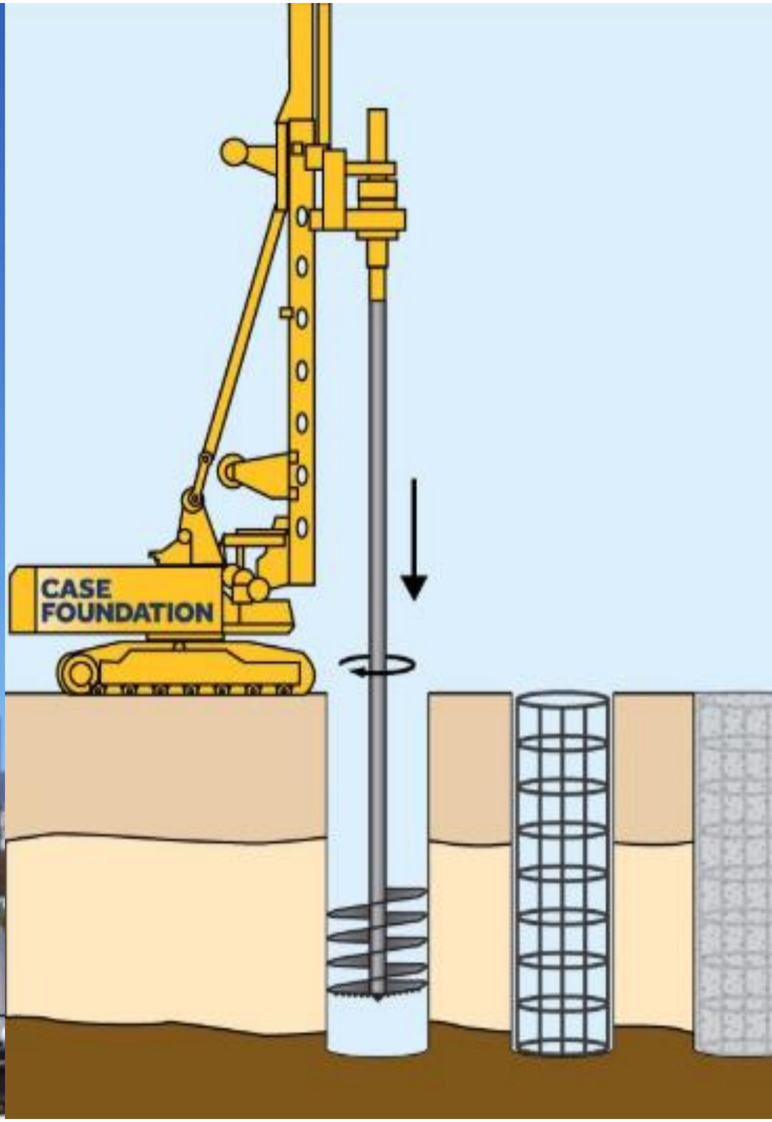
JUL 29 2004

Deep Water Foundations – Piles



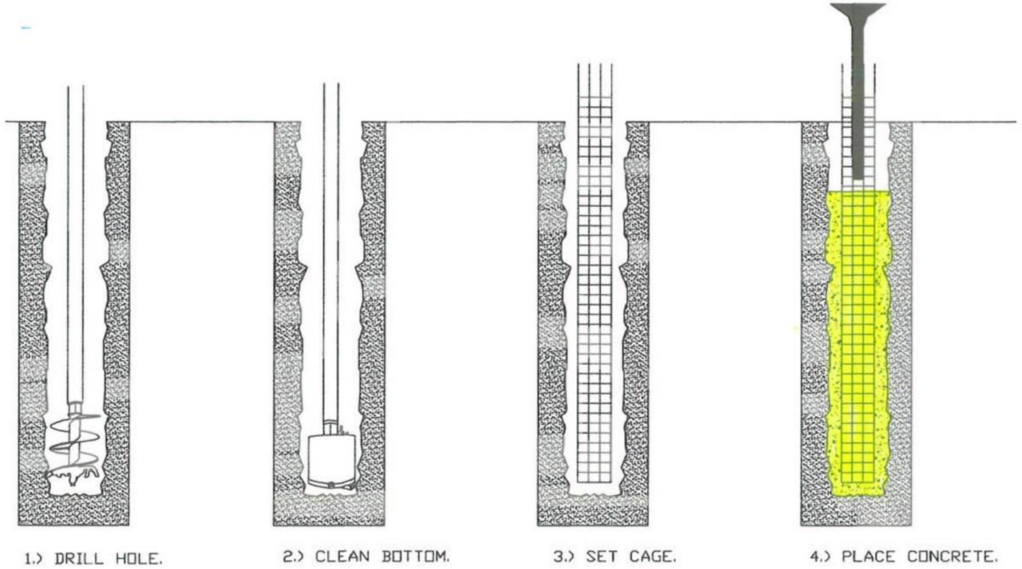
- Deep water foundations transfer the load of the bridge and traffic into deeper layers of earth materials.
- Types of Deep-water foundations:
  - Driven piles
  - Drilled shafts

Deep Water Foundations – Drilling

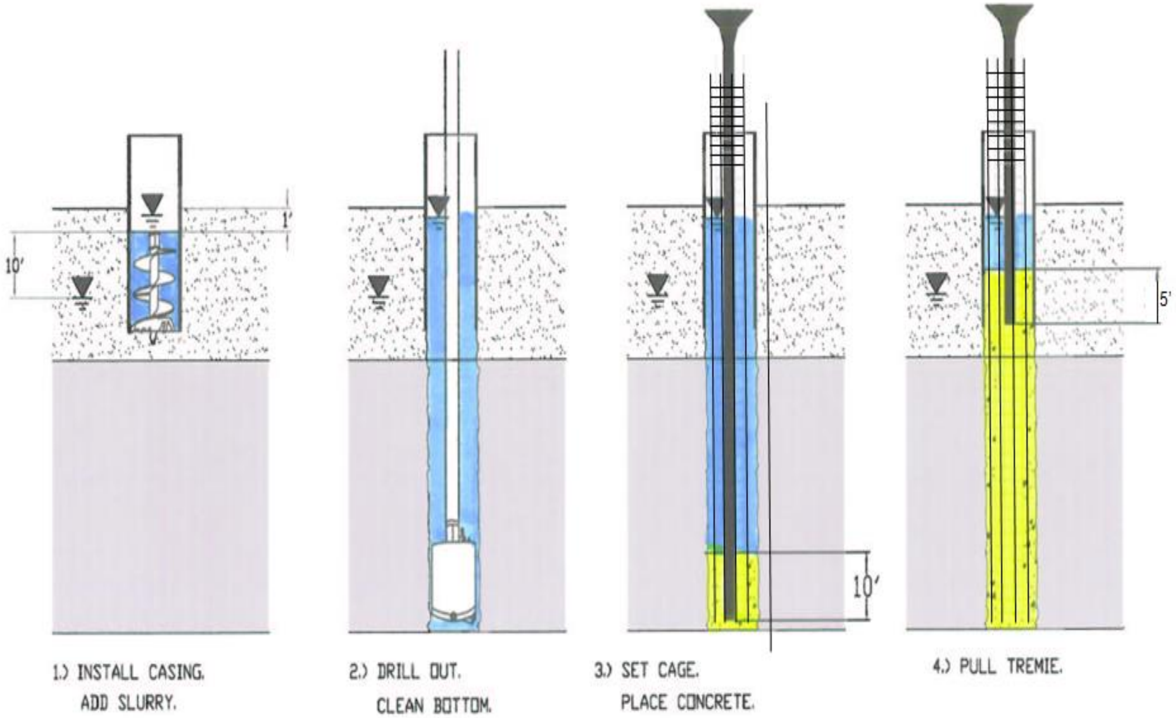


Drilling (continued)

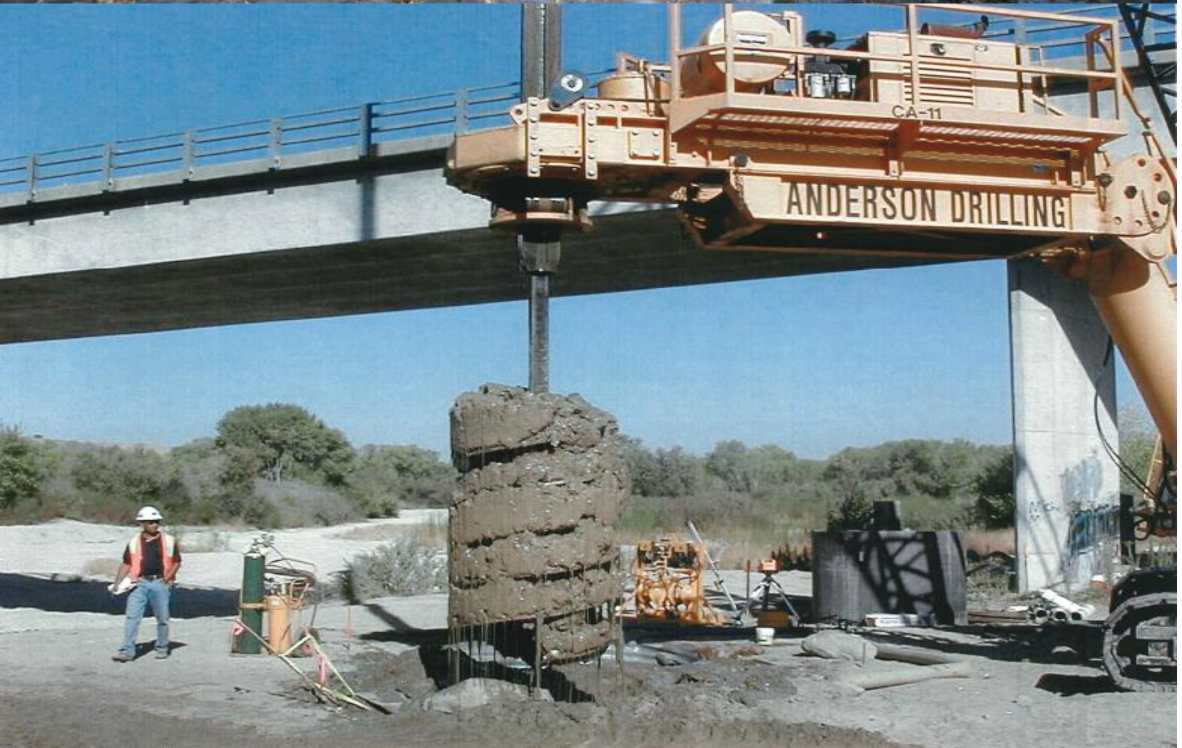
Dry Construction Method



Wet Construction Method



Drilling



- Drilling projects take longer than any other foundation type.
  - ~3 times longer than pile driving to construct bridges with drilled foundations.
  - Often multiple season bridge projects.
- If working in water, increased potential for drilling and equipment discharges to receiving waters.
- If drilling into fractured rock, potential for frac out.
- No casing to contain final concrete pour in areas where substrate is supersaturated.

Driven Piles





Driven Piles

- **H-beam piles** – often used for temporary access trestles piles, cofferdam shoring, and smaller bridge foundations.
  - 12”-16” H-beam
- **Smaller Cast in Steel Shell** (CISS) – often used for temporary access trestle piles, smaller bridge foundations, and grouped in footing arrays.
  - 12” to 36” CISS piles
- **Larger CISS piles** – Used for larger bridge foundations or areas of high liquefaction risk (seismicity).
  - 48” to 96” CISS piles

Vibratory Pile Start

- Piles can initially be vibrated into position.
  - At resistance, a hammer will drive the pile to TIP elevation.
- No fish hydroacoustic threshold for vibration (continuous).
  - Marine mammal thresholds apply.
- Consider potential of mechanized crushing of salmon and Steelhead redds.
- Depth achieved will vary between projects and pile locations in a project area based on;
  - Supersaturated soils
  - Substrate types
  - Pile type

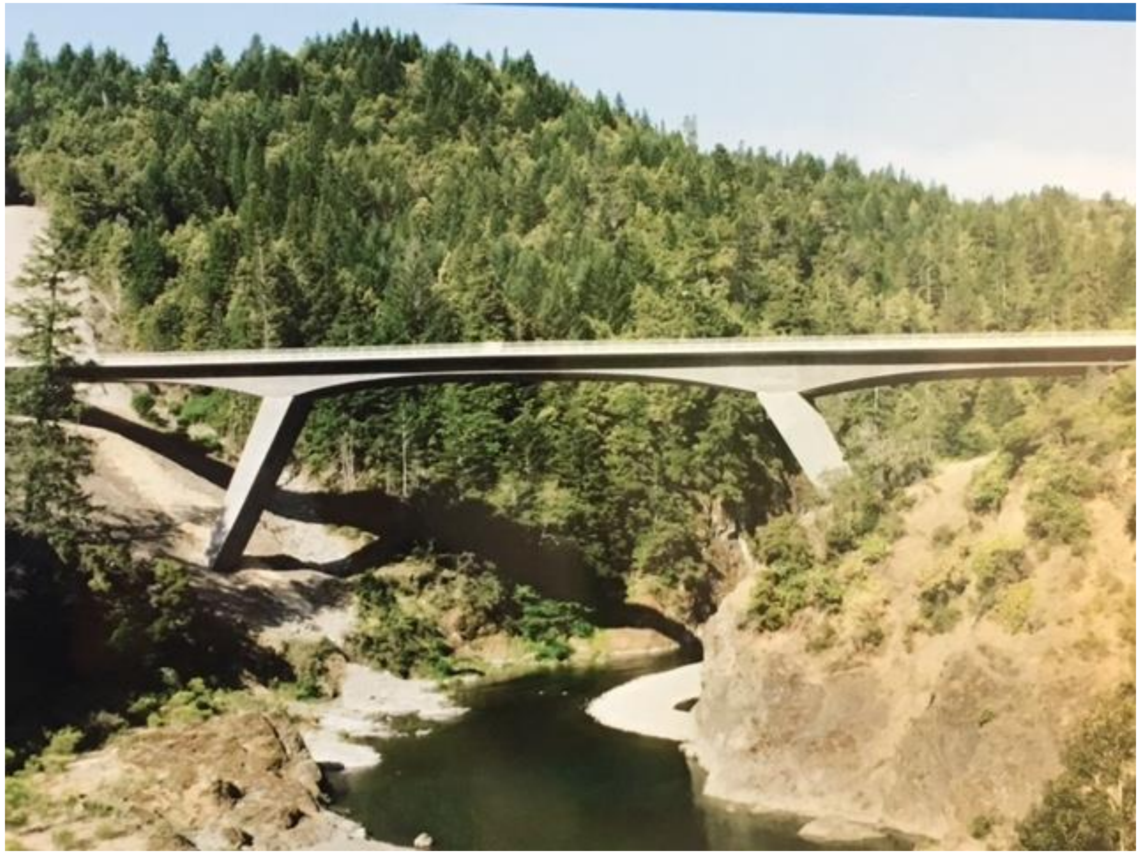
Caltrans

Deep Water Foundations – Pile Driving

- Reduce risk of construction delays, pier anomalies, and long-term scour risk.
- Small bridges with pile driven foundations can typically be built in one season.
- Working during low flow season, in dewatered and isolated work areas can avoid or significantly minimize hydroacoustic impacts.
- Span the wet channel if possible
  - New bridges - the most effective way to avoid and minimize underwater sound pressure during construction is by design.

Pile Driving on Land

Rock Shafts - Excavation and Low-Impact Blasting



Piers - Substructure

Terwer Creek, Tributary Klamath River

(Remove bent wall, replace with round pier)

Conventional Construction - Falsework and Form Support

Support - Conventional Cast in Place Bridge Construction

Metal Work and Forms to Shape and Contain Concrete Pour

Foundations constructed by conventional methods.

Accelerated Bridge Construction

(Abutments)

Photos: Dorie Mellon, ABC Structures Engineer

ABC Element Assembly

(Wingwalls, Voided Slab, Rails and Aesthetics)

Photos: Dorie Mellon, ABC Structures Engineer

Connections – Ultra High-Performance Concrete (UHPC)

- Strong, flexible, durable, excellent bond for ABC connections
- Performance exceeds conventional concrete
  - At 70 degrees, UHPC can cure in ~4 days as compared to 7-10 days for conventional concrete.

Photos: Dorie Mellon, ABC Structures Engineer

Small Watersheds – Removing a Culvert and Building a Bridge

Dewatering, Access Traffic

Salmon and Steelhead were safely relocated from the work area during the water diversion and early construction activities.

Reinforced Concrete Box Culvert to Small Bridge – Fish Passage Remediation

Staged and Half Width Construction

Photos: Jim McIntosh, Environmental Construction Liaison

Larger Bridge Access – Construction and Traffic

Hydroacoustic Impacts to Fish and Aquatic Species

West Coast fish kills 2000-2003

- In 2000 test piles were impact driven for SFOBB, to analyze foundation construction and performance.
  - In water, unattenuated 72-inch and 96-inch Steel Shell Pipe Piles
- Around that same time similar fish kills were observed during pile driving in Canada, and Washington State.

Species Killed

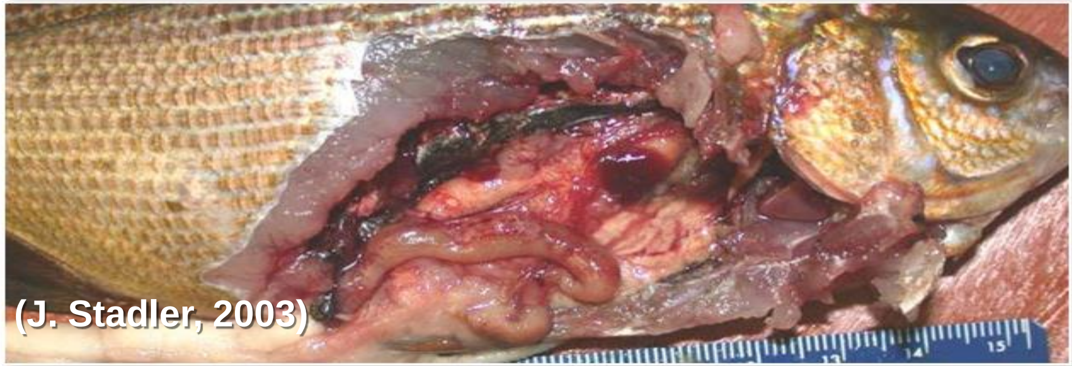
Salmon
Green sturgeon
Cod
Herring
Anchovies
Sardines
Smelt
Surf perches
Striped bass
Rockfishes

Severe Barotrauma Injury (mortality)

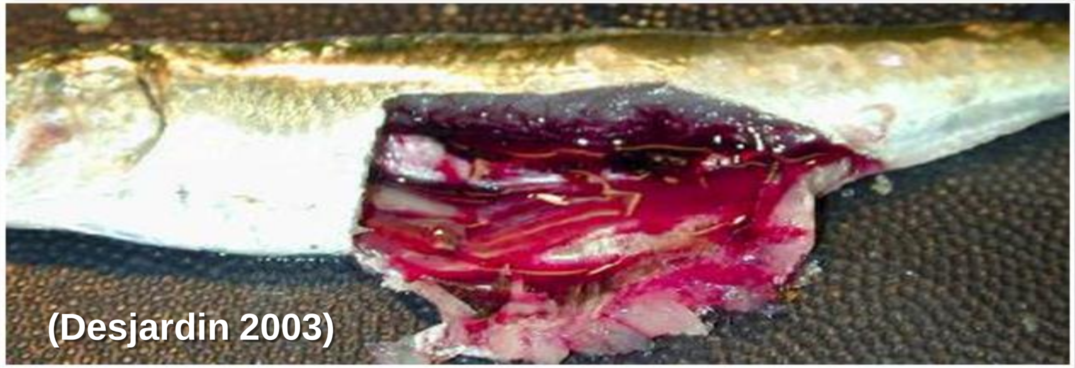

(J. Stadler, 2003)


(J. Stadler, 2003)


(J. Stadler, 2003)


(J. Stadler, 2003)


(Desjardin 2003)


(Desjardin 2003)

Typical Underwater Sound Pressure Levels

Sound Source	Sound Pressure Levels	
	dB	Pascals
High explosives at 100 meters	220	100,00
Air gun array at 100 meters	200	10,000
Un-attenuated 24” steel pipe piles at 10 meters		
Un-attenuated 12” H-beam piles at 10 meters	180	1,000
Large ship at 100 meters	160	100
Fish trawler (low speed) at 20 meter	140	10
Background with small boat traffic	100	0.1
	80	0.01

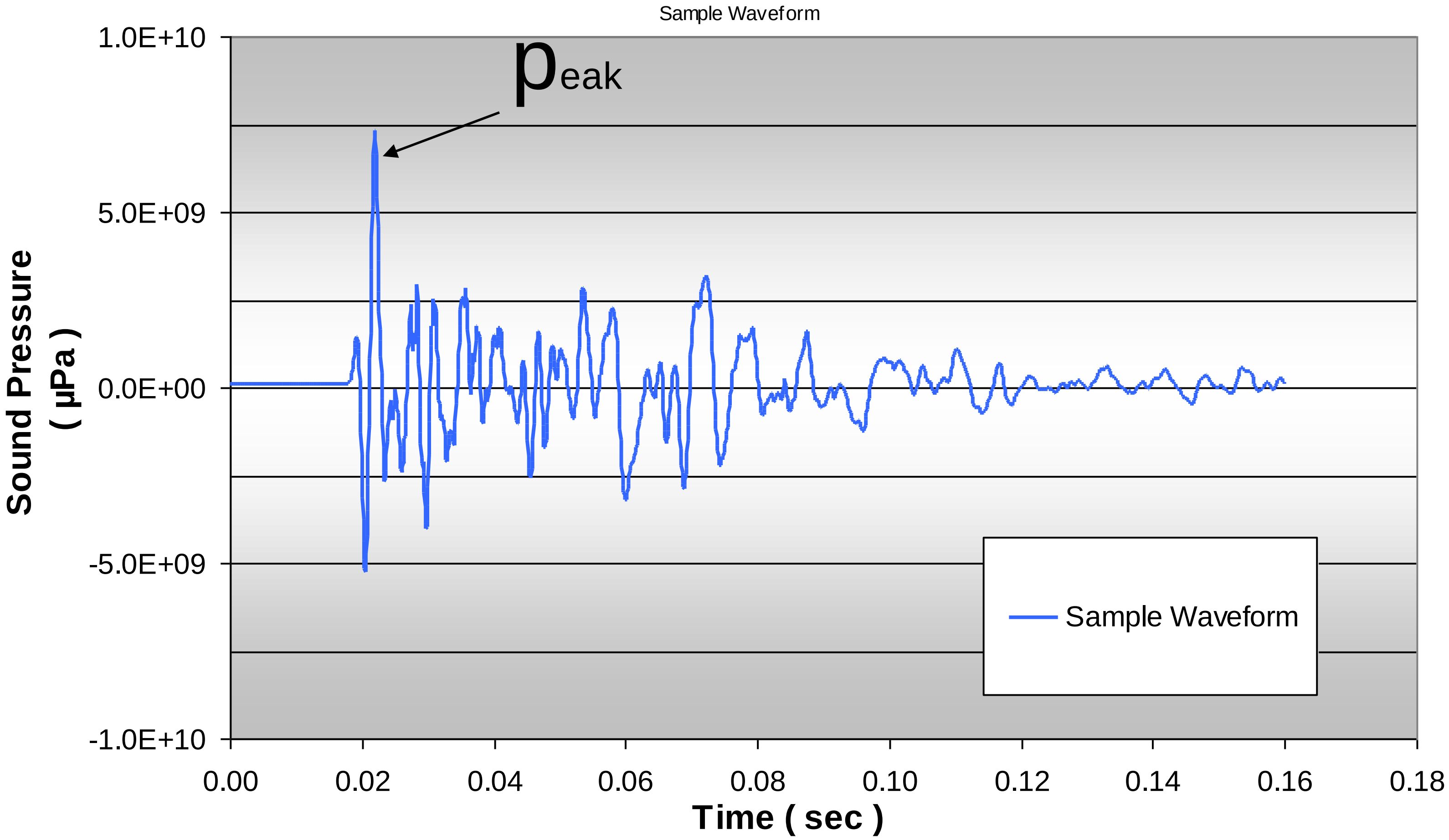
2008 Interim Pile Driving Criteria

In 2008 the Fisheries Hydroacoustic Working Group (FHWG) agreed on interim criteria. Minimal science and data available at the time so conservative levels were agreed upon by agencies involved; Caltrans, FHWA, NMFS, WSDOT, ODOT, and CDFW.

- Peak Sound Pressure Level (SPL)
  - **206 dB** for all sizes of fish
- Accumulated Sound Elevation Level (cSEL)
  - **187 dB** - fish two grams or greater
  - **183 dB** - fish less than two grams
- **150 dB** - Effective Quiet(RMS) assumed background levels

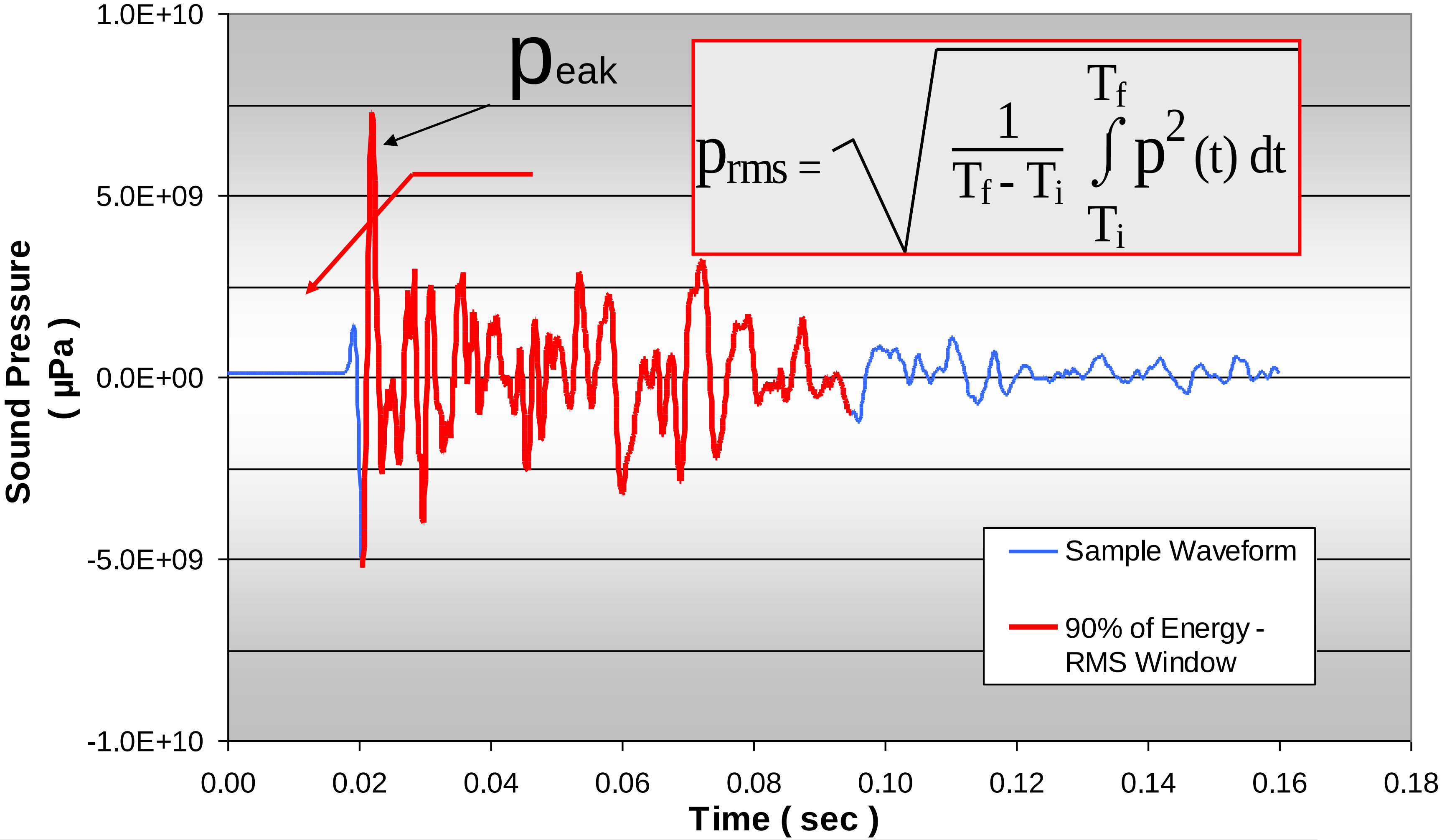
Note; the FHWG disbanded in 2018 due to members retiring, taking other positions, and lack of interest.

Peak Sound Pressure



Peak Sound Pressure Level: Maximum absolute value of the instantaneous sound pressure that occurs during a specified time interval (ANSI S12.7)

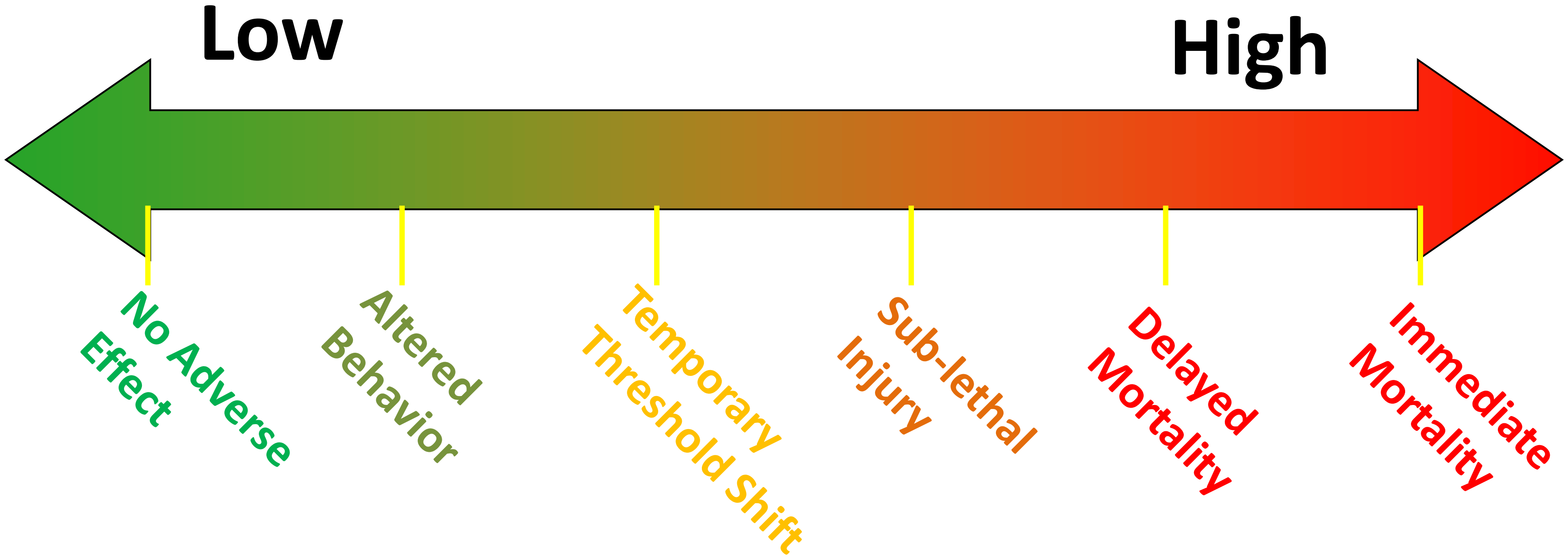
Sound Pressure Level (Single Strike)



$$p_{rms} = \sqrt{\frac{1}{T_f - T_i}\int_{T_i}^{T_f} p^2(t)\,dt}$$

Sound Pressure Level: Measure of the square root of mean square (RMS) pressure. For impulses, the average of the squared pressures over the time that comprise that portion of the waveform containing from 5% to 95% percent of the “effective” sound energy of the impulse.

Barotrauma Continuum of Effects



Low

High

No Adverse Effect

Altered Behavior

Temporary Threshold Shift

Sub-lethal Injury

Delayed Mortality

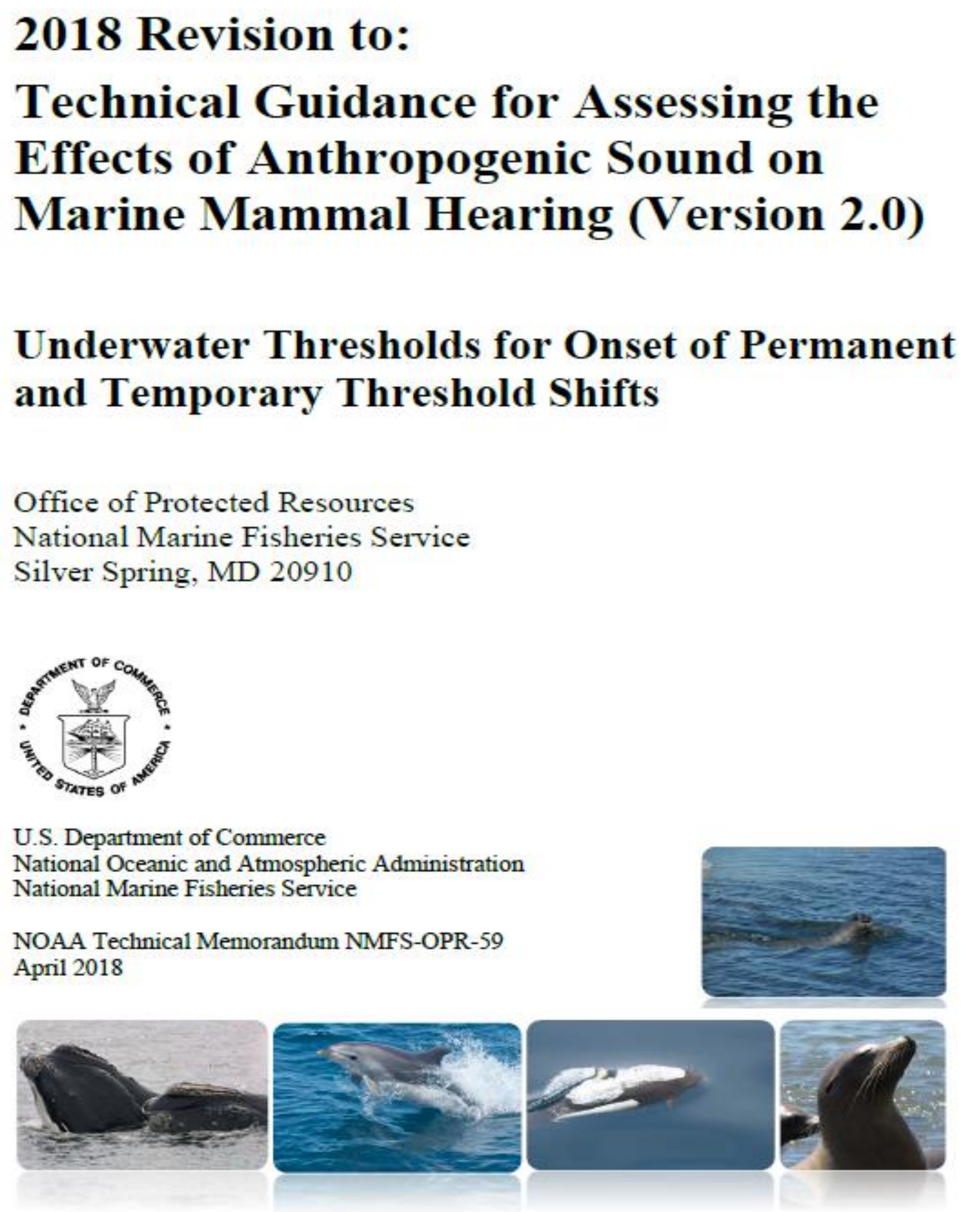
Immediate Mortality

RMS
150 dB

cSEL
183 dB/187 dB

PEAK
206 dB

Marine Mammals



2018 Revision to:

Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0)

Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts

Office of Protected Resources
National Marine Fisheries Service
Silver Spring, MD 20910

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

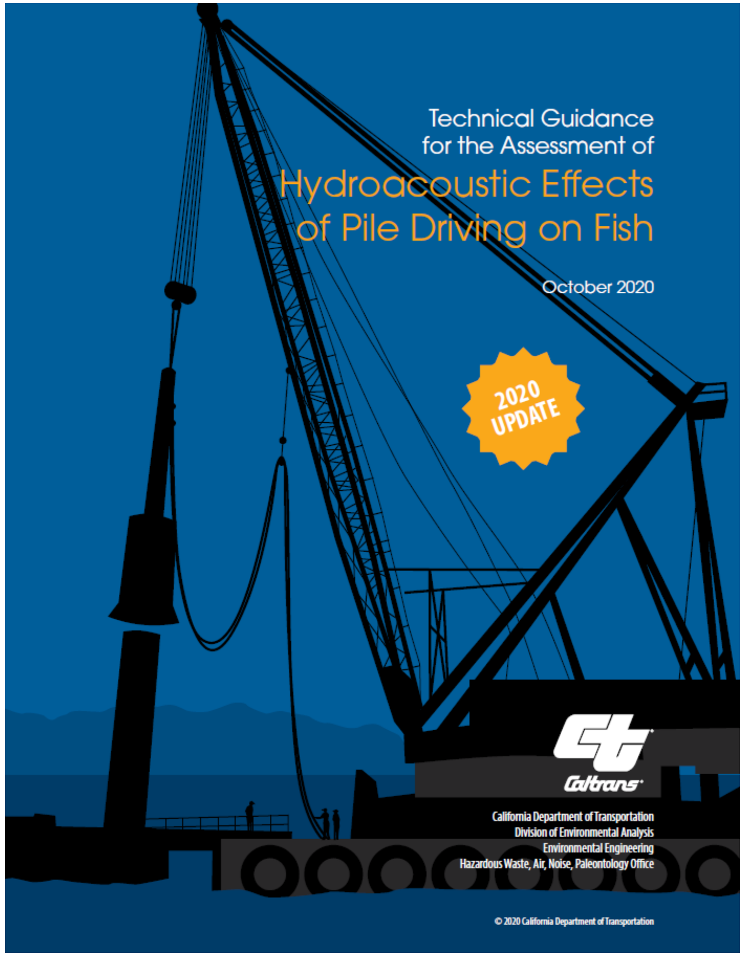
NOAA Technical Memorandum NMFS-OPR-59
April 2018

Hydroacoustic Effects of Pile Driving on Fish

- Originally published in 2009, updated 2012, 2015 and 2020.

- 2020 “Technical Guidance for Assessment & Mitigation of the Hydroacoustic Effects of Pile Driving on Fish”
  - ICF, Caltrans, Illingworth and Rodkin.

- http://www.dot.ca.gov/hq/env/bio/fisheries_bioacoustics.htm



Technical Guidance
for the Assessment of
Hydroacoustic Effects
of Pile Driving on Fish

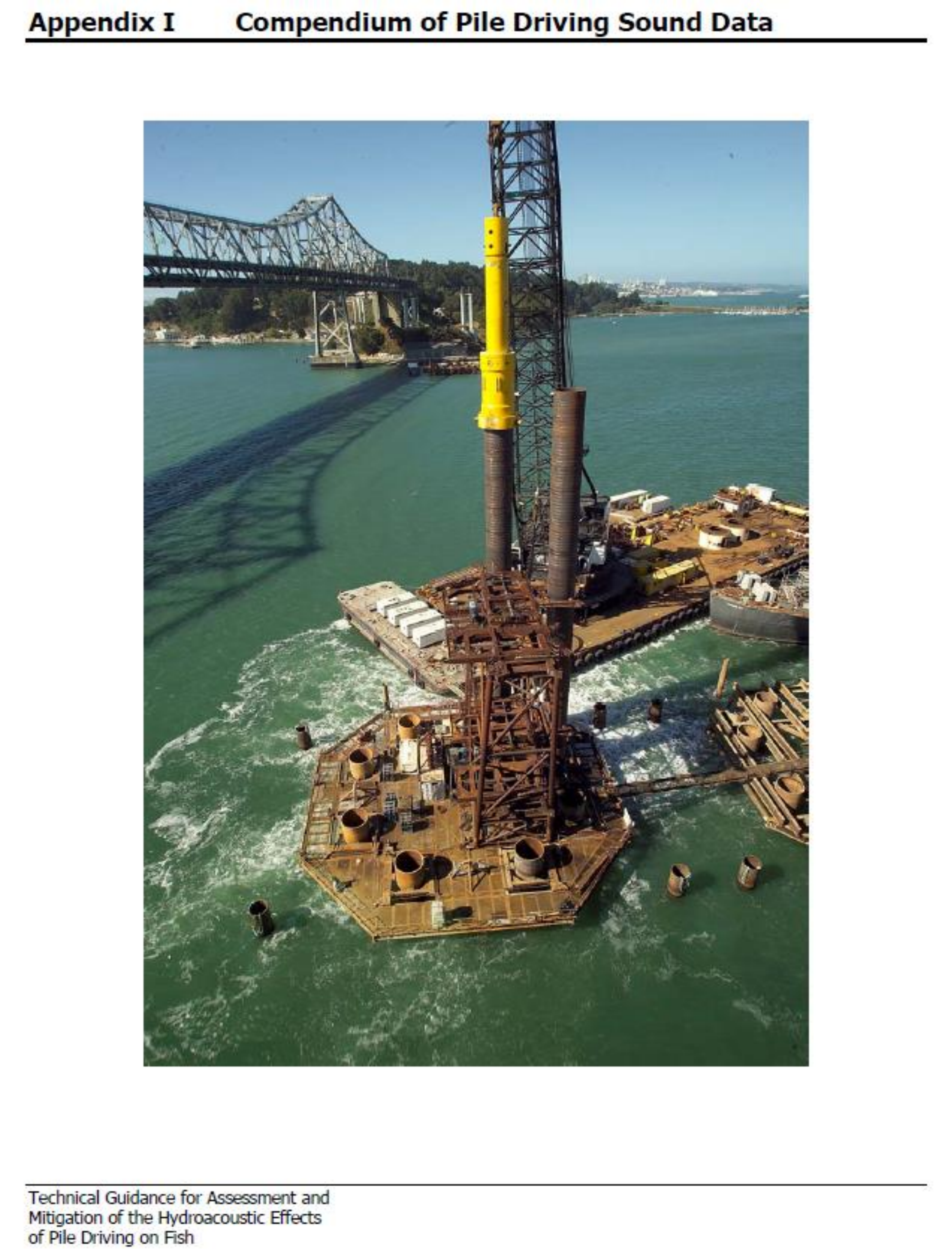
October 2020

2020 UPDATE

Caltrans

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

© 2020 California Department of Transportation



Appendix I **Compendium of Pile Driving Sound Data**

Technical Guidance for Assessment and
Mitigation of the Hydroacoustic Effects
of Pile Driving on Fish

Guidance Manual Contents

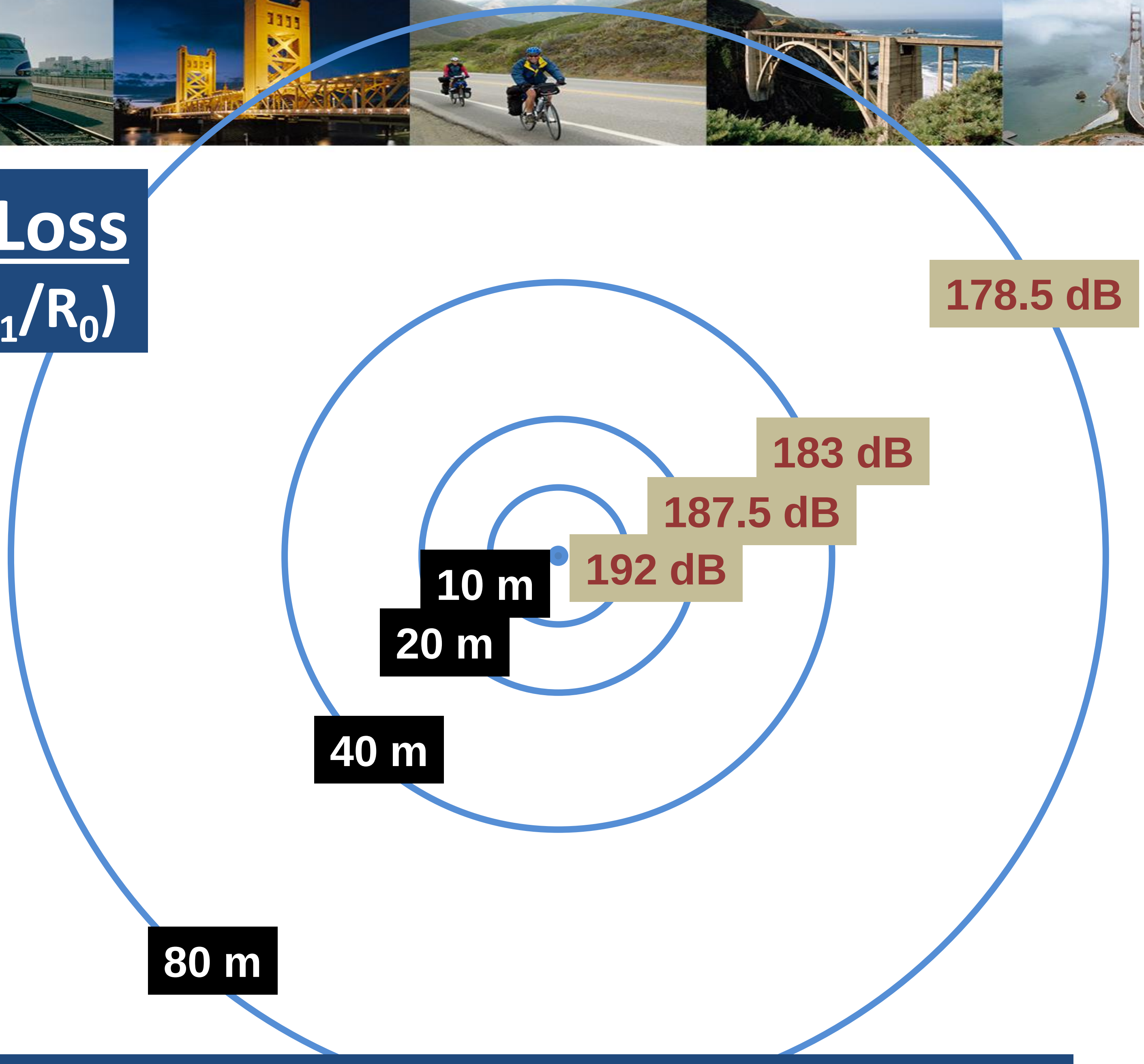
- Chapter 2 - Fundamentals of Hydroacoustics
  - Underwater Sound Propagation and Sound Levels
  - Common Attenuation Measures and Effectiveness
- Chapter 3 - Impacts to Fish
  - Effects of Pile Driving on Fish and Life History Considerations
  - Behavioral Effects and Environmental Factors to Consider
  - Methods for calculating underwater noise levels from pile driving
- Appendix I – Compendium of Pile Driving Sound Data
- Appendix IV – Tools for Preparing Biological Assessment

Sound Pressure Transmission Loss in Water

- Transmission loss;
  - In water ~4.5 dB/doubling of distance
- Attenuation of **<u>in-water</u>** pile driving is reasonable, feasible and should be a component of in-water pile driving projects.

Transmission Loss

$TL\ (dB) = 15\log(R_1/R_0)$



10 m

20 m

40 m

80 m

192 dB

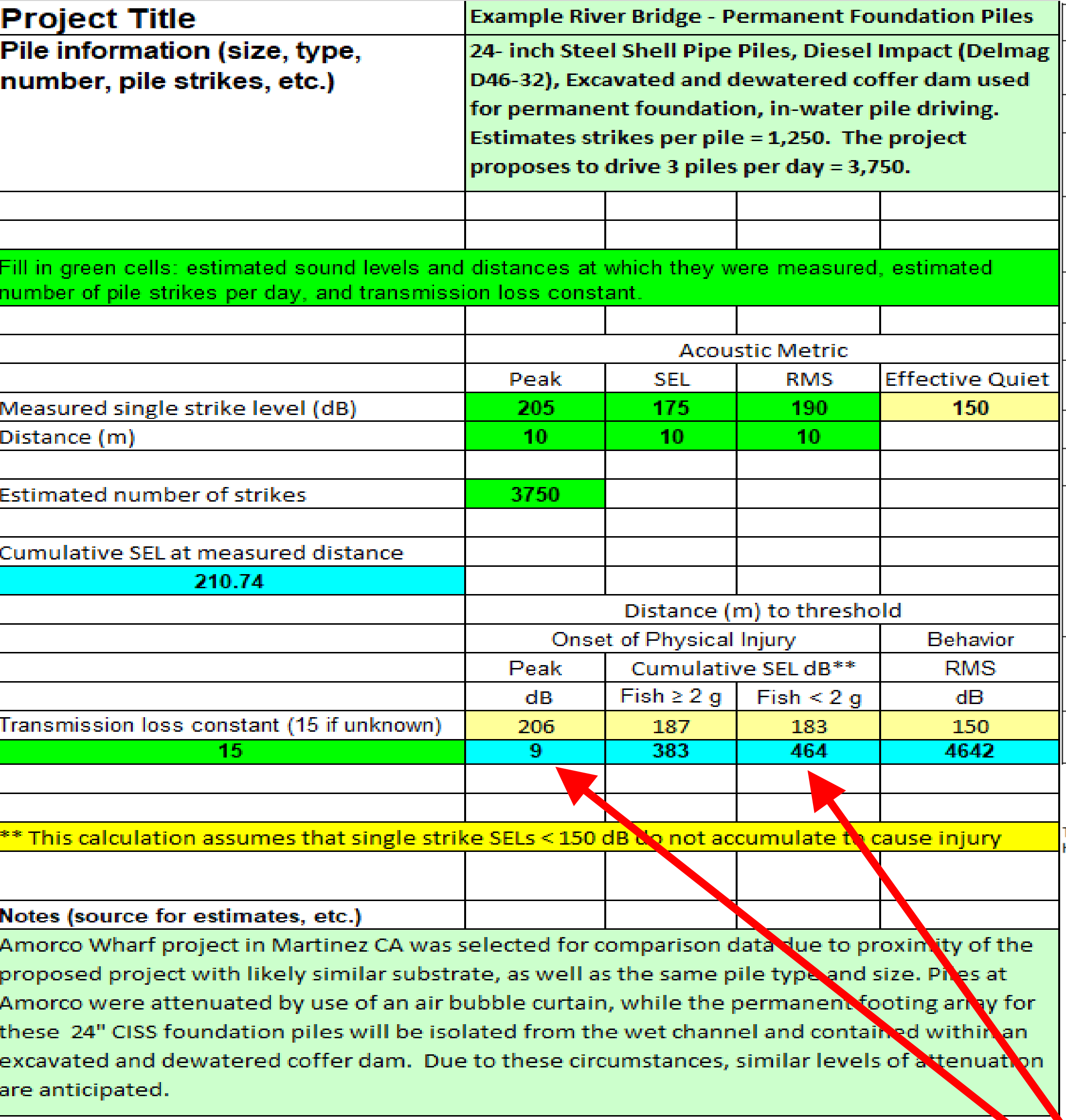
187.5 dB

183 dB

178.5 dB

~4.5 dB decrease for each doubling of distance

NMFS Tool
Hydroacoustic Analysis

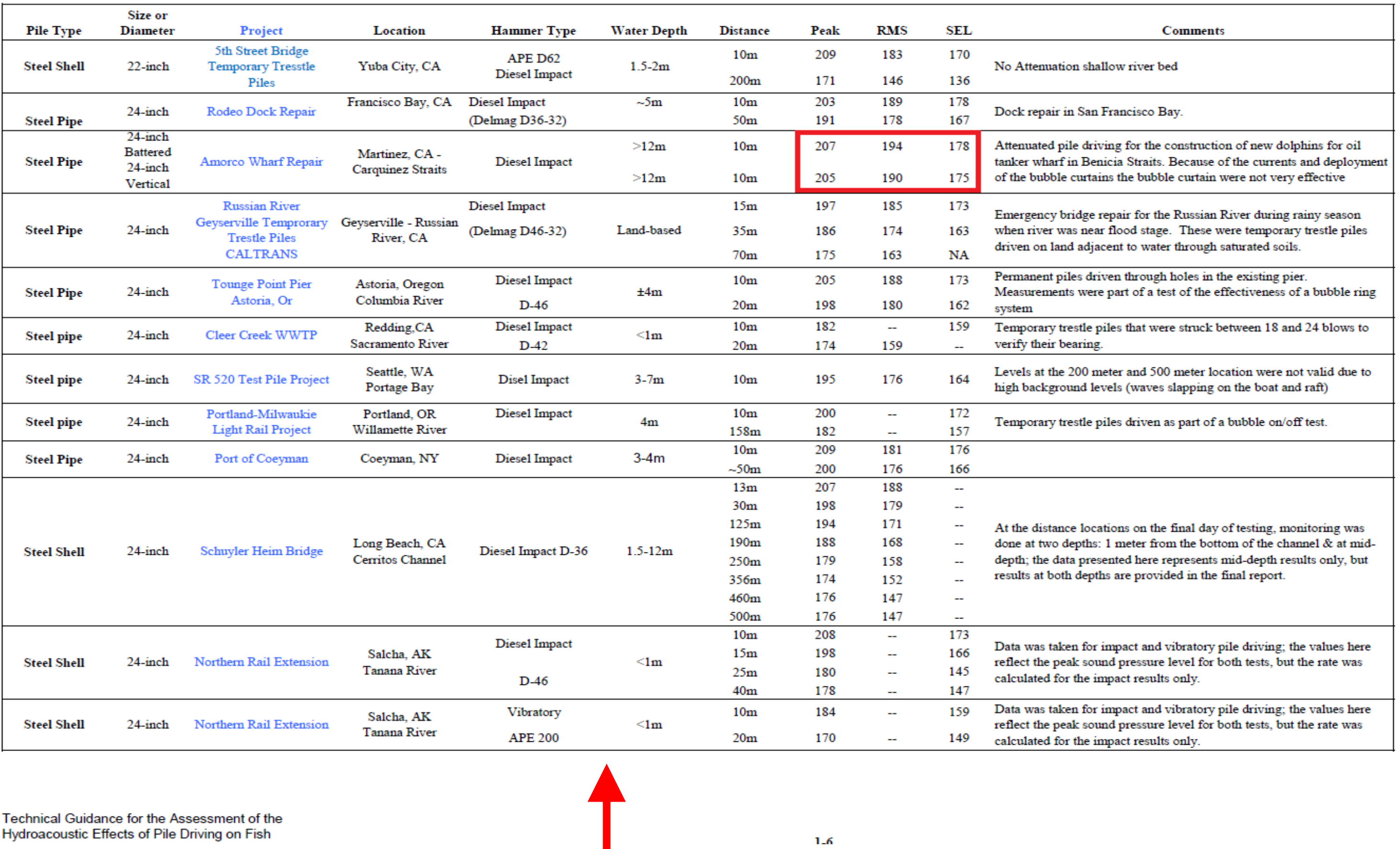


Project Title	Example River Bridge - Permanent Foundation Piles			
Pile information (size, type, number, pile strikes, etc.)	24- inch Steel Shell Pipe Piles, Diesel Impact (Delmag D46-32), Excavated and dewatered coffer dam used for permanent foundation, in-water pile driving. Estimates strikes per pile = 1,250. The project proposes to drive 3 piles per day = 3,750.			
Fill in green cells: estimated sound levels and distances at which they were measured, estimated number of pile strikes per day, and transmission loss constant.				
	Acoustic Metric			
	Peak	SEL	RMS	Effective Quiet
Measured single strike level (dB)	205	175	190	150
Distance (m)	10	10	10	
Estimated number of strikes	3750			
Cumulative SEL at measured distance				
210.74				
	Distance (m) to threshold			
	Onset of Physical Injury			Behavior
	Peak	Cumulative SEL dB**		RMS
	dB	Fish ≥ 2 g	Fish < 2 g	dB
Transmission loss constant (15 if unknown)	206	187	183	150
15	9	383	464	4642

** This calculation assumes that single strike SELs < 150 dB do not accumulate to cause injury

Notes (source for estimates, etc.)

Amorco Wharf project in Martinez CA was selected for comparison data due to proximity of the proposed project with likely similar substrate, as well as the same pile type and size. Piles at Amorco were attenuated by use of an air bubble curtain, while the permanent footing array for these 24" CISS foundation piles will be isolated from the wet channel and contained within an excavated and dewatered coffer dam. Due to these circumstances, similar levels of attenuation are anticipated.



Pile Type	Size or Diameter	Project	Location	Hammer Type	Water Depth	Distance	Peak	RMS	SEL	Comments
Steel Shell	22-inch	5th Street Bridge Temporary Tresstle Piles	Yuba City, CA	APE D62 Diesel Impact	1.5-2m	10m 200m	209 171	183 146	170 136	No Attenuation shallow river bed
Steel Pipe	24-inch	Rodeo Dock Repair	Francisco Bay, CA	Diesel Impact (Delmag D36-32)	~5m	10m 50m	203 191	189 178	178 167	Dock repair in San Francisco Bay.
Steel Pipe	24-inch Battered 24-inch Vertical	Amorco Wharf Repair	Martinez, CA - Carquinez Straits	Diesel Impact	>12m >12m	10m 10m	207 205	194 190	178 175	Attenuated pile driving for the construction of new dolphins for oil tanker wharf in Benicia Straits. Because of the currents and deployment of the bubble curtains the bubble curtain were not very effective
Steel Pipe	24-inch	Russian River Geyserville Temprorary Trestle Piles CALTRANS	Geyserville - Russian River, CA	Diesel Impact (Delmag D46-32)	Land-based	15m 35m 70m	197 186 175	185 174 163	173 163 NA	Emergency bridge repair for the Russian River during rainy season when river was near flood stage. These were temporary trestle piles driven on land adjacent to water through saturated soils.
Steel Pipe	24-inch	Tounge Point Pier Astoria, Or	Astoria, Oregon Columbia River	Diesel Impact D-46	±4m	10m 20m	205 198	188 180	173 162	Permanent piles driven through holes in the existing pier. Measurements were part of a test of the effectiveness of a bubble ring system
Steel pipe	24-inch	Cleer Creek WWTP	Redding,CA Sacramento River	Diesel Impact D-42	<1m	10m 20m	182 174	-- 159	159 --	Temporary trestle piles that were struck between 18 and 24 blows to verify their bearing.
Steel pipe	24-inch	SR 520 Test Pile Project	Seattle, WA Portage Bay	Disel Impact	3-7m	10m	195	176	164	Levels at the 200 meter and 500 meter location were not valid due to high background levels (waves slapping on the boat and raft)
Steel pipe	24-inch	Portland-Milwaukie Light Rail Project	Portland, OR Willamette River	Diesel Impact	4m	10m 158m	200 182	-- --	172 157	Temporary trestle piles driven as part of a bubble on/off test.
Steel Pipe	24-inch	Port of Coeyman	Coeyman, NY	Diesel Impact	3-4m	10m ~50m	209 200	181 176	176 166	
Steel Shell	24-inch	Schuyler Heim Bridge	Long Beach, CA Cerritos Channel	Diesel Impact D-36	1.5-12m	13m 30m 125m 190m 250m 356m 460m 500m	207 198 194 188 179 174 176 176	188 179 171 168 158 152 147 147	-- -- -- -- -- -- -- --	At the distance locations on the final day of testing, monitoring was done at two depths: 1 meter from the bottom of the channel & at mid-depth; the data presented here represents mid-depth results only, but results at both depths are provided in the final report.
Steel Shell	24-inch	Northern Rail Extension	Salcha, AK Tanana River	Diesel Impact D-46	<1m	10m 15m 25m 40m	208 198 180 178	-- -- -- --	173 166 145 147	Data was taken for impact and vibratory pile driving; the values here reflect the peak sound pressure level for both tests, but the rate was calculated for the impact results only.
Steel Shell	24-inch	Northern Rail Extension	Salcha, AK Tanana River	Vibratory APE 200	<1m	10m 20m	184 170	-- --	159 149	Data was taken for impact and vibratory pile driving; the values here reflect the peak sound pressure level for both tests, but the rate was calculated for the impact results only.

Technical Guidance for the Assessment of the
Hydroacoustic Effects of Pile Driving on Fish

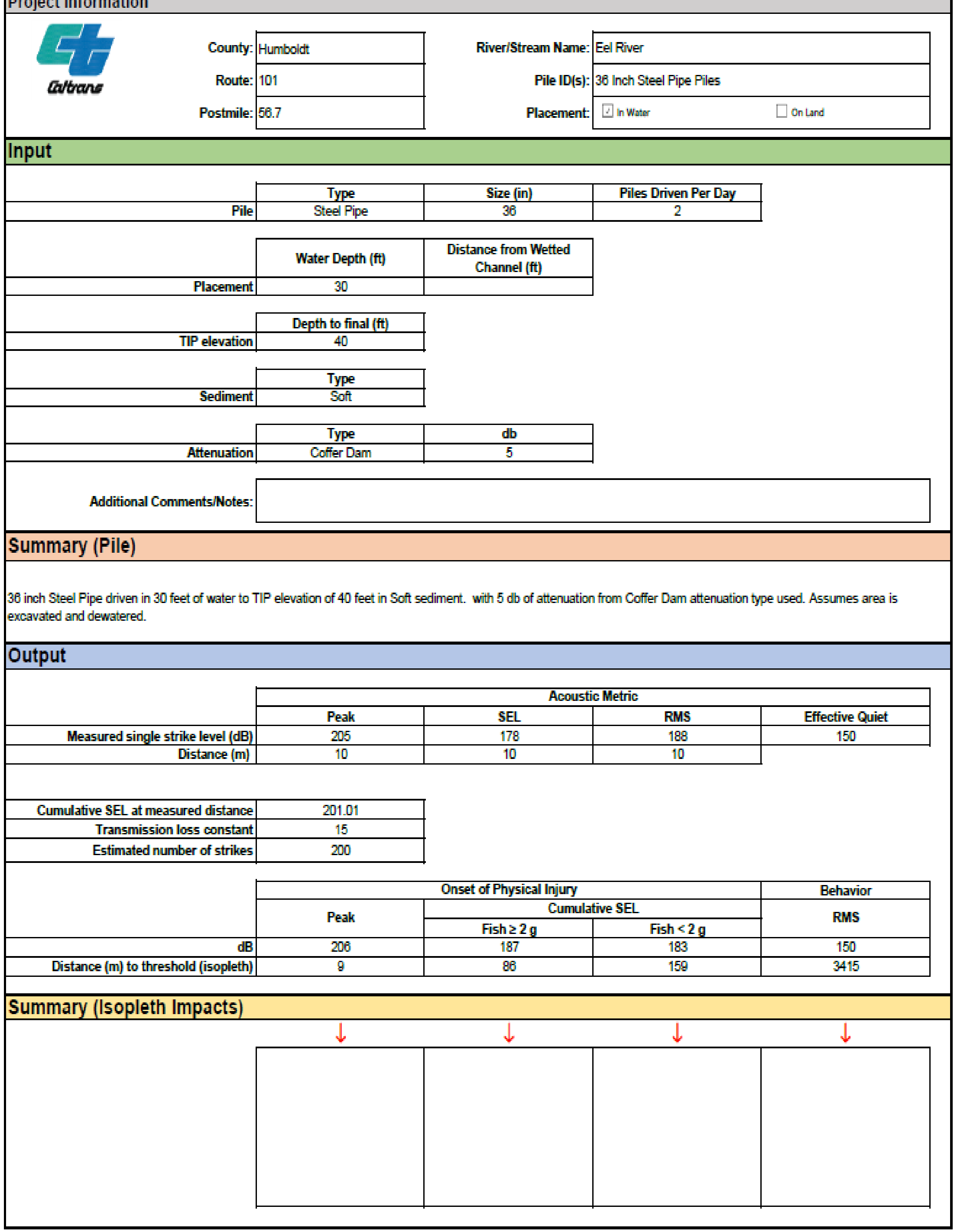
1-6

Caltrans Hydroacoustic Compendium Summary tables are useful to help determine appropriate comparison projects;
http://www.dot.ca.gov/hq/env/bio/fisheries_bioacoustics.htm

Estimated distance is a surrogate for fish populations anticipated to occur in the area during construction.

California Hydro-Acoustic Team (CHAT)

- Initiated in 2020
- Working on the Caltrans Compendium Tool
  - Database of hydroacoustic monitoring data
  - Automatically selects comparison project based on project design and sampling information;
    - Pile type and size,
    - Position – in wet channel or distance from wet channel,
    - Depth to final TIP elevation, and
    - Sediment type using a gradation analysis for categorization
- Pile strike analysis is ongoing to inform strike data for varied pile types, sizes, and substrate categories
- Drop-down selection for attenuation type
- A summary will generate for calculated areas and impacts for the Peak, accumulative SEL, and RMS distances.



Project Information

Caltrans

County: Humboldt
Route: 101
Postmile: 56.7
River/Stream Name: Eel River
Pile ID(s): 36 Inch Steel Pipe Piles
Placement: ☑ In Water ☐ On Land

Input

	Type	Size (in)	Piles Driven Per Day
Pile	Steel Pipe	36	2

	Water Depth (ft)	Distance from Wetted Channel (ft)
Placement	30	

	Depth to final (ft)
TIP elevation	40

	Type
Sediment	Soft

	Type	db
Attenuation	Coffer Dam	5

Additional Comments/Notes:

Summary (Pile)

36 inch Steel Pipe driven in 30 feet of water to TIP elevation of 40 feet in Soft sediment. with 5 db of attenuation from Coffer Dam attenuation type used. Assumes area is excavated and dewatered.

Output

	Acoustic Metric			
	Peak	SEL	RMS	Effective Quiet
Measured single strike level (dB)	205	178	188	150
Distance (m)	10	10	10	

Cumulative SEL at measured distance	201.01
Transmission loss constant	15
Estimated number of strikes	200

	Onset of Physical Injury			Behavior
	Peak	Cumulative SEL		RMS
		Fish ≥ 2 g	Fish < 2 g	
dB	206	187	183	150
Distance (m) to threshold (isopleth)	9	86	159	3415

Summary (Isopleth Impacts)

↓ ↓ ↓ ↓

Avoid and Minimize Underwater Sound Pressure

- Design Bridges to span waterways so pile driving can occur on land.
- If driving piles in water, use appropriate attenuation methods to include coffer dams, or bubble curtains, to disrupt or create discontinuity of the pressure wave.
- Start piles using vibratory methods to minimize total accumulative strikes needed.

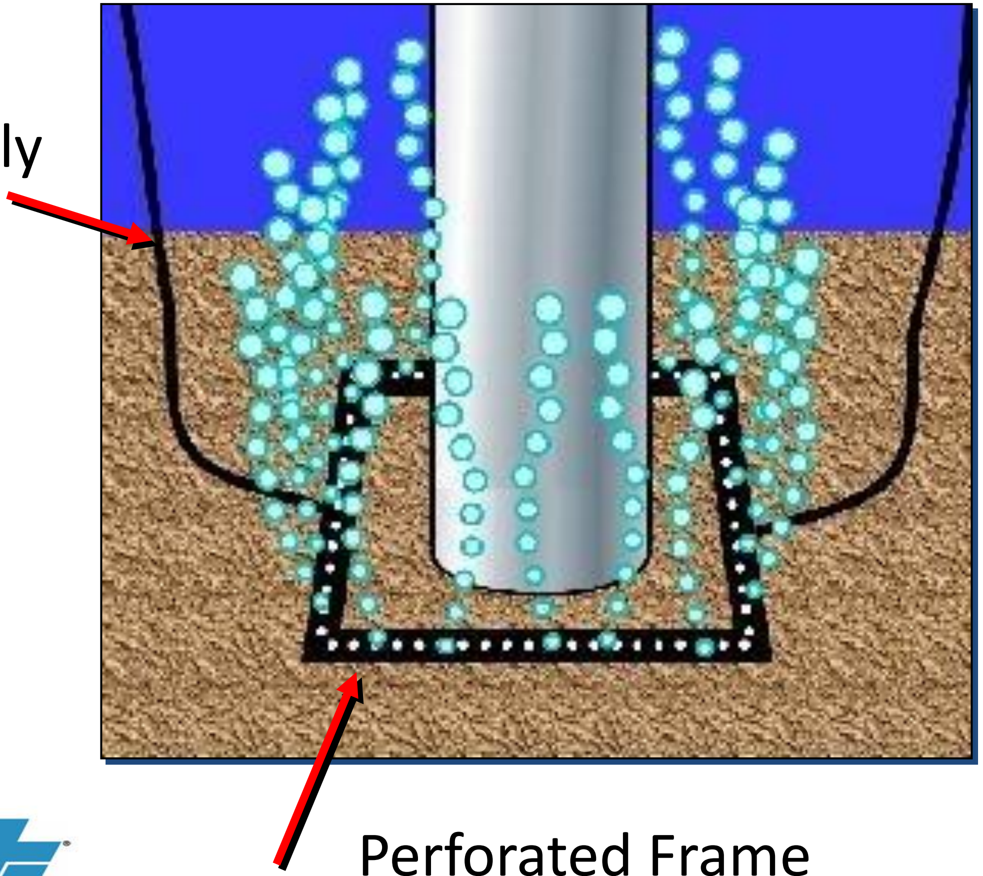
Attenuation

Isolation casings used to attenuate H-beam or other small piles

Must be annular gap of air to achieve reduction.

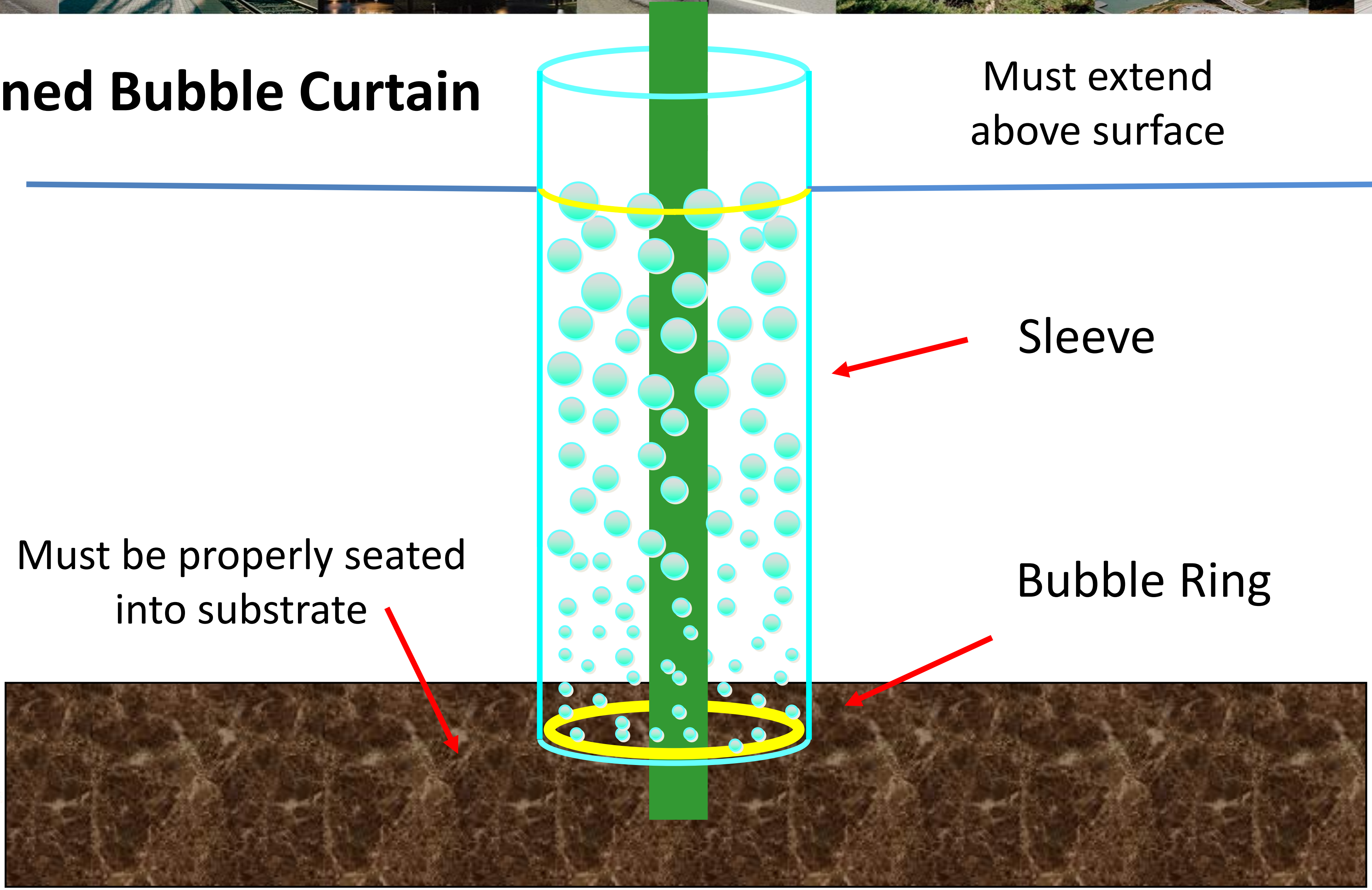
~ 1-3 dB of reduction

Bubble Curtain



- Requires generator(s) to pump air into frame
- Water/air density discontinuity attenuates pressure wave
- Cost-effective and relatively easy to deploy
- Average attenuation when properly designed and implemented **~6 to 8 dB** reduction.
- Unconfined best in low currents
- Additional rings needed in deeper water

Confined Bubble Curtain



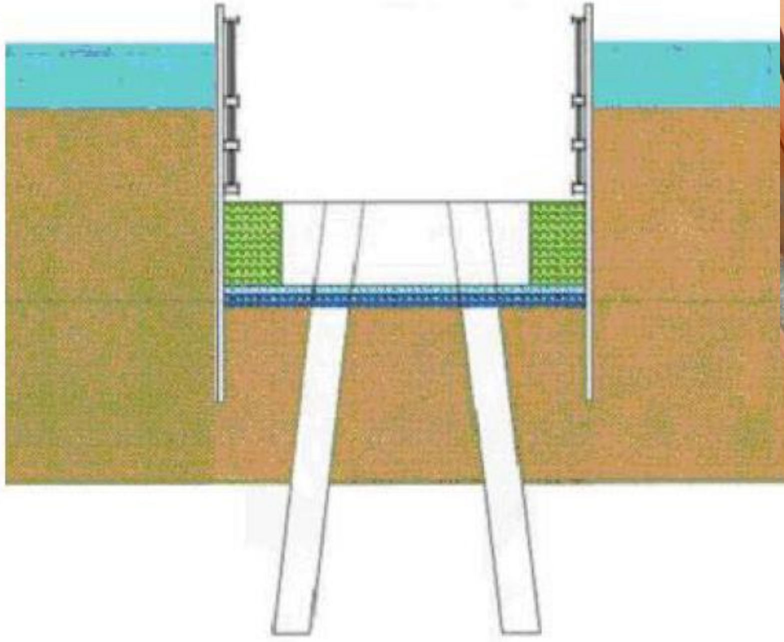
Must extend above surface

Sleeve

Bubble Ring

Must be properly seated into substrate

Cofferdams – Isolation and Attenuation



Cofferdams

~ 5-10 dB

attenuation

Dewatering and Isolation

Fish Exclusion - Netting Causes Mortality

Underwater Monitoring

- Monitoring is needed to verify underwater sound pressure estimates for project impacts
- Improve data and estimates for future projects
- More data and observations for understanding of hydroacoustic species impacts

Photo: James Reyff – Illingworth & Rodkin

Measurement Systems

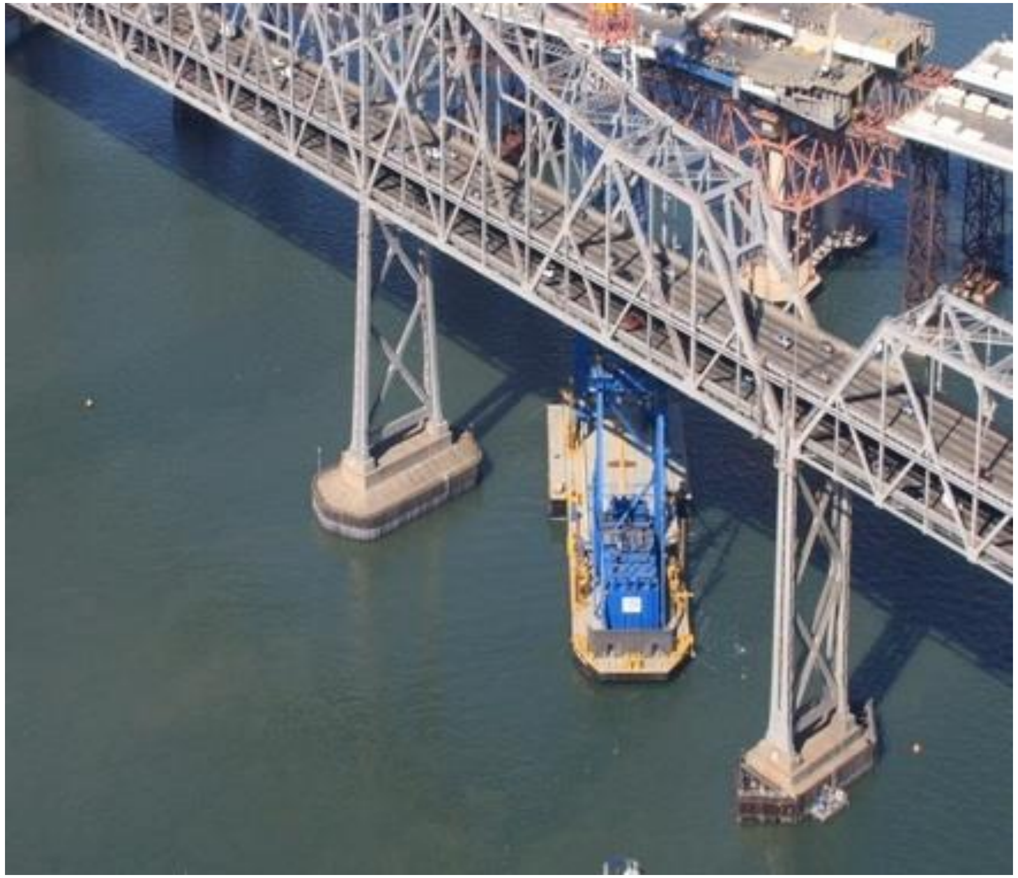
- Hydrophones
- Signal conditioning
- Signal processing
- Recording
- Descriptors

Photo: James Reyff, Illingworth & Rodkin

Qualified Oversighting Data Collection

Caltrans

SFOBB Demo - Pier E3, Largest deep-water pier



Species Avoidance and Minimization

- Seasonal work windows
- Bubble curtain attenuation
- Biological monitors
- Caged fish study (2004, 2016)

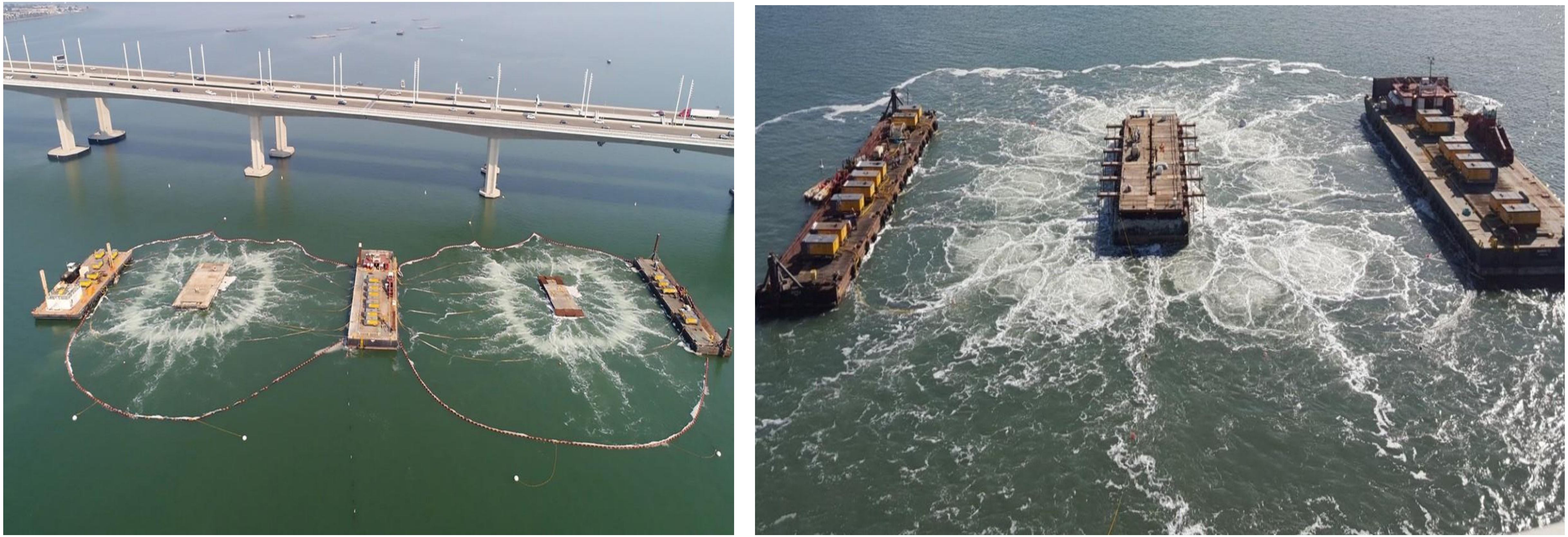
*Green boxes when species are not present
or expected at lower densities.

	J	F	M	A	M	J	J	A	S	O	N	D
Harbor Seal	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨
California Sea Lion	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨
Elephant Seal	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩
Gray Whale	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Longfin Smelt	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩
Northern Anchovy	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩
Pacific Herring	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩
Chinook Salmon[1]	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩
Pacific Sardine	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟩	🟨	🟨	🟨
Green Sturgeon[2]	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Nesting Birds	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩
Diving Birds	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟨

[1] Juvenile Chinook salmon densities around Pier E3 are low (highest value of 0.25 individuals/10,000 sq. meters in May).

[2] Green sturgeon have potential to occur around Pier E3 year-round, but in very low densities.

SFOBB – 2016/17 Low Impact Blasting - Demolition

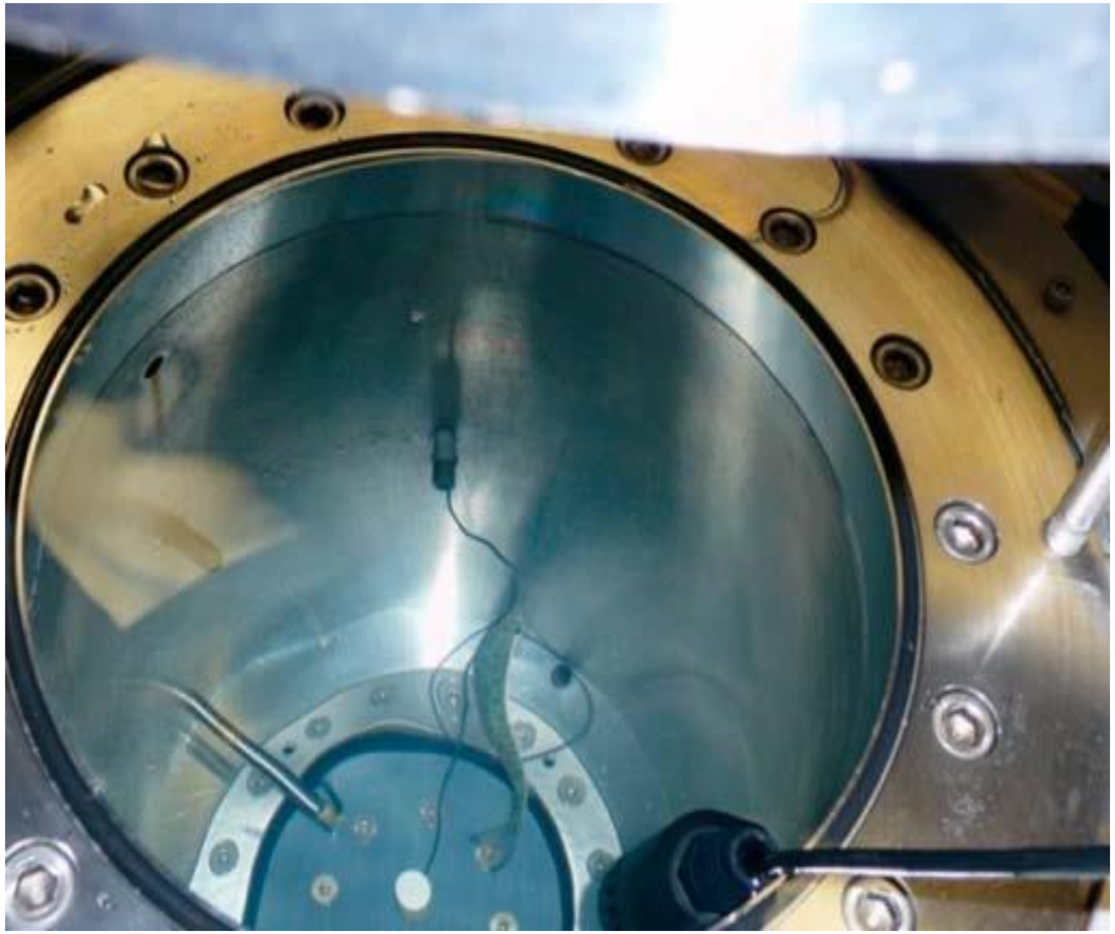


Hydroacoustic Research

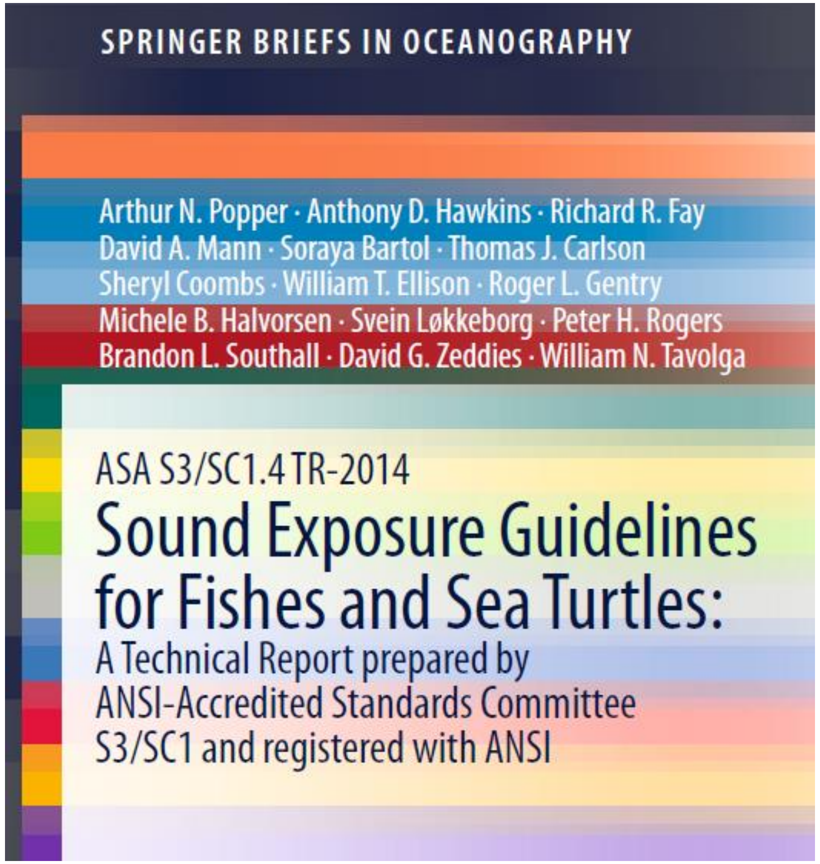
- Houghton et al. (2010)
- Exposed 133 caged juvenile Coho salmon to pile driving.
  - Distance: 1-50 meters from source.
  - PEAK as high as 195 dB
  - cSEL as high as 191 dB
- No mortalities or tissue damage from barotrauma reported as late as 48 hours post exposure.

Research – Hydroacoustic Impacts on Fish from Pile Driving

- Halvorsen et al. (2011), Univ. of Maryland
- Chinook salmon, size: ~ 103mm length, average 11.8 grams.
- Test used high intensity pile driving sound pressure in a lab setting (wave tube).
  - Average PEAK SPL – 199-213 dB
  - Average SEL_{cum} – 204-219 dB
- Post-exposed fish were euthanized and examined for external and internal injury.



Sound Exposure Guidelines for Fishes and Sea Turtles - Popper et al. (2014)



SPRINGER BRIEFS IN OCEANOGRAPHY

Arthur N. Popper · Anthony D. Hawkins · Richard R. Fay
David A. Mann · Soraya Bartol · Thomas J. Carlson
Sheryl Coombs · William T. Ellison · Roger L. Gentry
Michele B. Halvorsen · Svein Løkkeborg · Peter H. Rogers
Brandon L. Southall · David G. Zeddies · William N. Tavolga

ASA S3/SC1.4 TR-2014
Sound Exposure Guidelines for Fishes and Sea Turtles:
A Technical Report prepared by
ANSI-Accredited Standards Committee
S3/SC1 and registered with ANSI

Endangered Species Acts (ESA), recoverable injury is not consistent or in compliance with the Federal Endangered Species Act (FESA) definition, or the California Endangered Species Act (CESA) definitions of *take*;

Assume mortality at the onset of physical injury, even those deemed "recoverable".

Peak = increase by 1 dB to 207

cSEL = increase to 203 cSEL

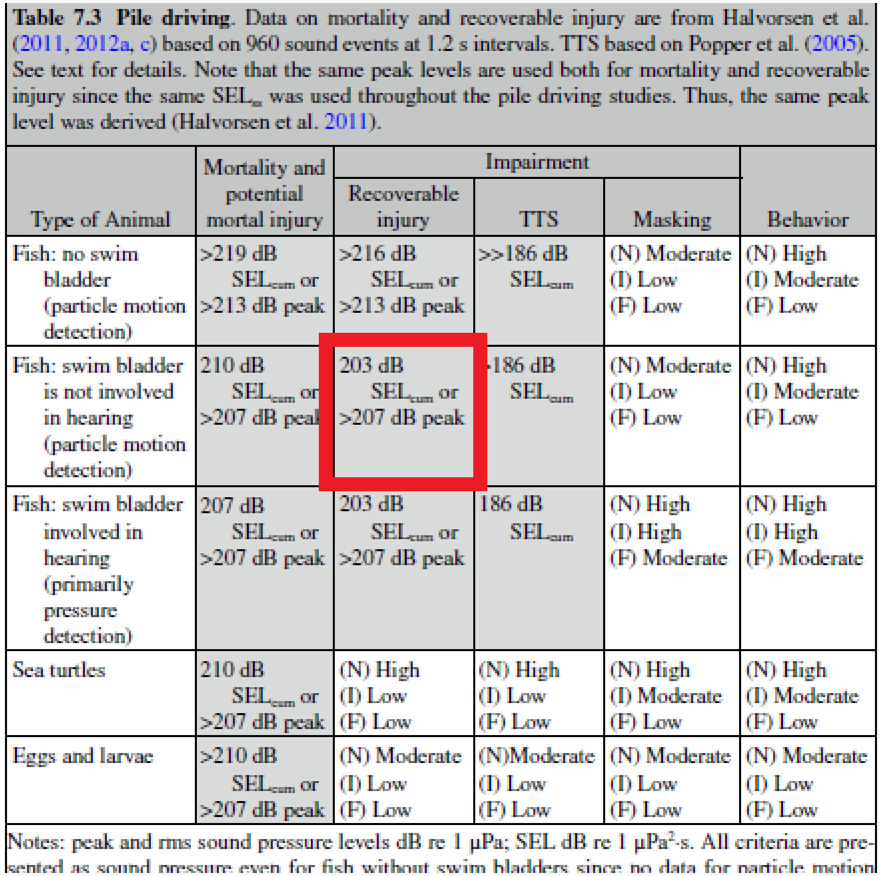


Table 7.3 Pile driving. Data on mortality and recoverable injury are from Halvorsen et al. (2011, 2012a, c) based on 960 sound events at 1.2 s intervals. TTS based on Popper et al. (2005). See text for details. Note that the same peak levels are used both for mortality and recoverable injury since the same SEL$_{ss}$ was used throughout the pile driving studies. Thus, the same peak level was derived (Halvorsen et al. 2011).

Type of Animal	Mortality and potential mortal injury	Impairment			Behavior
		Recoverable injury	TTS	Masking	
Fish: no swim bladder (particle motion detection)	>219 dB SEL_{cum} or >213 dB peak	>216 dB SEL_{cum} or >213 dB peak	>>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)	210 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	186 dB SEL_{cum}	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea turtles	210 dB SEL_{cum} or >207 dB peak	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) Moderate (F) Low
Eggs and larvae	>210 dB SEL_{cum} or >207 dB peak	(N) Moderate (I) Low (F) Low	(N)Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

Notes: peak and rms sound pressure levels dB re 1 μPa; SEL dB re 1 μPa^2-s. All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion

- In 2017, pooled-fund study initiated by WSDOT.
  - Oregon DOT, Caltrans, and FHWA also contributed.
- Inventory and summarize post-2008 research to consider underwater sound pressure levels that cause mortality, injury, and harm. Findings;
  - Agree that Interim thresholds are protective of fish but that the cSEL is consistent with TTS, not injury.
  - Reiterate 2014 guidelines in support of needed updates.
  - Outline deficiencies of XL analysis tool, such as substrate type, strike estimates, and water depth.
- Identify particle motion research needed to determine potential effects on fish.

Anthropogenic Sound and Fishes

WA-RD 891.1

Arthur N. Popper
Anthony D. Hawkins
Michele B. Halvorsen

February 2019

Washington State Department of Transportation
Office of Research & Library Services

WSDOT Research Report

Recommended Training and Education for Bridge Elements, Foundations Design, Watershed and Hydroacoustic Analysis www.cafishpac.org/training

- **Basic Bridge Components** - Ryan Stiltz, Caltrans Senior Bridge Engineer (https://vimeo.com/397674263)
- **Geotechnical Investigations and Foundations Design** – Hector Valencia, Caltrans Senior Geotechnical Engineer (https://vimeo.com/397665887)
- **Intersection of Fluvial Processes, Fish Passage, and Road Stream Crossings** – John Wooster, NOAA Fisheries Fluvial Geomorphologist (https://vimeo.com/397667601)
- **Environmental Advantages of Accelerated Bridge Design (ABC)** – Dorie Mellon, Senior Bridge Engineer ABC Policy (https://vimeo.com/397662964)
- **Pre-Design Fish Passage Bridges** – Doug Menzmer, Caltrans Senior Bridge Engineer (https://www.cafishpac.org/training)
- **Software for Road Stream Crossings and Fish Passage Analysis and Design** – Rick Macala, CDFW Senior Fish Passage Engineer (https://www.cafishpac.org/training)
- **Evaluating and Monitoring the Effects of Impact Pile Driving on Fish** – David Buehler, ICF Principal, Acoustic Engineer (https://vimeo.com/397662555)
- **San Francisco**-Oakland Bay Bridge-Case Study – Brian Maroney, SFOBB Chief Engineer, and Stefan Galvez, Caltrans District Principle Environmental Planner (https://vimeo.com/397674502)
- **Considerations for Design and Implementation of Bridges in Sensitive Biological Habitats –** Gudmund Setberg, Caltrans Structures Deputy, State Bridge Engineer (https://vimeo.com/397665372)
- **Stream and River Diversions – Minimizing Impacts During Diversions, Dewatering, and Species Relocation** – Mike Kelly, NOAA Fisheries Biologist (https://vimeo.com/397672952)

Mentors, Teachers, and Colleagues – Thank you!

- **Structures/Geotech** – Ryan Stiltz, Doug Menzmer, Gudmund Setberg, Dorie Mellon, Dan Adams, Steve Mellon, Brian Maroney, Hector Valencia, Ron Richmond, June James, Charlie Narwold, Hernan Perez, Tom Song, Tog Nordstrom
- **Construction** – Sebastian Cohen, Tom Fitzgerald
- **Hydroacoustics** – David Buehler, Bruce Rymer, David Woodbury, Dr. John Stadler, Marion Carey, Jimmy Walth

Photos: Kristine Pepper

Melinda Molnar, Senior Fish Biologist
Caltrans Office of Biology and Innovation
Melinda.Molnar@dot.ca.gov, ph. 916.247.8555