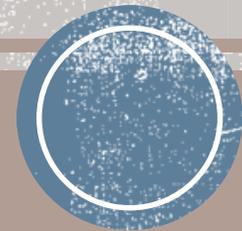


# **Pile Driving & Hammer Sizing**

**(Practice in the state of Indiana)**

Jose J. Ortiz  
Division Bridge Engineer  
Federal Highway Administration



# Let's talk about...

- Bridge foundations in Indiana
- History of pile driving
  - Pile testing
  - Hammer sizing
- The challenges
- INDOT's approach
  - Pile Driving Analyzer
  - Hammer size memorandum
- Statistics



# Bridge foundations in Indiana

- Types

- Spread footing
- Micropiles
- Drilled shaft
- Driven Piles
  - Prestressed concrete piles (Not often used)
  - H-piles (HP12x53)
  - Pipe piles (14 in.)
- Hammers
  - Impact hammers
  - Vibrating hammers



# History... Pile testing & Hammer sizing

- Prior to 1990's, no field testing of piles
  - Indiana Department of transportation (INDOT) will relied completely on the engineering news record (ENR) formula for determining pile capacities.
  - ENR formula has factor of safety ranging from 0.5 to 12.
- Hammer sizing
  - First 30T, then 70T, and by 2010, with the use LRFD design load went up as high as 350T per pile.
  - Designers will make an effort to reduce the number of piles. Focus on integral abutments.
  - For hammer sizing, contractor will submit a hammer for INDOT's approval.



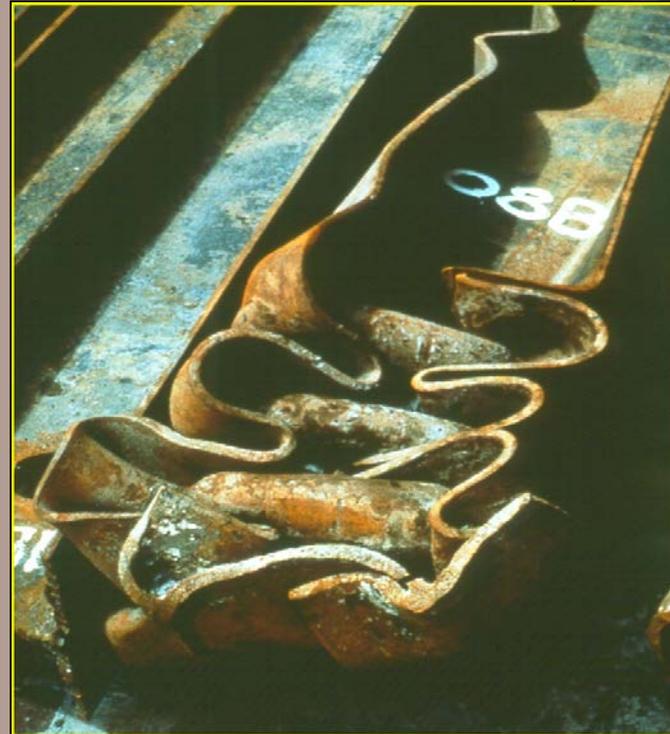
# The challenges

- Cost
  - Less piles = increase pile size
  - Increase pile size = higher driving resistance
  - Higher driving resistance = bigger hammer
  - Bigger hammer = bigger crane
  - = Higher cost
- Pile damage or hammer damage
  - Added cost



# The challenges

- Problems



# The challenges

- Problems



# The challenges

- Unknown hammer performance
- No validation of the estimated soil conditions
- No monitoring of the pile driving operations
- Change orders during construction due to pile quantities

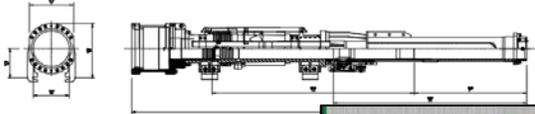
### B-3005 General Specifications

Performance		
Ram Weight X Max. Stroke	34,500 ft. lb	47 kN·m
Impact energy	21,533 ft. lb	29 kN·m
Ram weight/mass	3,000 lb	1,400 kg
Maximum ram stroke	11.5 ft	3.5 m
Impact block weight/mass	802 lbs	364 kg
Blows per minute	36-60	7.3
Operating Weight		
Total operating weight/mass	11,000 lb	4,989 kg
Weight of tool box	150 lb	68 kg
Total shipping weight/mass	11,150 lb	5,056 kg
Capacity		
Fuel tank capacity	16 gal (U.S)	62 liters
Fuel consumption	1.4 gal/hr.	5.3 liters/hr.
Oil tank capacity	1.9 gal (U.S)	7.3 liters
Oil consumption	0.16 gal/hr.	0.6 liters/hr.



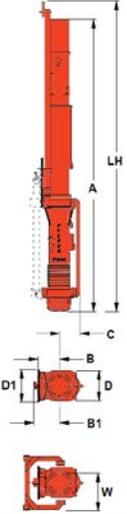
**Impact Hammers B-3005**

### Dimensional Specifications



### D19-42 Diesel Hammer

Energy Per Blow, Adjustable		
Pump Setting 1 (50%)	29,238ft·lb	21,510 MJ·ft
Pump Setting 2 (65%)	38,048ft·lb	28,035 MJ·ft
Pump Setting 3 (85%)	47,848ft·lb	35,250 MJ·ft
Pump Setting 4 (100%)	57,648ft·lb	42,465 MJ·ft
Frequency	37-52 blows per min.	
Rated Piston Stroke	3.2 - 1.6 m	10.5 - 5.3 ft
Max. Diameter (without upper cylinder extension)	15	
Max. Diameter (with upper cylinder extension)	11	
Fuel Consumption At Full Load	7.6 l/hr	2 gal/hr
Oil Consumption	0.6 l/hr	0.16 gal/hr
Approx. Weights		
Hammer	3,795 kg	8,355 lbs
Piston	1,620 kg	4,015 lbs
Hammer (with standard gading)	4,400 kg	9,700 lbs
Capacities		
Fuel Tank	75 l	20 gal
Oil Tank	19 l	5 gal
Dimensions		
A - Length	5,610 mm	18.4 ft
LH - Length (standard)	5,050 mm	16.6 ft
B - Center To Trip	355 mm	14 in
B1 - Center To Trip (with cylinder)	555 mm	21 in
C - Center To Pump Guard	405 mm	16 in
D - Width Of Hammer	495 mm	19.5 in
D1 - Width Of Trip	622 mm	24.5 in
W - Minimum Lead Width	534 mm	21 in



### MODEL D19-52 (1.9 metric ton ram)

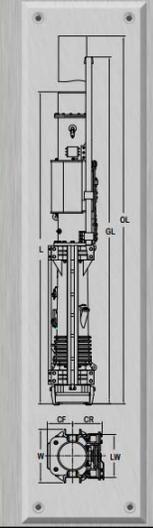


SPECIFICATIONS	
Stroke at maximum rated energy	135
Maximum rated energy (Setting 4)	47,132 ft·lb (64)
Setting 3	36,319 ft·lb (5)
Setting 2	25,506 ft·lb (4)
Maximum rated energy (Setting 1)	21,546 ft·lb (3)
<i>(Variable throttle allows for infinite fuel settings)</i>	
Maximum obtainable stroke	150
Maximum obtainable energy	52,362 ft·lb
Speed (blows per minute)	
WEIGHTS (Approximate)	
Piston	4,189 lbs
Anvil	750
Anvil cross sectional area	124.82 in <sup>2</sup>
Hammer weight (excludes trip device)	6,400 lbs
Typical opening weight with D19S and H-beam insert	11,052 lbs
CAPACITIES	
Fuel tank (run on diesel or bio-diesel)	8.3 gal (3)
Oil tank	2.3 gal
CONSUMPTION	
Diesel or Bio-diesel fuel	1.3 gal/hr (5)
Lubrication	0.13 gal/hr (4)
Grease	8 to 10 pumps every 20 minutes of operation

STRIKER PLATE FOR DR-26	
Weight	425 lb
Diameter	22.5 in
Area	398 in <sup>2</sup> (25)
Thickness	6 in
STRIKER PLATE FOR DR-20	
Weight	440 lb
Diameter	17.75 in
Area	247 in <sup>2</sup> (19)
Thickness	6 in
CUSHION MATERIAL	
Type	Monocon
Diameter-DH26	22.5 in
Diameter-DH20	17.75 in
Thickness	2 in
Elastic modulus	285 ksi (1,967 MPa)
Coeff. of restitution	0.5
DRIVE CAP	
DR-26	1,076 lbs (480 kg)
DR-20	730 lbs (330 kg)
INSERT WEIGHT	
H-beam insert for 12" (305 mm) and 14" (355 mm)	948 lbs (430 kg)
Large pipe insert for sizes 12" to 24" diameter	1,830 lbs (830 kg)

### Working Specifics

Ram weight	
Rated energy (fuel x stroke at rated energy)	69,255 ft·lb (94,145 Nm)
Energy at fuel setting 2	62,925 ft·lb (85,315 Nm)
Energy at fuel setting 1	56,415 ft·lb (76,490 Nm)
Energy at maximum stroke	83,370 ft·lb (113,030 Nm)
Maximum geometric stroke	12.60 feet (3,840 mm)
Blows per minute	35-52
Weights	
Bare hammer with trip	13,440 lbs (6,095 kg)
Hammer with box lead guides	14,750 lbs (6,690 kg)
Drive cap base	DCB-1HD
Drive cap base weight	1,245 lbs (565 kg)
Striker plate	460 lbs (209 kg)
Cushion material	110 lbs (25 kg)
Pile insert	DCH-1
Pile insert weight	780 lbs (345 kg)
Operating weight with drive cap above	17,345 lbs (7,834 kg)
Capacities	
Fuel tank	16.8 gal (63.5 l)
Lube oil tank	4.6 gal (17.5 l)
Dimensions	
Hammer length (L)	16.9 ft (5,160 mm)
Length with trip guides (GL)	20.8 ft (6,325 mm)
Length at max stroke (OL)	24.4 ft (7,445 mm)
Overall width (W)	32.3 in (820 mm)
Standard box leads width (LW)	26 in (660 mm)
Overall depth (CR + CF)	34.0 in (863 mm)
Centerline to rear (CR)	18.8 in (477 mm)
Centerline to front (CF)	15.2 in (386 mm)

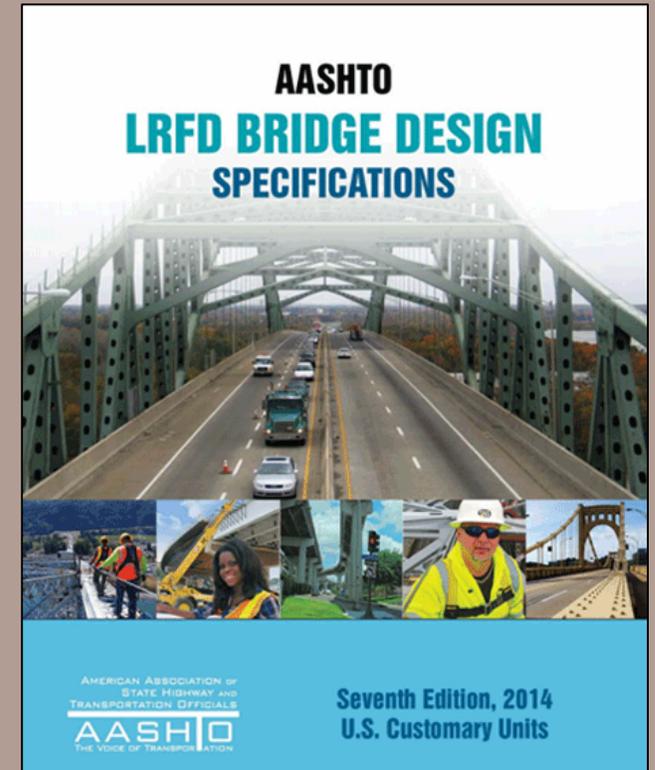






# Let's get to work...

- In 2010, based on FHWA/AASHTO requirements, INDOT required all foundation designs to follow AASTHO LRFD.
  - Resistance factor is computed in terms of probability of failure (reliability index)
  - Increase the resistance factor to make it more economical
  - With risk of foundation failure, capacity evaluation is necessary.



Less Testing = Higher Risk

Accurate Testing = Lower Risk



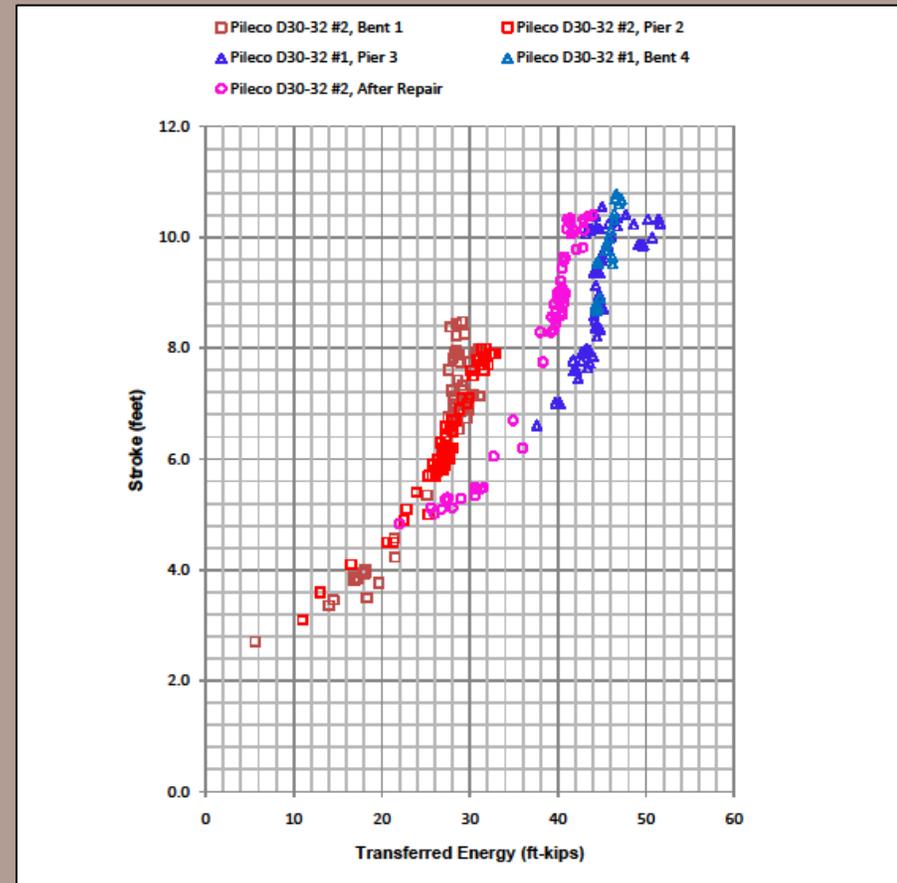
# Pile Driving Analyzer (PDA)

- Improve understanding of driven pile design and construction
- Improve understanding of soil condition
- Improve construction practices
- Provide quality assurance



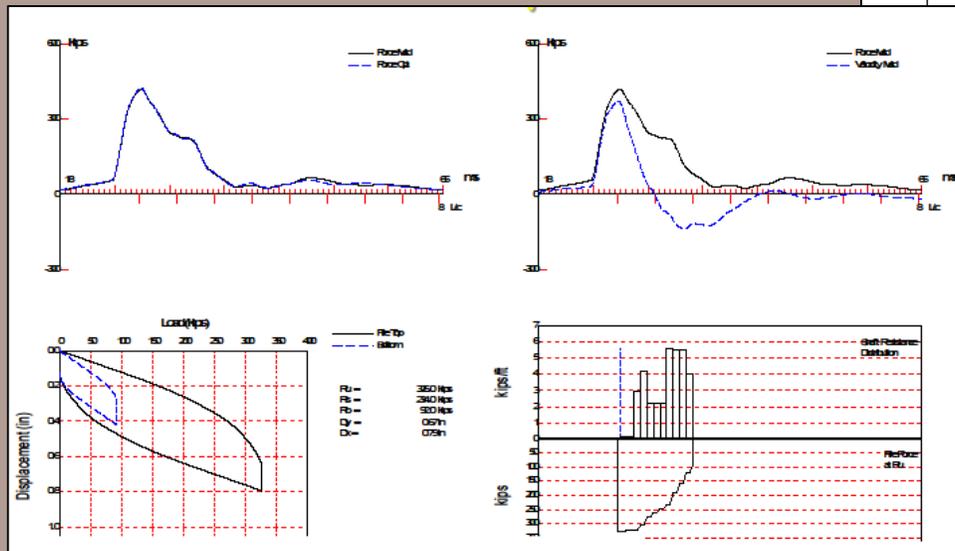
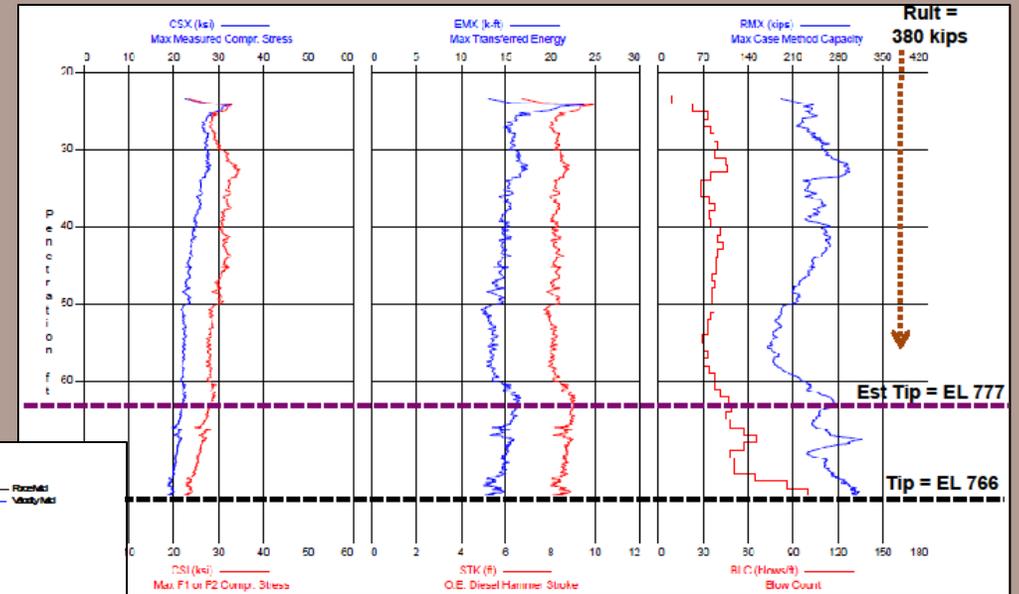
# Pile Driving Analyzer (PDA)

- Hammer performance
  - Same hammer model
  - Different location on the same project
  - Before and after hammer was repaired
- Engineers rely on the blow count as driving criteria for pile acceptance
- Checking the hammer performance assure that initial driving criteria is valid throughout the entire project



# Pile Driving Analyzer (PDA)

- Dynamic pile testing with signal matching CAPWAP is used to evaluate pile capacity
- It provides driving stresses; too large can cause pile damage



# Pile Driving Analyzer (PDA)

- Knowing the benefits
  - Reliability
  - Confidence (right depth and pile type)
- INDOT's criteria for the use of PDA
  - PDA is not required on every INDOT project because it will not be cost effective
  - Cost of piling < \$100,000, generally no PDA or Static load test is recommended (Unless soil conditions warrant it).
  - \$100,000 < Cost of piling < \$500,000, PDA is recommended.
  - Cost of piling > \$500,000, PDA and Static load test is recommended.
- When required, one PDA per bent.
  - If twin bridges are constructed, PDA can staggered between the two bridges.
  - No PDA if driving to bedrock.



# Hammer size memorandum

- Pile driving (No. 18-15), published on August 6, 2018
- Cost-effective pile foundation
  - Number of piles
  - Driving equipment
- Change the mentality of “make it bigger to have less piles”



**INDIANA DEPARTMENT OF TRANSPORTATION**  
*Driving Indiana's Economic Growth*

**Design Memorandum No. 18-15**  
**Technical Advisory**

August 6, 2018

**TO:** All Design, Operations, and District Personnel, and Consultants

**FROM:** */s/Elizabeth W. Phillips*  
Elizabeth W. Phillips  
Manager, Office of Standards and Policy  
Bridge Design Division

**SUBJECT:** Pile Driving

**REVISES:** *Indiana Design Manual (IDM) Section 408-3.01*

**EFFECTIVE:** Stage 3 submittals on or after September 1, 2018

A cost-effective pile foundation should consider both the number of piles driven, as well as the pile driving equipment necessary for installation. Increasing the nominal driving resistance,  $R_{db}$ , may reduce the total number of piles, but increase the installation costs when a contractor must rent a larger hammer and/or crane to achieve the higher driving resistance.

Designers should limit  $R_{db}$  to 426 kips for routine bridge projects. This value correlates to commonly owned pile hammers with maximum energy ratings of 69,000-75,000 ft-lbs. Limiting  $R_{db}$  also reduces the risk of pile damage during installation.

Higher  $R_{db}$  values may be feasible based on specific site conditions where higher installation costs are offset by a significant reduction in the number of piles. Where higher  $R_{db}$  values are considered appropriate, the designer should coordinate with the project geotechnical engineer.

The *Indiana Design Manual* has been revised to incorporate this guidance and is included for reference on the following page.

Contact Jeremy Hunter with questions and comments at (317) 233-2096 or by email at [jhunter@indot.in.gov](mailto:jhunter@indot.in.gov).



# Hammer size memorandum

- Designers should limit the nominal driving resistance to 426 kips
- Use hammer with a maximum energy rating of 69,000 lbs. – 75,000 lbs.

Pile Type	Section Area, in. <sup>2</sup>	Maximum Nominal Soil Resistance, $R_{n \text{ max.}}$ kip
HP 10x42	12.4	341
HP 10x57	16.8	462
HP 12x53	15.5	426
HP 12x63	18.4	506
HP 12x74	21.8	600
HP 12x84	24.6	677
HP 14x73	21.4	589
HP 14x89	26.1	718
HP 14x102	30.0	825
HP 14x117	34.4	946
Pipe pile, 14 in.	n/a	420
Pipe pile, 16 in.	n/a	480



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# Hammer size memorandum

- Benefits
  - Construction crews can use commonly owned pile hammers
  - Cost of mobilization reduced
  - Avoid delays (waiting for availability of a big hammer)
  - Reduce the risk of pile damage during the installation



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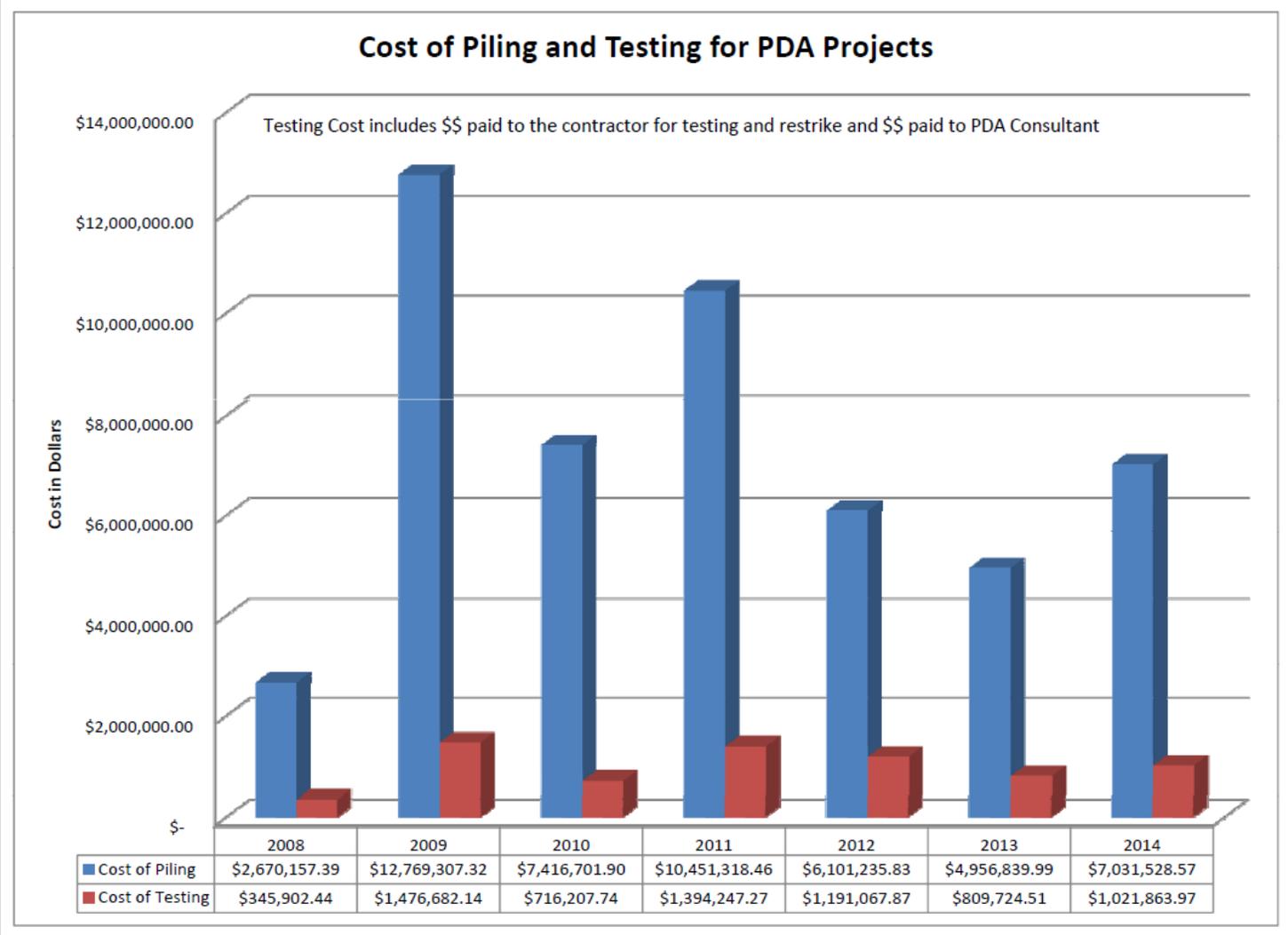
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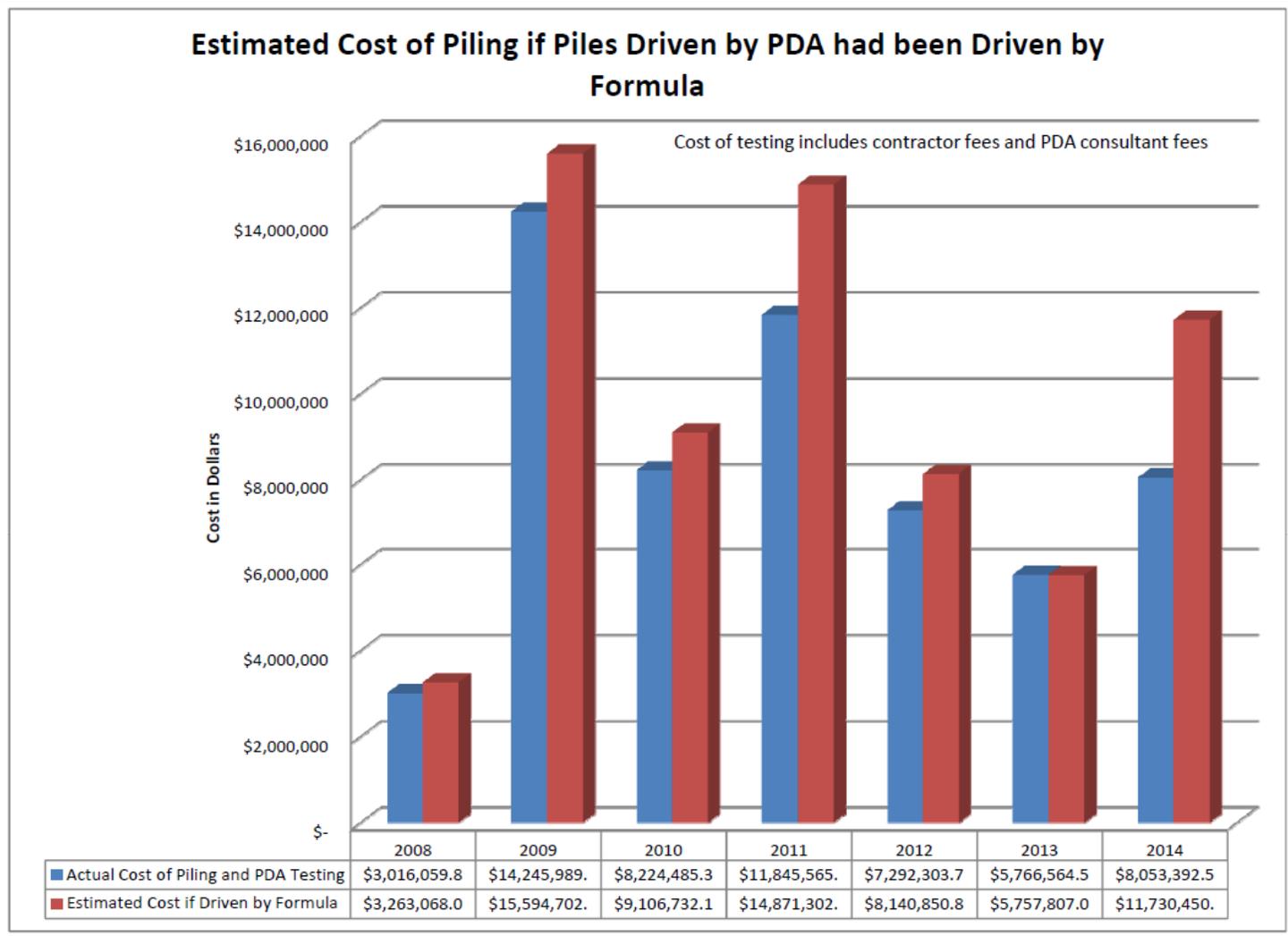
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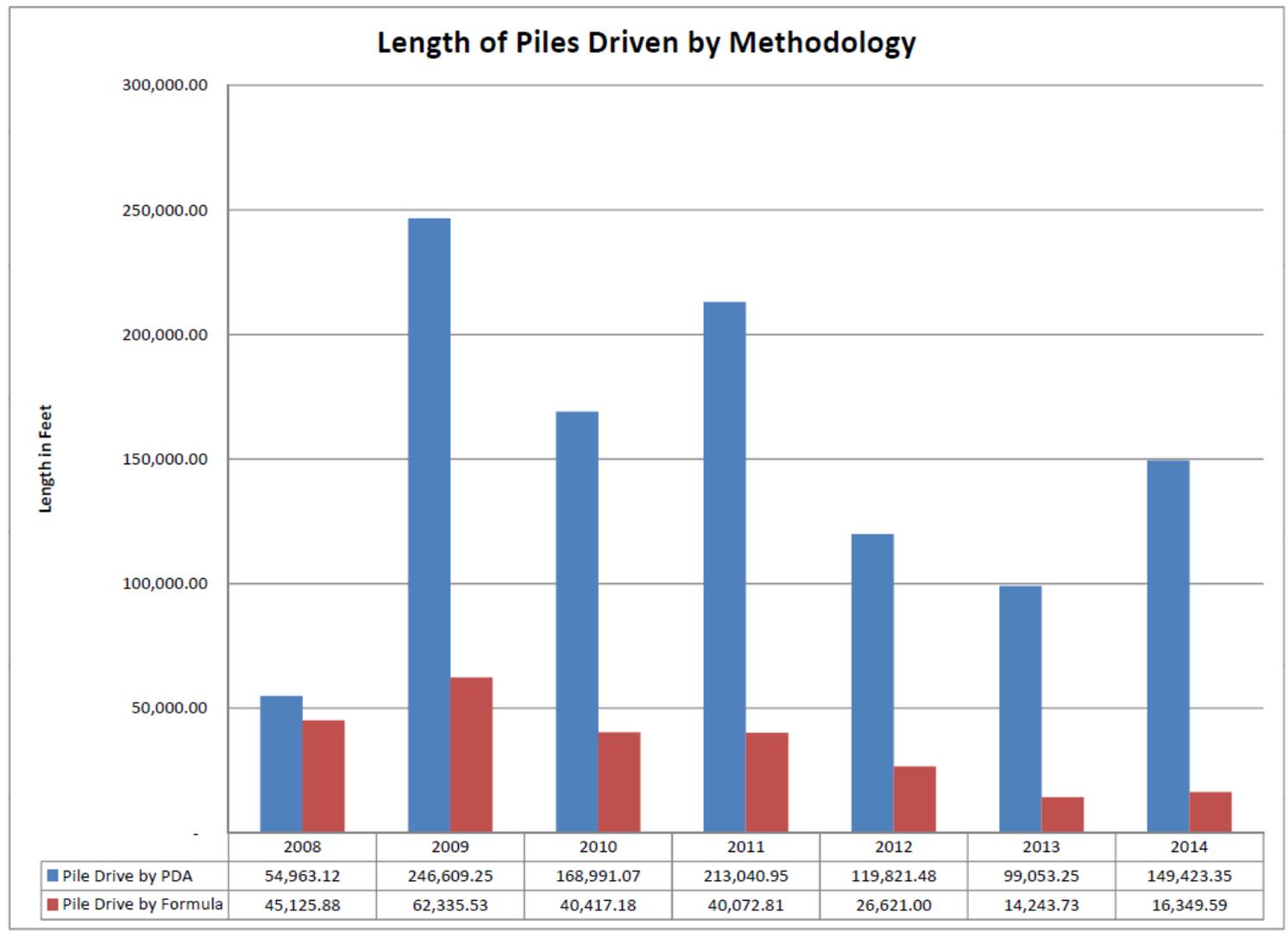
# Statistics



# Statistics



# Statistics



# Statistics

SECTION	ITEM	DESCRIPTION	UNIT	LOW PRICE	HIGH PRICE	WGT AVG	NO ITEMS	TOTAL (\$)	PDA Cost % of Piling Cost
<b>2008</b>									
701	701-06011	DYNAMIC PILE LOAD TEST	EACH	775.36	9,000.00	\$ 2,899.58	90.00	\$ 260,962.20	1.99
701	701-06012	TEST PILE, RESTRIKE	EACH	825.00	3,933.41	\$ 2,013.49	90.00	\$ 181,214.10	1.38
701		TOTAL PILING COST	LFT				254,800	\$ 13,142,856.43	
<b>2009</b>									
701	701-06011	DYNAMIC PILE LOAD TEST	EACH	800.00	5,000.00	1,722.97	169.00	\$ 291,181.93	2.92
701	701-06012	TEST PILE, RESTRIKE	EACH	800.00	3,332.86	1,380.23	96.00	\$ 132,502.08	1.33
701		TOTAL PILING COST	LFT				231,926	\$ 9,965,391.35	
<b>2010</b>									
701	701-06011	DYNAMIC PILE LOAD TEST	EACH	0.00	5,900.00	1,527.15	202.00	\$ 308,484.30	2.86
701	701-09559	TEST PILE, RESTRIKE	EACH	0.00	2,900.00	970.35	208.00	\$ 201,832.80	1.87
701		TOTAL PILING COST	LFT				263,190	\$ 10,782,760.20	
<b>2011</b>									
701	701-06011	DYNAMIC PILE LOAD TEST	EACH	\$250.00	\$3,500.00	\$1,552.14	201	\$ 311,980.14	3.08
701	701-09559	TEST PILE, RESTRIKE	EACH	\$250.00	\$3,500.00	\$1,138.41	201	\$ 228,820.41	2.26
701		TOTAL PILING COST	LFT				208,313	\$ 10,141,536.07	
<b>2012</b>									
701	701-06011	DYNAMIC PILE LOAD TEST	EACH	\$405.00	\$3,512.35	\$1,425.05	162.00	\$ 230,858.16	2.25
701	701-09559	TEST PILE, DYNAMIC, RESTRIKE	EACH	\$500.00	\$4,125.00	\$1,203.67	158.00	\$ 190,179.53	1.85
701		TOTAL PILING COST	LFT				234,367	\$ 10,272,846.64	
<b>2013</b>									
701	701-06011	DYNAMIC PILE LOAD TEST	EACH	\$1.00	\$6,300.00	\$1,839.60	131.00	\$ 240,988.05	3.24
701	701-09559	TEST PILE, DYNAMIC, RESTRIKE	EACH	\$500.00	\$4,000.00	\$1,317.67	128.00	\$ 168,661.84	2.27
701		TOTAL PILING COST	LFT				160,758	\$ 7,435,914.50	



# Contacts

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**Thank you!**

