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Research

Research on Evaluation and Standardization of Accelerated Bridge Construction Techniques

Appendices

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Part-I

Department of Civil & Construction Engineering
College of Engineering and Applied Sciences
Western Michigan University

Research on Evaluation and Standardization of Accelerated Bridge Construction Techniques

Appendices
(Report 2013-2015)

Project Manager: Mr. Corey Rogers, P.E.

Submitted to:

MDOT

Submitted by

Haluk Aktan, Ph.D., P.E.
Professor
(269) – 276 – 3206
haluk.aktan@wmich.edu

Upul Attanayake, Ph.D., P.E.
Associate Professor
(269) – 276 – 3217
upul.attanayake@wmich.edu

Western Michigan University
Department of Civil & Construction Engineering
College of Engineering and Applied Sciences
Kalamazoo, MI 49008
Fax: (269) 276 – 3211

TABLE OF CONTENTS

APPENDIX A

FOUNDATION CASE STUDIES

4500 South (SR-266) over I-215 in Salt Lake City, Utah

Bridge Configuration:

- Four-span 244-ft-long and 77.2-ft-wide bridge was replaced with a 172-ft long and 82-ft wide single-span bridge (Figure A-1).

Existing Foundation Type:

- Abutments are labeled as #1 and #2 (Figure A-1).
- Abutment #1 was on spread footing while #2 was on piles.
- All three piers were supported on spread footing.

Constraints:

- Maintaining traffic on the bridge during substructure construction (two abutments)
- The bridge is in a steep grade (11.89%); hence, headroom at one of the abutments is limited.

Alternatives Considered for the Site:

- N/A.

Solution:

- Each new abutment was constructed in front of the existing abutment and required excavating in front of the existing abutments (Figure A-2).
- Temporary soil nail walls were constructed to retain the slopes in front of the existing abutments (Figure A-3 and Figure A-4).
- Micropiles were used to enhance the stability of abutment #1 on spread footing.

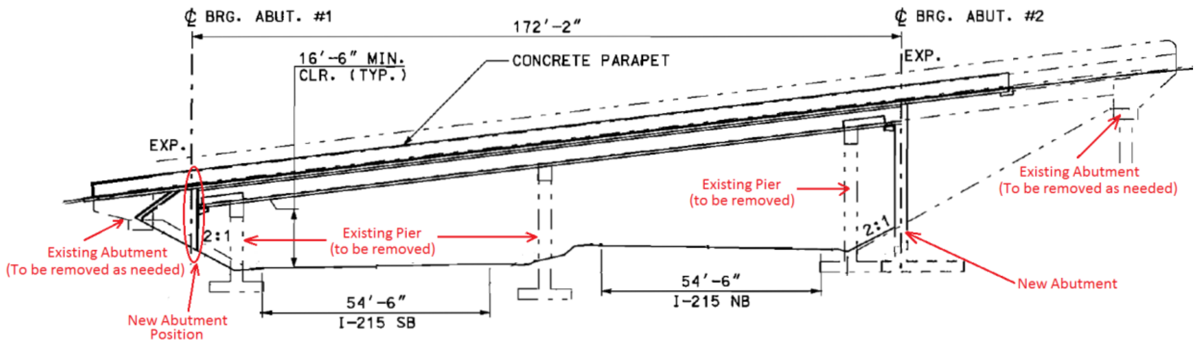


Figure A-1. 4500 South (SR-266) over I-215 bridge elevation view

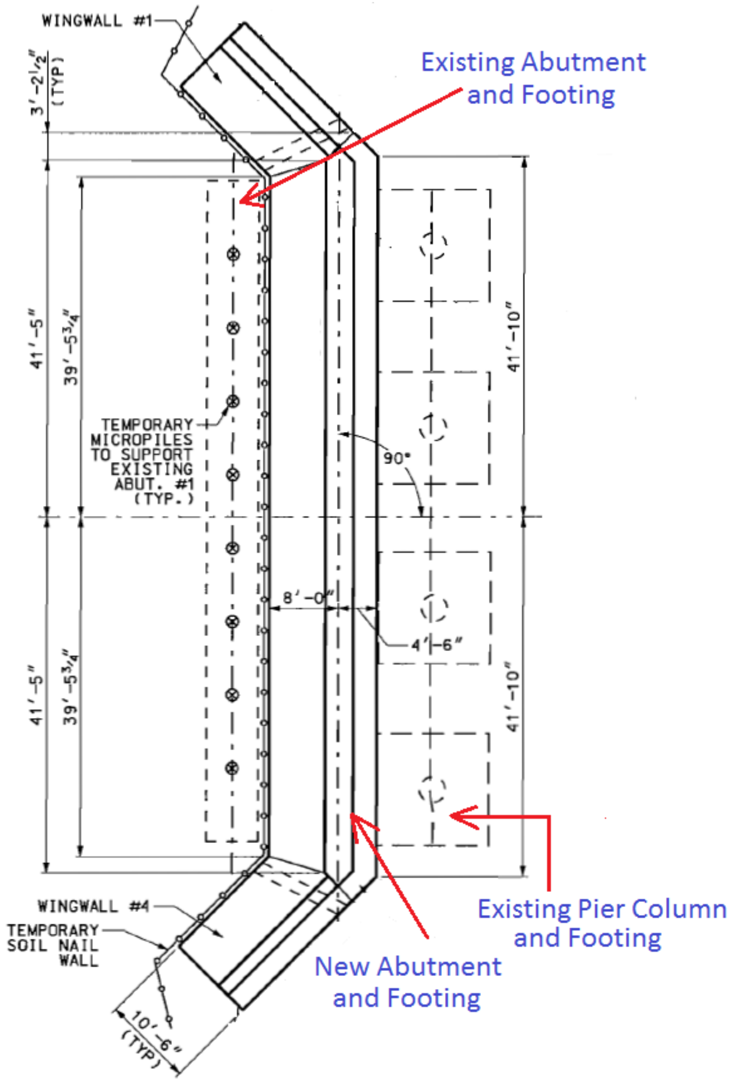


Figure A-2. Layout of new abutment # 1

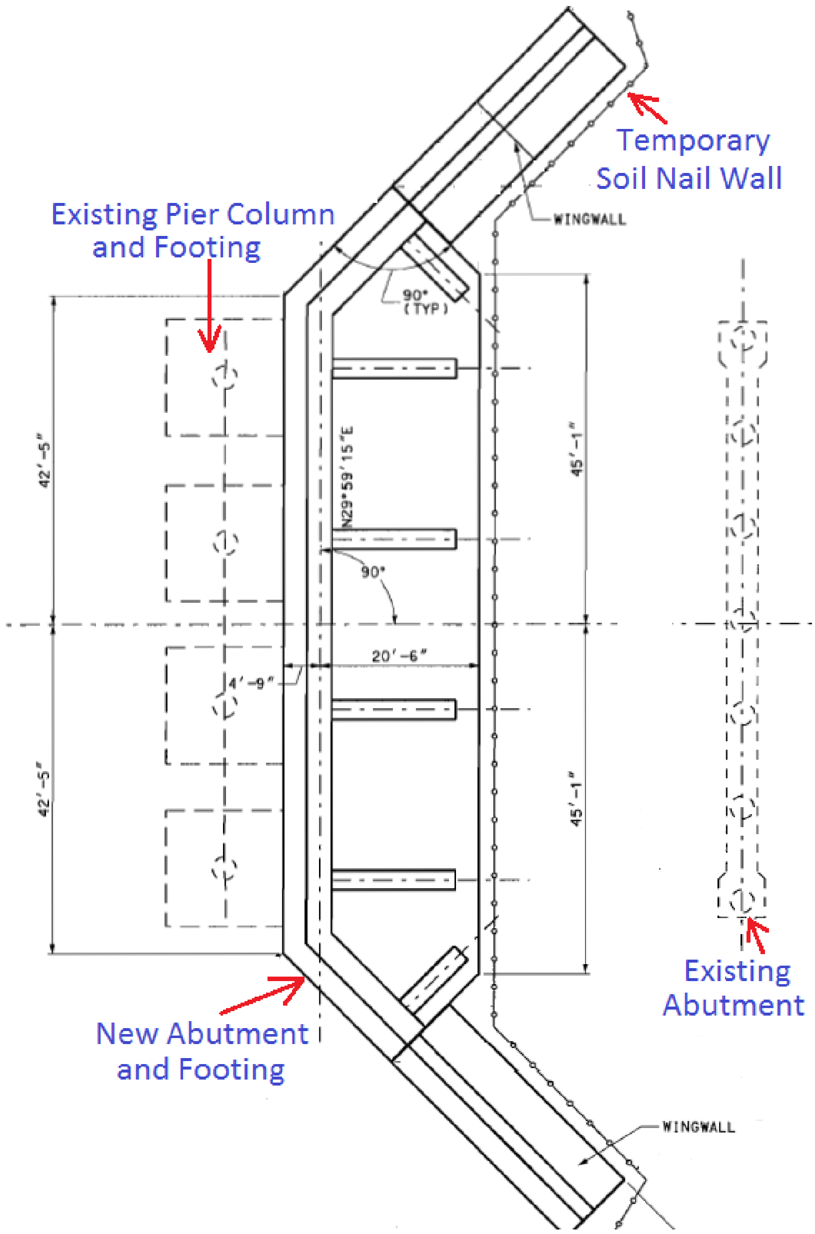


Figure A-3. Layout of new abutment # 2

Figure A-4. New abutment #1 construction (Photo courtesy: UDOT)

I-80 over SR-32 Bridge Replacement, Wanship, Utah

Bridge Configuration:

- Three-span 149-ft-long and 42-ft-wide bridge was replaced with a 96-ft long and 47-ft wide single span.
- New bridge was slid in place with 25ft long approach slabs.

Existing Foundation Type:

- Continuous footing of each abutment was approximately 6-ft wide.
- Footings under bent columns were approximately 5 feet by 8 feet with grade beams in between.

Constraints:

- Maintaining a minimum of 11 feet wide lane for traffic on I-80 in each direction while construction is taking place.
- Existing abutment footing is approximately at the same location as the sleeper slab.

Alternatives Considered for the Site:

- Information was not available.

Solution:

- New substructure is in a different footprint. Hence, cast-in-place abutments were constructed on spread footing.
- Existing abutments were partly removed to provide necessary space of sleeper slab placement (Figure A-5).

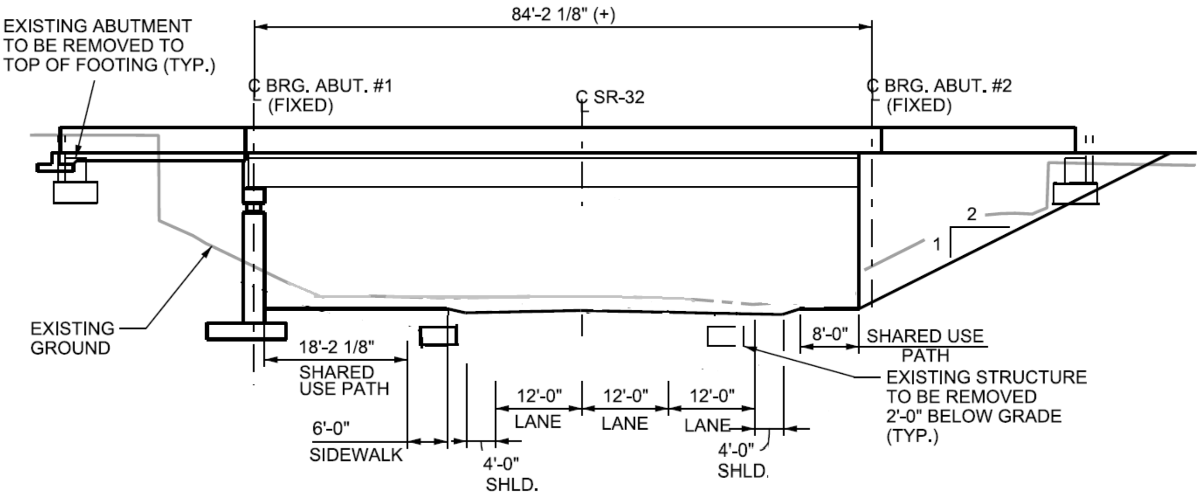


Figure A-5. I-80 over SR-32 bridge elevation view

I-80 Summit Park Bridge over Aspen Drive Bridge Replacement, Utah

Bridge Configuration:

- Three-span bridge was replaced with a 130-ft long and 76-ft wide single span.
- New bridge was slid in place with 25ft long approach slabs.

Existing Foundation Type:

- Each abutment had continuous shallow foundations.
- Footings under bent columns were pad foundations with grade beams in between.

Constraints:

- Maintaining at least 2 lanes of traffic on I-80 in both directions at all the other times except during bridge slide.
- Full closure of each bridge was allowed for up to 12 hours from 10 p.m. Saturday until 10 a.m. Sunday.
- Excessive settlement of abutment #2 requires deep foundations.
- Limited headroom clearance was at the site for deep foundation installation.

Alternatives Considered for the Site:

- Initially shallow spread footing, driven H-piles, pipe piles, micropiles, and drilled shafts were considered.
- Further analysis narrowed down the alternatives to micropiles, driven H-piles, and spread footings.

Solution:

- Shallow spread footings were selected for the abutment #1 (Figure A-6).
- Micropiles were selected for abutment #2 due to excessive settlement in the deep soil layers on that side.
- Limited overhead and foundation construction while the existing bridge is in service justified using micropiles for abutment #2.
- A total of 118 micropiles were used.
- Forty (40) micropiles were installed vertically. The remaining 78 were battered at 1H:3V to achieve the required lateral load capacity.
- Headroom for micropile driving can be slightly increased by locating micropiles in between existing bridge girders.
- Temporary soil nail walls (left in place) were used to maintain stability of the existing structure.
- Existing abutments were partly removed to provide necessary space of sleeper slab placement

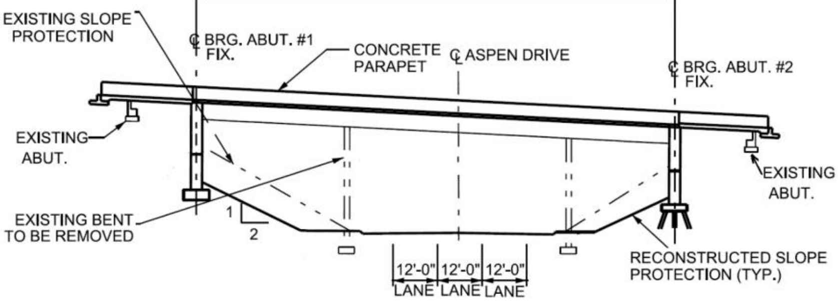


Figure A-6. I-80 over SR-32 bridge elevation view

Cascade Highway South (OR213) Bridge over Washington Street
Washington Street, Oregon

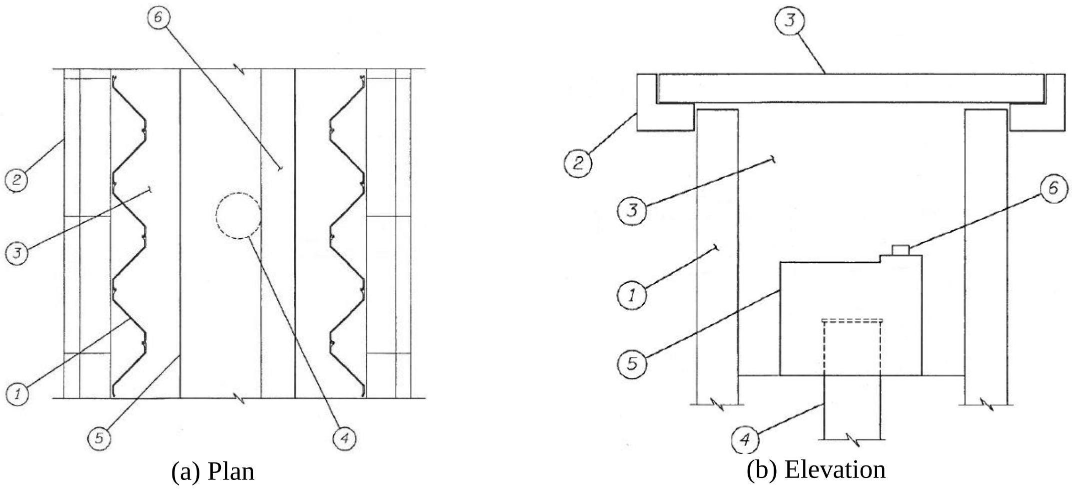
Bridge Configuration:
- The new single-span steel plate-girder bridge is 130-ft-long and 140-ft-wide.

Existing Foundation Type:
- Information was not available.

Constraints:
- The permanent foundations for the new bridge were constructed on the existing alignment while maintaining the five existing travel lanes of traffic on OR 213 during day time.
- Temporary lane closures occurred between 8:00 pm and 5:00 am during night time to install piles and the pile cap.

Alternatives Considered for the Site:
- Information was not available.

Solution:
- Steel closed-ended pipe piles with 2 ft outside diameter were used. Conical reinforced tips were attached to the driving end of the piles.
- Sixteen (16) piles were used at each abutment.
- Driven pile installation and pile cap construction sequence is presented in Figure A-7.



(a) Plan (b) Elevation

Note: Construction stages are denoted with the numerical labels shown in the above figures.

Foundation Construction Sequence under Nightly Lane Closures:
1. Install shoring. Remove existing paving slab as needed. Repair pavement as required prior to reopening lane to traffic.
2. Install temporary slab support beams. Repair pavement as required prior to reopening lane to traffic.
3. Excavate for pile cap and install temporary slabs. These slabs can be removed and reinstalled as needed for construction activities.
4. Remove the temporary slabs, drive piles, and reinstall the slabs.
5. Remove the slabs, construct pile cap, and reinstall the slabs.
6. Remove the slabs, install roller system for bridge slide, and reinstall the slabs.

Figure A-7. Foundation construction sequence

Figure A-8. Preparation for bridge slide (Photo courtesy: Nevada DOT)

SH-51 over Cottonwood Creek, Oklahoma

Bridge Configuration:

- Six-span bridge was replaced with a three-span bridge.
- New spans are 69 ft -5 7/16 in., 120 ft, and 69 ft - 5 7/16 in. long, and 42 ft – 2 in. wide (Figure A-9).
- Approach slabs were constructed after sliding the new superstructure.
- Closure duration was 10 days.
- Sliding sequence is as follows;
  - Span 1 and 3 were horizontal slid and vertical lifted using hydraulic jacks.
  - Span 2 was horizontal slid and vertical lifted using hydraulic jacks.
  - Wingwalls were constructed.
  - Backfill was placed.
  - Approach slabs were constructed.

Existing Foundation Type:

- Both abutments and two piers were on driven piles.
- Footings under middle three piers were spread footings.
- Footings as well as the piles were supported on the bedrock.

Constraints:

- The traffic on SH-51 was maintained in both directions during substructure construction.

Alternatives Considered for the Site:

- Initially, driven piles and drilled shafts were considered.
- Drilled shafts was chosen, but information related to selection decision was not available.

Solution:

- Drilled shafts were selected for abutments and two middle piers.
- New cast-in-place abutments were constructed in front of the existing abutment.
- Two middle piers were also constructed using cast – in – place concrete.
- Temporary soil nail walls were constructed to retain the slopes in front of the existing abutments.

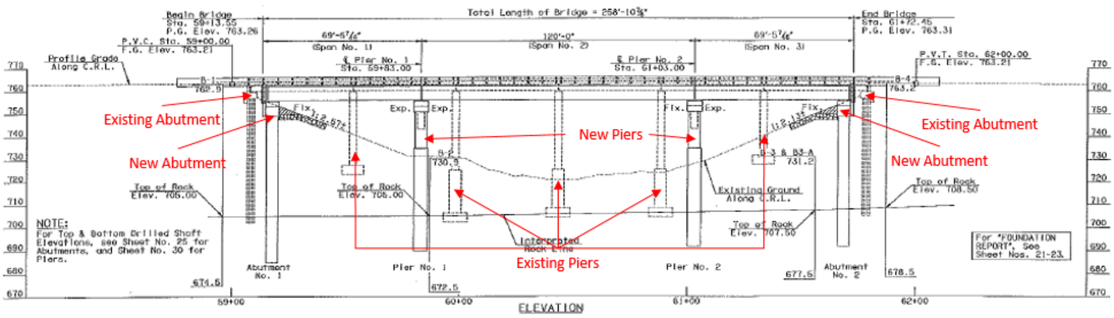


Figure A-9. Cotton Creek Bridge over Cottonwood Creek - elevation view

I-84 Bridge over Dingle Ridge Road, New York

Bridge Configuration:

- The three-span bridge was replaced with a 80-ft long 57-ft wide single span bridge (Figure A-10).
- New bridge was slid in place with 33-ft 1-in. long approach slab.

Existing Foundation Type:

- Abutments and piers were supported on shallow foundation.

Constraints:

- The traffic on I-84 was maintained in both directions during construction.
- Total ABC duration was limited to 16 hours.

Alternatives Considered for the Site:

- Information was not available.

Solution:

- Straddle bent abutments on drilled shafts were selected for abutments.
- Drilled shafts were placed outside the existing bridge footprints.
- New cast-in-place abutments were constructed behind of the existing abutments (Figure a-11).
- Existing abutments and piers were partly removed (Figure A-12.)
- After sliding the bridge with approach slab, low strength flowable backfill was placed behind the abutment.

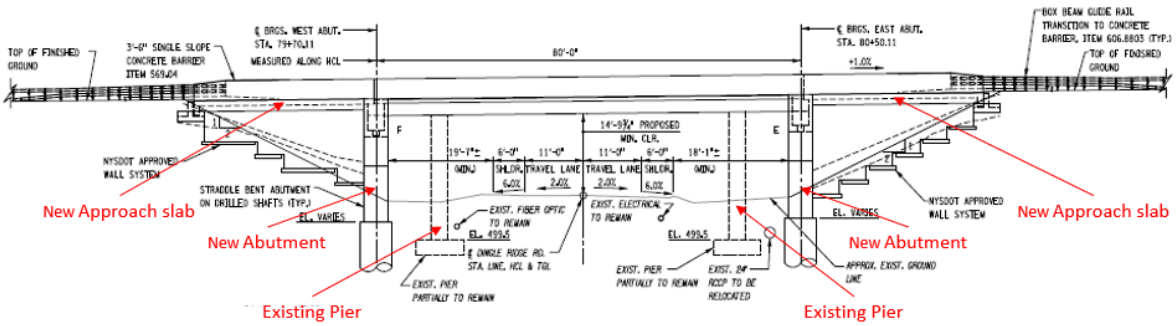


Figure A-10. I-84. Bridge over Dingle Ridge Road - elevation view

Figure A-11. New abutment construction (Source: http://earthcam.net/projects/nysdot/)

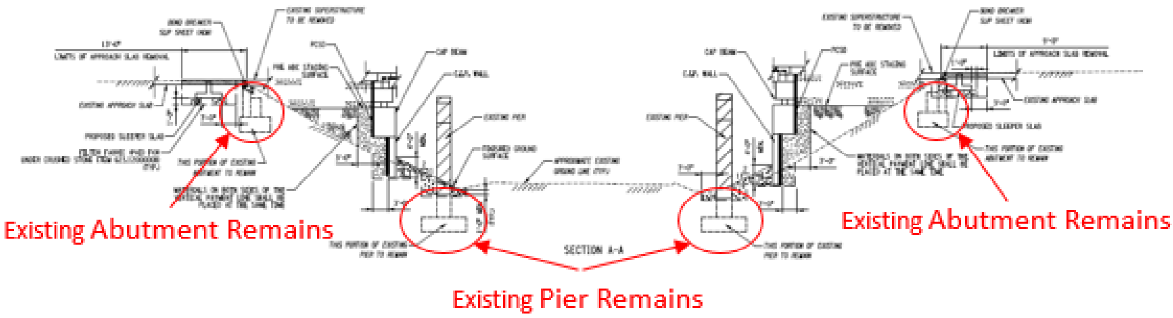


Figure A-12. Remaining sections of the existing substructure

I-15 over Falcon Ridge Parkway, Nevada

Bridge Configuration:

- The three-span bridge was replaced with a 111-ft 6-in. long and 45-ft 11-in. wide single span bridge (Figure A-13).
- New bridge was slid in place with 24-ft long approach slabs.

Existing Foundation Type:

- Abutments and piers were supported on spread footings.

Constraints:

- The traffic on I-15 was maintained during construction.

Alternatives Considered for the Site:

- Except spread footing, no other alternatives were considered.

Solution:

- Spread footings were selected for abutments.
- Temporary soil nail walls were constructed to retain the slopes in front of the existing abutments (Figure a-14).
- New cast-in-place abutments were constructed in front of the existing abutments (Figure A-14).
- HP 14 × 89 sections were driven at 24 ft from the new abutment. After the road was closed, the area was excavate and a grade beam (HP 14 × 89 section) was placed on top of the piles. Approach slabs were slid on the grade beam. Later, the grade beam was used as the permanent support (Figure A-15).
- After sliding the bridge with approach slab, slurry cement backfill was placed under the approach slabs.

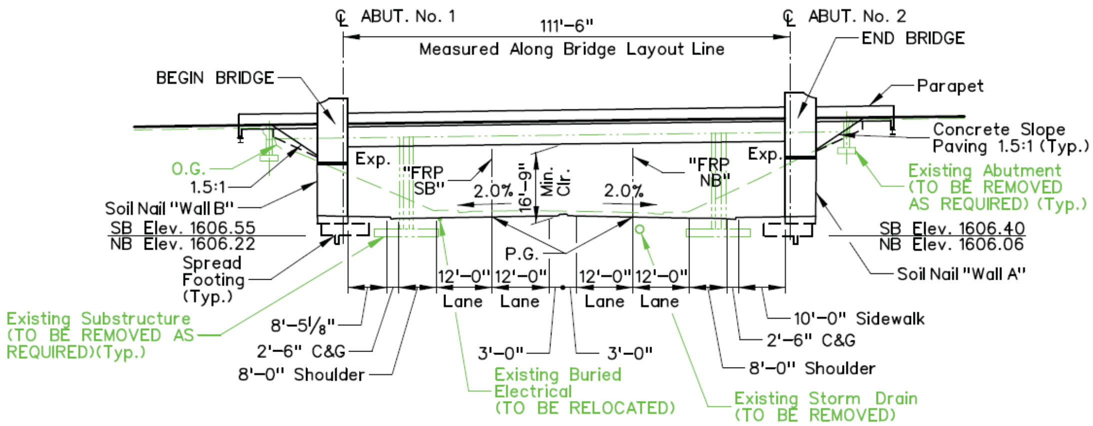


Figure A-13. I-15 over Falcon Ridge Parkway - elevation view

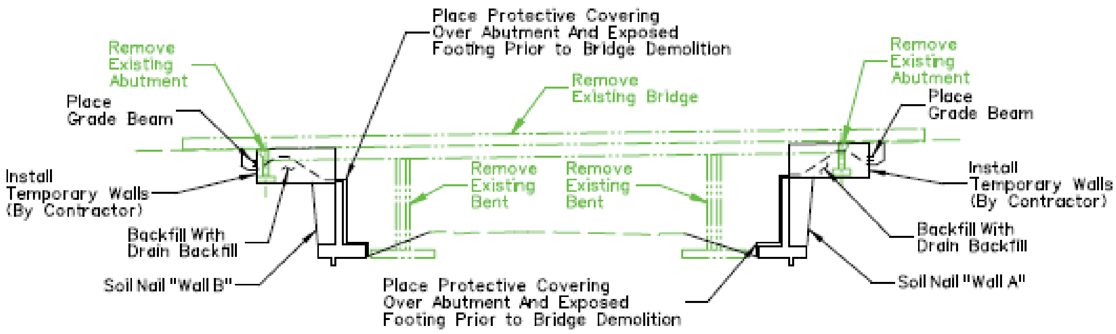
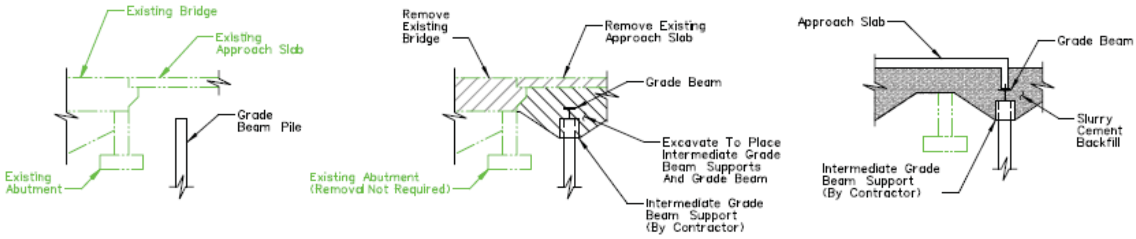
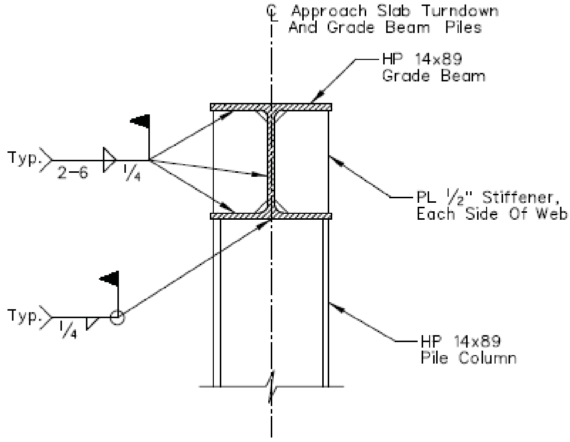


Figure A-14. West Mesquite Interchange at I-15 - elevation view



(a) Grade beam and approach slab construction



(b) Grade beam and pile connection detail

Figure A-15. Approach slab construction and grade beam – pile connection details

Route 38 at Milepost 39.64 over Elk Creek (Crossing No. 3), Oregon

Bridge Configuration:

- The existing two-lane six-span reinforced concrete deck girder bridge with steel truss was 340-ft long and 30-ft wide with pile bent substructure.
- This bridge was replaced with a 320.5-ft long and 38.2-ft wide three-span (56.5 ft – 207.5 ft – 56.5 ft) steel girder bridge (Figure A-16).
- Precast panel approach slabs were 30 ft 4 in. long and supported on sleeper slabs at the pavement side.

Existing Foundation Type:

- Information was not available.

Constraints:

- Construct a new substructure for the replacement bridge under the existing bridge while traffic was maintained.

Alternatives Considered for the Site:

- None.

Solution:

- Table A-1 shows the recommended foundations as per the geotechnical report and a memorandum submitted later.
- Two outrigger bents were used at Bent 3. Two 6 ft diameter drilled shafts constructed outside the existing bridge footprint supports the bent. Lateral loads governed the drilled shaft design.
- Even though the geotechnical report recommended a spread footing for Bent 2, the plans shows an 8 ft diameter drilled shaft (Figure A-16).
- Figure A-17 shows the foundation layout.
- Bents 1 to 4 were constructed while the existing bridge was in service. Drilled shaft, columns, and caps were cast-in-place concrete components. However, adequate information was not available to describe the construction procedures.

Table A-1. Foundation Recommendations

Location	Vertical Load (kips)	Preferred Foundation System	Minimum Embedment into Rock
Bent 1 (Abutment)	+/- 1500	Spread Footing	1 ft
Bent 2 (Hammer Head Pier)	+/- 2500	Spread Footing	2 ft or Thickness of Footing
Bent 3 (2 outrigger bents)	+/- 1000 to 1850	6 ft Diameter Drilled Shafts	12 ft
Bent 4	+/- 1500	HP 14 × 117	To Refusal

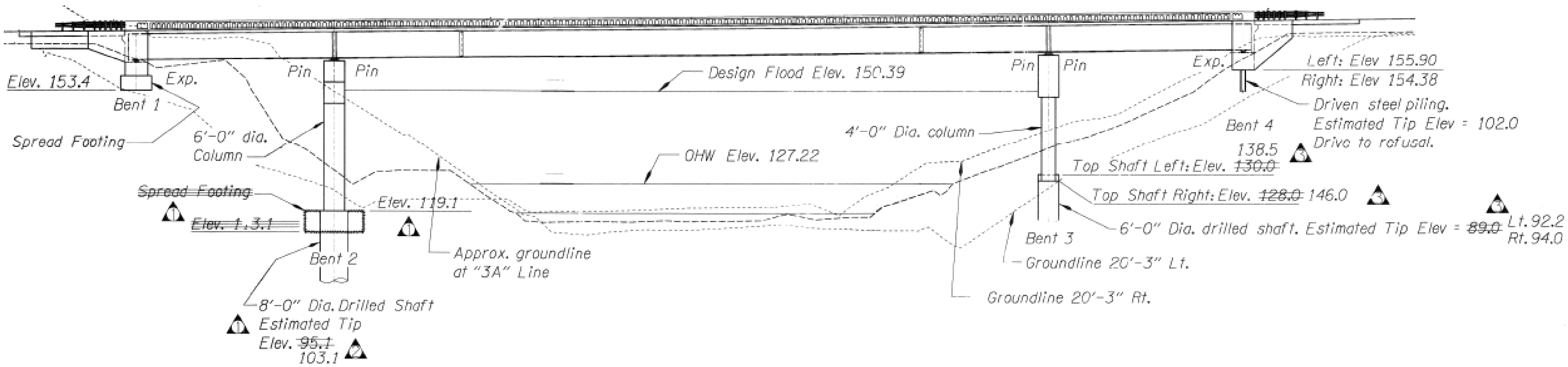


Figure A-16. Elevation of the proposed bridge

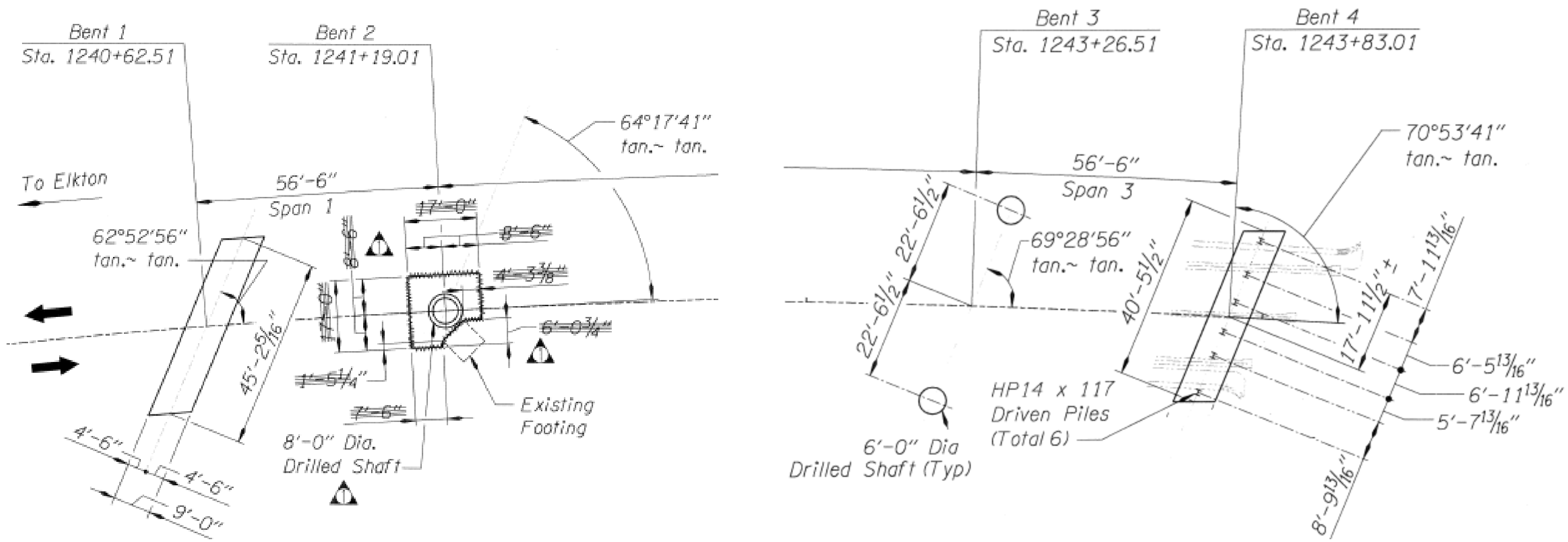


Figure A-17. Foundation layout

US 131 "S-Curve" Bridge - Grand Rapids, Michigan

Rabeler, R. C., Bedenis, T. H., and Thelen, M. J. (2000). “High Capacity Drilled Cast-in-Place Piles.” *Proceedings of Sessions of Geo-Denver 2000: New Technological and Design Developments in Deep Foundations,* ASCE, Denver, Co., 125-139.

Problem Description:

- Settlement of two piers supported on spread footing due to collapsing of cavities within the rock formation below the bottom of the footings.

Existing Foundation Type:

- Continuous reinforced concrete footings that are placed on a sand and gravel layer support the bridge piers (refer to Figure A-18 for the soil profile.)
- Reinforced concrete footing dimensions: width = 108 in., thickness = 30 in., and length = ranges from from 95.5 ft to 101 ft.
- Subfooting: A 6 in. thick mudmat is present below the reinforced concrete footing. The subfooting extends 18 in. out from all the sides of the footing. .
- The maximum design bearing pressure: ranges from 27 psi to 29 psi.

Constraints:

- Maintaining traffic on the bridge during foundation retrofit
- Presence of a large sewer line between the two piers
- Low overhead
- Presence of cavities that were formed due to dissolution of more soluable gypsum within the rock formation below the footing.

Alternatives:

- Compaction grouting,
- Drilled cast-in-place (D-CIP) micro-piles.

Solution:

- D-CIP micro-piles were installed outside the existing foundation footprint (refer to Figure A-19).
- Pile spacing is 7.9ft, capacity of 160 kips per pile, and 26 D-CIP piles per pier.
- As a means of connecting micro-piles to the existing footing, existing footing dimensions (thickness, length, and width) were increased by adding reinforced concrete over and around (refer to Figure A-19).
- Dowels were used to enhance shear capacity at the interface between existing and new concrete.
- Load testing was performed on production piles, and the bonded length of the production piles was reduced from 14.1 ft to 9.8 ft.
- Since the micro-piles were directly connected to the existing footing and socketed into a competent layer, the retrofitted foundation carries the total load and controls settlement.

Justification:

- Micro-piles were selected over compaction grouting due to proximity of the sewer.
- D-CIP micro-piles, a non-displacement method, was selected over driven methods to minimize vibrations, which is a concern when constructing piles next to an existing footing.
- Jacked micro-piles were not selected due to challenges with arranging a reaction weight.

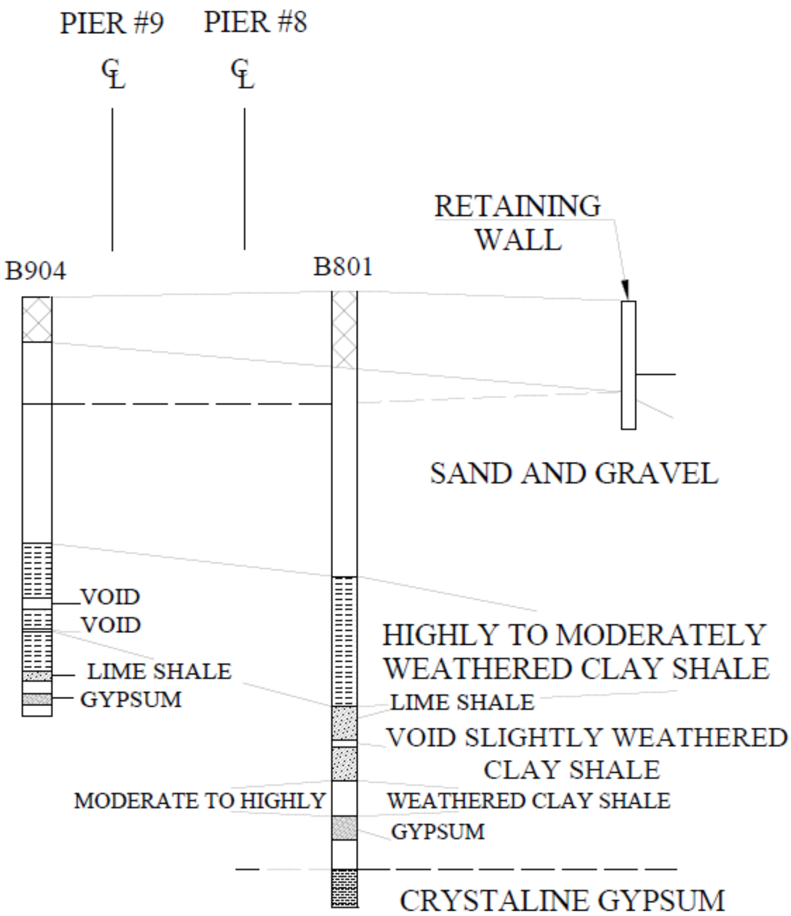


Figure A-18. Soil profile at bridge piers

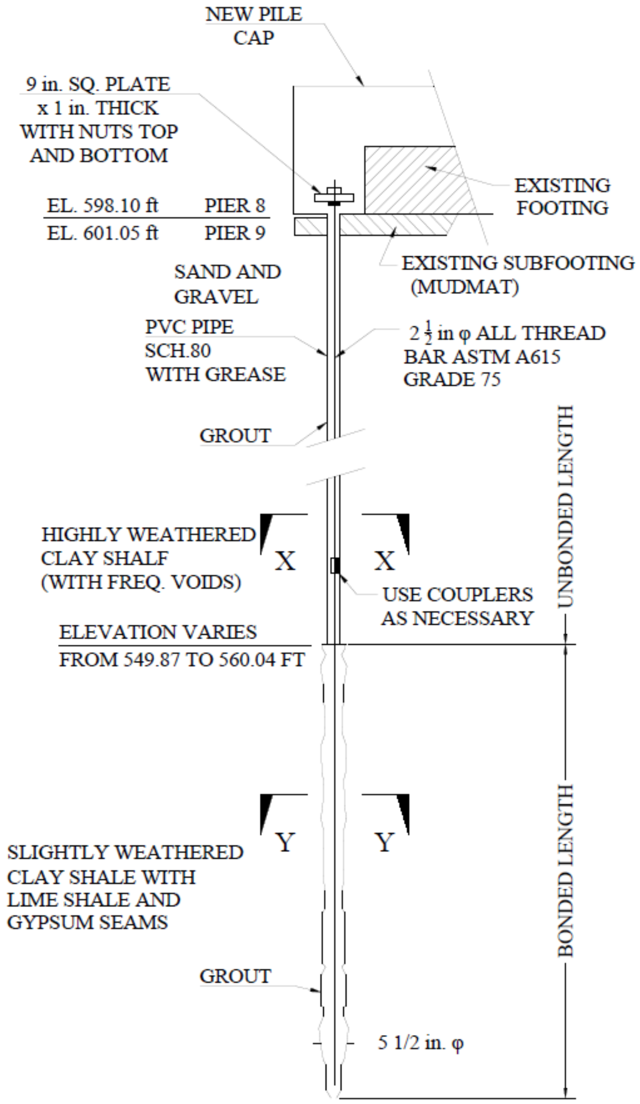


Figure A-19. Typical D-CIP pile section

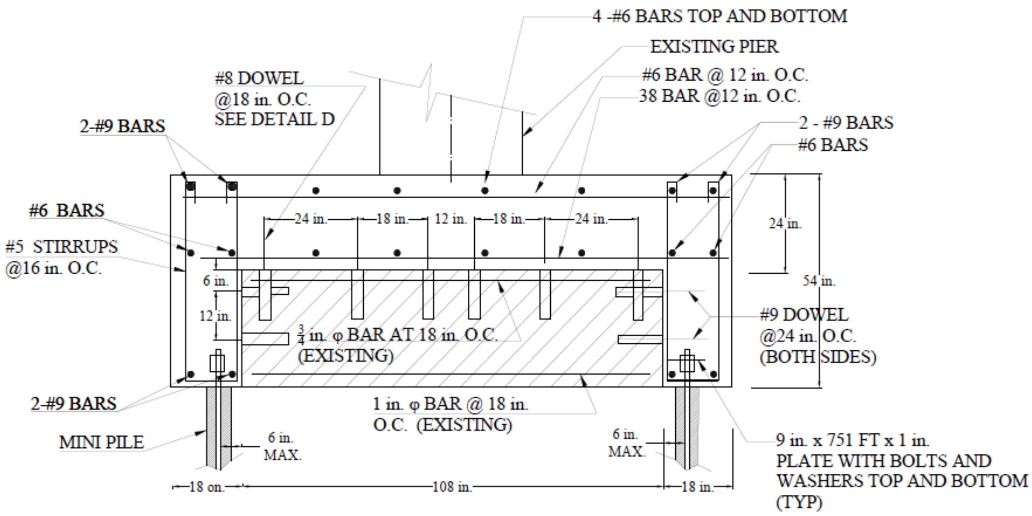


Figure A-20. Retrofitted footing detail

Design Considerations:

Among many empirical models, the following three models were selected based on their wide acceptance among the implemented case studies to calculate the side friction between rock and concrete based on the unconfined compression strength (Q_u) of rocks:

$$f_s = 2.5\sqrt{Q_u} \qquad \text{Eq. 1 (Horvath \& Kenny)}$$

Q_u (psi)

$$f_s/p_a = (0.63 \text{ to } 0.95)\sqrt{\frac{Q_u}{p_a}} \qquad \text{Eq. 2 (Carter \& Kalhawy)}$$

Pa=Atmospheric Pressure

$$f_s = 0.45\sqrt{Q_u} \qquad \text{Eq. 3 (Rowe \& Armitage)}$$

Q_u (Mpa)

- Unconfined compression strength = 2.5 ksi – 10 ksi (Clay shale had the lowest strength but was the dominant type. Lime shale and gypsum layers had the highest strength, but consisted of layers and seams of various thickness.)

- The lowest value was selected for the design = 2.5 ksi
- Estimated side friction from the above models = 0.12 – 0.54 ksi
- Side friction value used for pile design = 0.13 ksi
- Length of the bonded (friction) zone of the D-CIP pile= 11.8 ft (based on 0.13 ksi side friction, 160 kips design pile load, and 5 33/64 in. outside nominal diameter of the pile)
- Increase in the bonded length to account for potential soft zones within the competent rock = 20%
- Test pile length = 14.11 ft
- The pile included a 2 ½ in. diameter threaded bar (cross sectional area of 4 in^2), with a yield strength of 75 ksi. Hence, the allowable axial load capacity was 180 kips.
- Design was based only on the side friction; hence, an uplift test was performed to eliminate the contribution of the end bearing capacity. Pile was loaded up to twice the design capacity, 320 kips.
- Production pile length = 9.8 ft (friction zone length was reduced after performing an uplift load test).

Remarks:

- The foundation retrofit design was performed by Soil and Materials Engineers, Inc., Michigan.
- The D-CIP-piles were installed by Hayward Baker, Inc.

House of Representatives Building - Lansing, Michigan

Rabeler, R. C., Bedenis, T. H., and Thelen, M. J. (2000). “High Capacity Drilled Cast-in-Place Piles.” *Proceedings of Sessions of Geo-Denver 2000: New Technological and Design Developments in Deep Foundations,* ASCE, Denver, Co., 125-139.

Problem Description:

- To provide additional office spaces, it was decided to construct 9 additional floors on top of the five-story west end of the Board and Water Light (BWL) building in Lansing, Michigan.
- While some of the existing columns were strengthened, new columns were extended through the existing building all the way down to the basement, which was used for parking, offices, and storing mechanical equipment.

Existing Foundation Type:

Information is not given in the publication.

Constraints:

- Construction of new foundations at the basement level
- Uninterrupted regular functioning of the building with the original tenants
- Low headroom (7.90 ft to 9.85 ft)
- Limited pile cap dimensions at several locations for the new piles (limited by hallway width of 3.30 ft)
- Heavy loads on the new foundations (ranging from 1,000 kips to 2,000 kips)

Alternatives:

- Low headroom drilled piers (caissons)
- Drilled cast-in-place (D-CIP) micro-piles

Solution:

- High capacity, 9 in. diameter, D-CIP micro-piles with a single threaded steel bar was used (see Figure A-21 for details.) Also, a 5 ft long permanent steel casing was included at the top to enhance the lateral load capacity.
- Size of the diesel powered hydraulic-tracked drill that was selected for the project could move through doorways that were as narrow as 32 in.
- No. 18 or No. 20, Grade 75, continuously threaded DYWIDAG bars were used as pile core steel. Rebar size was selected based on the load capacity demand.
- Steel bars were cut into a nominal length of 7.9 ft to handle within the limited space.
- DYWIDAG couplers were used to connect the bars, and PVC centralizers (Figure A-22) were used to position the reinforcing bar in the borehole.
- A neat cement grout mix with Type II cement, water, and an admixture to increase workability with lower w/c ratio was used.
- Construction activities and pile installation was scheduled not to disturb the newly placed piles at a distance +/- 3 ft within a pile cap. Basically, the adjacent piles were not started until the grout had a chance to cure overnight.
- Individual pile capacities ranged from 150 kip to 190 kip.
- Overall pile lengths ranged from 32 ft to 54 ft.
- A small diesel powered hydraulic-tracked drill was used to pass through a 2.7 ft doorway.

Justification:

- Bids for low headroom drilled piers (caissons) were expensive and determined to be cost prohibitive.
- Shallow depth to dense clay till (20 ft) and weathered sandstone (30 ft) from the ground surface made it possible to design high capacity D-CIP micro-piles.
- High capacity of the D-CIP micro-piles reduced the number of piles and the pile cap dimensions to address the space constraint for pile cap size.

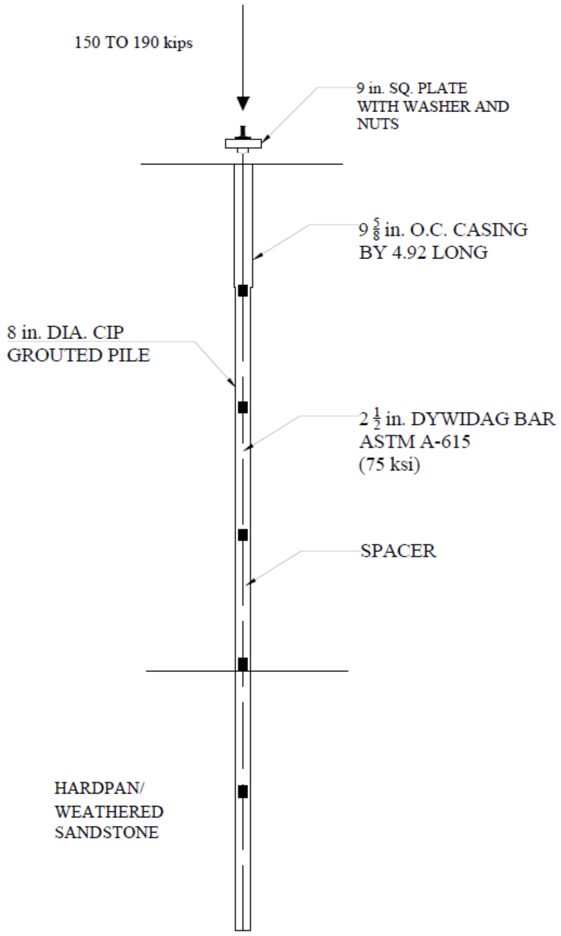


Figure A-21. Micro-pile profile

Figure A-22. PVC centralizer (Source: DSI 2015)

Remarks:

- Specialty contractor, Spencer White and Prentis (SWP)
- Construction was scheduled during off-hours not to disturb the normal operation of the building.
- The pile production ranged from 1 to 2 piles completed per 8-hour working shift.

Soil Profile at the Site and Design Considerations:

Table A-2. Generalized soil conditions

Elevation (ft)			Depth (ft)
	Ground Surface		0
821.2-832.7	Sand & Clay Fill	N=2 to 8 blows/1 ft	1.97-9.84
806.1-803.1	Sand/Clay Silt	N=12 to 30 blows/1 ft	19.7-24.9
796.6-799.2	Sandy Clay/Clayey Sand (Hardpan)	N=30 to 81 blows/1 ft	29.8-40.0
	Weathered Sandstone	N=37 to 100 blows/1 ft	

Pressure meter test was performed to develop stress-volume relationship for the hardpan. The soil yield stress (p_f), soil limit pressure (p_l), and pressuremeter moduli (E_d) were determined.

Table A-3. Pressuremeter Test Results

Test Depth (ft)	Soil Type	N-Value (blow/1 ft)	P_f (ksi)	P_l (ksi)	E_d (ksi)
34.45	Hardpan	60	0.51	0.87	6.02
34.45	Hardpan	40	0.36	0.65	3.55
39.37	Hardpan	45	0.41	0.58	2.90

Due to site constraints and the loads, allowable pile capacity of at least 150 kips was required. Based on soil borings, in-situ pressuremeter tests, and experience micro-pile design recommendations were developed as shown in the table below.

Table A-4. Micropile Design Recommendations

Soil Type	Side Friction	End Bearing
Existing Fill/Overburden	1.74	n/a
Dense Clay Till (Hardpan) or Weathered Sandstone	69.611	0.28 ksi

With a factor of safety of 2, an 8 in. pile was designed. A 4.92 ft long permanent steel casing was added to the top of the pile to provide additional lateral support.

Additional Citations:

DSI. (2015). DYWIDAG-Systems International. http://www.dsiamerica.com/ (Last Accessed: March 1, 2015)

St. Joseph’s Mercy Hospital in Georgetown, Guyana, South America

Stulgis, P. R., Barry, B. E., Harvey, F. S. (2004). "Foundation Underpinning with Mini-piles – “A First” in Guyana, South America." Proceedings, *GeoSupport Conference 2004: Drilled Shafts, Micropiling, Deep Mixing, Remedial Methods, and Specialty Foundation Systems*, Orlando, Florida, Dec. 29 – 31.

Problem Description:

- Three-story expansion to the St. Joseph’s Mercy Hospital in Georgetown, Guyana, South America.
- Subsurface consist of 54.13 ft of very soft to soft marine clay overlying stiff to very stiff clays.
- The existing structure next to the new addition is supported on timber piles.
- The designer of the new structure mat foundation assumed a bearing pressure of 2.9 psi without performing any geotechnical investigations. Subsequent calculations have shown a bearing pressure of 3.63 psi.
- Excessive damaging settlement was recorded within the first 4 to 5 years after construction. Settlement varied from 2 1/2 to 3 1/2 cm across the new structure.
- Subsequent geotechnical investigations revealed the following:
  a) Groundwater level is within several feet from the ground surface.
  b) Soft marine clay is highly plastic and extremely sensitive.
  c) Preconsolidation of the first 14.76 ft deep clay layer is only about 1.38 psi greater than the existing effective overburden pressure while the layer below that had an overconsolidation pressure of approximately 2.76 psi greater than the existing effective overburden pressure.
  d) Shear strength of the soft clay within approximately the first 6m is about 1.02 to 1.31 psi. The clay is highly sensitive and shear strength can reduced to less than 0.36 psi due to disturbances during construction.
- Based on the field investigations and local experience, the reason for excessive vertical settlement was attributed to progressive local shear failure in clay rather than the consolidation settlement.

Existing Foundation Type:

- Monolithically-cast, reinforced concrete mat foundation with down-turned beams arranged in a grid pattern below the mat.

Alternatives:

- Several micropile construction alternatives were evaluated to develop the required pile capacities within the stiff/hard clay bearing stratum. The alternatives are:
  - single stage tremie grouting
  - multiple stage post-grouting
  - mechanically over-reaming the embedded length within the bearing stratum
- No. 11 DYWIDAG reinforcing steel bar encapsulated in cement grout of 5 ksi ultimate strength was considered. Polyethylene-coated steel casing (6 in. O.D) was considered for the pile segment within the soft clay to reduce potential for negative skin friction loading.

Solution and Justification:

Grouted micropiles were selected due to limited access and the constraints due to existing utility lines within and below the existing mat foundation. Post-grouting method was selected to enhance the ultimate side shear strength. Holes were drilled through the foundation mat and upper soft clay layer into the underlying stiff to very stiff clay stratum. 6 in. diameter, 69 to 95 ft long, 102 grouted micropiles were installed. The following modifications were made as per contractor's suggestions:

- Eliminated the DYWUDAG bar by using a fully cased composite structural section.
- Eliminated the polyethylene coating by increasing the embedment length to account for negative friction.

Existing columns were connected to the micropiles using 28 reinforced concrete pile caps.

As part of the quality control during test pile installation, micropile casing installation rates, grouting pressures, and grout volumes were closely monitored and documented. Before casting, freely moving 25/64 in. diameter tell-tales that extended to the bottom of the micropiles and to the top of the embedment length were mounted on the interior of the pile casings.

The embedment length into the hard strata was pressure grouted while the pile segment in soft clay was grouted using a tremie mix. Pressure grouting developed a grout bulb as shown in Figure A-23 and increased the pile capacity.

Test pile load capacity was evaluated by performing axial compression load tests in accordance with ASTM D 1143. Test pile was loaded to 68 metric tons; almost twice its design capacity. Pile failed due to punching shear. Tell-tale at the bottom indicated that the applied load was carried entirely by the side friction within the embedment length until between 50 to 60 metric tons. After that, the pile load was carried by the end bearing until punching shear failure. Based on the load test, the allowable shear capacity was calculated as 11 psi.

Installation:

Four pilot holes were drilled around each column using a 5 in. cutting head attached to 3 ½ in. diameter hollow stem smooth casing to determine the top of the embedment length. Threaded casing sections of about 3.28 ft length were used to help installation under low headroom conditions. Bentonite slurry was used to maintain the pilot hole integrity.

After completing the pilot holes, permanent casings were advanced to the design bottom of the embedment length using a 6 1/8 in. tricone roller bit and a permanent casing sections made of Grade 2 steel with an outside diameter of 3 ½ in. and an inside diameter of 2 ¾ in. Due to low headroom conditions, 3.28 ft long permanent casings were used. After grouting and grout curing was completed, the load transfer mechanism between the existing columns and the micropiles was developed using the details shown in Figure A-24.

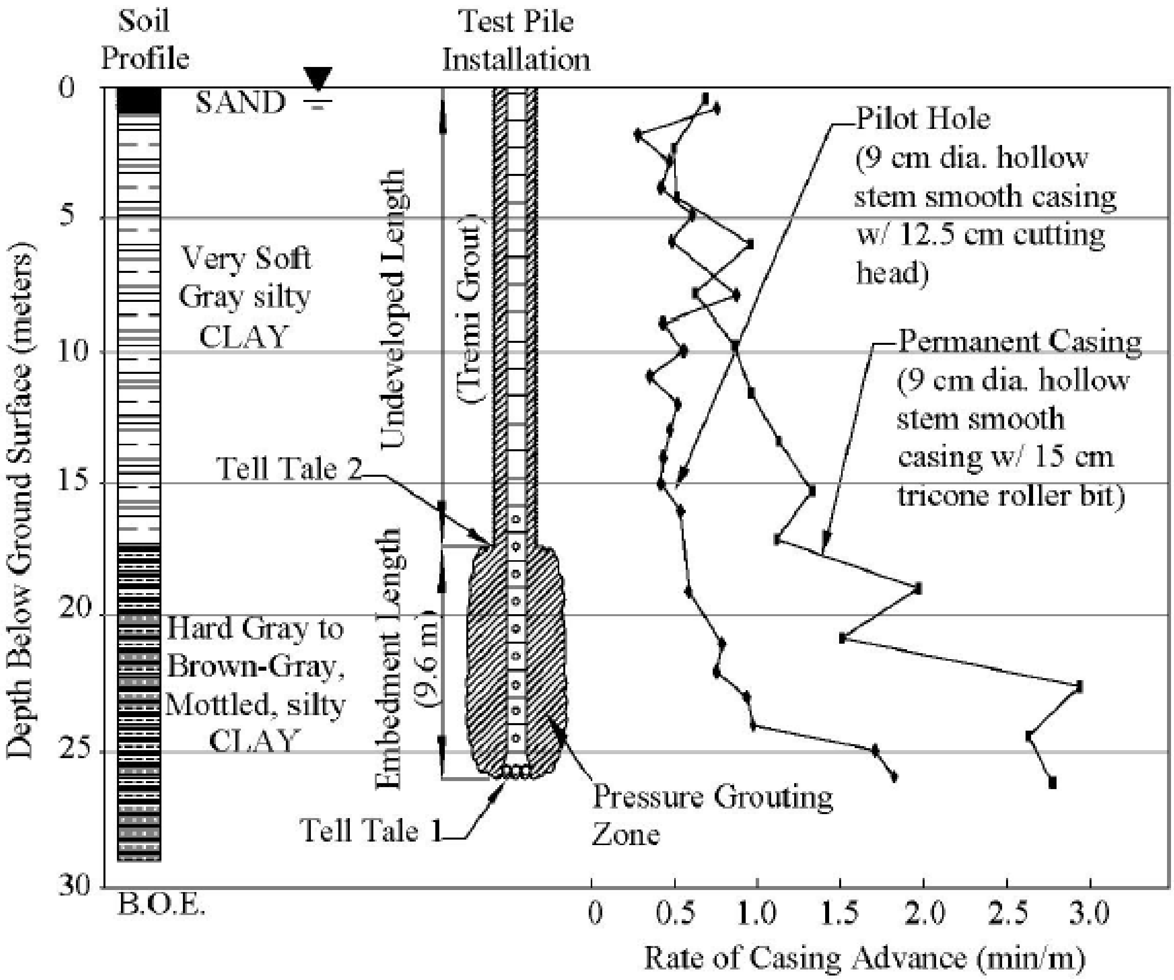


Figure A-23. Test pile details

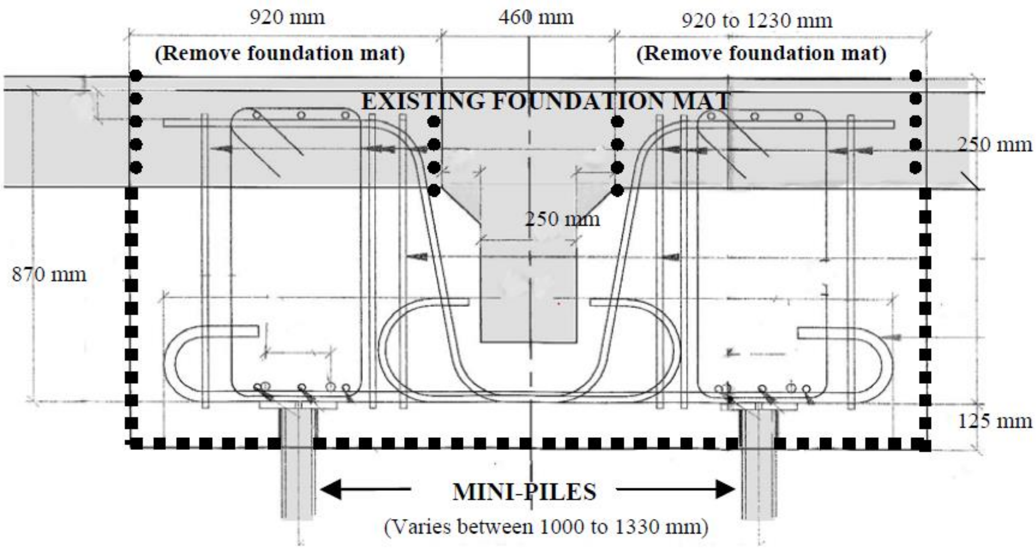


Figure A-24. Connection details between the existing foundation and the micropiles

The Staybridge hotel in Irving, Texas

Witherspoon, W. T. and Taylor, J. E. (2009). "Foundation Replacement with No Disturbance." Contemporary Topics in Ground Modification, Problem Soils, and Geo-Support, Proceedings of the International Foundation Congress and Equipment Expo - IFCEE '09, pp. 534-541.

Problem Description:

- The three story Staybridge hotel in Irving, Texas, is located on a highly active clay layer that extends more than 20 ft below the surface.
- Building is supported on 198 drilled shafts. Shafts were extended several feet above the ground surface to provide a gap between the floor and the ground to prevent any pressure pushing the floor due to upheave.
- The original design called for a 24 in. deep grade beam on top of the piers. As per the original design, a gap between the bottom of the grade beam and ground was required.
- However, the survey of the site due to uneven uplift of the building floor showed that the grade beam was partly embedded into the ground at some places. Also, poor formwork had allowed grade beam concrete to flow into soil creating lugs (Figure A-25).
- Upheave pressure pushed the grade beam bottom surface as well as the lugs creating differential displacement of the structure.
- At some locations, the grade beam and shaft connections damaged severely due to uplift pressure.
- Poor construction and drainage were the main reasons to cause upheave damage due to upheave.

Existing Foundation Type:

- Fifteen (15) ft long, 18 in. diameter drilled shafts.
- In order to enhance the axial load capacity and to provide resistance to upheaval, 30 in. diameter bells were provided at the end of each shaft.

Alternatives:

Information is not given in the publication.

Solution and Justification:

- First, drainage problem was fixed by providing a surface drainage system, and a capillary drain system to collect excess moisture (Figure A-26).
- Then the concrete lugs were removed, and a gap between the ground and grade beam bottom surface was provided by using fiberglass backfill retainers (Figure A-26).
- Additionally, it was decided to replace all the drilled shaft since they were not placed deep enough.
- The new 18 in. diameter drilled shafts are 35 ft deep, and extended 10 ft into gray shale.
- Constraints included accessing the pier replacement area by excavating under the building with small rigs, relocating utilities where needed, and keeping the building operational without any interruption (Figure A-27).
- The headroom for drilled shaft installation under the grade beams was about 5 ft.
- Once the new drilled shafts were constructed, screw jacks were placed to support the beams while demolishing connection between the existing shafts and the beams.
- Later, the top of the existing shafts were smoothed out and placed screw jacks to transfer loads from the new drilled shafts to the existing shafts (Figure A-28).

- Finally, screw jacks were adjusted to level the floors, and shaft and beam connections were cast using rapid set grout (Figure A-28).

Remarks:

- Smaller rebars were used to minimize lap length. This is significant when several small segments are used to construct drilled shafts.
- Requires longer construction duration due to restricted space.

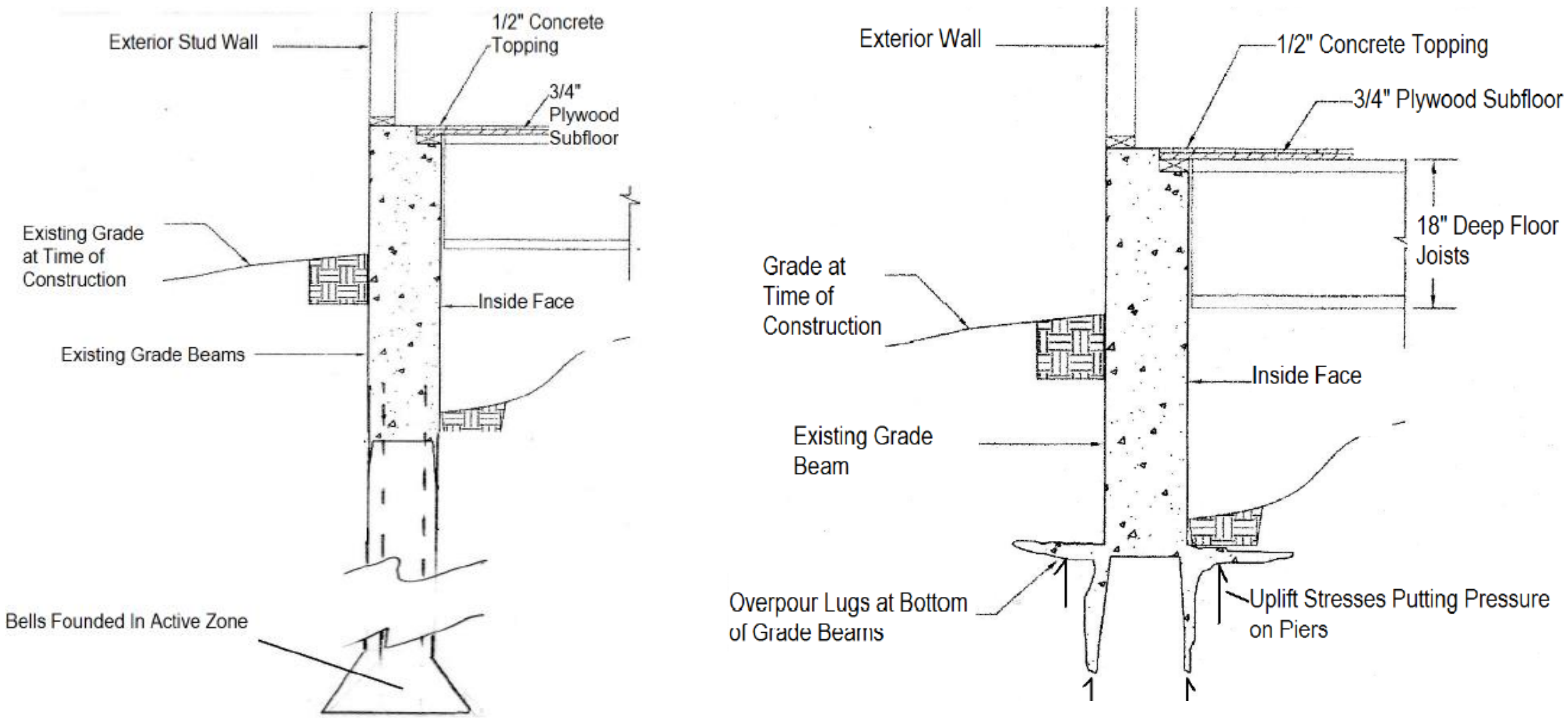


Figure A-25. As constructed details of the grade beam

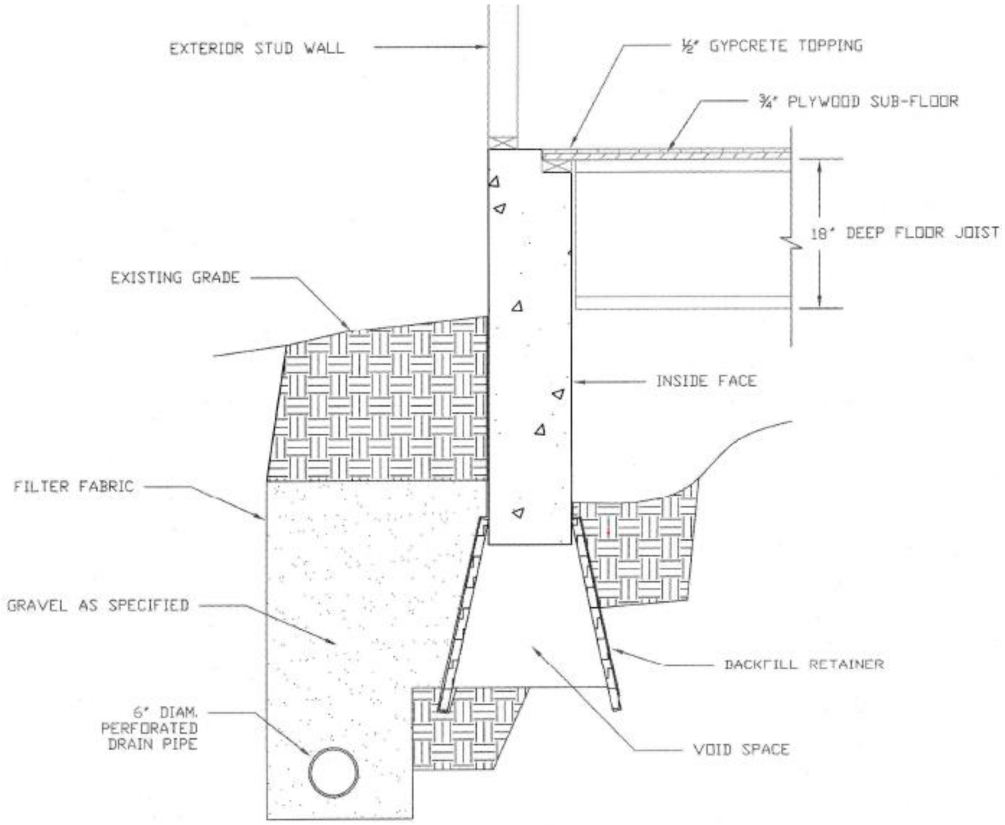
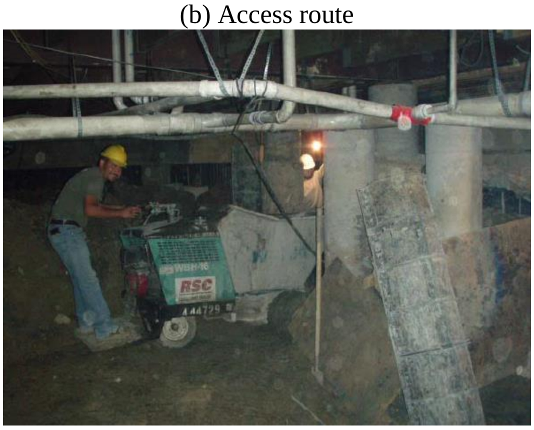


Figure A-26. Installation of French drain system and backfill retainers

(a) Entrance to work area

(b) Access route

(c) Drilling under a beam



(d) Concrete placement

Figure A-27. Construction site access and drilled shaft construction

(a) Spreader bar breaking the top of an existing shaft

(b) Screw jacks placed on top of the existing shafts

(c) Grouted connection

(d) Finished drilled shaft-beam connecitons

Figure A-28. (a) Spreader bar breaking the top of an existing shaft, (b) screw jacks placed on top of the existing shafts, (c) grouted connection, and (d) finished drilled shaft – beam connection.

U.S. Rt. 131, Grand Rapids, Michigan

Boehm D. W. and Gorski, G. A. (2000). "Assessing and repairing deep foundations for transportation projects." Proceedings of the 51st Annual Highway Geology Symposium, Seattle, Washington.

Problem Description:

- U.S. Rt. 131 Bridge over West River Drive widening project consisted of constructing additional piers for two new bridges, identified as RO1 and RO2.
- Construction was performed adjacent to the existing northbound and southbound lanes.
- Five piers were constructed to support each new bridge.
- At each new pier location, 36 ft deep sheetpile cofferdams were constructed to provide excavation support and water control during concrete pile cap placement.
- Sheetpiling was removed after driving the pipe piles to refusal in the medium dense silty sand and gravel strata, filling concrete into the pipe piles, and casting pile cap and piers.
- Once the sheetpiiling was removed, and before placing girders, a pier settlement of about 1 in. was recorded at pier 1 and 2 of Bridge RO1 and pier 1 of RO2.
- The cause of settlement was attributed to the reduction in confinement of the piles, and additional settlement was expected during girder placement and completion of the rest of the construction activities.

Existing Foundation Type:

Information was not available

New Foundation:

- Concrete-filled driven pipe piles.

Alternatives:

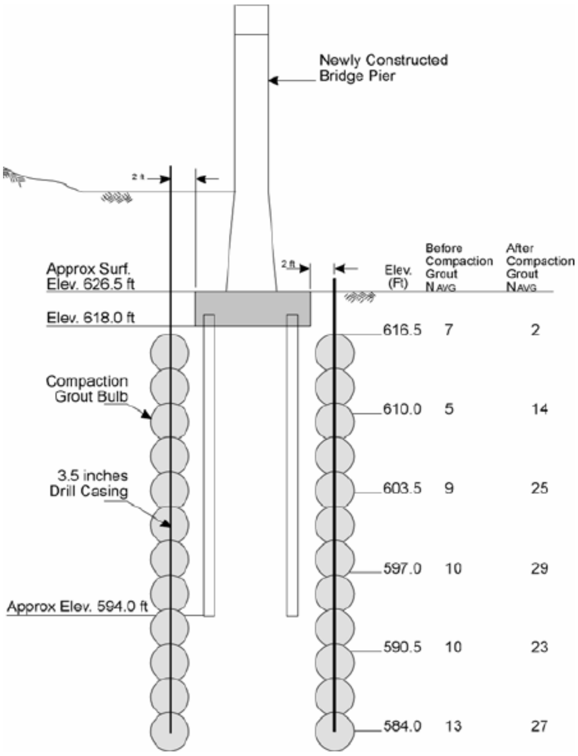
- Replacement of the piles
- Adding additional foundation elements
- Compaction grouting

Solution and Justification

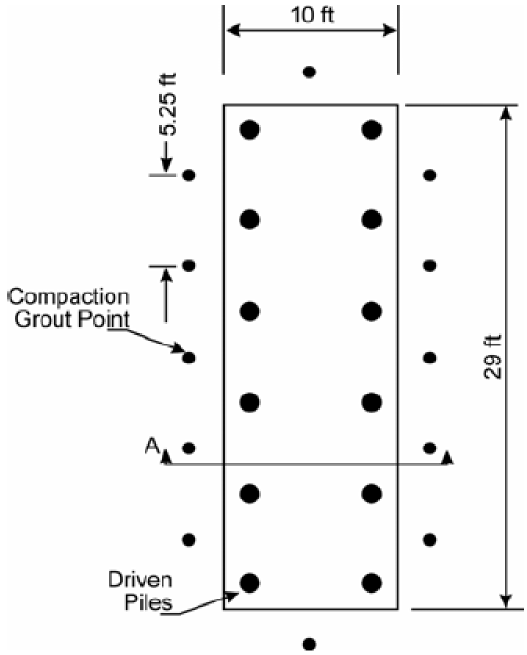
- Compaction grouting was selected because of the following reasons:
  - Lower cost compared to replacement of the driven piles
  - Compaction grouting can be performed without performing any modifications to the already built foundation system.
  - Compaction grouting process is much faster than designing and constructing additional foundation elements.
- Compaction grouting was performed from the bottom of the pile cap to a depth of 36 ft.
- Compaction grouting locations and relevant information are shown in Figure A-29.

Remarks:

None



(a) Cross-section showing compaction grouting



(b) Plan view of pile cap showing grout locations

Figure A-29. Compaction grouting of a bridge pier

Muddy River Bridge, Overton, Nevada

Boehm D. W. and Gorski, G. A. (2000). "Assessing and repairing deep foundations for transportation projects." Proceedings of the 51st Annual Highway Geology Symposium, Seattle, Washington.

Problem Description

- Use of crosshole sonic logging (CSL) as a post construction investigation of two drilled shafts that supported the central piers of the Muddy River bridge reveled the extent of weak zones in the shafts.
- The findings from CSL were verified using cores.
- Due to concerns related to shaft integrity, remediation measures were needed.

Existing Foundation Type:

- Two, 7 ft diameter, 68 ft deep, drilled shafts support the central piers of the 188 ft long bridge.

Alternatives:

- Compaction grouting and jet grouting were considered.
- Adding reinforcing bars to the shaft for enhancing strength was considered.

Solution and Justification

- Ten vertical holes were drilled symmetrically around the perimeter of each shaft (Figure A-30).
- At certain locations, soil sloughed into the core holes making the drilling very difficult.
- Due to challenges with compaction grouting the weak zones around the shafts, jet grouting was used to remove the weak soil and replace with pressure grouted cement slurry.
- Finally, additional reinforcing bars were installed in the completed jet grout material to enhance the shaft capacity.

Remarks

Boehm and Gorski (2000) defines compaction grouting and jet grouting as follows:

Compaction grouting is the injection of low slump grout into granular soils to limit structural settlement or for improvement of loose of soft soil strata. As the low slump grout is injected, grout bulbs form that displaces and thus densify the surrounding soils. In deep foundation repair, compaction grouting is typically used to increase side friction resistance or to increase the end bearing condition of the existing deep foundation element. This type of repair can be performed while the structure is being built. In some cases, compaction grouting also allows the raising of the affected deep foundation.

Jet grouting is utilized for heavier loads and can be applied to increase side friction and end bearing. In the jet grouting process, the soil is eroded and simultaneously missed with a cement grout to form a low-permeability product of design geometry known as soilcrete (Figure A-31). The use of jet grouting to underpin structures does not require any load transfer device, which in some case is an advantage over micropiles.

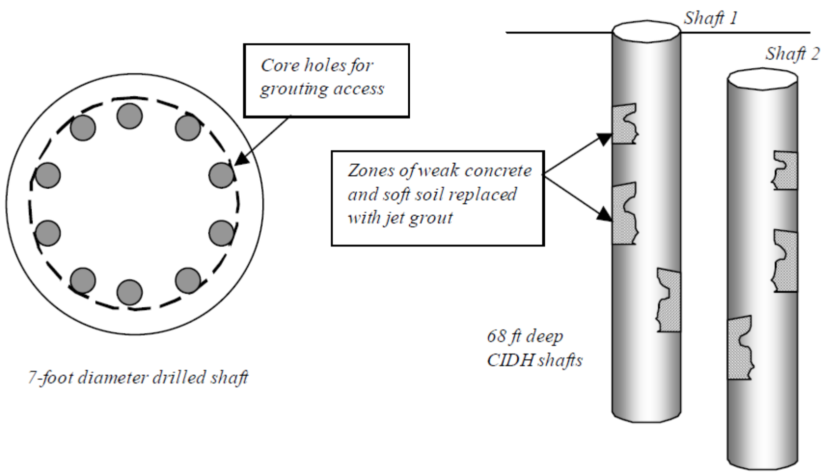


Figure A-30. Layout of core holes for grouting and weak zones identified through CSL

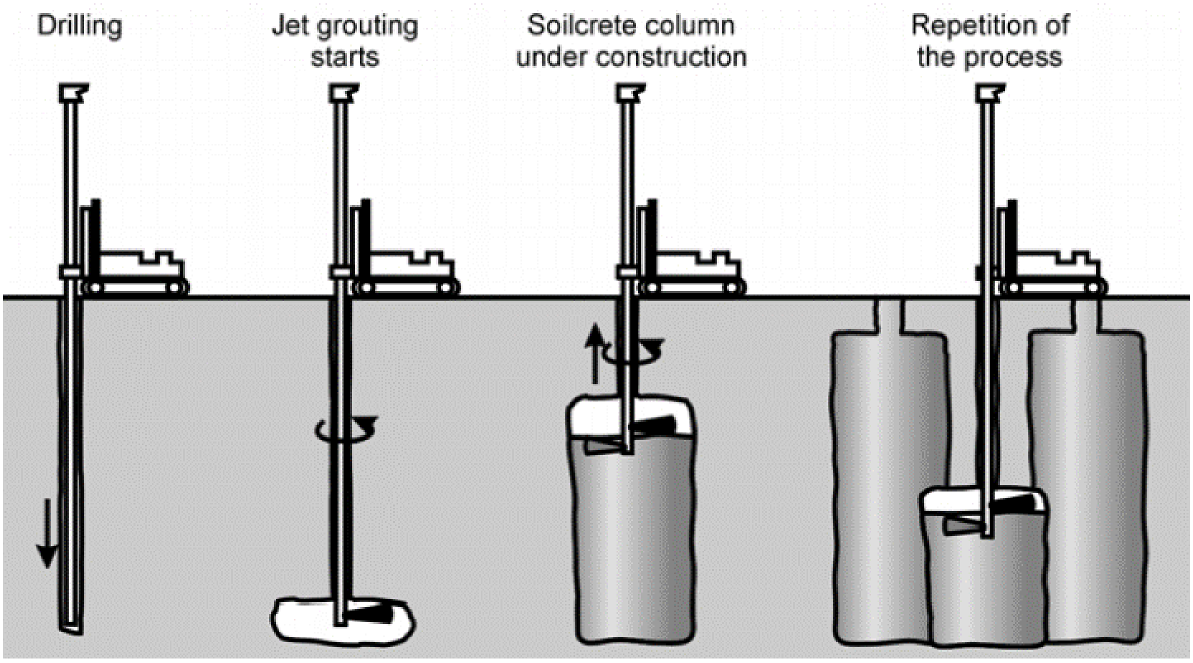


Figure A-31. Jet grouting process

Erlanger Medical Center, Chattanooga, Tennessee

Boehm D. W. and Gorski, G. A. (2000). "Assessing and repairing deep foundations for transportation projects." Proceedings of the 51st Annual Highway Geology Symposium, Seattle, Washington.

Problem Description

- Drilled shafts were selected as the foundation system for the new addition to the existing medical facility.
- Soil boring indicated the presence of silty clay fill underlain by residuum with hard but erratic limestone at about 75 ft.
- At one drilled shaft location, competent rock was not found even after reaching about 115 ft depth.
- Even though further investigations identified rock at 145 ft depth, solutioning was suspected.
- The challenge was to identify means of providing a foundation with the required load capacity.

Existing Foundation Type:

- 115 ft deep concrete drilled shaft.

Constraints:

- Cost
- Schedule

Alternatives:

- Extend drilled shaft to bedrock.
- Provide necessary load capacity by using micropiles supported on the bedrock.

Solution and Justification

- Due to cost of drilled shaft construction up to competent rock, drilled shaft depth was limited to 115 ft, and decided to use micropiles up to the bedrock.
- Contractor wanted to stick to the original schedule. Hence, the construction was to continue while the foundation capacity was enhanced. This required using equipment that can be maneuvered with limited headroom.
- Seven (7) in. diameter, 150 ton micropiles that were socketed 15 ft into bedrock were selected (Figure A-32).
- Eight micropiles were used. The total length of piles ranged between 158 and 162 ft.
- The length of micropiles extended beyond the drilled shaft ranged between 43 and 47 ft.

Remarks:

- This application shows that the micropiles can be installed through deficient deep foundation if the element is large enough and has sufficient structural capacity.

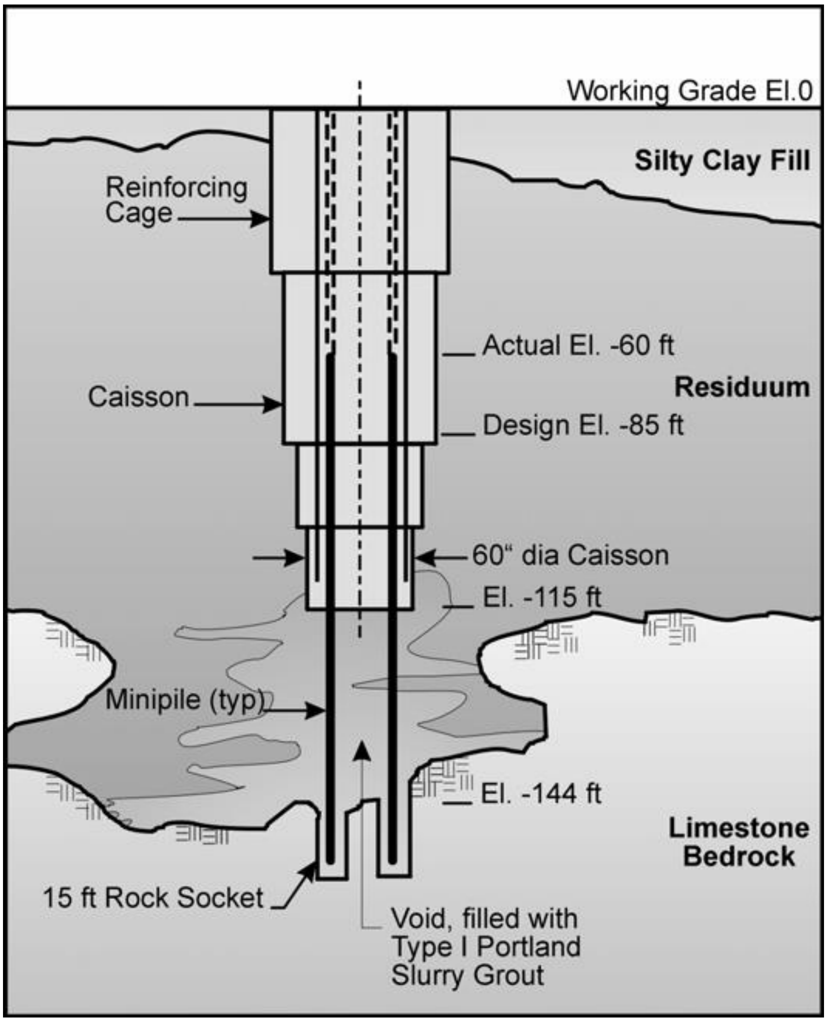


Figure A-32. Drilled shaft underpinning with micropiles

APPENDIX B

SIBC – SITE AND TEMPORARY STRUCTURE CHARACTERISTICS

M-50 OVER I-96 – MICHIGAN

Site Characteristics

The new two-span continuous bridge with four lanes carries M-50 northbound and southbound traffic over I-96. Westbound and eastbound of I-96, each carries 2 lanes. M-50's profile grade consisted of mirrored downgrades of 2.0% from the roadway crown that transitioned into 3.0% downgrades on the shoulders. The grade for each I-96 roadway consisted of 1:10 downgrade embankments adjacent to the existing abutments.

Superstructure

Length and width of each new prestressed concrete span are 99 ft and 71 ft - 3 in., respectively. The change in longitudinal grade along the bridge superstructure was insignificant. A minimum clearance of 16 ft - 8.75 in. was required over I-96.

Temporary Structure

The new bridge superstructure was built on temporary substructures that were located on the west side of the existing M-50 Bridge. The construction was performed in phases to minimize the M-50 closure duration. After the new superstructure construction was completed on the temporary substructure, 2-lanes of the new superstructure were used as temporary bypass for M-50 traffic. This allowed the old bridge demolition and permanent substructure construction without closing M-50 for traffic. During bridge slide, M-50 was closed and a detour was in place while westbound and eastbound I-96 traffic was routed through the M-50 entrance and exit ramps.

The temporary substructure was designed using HL-93 Mod live load defined in the Michigan Department of Transportation (MDOT) Bridge Design Manual (i.e., 1.2 times the AASHTO LRFD HL-93 live load). The materials used and workmanship for the temporary substructure complied with the MDOT Standard Specification for Construction, 2012 Edition. Since the new bridge superstructure had two simple spans made continuous for live load, a temporary pier was fabricated in the I-96 median. The extended pile spacing varied for the temporary abutments and pier. The smallest extended pile spacing was located near the permanent bridge location. Also, the temporary abutments and pier were tall enough to require lateral bracing which was connected diagonally across the face of multiple extended piles (Figure B-1 and Figure B-3). A W 14×426 beam was placed on top the extended piles as the railing beam (Figure B-2 and Figure B-4). The new bridge superstructure weight and the temporary substructures details are provided in Table B-1.

Table B-1. M-50 over I-96 Temporary Structure Details

Total weight of the superstructure per span (tons)	892.86
Extended piles at the abutment	
Type	HP 14 × 73
Spacing range (ft)	4.00 – 6.00
Max. unbraced height (ft)	20.00
Bracing member between extended piles	WT 8 × 28.8
Extended piles at the pier	
Type	HP 14 × 73
Spacing range (ft)	4.00 – 6.00
Max. unbraced height (ft)	19.50
Bracing member between extended piles	WT 8 × 28.8

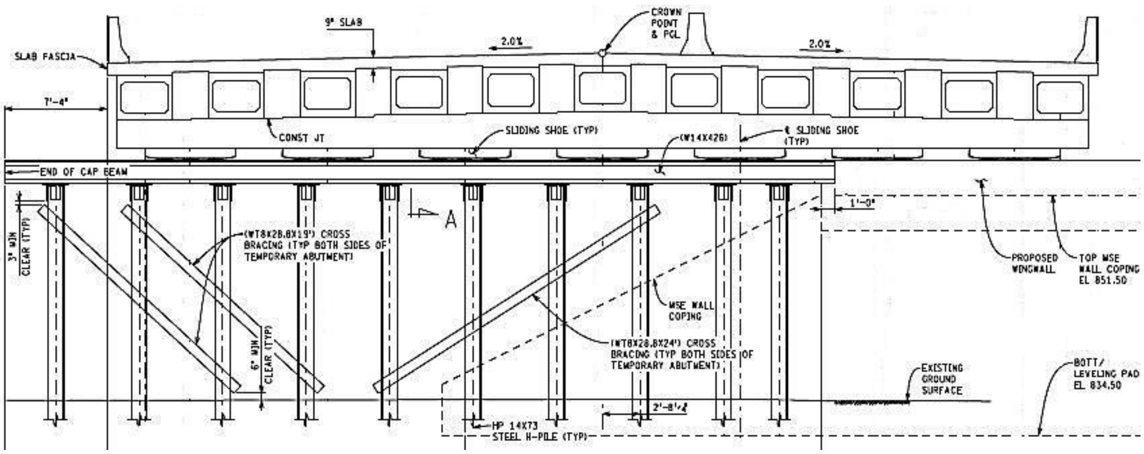


Figure B-1. Side view of the M-50 temporary abutment substructure

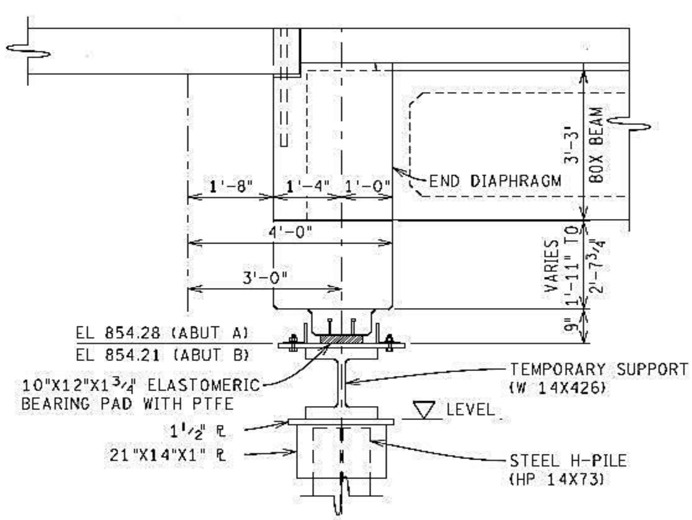


Figure B-2. End view of the M-50 temporary abutment substructure

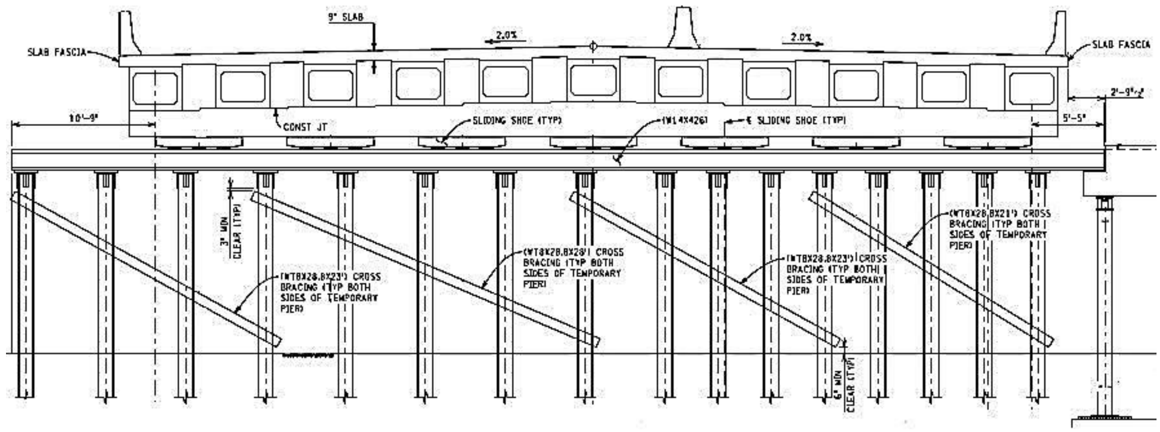


Figure B-3. Side view of the M-50 temporary pier substructure

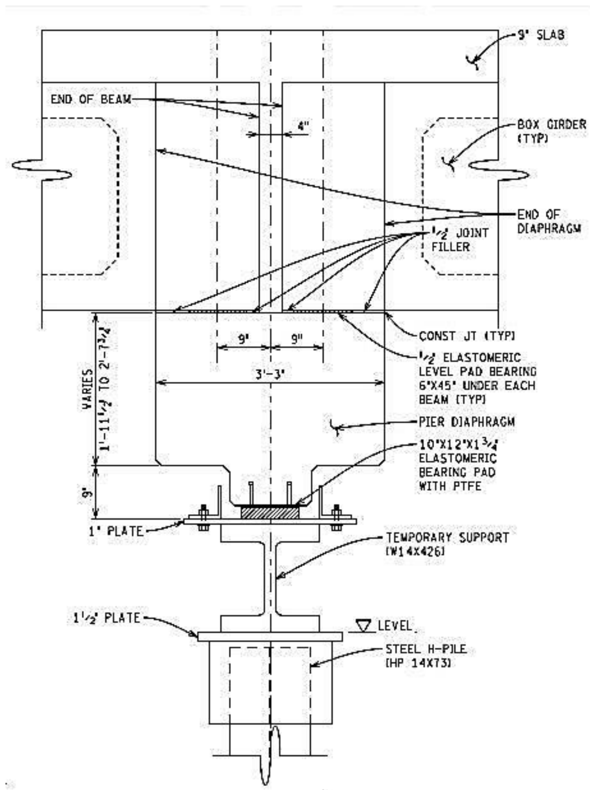


Figure B-4. End view of the M-50 temporary pier substructure

US-131 OVER 3 MILE ROAD - MICHIGAN

Site Characteristics

Each new single span bridge has two lanes and carries US-131 northbound and southbound traffic over 3 Mile Road, a 2-lane road. The replaced northbound and southbound bridges had a superelevation from east to west of -1.5% and adjacent profile downgrade embankments of 1:2. While the profile grade for the 3 Mile Road consisted of mirrored downgrades of 1.5% from the roadway crown which transitions into a 1:2 upgrade paved concrete embankment on the south side and a 1:6 downgrade embankment on the north side.

Superstructure

Length and width of each new single span, prestressed concrete box-beam superstructure are 86 ft and 42 ft, respectively. The change in longitudinal grade of the bridge superstructure was insignificant. A minimum clearance of 14 ft - 6 in. was provided over the 3 Mile Road.

Temporary Structure

Each new superstructure was built on a set of temporary substructures. One set of temporary substructures was built on the east side of US-131 northbound while the other set was built on the west side of the southbound bridge. Traffic was detoured during the sliding and placement of the new bridge superstructure. Several specifications and codes were used for temporary substructure design. The temporary substructure was designed in accordance with the AASHTO Guide Specification for Bridge Temporary Works, 1st Edition, with 2008 Interim Revisions and the AASHTO Standard Specifications for Highway Bridges, 17th Edition. The materials used and workmanship for the temporary substructure complied with the Michigan Department of Transportation Standard Specification for Construction, 2012 Edition.

Both the northbound and southbound temporary substructures required lateral bracing in between the extended piles (Figure B-5 and Figure B-7). At each temporary support, there were two separate rows of piles, vertical and battered extended piles. Battered extended piles were driven in at an angle and provided lateral support for the temporary substructure (Figure B-6 and Figure B-8). The vertical extended pile spacing varied with the closest spacing adjacent to the permanent bridge position, whereas the majority battered extended piles were evenly spaced. A W 14×311 railing beam was placed on top of the vertical extended piles in order to support and guide the new superstructure to the existing bridge (Figure B-9). Table B-2 provides a summary of the new bridge superstructure weight and the temporary substructure details.

Table B-2. US-131 over 3 Mile Road Temporary Substructure Details

Total weight of the superstructure per span (tons)	583.93
Vertical extended pile	
Type	HP 14 × 73
Spacing range (ft)	3.50 – 7.00
Max. unbraced height (ft)	12.00
Bracing between extended piles	L 5 × 5 × ¾
Battered extended pile	
Type	HP 14 × 73
Spacing range (ft)	14.00 – 14.50
Max. unbraced height (ft)	12.00

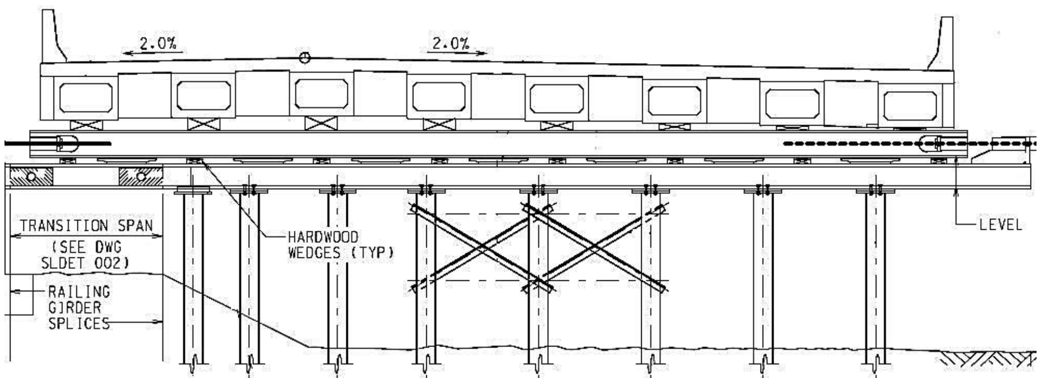


Figure B-5: Side view of the US-131 NB bridge temporary substructure

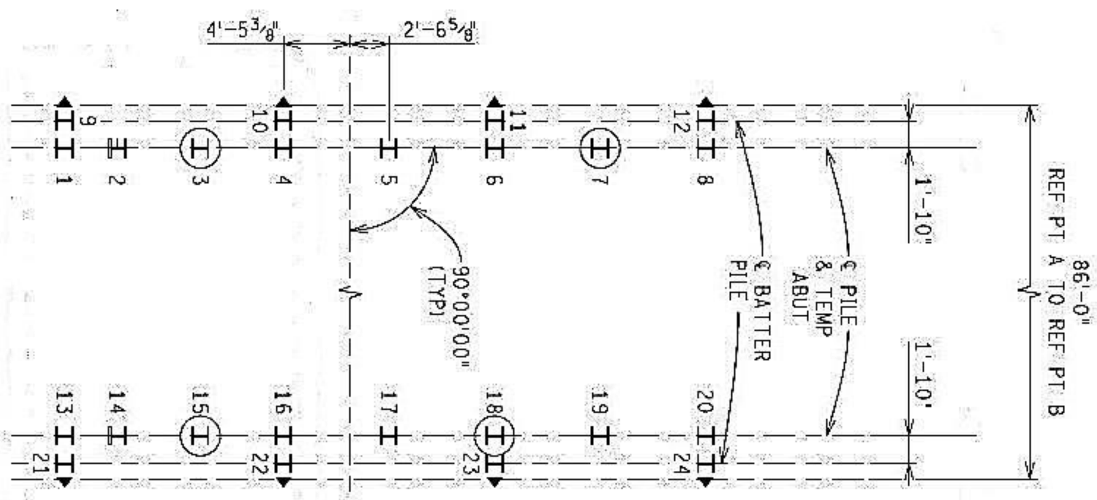


Figure B-6: Top view of the US-131 NB bridge temporary extended pile arrangement

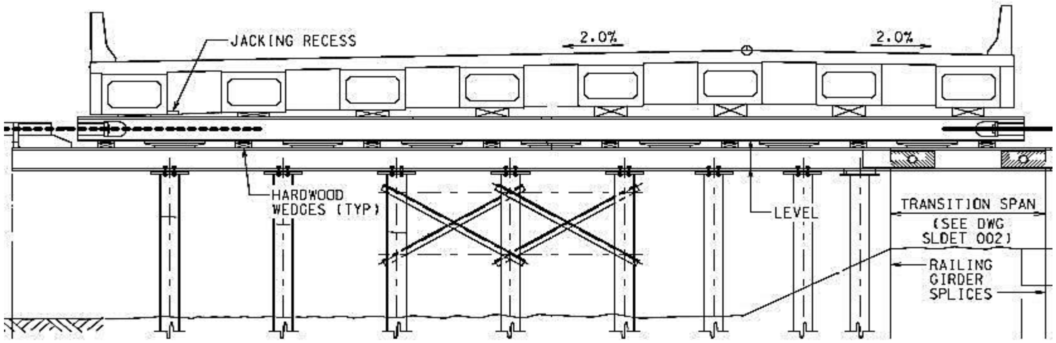


Figure B-7: Side view of the US-131 SB bridge temporary substructure

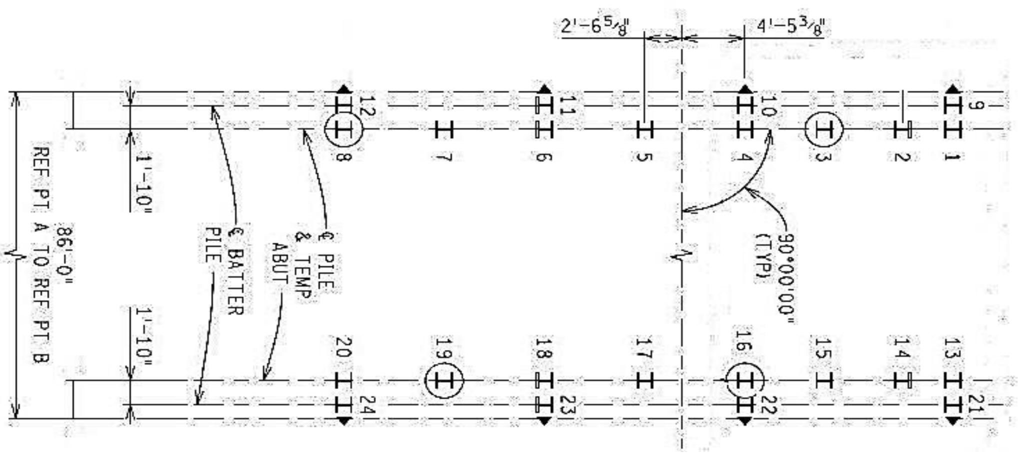


Figure B-8: Top view of the US-131 SB bridge temporary extended pile arrangement

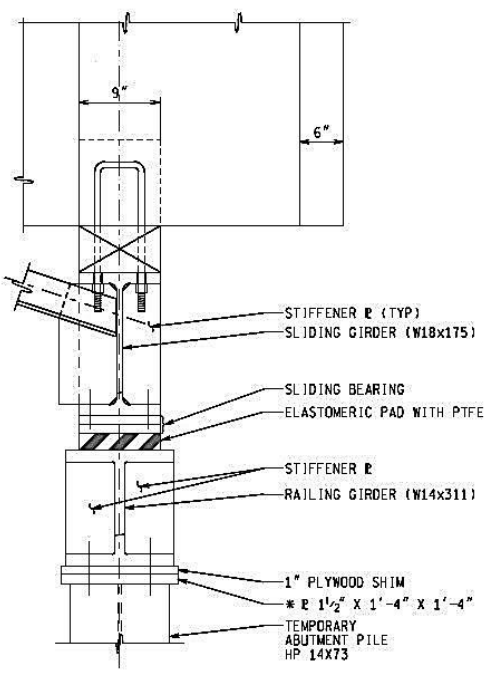


Figure B-9: End view of the US-131 NB and SB bridge temporary substructure

LARPENTEUR AVENUE BRIDGE – MINNESOTA

Site Characteristics

The new two-span continuous bridge with five lanes carries Larpenteur Avenue westbound and eastbound traffic over I-35E. Northbound and southbound of I-35E, each carries 4 lanes. The profile grade for Larpenteur Avenue consisted of mirrored downgrades of 2.00% from the roadway crown. The profile grade of I-35E northbound and southbound from the roadway crown to the intermediate pier has a downgrade of 1.50% to 6.00%. While the profiled grade from the roadway crown to the abutment has a 2.00% downgrade that transitions into an upgrade 1:2 concrete slope. Also, the longitudinal grade of I-35E, right below the bridge, decreases by 2.07% from north to south.

Superstructure

Length and width of each prestressed concrete girder span are 91 ft - 9 in. and 75 ft - 10 in., respectively. There was no variation in the longitudinal grade along the bridge superstructure. A minimum clearance of 16 ft - 5 in. and 16 ft - 6 in. was provided over I-35E northbound and southbound, respectively.

Temporary Structure

The new bridge superstructure was fabricated on temporary substructures that were constructed adjacent to the north side of the existing bridge. Larpenteur Avenue was closed for approximately 35 days for the demolishing and the reconstruction of the bridge. I-35E traffic was detoured in both directions during the overnight slide of the new bridge superstructure for Larpenteur Avenue. The temporary substructures were designed in accordance with the AASHTO Guide Specification for Bridge Temporary Works, 1st Edition, with 2008 Interim Revisions and the Minnesota Department of Transportation (MnDOT) Bridge Construction Manual. The materials used and workmanship for the temporary substructure complied with the requirements set by MnDOT and AASHTO Construction Handbook for Bridge Temporary Works, 1st Edition, with 2008 Interim Revisions.

Since the new bridge superstructure was a continuations two-span, a temporary pier was fabricated in the median between I-35E northbound and southbound (Figure B-13).

Extended pile spacing at the temporary substructures next to the abutments varied and the spacing of the piles close to the permanent abutment was the smallest (Figure B-10). The extended piles were evenly spaced at the temporary pier (Figure B-12). At the temporary abutments, bracings were provided to control out of plane deformations (Figure B-11). A 12 ft long W 27×84 section was placed on top of each extended pile at the temporary abutments and pier. Then, four HP 14×89 sections that extended the entire length of the temporary substructure were placed on top of the W 27×84 beams (Figure B-10 and Figure B-13). Table B-3 presents superstructure weight and temporary substructures details.

Table B-3. Larpenteur Ave Bridge Temporary Substructure Details

Total weight of the superstructure per span (tons)	811.29
Extended piles at the abutments	
Type	HP 14 × 89
Spacing range (ft)	6.00 – 12.00
Max. unbraced height (ft)	7.00
Bracing between temporary substructure and stub extended piles	HP 10 × 42
Extended piles at the pier	
Type	HP 14 × 89
Spacing (ft)	6.00
Max. unbraced height (ft)	12.00

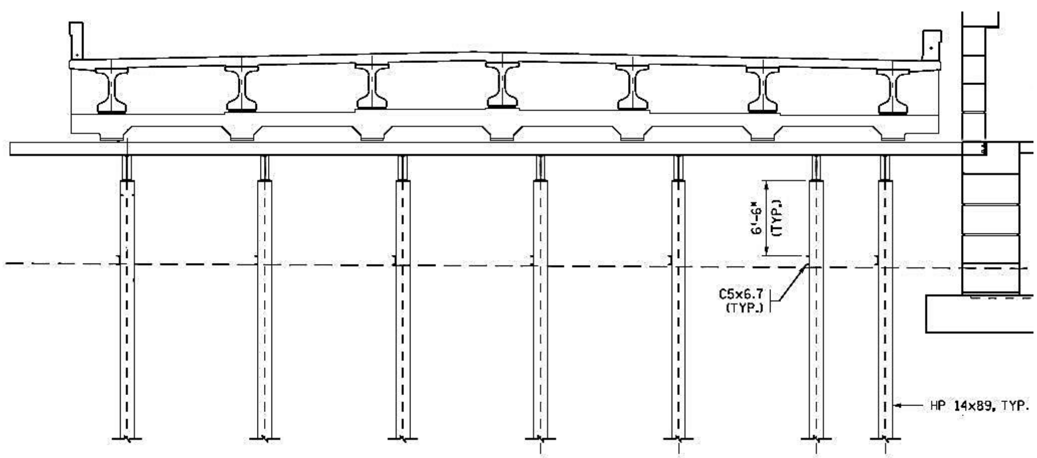


Figure B-10. Side view of the Larpenteur Ave temporary abutment substructure

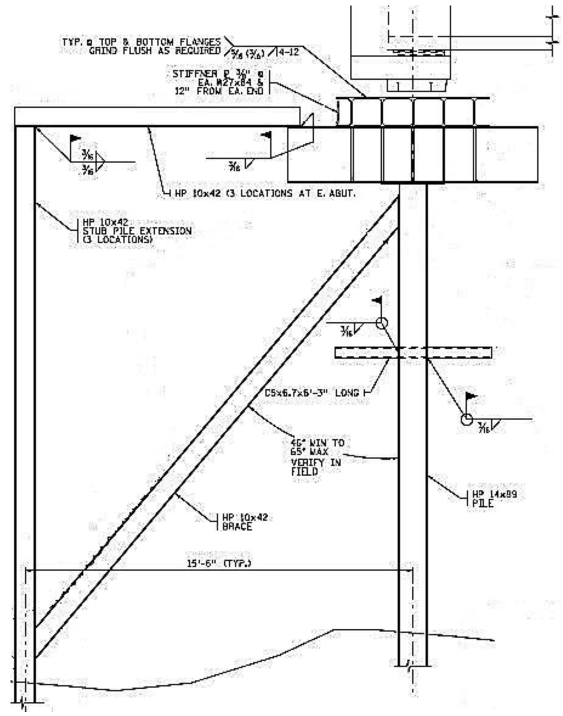


Figure B-11. End view of the Larpenteur Ave temporary abutment substructure

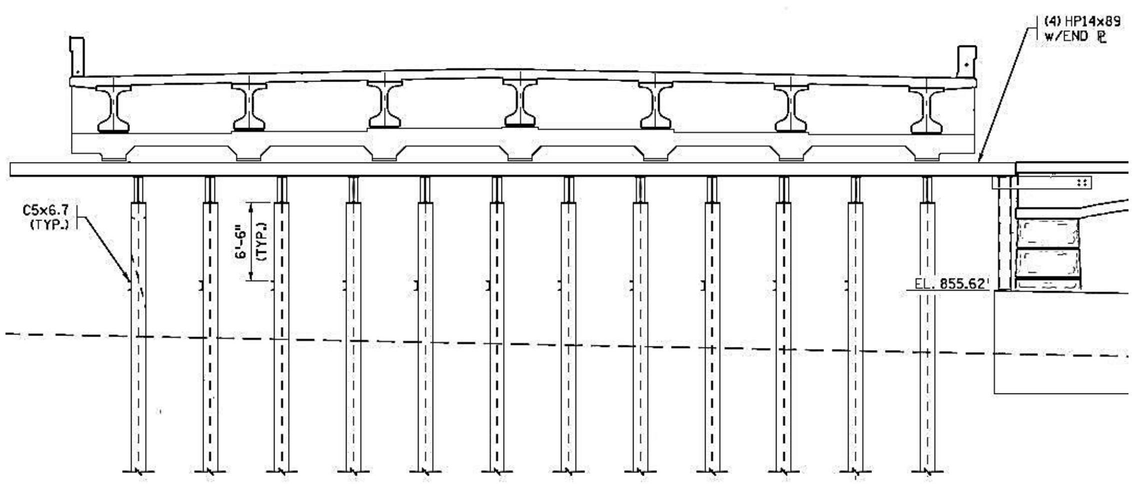


Figure B-12. Side view of the Larpenteur Ave temporary pier substructure

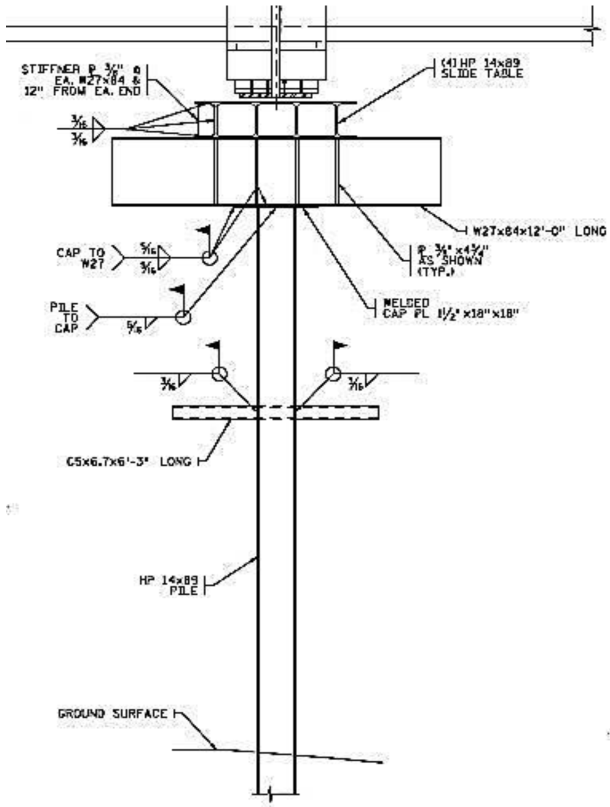


Figure B-13. End view of the Larpenteur Ave temporary pier substructure

WEST MESQUITE INTERCHANGE AT I-15 – NEVADA

Site Characteristics

Each new single span bridge has two lanes that carry I-15 northbound and southbound traffic over Falcon Ridge Parkway, a 4-lane road. However, at the interchange, I-15 southbound bridge is aligned in the south-west direction while the northbound bridge is aligned in the north-east direction (Figure B-14). Yet, I-15 bridges at the intersection will be referred in this document as northbound and southbound bridges. The replaced northbound and southbound bridges had a superelevation from west to east of –4.70% and –4.60%, respectively. The superelevations of the northbound and southbound Falcon Ridge Parkway lanes are decreased by 2.00% from the inner roadway edge towards the bridge abutments. Additionally, the longitudinal grade of Falcon Ridge Parkway is increased by 0.30% from north to south.

Figure B-14. Orientation of the West Mesquite Interchange at I-15

Superstructure

Length and width of each prestressed concrete girder span are 111 ft - 6 in and 45 ft - 11 in, respectively. These single span bridges were slid into place with the approach slabs. Each approach slab is 24 ft long. Each of these structures has a skew of about 31^0. The longitudinal grade increases by 1.34% from west to east for both of the bridge superstructures. A minimum clearance of 16 ft - 9 in. was provided over Falcon Ridge Parkway.

Temporary Structure

Each new superstructure was built on a set of temporary substructures. Since each bridge was slid into place with the approaches, superstructure and approach slab construction required four temporary structures; one at each end of the bridge span and one at each end of the approach slabs. All four temporary structures for each bridge were constructed using extended piles. One set of temporary substructures was built on the east side of I-15 northbound while the other set was built on the west side of southbound bridge. The new bridge foundation was constructed below the existing bridges to minimize traffic disruption. During the demolishing of the existing bridge, sliding, and placement of the new superstructure; Falcon Ridge Parkway was closed and I-15 traffic was detoured by using the

West Mesquite Interchange on- and off-ramps. Several specifications and codes were used for temporary substructure design. The dead and live loads for the temporary substructure design were determined in accordance with the AASHTO Guide Specification for Bridge Temporary Works, 1st Edition, with 2008 Interim Revisions; whereas the seismic design loading was calculated in accordance to the AASHTO LRFD Bridge Design Specifications, 5th Edition. Structural steel members were designed in accordance with the AISC Steel Construction Manual, 13th Edition.

Steel wire ropes were used as bracings for the temporary structures at the abutments to increase the stiffness in the direction of sliding (Figure B-15). WT 8×25 sections were used to provide bracings between the temporary structures at the abutments and at the end of the approach slabs (Figure B-17). Near the top of each extended pile, 2 ft - 6 in. long HP 14×89 sections were welded to the extended pile flanges as braces for the slide rail (Figure B-16). Three HP 14×117 sections were placed on top of the extended piles and served as the slide rails. Each new superstructure was constructed on top of the slide rails (Figure B-15 and Figure B-16). Table B-4 provides a summary of the new bridge superstructure weight and the temporary substructure details.

Table B-4. West Mesquite Interchange at I-15 Temporary Substructure Details

Total weight of the superstructure per span (tons)	852.68
Extended piles at the abutments	
Type	HP 14 × 89
Spacing (ft)	12.83
Max. unbraced height (ft)	21.25
Bracing between extended piles	½ in. Steel Wire Rope
Bracing between the temporary structures at the abutment and the end of approach slabs	WT 8 × 25

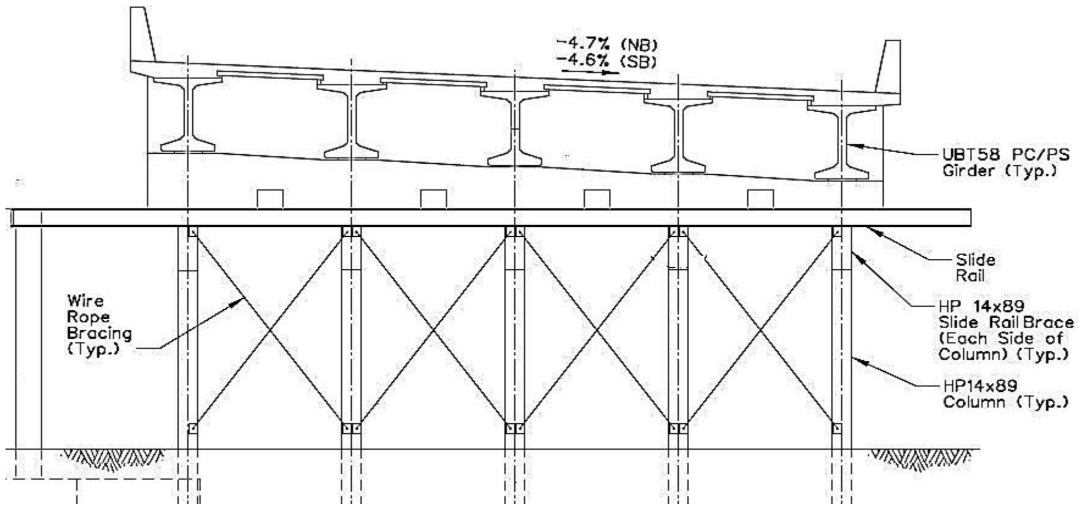


Figure B-15. Side view of the I-15 temporary substructure

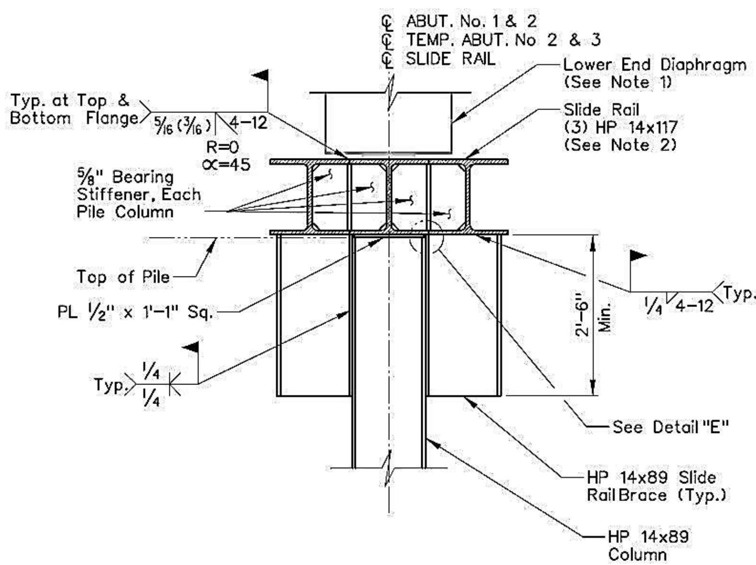


Figure B-16. End view of the I-15 temporary substructure

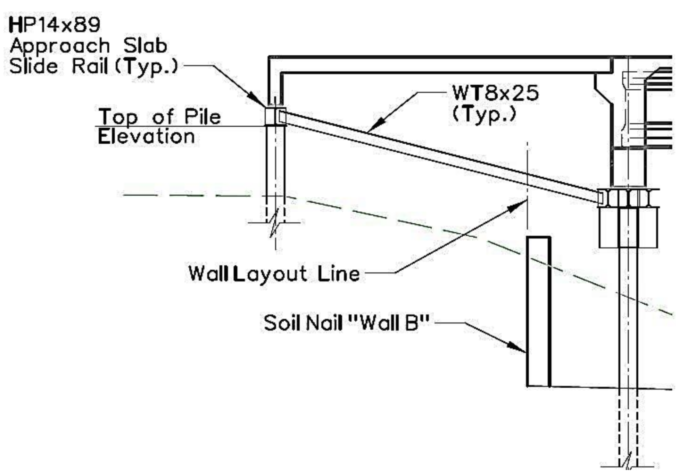


Figure B-17. End view of the I-15 temporary substructure at the abutment and the end of approach with lateral bracing

I-80 AT SUMMIT PARK - UTAH

Site Characteristics

The project included replacing two single span bridges. Each bridge has four lanes and carries I-80 eastbound or westbound traffic over Aspen Drive, a 3-lane road. The replaced eastbound and westbound bridges had a superelevation from north to south of -4.32% and -4.12%, respectively. While the profile grade of Aspen Drive consist of mirrored 2.00% downgrades from the roadway crown. Also, the longitudinal grade of Aspen Drive, right below the bridges, decreases from 8.00% to 6.74% from north to south.

Superstructure

Length and width of each new single span, steel girder superstructure are 130 ft and 74 ft, respectively. These single span bridges were slid into place with the approach slabs. Length of each approach slab is 25 ft. Bridge skew was less than 9^0. The longitudinal grade decreases by 8.11% from west to east for both of the bridge superstructures. A minimum clearance of 17 ft - 2 in. was required over Aspen Drive. Hence, the westbound bridge was raised to meet this required minimum clearance.

Temporary Structure

Each superstructure was built on a set of temporary substructures. Since each bridge was slid into place with the approaches, superstructure and approach slab construction required four temporary structures; one at each end of the bridge span and one at each end of the approach slabs. All four temporary structures for each bridge were constructed using extended piles. One set of temporary substructures was built on the north side of I-80 westbound while the other set was built on the south side of eastbound bridge. The new bridge abutments were constructed below the existing bridges to minimize traffic disruption. Also, the construction was performed in phases which allowed the eastbound and westbound bridges to remain open throughout the entire project. Each bridge was slid in place overnight on the weekends to prevent traffic interruptions. Several specifications and codes were used for temporary substructure design. The design loading for the temporary substructures was calculated in accordance with the AASHTO Guide Specification for Bridge Temporary Works, 1st Edition, with 2008 Interim Revisions. The structural steel members were designed in accordance with the AISC Steel Construction Manual, 13th Edition. The weld designs complied with the Structural Building Code – Steel AWS D1.1.

Only three extended piles at the eastbound bridge temporary abutment required bracings (Figure B-18). Also, bracings were provided between the temporary structures at the end of bridge spans and the end of approach slab (Figure B-20). Near the top of each extended pile, two 1 ft - 10 in. long W 27×84 sections were welded to the extended pile flanges as braces for the support beam (Figure B-19). The extended piles and W 27×84 sections provided support for four HP 14×89 sections used as the support beams that extended the entire length of the temporary substructure (Figure B-19). The westbound bridge elevation at the abutments was much closer to the ground. Hence, westbound temporary substructure did not required extended piles or bracings, and consisted of connected HP 14×89 driven piles and W 27×84 beams with four HP 14×89 support beams on top (Figure B-21). Table B-5 provides a summary of the new bridge superstructure weight and the temporary substructure details.

Table B-5. I-80 at Summit Park EB Bridge Temporary Substructure Details

Total weight of the superstructure per span (tons)	1071.40
Extended piles at abutments	
Type	HP 14 × 89
Spacing (ft)	13.30
Max. unbraced height (ft)	21.25
Bracing between extended piles	WT 8 × 25
Bracing between abutment and end approach temporary substructures	W 12 × 65

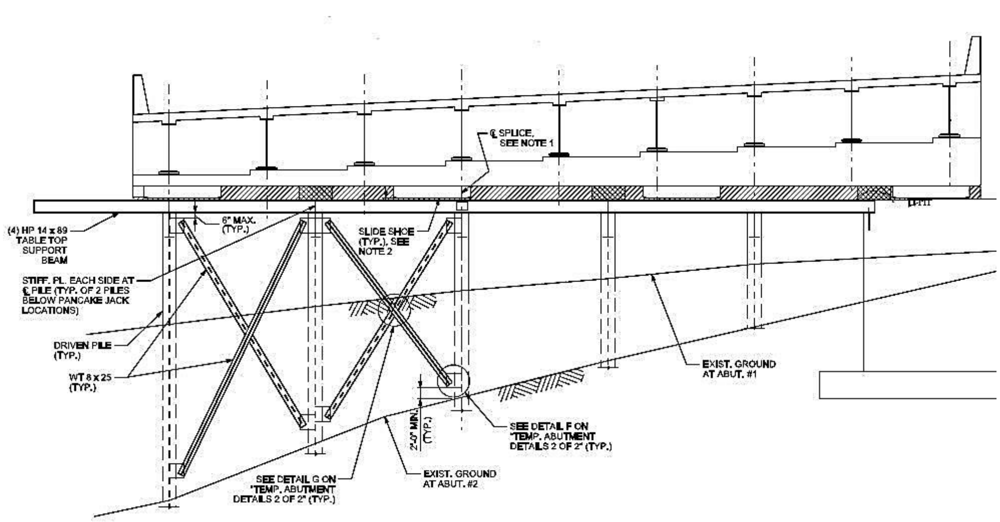


Figure B-18. Side view of the I-80 Summit Park EB bridge temporary substructure

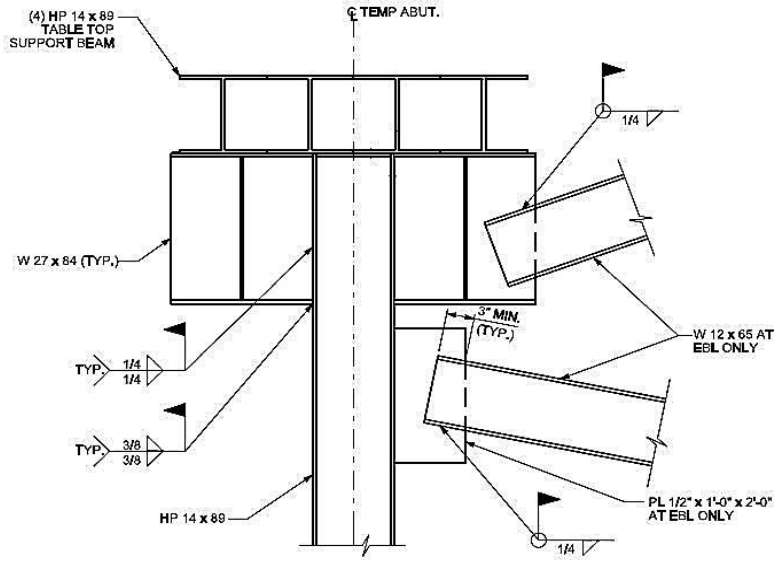


Figure B-19. End view of the I-80 Summit Park EB bridge temporary substructure

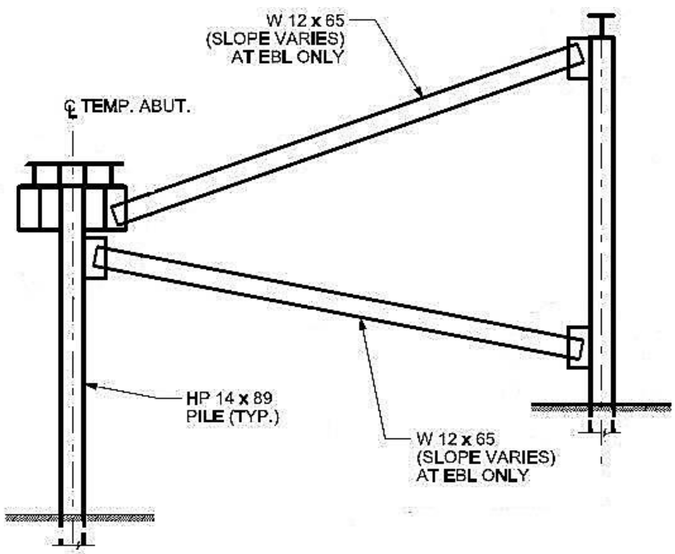


Figure B-20. End view of the I-80 Summit Park EB bridge temporary substructure at the abutment and the end of approach with lateral bracing

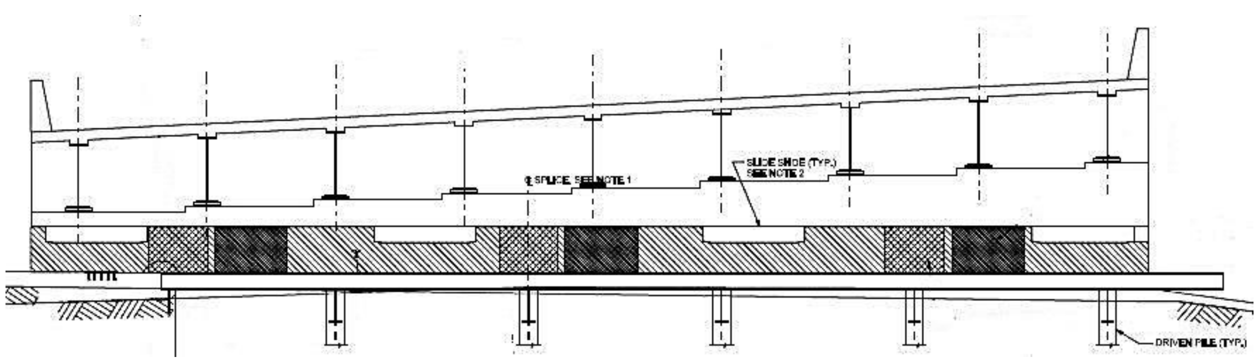


Figure B-21. Side view the of I-80 Summit Park WB bridge temporary substructure

I-80 AT WANSHIP – UTAH

Site Characteristics

The project included replacing two single span bridges. Each bridge has two lanes. The bridges carry I-80 eastbound and westbound traffic over SR-32, a 3-lane road. The replaced eastbound and westbound bridges had a superelevation from north to south of +6.00%. While the profile grade for SR-32 northbound and southbound has mirrored downgrades of 2.00% that transition into 0.50% upgrades from the roadway crown to the abutment. Also, the longitudinal grade of SR-32, right below the bridges, decreases 1.18% and transitioned into a 1.27% upgrade from south to north.

Superstructure

Length and width of each new single span, steel girder superstructure are 87 ft and 46 ft - 6 in., respectively. These single span bridges were slid into place with the approach slabs. Length of each approach slab is 25 ft. Bridge skew was about 15^0. The longitudinal grade decreases by 3.00% from west to east for both of the bridge superstructures. A minimum clearance of 16 ft - 9 in. was provided over SR-32.

Temporary Structure

Each new superstructure was built on a set of temporary substructures. Since each bridge was slid into place with the approaches, superstructure and approach slab construction required four temporary structures; one at each end of the bridge span and one at each end of the approach slabs. All four temporary structures for each bridge were constructed using extended piles. One set of temporary substructures was built on the north side of I-80 westbound while the other set was built on the south side of the eastbound bridge. In order to maintain traffic during the construction, the new bridge abutments were constructed below the existing bridges. During the demolishing of the existing bridge, sliding and placement of the new superstructure; I-80 traffic was diverted by using the freeway on- and off-ramps. The design loading for the temporary substructures was performed in accordance with the AASHTO Guide Specification for Bridge Temporary Works, 1st Edition, with 2008 Interim Revisions. The steel was designed in accordance with the AISC Steel Construction Manual, 13th Edition.

Both the westbound and eastbound temporary substructures required lateral bracing in between the extended piles (Figure B-22 and Figure B-23). Bracings were provided between the temporary structures at the end of bridge spans and the end of approach slab (Figure B-25). Also, two different pile top designs were employed in the temporary abutment substructures. Figure B-24 was the extended pile top design utilized when there was bracing between the abutment and end approach temporary substructures. Near the top of each extended pile, two 1 ft - 10 in. long W 27×84 beams were welded to the extended pile flanges as braces for the support beam. Alternatively, the extended pile top design in Figure B-26 was used at locations where bracing between the abutment and end approach temporary substructures did not occur. A 5 ft - 2 in. long HP 14×89 section was placed on top of each extended pile. WT 8×25 knee brace sections were placed between the flanges of the extended pile and the HP 14×89 section. For each pile top design, four HP 14×89 support beams were place on top of the extended piles which extended entire length of the westbound and eastbound temporary substructures. Table B-6 provides a summary of the new bridge superstructure weight and the temporary substructure details.

Table B-6. I-80 at Wanship Temporary Substructure Details

Total weight of the superstructure per span (tons)	504.42
Extended piles at the abutments	
Type	HP 14 × 89
Spacing (ft)	8.00
Max. unbraced height (ft)	11.00
Bracing between extended piles	WT 8 × 25
Bracing between abutment and end approach temporary substructures	WT 8 × 25 W 14 × 30

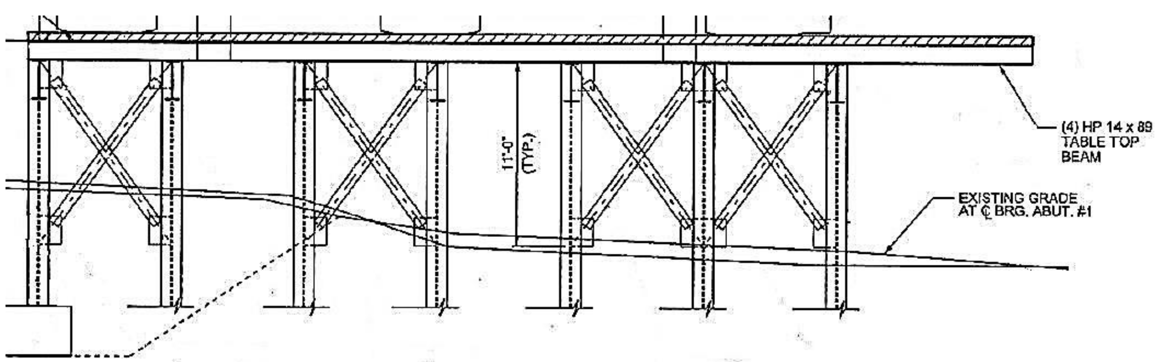


Figure B-22. Side view of the I-80 at Wanship temporary substructure for the WB bridge

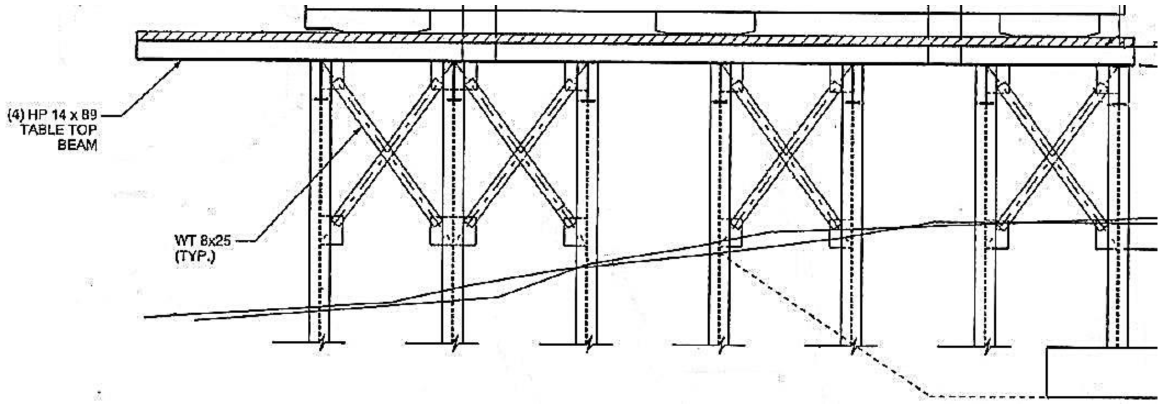


Figure B-23. Side view of the I-80 at Wanship temporary substructure for the EB bridge

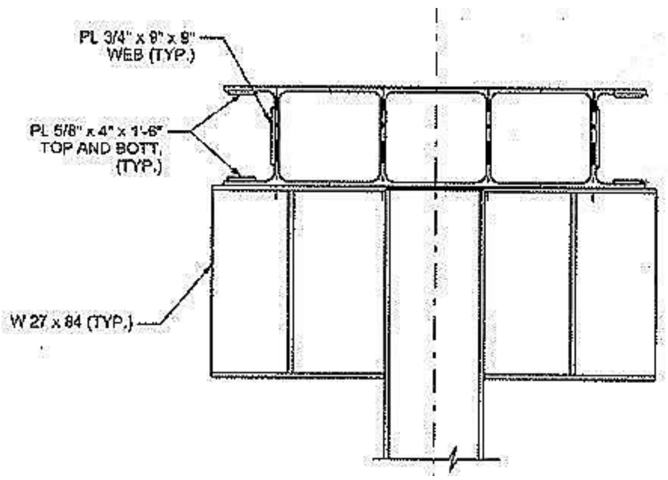


Figure B-24. End view of the I-80 at Wanship pile top design with abutment and end approach bracing for the WB and EB bridge

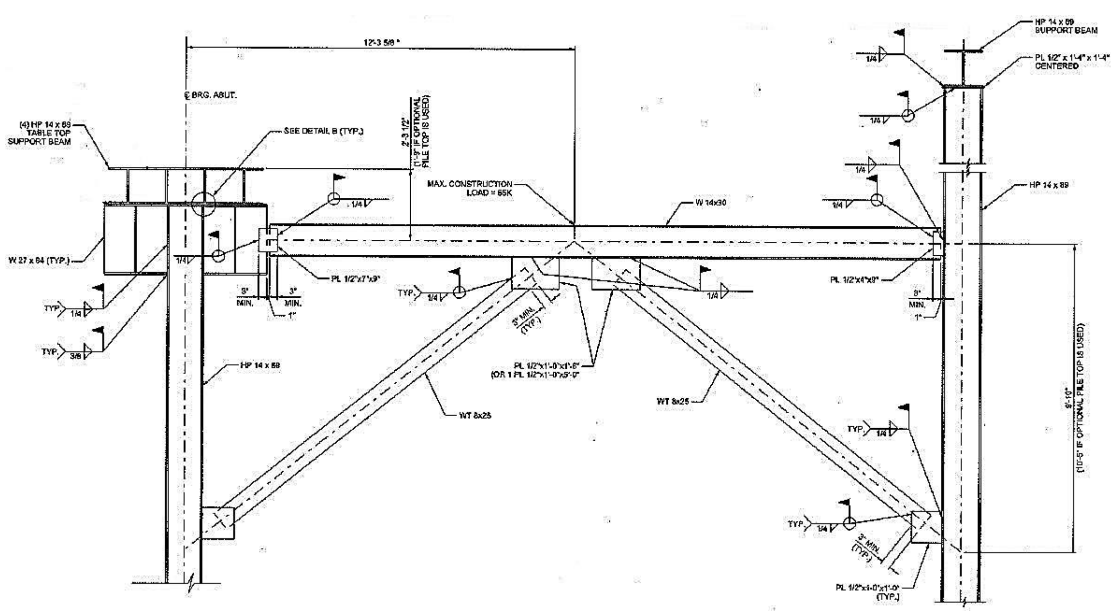


Figure B-25. End view of the I-80 at Wanship WB and EB bridge temporary substructure at the abutment and the end of approach with lateral bracing

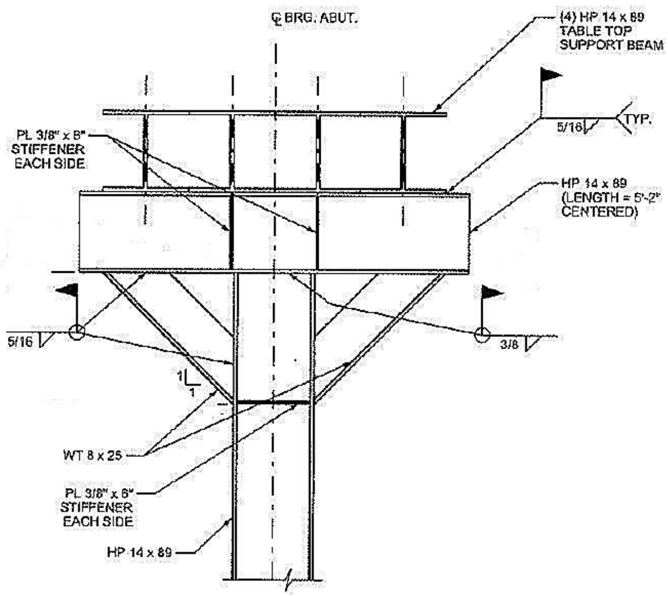


Figure B-26. End view of the I-80 at Wanship pile top design without abutment and end approach bracing for the WB and EB bridge

I-80 OVER 2300 EAST- UTAH

Site Characteristics

Each new single span bridge has three lanes that carry I-80 eastbound and westbound over 2300 East, a 1-lane road. The longitudinal grade of 2300 East, right below the bridges, decreases 1.26% and transitions into a 6.74% upgrade from north to south.

Superstructure

Length and width of each prestressed concrete girder span are 80 ft and 62 ft - 10 in., respectively. The longitudinal grade decreases by 4.00% from west to east for both of the bridge superstructures. Length of each westbound and eastbound bridge approach slab is 23 ft – 2 in. and 25 ft, respectively. A minimum clearance of 15 ft was required over 2300 East. Hence, the westbound bridge was raised 5 ft to meet this required minimum clearance.

Temporary Structure

Each new superstructure was built on a set of temporary substructures. Since each bridge was slid into place with the approaches, superstructure and approach slab construction required four temporary structures; one at each end of the bridge span and one at each end of the approach slabs. All four temporary structures for each bridge were constructed using extended piles. One set of temporary substructures was built on the north side of I-80 westbound while the other set was built on the south side of eastbound bridge. In order to maintain traffic during the construction, the new bridge abutments were constructed below the existing bridges. Each I-80 bridge was temporary closed at night for an eight-hour period during the demolishing of the existing bridges and the sliding and placement of the new superstructures. Several specifications and codes were used for temporary substructure design. The design loading for the temporary substructures was calculated in accordance with the AASHTO Guide Specification for Bridge Temporary Works, 1st Edition, with 2008 Interim Revisions. The structural steel members were designed in accordance with the AISC Steel Construction Manual, 13th Edition. The weld designs complied with the Structural Building Code – Steel AWS D1.1.

Both the westbound and eastbound temporary substructures required lateral bracing in between the extended piles (Figure B-27). Bracings were provided between the temporary structures at the end of bridge spans and the end of approach slab (Figure B-29 and Figure B-31). The westbound and eastbound temporary abutments had dissimilar pile top designs which were influenced by ground elevation differences between the locations. The westbound abutments had a larger ground elevation differences and required multiple layers of structures in order to achieve the required height. Near the top of each extended pile, two 1 ft - 10 in. long W 27×84 sections were welded to the extended pile flanges. On top the extended pile and W 27×84 sections, three layers of structures which were placed in the following order: two HP 14×89 beams, solid wood blocking, and three support beams. Two types of support beams were used for the westbound temporary abutments. The west side abutment utilized W 14×120 support beams, whereas the east side abutment had HP 14×89 support beams (Figure B-28). Since the eastbound temporary abutments had a smaller ground elevation difference, multiple layers of structures were not required. Near the top of each extended pile, two 1 ft - 10 in. long W 27×84 sections were welded to the extended pile flanges as braces for the support beam. The extend pile and W 27×84 sections provided vertical support for four HP 14×89 support beams (Figure B-30). Table B-7 presents superstructure weight and the temporary substructure details.

Table B-7: I-80 over 2300 East Temporary Substructure Details

Total weight of the superstructure per span (tons)	650.00
Extended piles at the abutments	
Type	HP 14 × 89
Spacing (ft)	15.17
Max. unbraced height (ft)	9.37
Bracing between extended piles	HSS 4.5 × 0.237
Bracing between abutment and end approach temporary substructures	WT 8 × 25

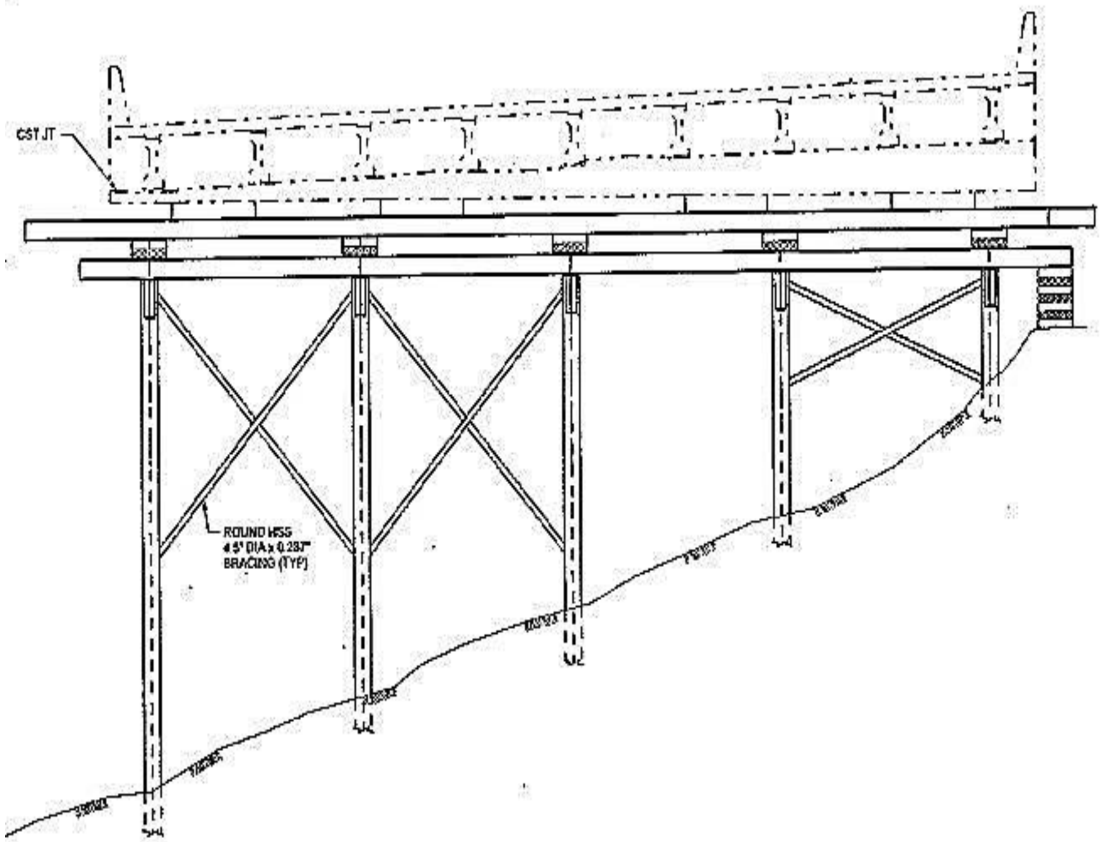


Figure B-27. Side view of the I-80 over 2300 East temporary substructure for the WB and EB bridges

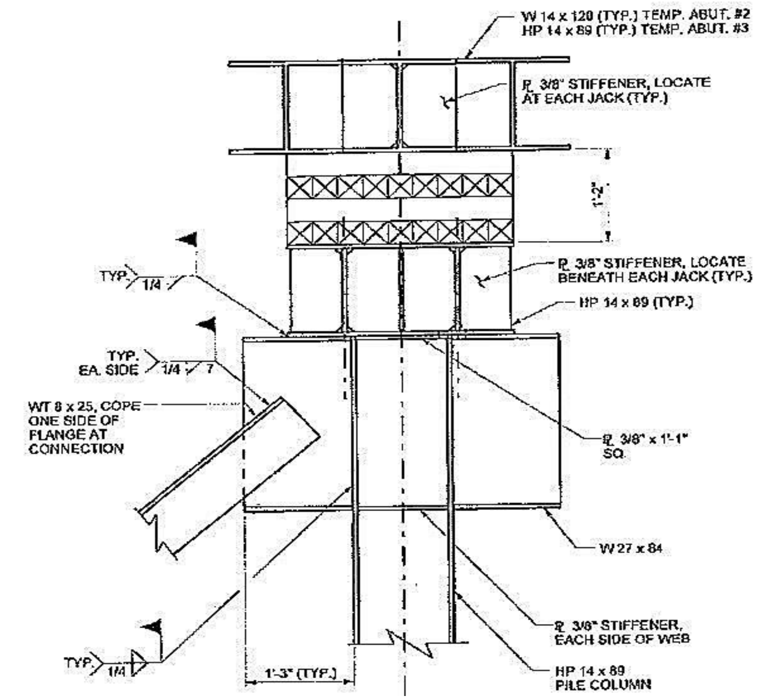


Figure B-28. End view of the I-80 over 2300 East temporary substructure for the WB bridge

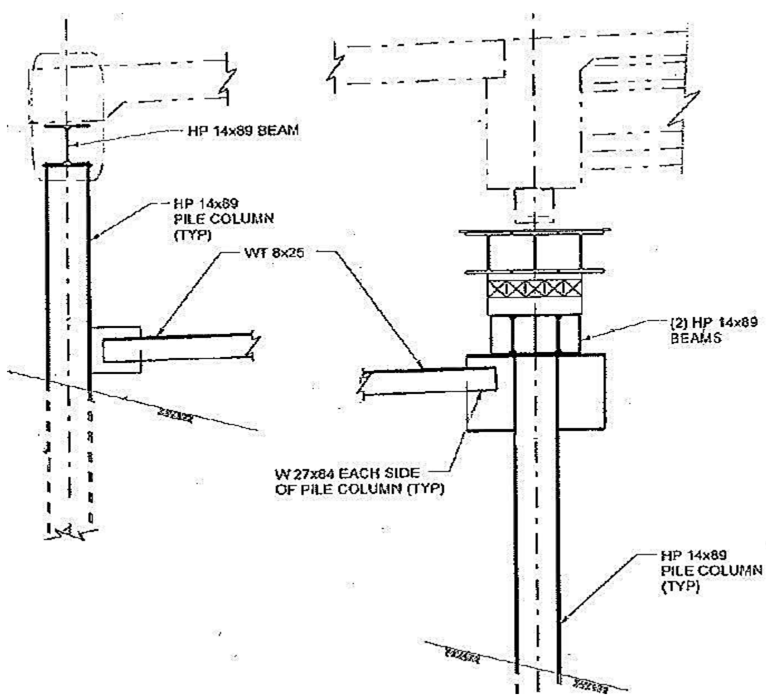


Figure B-29. End view of the I-80 over 2300 East, WB bridge temporary substructure at the abutment and the end of approach with lateral bracing

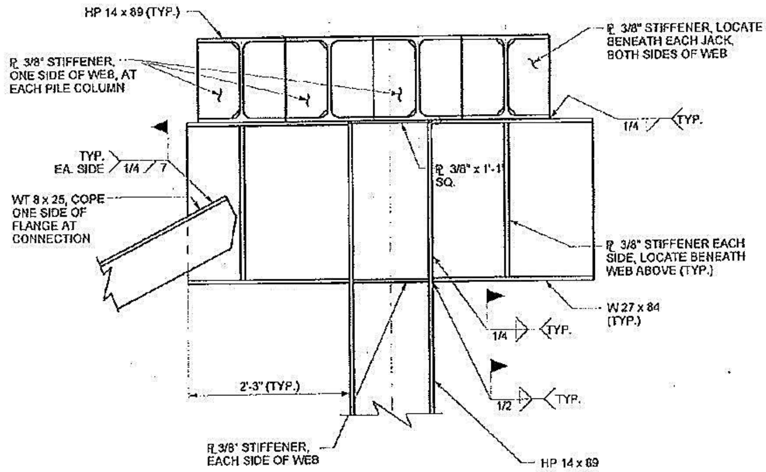


Figure B-30. End view of the I-80 over 2300 East temporary substructure for the EB bridge

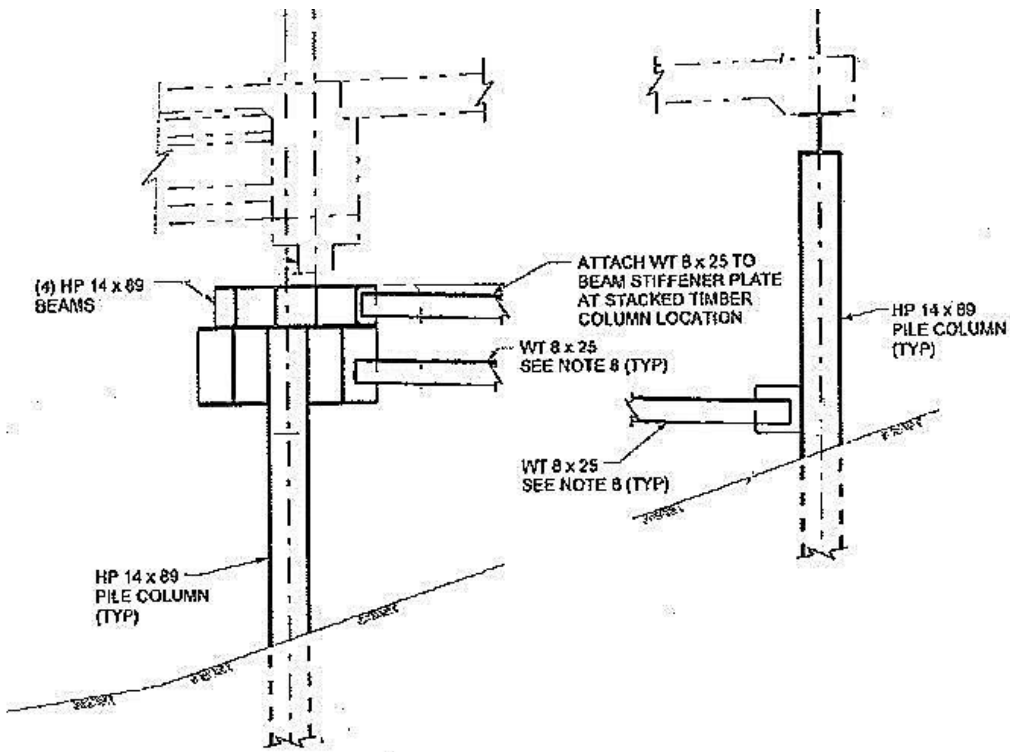


Figure B-31. End view of the I-80 over 2300 East, EB bridge temporary substructure at the abutment and the end of approach with lateral bracing

APPENDIX C

SPMT MOVE-SPECIFIC COSTS ANALYSIS DATA

SPMT-Mobilization Cost Analysis Data

Super-structure type	One span length (ft)	Width (ft)	Th. of slab (ft)	Depth of girders (ft)	Total shoulder /sidewalk width (ft)	No. of spans per move	Total load per span (kips)	Load per sq. ft area (kip/ft^2)	Th. of slab req. to add up to 9 in. (0.75 ft)	Total load per span w/ 9in. th. normal wt. conc. slab (kips)	Load per sq. ft area w/ 9in. slab (kip/ft^2)	No. of SPMT axle lines per span	Statistically estimated no. of axle lines per span
Steel girders w/ CIP deck (Louisiana)	85	30.5	0.63	3	4	1	430	0.166	0.12	477	0.184	12	16
Steel girders w/ CIP deck (MassDOT-Ceder St.)	41.54	53.33	0.67	2.17	11	2	530	0.239	0.08	557	0.251	12	18
Steel girders w/ CIP deck (MassDOT-Phillipston)	60.67	50.67	0.67	2.1	16	1	490	0.159	0.08	527	0.171	24	18
Steel girders w/ light-weight CIP deck (UDOT-4500S over I-215)	172	82	0.75	4	28	1	3200	0.227	0.00	3611	0.256	64	68
Steel plate girders w/ light-weight CIP deck (UDOT-Sam White over I-15)	177	76.8	0.84	6.17	36	2	1910	0.141	-0.09	2166	0.159	48	50
Florida bulb-tee girders w/ CIP deck (Florida-Graves Ave.)	143	59	0.67	6.5	30	1	2600	0.308	0.08	2701	0.320	48	58
WashingtonState bulb-tee girders w/ CIP deck (UDOT-Pioneer crossing over I-15)	191	69	0.71	7.88	18.5	1	4600	0.349	0.04	4679	0.355	80	78
WisDOT wide-flange PCI girders w/ CIP deck, parapets, and sidewalks (WisDOT-Rawson Ave.)	98.5	138.17	0.84	3.75	11	1	3090	0.227	-0.09	2906	0.214	72	60

				t-distribution	
Superstructure Type	**Representative Value (kip/ft^2)**	**No. of Samples**	**Standard Deviation**	**95% CI LL**	**95% CI UL**
Steel Girders w/ 9 in. normal weight concrete deck	0.195	5	0.046	0.138	0.252
Prestressed Concrete Girders w/ 9 in. normal weight concrete deck	0.279	3	0.074	0.161	0.397

Analysis for 1 Span					
Total load (kips)	No. of SPMT axle lines	Estimated no. of SPMT axle lines (linear eq.)	Estimated no. of SPMT axle lines (2 deg. polynomial eq.)	Estimated no. of SPMT axle lines (3 deg. polynomial eq.)	Estimated no. of SPMT axle lines (4 deg. polynomial eq.)
430	12	10	12	14	16
490	24	10	14	16	18
530	12	12	16	18	18
1910	48	40	48	46	42
2600	48	52	62	56	50
3090	72	62	70	62	54
3200	64	64	72	64	54
4600	80	92	90	78	42

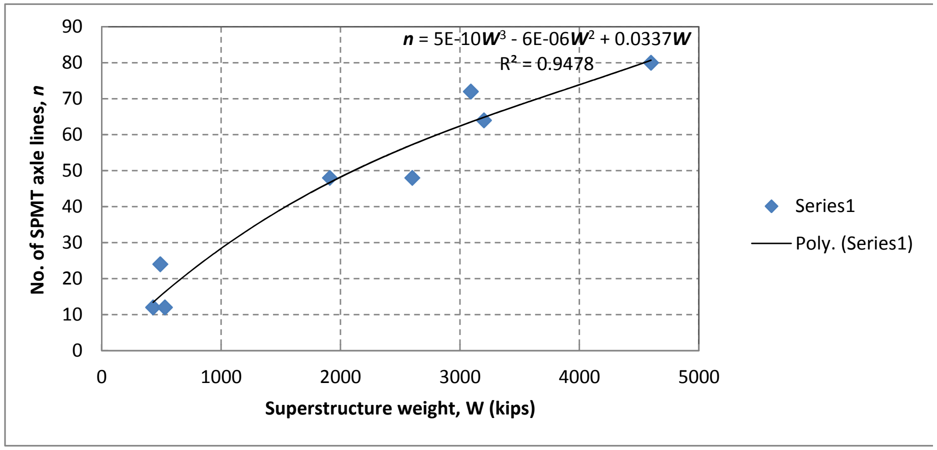
y = 0.0199x	y = -2E-06x2 + 0.0286x	y = 5E-10x3 - 6E-06x2 + 0.0337x	y = -7E-13x4 + 6E-09x3 - 2E-05x2 + 0.0423x

R^2=	R^2=	R^2=	R^2=
0.884	0.9446	0.9478	0.9529

Mean=
45

Mean=	**Mean=**	**Mean=**	**Mean=**
#DIV/0!	48	44.25	36.75

	P-value=	**P-value=**	**P-value=**	**P-value=**
Paired t-test	0.469	0.303	0.743	0.149
ANOVA test	0.877	0.837	0.954	0.4699



t-Test: Paired Two Sample for Means   3rd Degree Polynomial Equation

	Variable 1	*Variable 2*
Mean	45	44.25
Variance	707.4285714	626.7857143
Observations	8	8
Pearson Correlation	0.972708325	
Hypothesized Mean Difference	0	
df	7	
t Stat	0.340620169	
P(T<=t) one-tail	0.371691795	
t Critical one-tail	1.894578605	
P(T<=t) two-tail	0.74338359	
t Critical two-tail	2.364624252	

Anova: Single Factor   3rd Degree Polynomial Equation

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	360	45	707.4286
Column 2	8	354	44.25	626.7857

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.25	1	2.25	0.003373	0.954509	4.60011
Within Groups	9339.5	14	667.1071			
Total	9341.75	15				

SPMT-Travel Path Preparation Cost Analysis Data

	Wt. per axle line (kips)	Wt. per power pack (kips)	Wt. of 6 axle lines (kips)	Wt. of SPMT with 6 axle lines (kips)	Area under 6 axle lines (ft^2)	Normalized wt. for 1 axle line (kips)	Normalized area under 1 axle line (ft^2)	Capacity per axle line (kips)	Max. pressure applied by 1 axle line (k/ft^2)
Sarens	8.82	13.67	52.92	66.59	219.65	11.10	36.61	79.37	2.17
Sterling	8.82	16.53	52.92	69.45	219.65	11.58	36.61	88.18	2.41
Mammoet Scheuerle 2nd Gen	8.82	14.77	52.92	67.69	219.65	11.28	36.61	70.55	1.93
Mammoet Scheuerle 3rd Gen	8.82	14.77	52.92	67.69	219.65	11.28	36.61	79.37	2.17
Mammoet Scheuerle 4rth Gen	9.70	26.46	58.20	84.66	219.65	14.11	36.61	96.12	2.63
Mammoet Kamag 2nd Gen	9.70	14.77	58.20	72.97	219.65	12.16	36.61	65.27	1.78
Misc. 1	8.82	14.77	52.92	67.69	219.65	11.28	36.61	55.12	1.51
Misc. 2	9.56	14.77	57.33	72.10	219.65	12.02	36.61	66.14	1.81
Misc. 3	8.82	14.77	52.92	67.69	219.65	11.28	36.61	74.96	2.05

Allowable or Factored bearing pressure (k/ft^2)	Ordinal capacity	Prepared base th. (in.) for SPMT capacity <=56 kips per axle	Prepared base th. (in.) for SPMT capacity <=56 kips per axle	Prepared base th. (in.) for SPMT capacity >56 & <=74 kips per axle	Prepared base th. (in.) for SPMT capacity >56 & <=74 kips per axle	Prepared base th. (in.) for SPMT capacity >74 kips per axle	Prepared base th. (in.) for SPMT capacity >74 kips per axle
>8	1	0 – 1.6	0.8	0 – 2.3	1.15	0 – 2.9	1.45
>6 to <=8	2	1.7 – 2.4	2.05	2.4 – 3.5	2.95	3.0 – 3.9	3.45
>4 to <=6	3	2.5 – 4.3	3.4	3.6 – 5.1	4.35	4.0 – 7.1	5.55
>2 to <=4	4	4.4 – 11.0	7.7	5.2 – 13.0	9.1	7.2 – 15.4	11.3
<=2	5	11.1 – 21.3	16.2	13.1 – 21.3	17.2	15.5 – 21.3	18.4

Significance category	Allowable bearing pressure (k/ft^2)	Normalized base thickness required (in.)	Minimum base thickness (in.)
I	>8	1.13	1.25
II	>6 to <=8	2.82	3.00
III	>4 to <=6	4.43	4.50
IV	>2 to <=4	9.37	9.50
V	<=2	17.27	17.50

SPMT-Staging Area Preparation Cost Analysis Data

Super-structure type	Year	One span length (ft)	Width (ft)	Th. of slab (ft)	Depth of girders (ft)	Total shoulder /sidewalk width (ft)	No. of spans per move	Total weight per span (kips)	Total no. of spans moved	Total superstructure area (sq. ft)	Staging area size (sq. ft)	RATIO	Staging area prepartion cost	Staging area prep 2014 $ value	$ per sq. ft of staging area
Florida bulb-tee girders w/ CIP deck (Florida I-4/Graves Ave.)	2006	143	59	0.67	6.5	30	1	2600	2	16874	59004	3.50	$ 47,991	$ 55,000	$ 0.93
Steel girders w/ CIP deck (Louisiana I-20/Well Road)	2011	85	30.5	0.63	3	4	1	430	4	10370	18923	1.82	$ 25,000	$ 26,000	$ 1.37
Steel girders w/ CIP deck (MassDOT-Ceder Street-Wellesley)	2011	41.54	53.33	0.67	2.17	11	2	530	2	4431	6646	1.50	$ 10,000	$ 10,400	$ 1.56
Steel girders w/ CIP deck (MassDOT-Phillipston)	2010	60.67	50.67	0.67	2.1	16	1	490	1	3074	6148	2.00	$ 18,000	$ 19,000	$ 3.09
MN45" Prestressed Concrete I-Beam w/ CIP deck (Minnesota - I-35E / Maryland Ave)	2012	102.75	114	0.75	3.75	40.33	1	2646	2	23427	33264	1.42	$ 80,499	$ 82,800	$ 2.49
Steel girders w/ light-weight CIP deck (UDOT-4500S over I-215)	2007	172	82	0.75	4	28	1	3200	1	14104	21156	1.50	$ 51,198	$ 57,000	$ 2.69
WashingtonState bulb-tee girders w/ CIP deck (UDOT- WB Pioneer crossing over I-15)	2010	191	69	0.71	7.88	18.5	1	4600	2	26358	39537	1.50			$ -
Steel plate girders w/ light-weight CIP deck (UDOT-Sam White over I-15)	2011	177	76.8	0.84	6.17	36	2	1910	2	27187	40781	1.50			$ -
WisDOT wide-flange PCI girders w/ CIP deck, parapets, and sidewalks (WisDOT-Rawson Ave.)	2013	98.5	138.17	0.84	3.75	11	1	3090	2	27219	40829	1.50			$ -
												1.80 Preparing Staging Area Factor			**$ 2.24** Preparing Staging Area Unit Cost

SPMT-Temporary Structures Cost Analysis Data

Super-structure type	Year	One span length (ft)	Width (ft)	Th. of slab (ft)	Depth of girders (ft)	Total shoulder /sidewalk width (ft)	No. of spans per move	Total weight per span (kips)	Total no. of spans moved	Total superstructure area (sq. ft)	Type of temporary supports for SPMT	Temporary supports cost	Temp. supports cost per 1 kip per span [2014 $]		Representative unit cost for temporary structure per 1 kip span weight [2014 $]
Florida bulb-tee girders w/ CIP deck (Florida I-4/Graves Ave.)	2006	143	59	0.67	6.5	30	1	2600	2	16874	Temp. steel beams on ground. The superstructure was lifted using climbing jacks onto steel containers before moving.	$ 46,000	$ 10.13	**Temp Steel Beams on Ground**	**$ 10**
Steel girders w/ CIP deck (Louisiana I-20/Well Road)	2011	85	30.5	0.63	3	4	1	430	4	10370	Temp. shorings were used. The superstructure was built lower than final elevation. Climbing jacks on SPMTs were used for lifting to final elevation before moving. Paved road was available for travel path.	$ 108,885	$ 63	**Temporary shorings**	**$ 59**
Steel girders w/ CIP deck (MassDOT-Ceder Street-Wellesley)	2011	41.54	53.33	0.67	2.17	11	2	530	2	4431	Temp. shorings were used. The superstructure was built at the final elevation. Paved road was available for travel path.	$ 46,522	$ 87.78		
Steel girders w/ CIP deck (MassDOT-Phillipston)	2010	60.67	50.67	0.67	2.1	16	1	490	1	3074	New superstructure was built alongside the existing structure and then rolled using SPMTs. Temp. shorings were used. The superstructure was built at the final elevation. Embankment fill and steel plates were used for the travel path.	$ 32,279	$ 65.87	**Shipping containers**	**$ 5**
MN45" Prestressed Concrete I-Beam w/ CIP deck (Minnesota - I-35E / Maryland Ave)	2012	102.75	114	0.75	3.75	40.33	1	2646	2	23427	8.5 ft × 7.5 ft × 20 ft shipping containers (214.3 kips ultimate capacity) on timber mats to support the superstructure at the staging area.	$ 26,100	$ 5.06		
Steel girders w/ light-weight CIP deck (UDOT-4500S over I-215)	2007	172	82	0.75	4	28	1	3200	1	14104	Temp. driven H-piles were used. The superstructure was built at the final elevation.	$ 166,400	$ 52		
WashingtonState bulb-tee girders w/ CIP deck (UDOT- WB Pioneer crossing over I-15)	2010	191	69	0.71	7.88	18.5	1	4600	2	26358	Temp. driven H-piles were used. The superstructure was built at the final elevation.	$ 478,400	$ 52		
Steel plate girders w/ light-weight CIP deck (UDOT-Sam White over I-15)	2011	177	76.8	0.84	6.17	36	2	1910	2	27187	Temp. driven H-piles were used. The superstructure was built at the final elevation.	$ 99,320	$ 52		
WisDOT wide-flange PCI girders w/ CIP deck, parapets, and sidewalks (WisDOT-Rawson Ave.)	2013	98.5	138.17	0.84	3.75	11	1	3090	2	27219	Temp. shorings were used. The superstructure was built at the final elevation.	$ 285,805	$ 46		

SPMT-Specialty Equipment/Contractor Cost Analysis Data

Super-structure type	Year	One span length (ft)	Width (ft)	Th. of slab (ft)	Depth of girders (ft)	Total shoulder /sidewalk width (ft)	No. of spans per move	Total weight per span (kips)	Total no. of spans moved	Total superstructure area (sq. ft)	Specialty contractor cost	Specialty contractor 2014 $ value	$ per sq. ft. of superstructure	Superstructure cost	Total project cost
Florida bulb-tee girders w/ CIP deck (Florida I-4/Graves Ave.)	2006	143	59	0.67	6.5	30	1	2600	2	16874	$ 345,000	$ 395,000	$ 23.41	$ 482,000	$ 4,022,788
Steel girders w/ CIP deck (Louisiana I-20/Well Road)	2011	85	30.5	0.63	3	4	1	430	4	10370	$ 372,000	$ 386,000	$ 37.22		$ 3,174,512
Steel girders w/ CIP deck (MassDOT-Ceder Street-Wellesley)	2011	41.54	53.33	0.67	2.17	11	2	530	2	4431	$ 338,000	$ 351,000	$ 79.22	$ 1,157,000	$ 3,450,000
Steel girders w/ CIP deck (MassDOT-Phillipston)	2010	60.67	50.67	0.67	2.1	16	1	490	1	3074	$ 360,500	$ 381,000	$ 123.94	$ 300,000	$ 3,143,500
MN45" Prestressed Concrete I-Beam w/ CIP deck (Minnesota - I-35E / Maryland Ave)	2012	102.75	114	0.75	3.75	40.33	1	2646	2	23427			$ -		$ 4,034,052
Steel girders w/ light-weight CIP deck (UDOT-4500S over I-215)	2007	172	82	0.75	4	28	1	3200	1	14104	$ 868,121	$ 967,000	$ 68.56		$ 3,506,597
WashingtonState bulb-tee girders w/ CIP deck (UDOT- WB Pioneer crossing over I-15)	2010	191	69	0.71	7.88	18.5	1	4600	2	26358			$ -		$ 4,169,697
Steel plate girders w/ light-weight CIP deck (UDOT-Sam White over I-15)	2011	177	76.8	0.84	6.17	36	2	1910	2	27187			$ -		$ 3,185,360
WisDOT wide-flange PCI girders w/ CIP deck, parapets, and sidewalks (WisDOT-Rawson Ave.)	2013	98.5	138.17	0.84	3.75	11	1	3090	2	27219			$ -		$ 4,200,000

$ 67
SPMT Specialty Contractor Unit Cost

APPENDIX D

SIBC-SPECIFIC COSTS ANALYSIS DATA

SIBC-Specific Costs Analysis Data

No.	Project and State	Year	Methodology	Slide Technology	Superstructure Type	No. of Spans	Length (ft)	Width (ft)	Th. of Slab (ft)	Depth of Girders (ft)
1	Oak Creek Bridge, Coconino County, Arizona	1992	Diverting traffic on new structure for substructure construction and demolition	Lateral slide (26.33 ft) using bearings coated with Teflon	Post-tensioned two-cell box girder	1	190	41.17	0.75	Vary from 8.5 at mid-span to 16 at ends
2	I-10 Escambia Bay - Repair, Escambia County, Florida	2004	Existing spans were lifted off the east bound bridge and placed on missing sections on westbound bridge. 58 temporary metal deck spans were used on eastbound bridge later.	Slide using conventional modular transporters and ringer crane		63 spans reconstructed	3400			
3	Carquinez Strait Bridge, San Francisco Bay system, California	2003	The 24 superstructure units (10-ft-deep and 95-ft-wide orthotropic box girder units) were fabricated in Japan, shipped to the site, erected with strand jacks and skids, and welded together.	Erected with strand jacks and Skids	Steel orthotropic box girder suspension bridge. Total length = 3465 ft (482ft - 2389ft - 594ft)	3	79 to 163 ft length units	95	0.052	10
4	Hardscrabble Creek, Del Norte County, California	2008	Diverting traffic on new structure for abutment construction and demolition. Drilled pile foundation was changed to spread footing to speed up construction	Jacked up and laterally slid (48 ft) in 8 hrs	Prestressed multi-cell box girder	1	133.5	43		
5	Milton-Madison Bridge, Indiana	2013	Diverting traffic from existing structure to new 4-spans using temporary approach ramps	Lateral slide of four middle spans. Total length of 11 spans = 3200 ft	Steel through-truss bridge	11 (4 spans slide)	2430	40	0.667	
6	Massena Lateral Bridge Slide, Iowa	2014	Closed the roadway completely for demolishing existing bridge and installing precast substructure	Lateral slide using Hilman Rollers	Prestressed concrete-I girders	1	120	44	0.729	3.75
7	I-44 over Gasconade River, Missouri	2011	Two bridges were present, the traffic was diverted to eastbound bridge while the westbound bridge was demolished, substructure repaired, and slided	Bridge was supported on sliding bearings to eliminate the need for bearing transitions. Lateral slide of 45 ft	Steel plate girders w/ composite concrete deck	6	670	36.67	0.708	3.5 ft in end spans, 6 ft in middle span
8	Depot Street Bridge, Oregon	2006	The contractor built the tied arch span on temporary supports approximately 25 ft from the existing bridge and built the new abutments and pier under the existing bridge while maintaining traffic. The traffic was then temporarily re-routed onto the new bridge. The existing bridge was demolished and the substructure for the new bridge was finished.	Lateral slide of main span (306 ft)	Concrete tied arch main span. Prestressed concrete girders side span (addtl. 104 ft side span)	2 (1 Main span)	306	76		
9	Elk Creek Crossing 3 Bridge, Oregon	2008	Construct a new substructure for the replacement bridge under the existing bridge. Construct a temporary substructures on both sides of existing bridge (for new and existing structures)	Old superstructure was lifted and slid laterally onto temporary supports, and the replacement bridge was slid laterally onto the original alignment	Steel I-beams w/ CIP deck	3	320	38.2	0.896	7.5
10	Imnaha Bridge over Little Sheep Creek, Oregon	1997	The new right half of the bridge was constructed slightly offset from the existing bridge while the existing bridge remained open to one lane of traffic. The one lane of traffic was diverted to the new half of the bridge. The existing bridge was demolished and the left half of the new bridge was built on the original alignment.	Traffic was diverted to the left half of the bridge and the right half was skid laterally to connect with the new left half of the bridge using hydraulic jacks.	Grade 50W steel curved girders	1	110	30	0.354 ft concrete filled steel grid deck	4.75
11	OR 213 Jughandle Bridge over Washington St, Oregon	2012	New bridge was built on temporary foundations next to existing OR 213, then the traffic was diverted onto it to construct new permanent foundations on existing alignment. Temporary lane closures occurred on the new bridge between 8:00 pm and 5:00 am during night time.	Lateral slide of the new bridge. A test bridge slide was performed prior to final slide of the bridge.	Steel plate girder bridge	1	130	140	0.833	4.58
12	SC 703 Ben Sawyer Bridge, South Carolina	2010	The approach spans were conventionally built on temporary flasework adjacent to existing bridge on the south side while traffic was maintained. The existing approach spans were transversely shifted onto temporary supports adjacent to the existing bridge piers. The six new approach spans on each end were simultaneously pulled onto the existing piers. Center swing span = 247 ft through truss of 640 ton	30 ft transverse pull along horizontal tracks using post-tensioning jacks with jack stroke limited to 3 in. per pull. Total length = 1154ft. Lateral slide of both old and new approach spans (6 continuous spans as one unit at each end).	Steel plate girders w/ lightweight conc. Deck	13 (6+6 spans slide-in)	904	36.5	0.667	5.75
13	I-80 over 2300 East Bridge, Salt Lake City, Utah	2009	Substructures that act as permanent slide guides for the new spans were built low enough underneath the existing bridges, while traffic was maintained. A steep grade combined with ramp access to I-15 on the north side of the westbound bridge necessitated to build the new westbound span 5 ft higher in elevation. The new westbound span was jacked down from its elevated position before being slid into place.	New spans were slid off the temporary abutments onto the new abutments. A partial slide was performed on Friday night of ABC weekend, which reduced the three lanes down to two lanes all day on Saturday. This enabled the contractor to shorten the Saturday night closure.	AASHTO Type II prestressed girders at 7.08 ft spacing, w/ CIP lightweight concrete deck	1	80	62.83	0.667	3
14	Layton Parkway over I-15, Davis County, Utah	2010	Poor soil conditions at the project site required that 13 ft of surcharge be placed to expedite settlement of new embankments. The temporary supports for the spans were built high because of the surcharge behind the abutments. Once settlement had occurred and the surcharge was removed, each span was lowered to finished grade using self-climbing jacks and onto a skid beam at the rear end and sliding pads placed on top of slide shoe at forward end.	Longitudinal launch	Steel girder bridge w/ CIP lightweight concrete deck	2	214.8	134.3	0.75	
15	Hood Canal East Approach Bridge, Washington	2005	While traffic was maintained on the existing bridge, the replacement substructures were built underneath the bridge, clear of existing piers. Work trestles and temporary supports were then built underneath and beside the existing bridge. The existing deck was cut at both ends, and jacks were placed under the spans. The old spans were jacked up onto rollers and rolled onto temporary false work.	The new spans were built on the temporary supports and multiple synchronized jacks lifted them onto rollers for rolling into place.	Prestressed (W74G) bulb-tee girder	5	605	40	0.625	6.167
16	Northeast 8th Street Bridge, Washington	2003	The south half of new bridge was constructed on temporary piers south of the old bridge. The three eastbound traffic lanes were shifted onto the new portion while the north half of old bridge was removed and rebuilt conventionally. Next, the three westbound traffic lanes were shifted onto the new north half, and the old south portion was demolished and substructures constructed for the south half.	Lateral roll-in of half-width of the bridge. The new south half of the bridge was jacked off its temporary piers and rolled 64 ft north to its permanent location in about 12 hours.	Steel I-girders (11) spaced at 11.25 ft w/ CIP deck	2	328	60.75	0.75	5

SIBC-Specific Costs Analysis Data (Cont'd)

No.	Project and State	Slide-In Deck Area (ft^2)	Total Load	Total Load per Span	Temporary Structure Cost ($)	Mobilization cost ($)	Bridge Slide Cost (incl. Temp. Str.) ($)	Total Project Cost ($)	Year	2014 Value of Temporary Structure Cost ($)	2014 Value of Bridge Slide Cost (incl. Temp. Str.) ($)	2014 Value of Slide Operation Cost (excl. Temp. Str.) ($)
			(ton)	(kips)			[Selected Bid Cost]					
1	Oak Creek Bridge, Coconino County, Arizona	7822	1233	2467	$86,828	$101,299	$198,430	$1,157,700	1992	$131,000	$299,000	$168,000
2	I-10 Escambia Bay - Repair, Escambia County, Florida								2004			
3	Carquinez Strait Bridge, San Francisco Bay system, California	7505 to 15485 sq ft.	570 to 880	1140 to 1760	$14,085,000	$16,432,500	$32,188,920	$187,800,000	2003	$17,300,000	$39,500,000	$22,200,000
4	Hardscrabble Creek, Del Norte County, California	5741	900	1800	$7,793,995	$9,092,994	$17,811,876	$103,919,927	2008	$8,370,000	$19,100,000	$10,730,000
5	Milton-Madison Bridge, Indiana	97200	15260	30520	$7,775,237	$9,071,110	$17,769,009	$103,669,833	2013	$7,780,000	$17,800,000	$10,020,000
6	Massena Lateral Bridge Slide, Iowa	5280	721	1442	$76,540	$100,000	$172,000	$1,346,648	2014	$76,540	$172,000	$95,460
7	I-44 over Gasconade River, Missouri	24569	2050	4100	$1,094,272	$941,583	$2,544,819	$13,960,359	2011	$1,130,000	$2,630,000	$1,500,000
8	Depot Street Bridge, Oregon	23256	6000	12000	$502,330	$586,051	$1,147,991	$6,697,728	2006	$565,000	$1,290,000	$725,000
9	Elk Creek Crossing 3 Bridge, Oregon	12224	1423	2845	$922,500	$1,076,250	$2,108,220	$12,300,000	2008	$991,000	$2,270,000	$1,279,000
10	Imnaha Bridge over Little Sheep Creek, Oregon	3300							1997			
11	OR 213 Jughandle Bridge over Washington St, Oregon	18200	800	1600	$1,528,800	$1,750,000	$3,640,000	$17,570,000	2012	$1,550,000	$3,690,000	$2,140,000
12	SC 703 Ben Sawyer Bridge, South Carolina	32996	2256	4512	$2,437,500	$2,843,750	$5,570,500	$32,500,000	2010	$2,570,000	$5,870,000	$3,300,000
13	I-80 over 2300 East Bridge, Salt Lake City, Utah	5026	650	1300	$450,000	$437,500	$1,000,000	$5,000,000	2009	$480,000	$1,070,000	$590,000
14	Layton Parkway over I-15, Davis County, Utah	28848	2100	4200	$585,000	$585,000	$1,300,000	$9,300,000	2010	$616,000	$1,370,000	$754,000
15	Hood Canal East Approach Bridge, Washington	24200	3800	7600	$1,100,000	$19,829,477	$2,080,000	$204,000,000	2005	$1,270,000	$2,410,000	$1,140,000
16	Northeast 8th Street Bridge, Washington	19926	2200	4400	$324,894	$1,275,000	$5,190,000	$12,779,599	2003	$399,000	$6,380,000	$5,981,000

SIBC-Specific Costs Analysis Data (Cont'd)

No.	Project and State	Temporary Structure Cost Percentage of Bridge Slide Cost	Temporary Structure Cost Percentage of Total Cost	Mobilization Cost Percentage of Total Cost	Bridge Slide Cost (incl. Temp. Str.) Percentage of Total Cost	Temporary Structure Cost per 1 kip per Span	Slide Operation Cost per 1 kip per Span
						($)	($)
1	Oak Creek Bridge, Coconino County, Arizona		7.5	8.8	17.1	$53.11	$68.11
2	I-10 Escambia Bay - Repair, Escambia County, Florida						
3	Carquinez Strait Bridge, San Francisco Bay system, California		7.5	8.8	17.1	$3,977	$5,103
4	Hardscrabble Creek, Del Norte County, California		7.5	8.8	17.1	$4,650	$5,961
5	Milton-Madison Bridge, Indiana		7.5	8.8	17.1	$63.73	$82.08
6	Massena Lateral Bridge Slide, Iowa	44.5	5.7	7.4	12.8	$53.08	$66.20
7	I-44 over Gasconade River, Missouri	43.0	7.8	6.7	18.2	$45.93	$60.98
8	Depot Street Bridge, Oregon		7.5	8.8	17.1	$47.08	$60.42
9	Elk Creek Crossing 3 Bridge, Oregon		7.5	8.8	17.1	$116.11	$149.85
10	Imnaha Bridge over Little Sheep Creek, Oregon						
11	OR 213 Jughandle Bridge over Washington St, Oregon	42.0	8.7	10.0	20.7	$968.75	$1,337.50
12	SC 703 Ben Sawyer Bridge, South Carolina		7.5	8.8	17.1	$47.47	$60.95
13	I-80 over 2300 East Bridge, Salt Lake City, Utah	45.0	9.0	8.8	20.0	$369.23	$453.85
14	Layton Parkway over I-15, Davis County, Utah	45.0	6.3	6.3	14.0	$73.33	$89.76
15	Hood Canal East Approach Bridge, Washington	52.9	0.5	9.7	1.0	$33.42	$30.00
16	Northeast 8th Street Bridge, Washington	6.26	2.5	10.0	40.6	$45.34	$679.66

SIBC-Specific Costs Analysis Data (Cont'd)

	Representative temporary structure cost per 1 kip per span (i.e., per two supports) [2014 dollar]	Representative equipment and accessories and preparing and operating cost per 1 kip per span (i.e., Slide Operation Cost) [2014 dollar]
B. Bridge slide with diverting traffic on new structure while old bridge is demolished	**$52**	**$70**
C. Bridge slide with complete closure of roadway, i.e., without traffic diversion	**$50**	**$64**
A. Bridge slide with sliding of both old and new structures	**$66**	**$80**

APPENDIX E

FOUNDATION TYPES COST ESTIMATES

Foundation Types Cost Estimates Analysis Data

ID	Foundation type	Displacement Type	Project Name (s)	Substructure construction time (i.e., before or after demolition) and details	Year	Tier
1	**Spread Footing**	N/A	LA 3249 (Well Road) Bridge, Louisiana (2011)	Constructed before bridge closure and demolition. Existing substructure was strengthened by adding spread footings between existing pile footings. Abutment extensions were added on columns/drilled shafts at the ends of existing abutments.	2011	2
			Vista Interchange Bridge, Idaho (2010)	The new bridge was wider than the old bridge. First half of the new bridge including the substructure was built adjacent to existing bridge. The traffic was diverted onto the new bridge, the old bridge demolished and the second half of the bridge was built including the substructure.	2010	5
			Hardscrabble Creek Bridge, California (2008)	New bridge was built conventionally on temporary supports next to existing bridge. The traffic was diverted onto the new bridge while the old bridge was demolished and abutments constructed. Drilled pile foundation was changed to spread footing for abutments to accelerate the construction.	2008	1
			I-215 / 4500 South Bridge, Utah (2007)	The replacement abutments were built below the existing bridge (4500 South) while maintaining traffic on both 4500 South (facility carried) and I-215 (feature intersected). The abutments were built on CIP spread footing foundation with full height CIP wing walls.	2007	2
			I-40 Bridges, California (2006)		2006	4
			Hilltop Drive Overcrossing, California (2006)		2006	5
			Mill Street Bridge, New Hampshire (2004)		2004	3
			I-405 / Northeast 8th Street Bridge, Washington (2003)	South half of the new bridge was constructed on temporary piers on the south-side of the old bridge. Three lanes were diverted onto the new portion and other three lanes remained on south-half of the old bridge. The north half of old bridge was demolished and rebuilt conventionally. Three traffic lanes were then diverted onto the new north half of the bridge and the old south portion was demolished and substructures were constructed.	2003	1
			Keaiwa Stream Bridge, Hawaii (2001)		2001	5
			I-5 / South 38th Street Bridge, Washington (2001)		2001	5
2	**H-Pile**	Low	TH 53 Bridge over Paleface River, Minnesota (2012)		2012	4

2	**H-Pile**	Low	Route 202 Bridge over Passaic River, New Jersey (2012)	Traffic was maintained on the bridge with single lane traffic closures during nights to drive steel H-piles. The piles were cut just below the roadway and the roadway was patched with asphalt prior to opening the bridge in the mornings.	2012	3
			US 6 over Keg Creek Bridge, Iowa (2011)	Before demolishing the existing bridge, concrete drilled shafts were constructed outside the bridge footprint at the two interior support locations. After demolishong the existing bridge, abutment steel H-piles were driven and precast abutment stem and wingwalls were assembled.	2011	3
			Little Cedar Creek Bridge, Iowa (2011)		2011	4
			UPRR Bridge, Kansas(2011)		2011	1
			Buffalo Creek Bridge, South Dakota (2011)		2011	5
			US 17 Bridge over Tar River, North Carolina (2010)		2010	5
			41st Street Bridge, South Dakota (2010)		2010	5
			Kickapoo Bridge, Mississippi (2010)		2010	4
			640th Street over Branch Racoon River Bridge, Iowa (2009)		2009	3
			Inyan Kara Creek Bridge, Wyoming (2009)		2009	4
			Kia Blvd Bridge, Georgia (2008)		2008	5
			Jakway Park Bridge, Iowa (2008)		2008	4
			MD 28 over Washington Run Creek Bridge, Maryland (2008)		2008	4
			Parkview Avenue Bridge, Michigan (2008)		2008	4
			Riverdale Road Bridge over I-84, Utah (2008)		2008	1
			Madison Co. Bridge, Iowa (2007)		2007	5
			Grayling Creek Bridge, Alaska* (2006)		2006	4
			Mackey Bridge, Iowa (2006) (abutment)		2006	5

			O'Malley Bridge, Alaska* (2005) (abutment)		2005	4
			SH 66 over Mitchell Gulch, Colorado (2002)		2002	2
			Kouwegok Slough Bridge, Alaska* (2000)		2000	4
3	**Open-Ended Pipe Pile**	Low	OR213 Bridge over Washington Street, Oregon (2012)	Permanent foundations for the new bridge were constructed on existing alignment while maintaining traffic on the old bridge during the day. Temporary lane closures occurred between 8 pm and 5 am.	2012	3
			Volmer and Johnson Creek Bridges, Oregon (2011)	Traffic was reduced to one-lane and the pipe piles and sheet pile walls were driven in the closed lanes. Afterwards, the roadway of those lanes was covered and the traffic was diverted on them. The process was repeated for the remaining half of the bridge.	2011	4
			MD 450 over Bacon Ridge Branch Bridge, Maryland (2008)		2008	4
			Kimberly Bridge, Oregon (2008)		2008	3
			Mackey Bridge, Iowa (2006) (pile caps)		2006	5
			O'Malley Bridge, Alaska* (2005) (pile caps)		2005	4
			U.S. Route 22 Bridge, Ohio (2003)		2003	4
			Pelican Creek Bridge, Alaska *(1992)		1992	4
4	**Pile Driven in Predrilled or Jetted Hole**	Low	I-15 / Layton Parkway Bridge, Utah (2010)	Constructed after demolition of existing bridge (Layton Parkway Bridge). The goal was to minimize construction impact on I-15 (feature intersected) traffic.	2010	1
			San Francisco Yerba Buena Island Viaduct, California (2007)	New support columns and foundations were built to the side of existing Viaduct (outside of existing footprint) while the Viaduct was in service.	2007	2
			Russian River Bridge, California (2006)		2006	4
			Boothbay Bridge, Maine (2011)	New bridge including the substructure was built parallel to existing structure while maintaining traffic on the existing structure.	2011	5

5	**Closed-Ended Pipe Pile**	High	I-15 / Sam White Lane Bridge, Utah (2011)	The new superstructure was built offsite from August 2010 to March 2011. In the meantime the old bridge was demolished and the abutments and interior support were constructed conventionally with concrete-filled pipe pile foundations.	2011	1
			MD Route 362 over Monie Creek Bridge, Maryland (2009)		2009	4
			Route 70 Bridge over Manasquan River, New Jersey (2008)		2008	5
			Belt Parkway Bridge, New York (2004)		2004	4
6	**Mandrel-Driven Shell Pile**	High	Craig Creek Bridge, California (2011)		2011	4
			Black Cat Road Bridge, Idaho (2009)		2009	5
7	**Precast Concrete Pile**	High	TH 61 Bridge over Gilbert Creek, Minnesota (2011)		2011	4
			NC 12 Bridge over Molasses Creek, North Carolina (2008)		2008	4
			Parker River Bridge, Massachusetts (2007)		2007	5
			Graves Avenue Bridge, Florida (2006)	Existing bridges were removed using SPMT in January 2006. Concurrent construction of the substructures onsite and superstructure in the staging area took place from January to June. I-4 (feature intersected) was widened and the abutments and interior bent were built conventionally onsite.	2006	1
			Beaufort and Morehead Railroad Trestle Bridge, North Carolina (1999)		1999	3
8	**Drilled Shaft**	None	South Punaluu Stream Bridge, Hawaii (2011)	The traffic was diverted onto a temporary prefabricated steel truss bridge adjacent to the site. The existing bridge was demolished and drilled shafts were constructed. Pier caps were cast over the drilled shafts with top surface of the caps confirming to roadway cross-slope.	2011	5
			North Kahana Stream Bridge, Hawaii (2010)		2010	5

			Willis Avenue Bridge over Harlem River, New York (2010)	The new bridge was built on a new alignment, adjacent to existing bridge. This was the final position of the bridge. The traffic remained open on the old bridge throughout the construction . [The river pier foundations were constructed by first drilling 4- and 5-ft-diameter shafts into bedrock. Precast concrete modular pier boxes (precast cap shells) were fabricated off site and barged to the site where they were lifted over the drilled shafts and suspended on temporary hanger supports. A sequence of phased load transfer allowed for sealing of the pier box to keep out seawater, removal of the upper part of the steel casings, and casting the concrete pier cap in the dry. These modular pier boxes are an integral part of the pier caps.]	2010	1
			Elk Creek Bridge, Oregon (2008)	The replacement superstructure was built adjacent to the existing bridge and laterally slid into position over a weekend. With traffic maintained on the existing bridge (1) a new substructure was constructed for the replacement bridge under the existing bridge (cast-in-place drilled shafts, columns, and caps); (2) a temporary substructure was constructed for the existing superstructure on one side of the existing bridge; (3) a temporary substructure was constructed for the replacement superstructure on the other side of the existing bridge.	2008	2
			SH 290 Bridge over Live Oak Creek, Texas (2008)	The project was a pilot project with limited traffic and constructed detour. No time constraints or special financial incentives were introduced. The traffic was detoured onto the planned detour route. Then, the existing bridge was demolished, drilled shafts constructed, and conventional concrete abutments and interior supports were constructed on the drilled shafts.	2008	5
			Hood Canal Bridge, Washington (2005)	While traffic was maintained on the existing bridge, the contractor built the replacement substructures underneath the bridge, clear of existing piers. Work trestles and temporary supports were then built underneath and beside the existing bridge.	2005	2
8	**Drilled Shaft**	None	State Highway 36, Texas (2003)		2003	5

			Carniquez Strait Bridge, California (2003)	The new bridge was constructed on a new alignment. The traffic remained open on the old bridge throughout the construction. The new superstructure units were each 79 to 163 ft in length. They could not be erected using a gantry mounted on the main cable because the adjacent bridge scheduled for demolition was only 40 to 60 ft from the new bridge. Some units were raised directly into their final locations and connected to their permanent suspenders. Some units in the main span were raised into a temporary position, then were transferred along the main cable by a series of trapeze-like swings to their final locations in the main span. The units in the side spans were raised onto temporary supports and jacked into position for final erection in the side spans.	2003	1
			Sauvie Island Bridge, Oregon (2007)	The new bridge was built on a new alignment adjacent to existing bridge. The contractor chose to assemble the steel span off site and barge into place. The existing bridge remained in service the entire time while the new bridge was being built adjacent to it. At the staging area the arch span was transferred from its temporary supports to SPMTs and driven onto barges. The barges transported the span to the site.	2007	1
9	**Micropile**	None	Biltmore Avenue Bridge, North Carolina (2010)	The new bridge was longer and wider than the existing bridge. The existing bridge was demolished and traffic was detoured with an off-site detour for 4 months. The contractor constructed the superstructure units at an adjacent staging area while the substructure was constructed. Foundations were constructed of micropiles and the abutments were constructed using cast-in-place concrete.	2010	5
			Linn Cove Viaduct, North Carolina (1983)		1983	5

Foundation Types Cost Estimates Analysis Data (Cont'd)

ID	Foundation type	Displacement Type	Project Name (s)	Project Description	Span length (ft)	Span Classification	Length (ft)	Widht (ft)	Area (sft)	Construction type
1	Spread Footing	N/A	LA 3249 (Well Road) Bridge, Louisiana (2011)	260-ft long and 30.5-ft wide four-span composite steel girder bridge	65.00	Short-to-medium	260.00	30.50	7,930.00	**SPMT**
			Vista Interchange Bridge, Idaho (2010)	182-ft-long and 197-ft-wide two-span prestressed I-beam bridge	91.00	Short-to-medium	182.00	197.00	35,854.00	PBES
			Hardscrabble Creek Bridge, California (2008)	133.5-ft-long and 43-ft-wide single-span prestressed multi-cell box girder bridge; 900-ton lateral slide	133.50	Medium	133.50	43.00	5,740.50	**Lateral Sliding**
			I-215 / 4500 South Bridge, Utah (2007)	172-ft long and 82-ft wide single-span bridge	172.00	Medium	172.00	82.00	14,104.00	**SPMT**
			I-40 Bridges, California (2006)	106-ft long (aprox.) and 42.88-ft wide single span bridges, precast bulb-T girders, precast abutment	106.00	Short-to-medium	106.00	42.88	4,545.28	PBES
			Hilltop Drive Overcrossing, California (2006)	95-ft long and 87-ft wide 2-Spans bridge, precast box girder, seat-type abutment	47.50	Short	95.00	87.00	8,265.00	PBES
			Mill Street Bridge, New Hampshire (2004)	115-ft long and 28-ft wide single-span adjacent box beam bridge	115.00	Short-to-medium	115.00	28.00	3,220.00	PBES
			I-405 / Northeast 8th Street Bridge, Washington (2003)	328-ft long and 121.5-ft wide two-span steel girder bridge	164.00	Medium	328.00	121.50	39,852.00	**Lateral Sliding**
			Keaiwa Stream Bridge, Hawaii (2001)	230-ft-long and 42.33-ft-wide seven-span prestressed concrete slab beam bridge	32.86	Short	230.00	42.33	9,735.90	PBES
			I-5 / South 38th Street Bridge, Washington (2001)	325-ft-long and 106-ft-wide two-span prestressed trapezoidal tub girder bridge	162.50	Medium	325.00	106.00	34,450.00	PBES
2	H-Pile	Low	TH 53 Bridge over Paleface River, Minnesota (2012)	75-ft-long and 45-ft-wide single-span prestressed I-beam bridge	75.00	Short-to-medium	75.00	45.00	3,375.00	PBES
			Route 202 Bridge over Passaic River, New Jersey (2012)	92-ft-long and 36-ft-wide single-span modular decked steel beam bridge	92.00	Short-to-medium	92.00	36.00	3,312.00	PBES
			US 6 over Keg Creek Bridge, Iowa (2011)	204.5-ft-long and 47.2-ft wide three-span bridge	68.17	Short-to-medium	204.50	47.20	9,652.40	PBES
			Little Cedar Creek Bridge, Iowa (2011)	60-ft long and 33.17-ft wide single-span prestressed I-beam bridge	60.00	Short-to-medium	60.00	33.17	1,990.20	PBES
			UPRR Bridge, Kansas(2011)	150-ft long and 18.5-ft wide five-span precast prestressed concrete box girder railroad bridge	30.00	Short	150.00	18.50	2,775.00	PBES
			Buffalo Creek Bridge, South Dakota (2011)	60-ft-long and 30.67-ft-wide single-span prestressed double tee beam bridge	60.00	Short-to-medium	60.00	30.67	1,840.20	PBES
			US 17 Bridge over Tar River, North Carolina (2010)	2.8-mile-long and 70-ft-wide (typical clear roadway width) 128-span prestressed bulb-tee girder bridge	115.50	Short-to-medium	14,784.00	70.00	1,034,880.00	PBES
			41st Street Bridge, South Dakota (2010)	305-ft-long and 112.33-ft wide three-span bridge	101.67	Short-to-medium	305.00	112.33	34,260.65	PBES
			Kickapoo Bridge, Mississippi (2010)	124-ft-long and 34.5-ft-wide four-span precast adjacent slab beam bridge	31.00	Short	124.00	34.50	4,278.00	PBES

2	**H-Pile**	Low	640th Street over Branch Racoon River Bridge, Iowa (2009)	50.83-ft-long and 28-ft-wide single-span precast adjacent box beam bridge	50.83	Short	50.83	28.00	1,423.24	PBES
			Inyan Kara Creek Bridge, Wyoming (2009)	85-ft long and 29.33-ft wide single-span prestressed deck bulb tee girder bridge	85.00	Short-to-medium	85.00	29.33	2,493.05	PBES
			Kia Blvd Bridge, Georgia (2008)	384-ft-long and 119.25-ft-wide four-span prestressed bulb tee girder bridge	96.00	Short-to-medium	384.00	119.25	45,792.00	PBES
			Jakway Park Bridge, Iowa (2008)	115.33-ft long and 24.75-ft wide three-span ultra-high-performance concrete (UHPC) pi-girder bridge	38.44	Short	115.33	24.75	2,854.42	PBES
			MD 28 over Washington Run Creek Bridge, Maryland (2008)	40-ft-long and 41-ft-wide single-span prestressed concrete slab beam bridge	40.00	Short	40.00	41.00	1,640.00	PBES
			Parkview Avenue Bridge, Michigan (2008)	249-ft-long and 55-ft wide, three-lane, four-span bridge	62.25	Short-to-medium	249.00	55.00	13,695.00	PBES
			Riverdale Road Bridge over I-84, Utah (2008)	155.5-ft-long and 170.83-ft-wide two-span steel plate-girder bridge	77.75	Short-to-medium	155.50	170.83	26,564.07	PBES
			Madison Co. Bridge, Iowa (2007)	46.67-ft long and 24.08-ft wide single-span adjacent box beam bridge	46.67	Short	46.67	24.08	1,123.81	PBES
			Grayling Creek Bridge, Alaska* (2006)	148-ft long and 27-ft wide single-span steel girder bridge	148.00	Medium	148.00	27.00	3,996.00	PBES
			Mackey Bridge, Iowa (2006) (abutment)	151.33-ft-long and 33.17-ft-wide three-span prestressed I-beam bridge	50.44	Short	151.33	33.17	5,019.62	PBES
			O'Malley Bridge, Alaska* (2005) (abutment)	223-ft long and 39-ft wide two-span prestressed decked bulb-tee girder bridge	111.50	Short-to-medium	223.00	39.00	8,697.00	PBES
			SH 66 over Mitchell Gulch, Colorado (2002)	40-ft-long and 43-ft-wide single-span prestressed concrete slab bridge	40.00	Short	40.00	43.00	1,720.00	PBES
			Kouwegok Slough Bridge, Alaska* (2000)	378-ft long and 25-ft wide three-span steel beam bridge	126.00	Short-to-medium	378.00	25.00	9,450.00	PBES
3	**Open-Ended Pipe Pile**	Low	OR213 Bridge over Washington Street, Oregon (2012)	130-ft-long and 140-ft-wide single-span steel plate-girder bridge	130.00	Medium	130.00	140.00	18,200.00	**Lateral Sliding**
			Volmer and Johnson Creek Bridges, Oregon (2011)	29-ft-long and 44-48 ft-wide single-span precast prestressed slab beam bridges	29.00	Short	29.00	48.00	1,392.00	PBES
			MD 450 over Bacon Ridge Branch Bridge, Maryland (2008)	58-ft-long and 44-ft-wide single-span prestressed concrete slab beam bridge	58.00	Short	58.00	44.00	2,552.00	PBES
			Kimberly Bridge, Oregon (2008)	Two 29-ft-wide prestressed slab beam approach span replacements	29.00	Short			-	PBES
			Mackey Bridge, Iowa (2006) (pile caps)	151.33-ft-long and 33.17-ft-wide three-span prestressed I-beam bridge	50.44	Short	151.33	33.17	5,019.62	PBES
			O'Malley Bridge, Alaska* (2005) (pile caps)	223-ft long and 39-ft wide two-span prestressed decked bulb-tee girder bridge	111.50	Short-to-medium	223.00	39.00	8,697.00	PBES
			U.S. Route 22 Bridge, Ohio (2003)	High performance steel girders and concrete deck, and a galvanized steel pier cap substructure bridge					-	PBES
			Pelican Creek Bridge, Alaska *(1992)	178-ft long and 19.08-ft wide three-span decked double-tee girder bridge	59.33	Short	178.00	19.08	3,396.24	PBES
			I-15 / Layton Parkway Bridge, Utah (2010)	217.8-ft long and 134.3-ft wide two-span steel girder bridge longitudinal launch	108.90	Short-to-medium	217.80	134.30	29,250.54	**Longitudinal Launching**

4	**Pile Driven in Predrilled or Jetted Hole**	Low	San Francisco Yerba Buena Island Viaduct, California (2007)	6-Spans bridge: 18.83 ft to 75.62 ft longitudinal, total width= 93.8ft transverse, CIP/PS box girder with transverse girders and large edge beams	75.62	Short-to-medium			-	**Lateral Sliding**
			Russian River Bridge, California (2006)	10-Spans: 8-spans @ 102 ft length, 2-spans @ 80 ft length total width= 49.15 ft, Non-standard double-T precast girders	102.00	Short-to-medium	976.00	49.15	47,970.40	PBES
5	**Closed-Ended Pipe Pile**	High	Boothbay Bridge, Maine (2011)	540-ft-long and 32-ft-wide eight-span continuous-for-live-load replacement bridge	67.50	Short-to-medium	540.00	32.00	17,280.00	PBES
			I-15 / Sam White Lane Bridge, Utah (2011)	354-ft long and 76.8-ft wide two-span continuous steel plate-girder bridge	177.00	Medium	354.00	76.80	27,187.20	**SPMT**
			MD Route 362 over Monie Creek Bridge, Maryland (2009)	55-ft-long and 45-ft-wide single-span prestressed concrete slab bridge	55.00	Short	55.00	45.00	2,475.00	PBES
			Route 70 Bridge over Manasquan River, New Jersey (2008)	724-ft-long and 94.67-ft-wide six-span prestressed bulb-tee girder twin bridges	120.67	Short-to-medium	724.00	94.67	68,541.08	PBES
			Belt Parkway Bridge, New York (2004)	3-span 221-ft long, 134-ft wide bridge, precast T-walls, precast post-tensioned cap beams, prefabricated superstructure segments	73.67	Short-to-medium	221.00	134.00	29,614.00	PBES
6	**Mandrel-Driven Shell Pile**	High	Craig Creek Bridge, California (2011)	108-ft long and 44-ft wide single-span precast adjacent box beam bridge	108.00	Short-to-medium	108.00	44.00	4,752.00	PBES
			Black Cat Road Bridge, Idaho (2009)	196-ft-long and 53.67-ft-wide two-span prestressed modified bulb tee beam bridge	98.00	Short-to-medium	196.00	53.67	10,519.32	PBES
7	**Precast Concrete Pile**	High	TH 61 Bridge over Gilbert Creek, Minnesota (2011)	123-ft-long and 76.66-ft-wide three-span Precast Composite Slab Span (PCSS) bridge	41.00	Short	123.00	76.66	9,429.18	PBES
			NC 12 Bridge over Molasses Creek, North Carolina (2008)	252-ft-long and 36-ft-wide five-span adjacent prestressed cored slab beam bridge	50.40	Short	252.00	36.00	9,072.00	PBES
			Parker River Bridge, Massachusetts (2007)	90-ft-long and 30-ft-wide three-span continuous-for-live-load precast slab beam bridge (30 ft – 30 ft – 30 ft)	30.00	Short	90.00	30.00	2,700.00	PBES
			Graves Avenue Bridge, Florida (2006)	286-ft-long and 59-ft-wide two-span full-width decked prestressed beam bridge	143.00	Medium	286.00	59.00	16,874.00	**SPMT**

			Beaufort and Morehead Railroad Trestle Bridge, North Carolina (1999)	495-ft-long (15 spans @ 33 ft) 12-ft-wide prestressed concrete tee-beam trestle-span approaches on the west side of the bascule span and 1,749-ft-long (53 spans @ 33 ft) 12-ft-wide prestressed concrete tee-beam trestle-span approaches on the east side of the bascule span	33.00	Short	2,244.00	12.00	26,928.00	PBES
8	**Drilled Shaft**	None	South Punaluu Stream Bridge, Hawaii (2011)	170-ft-long and 50-ft-wide three-span precast prestressed "trideck" adjacent tee beam bridge	56.67	Short	170.00	50.00	8,500.00	PBES
			North Kahana Stream Bridge, Hawaii (2010)	128-ft-long and 42.33-ft-wide three-span precast prestressed concrete slab beam bridge	42.67	Short	128.00	42.33	5,418.24	PBES
			Willis Avenue Bridge over Harlem River, New York (2010)	350-ft-long, 77-ft-wide, and 65-ft-high steel through-truss swing span (2,400 tons) of 2,012-ft-long 15-span mainline bridge	134.13	Medium	350.00	77.00	26,950.00	**SPMT**
			Elk Creek Bridge, Oregon (2008)	320.5-ft long and 38.2-ft wide three-span (56.5 ft – 207.5 ft – 56.5 ft) steel girder bridge	106.83	Short-to-medium	320.50	38.20	12,243.10	**Lateral Sliding**
			SH 290 Bridge over Live Oak Creek, Texas (2008)	700-ft-long and 32-ft-wide seven-span bridge	100	Short-to-medium	700.00	32.00	22,400.00	PBES
			Hood Canal Bridge, Washington (2005)	605-ft long and 40-ft wide five-span bridge	121.00	Short-to-medium	605.00	40.00	24,200.00	**Lateral Sliding**
8	**Drilled Shaft**	None	State Highway 36, Texas (2003)	32 span prestressed concrete U-Beam bridge, supported on twin column reinforced concrete pier bents with a hammerhead bent cap					-	PBES
			Carniquez Strait Bridge, California (2003)	3,465-ft-long and 95-ft-wide three-span steel orthotropic box girder suspension bridge	1,155.00	long	3,465.00	95.00	329,175.00	**Lateral Sliding**
			Sauvie Island Bridge, Oregon (2007)	365-ft-long and 85-ft tall steel tied arch main span of the 1,177-ft-long and 66-ft-wide five-span bridge with post-tensioned box girder approach spans	365.00	Medium-to-long	365.00	85.00	31,025.00	**SPMT**
9	**Micropile**	None	Biltmore Avenue Bridge, North Carolina (2010)	135-ft-long and 72.5-ft wide single-span modular-beam-and-deck bridge	135.00	Medium	135.00	72.50	9,787.50	PBES
			Linn Cove Viaduct, North Carolina (1983)	1,243-ft-long and 37.5-ft-wide 8-span precast concrete segmental bridge	155.38	Medium	1,243.00	37.50	46,612.50	PBES

Foundation Types Cost Estimates Analysis Data (Cont'd)

Spread Footing									
Item Description	**Quantity**	**Unit**	**Low Unit Price**	**High Unit Price**	**Representative Unit Price**	**Low Cost**	**High Cost**	**Representative Cost [2014 $]**	**Factors affecting cost**
Excavation	3.57	CUYD	40.65	143.53	52.85	145.32	513.05	188.91	Type of soil, Site access
Concrete	1.00	CUYD	505.53	1,230.99	657.18	505.53	1,230.99	657.18	Distance to closest concrete plant
Reinforcing Steel	273.61	LB	3.27	4.91	3.58	894.29	1,342.71	980.43	Transportation
					TOTAL/CUYD	**1,545.14**	**3,086.75**	**1,826.53**	

Item Description: ***Excavation***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
29.40	CUYD	50.00	100.00	65.00	5.00	Well Road Bridge, Louisiana (2011)
						Vista Interchange Bridge, Idaho (2010)
270.00	M3	63.00	300.00	81.90	3.00	Hardscrabble Creek Bridge, California (2008)
						I-215 / 4500 South Bridge, Utah (2007)
						I-40 Bridges, California (2006)
						Hilltop Drive Overcrossing, California (2006)
13.00	CUYD	8.00	40.00	10.40	6.00	Mill Street Bridge, New Hampshire (2004)
7,783.00	M3	17.00	25.00	22.10	3.00	I-405 / Northeast 8th Street Bridge, Washington (2003)
1,250.00	CUYD	40.00	150.00	52.00	3.00	Keaiwa Stream Bridge, Hawaii (2001)
						I-5 / South 38th Street Bridge, Washington (2001)

Item Description: ***Concrete***

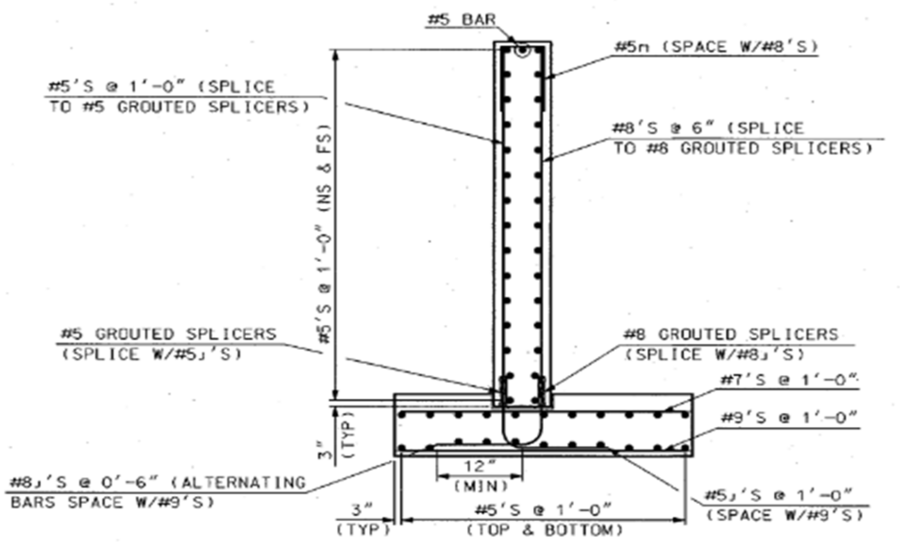
Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
12.63	CUYD	830.00	1,450.00	1,079.00	5.00	Well Road Bridge, Louisiana (2011)
					-	Vista Interchange Bridge, Idaho (2010)
56.00	M3	330.00	1,500.00	429.00	3.00	Hardscrabble Creek Bridge, California (2008)
					-	I-215 / 4500 South Bridge, Utah (2007)
					-	I-40 Bridges, California (2006)
					-	Hilltop Drive Overcrossing, California (2006)
90.00	CUYD	100.00	295.00	130.00	6.00	Mill Street Bridge, New Hampshire (2004)
150.00	M3	500.00	916.00	650.00	3.00	I-405 / Northeast 8th Street Bridge, Washington (2003)
					3.00	Keaiwa Stream Bridge, Hawaii (2001)

					-	I-5 / South 38th Street Bridge, Washington (2001)

Item Description: ***Reinforcing Steel***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
64,744.00	LB	0.85	2.50	0.95	5.00	Well Road Bridge, Louisiana (2011)
					-	Vista Interchange Bridge, Idaho (2010)
27,200.00	KG	2.80	4.00	3.00	3.00	Hardscrabble Creek Bridge, California (2008)
					-	I-215 / 4500 South Bridge, Utah (2007)
					-	I-40 Bridges, California (2006)
					-	Hilltop Drive Overcrossing, California (2006)
					6.00	Mill Street Bridge, New Hampshire (2004)
1,000.00	KG	1.23	1.50	1.41	3.00	I-405 / Northeast 8th Street Bridge, Washington (2003)
					3.00	Keaiwa Stream Bridge, Hawaii (2001)
					-	I-5 / South 38th Street Bridge, Washington (2001)

Mill Street Bridge, New Hampshire



Volume	*23*	*ft3*		
Bar #	Quantity	Length (ft)	lb/ft factor	Total lb
7	2	11.50	2.04	47.01
9	2	11.50	3.38	77.72
5	2	11.50	1.04	23.99
8	2	11.50	2.67	61.41
5	22	1.00	1.04	22.95
			Total	233.07

lb/ft3	10.13
lb/CUYD	273.61

Foundation Types Cost Estimates Analysis Data (Cont'd)

H-pile (Diam. 10" - 14")								
Item Description	**Quantity**	**Unit**	**Low Unit Price**	**High Unit Price**	**Representative Unit Price**	**Low Cost**	**High Cost**	**Representative Cost**
H-pile (furnish and drive)	1.00	LF	70.02	177.66	83.10	70.02	177.66	83.10
Test Pile	0.19	LF	64.75	92.78	78.80	12.29	17.60	14.95
Pile Point	0.03	EA	73.42	140.00	104.00	2.08	3.96	2.94
					TOTAL/LF	**84.38**	**199.22**	**101.00**

Deployment of pile driver	1.00	LS	26,500.00	120,000.00	45,650.00	26,500.00	120,000.00	45,650.00

Item Description: ***H-Pile (furnish and drive)***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
420.00	LF	22.00	95.17	28.60	4.00	TH 53 Bridge over Paleface River, Minnesota (2012)
627.00	LF	61.00	135.00	79.30	6.00	Route 202 Bridge over Passaic River, New Jersey (2012)
1,920.00	LF	37.00	60.00	45.00	7.00	US 6 over Keg Creek Bridge, Iowa (2011)
840.00	LF	42.00	42.00	42.00	1.00	Little Cedar Creek Bridge, Iowa (2011)
1,100.00	LF	14.00	124.00	40.00	7.00	UPRR Bridge, Kansas(2011)
1,058.00	LF	44.00	44.00	44.00	1.00	Buffalo Creek Bridge, South Dakota (2011)
						US 17 Bridge over Tar River, North Carolina (2010)
170.00	LF	50.82	146.00	66.07	6.00	41st Street Bridge, South Dakota (2010)
						Kickapoo Bridge, Mississippi (2010)
137.50	LF	38.00	47.00	42.00	4.00	640th Street over Branch Racoon River Bridge, Iowa (2009)
480.00	LF	50.92	75.50	66.20	3.00	Inyan Kara Creek Bridge, Wyoming (2009)
						Kia Blvd Bridge, Georgia (2008)
640.00	LF	35.00	45.00	40.00	2.00	Jakway Park Bridge, Iowa (2008)
542.00	LF	140.00	1,040.00	182.00	7.00	MD 28 over Washington Run Creek Bridge, Maryland (2008)
1,488.00	LF	28.00	50.00	36.40	4.00	Parkview Avenue Bridge, Michigan (2008)
						Riverdale Road Bridge over I-84, Utah (2008)
350.00	LF	21.00	30.50	27.30	6.00	Madison Co. Bridge, Iowa (2007)
1,074.00	LF	60.59	445.44	90.89	3.00	Grayling Creek Bridge, Alaska* (2006)
575.00	LF	27.70	40.50	32.00	7.00	Mackey Bridge, Iowa (2006) (abutment)

615.00	M	150.00	175.00	160.00	3.00	O’Malley Bridge, Alaska* (2005) (abutment)
240.00	LF	27.80	27.80	27.80	1.00	SH 66 over Mitchell Gulch, Colorado (2002)
						Kouwegok Slough Bridge, Alaska* (2000)

Item Description: ***Test Pile***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
80.00	LF	54.00	118.13	70.20	4.00	TH 53 Bridge over Paleface River, Minnesota (2012)
						Route 202 Bridge over Passaic River, New Jersey (2012)
						US 6 over Keg Creek Bridge, Iowa (2011)
						Little Cedar Creek Bridge, Iowa (2011)
						UPRR Bridge, Kansas(2011)
84.00	LF	70.00	70.00	70.00	1.00	Buffalo Creek Bridge, South Dakota (2011)
						US 17 Bridge over Tar River, North Carolina (2010)
74.00	LF	110.00	133.00	125.00	6.00	41st Street Bridge, South Dakota (2010)
						Kickapoo Bridge, Mississippi (2010)
						640th Street over Branch Racoon River Bridge, Iowa (2009)
						Inyan Kara Creek Bridge, Wyoming (2009)
						Kia Blvd Bridge, Georgia (2008)
						Jakway Park Bridge, Iowa (2008)
						MD 28 over Washington Run Creek Bridge, Maryland (2008)
80.00	LF	25.00	50.00	50.00	4.00	Parkview Avenue Bridge, Michigan (2008)
						Riverdale Road Bridge over I-84, Utah (2008)
						Madison Co. Bridge, Iowa (2007)
						Grayling Creek Bridge, Alaska* (2006)
						Mackey Bridge, Iowa (2006) (abutment)
						O’Malley Bridge, Alaska* (2005) (abutment)
						SH 66 over Mitchell Gulch, Colorado (2002)
						Kouwegok Slough Bridge, Alaska* (2000)

Item Description: ***Pile tip reinforcement***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
320.00	LF	4.69	5.04	4.80	4.00	TH 53 Bridge over Paleface River, Minnesota (2012)
						Route 202 Bridge over Passaic River, New Jersey (2012)
						US 6 over Keg Creek Bridge, Iowa (2011)
						Little Cedar Creek Bridge, Iowa (2011)
						UPRR Bridge, Kansas(2011)

						Buffalo Creek Bridge, South Dakota (2011)
						US 17 Bridge over Tar River, North Carolina (2010)
3,381.00	LF	37.00	48.64	40.00	6.00	41st Street Bridge, South Dakota (2010)
						Kickapoo Bridge, Mississippi (2010)
						640th Street over Branch Racoon River Bridge, Iowa (2009)
						Inyan Kara Creek Bridge, Wyoming (2009)
						Kia Blvd Bridge, Georgia (2008)
						Jakway Park Bridge, Iowa (2008)
						MD 28 over Washington Run Creek Bridge, Maryland (2008)
						Parkview Avenue Bridge, Michigan (2008)
						Riverdale Road Bridge over I-84, Utah (2008)
						Madison Co. Bridge, Iowa (2007)
						Grayling Creek Bridge, Alaska* (2006)
						Mackey Bridge, Iowa (2006) (abutment)
						O'Malley Bridge, Alaska* (2005) (abutment)
						SH 66 over Mitchell Gulch, Colorado (2002)
						Kouwegok Slough Bridge, Alaska* (2000)

Item Description: ***Furnishing equipment***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
						TH 53 Bridge over Paleface River, Minnesota (2012)
1.00	LS	51,000.00	200,000.00	66,300.00	6.00	Route 202 Bridge over Passaic River, New Jersey (2012)
						US 6 over Keg Creek Bridge, Iowa (2011)
						Little Cedar Creek Bridge, Iowa (2011)
						UPRR Bridge, Kansas(2011)
						Buffalo Creek Bridge, South Dakota (2011)
						US 17 Bridge over Tar River, North Carolina (2010)
						41st Street Bridge, South Dakota (2010)
						Kickapoo Bridge, Mississippi (2010)
						640th Street over Branch Racoon River Bridge, Iowa (2009)
						Inyan Kara Creek Bridge, Wyoming (2009)
						Kia Blvd Bridge, Georgia (2008)
						Jakway Park Bridge, Iowa (2008)
						MD 28 over Washington Run Creek Bridge, Maryland (2008)
1.00	LS	2,000.00	40,000.00	25,000.00	4.00	Parkview Avenue Bridge, Michigan (2008)
						Riverdale Road Bridge over I-84, Utah (2008)

						Madison Co. Bridge, Iowa (2007)
						Grayling Creek Bridge, Alaska* (2006)
						Mackey Bridge, Iowa (2006) (abutment)
						O'Malley Bridge, Alaska* (2005) (abutment)
						SH 66 over Mitchell Gulch, Colorado (2002)
						Kouwegok Slough Bridge, Alaska* (2000)

Item Description: ***Pile point***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
						TH 53 Bridge over Paleface River, Minnesota (2012)
22.00	EA	65.00	180.00	118.00	6.00	Route 202 Bridge over Passaic River, New Jersey (2012)
						US 6 over Keg Creek Bridge, Iowa (2011)
						Little Cedar Creek Bridge, Iowa (2011)
						UPRR Bridge, Kansas(2011)
						Buffalo Creek Bridge, South Dakota (2011)
						US 17 Bridge over Tar River, North Carolina (2010)
						41st Street Bridge, South Dakota (2010)
						Kickapoo Bridge, Mississippi (2010)
						640th Street over Branch Racoon River Bridge, Iowa (2009)
						Inyan Kara Creek Bridge, Wyoming (2009)
						Kia Blvd Bridge, Georgia (2008)
						Jakway Park Bridge, Iowa (2008)
						MD 28 over Washington Run Creek Bridge, Maryland (2008)
32.00	EA	81.84	100.00	90.00	4.00	Parkview Avenue Bridge, Michigan (2008)
						Riverdale Road Bridge over I-84, Utah (2008)
						Madison Co. Bridge, Iowa (2007)
						Grayling Creek Bridge, Alaska* (2006)
						Mackey Bridge, Iowa (2006) (abutment)
						O'Malley Bridge, Alaska* (2005) (abutment)
						SH 66 over Mitchell Gulch, Colorado (2002)
						Kouwegok Slough Bridge, Alaska* (2000)

Foundation Types Cost Estimates Analysis Data (Cont'd)

Open-ended pipe pile (Diam. 12" - 12.75")								
Item Description	**Quantity**	**Unit**	**Low Unit Price**	**High Unit Price**	**Representative Unit Price**	**Low Cost**	**High Cost**	**Representative Cost**
Steel pipe pile	1.00	LF	83.75	118.78	92.62	83.75	118.78	92.62
Steel pipe pile test	0.08	LF	80.00	390.00	104.00	6.68	32.58	8.69
					TOTAL/LF	**90.43**	**151.36**	**101.30**
Deployment of pile driver	1.00	LS	45,000.00	45,000.00	45,000.00	45,000.00	45,000.00	45,000.00

Item Description: ***Steel pipe pile (furnish and drive)***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
1,792.00	LF	72.50	72.50	72.50	1.00	OR213 Bridge over Washington Street, Oregon (2012)
						Volmer and Johnson Creek Bridges, Oregon (2011)
1,700.00	LF	76.50	150.00	91.50	7.00	MD 450 over Bacon Ridge Branch Bridge, Maryland (2008)
						Kimberly Bridge, Oregon (2008)
						Mackey Bridge, Iowa (2006) (pile caps)
						O'Malley Bridge, Alaska* (2005) (pile caps)
						U.S. Route 22 Bridge, Ohio (2003)
650.00	LF	102.25	133.85	113.85	3.00	Pelican Creek Bridge, Alaska *(1992)

Item Description: ***Steel pipe pile test***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
						OR213 Bridge over Washington Street, Oregon (2012)
						Volmer and Johnson Creek Bridges, Oregon (2011)
142.00	LF	80.00	390.00	104.00	7.00	MD 450 over Bacon Ridge Branch Bridge, Maryland (2008)
						Kimberly Bridge, Oregon (2008)
						Mackey Bridge, Iowa (2006) (pile caps)
						O'Malley Bridge, Alaska* (2005) (pile caps)
						U.S. Route 22 Bridge, Ohio (2003)
						Pelican Creek Bridge, Alaska *(1992)

Item Description: ***Furnish pile driving equipment***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
1.00	LS	45,000.00	45,000.00	45,000.00	1.00	OR213 Bridge over Washington Street, Oregon (2012)
						Volmer and Johnson Creek Bridges, Oregon (2011)
						MD 450 over Bacon Ridge Branch Bridge, Maryland (2008)
						Kimberly Bridge, Oregon (2008)

						Mackey Bridge, Iowa (2006) (pile caps)
						O'Malley Bridge, Alaska* (2005) (pile caps)
						U.S. Route 22 Bridge, Ohio (2003)
						Pelican Creek Bridge, Alaska *(1992)

Foundation Types Cost Estimates Analysis Data (Cont'd)

Micropiles (Diam. 10.75")								
Item Description	**Quantity**	**Unit**	**Low Unit Price**	**High Unit Price**	**Representative Unit Price**	**Low Cost**	**High Cost**	**Representative Cost**
Micropile	1.00	LF	163.64	261.21	205.21	163.64	261.21	205.21
Micropile Load Test	0.01	EA	9,050.00	18,373.17	12,430.75	129.13	262.16	177.37
					TOTAL/LF	**292.77**	**523.36**	**382.58**

Deployment of Equipment	1.00	LS	42,750.00	129,068.75	68,558.50	42,750.00	129,068.75	68,558.50

Item Description: ***Micropile***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
24.00	EA	5,844.00	8,316.61	6,800.00	3.00	Biltmore Avenue Bridge, North Carolina (2010)
						Linn Cove Viaduct, North Carolina (1983)
1,100.00	LF	154.00	240.00	200.20	4.00	
28.00	EA	6,600.00	9,000.00	7,920.00	4.00	
1,417.00	LF	250.00	305.00	264.25	6.00	
305.00	EA	7,500.00	20,000.00	12,220.00	5.00	
1,597.00	LF	155.00	200.00	174.50	8.00	
181.00	EA	5,800.00	6,850.00	6,363.00	4.00	
60.00	EA	4,260.00	9,620.00	6,807.00	6.00	

Item Description: ***Micropile Load Test***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
1.00	EA	5,600.00	18,292.68	7,280.00	3.00	Biltmore Avenue Bridge, North Carolina (2010)
						Linn Cove Viaduct, North Carolina (1983)
					4.00	
1.00	EA	10,000.00	15,000.00	13,000.00	4.00	
					6.00	
					5.00	
					8.00	
5.00	EA	8,600.00	20,000.00	13,550.00	4.00	
3.00	EA	12,000.00	20,200.00	15,893.00	6.00	

Item Description: ***Furnish drilling equipment***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
					3.00	Biltmore Avenue Bridge, North Carolina (2010)
						Linn Cove Viaduct, North Carolina (1983)
1.00	LS	40,000.00	94,000.00	52,000.00	4.00	
1.00	LS	30,000.00	85,000.00	39,000.00	4.00	
					6.00	
					5.00	
					8.00	
1.00	LS	75,000.00	175,000.00	112,500.00	4.00	
1.00	LS	26,000.00	162,275.00	70,734.00	6.00	

Foundation Types Cost Estimates Analysis Data (Cont'd)

Drilled Shaft (Diam. 60")								
Item Description	**Quantity**	**Unit**	**Low Unit Price**	**High Unit Price**	**Representative Unit Price**	**Low Cost**	**High Cost**	**Representative Cost**
Drilled Shaft	1.00	LF	519.00	750.00	590.00	519.00	750.00	590.00
Shaft Excavation	1.00	LF	254.00	750.00	301.50	254.00	750.00	301.50
Permanent Casing	0.47	LF	457.50	850.00	487.50	216.25	401.77	230.43
Load test	0.0004	EA	172,500.00	275,000.00	199,000.00	67.16	107.07	77.48
Corring for integrity testing	0.23	LF	62.50	200.00	135.00	14.59	46.69	31.51
					TOTAL/LF	**1,071.00**	**2,055.52**	**1,230.92**

Deployment of Equipment	1.00	LS	523,840.00	1,446,666.67	702,158.67	523,840.00	1,446,666.67	702,158.67

Item Description: ***Drilled Shaft***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
2,885.00	LF	450.00	700.00	585.00	3.00	South Punaluu Stream Bridge, Hawaii (2011)
2,110.00	LF	588.00	800.00	595.00	5.00	North Kahana Stream Bridge, Hawaii (2010)
5,265.00	M	10,000.00	10,000.00	10,000.00	2.00	Willis Avenue Bridge over Harlem River, New York (2010)
						Elk Creek Bridge, Oregon (2008)
						SH 290 Bridge over Live Oak Creek, Texas (2008)
						Hood Canal Bridge, Washington (2005)
						State Highway 36, Texas (2003)
						Carniquez Strait Bridge, California (2003)
						Sauvie Island Bridge, Oregon (2007)

Item Description: ***Shaft Excavation***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
2,885.00	LF	220.00	700.00	286.00	3.00	South Punaluu Stream Bridge, Hawaii (2011)
2,110.00	LF	288.00	800.00	317.00	5.00	North Kahana Stream Bridge, Hawaii (2010)
623.00	EA	6,000.00	30,000.00	7,800.00	2.00	Willis Avenue Bridge over Harlem River, New York (2010)
						Elk Creek Bridge, Oregon (2008)
						SH 290 Bridge over Live Oak Creek, Texas (2008)
						Hood Canal Bridge, Washington (2005)

						State Highway 36, Texas (2003)
						Carniquez Strait Bridge, California (2003)
						Sauvie Island Bridge, Oregon (2007)

Item Description: ***Permanent Casing***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
1,360.00	LF	400.00	600.00	425.00	3.00	South Punaluu Stream Bridge, Hawaii (2011)
1,000.00	LF	515.00	1,100.00	550.00	5.00	North Kahana Stream Bridge, Hawaii (2010)
					2.00	Willis Avenue Bridge over Harlem River, New York (2010)
						Elk Creek Bridge, Oregon (2008)
						SH 290 Bridge over Live Oak Creek, Texas (2008)
						Hood Canal Bridge, Washington (2005)
						State Highway 36, Texas (2003)
						Carniquez Strait Bridge, California (2003)
						Sauvie Island Bridge, Oregon (2007)

Item Description: ***Load Test***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
1.00	EA	170,000.00	250,000.00	180,000.00	3.00	South Punaluu Stream Bridge, Hawaii (2011)
1.00	EA	175,000.00	300,000.00	218,000.00	5.00	North Kahana Stream Bridge, Hawaii (2010)
6.00	EA	23,000.00	70,000.00	29,900.00	2.00	Willis Avenue Bridge over Harlem River, New York (2010)
						Elk Creek Bridge, Oregon (2008)
						SH 290 Bridge over Live Oak Creek, Texas (2008)
						Hood Canal Bridge, Washington (2005)
						State Highway 36, Texas (2003)
						Carniquez Strait Bridge, California (2003)
						Sauvie Island Bridge, Oregon (2007)

Item Description: ***Corring for integrity testing***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
800.00	LF	75.00	150.00	120.00	3.00	South Punaluu Stream Bridge, Hawaii (2011)
400.00	LF	50.00	250.00	150.00	5.00	North Kahana Stream Bridge, Hawaii (2010)
					2.00	Willis Avenue Bridge over Harlem River, New York (2010)
						Elk Creek Bridge, Oregon (2008)
						SH 290 Bridge over Live Oak Creek, Texas (2008)

					3.00	Hood Canal Bridge, Washington (2005)
						State Highway 36, Texas (2003)
						Carniquez Strait Bridge, California (2003)
						Sauvie Island Bridge, Oregon (2007)

Item Description: ***Furnishing equipment***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
1.00	LS	356,520.00	900,000.00	463,476.00	3.00	South Punaluu Stream Bridge, Hawaii (2011)
1.00	LS	215,000.00	440,000.00	343,000.00	5.00	North Kahana Stream Bridge, Hawaii (2010)
1.00	LS	1,000,000.00	3,000,000.00	1,300,000.00	2.00	Willis Avenue Bridge over Harlem River, New York (2010)
						Elk Creek Bridge, Oregon (2008)
						SH 290 Bridge over Live Oak Creek, Texas (2008)
					3.00	Hood Canal Bridge, Washington (2005)
						State Highway 36, Texas (2003)
						Carniquez Strait Bridge, California (2003)
						Sauvie Island Bridge, Oregon (2007)

Foundation Types Cost Estimates Analysis Data (Cont'd)

Close-ended pipe pile (Diam. 24'')								
Item Description	**Quantity**	**Unit**	**Low Unit Price**	**High Unit Price**	**Representative Unit Price**	**Low Cost**	**High Cost**	**Representative Cost**
Concrete filled steel pipe pile (furnish and drive)	1.00	LF	156.00	156.00	156.00	156.00	156.00	156.00
Test pile (furnish and drive)	0.09	LF	205.00	205.00	205.00	19.20	19.20	19.20
Dinamic Pile load test	0.001	EA	2,100.00	2,100.00	2,100.00	1.64	1.64	1.64
Splices	0.01	EA	250.00	250.00	250.00	1.74	1.74	1.74
					TOTAL/LF	**178.58**	**178.58**	**178.58**

Deployment of pile driver	1.00	LS	3,420,000.00	3,420,000.00	3,420,000.00	3,420,000.00	3,420,000.00	3,420,000.00

Item Description: ***Concrete filled steel pipe pile (furnish and drive)***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
						Boothbay Bridge, Maine (2011)
						I-15 / Sam White Lane Bridge, Utah (2011)
						MD Route 362 over Monie Creek Bridge, Maryland (2009)
35,836.00	LF	156.00	156.00	156.00	1.00	Route 70 Bridge over Manasquan River, New Jersey (2008)
						Belt Parkway Bridge, New York (2004)

Item Description: ***Test pile (furnish and drive)***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
						Boothbay Bridge, Maine (2011)
						I-15 / Sam White Lane Bridge, Utah (2011)
						MD Route 362 over Monie Creek Bridge, Maryland (2009)
3,356.00	LF	205.00	205.00	205.00	1.00	Route 70 Bridge over Manasquan River, New Jersey (2008)
						Belt Parkway Bridge, New York (2004)

Item Description: ***Dinamic Pile load test***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
						Boothbay Bridge, Maine (2011)
						I-15 / Sam White Lane Bridge, Utah (2011)
						MD Route 362 over Monie Creek Bridge, Maryland (2009)
28.00	EA	2,100.00	2,100.00	2,100.00	1.00	Route 70 Bridge over Manasquan River, New Jersey (2008)

						Belt Parkway Bridge, New York (2004)

Item Description: ***Furnishing equipment***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
						Boothbay Bridge, Maine (2011)
						I-15 / Sam White Lane Bridge, Utah (2011)
						MD Route 362 over Monie Creek Bridge, Maryland (2009)
1.00	LS	3,420,000.00	3,420,000.00	3,420,000.00	1.00	Route 70 Bridge over Manasquan River, New Jersey (2008)
						Belt Parkway Bridge, New York (2004)

Item Description: ***Splices***

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
						Boothbay Bridge, Maine (2011)
						I-15 / Sam White Lane Bridge, Utah (2011)
						MD Route 362 over Monie Creek Bridge, Maryland (2009)
364.00	EA	250.00	250.00	250.00	1.00	Route 70 Bridge over Manasquan River, New Jersey (2008)
						Belt Parkway Bridge, New York (2004)

Foundation Types Cost Estimates Analysis Data (Cont'd)

Precast Concrete pile 16"								
Item Description	**Quantity**	**Unit**	**Low Unit Price**	**High Unit Price**	**Representative Unit Price**	**Low Cost**	**High Cost**	**Representative Cost**
Precast Prestressed Concrete Pile	1.00	LF	101.23	266.18	179.25	101.23	266.18	179.25
Test Pile	0.18	LF	136.56	465.63	215.03	23.92	81.56	37.66
					TOTAL/LF	**125.14**	**347.73**	**216.91**

Deployment of pile driver	1.00	LS	-	-	-	-	-	-

Item Description: Precast Prestressed Concrete Pile

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
1,120.00	LF	45.00	70.50	58.50	2.00	TH 61 Bridge over Gilbert Creek, Minnesota (2011)
						NC 12 Bridge over Molasses Creek, North Carolina (2008)
774.00	LF	157.45	461.85	300.00	7.00	Parker River Bridge, Massachusetts (2007)
						Graves Avenue Bridge, Florida (2006)
						Beaufort and Morehead Railroad Trestle Bridge, North Carolina (1999)

Item Description: Test Pile

Quantity	Unit	Low Unit Price	High Unit Price	Representative Unit Price	No. of Bids	Project Name
320.00	LF	23.13	31.25	30.06	2.00	TH 61 Bridge over Gilbert Creek, Minnesota (2011)
						NC 12 Bridge over Molasses Creek, North Carolina (2008)
50.00	LF	250.00	900.00	400.00	7.00	Parker River Bridge, Massachusetts (2007)
						Graves Avenue Bridge, Florida (2006)
						Beaufort and Morehead Railroad Trestle Bridge, North Carolina (1999)