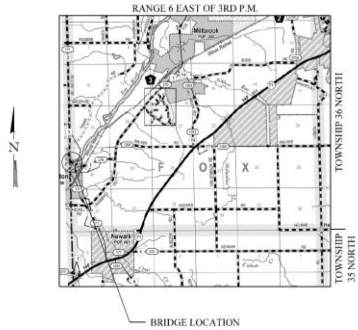
Millington Bridge Pier Replacement

Brian K. Converse, P.E., S.E.
Satyam Mandloi, E.I.
2022

WILLETT HOFMANN

Project Location – Kendall/LaSalle County



MILLINGTON ROAD (C.H. 3) OVER FOX RIVER
EXISTING S.N. 047-3000
FOX TOWNSHIP

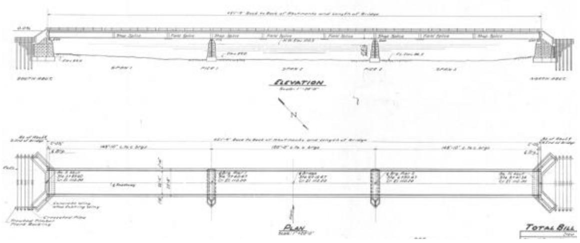
Summary

- Critical Scouring of soil beneath the pier resulting in settlement of bridge support as determined from routine bridge inspections by WHA.
- Temporary steel frames were used to support the bridge deck and girders in place.
- The existing pier was replaced by the reinforced-concrete strut-tie piers spanning between two battered-steel-pile-supported foundations.
- Pier replacement was completed successfully, and the bridge is now under operation.

Existing Bridge Info

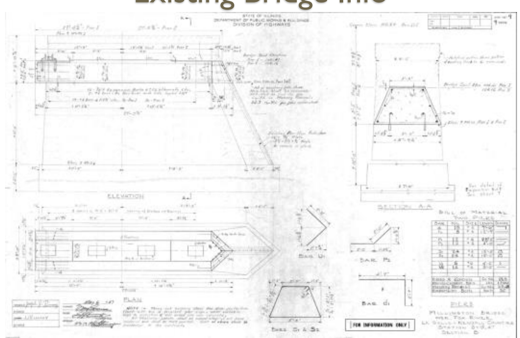
- The existing bridge is a three-span reinforced concrete deck bridge supported by riveted plate girders. The total length back-to-back of abutments is 451'-9". The spans are: 148'-10", 150'-0" and 148'-10". The out-to-out width of the structure is 25'-8". The substructure consists of closed masonry abutments and solid masonry piers supported on spread footings. The structure was built as Millington Bridge in 1958, rehabilitated in 2000, and painted in 2015.

Existing Bridge Info



General Plan & Elevation (1958 Plans)

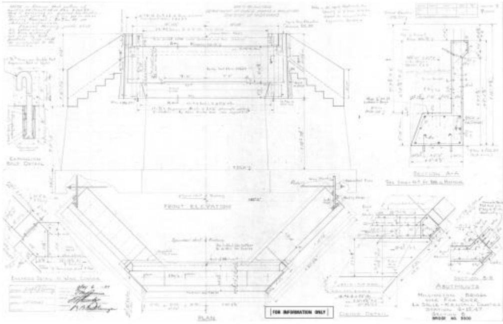
Existing Bridge Info



Piers (1958 Plans)

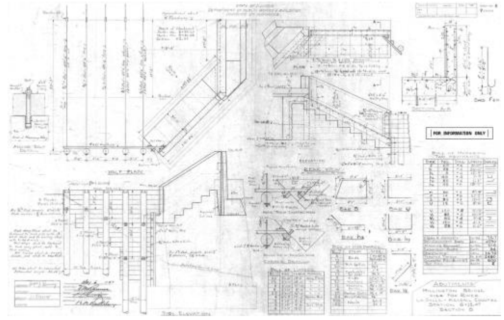
Note: We don't know exactly when the pier was built.

Existing Bridge Info



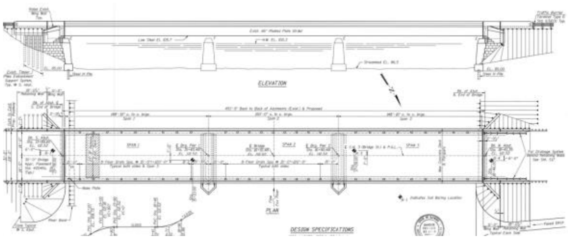
Abutments (1958 Plans)

Existing Bridge Info



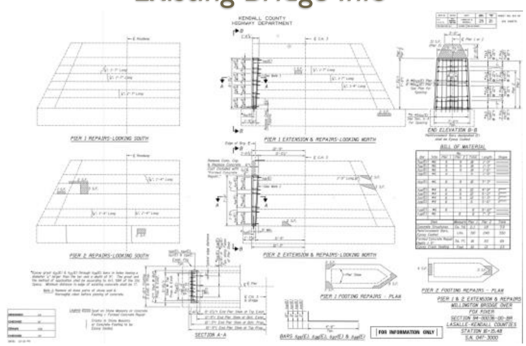
Abutments (1958 Plans)

Existing Bridge Info



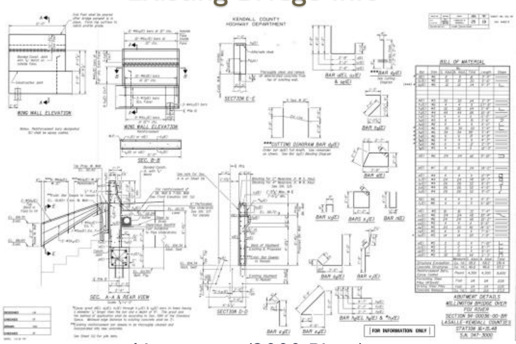
General Plan & Elevation (2000 Plans)

Existing Bridge Info



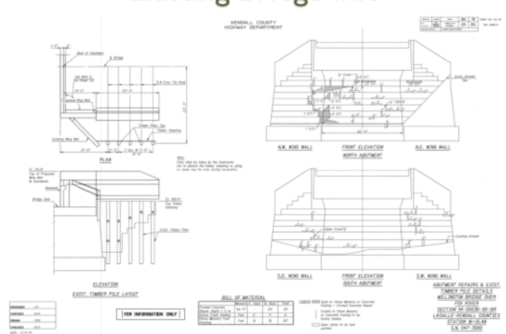
Piers (2000 Plans)

Existing Bridge Info



Abutments (2000 Plans)

Existing Bridge Info



Abutments (2000 Plans)

Existing Bridge Info

13

Existing Bridge Info

14

Existing Bridge Info

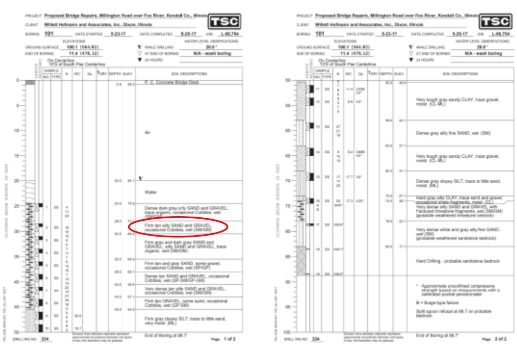
15

Underwater Inspection

- WHA performs routine bridge inspections for LaSalle and Kendall counties.
- WHA found scour underneath the north pier and deemed further investigation was required to figure what the pier was actually resting on.
- WHA contracted Collins Engineering Inc. to perform underwater inspection of the scoured pier with the help of divers.
- WHA surveyed the bridge and ascertained that the bridge deck over north pier settled an inch.
- The problem was that the piers 1 and 2 consist of a solid stone masonry pier founded on concrete spread footing resting on firm tan silty sand and gravel.

16

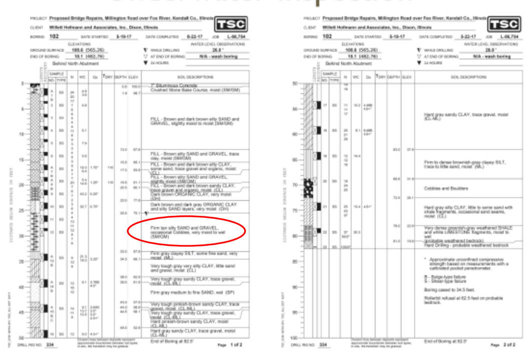
Underwater Inspection



Pier 1 Borings (South Pier)

17

Underwater Inspection



Pier 2 Borings (North Pier)

18

Underwater Inspection

- Pier 1 (South Pier) was in poor condition at the time of inspection. Two areas of footing undermining were observed at the upstream nose and the southeast corner of the pier.

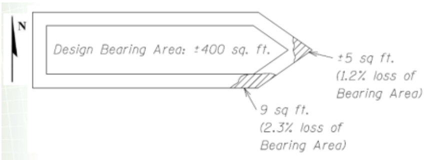


Figure 1: Extents of Undermining at Pier 1

Underwater Inspection

Photograph 3: Overall View of Pier 1 (South Pier), Looking Northeast.

Underwater Inspection

Photograph 4: Overall View of Pier 1 (South Pier), Looking Southwest.

Underwater Inspection

- Pier 2 (North Pier) was in critical condition at the time of inspection. Channel bottom scour and footing undermining was observed at the upstream half of the pier.

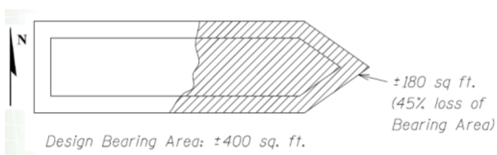
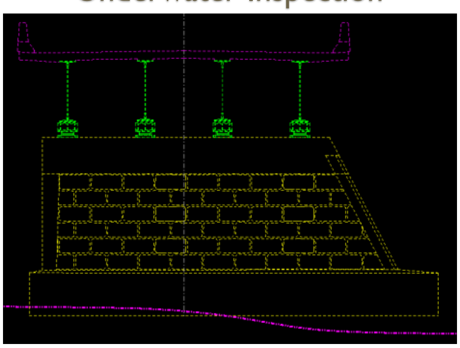


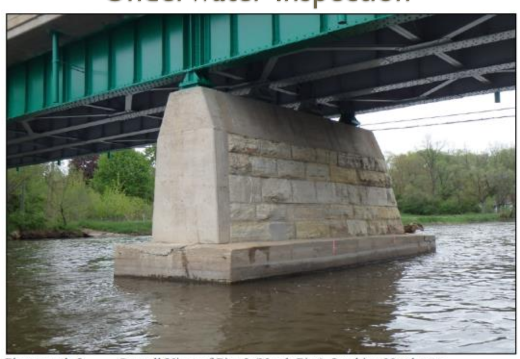
Figure 2: Extents of Undermining at Pier 2

Underwater Inspection



Scour at Pier 2 (North Pier)

Underwater Inspection



Photograph 5: Overall View of Pier 2 (North Pier), Looking Northeast.

Underwater Inspection

Photograph 6: Overall View of Pier 2 (North Pier), Looking Southwest.

Scouring in Bridge Pier

- Removal of sediments near and under the pier by the water flowing past a pier.
- It is the most common cause of highway bridge failure in the United States.
- During the year 1961 to 1976, it was found that 46 out of 86 major bridge failures were resulted from scour near piers.

Scouring in bridge piers

Source:
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.ayresassociates.com%2Fbattling-bridge-scour-with-research-inspections-andtraining%2F&psig=AOvVaw2Tz2J0kR_b1Hx3eu50cHCS&ust=1625173251581000&source=images&cd=vfe&ved=0CAoQjRxqFwoTCOjRnsWgwPECFQAAAAAdAAAAABAK

Scouring in Bridge Pier

Causes of scouring

- Stream Channel Instability
- Flood
- Debris build up on the channel deflecting the water flow and changing the angle of attack resulting in scouring at other location

Mississippi Highway 33 bridge over Homochitto River failure due to flood induced erosion

Source:
https://www.usgs.gov/media/images/scour-hole-around-bridge-pier

Scouring in Bridge Pier

Effect of scouring

- Deflection and settlement of the pier.
- Loss of life and property due to complete failure of the structure.

Failure of bridge due to scouring in bridge piers

Source:
https://publikationsserver.tu-braunschweig.de/servlets/MCRFileNodeServlet/dbbs_derivate_00022866/Meyering_Final.pdf

Critical Finding & Bridge Closure

- County closed the bridge immediately and had to accommodate traffic with alternate route that was approx. 14 miles. The average daily traffic (ADT) on the bridge was 1,660 including 172 trucks.
- County would measure the top of parapet every week to verify that the bridge wasn't settling more.

Scouring in Bridge Pier

Solution to scouring of Piers?

Underwater scour repair of bridge piers or bridge replacement?

Source:
https://www.jfbrennan.com/blog/effective-solutions-for-underwater-scour-repair

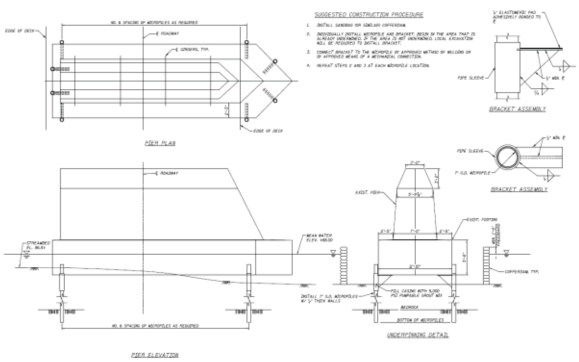
Pier Retrofit Analyis Evaluation or Replacement

- WHA hired Benesch as a pier reviewer to aid in evaluating pier retrofit alternatives to present to Kendall/LaSalle County.
- Seven (7) pier retrofit alternatives were deemed feasible.
- The best retrofit alternative was compared against complete replacement.

Alternative 1, Micropile and Bracket Underpinning

- Alternative 1 proposes the use of micropiles and a bracket assembly to underpin the existing footing.
- This alternative would require a shallow cofferdam to provide access for the installation of the underpinning brackets.
- This alternative directly transfers the load from the existing footing to the bracket to the micropile.
- The connection between the bracket and the micropile will be the weak point of the system. This creates an inefficient use of the micropiles increasing the amount of required micropiles.
- A potential drawback to this system is the geometry of the existing footing could create significant challenges to obtaining an effective transfer of force to the bracket.

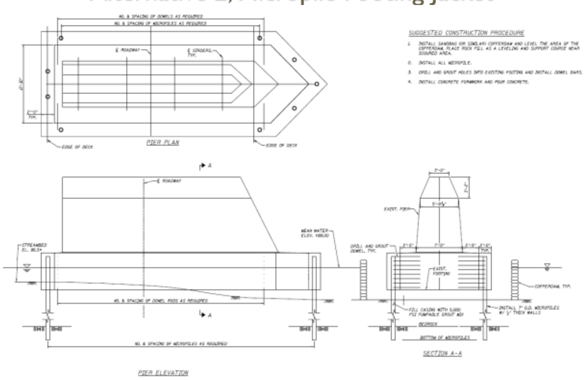
Alternative 1, Micropile and Bracket Underpinning



Alternative 2, Micropile Footing Jacket

- To mitigate the concerns about engaging the footing via a bracket, Alternative 2 utilizes micropiles driven around the outside of the existing footing.
- After the micropiles are installed, dowel bars will be installed into the existing footing and concrete will be placed to create a force transfer from the existing footing, through the bars and into the micropiles.
- This alternate has two significant drawbacks:
  - The condition of the existing footing may be too deteriorated to provide adequate bonding and load transfer to the new footing jacket.
  - The footing jacket would also increase the total width by 2'-0" on every side of the existing footing, and therefore, the hydraulic opening will decrease.

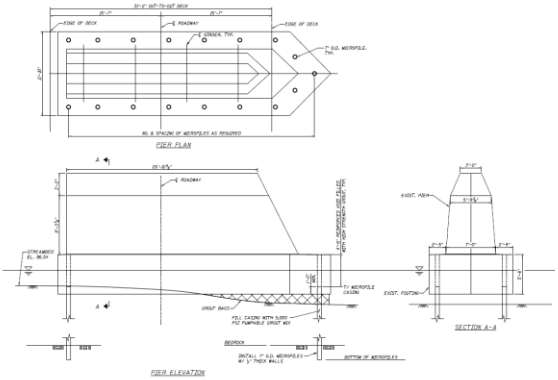
Alternative 2, Micropile Footing Jacket



Alternative 3, Micropile Thru Footing

- With the understanding that hydraulic impacts need to be avoided, Alternative 3 involves drilling micropiles through the existing footing.
- This alternative transfers the load directly from the footing to the micropiles via the bond between the grout and the existing footing.
- While this solution maintains a simpler load path, it still relies on the existing footing to transfer load.
- This option is also difficult to construct as the micropile equipment would have to work on the uneven surface of the existing footing and the drilled hole would have to be constructed so as to not compromise the integrity of the footing.

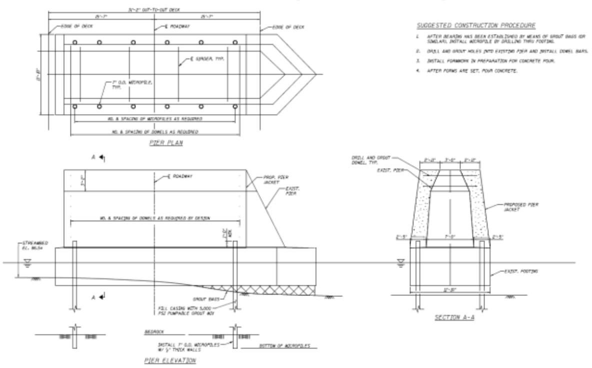
Alternative 3, Micropile Thru Footing



Alternative 4, Micropile with Pier Jacket

- Alternative 4 proposes to drill through the existing footing and install micropiles using similar methods as illustrated in Alternative 3.
- After the micropiles are installed, drill and grout holes into the existing pier cap and install dowel bars. To alleviate the moment failure from the unreinforced footing seen in Alternative 3, a pier jacket varying in width from 2'-3" at the base of the cap to 2'-11" at the top of the cap will be placed from the top of the footing to the top of the cap.
- The overall width of pier jacket will decrease from 11'-10" at the top of the footing to 8'-10" at the top of the cap.
  - Increasing the pier size will strengthen the pier, extending the design life of the bridge.
  - However, it will significantly increase the weight of the piers, requiring more micropiles, and decrease the hydraulic opening at the proposed column.

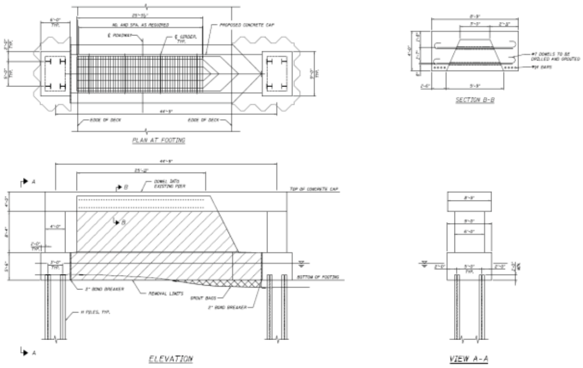
Alternative 4, Micropile with Pier Jacket



Alternative 5, Cast-In-Place Pier Cap Retrofit

- Alternative 5 constructs a "new" pier utilizing new footings and pier columns on the outer limits of the existing pier.
- The existing pier cap is retained and incorporated into construction of the new pier cap. The proposed pier footings can be supported by any deep foundation, H-piles, drilled shafts, or micropiles.
- The pier cap will be designed such that the entire load would be carried by the new cap and new reinforcement. Once the new cap is fully cured, the existing pier stem and footing may be removed.
- This solution would create an entirely new load path to a deep foundation and presents structural benefits.
- However, this solution would be difficult to construct and there would be temporary support requirements in order to replace the bearings and properly transfer load to the new cap.

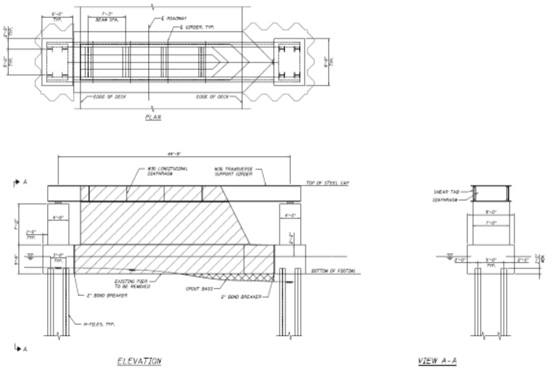
Alternative 5, Cast-In-Place Pier Cap Retrofit



Alternative 6, Straddle Bent Pier Retrofit

- Alternative 6 is similar to alternative 5 except that a steel transverse straddle bent is used for the new pier cap in lieu of the cast-in-place options.
- After constructing the proposed columns and footings, Alternative 6 will place two transverse support girders on the proposed columns. These transverse girders will support the bridge during the removal of the existing pier.
- After the existing pier has been removed, longitudinal diaphragms will be installed beneath the four existing girders. Bearings will be installed on the longitudinal girders which will then transfer load to the support girders
- While this solution also creates an entirely new load path, there are a few challenges. The transverse steel beams could end up as rather large members after all design is complete and these members would also be fracture critical (which creates increased inspection requirements).

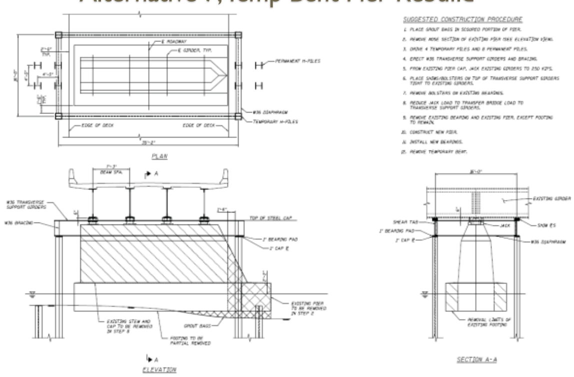
Alternative 6, Straddle Bent Pier Retrofit



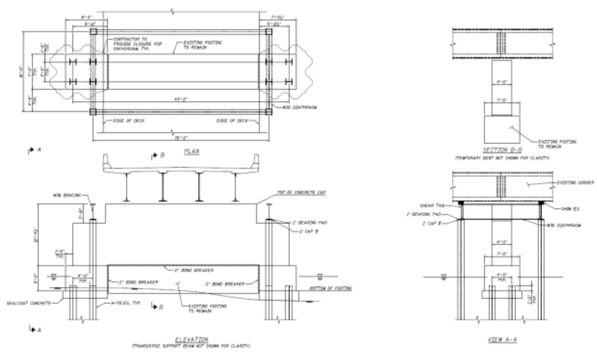
Alternative 7, Temporary Bent Pier Rebuild

- Alternative 7 involves a different approach to reconstructing the pier.
- The first step in this alternative is to remove a portion of the pier nose and build a temporary bent system to support the bridge. Once the load is on the temporary bent, the existing pier will be removed, and a new pier will be constructed.
- Supporting the bridge in a temporary manner and fully removing the existing pier prior to construction of any new elements allows for several advantages.
  - A more "typical" pier can be constructed, and the overall pier dimensions can be greatly reduced.
  - Self-consolidating concrete may be considered for use in the pier stem as the concrete may have to be placed from the ends (although a conveyor type system could potentially allow for distributed placement of conventional concrete along the length of the pier and beneath the existing bridge).
- While this alternative technically has more steps involved in the construction (must build temporary bent and transfer load, prior to removal and reconstruction of the pier), it is likely more efficient due to much smaller span lengths for the transverse steel beams and much smaller dimensions for the new pier.
- Alternate 7 was chosen by Kendall/LaSalle County as the preferred option because it involves removing the existing pier stem and constructing a scour resistant reinforced concrete pier.

Alternative 7, Temp Bent Pier Rebuild



Alternative 7, Temp Bent Pier Rebuild



Cost Comparison

- Due to the pier scour severity, the potential courses of action were as follows:
  - Option 1. Rehabilitation ($1.5M) (Bid Price - $1.52M)
  - Option 2. Complete Replacement ($6M)
- Rehabilitation of the existing structure carrying C.H. 3 (Millington Rd.) over the Fox River was chosen to be the most cost-effective solution.

Permits

- Environmental Survey Request (ESR)
  - Required for clearance from:
    - Natural Resources (Bio) Unit
      - Endangered Species
      - Wetlands
      - Nature Preserves
    - Cultural Resources Unit
      - Historic Properties
      - Archaeological sites
    - Special Waste Unit
      - Hazardous waste

Permits

- Section 4f Permit
  - Required for clearance from:
    - Park
    - Recreation Area
    - Wildlife & Waterfowl Refuge
- There was a Freeman Forest Preserve (FFP) located to the South of the bridge and we needed the bike path in it to access the construction site.
- WHA coordinated with FHWA through IDOT and OWJ (Official with Jurisdiction) to get the permit.

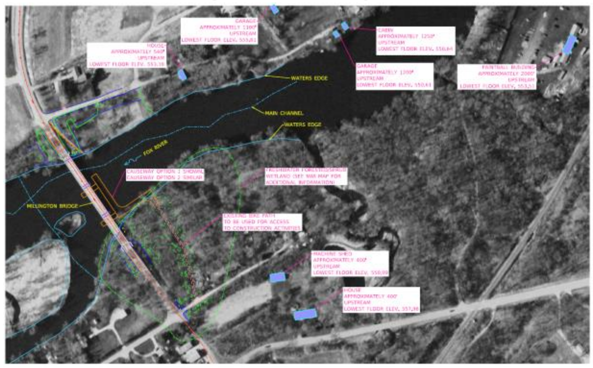
Permits

- Bridge Condition report (BCR)
  - For funding approval
- Preliminary Bridge Design & Hydraulic Report (PBDHR)
- Army Corp Permit (USACE)
  - For getting into the river
- Office of Water Resources (OWR) & Illinois Environmental Protection Agency (IEPA) Permits
  - For causeway permits
- Project Development Report (PDR)
- WHA initiated all the permits in advance to make sure the contractor does not have to get any permits and there was no delay in construction.

Hydraulic Analysis

- Hydraulic modeling was performed to determine the effect the proposed causeways, spurs and cofferdams will have on the water surface elevations and subsequently on nearby properties/houses.
- The design criteria for the causeways was based on creating no impact on the base flood event and minimizing created head while still allowing access to construction equipment for a wide range of flows.
- The temporary causeways and cofferdam obstructions were designed to provide approximately one foot of freeboard for the structures above the five-year event.

Hydraulic Analysis



Hydraulic Impact

Bike Path

Bike path used to access the construction site.

Causeway

- Causeway was utilized in the installation of the cofferdams and temporary deck supports, demolition of the existing pier stems and construction of the new pile supported footings and pier stems.
- The project was permitted for two causeway options to give the Contractor a choice on which one would be the easiest and cheapest to construct.
  - Option #1a consists of using an old bike path on the Southeast side of the bridge to gain access to the river and construct a causeway to both piers.
  - Option #1b consists of using the bike path on the Southeast side of the bridge to build a causeway to the South Pier and using a clearing on the Northeast side of the bridge to build a causeway to the North Pier.

Causeway

WATERWAY INFORMATION TABLE
Causeway Plus Cofferdams
(Note: Existing and Proposed columns do not include causeways, but represent before and after construction conditions.)

Route:	CH 3 (Bridge Street)	S.N. (Exist):	047-3000
Section:	17-00142-00-BR	S.N. (Prop):	047-3000
County:	Kendall	Waterway:	Fox River
Prepared by:	Willett, Hofmann & Associates	Date:	6/12/2017

Drainage Area:	2140 sq mi	Exist. Low Grade El. = 552.58 @ Sta. 13 + 43					Prop. Low Grade El. = 552.58 @ Sta. 13 + 43						
FLOOD	FREQUENCY (yr.)	Q (cfs)	Nat. H.W.E.	HEAD – FT					HEADWATER EL.				
				Exist.	Prop.	w/Causeway 1	w/Causeway 2	w/Causeway 3	Exist.	Prop.	w/Causeway 1	w/Causeway 2	w/Causeway 3
Causeway 1 Overtop	~ 0.7	1510	542.5	0.1	0.1	0.4	0.1	0.4	542.6	542.6	542.9	542.6	542.9
Causeway 2 Overtop	~ 0.8	2500	543.3	0.1	0.1	0.4	0.1	0.4	543.4	543.4	543.7	543.4	543.7
Causeway 3 Overtop	~ 0.7	1900	542.9	0.0	0.0	0.3	0.1	0.3	542.9	542.9	543.2	543.0	543.2
	5	15500	548.7	0.2	0.2	0.4	0.2	0.3	548.9	548.9	549.1	548.9	549.1
	10	20360	550.0	0.2	0.2	0.5	0.3	0.4	550.2	550.2	550.5	550.3	550.4
Design	30	28100	551.9	0.2	0.2	0.4	0.3	0.4	552.1	552.1	552.3	552.2	552.3
Base	100	36100	553.6	0.4	0.3	0.4	0.4	0.4	554.0	553.9	554.0	554.0	554.0
Max Calc	500	48400	555.9	0.4	0.4	0.4	0.4	0.4	556.3	556.3	556.3	556.3	556.3

Scope of Work: Pier Rehabilitation

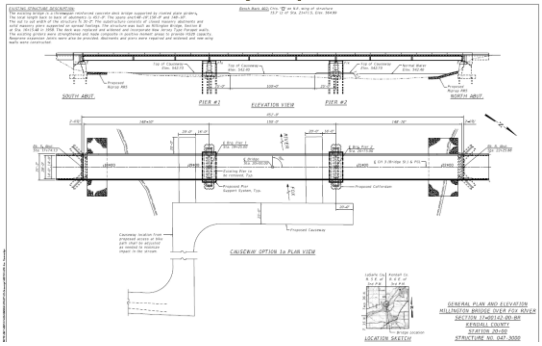
EXISTING STRUCTURE		PROPOSED STRUCTURE	
Type:	Closed Abutments	Type:	Closed Abutments
Length:	451'-9" back -back abutments	Length:	451'-9" back -back abutments
Spans:	2	Spans:	2
Low Beam:	557.9	Low Beam:	557.9
Skew:	None	Skew:	None

Note: The Natural HWE was taken at the upstream face of the bridge.
The created head was taken at the approach section of the bridge.
Flows are from LaSalle County FIS.
Starting water surface is calculated by HEC-RAS utilizing the slope-conveyance method.
All Elevations are based on NAVD88.

Waterway Table

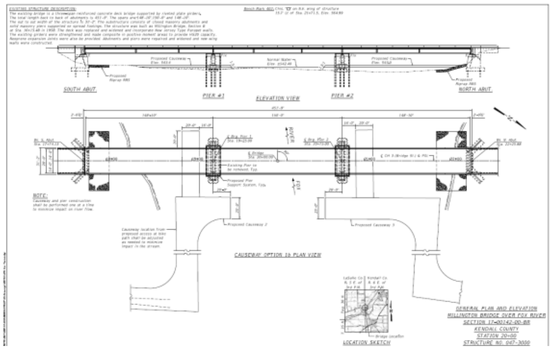
55

Causeway Option 1a



56

Causeway Option 1b



57

Causeway

58

Causeway

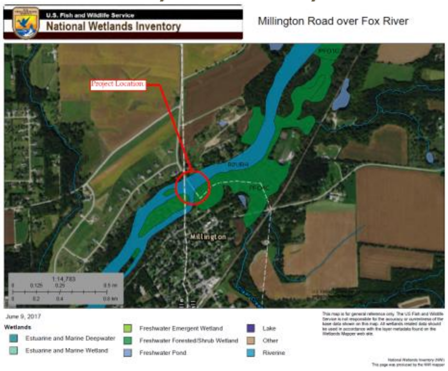
59

Causeway

Construction of Causeway to the access the bridge

60

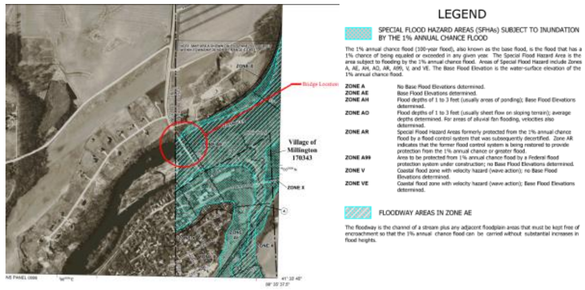
Hydraulic Analysis



National Wetland Inventory Map

61

Hydraulic Analysis

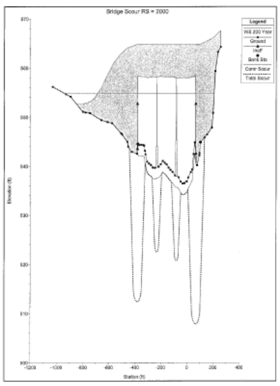


FEMA Map

62

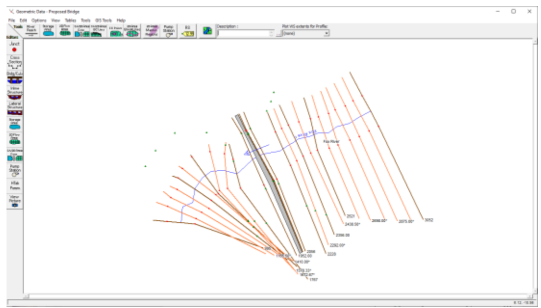
Hydraulic Analysis

- Scour Analysis was performed to determine if riprap was necessary to protect the abutments.



63

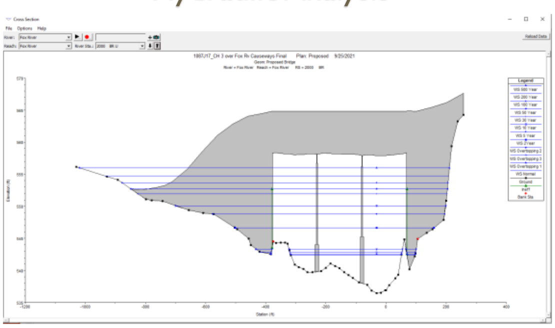
Hydraulic Analysis



Plan View

64

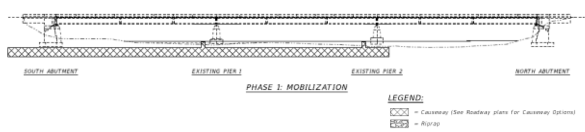
Hydraulic Analysis



Cross Section

65

Proposed Construction Sequence



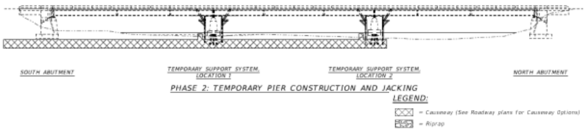
PROPOSED CONSTRUCTION SEQUENCE:

PHASE 1: MOBILIZATION

1) Install Causeway
2) Perform Grout Repair & Remove Debris
3) Drive Piles for Temporary Support System, Location 2
4) Drive Piles for Temporary Support System, Location 1

66

Proposed Construction Sequence



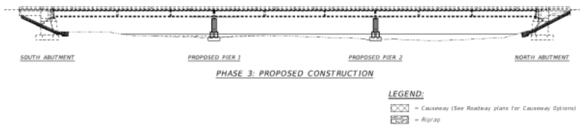
PROPOSED CONSTRUCTION SEQUENCE:

PHASE 2: TEMPORARY PIER CONSTRUCTION AND JACKING

5) Erect Steel for Temporary Support System, Location 2
6) Jack girders to transfer bridge support to Temporary Support System, Location 2
7) Remove designated/remaining portions of Existing Pier 2 (including designated grout bags)
8) Drive Proposed Pier 2 Piles
9) Drive and install Proposed Pier 2 Cofferdam sheets
10) At Pier 1, preform Steps 5-9 for Temporary Support System, Location 1 simultaneously with Location 2

67

Proposed Construction Sequence



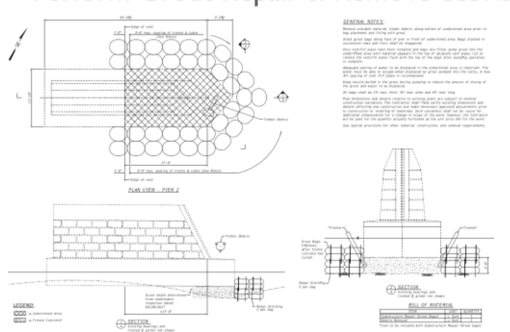
PROPOSED CONSTRUCTION SEQUENCE:

PHASE 3: PROPOSED CONSTRUCTION

11) Excavate Cofferdams, pour seal coat concrete, cure, and dewater
12) Construct proposed pier footings and cure
13) Construct proposed pier walls and cure
14) Install retrofit pier bearings
15) De-jack/disassemble temporary piers
16) Remove all temporary support system items and cutoff temporary pile per the Special Provisions
17) Install riprap
18) Perform designated deck repairs

68

Perform Grout Repair & Remove debris



- Contractor jetted all the mud before performing grout repairs.
- Grout repair was also necessary to install piles and prevent shaking of the existing pier.
- There was a flood during the construction work. Since, the existing pier was stabilized using the grout bags around it, the bridge was still under operation, but the traffic was limited to only normal weight traffic i.e., less than 5 tons.
- Contractor proposed an alternative method to stabilize the pier utilizing steel plates and we approved it.

69

Perform Grout Repair & Remove debris

70

Perform Grout Repair & Remove debris

71

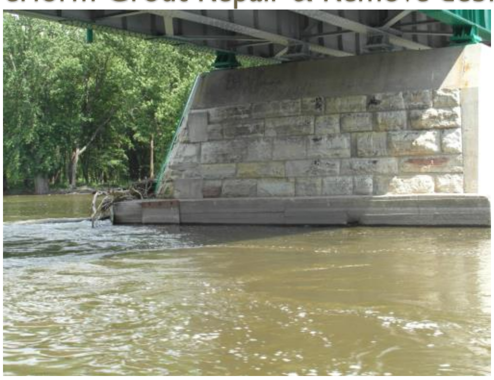
Perform Grout Repair & Remove debris

72

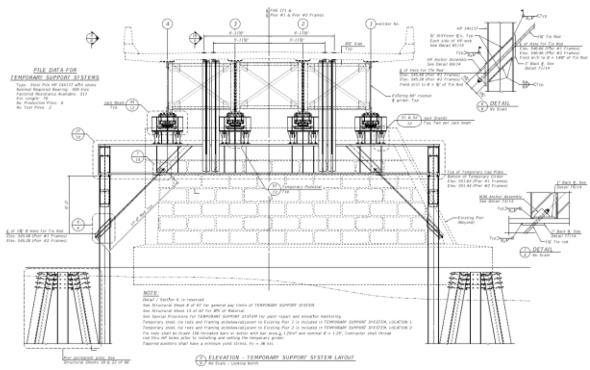
Perform Grout Repair & Remove debris

Perform Grout Repair & Remove debris

Perform Grout Repair & Remove debris

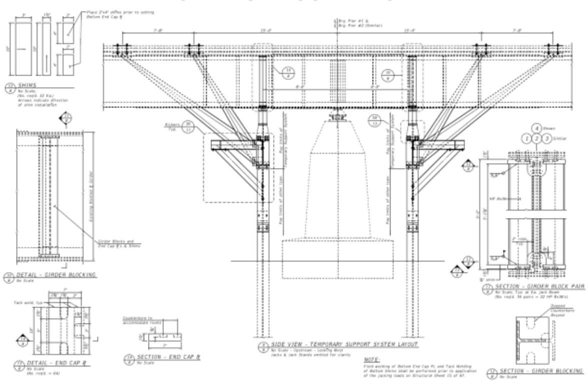


Temporary Support System

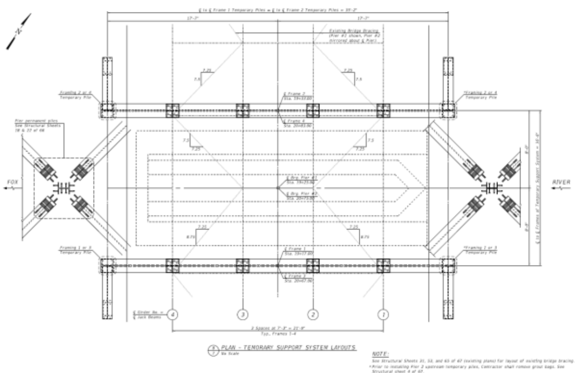


The transverse beam was W36x395.

Temporary Support System



Temporary Support System



Temporary Support System

Temporary Support System

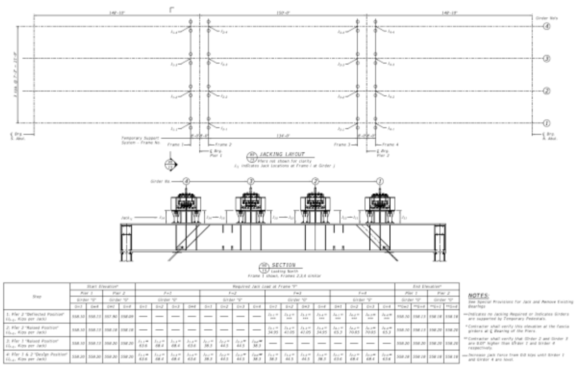
Temporary Support System

Use of kickers to provide stability for the beams in the temporary steel support system

Temporary Support System

Holes for the brace were slotted.

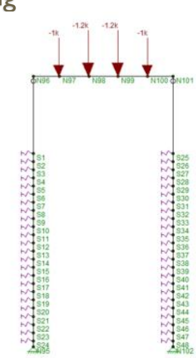
Jacking



Use of hydraulic jack to lift the bridge deck and girder during construction work

Jacking

When the bridge was lifted upwards using the hydraulic jack, the steel frame would deflect downwards to take the load. Thanks to the iterative solution that we came up with and we were finally able to design the frame to take this effect into account.



Jacking Analysis

Jacking

85

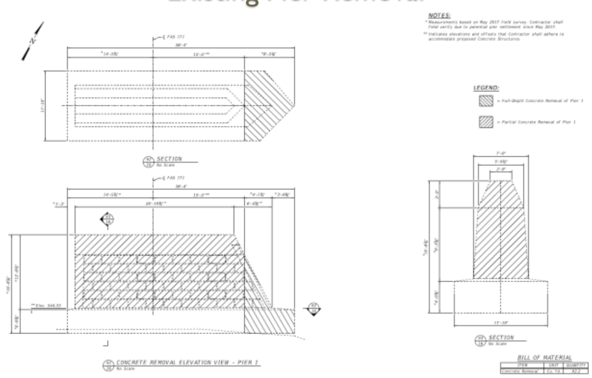
Jacking

86

Jacking

87

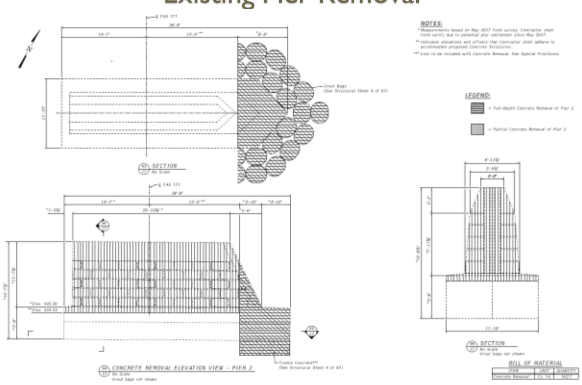
Existing Pier Removal



Pier 1 Removal

88

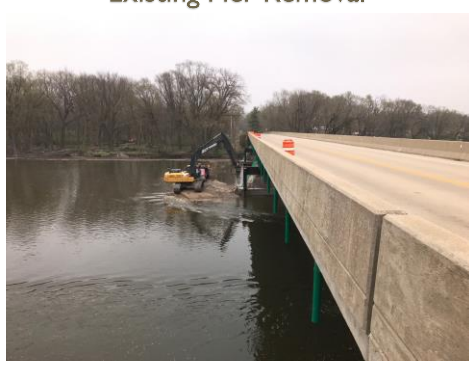
Existing Pier Removal



Pier 2 Removal

89

Existing Pier Removal



90

Existing Pier Removal

91

Existing Pier Removal

92

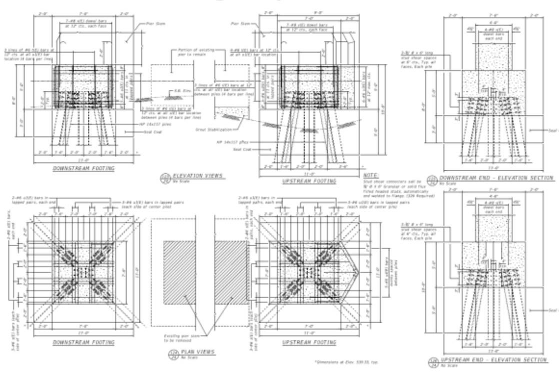
Cofferdam Installation

93

Cofferdam Installation

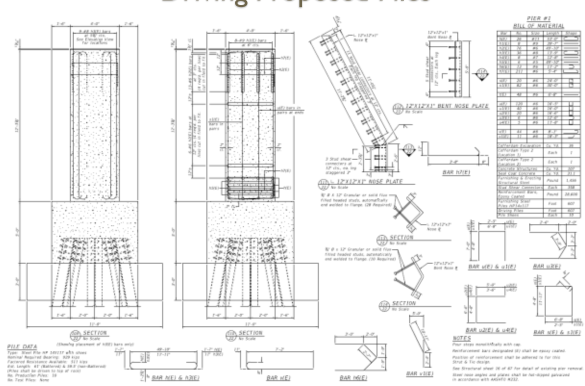
94

Driving Proposed Piles



95

Driving Proposed Piles

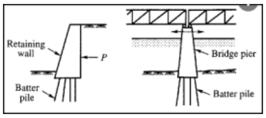


Proposed piles were HP 14X117 and 60' long driven to refusal.

96

Battered Pile Foundation

- Battered piles were used as a foundation for the pier.
- Battered piles are the piles which are driven at a certain angle to resist the vertical and lateral forces
- It gives additional stability against the lateral forces



Battered Pile Foundation

https://www.google.com/url?sa=i&url=http%3A%2F%2Fwww.abuildersengineer.com%2F2012%2F11%2Fuses-of-piles.html&psig=AOvVaw2by-oP1hffPTIkyAp5XW37&ust=1625351072433000&source=images&cd=vfe&ved=0CAcQjRxqFwoTCJievva2xfECFQAAAAAdAAAAABAD

97

Driving Proposed Piles

98

Driving Proposed Piles

99

Driving Proposed Piles

Contractor monitored the deck continuously to make sure the pier did not settle much.

100

Driving Proposed Piles

101

Construct Proposed Footings

102

Construct Proposed Footings

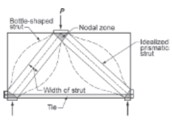
103

Construct Proposed Footings

104

Struct & Tie Pier

- Strut-tie model of piers resting on two battered pile support system.
- Strut-and tie method was suitable in this case as it can efficiently transfer the load from the superstructure to the footing below.
- Strut-tie model for beam is a concept of designing the deep beams where the load path within the structural member is idealized in the form of truss system.

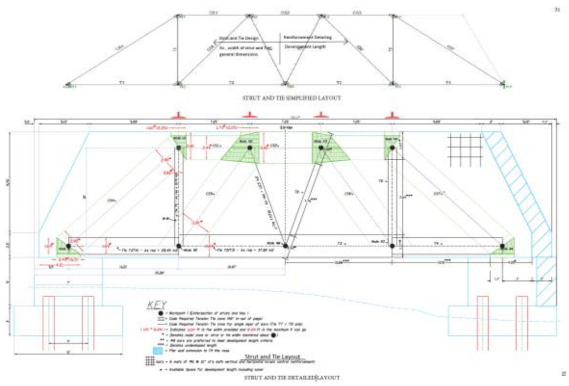


Description of Strut-and-tie model

Source: ACI 318-14

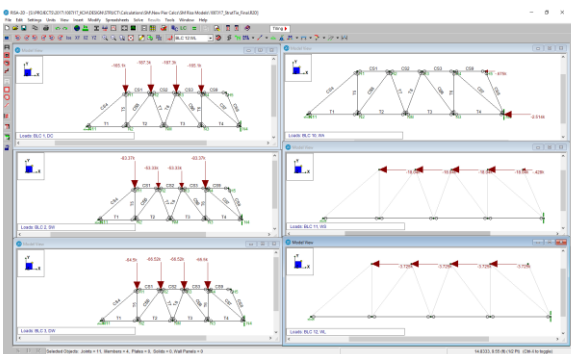
105

Struct & Tie Pier



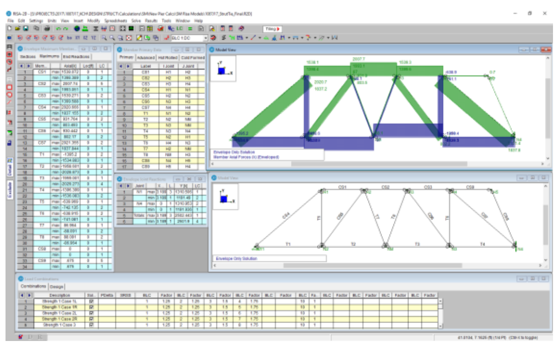
106

Struct & Tie Pier



107

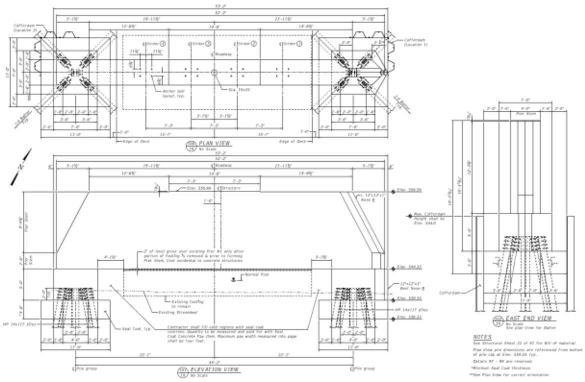
Struct & Tie Pier



RISA Model

108

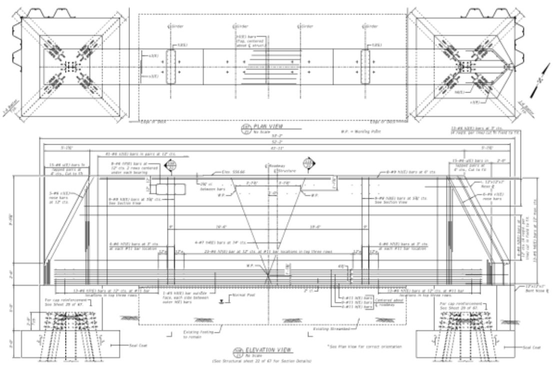
Struct & Tie Pier



Existing footing was assumed to provide no bearing.

109

Struct & Tie Pier



110

Struct & Tie Pier

Removal of existing pier

111

Struct & Tie Pier

Existing footing used as a base to construct proposed pier.

112

Struct & Tie Pier

Reinforcement Mat

113

Struct & Tie Pier

Reinforcement Mat

114

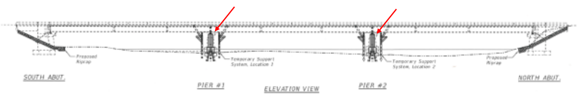
Struct & Tie Pier

Reinforcement Mat

Struct & Tie Pier

Bearing Modifications

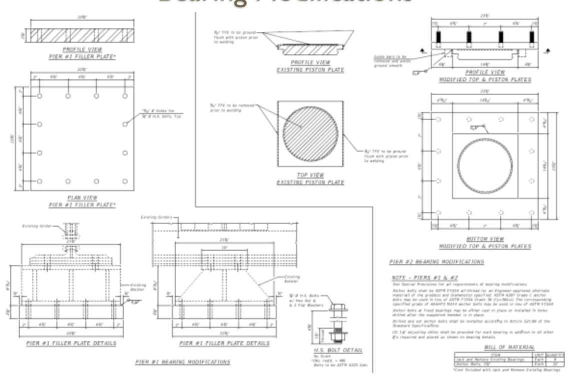
Existing Bridge



Proposed Bridge

Both the piers resist equal force.

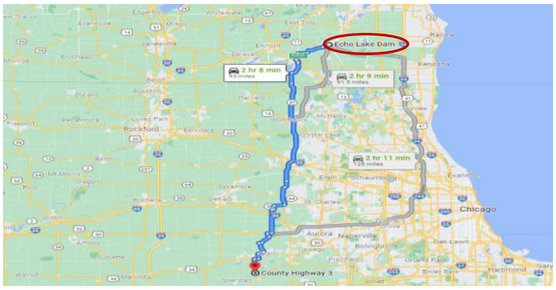
Bearing Modifications



Bearing Modifications

Disassemble Temporary Support System

Constructability Challenges



There is a dam upstream of the bridge and the Army Corps would release water during heavy rains. This would raise water level unexpectedly and flood the causeway.

121

Constructability Challenges

We were not able to do any construction work because of the flooding for 1 construction season.

122

Conclusion

- Despite many challenges, we were able to replace the Millington Bridge Piers and it is under operation carrying the loads efficiently.
- We were able to incorporate the concept of strut-and-tie model of beam in this new pier design and construction with battered piles foundation at the ends.

123

Conclusion

124

Millington Bridge Pier Replacement

Brian K. Converse, P.E., S.E. : bconverse@willetthofmann.com
Satyam Mandloi, E.I. : smandloi@willetthofmann.com

Questions?

WILLETT HOFMANN & ASSOCIATES INC

WillettHofmann.com

125