I-94 Advanced Bridge Replacement

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ACKNOWLEDGMENTS

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7.1.1 Critical Path
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1. INTRODUCTION

1.1 BACKGROUND

The Michigan Department of Transportation has always felt the need of improving and increasing the capacity of the most critical highway in the state of Michigan, I-94. Part of the improvement plan is to increase the capacity of a 6-mile segment along a corridor of I-94 from French Avenue to Trumbull Avenue which is in a suburban neighborhood of Detroit. There are eight bridges built in the 1950’s that need to be re-constructed for a capacity increase. Vehicular and non-motorized traffic must be accounted for in the design of these bridges. The project is intended to increase the service life of the new bridges to 75 years. The anticipated service completion date is Fall 2018.

This project is being managed by HNTB Michigan, Inc. and was given the authority by MDOT as the Owner’s Representative Consultant. HNTB has asked Western Michigan University to provide this project as one of the projects for students to work on for the Civil Engineering Senior Design Project.
Figure 1.1.3 Brush Street Bridge

Figure 1.1.4 Piers Existing Condition
Figure 1.1.5 Sidewalks Existing Condition

Figure 1.1.6 Girders Existing Condition
1.2 SCOPE OF WORK

From the eight bridges that need replacement, our team decided to focus our work on Brush Street bridge. One reason is because in 2014 alone, there have been 15 accidents on or near this bridge. Our team wants to increase safety in the specific area. Another reason to choose this bridge, is because of its location near a high traffic volume area. The completion of this bridge will bring the most benefits to people and businesses alike. The estimated cost of construction is shown below:

- Bridge Cost: $8,800,000
- Road Cost: $500,000
- Total Cost: $9,300,000

The work will conform with the current MDOT, FHWA, and AASHTO practices, guidelines, policies, and standards.

The work that is part of the responsibility of our team includes the following:

- Bridge Design
- Preliminary Construction Planning
- Cost Estimate
- Sustainability
- Transportation Study
1.3 DELIVERABLES

The deliverables of this project include:

- Design of the substructure
- Transportation planning and pedestrian safety
- Sustainability

Structural analysis for the bridge deck was conducted using Bentley Leap Bridge Concrete to determine the loadings necessary to complete the new design. During the design process, we will be looking at the substructure of the Brush Street bridge. Detailed design calculations of the pier cap and piers will be completed.

Our team has considered different safety aspects. Pedestrian safety will be addressed during the design phase of the bridge. Other factors that will be considered are sidewalk width, potential bicycle lanes, and necessary fencing on the bridge.

Our team considered different sustainability aspects during all phases of construction. During demolition, existing materials such as asphalt, aggregate, and steel will be considered for recycling. For traffic planning, our team will come up with the most effective routes to minimize delay time. LED lighting has been implemented along the bridge for safety and sustainable purposes.

1.4 PROJECT CONSTRAINTS

The eight bridges are to be constructed using partial Advanced Bridge Construction (ABC) Technology. ABC is applied by pre-casting the substructure and shipping it to the construction site. By doing so, it will minimize traffic impacts. Other benefits to this method of construction include: safety, durability, and environmental impacts. ABC technology is anticipated to complete the replacement within a three-week local roadway closure period. I-94 itself is limited to only three weekend closures so demolition and erection of bridges can take place. Self-Propelled Modular Transporters (SPMT’s) will be used to move components of the bridge from the side of the road to its final location. SPMT’s will allow the project to be completed in the required timeframe. ABC technology is anticipated to reduce user delay costs, enhance work zone safety, and keep traffic on I-94 flowing while the bridge is under construction. The technology is anticipated to save, for this type of project, 1.6 million dollars per bridge of user delay costs.
Another major constraint is utilities. A sewer line, eleven feet in diameter running four and a half feet underground along the centerline of the bridge will be considered for the configuration of the pile foundations.

1.5 Significance

The purpose of this project is to improve the capacity and existing road conditions of I-94 for all traffic modes on the bridge, including motorized and non-motorized paths, using ABC methods. This technology is relatively new and aims to increase quality while reducing environmental impacts. After researching different methods of ABC, the most efficient one will be implemented. In Michigan, specifically, ABC has not been used very much. However, in this project, it will be used eight different times, on this project alone. This will be a turning point for bridge construction, giving Michigan the opportunity to refine the process ABC requires.

1.5 Research Goals

The goals of this project include, but is not limited to: safety, ease of use, cost, increase in service life, and minimum disruption of traffic. The increase of traffic safety includes drivers, transit users, pedestrians, as well as bicyclists. The project will make the corridor more accessible to neighboring residents along with visitors who are passing by the corridor. Another goal will be to develop a strategy that will reduce the cost on both traffic and the loss of neighboring industries. The project will assure access for homes and businesses that are affected by construction. In addition, increasing service life of the bridge up to 75 years is one of the main goals on this project.
2. STRUCTURAL DESIGN

2.1 DESIGN ASSUMPTIONS & CONSIDERATIONS

Design began by modeling the bridge using Bentley Leap Bridge Concrete software. The required loading was Michigan Department of Transportation HL-93. A pedestrian live load of 450 pounds per foot was assumed. The pier cap was designed as a continuous beam. Live load reaction forces of the girders from both spans were added together and treated as point loads in the analysis of the pier cap. Live load distribution factors were also considered. These factors account for the uncertainty of the orientation of cars, trucks, and pedestrians on the bridge deck. Software implemented the factors itself, however, these were also calculated by hand to ensure accuracy. The dead loads were imported into the analysis of the substructure via software. The bridge deck, girders, sidewalks, and fencing was all accounted for. The piers were designed as non-slender beam-columns. Analysis was also completed using Bentley software. Designs were hand calculated, and after completion, they were entered into the bridge model for review and acceptance.

2.2 LOAD CALCULATIONS SUMMARY

The table below summarizes the maximum loadings used in the design. Refer to Appendix A for detailed diagrams.

**Table 2.2.1 Load calculations summary**

<table>
<thead>
<tr>
<th>Loads</th>
<th>Pier Cap</th>
<th>Pier</th>
<th>Footing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Moment</td>
<td>502.2 kip-ft</td>
<td>55.42 kip-ft</td>
<td>987 kip feet</td>
</tr>
<tr>
<td>Negative Moment</td>
<td>897.3 kip-ft</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Shear</td>
<td>366.2 kip</td>
<td>-</td>
<td>145 kip</td>
</tr>
<tr>
<td>Axial</td>
<td>-</td>
<td>556.3 kip</td>
<td>-</td>
</tr>
</tbody>
</table>
2.3 DESIGN STEPS

2.3.1 PIER CAP

After analysis was finished, design of the pier cap was to be completed first. A cross section of 36 inches tall by 36 inches wide was chosen to establish a baseline. Concrete strength was decided to be 3000 pounds per square inch (psi). ACI’s maximum reinforcement ratio for 3000 psi concrete is 0.0181, this was used initially and refined later. After reading AASHTO code, there were spacing ratios, regarding the cross-section depth and the pier cap span, that needed to be met. Our cross section was not up to code, therefore requiring a larger cross section. After increasing the cross section to 42 inches tall and 40.5 inches wide, the standards were satisfied. Once a cross section was established, the reinforcement ratio was refined using the equation below.

\[ \rho := \left(0.85 \cdot \frac{f_c}{f_y}\right) \cdot \left(1 - \sqrt{1 - \left(2 \cdot \frac{R_n}{0.85 \cdot f_c}\right)}\right) = 0.002 \]

From there, the required area of reinforcement was determined and compared to the minimum amount needed. The minimum area of steel controlled, requiring 5.33 square inches of reinforcement. Eight number eight rebar were used, totaling 6 square inches of reinforcement. A final strength check was completed to determine the adequacy of the member, below shows the calculation of the nominal moment capacity.

\[ M_n := A_s \cdot f_y \cdot \left(d - \frac{a}{2}\right) = (1.133 \cdot 10^3) \text{ kip} \cdot \text{ft} \]

\[ \phi \cdot M_n = (1.019 \cdot 10^3) \text{ kip} \cdot \text{ft} \]

As you can see, the reinforcement configuration designed satisfies the moment requirement for the positive flexural section of the beam. The process of designing the negative moment section was a bit simpler because a cross section had already been determined. Apart from sizing the cross section, the same design process was followed. For detailed calculations for flexural reinforcement, see Appendix A.
After the flexural design was completed, shear design began. First, the shear strength of concrete was determined using the equation below.

\[ V_c := 0.0316 \cdot \beta \cdot z \cdot \sqrt{f_{c'}} \cdot b_v \cdot d_v = 162.545 \text{ kip} \]  
AASHTO S5.8.3.3-3

Next was to determine the required shear reinforcement to satisfy the ultimate shear force the pier cap was subjected to. A maximum spacing of stirrups was calculated to be twelve inches, using AASHTO code S5.8.2.7-2. Number four stirrups were selected for use. Using the equation below, we determined the required spacing to satisfy the ultimate shear force.

\[ V_s := \frac{(A_v \cdot f_y \cdot d_v)}{s} = 272.781 \text{ kip} \]  
AASHTO S5.8.3.3-4

Choosing the final design, 4 leg stirrups were used at a spacing of ten inches. This configuration proved to be the most economical choice. Since four leg stirrups were used, it was concluded that the stirrups needed to be spaced at ten inches throughout the beam, to support the shear reinforcement, flexural rebar was spanned along the entire pier cap length. Below are the equations showing the nominal shear capacity exceeding the ultimate shear force. For detailed shear force calculations, refer to Appendix A.

\[ V_n := V_s + V_c = 435.326 \text{ kip} \quad \phi \cdot V_n = 391.794 \text{ kip} \]

2.3.2 PIER

After the design of the pier cap was finished, we had a baseline dimension to start with our piers. AASHTO code requires the pier cap to have an overhang of at least four and a half total inches. A diameter of 36 inches was chosen. A conservative approach was taken for design. the maximum axial load and moment of the pier configuration was used in an interaction diagram to find a reinforcement ratio of 0.01. This gave us a required steel reinforcement area of 10.18 square inches. AASHTO code S5.7.4.2-3 states that the ratio listed below must be greater than 0.135 to meet the minimum requirement of reinforcement.

\[ A_{smin} := \left( \frac{A_s \cdot f_y}{A_g \cdot f_{c'}} \right) = 0.2 \]
Twelve number nine longitudinal reinforcement bars were used to keep uniform spacing throughout the pier, making the total reinforcement area twelve square inches. From AASHTO table 5.12.3-1, a clear cover of 2 inches was used, referring to normal exposure conditions. For detailed calculations on, refer to Appendix A.

2.3.3 FOOTING

Analysis was conducted using LEAP concrete software to determine the maximum loads the footings needed to resist. Design was also completed using the same software. A different approach was taken to design the footings. The program determined the required number of reinforcement required to resist the applied forces. From there, different configurations were entered into the program. After iterating, two rows of ten number eight bar, crossing perpendicularly, on the top and bottom proved to be sufficient. A table detailing reinforcement can be found in Appendix A.

*disclaimer* all calculations, moment, and shear diagrams can be found in Appendix A
2.4 CAD DRAWINGS

**Figure 2.4.1** Pier cap side view

**Figure 2.4.2** Pier cap cross section
FIGURE 2.4. 3 PIER ELEVATION VIEW

FIGURE 2.4. 4 PIER CROSS SECTION
FIGURE 2.4. 5 FOOTING TOP AND SIDE VIEW
2.5 COST ANALYSIS

Instead of doing an approximate cost estimate of the entire project, a detailed cost estimate of the substructure was completed. This decision was based on accuracy. The estimate was started by first calculating the amount of rebar (in tons), followed by the volume of concrete (in cubic yards), and finished with earthwork. RS Means 2012 was used to determine unit prices. Labor, material and equipment were included in the unit prices. The bare cost was calculated, this does not include sales tax, contingency, bonds, insurance, overhead, and profit. The breakdown of quantities, unit prices, and totals can be seen in the table below.

**Table 1.5.1 Substructure Cost Estimate**

<table>
<thead>
<tr>
<th>Item</th>
<th>Measurement</th>
<th>Amount (tons)</th>
<th>Unit Cost ($/ton)</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rebar</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier Cap</td>
<td>per ton</td>
<td>2.4</td>
<td>$1,560</td>
<td>$3,744</td>
</tr>
<tr>
<td>Pier</td>
<td>per ton</td>
<td>1.11</td>
<td>$1,665</td>
<td>$1,848</td>
</tr>
<tr>
<td>Footing</td>
<td>per ton</td>
<td>3.07</td>
<td>$1,315</td>
<td>$4,037</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>$9,629</td>
</tr>
<tr>
<td><strong>Concrete</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier cap</td>
<td>per CY</td>
<td>37.1</td>
<td>$840</td>
<td>$31,164</td>
</tr>
<tr>
<td>Piers</td>
<td>per CY</td>
<td>14.3</td>
<td>$696</td>
<td>$9,951</td>
</tr>
<tr>
<td>Footings</td>
<td>per CY</td>
<td>80</td>
<td>$240</td>
<td>$19,229</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>$60,343</td>
</tr>
<tr>
<td><strong>Earthwork</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excavation and Backfill</td>
<td>Per BCY</td>
<td>5754</td>
<td>$4.37</td>
<td>$25,145</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>$95,118</td>
</tr>
</tbody>
</table>

For detailed calculations of quantities of material and earthwork refer to Appendix A.
3. TRANSPORTATION

3.1 TRAFFIC ANALYSIS & BRUSH STREET OVERVIEW

3.1.1 EXISTING CONDITION

Brush Street bridge over I-94 currently has four northbound thru lanes with a speed limit of 25 miles per hour. Average Annual Daily Traffic (AADT) on Brush Street bridge is 6,160 veh/day in 2010.

The existing intersection of Brush Street and I-94 Eastbound Service Dr. is signalized and consists of the following lane configurations:

- Eastbound Approach: One left-turn lane and two through lanes
- Westbound Approach: No approach present (one-way)
- Northbound Approach: Three through lanes and one shared thru/right-turn lane
- Southbound Approach: No approach present (one-way)

The existing intersection of Brush Street and I-94 Westbound Service Dr. is signalized and consists of the following lane configurations:

- Eastbound Approach: No approach present (one-way)
- Westbound Approach: One through lane and one shared thru/right-turn lane
- Northbound Approach: Three through lanes and one shared thru/left-turn lane
- Southbound Approach: No approach present (one-way)

**Intersection LOS for Brush Street Over I-94:**

<table>
<thead>
<tr>
<th>Table 3.1.1</th>
<th>Traffic Analysis of Brush St Intersections</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intersection</strong></td>
<td><strong>Peak Hour</strong></td>
</tr>
<tr>
<td>Brush Street &amp; I-94 EB Service Dr</td>
<td>AM Peak Hour</td>
</tr>
<tr>
<td></td>
<td>PM Peak Hour</td>
</tr>
<tr>
<td>Brush Street &amp; I-94 WB Service Dr</td>
<td>AM Peak Hour</td>
</tr>
<tr>
<td></td>
<td>PM Peak Hour</td>
</tr>
</tbody>
</table>

Outputs from Synchro for individual movements which include Level of Service (LOS) are summarized in Table 3.1.1.1
The detailed peak hour traffic volumes on Brush Street bridge is given in Table 3.1.2 below:

**Table 3.1.2: Brush St Peak Hour and Traffic Volume Data**

<table>
<thead>
<tr>
<th>Peak Hour</th>
<th>Traffic Volume (AADT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 AM – 8:00 AM</td>
<td>349 veh/day</td>
</tr>
<tr>
<td>4:00 PM – 5:00 PM</td>
<td>885 veh/day</td>
</tr>
</tbody>
</table>

**3.1.2 MAINTENANCE OF TRAFFIC (MOT)**

Brush Street bridge and the affected segment of I-94 east and west bound will be closed and detoured during the construction. Removal of the existing structure and placement of the beams will require intermittent closure of I-94. Full closures of I-94 will only be permitted on weekends from 10:00 PM Friday to 5:00 AM Monday per the Michigan Department of Transportation (MDOT). Table 3.1.2.3 is a summary of I-94 existing conditions:

**Table 3.1.2.1 Summary of I-94 Existing Conditions**

<table>
<thead>
<tr>
<th>Existing Condition</th>
<th>I-94 East Bound</th>
<th>I-94 West Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane Configuration</td>
<td>3 Lanes</td>
<td>3 Lanes</td>
</tr>
<tr>
<td>MOT Lane Configuration</td>
<td>Detour: 3 Lanes</td>
<td>Detour: 3 Lanes</td>
</tr>
<tr>
<td>Peak Hour Volume (PHV)</td>
<td>4,255 veh/hour</td>
<td>3,975 veh/hour</td>
</tr>
<tr>
<td>Hourly Capacity</td>
<td>6,000 veh/hour</td>
<td>6,000 veh/hour</td>
</tr>
<tr>
<td>PHV Timeframe</td>
<td>3:00 PM – 4:00 PM</td>
<td>2:00 PM – 3:00 PM</td>
</tr>
<tr>
<td>Level of Service (LOS)</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

The Average Annual Daily Traffic (AADT) on I-94 in weekends is 63,239 veh/day. The full closure of I-94 is only three weekends. Due to the substructure construction activities of Brush Street bridge, detour routes were designed for motorists who need to pass through this segment.
3.2 DETOUR ROUTES

Two different alternative detour routes were created due to the closure of Brush Street bridge. These detour routes had been determined based on the shortest distance and minimum Level of Service (LOS) to reach Northbound of Brush Street. Figure 4 represents two alternative detour routes:

- **Alternative 1** – Black Line (Northbound Brush Street Detour): 0.67 miles.
  - WB Hendrie Street – NB Woodward Avenue – EB Harper Street
- **Alternative 2** – Blue Line (Northbound Brush Street Detour): 0.89 miles.
  - SB John R Street – EB Palmer Street – NB St Antoine Street – EB Hendrie Street – NB Beaubien Street – WB Harper Avenue

![Figure 3.2.1 Northbound Brush Detour & Westbound I-94 Service Detour](image-url)
### Table 3.2.1 Traffic Analysis Due To Brush St Bridge Closure

<table>
<thead>
<tr>
<th>Route</th>
<th>Total Distance (miles)</th>
<th>Maximum Volume (AADT)</th>
<th>Minimum LOS</th>
<th>Intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>0.67</td>
<td>22,800</td>
<td>B</td>
<td>John R St &amp; Hendrie St</td>
</tr>
<tr>
<td>(Black Line)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative 2</td>
<td>0.89</td>
<td>6,800</td>
<td>C</td>
<td>Beaubien St &amp; Harper St</td>
</tr>
<tr>
<td>(Blue Line)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The total distance of alternative 1 is 0.67 miles starting from I-94 EB Service Drive until motorists reach Northbound Brush Street. These two alternative detour routes were created assuming by 70% of motorists would choose the alternative 1 and 30% of motorists would choose alternative 2 after they got into I-94 EB Service Drive. Therefore, the maximum vehicles in a day would reach 22,800 for alternative 1. Based on this assumption, John R Street and Hendrie Street intersection would have a Level of Service (LOS) B.

The total distance of alternative 2 is 0.89 miles starting from I-94 EB Service Drive until motorists reach Northbound Brush Street. The maximum vehicles in a day would reach 6,800 for alternative 2. Based on this assumption, the Beaubien Street and Harper Avenue intersection will have a Level of Service (LOS) C.

Detour route traffic analyses has shown that even though alternative 1 is reaching 22,800 vehicles a day, it would be a better option for motorists since Woodward Avenue has a total of 7 lanes. Also, the minimum Level of Service in alternative 1 would be B, so that is another criterion to select alternative 1 over alternative 2.

The detour route was created in Figure 6 for full closure of I-94 due to construction activities on Brush Street bridge. The full closure will be only three weekends. The working timeframe is starts from 10:00 PM Friday until 5:00 AM Monday per Michigan Department of Transportation (MDOT) requirements.

- Detour route – Green Line breaks down into two parts:
  - Eastbound I-94 Detour: 5.1 miles
  - SB I-75 – NB I-75 – Exit NB I-75 – NB I-75
Motorists who are travelling from Eastbound of I-94 to Westbound of I-94 take exit 214C to merge Southbound of M-10 and take exit 2A to connect EB I-75 and take exit 53B to connect NB of I-75 and finally take exit 53A to reach back to I-94.

- Westbound I-94 Detour: 5.1 miles
  - SB I-75 – WB I-75 – NB M-10

Motorists who are travelling from Westbound of I-94 to Eastbound of I-94 take exit 216A to merge Southbound of I-75 and take exit 51B to connect WB of I-75 and take exit 49B to connect NB of M-10 and finally take exit 4B to reach back to I-94.

**Figure 3.2. 2 Detour on EB and WB of I-94**
3.3 SAFETY ANALYSIS

Safety analysis is conducted to improve the traffic safety on Brush Street bridge and its surrounding area. There are total of 17 crashes that happened at the intersection of Brush Street and I-94 EB Service Drive. Figure 3.3.1 shows the location of all the crashes happened on Brush Street.

![Figure 3.3.1 Location of the crashes](image)

Per the Southeast Michigan Council of Governments (SEMCOG) crash and road data five of these crashes are C-Level type injuries, which is the worst injury possible. Twelve of these crashes are Property Damage Only (PDO) type of crashes, which resulted no injuries. Figure 3.3.2 is a pie chart shows a detailed crash types that happened in the year between 2011 and 2015. Based on the data, 50% of the crashes were intersection involved, 14% of the crashes were young drivers involved and red light running.
Increasing the number of lanes based on the new recommended bridge configuration will decrease the amount of intersection involved crashes by assuming the traffic volume will remain approximately the same. Effectively, less cars will pass and ideally have less crashes. In addition to increasing the number of lanes, installing LED lighting and increasing the number of street lights will give a clear vision to drivers, avoiding significant crashes. A Proposed bridge model has new bike lanes and plants to provide a sustainable area around Brush Street bridge so that drivers could be more careful while driving. This will ideally decrease the number of crashes occurring due to running red lights, drivers will be more cautious from pedestrians walking or biking around the area.
4. CONSTRUCTION MANAGEMENT

4.1 WORK BREAKDOWN STRUCTURE

The construction schedule was developed with the aid of Microsoft Project software. The use of Critical Path Method resulted in a total duration of 193 working days. The use of Work Breakdown Structures was implemented to help organize the project and better deliver a more detailed cost estimate that would be done by the estimators. The chart below shows the WBS for all the phases of the project.

**Figure 4.1.1 Project WBS**

The start date of the project is planned to begin March 3rd, 2016. The project will start with the mobilization phase and collection of all the required permits. The actual move in to the site will not be starting until the beginning of the 2018 construction season. That would be around the beginning of April, 2018. The figure below shows the estimated timeline of the project.

**Figure 4.1.2 Project Timeline**

It is assumed that some of the activities are interruptible and that is reflected in the overall duration of each main activity.
The list of activities for the completion of the bridge replacement are as follows:

**Table 4.1.1 Summary Tasks**

<table>
<thead>
<tr>
<th>WBS</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Unique ID Predecessors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Brush St. Bridge Replacement</td>
<td>193 days</td>
<td>Mon 3/5/18</td>
<td>Wed 11/28/18</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Project Mobilization</td>
<td>60 days</td>
<td>Mon 3/5/18</td>
<td>Fri 5/25/18</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>Demolition</td>
<td>19 days</td>
<td>Mon 4/16/18</td>
<td>Thu 5/10/18</td>
<td>3,52,53,2</td>
</tr>
<tr>
<td>1.3</td>
<td>Substructure</td>
<td>104 days</td>
<td>Fri 5/11/18</td>
<td>Wed 10/3/18</td>
<td>70</td>
</tr>
<tr>
<td>1.4</td>
<td>Superstructure</td>
<td>27 days</td>
<td>Thu 10/4/18</td>
<td>Fri 11/9/18</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Paving</td>
<td>76 days</td>
<td>Mon 7/30/18</td>
<td>Mon 11/12/18</td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>Finish Work</td>
<td>21 days</td>
<td>Wed 10/17/18</td>
<td>Wed 11/14/18</td>
<td></td>
</tr>
<tr>
<td>1.7</td>
<td>Project Closeout &amp; Termination</td>
<td>10 days</td>
<td>Thu 11/15/18</td>
<td>Wed 11/28/18</td>
<td></td>
</tr>
</tbody>
</table>
4.2 CRITICAL PATH

Critical path method was followed to determine the overall duration as well as all phases of the project.

The summary of critical activities that would directly affect the overall duration of the project are tabulated below:

**Table 4.2.1 Critical Activities**

<table>
<thead>
<tr>
<th>WBS</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Unique ID Predecessors</th>
<th>Resource Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1.2.1.2</td>
<td>Paving subcontract</td>
<td>20 days</td>
<td>Mon 3/5/18</td>
<td>Fri 3/30/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.2.1.3</td>
<td>Painting subcontract</td>
<td>20 days</td>
<td>Mon 3/5/18</td>
<td>Fri 3/30/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.2.1.4</td>
<td>Procure structural steel</td>
<td>60 days</td>
<td>Mon 3/5/18</td>
<td>Fri 5/25/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.3.1</td>
<td>Set up site</td>
<td>5 days</td>
<td>Mon 4/2/18</td>
<td>Fri 4/6/18</td>
<td>55,2,53,3</td>
<td></td>
</tr>
<tr>
<td>1.1.3.2</td>
<td>Move Equipment</td>
<td>5 days</td>
<td>Mon 4/9/18</td>
<td>Fri 4/13/18</td>
<td>55,2,53,3,12</td>
<td></td>
</tr>
<tr>
<td>1.2.1</td>
<td>Paving removal</td>
<td>2 days</td>
<td>Mon 4/23/18</td>
<td>Tue 4/24/18</td>
<td></td>
<td>69</td>
</tr>
<tr>
<td>1.2.2</td>
<td>Utility Line removal</td>
<td>5 days</td>
<td>Mon 4/16/18</td>
<td>Fri 4/20/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.3</td>
<td>Bridge Demolition</td>
<td>12 days</td>
<td>Wed 4/25/18</td>
<td>Thu 5/10/18</td>
<td>69,71</td>
<td>Crane, piling subcontract</td>
</tr>
<tr>
<td>1.3.1.1</td>
<td>N. abutment piling</td>
<td>4 days</td>
<td>Fri 5/11/18</td>
<td>Wed 5/16/18</td>
<td>2,54,4,11,12</td>
<td></td>
</tr>
<tr>
<td>1.3.1.2</td>
<td>N. abutment dewatering</td>
<td>5 days</td>
<td>Thu 5/17/18</td>
<td>Wed 5/23/18</td>
<td>10,13</td>
<td></td>
</tr>
<tr>
<td>1.3.1.3</td>
<td>N. abutment excavation</td>
<td>2 days</td>
<td>Thu 5/24/18</td>
<td>Fri 5/25/18</td>
<td></td>
<td>Backhoe</td>
</tr>
<tr>
<td>1.3.1.4</td>
<td>N. abutment footing</td>
<td>10 days</td>
<td>Mon 5/28/18</td>
<td>Fri 6/8/18</td>
<td>8,17,9</td>
<td>Crane</td>
</tr>
</tbody>
</table>
The network chart below shows all the activities that are in the critical path of the project.

**FIGURE 4.2.1 NETWORK CHART FOR CPM**
5. ELEMENTS OF SUSTAINABILITY

A sustainability study was conducted by looking at different researches and online material that was found from construction companies and personals. Sustainability is a significant aspect of engineering. Considering the size of projects civil engineers complete, the impact on environment, society, and economy could be astronomical if this topic is not carefully considered.

5.1 RESEARCH

When talking about sustainability all aspects must be considered. A balance is found to come up with the most beneficial design that fits all these aspects of sustainability. A Sustainable design would reduce the amount of waste, minimize impacts of traffic congestions, and cost less per year for maintenance. Achieving sustainability in these aspects could be done in many ways. Here are some of the ways that will be discussed in this report:

- **Rapid construction**
  - Reduce traffic delays; lowering emissions
  - Hours waiting for concrete curing
  - User delay costs
- **Extended service life using reliable and durable systems**
- **Improving material quality and concrete mixes**
  - Use of organic paint, stains, and other coating materials used on steel
  - Use fly ash or silica fume to help reduce CO$_2$ emissions by reducing cement usage
- **Reduce traffic delays to minimize effect on businesses and commuters**
- **Reduce distance traveled which would help reduce gas consumption by subcontracting with local companies for material and work**
- **Non-motorized facilities**
- **Ultra-high performance concrete**
  - 25,000-30,000psi
  - High cement content with 1200 pcy
  - Lightweight aggregates
- **Use of HCB (Hybrid composite Beams)**
  - Lighter
    - No need to replace the foundation
  - Less transportation costs
  - Less maintenance
  - Extended life span +100 years
  - No corrosion
5.2 RECOMMENDATIONS

By researching sustainability our team found that we could cover this area by three components. Environmental, social, and economical aspects. As Dr. Aktan suggested, we will focus more on the social and the economic impacts of sustainability. Designing the bridge to accommodate non-motorized facilities would be an important part of the project.

The bridge need to accommodate 2-way traffic as well as sidewalks and bike paths. That would greatly help the community cross from north to south without having the need to interfere with vehicular traffic. Non-motorized facilities will promote the use of alternate transportation methods, such as walking and biking. That eventually would have a great impact on the environment and promote a healthier community in the surrounding area.

The partial use of ABC technology would have a large economic impact. We will apply the ABC methodology using a pre-cast concrete for the different components of the bridge. Doing so will help reduce the overall road closure time. That will reduce the user delay costs. The precast provider will be from the Detroit and its surrounding area which would help reduce the transportation cost and carbon emissions caused by the extra gas consumed to ship the pre-casted material.

The bridge design will call for some planting areas on the sides of the bridge to encourage more people to walk across the bridge. Our team will also consider the use of organic paint, stains, and other coating materials that would reduce corrosion and carbon emission.
6. SUMMARY & CONCLUSIONS

6.1 DELIVERABLES ACCOMPLISHED

The project deliverables that was accomplished are as follows:

- **Design of the substructure**
  Structural analysis for the bridge deck was conducted using Bentley Leap Bridge Concrete to determine the loadings necessary to complete the new design. During the design process, only the substructure of the Brush Street bridge was considered. Detailed design calculations of the pier cap and piers was completed.

- **Transportation planning and pedestrian safety**
  Pedestrian safety was addressed during the design phase of the bridge. Other factors that will be considered are sidewalk width on the bridge, potential bicycle lanes, and necessary fencing around the bridge. The new bridge configurations include six feet sidewalks in both sides that will be separated from vehicular traffic by a 14.5 feet buffer zone on both sides.

- **Sustainability**
  Consideration of sustainability aspects was addressed during all phases of construction. During demolition, existing materials such as asphalt, aggregate, and steel will be considered for recycling. For traffic planning, our team will come up with the most effective routes to minimize delay time. LED lighting has been implemented along the bridge for safety and sustainable purposes.
7. APPENDICES

7.1 APPENDIX A

7.1.1 CRITICAL PATH

Network Chart for all activities on the critical path
# Brush St. Bridge Replacement Project

## Project Mobilization

- Buy Out
- Finalise Subcontractors
- Procure Materials
- Move In

## Demolition

- Substructure
  - North Abutment
  - South Abutment
- Pier
- Superstructure
  - Deck
- Finish Work

## Project Closeout & Termination

- Paving subcontract
- Painting subcontract
- Procure structural steel
- Set up site
- Move Equipment
- Paving removal
- Utility Line removal
- Bridge Demolition
- N. abutment piling
- N. abutment
dewatering
- N. abutment excavation
- N. abutment footing
- N. abutment structure
- S. abutment structure
- Pier structure
- North girders
- South girders
- Concrete Deck
- Gurdrails

## Progress Timeline

<table>
<thead>
<tr>
<th>Task</th>
<th>Start Date</th>
<th>Duration</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procure Materials</td>
<td>3/5/18</td>
<td>20 days</td>
<td>3/30/18</td>
</tr>
<tr>
<td>Move In</td>
<td>3/5/18</td>
<td>0%</td>
<td>3/30/18</td>
</tr>
<tr>
<td>Demolition</td>
<td>3/5/18</td>
<td>60 days</td>
<td>5/25/18</td>
</tr>
<tr>
<td>Substructure</td>
<td>4/2/18</td>
<td>5 days</td>
<td>4/6/18</td>
</tr>
<tr>
<td>Substructure</td>
<td>4/9/18</td>
<td>0%</td>
<td>4/13/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>4/23/18</td>
<td>2 days</td>
<td>4/24/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>4/16/18</td>
<td>5 days</td>
<td>4/20/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>4/25/18</td>
<td>12 days</td>
<td>5/10/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>5/11/18</td>
<td>4 days</td>
<td>5/16/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>5/17/18</td>
<td>0%</td>
<td>5/23/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>5/24/18</td>
<td>2 days</td>
<td>5/25/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>5/28/18</td>
<td>10 days</td>
<td>6/8/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>6/21/18</td>
<td>25 days</td>
<td>7/25/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>8/9/18</td>
<td>20 days</td>
<td>9/5/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>9/6/18</td>
<td>0%</td>
<td>10/3/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>10/4/18</td>
<td>5 days</td>
<td>10/10/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>10/11/18</td>
<td>0%</td>
<td>10/16/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>10/17/18</td>
<td>15 days</td>
<td>11/6/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>11/15/18</td>
<td>0%</td>
<td>11/21/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>11/15/18</td>
<td>5 days</td>
<td>11/21/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>11/15/18</td>
<td>0%</td>
<td>11/21/18</td>
</tr>
<tr>
<td>Superstructure</td>
<td>11/22/18</td>
<td>5 days</td>
<td>11/28/18</td>
</tr>
</tbody>
</table>

---

Western Michigan University
Department of Civil and Construction Engineering
7.1.2 COST ESTIMATE

**Quantity Calculations For Cost Estimates**

**Rebar**

Pier Cap 
#8 bar

\[ l_b = 84.25 \text{ ft} \quad N_b = 8 \quad W_b = 2.67 \frac{\text{lb}}{\text{ft}} \]

\[ T_w = l_b \cdot N_b \cdot W_b = 0.9 \text{ ton} \]

Pier Cap 
#7 bar

\[ l_b = 84.25 \text{ ft} \quad N_b = 10 \quad W_b = 2.04 \frac{\text{lb}}{\text{ft}} \]

\[ T_w = l_b \cdot N_b \cdot W_b = 0.859 \text{ ton} \]

Pier Cap #4 
stirrups

\[ l_s = 18.42 \text{ ft} \quad N_s = 101 \quad W_b = .67 \frac{\text{lb}}{\text{ft}} \]

\[ T_w = l_s \cdot N_s \cdot W_b = 0.623 \text{ ton} \]

Pier #9 bar

\[ l_b = 10.91 \text{ ft} \quad N_b = 12 \quad W_b = 3.40 \frac{\text{lb}}{\text{ft}} \quad N_p = 5 \]

\[ T_w = l_b \cdot N_b \cdot W_b \cdot N_p = 1.113 \text{ ton} \]

Pier #3 ties

\[ l_t = 8.9 \text{ ft} \quad N_b = 11 \quad W_b = 0.38 \frac{\text{lb}}{\text{ft}} \]

\[ T_w = l_b \cdot N_b \cdot W_b = 0.023 \text{ ton} \]

Footing #8 bar

\[ l_b = 460 \text{ ft} \quad N_f = 5 \quad W_b = 2.67 \frac{\text{lb}}{\text{ft}} \]

\[ T_w = l_b \cdot N_f \cdot W_b = 3.071 \text{ ton} \]
Concrete

Pier Cap

\[ h = 42 \text{ in} \quad b = 40.5 \text{ in} \quad l = 84.75 \text{ ft} \]

\[ V_{pc} = h \cdot b \cdot l = \left(1.001 \cdot 10^3\right) \text{ ft}^3 \]

Pier

\[ N_p = 5 \quad r_p = 1.5 \text{ ft} \quad l = 10.91 \text{ ft} \]

\[ V_p = \pi \cdot r_p^2 \cdot l \cdot N_p = 385.591 \text{ ft}^3 \]

Footing

\[ l = 12 \text{ ft} \quad b = 12 \text{ ft} \quad h = 3 \text{ ft} \quad N_f = 5 \]

\[ V_f = l \cdot b \cdot h \cdot N_f = \left(2.16 \cdot 10^3\right) \text{ ft}^3 \]

Total amount

\[ z = \frac{1}{\text{ft}^3} \]

\[ T = \frac{(V_{pc} + V_p + V_f) \cdot z}{27} = 131.359 \text{ Cubic yards} \]

Earth Work

\[ LB = 1420 \text{ ft}^2 \quad UB = 2463.5 \text{ ft}^2 \quad h = 3 \text{ ft} \]

\[ V = \left(\frac{1}{3}\right) \cdot h \cdot (LB + UB + \sqrt{LB \cdot UB}) = \left(5.754 \cdot 10^3\right) \text{ ft}^3 \]
7.1.3 DETAILED DESIGN CALCULATIONS

**Pier cap Design**

*Assume:* \( h = 36 \text{ in} \) \( b = 12 \text{ in} \) \( f_c = 3000 \text{ psi} \) \( \rho = 0.0181 \)

\[ f_y = 60000 \text{ psi} \quad d = 33.5 \text{ in} \quad \phi = 0.9 \]

\[ M_{ap} = 502.2 \text{ kip} \cdot \text{ft} \]

\[ A_y = b \cdot h = 432 \text{ in}^2 \quad A_z = A_y \cdot \rho = 7.819 \text{ in}^2 \]

\[ M_n = A_z \cdot f_y \left( d - \left( 0.59 \cdot A_z \cdot \left( \frac{f_y}{b \cdot f_c} \right) \right) \right) = (1.009 \cdot 10^3) \text{ kip} \cdot \text{ft} \quad \text{(Equation 6.7 Fanella, 2nd Edition)} \]

\[ \phi \cdot M_n = 908.2 \text{ kip} \cdot \text{ft} \]

Cross section dimensions were increased to satisfy AASHTO requirements

\( h = 42 \text{ in} \quad b = 40.5 \text{ in} \quad d = 39.5 \text{ in} \)

\[ A_y = b \cdot h = (1.701 \cdot 10^3) \text{ in}^2 \quad A_z = \rho \cdot A_y = 30.788 \text{ in}^2 \]

\[ M_n = A_z \cdot f_y \left( d - \left( 0.59 \cdot A_z \cdot \left( \frac{f_y}{b \cdot f_c} \right) \right) \right) = (4.7 \cdot 10^3) \text{ kip} \cdot \text{ft} \]

\[ \phi \cdot M_n = (4.23 \cdot 10^3) \text{ kip} \cdot \text{ft} \quad \text{greater than Mu, ok.} \]

\[ A_{min} = 200 \text{ psi} \left( \frac{b \cdot d}{f_y} \right) = 5.333 \text{ in}^2 \quad \text{(ACI 318 equation 9.6.1.2)} \]

\[ R_n = \frac{M_{ap}}{\phi \cdot b \cdot d^2} = 103.966 \text{ psi} \]

\[ \rho = \left( 0.85 \cdot \frac{f_c}{f_y} \right) \left( 1 - \sqrt{1 - \left( 2 \cdot \frac{R_n}{0.85 \cdot f_c} \right)} \right) = 0.002 \]

\[ A_z = \rho \cdot b \cdot d = 2.887 \text{ in}^2 \]

\[ a = \frac{(A_z \cdot f_y)}{0.85 \cdot f_c \cdot b} = 0.14 \text{ ft} \quad M_n = \phi \cdot A_z \cdot f_y \left( d - \frac{a}{2} \right) = 502.2 \text{ kip} \cdot \text{ft} \]

As less than
Asmin use Asmin

As less than
\[
\begin{align*}
\text{Whitney stress block equations} \\
\alpha := \frac{(A_s f_y)}{0.85 f_c b} = 0.29 \text{ ft} \\
M_n := A_s f_y \left( d - \frac{a}{2} \right) = (1.133 \cdot 10^3) \text{ kip ft} \\
\phi \cdot M_n = (1.019 \cdot 10^2) \text{ kip ft} \\
\text{Greater than Mup, ok.}
\end{align*}
\]

Development length for positive moment sections

\[
\begin{align*}
d_y := 1 \text{ in} \\
l_d := 47 \cdot d_y = 47 \text{ in} \quad \text{ACI 318 Equation R25.4.2.2}
\end{align*}
\]

Spacing of rebar

\[
\begin{align*}
C_e := 2 \text{ in} \\
f_s := \left( \frac{2 \cdot f_y}{3} \right) = (4 \cdot 10^4) \text{ psi} \\
S_c := 3 \text{ in}
\end{align*}
\]

\[
\begin{align*}
S_{\text{max}} := 15 \text{ in} \left( \frac{40000 \text{ psi}}{f_s} \right) - 2.5 \cdot C_e = 10 \text{ in} \quad \text{(ACI Code 24.3.2)} \\
S_{\text{min}} := 1 \text{ in} \\
S := \frac{(b - 2 \cdot S_c)}{9} = 3.833 \text{ in}
\end{align*}
\]
Negative Moment Design

\[ \rho_i = 0.0181 \quad b = 40.5 \text{ in} \quad h = 42 \text{ in} \quad d = 39.5 \text{ in} \quad A_g = b \cdot h = (1.701 \cdot 10^3) \text{ in}^2 \]

\[ M_{un} = 897.3 \text{ kip \cdot ft} \]

\[ R_n = \frac{M_{un}}{\phi \cdot b \cdot d^2} = 189.333 \text{ psi} \]

\[ \rho = \left( \frac{0.85 \cdot f_c}{f_y} \right) \left( 1 - \sqrt{1 - \left( \frac{2}{0.85 \cdot f_c} \right) R_n} \right) = 0.003 \]  
(Equation 6.10, Fanella 2nd Edition)

\[ A_s = \rho \cdot A_g = 5.583 \text{ in}^2 \quad A_{min} = 200 \text{ psi} \cdot \left( \frac{b \cdot d}{f_y} \right) = 5.333 \text{ in}^2 \]

Select 8 #8 bars

\[ A_s = 6.32 \text{ in}^2 \]

\[ a = \frac{(A_s \cdot f_y)}{0.85 \cdot f_c \cdot b} = 0.306 \text{ ft} \quad M_n = A_s \cdot f_y \cdot \left( d - \frac{a}{2} \right) = (1.19 \cdot 10^3) \text{ kip \cdot ft} \]

\[ \phi \cdot M_n = (1.071 \cdot 10^3) \text{ kip \cdot ft} \quad \text{greater than Mun, ok.} \]

Spacing and Development length

\[ C_c = 2 \text{ in} \quad f_s = \frac{2}{3} \cdot f_y = (4 \cdot 10^4) \text{ psi} \quad S_c = 3 \text{ in} \]

\[ l_d = 47 \cdot d_b = 47 \text{ in} \]

\[ S_{max} = 15 \text{ in} \cdot \left( \frac{40000 \text{ psi}}{f_s} \right) - 2.5 \cdot C_c = 10 \text{ in} \]

\[ S_{min} = 1 \text{ in} \]

\[ S_i = \frac{(b - 2 \cdot S_c)}{7} = 4.929 \text{ in} \]
Shear Design

\[ \phi = 0.9 \quad \text{AASHTO S5.5.4.2} \quad d_v = \frac{d}{2} = 37.664 \text{ in} \quad \text{AASHTO S5.8.2.9} \quad f_{ct} = 3 \]

\[ \beta = 2 \quad \text{AASHTO S5.8.3.4} \quad b_v = 40.5 \text{ in} \quad \text{AASHTO S5.8.2.9} \quad z = 1 \text{ ksi} \]

\[ V_u = 366.2 \text{ kip} \quad f_y = 60 \text{ ksi} \]

\[ V_c = 0.0316 \cdot \beta \cdot z \cdot \sqrt{f_{ct} \cdot b_v \cdot d_v} \quad \text{AASHTO S5.8.3.3-3} \]

\[ A_b = 0.31 \text{ in}^2 \quad s = 10 \text{ in} \quad \theta = 45 \quad \text{AASHTO S5.8.3.4} \quad \alpha = 90 \quad A_v = 4 \cdot A_b = 1.24 \text{ in}^2 \]

\[ V_s = \frac{(A_v \cdot f_y \cdot d_v)}{s} = 280.221 \text{ kip} \quad \text{AASHTO S5.8.3.3-4} \]

\[ \phi V_n = \phi \cdot (V_s + V_c) = 402.48 \text{ kip} \quad \text{Greater than } V_u, \text{ ok} \]

Max Spacing AASHTO S5.8.2.7-2

Cannot exceed 12"

12" > 10", ok
Circular Pier Design

\[ h = 36 \text{ in} \quad P_u = 556.3 \text{ kip} \quad A_g = \pi \left( \frac{h}{2} \right)^2 = \left( 1.018 \cdot 10^3 \right) \text{ in}^2 \]

\[ f_c = 3000 \text{ psi} \quad \phi = 0.65 \quad M = 55.42 \text{ kip ft} \]

From ACI interaction Diagram C3-50.6

\[ R_u = \frac{M}{f_c \cdot A_g \cdot h} = 0.006 \quad K_u = \frac{P_u}{f_c \cdot A_g} = 0.182 \]

Interaction diagram gives a value of \( \rho = 0.01 \)

\[ A_s = A_g \cdot \rho = 10.179 \text{ in}^2 \]

\[ A_{smin} = \frac{A_s \cdot f_y}{A_g \cdot f_c} = 0.2 \quad \text{Greater than 0.135 ok AASHTO S5.7.4.2-3} \]

Ties use #3 bars at 12" spacing AASHTO 5.10.6.3

Select 12 #9 bars

\[ A_b = 1 \text{ in}^2 \quad A_s = 12 \cdot A_b = 12 \text{ in}^2 \]
Live load distribution factors

\[ S_1 = 7.75 \text{ ft} \]

\[ g_{mi} := 0.2 + \left( \frac{S_1}{12 \text{ ft}} \right) - \left( \frac{S_1}{35 \text{ ft}} \right)^2 = 0.797 \]

\[ S_2 = 7.505 \text{ ft} \quad d_e = 2.79 \text{ ft} \]

\[ e = 0.6 + \left( \frac{d_e}{10 \text{ ft}} \right) = 0.879 \]

\[ g_{ext} := g_{mi} \cdot e = 0.7 \]

Table 4.6.2.3a-1
applicable cross section k
AASHTO LRFD Bridge Design Manual

Table 4.6.2.3b-1
applicable cross section k
AASHTO LRFD Bridge Design Manual

DISCLAIMER: Distribution factors were factored into the loadings in the program, they were calculated as a check for accuracy.
8.1.5 STRUCTURAL ANALYSIS SOFTWARE OUTPUTS

Pier Cap Shear Diagram
### Footing Flexural Summary Table

<table>
<thead>
<tr>
<th>Flexure</th>
<th>Dir</th>
<th>Loc ft</th>
<th>d in</th>
<th>Mmax kft</th>
<th>Comb</th>
<th>CL</th>
<th>Asb_req in^2</th>
<th>Asb_prv in^2</th>
<th>Asb_eff in^2</th>
<th>Ast_req in^2</th>
<th>Ast_prv in^2</th>
<th>Ast_eff in^2</th>
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<td>5.13 *</td>
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<td>4.96 *</td>
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### Footing One-Way and Two-Way Shear Summary Tables

#### One Way Shear (Beta-Theta Method)

<table>
<thead>
<tr>
<th>Col</th>
<th>Dir</th>
<th>Dist ft</th>
<th>Comb</th>
<th>dv in</th>
<th>Vu kips</th>
<th>Mu kft</th>
<th>theta deg</th>
<th>beta</th>
<th>phi*Vc kips</th>
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</thead>
<tbody>
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<td>153.1</td>
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<td>0.87</td>
<td>269.0</td>
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<tr>
<td>Z</td>
<td>4.95</td>
<td>1</td>
<td>43.42</td>
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#### Two Way Shear

<table>
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<tr>
<th>#</th>
<th>Bo ft</th>
<th>Ao ft^2</th>
<th>Comb</th>
<th>Avg. dv in</th>
<th>Vu kips</th>
<th>phi*Vc kips</th>
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<td>Columns</td>
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Pier Cap Flexural Summary Tables

<table>
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<th>Span 1: From 0.0 ft to 6.0 ft</th>
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<tbody>
<tr>
<td>Loc</td>
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<tr>
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<tr>
<td>3.6</td>
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<td>5.8</td>
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<table>
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<tr>
<th>Span 2: From 6.00 ft to 24.19 ft</th>
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</thead>
<tbody>
<tr>
<td>Loc</td>
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<td>13</td>
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<td>15.1</td>
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<td>16.9</td>
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<table>
<thead>
<tr>
<th>Span 3: From 24.19 ft to 42.36 ft</th>
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<tbody>
<tr>
<td>Loc</td>
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<td>16.9</td>
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<table>
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<tbody>
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<td>Loc</td>
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<td>16.9</td>
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<table>
<thead>
<tr>
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# Pier Cap Shear Summary Table

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<th>Abs Loc ft</th>
<th>Pos</th>
<th>Vp kips</th>
<th>Vs kips</th>
<th>Tu kips</th>
<th>Comb</th>
<th>phi*Vn kips</th>
<th>T-lim in^2</th>
<th>Avs in^2</th>
<th>2Avs/s in^2</th>
<th>Avs/s in^2</th>
<th>Aprvs in^2</th>
<th>Avs in^2</th>
<th>Vc kips</th>
<th>Vs kips</th>
<th>Beta</th>
<th>Theta deg</th>
<th>b in</th>
<th>dv in</th>
<th>Eps_s</th>
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### Pier Summary Tables

#### Design values used - ( e-min effect included )

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<th>Loc ft</th>
<th>Comb</th>
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<th>Fy kips</th>
<th>Fz kips</th>
<th>Mx kips-ft</th>
<th>My kips-ft</th>
<th>Mz kips-ft</th>
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#### COLUMN DESIGN

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<tr>
<th>Bot/Top Elev. ft</th>
<th>Comb</th>
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<th>Fy kips</th>
<th>Fz kips</th>
<th>Mx kips-ft</th>
<th>My kips-ft</th>
<th>Mz kips-ft</th>
<th>Pu kips</th>
<th>Mux kips-ft</th>
<th>Muz kips-ft</th>
<th>pMn kips-ft</th>
<th>pMn/Mu</th>
<th>Incl deg</th>
<th>pPn/Pu</th>
<th>pPn/Mu</th>
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#### COLUMN DESIGN

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<th>Ae_max in^2</th>
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<td>12.00</td>
</tr>
</tbody>
</table>
7.2 TRANSPORTATION SIMULATION SOFTWARE OUTPUTS
8. REFERENCES

8.1 PEOPLE

Dr. Decker Hains (Professor)
Dr. Haluk Aktan (Faculty Advisor)
Timothy Schnell (Teacher Assistant)

8.2 ORGANIZATIONS

HNTB Corporation (Sponsor Firm)
Michigan Department of Transportation (Owner)

8.3 WEBSITES

ABC Concept Reports from MDOT FTP Site (ftpmdot.state.mi.us)
ASCE 7-10
Michigantrafficcrashfacts.org

8.4 BOOKS

AASHTO LRFD Bridge Design Specifications
ACI Manual
FHWA Manual
Published MDOT Design Advisories
Road Design Manual
Standard Plans