Structural Bridge Design and Construction Traffic Management Plan for the Route 24/140 Interchange

A Major Qualifying Project Submitted to the Faculty

Of

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In Partial Fulfillment of the requirements for the Bachelor of Science Degree

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Abstract

The purpose of this project was to provide a structural design recommendation for a bridge replacement in Taunton, MA. The team evaluated the current conditions, and presented a bridge layout that met MassDOT, FHWA, and AASHTO requirements. Additionally, the group provided a cost estimate, traffic management plan and construction staging schedule as a supplement to the design. In the end, the team determined that a one-span steel bridge using slide-in bridge construction methods was cost-effective and best satisfied project requirements.

Executive Summary

In efforts to improve the highway system, MassDOT initiated the Accelerated Bridge Program (ABP), whose goal is to reduce the number of structurally deficient bridges and increase the overall Bridge Health Index in the state by designing innovative and sustainable bridges (MassDOT, 2008). One of these "structurally deficient" bridges in need of replacement is situated at the interchange between Route 140 and Route 24 in Taunton, Massachusetts.

The interchange redesign is part of a larger project in Taunton, known as Project First Light. Project First Light consists of a casino development, as well as roadway improvements at surrounding intersections along Route 24 and Route 140 in order to alleviate traffic congestion. This Major Qualifying Project (MQP) was completed in conjunction with Stantec Consulting Services Ltd. to provide a preliminary structural design, construction schedule, and traffic management plan for the Route 24 bridge replacement.

The goal of this project was to develop a bridge design to accommodate the proposed bridge expansion and the increase in vertical clearance. Once the design was selected, the team had to develop a construction and traffic plan that reduced project cost and impacts for users of the interchange. In order to achieve the project goal, the following objectives were defined:

- Evaluate the current site conditions.
- Develop the bridge structural design options, based on geometric requirements and constraints.
- Define evaluation criteria to determine feasibility, and subsequently, the best design, through comparative qualitative and quantitative analyses.
- Present recommendations in the form of a final design, an accelerated construction schedule, as well as a traffic detour plan for the bridge closure.

In order to understand the site conditions, the team gathered information using the existing site reports, traffic studies, and AutoCAD drawings. During the evaluation stage, factors such as shear-moment diagrams, structure weight, simplicity of construction, possibility of future improvements, were considered for the four preliminary cases. A quantitative and qualitative comparison was completed between four options to help select the option for the final design

recommendation that met MassDOT, FHWA, and AASHTO requirements.

This project concluded that a single span, steel plate girder bridge was the design that best satisfied the project requirements. Additionally, slide-in bridge construction was determined to be a lower cost alternative to traditional construction methods. After comparing project cost estimates between SIBC methods and temporary bridge construction, the team found that the accelerated schedule and short-term shutdown reduced construction costs by about $900,000. The recommended design and management plan was determined to not only reduce the overall project cost, but also significantly minimize impacts to the Taunton community.

Acknowledgements

Without the help of these people, the completion of this project would not have been possible. First, we would like to thank Worcester Polytechnic Institute for the opportunity to experience the professional world as students. We would especially like to thank our advisors Leonard Albano and Suzanne LePage for their guidance throughout our MQP. We thank Stantec Consulting Services, Ltd. for the resources and workspace to complete the project. Finally, we would like to thank Fred Moseley, Christie Dennesen, Walt Woo, and Alexis Simpson for always making themselves available as resources; their help in the areas of traffic management, structural design, and construction staging, was vital in the development of the final project.

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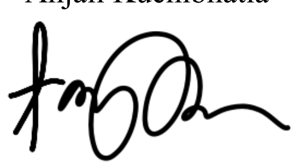
Anjali Kuchibhatla



Carolina Leguizamón

Maitane Sesma

Capstone Design Statement

In this Major Qualifying Project (MQP), the team was tasked to assist in a preliminary bridge type study for a bridge replacement. The bridge is located in Taunton, Massachusetts, and carries Route 24 over Route 140. In order to develop bridge options that met the project design requirements and also accommodated the existing infrastructure, the team needed to consider real world constraints, such as: economic, environmental, sustainability, constructability, ethical, health and safety, social, and political. By meeting these constraints, this design project satisfies the requirements for a Capstone Design Experience, as outlined by the Accreditation Board for Engineering and Technology (ABET). The following description includes the considerations that were involved with the MQP.

Economic

In any construction project, economics is an important factor that helps to define the methods and materials used. Although the team was not given a specific budget, the overall cost of the project became a consideration that made certain design options more favorable than others. In other words, cost-effective bridge designs and construction methods were desirable, rather than more expensive approaches. In order to address this, a preliminary cost estimate using MassDOT average unit prices from 2016 was completed to help compare the feasibility of the final designs.

Environmental and Sustainability

The investigated area is classified as a wetland region. Under the Wetlands Protection Act, the environmental preservation of this area became an important consideration. Impacts on the wetland zones were carefully taken into account when the team designed structural layouts and construction methods.

Constructability and Manufacturing

The replacement of this bridge occurs in a high traffic area, with drivers coming into the interchange from multiple directions. Construction staging options that made efficient use of space, time, and labor were determined by the team as the “best fit methods” for the project constraints, ensuring that the chosen design would be “constructible”.

Ethics

The National Society of Professional Engineers (NSPE) and American Society of Civil Engineers (ASCE) Codes of Ethics were followed throughout this project. Engineers have a direct impact on people's lives, and must hold themselves to high standards of integrity. The safety and welfare of the public were taken into account in this project. The team gave higher consideration to construction and traffic management methods that reduced the risk of vehicular accidents.

Health and Safety

The number one priority during construction is the safety of both users and the labor force. The use of mostly prefabricated elements was not only used to accelerate the construction process but also to minimize safety hazards during construction. These pieces are placed with machinery, taking the necessary parameters and following OSHA standards, to ensure safety in the surrounding area. Once these pieces are in place, there is still a safety aspect associated with their serviceability. Therefore, the preliminary sizing of the bridge components and their compliance with AASHTO specifications were taken into account.

Social and Political

Societal impacts were heavily considered in choosing the solution path for the construction management. The idea of trying to minimize the impacts on the users of the bridge was key when deciding to use Slide-In Bridge Construction methods. Furthermore, this project aims to improve a very busy intersection that is expecting further development in the surrounding area. In the long run, this project will lead to a better quality of life for the people who drive through this area by reducing the traffic as well as making the area more likeable and easy to visit. Also, since the bridge is a part of the Massachusetts infrastructure, it was important to consider not only federal regulations from FHWA, but also state regulations from MassDOT.

Professional Licensure Statement

According to the National Council of Examiners for Engineering and Surveying (NCEES), Professional Licensure is a standard that restricts engineering practice to individuals who are certified. It protects the public by ensuring that any work is completed by an engineer who has met "specific qualifications in education, work experience, and exams" (NCEES, 2017).

Therefore, it has become increasingly important to become Professional Engineers (PE) through this professional licensure process. This certification is not only an indication of an engineer's ability to take on more responsibilities, but is also an assurance of quality work and a high standard of ethical practice. A licensed engineer can take on larger managerial roles in the industry, and has more career opportunities to be a lead engineer on a project. Furthermore, it has become commonplace that only PEs are allowed to prepare and sign engineering work for clients (NSPE, 2017). In order to become a licensed Professional Engineer, the following requirements must be satisfied:

- Earn a four-year degree in engineering from an accredited engineering program
- Pass the Fundamentals of Engineering (FE) exam
- Complete four years of progressive engineering experience under a PE
- Pass the Principles and Practices of Engineering (PE) exam

Additional requirements may vary based on the state of practice and can be found online on the National Council of Examiners for Engineering and Surveying (NCEES) website (NCEES, 2017).

1.0 Introduction

According to the Federal Highway Administration (FHWA), there are over two hundred million trips taken in metropolitan areas over structurally deficient bridges. As defined by the Massachusetts Department of Transportation (MassDOT), “structurally deficient bridges are those in need of extensive repair in order to address deficiencies” (MassDOT, 2010). In efforts to improve the highway system, MassDOT initiated the Accelerated Bridge Program (ABP), whose goal is to reduce the number of structurally deficient bridges and increase the overall Bridge Health Index in the state by designing innovative and sustainable bridges (MassDOT, 2008).

One of the bridges in need of replacement is situated at the interchange between Route 140 and Route 24 in Taunton, Massachusetts; this bridge has four travel lanes with an approximate center span of 106 feet. The goal of this project is to increase the width and the vertical clearance of the Route 24 and 140 interchange to accommodate for traffic flow and structural requirements, by considering factors such as cost, environmental impacts, and construction staging phases, along with traffic detouring and mitigation.

2.0 Background

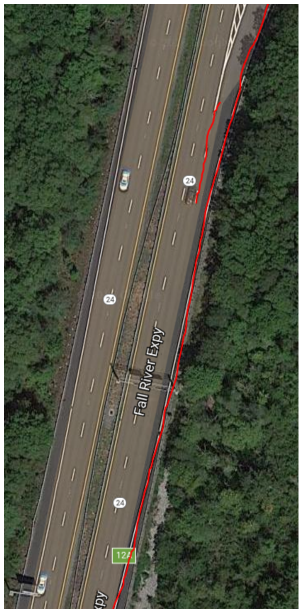
This chapter provides an overview of the characteristics of Route 24/Route 140 interchange in the city of Taunton, Massachusetts. The interchange redesign is part of a larger project in Taunton, known as Project First Light. Project First Light consists of a casino development, as well as roadway improvements at surrounding intersections along Route 24 and Route 140 in order to alleviate potential traffic congestion. The existing and projected site conditions were investigated by reviewing the geotechnical report, traffic flow studies, and structural conditions of the bridge. The team also visited the site to observe the current status of the interchange.

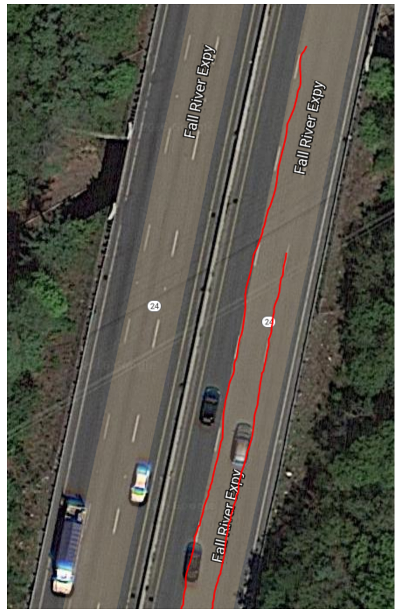
2.1 Site Conditions

2.1.1 Existing Interchange and Bridge Layout

An interchange is an intersection where one road passes over another one (OhDOT, 2015). This interchange of Route 24 over Route 140 has a five-ramp partial cloverleaf configuration, and is located on Exit 12 (**Figure 1**). In the vicinity of the interchange, both ramp locations are controlled by traffic signals (Hudson, 2016). Route 24 has four operating lanes, and provides a major link between the greater Boston area and communities to the Southeast of Taunton. Route 140 is a state highway that passes through parts of southeastern and central Massachusetts. Since its installation in 1950, the Route 24 bridge has been updated with lane modifications and widening occurring in 2005. MassDOT completed a project to add 2,700 feet "north in advance of Exit 12" on Route 24 southbound. The acceleration lane on Route 24 northbound was also lengthened by 2,000 feet (Fay, Spofford, & Thorndike, 2015). An aerial view of these additions is shown in **Figure 2** and **Figure 3**.

Figure 1: Route 140/Route 24 Interchange Existing Conditions.





Figures 2 and 3: Deceleration lane off Route 24 northbound and acceleration lane on Route 24 northbound (Google Maps, 2016b).

The Route 24 bridge is a four-lane, composite steel I-beam girder bridge with two lanes going in each respective direction (**Figure 4**). **Figure 5** is a lateral view of the interchange at Route 24 and 140. The bearing to bearing span of the bridge is 115 feet, with connected wingwall lengths of about 40 feet and 30 feet on the north and south side of the bridge, respectively. The current width of the Route 24 bridge is 88 feet. This is considered a medium span sized bridge.

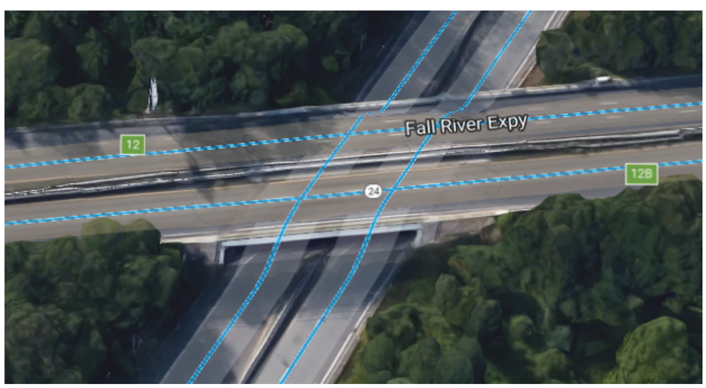


Figure 4: Aerial view of Rte. 24 bridge (Google Maps, 2016c).

Figure 5: Route 24/140 Interchange.

2.1.1.1 Geotechnical and Environmental Considerations

In preparation for the development of Project First Light Casino, GEI Consultants provided Stantec with a geotechnical report of the Taunton site. The scope of the geotechnical report included soil surveys, boring logs, and a final recommended foundation design for the bridge. There were six soil samples taken on site using split-spoon sampling in 5 ft intervals. The boring logs show that the groundwater levels range from 4-8 ft and bedrock is found between 30-38 ft below ground level. Furthermore, the soil has a coefficient of friction of 0.7 using cast-in-place footings. The hammer efficiency was 80%. The soil bearing capacity is dependent on the effective footing width used. Appendix B outlines the factored bearing resistance versus effective footing width chart, as determined in the report (GEI Consultants, 2015).

The soil information obtained from the boring logs resulted in a suggested foundation, as provided by GEI Consultants. Their recommendation was to proceed with a two-span bridge with center piers, cantilever abutments, wingwalls, and supported spread footings at least four feet below the exterior grade surface for frost protection.

The Wetland Protection Act was developed by the Massachusetts Department of Environmental Protection in efforts to preserve wildlife habitat, to protect the groundwater and public water supply, and to prevent flooding (MassDEP, 2014). The geotechnical report outlined wetland regions in the site, and the consultants took this into account when providing their recommended shallow foundation designs. Wetland regions can impact design; layout and design of the foundation can cause concern for the effective soil pressure, and for stormwater runoff storage in an overly-saturated area (Texas A&M University, 2007). Lastly, construction needs to be monitored in order to ensure there is no pollution or additional costs to the wetlands.

2.1.1.2 Structural Considerations

As previously stated, this bridge is considered "structurally deficient." This means that the bridge's deck, substructure, and superstructure have received a rating between 0-4 on the National Bridge Inventory (NBI) Rating Scale. Although the bridge can remain in service, it does require immediate attention (MDOT, 2015). **Figure 6** is a picture that highlights areas of corrosion, deterioration of the concrete cover, and rust on the existing bridge. Additionally, due to its deficiencies, there must be signage before entering the bridge indicating the permissible vehicle weight, since it is lower than the state's gross weight limit for trucks. Currently, the bridge meets FHWA's minimum vertical clearance requirements for urban highways at 14 feet (FHWA, 2014). However, MassDOT increased its highway vertical clearance requirements to a minimum of 16.5 feet (MassDOT, 2010).

Figure 6: Corrosion and Deterioration of Existing Structure (Google Maps, 2016a).

2.1.2 Existing Traffic Conditions

According to a study conducted in 2009 by Fay, Spofford, & Thorndike (FST), Route 140 carried 22,600 vehicles per average day (Fay, Spofford, & Thorndike, 2012). Comparatively, in a traffic study completed in 2012, MassDOT recorded an average of 43,400 vehicles per day in the area near the interchange. Over 3 years, this is approximately a 200% increase in the number of vehicles that use the route. Route 24 carried between 53,600 - 72,000 vehicles per day, which is also an increase from the average values in 2009. The interchange has been identified by the MassDOT as a "crash cluster," meaning that it is part of the top 5% of high crash locations in the state (MassDOT, 2015). This indicates that changes are necessary to improve driving conditions at the interchange, and to accommodate a growing number of vehicles.

A safety audit prepared by Fay, Spofford & Thorndike in 2015 analyzed operations, geometry, and crash history for both roads. Route 24 "operated poorly due to heavy afternoon volumes with significant queuing occurring on the main line," creating a driving environment prone to rear-end accidents. The audit found maintenance issues due to the deterioration of signage and pavement markings, as well as issues with the ramp that increase the possibility for off-ramp accidents. Additionally, ramps on Routes 140 and 24 face similar issues, having an excessive amount of signage in a short distance, missing lane delineations, and overall geometry limitations that increase the possibility of crashes and back ups. Under these conditions, surrounding intersections operate at an overall level-of-service[1] (LOS) D during peak hours. The intersection of Route 140/Route 24 SB ramps is the exception, operating at an overall LOS E during peak hours (Fay, Spofford, & Thorndike, 2012).

2.1.3 Projected Traffic Conditions

The traffic study conducted by FST also included three different scenarios for projected traffic conditions. The "2022 No-Build Conditions" are twofold: one is based on the existing infrastructure with the casino, and the other is based on the existing infrastructure with no casino (Fay, Spofford, & Thorndike, 2015). For both scenarios with and without the casino, it was concluded that intersections in the area will maintain its LOS D or better, with some intersections performing at a LOS F (Fay, Spofford, & Thorndike, 2015). The "2022 Build Conditions" are based on completed road improvements in each study intersection and the additional traffic flow due to the First Light Casino developments. Specifically, the projected statistics are based on the implementation of these changes: addition of a bypass lane on Route 140, widening of Route 24 southbound, and a new Route 24 southbound ramp at Exit 12B. This new geometry will allow for an overall improved level of service of LOS B, where several sections are expected to improve from LOS F. (Fay, Spofford, & Thorndike, 2015). Therefore, it can be concluded that roadway improvements must be made, regardless of the casino construction, in order to better the LOS of the study intersections.

[1] Level-of-service (LOS) "refers to a standard measurement used by transportation officials which reflects the

2.1.4 Proposed Bridge Extensions

Stantec's 25% Build Plans provided cross-sections and profile schematics for the new lane geometry of the interchange (Stantec, 2016). For the purposes of this project, the team replicated these schematics to understand the necessary bridge requirements. **Figure 7** illustrates Stantec's proposed lane configuration for Route 24 over 140. This new geometry consists of three travel lanes southbound, two travel lanes northbound, and a deceleration lane in both directions, resulting in an overall width of 135 feet. The separate deceleration lane on Route 24 southbound was incorporated to accommodate for the appropriate speed limits and traffic flow. This redirects casino traffic to use this additional lane, rather than affecting traffic that goes through. Moreover, the additional lane allows for a shorter turning radius of the ramps and decreases impacts on the surrounding wetlands. **Figure 8** illustrates this configuration, in the cross-section profile of Route 140 under the bridge. From this cross-section, it was determined that the new length of the Route 24 bridge would be 141 feet for a single span design, and 145 feet for a double-span, to account for a 4-ft center pier.

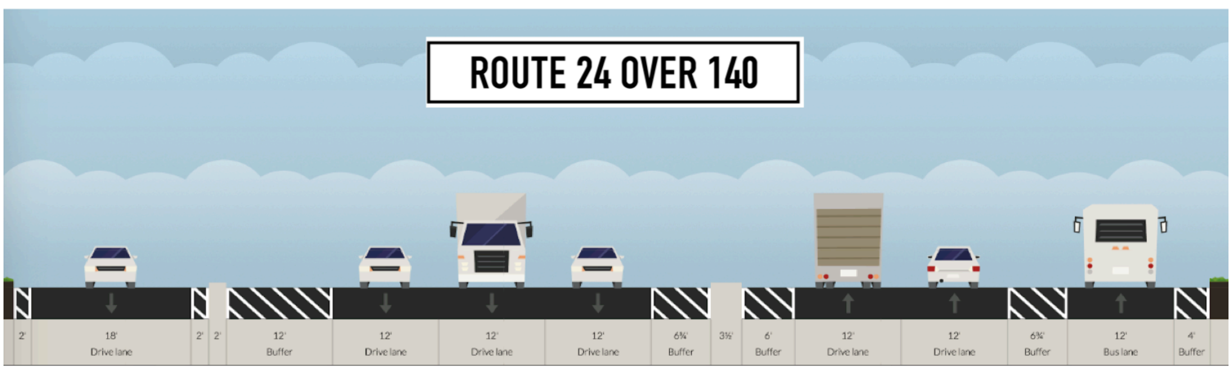


Figure 7: Proposed Route 24 bridge cross-section over Route 140 (Version 2, StreetMix 2017).

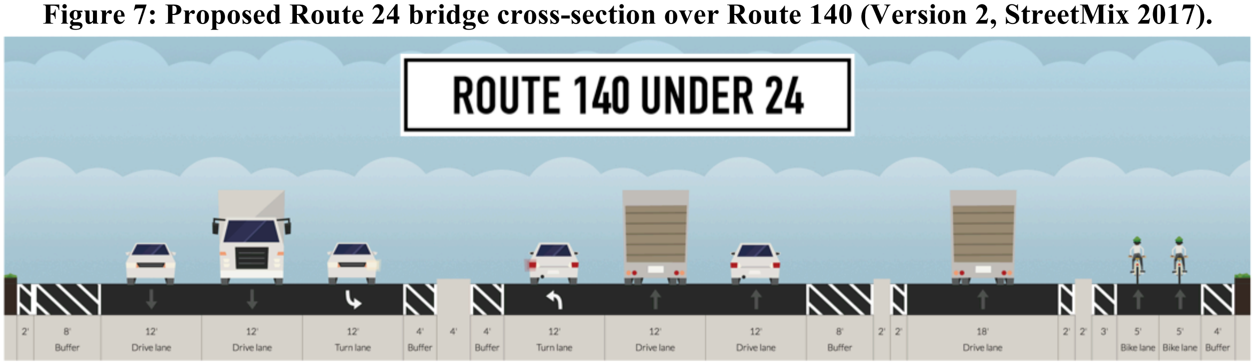


Figure 8: Proposed Route 140 cross-section under Route 24 (with center pier) (Version 2, StreetMix 2017).

2.2 Bridge Structural Components

A general understanding of bridge components is necessary for effective design. Through research, it was concluded that bridges can be separated into two sections: the superstructure and substructure (**Figure 9**). These two sections needed to be assessed and designed for structural integrity. Factors such as construction staging, project schedule, serviceability, and cost will also be considered when assessing bridge options.

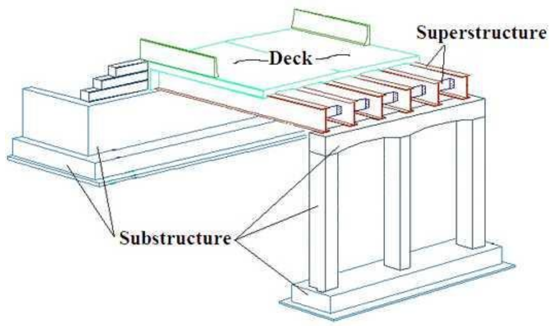


Figure 9: Superstructure and Substructure (Michigan Dept. of Transportation, 2016).

2.2.1 Superstructure Elements

Bridges are generally classified by span type such as simple span, rigid frame, cantilever, among many others. Once the bridge is classified by span type, it can also be classified by length. Depending on the span type, the span length classification may vary. A short bridge will be less than 100 feet to 200 feet, a midspan bridge would be from 100 feet to 600 feet, and a long span would be greater than 400 feet to 600 feet (Department of Civil and Environmental Engineering, 2003).

Bridges are composed of the following elements in its superstructure: deck and deck components, slab, and the girders underneath the bridge deck which can be made of multiple different materials or combined materials. Furthermore, depending on the required loading and moment, different materials and shapes can be used. A simple span bridge will have different requirements than a continuous span bridge, and thus, different applicable materials and shapes (Department of Civil and Environmental Engineering, 2003). The *PCI Design Manual* and *AISC Steel Manual* have design charts to aid in the selection of beam shapes that would satisfy loading requirements, and these charts were used to prepare preliminary designs of the Route 24 bridge.

2.2.2 Substructure Elements

The substructure is the foundation section of the bridge, allowing loads from the superstructure to be transferred to the earth. Therefore, its design is greatly influenced by the superstructure components, available construction space, bridge width, stage construction, and overall aesthetics. The substructure, illustrated in **Figure 10**, is mainly comprised of the abutments, piers, piles, and footings (MoDOT, 2010). The abutments are composed of breastwalls, wingwalls, bridge seats, and the footings. Conversely, the piers are composed of stem walls, columns or pier shafts, web walls, and footings. The selection and design of these elements can be based on recommendations made in Geotechnical Reports regarding site-specific design parameters, such as soil resistance and bearing capacity. (MassDOT, 2015).

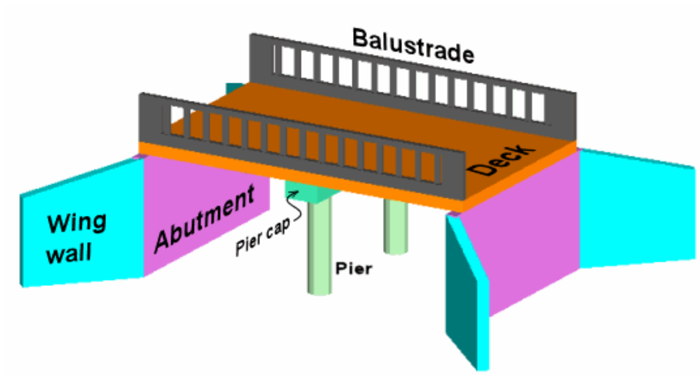


Figure 10: Substructure Components (MoDOT, 2010).

2.3 Construction Planning for Bridge Replacement

There are several construction methods that can be used for projects, and the decision process depends on a project's time schedule, site, and budget. In order to understand which method to consider, the team looked into utilizing MassDOT's Preliminary Decision Making Chart, provided in Chapter 3 of the *LRFD Bridge Manual* (MassDOT, 2013). **Figure 11** outlines the deciding factors and restrictions that would influence the final construction method. The preliminary decision value score is calculated from a series of factors that add to the final score. Points are added to the score based on factors such as an intersection's ADT value, detour value, or whether it is an emergency repair. A higher score equates to a more complex intersection that requires work.

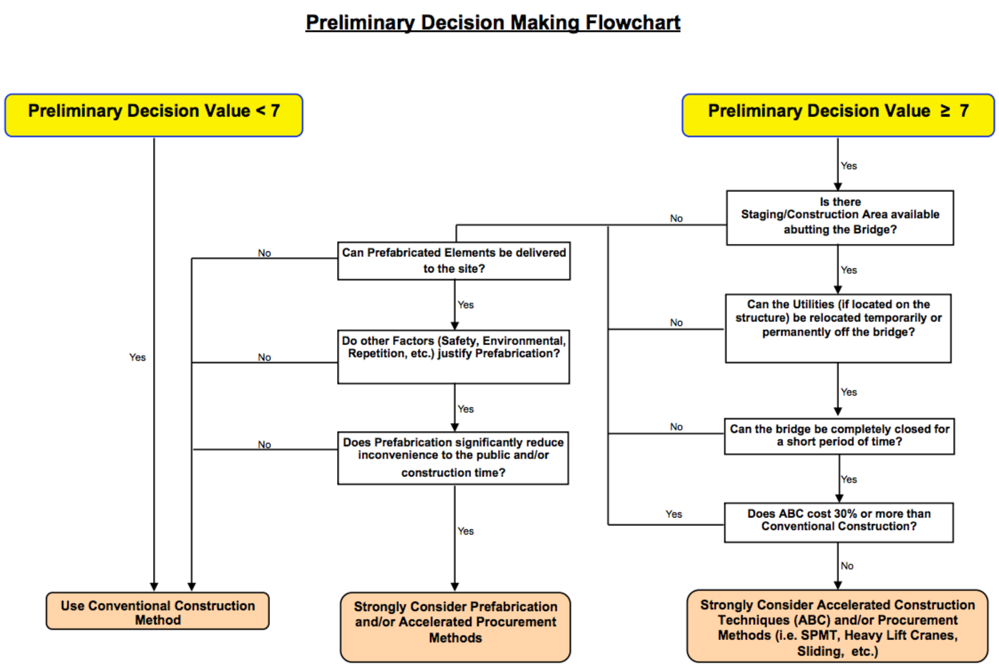


Figure 11: Preliminary decision making chart (MassDOT, 2013).

Due to the time constraints of this project, the chart helped the team to consider utilizing Accelerated Bridge Construction (ABC) Methods and Prefabrication. ABC methods are commonly used in the field; these methods improve total project delivery time, site constructability, and work-zone safety, and reduce on-site construction time and traffic impacts (FHWA, 2014). Segmental/phased construction and slide-in bridge construction are ABC methods that were considered in this project.

2.3.1 Segmental/Phased Bridge Construction

Segmental construction allows for a partial closure of the bridge with temporary bridges. This maintains traffic flow in a highly congested area, and is a time-efficient method, usually completing the construction cycle in 7 days (Sward, 2012), excluding construction of the temporary bridge. Temporary bridges can be pre-fabricated, disassembled after use and then re-used for future projects. However, the cost of erecting a temporary bridge can dramatically increase the total project cost due to costs from mobilization and demobilization of the temporary bridge.

Segmental construction can be completed span-by-span, cantilevering, full span, or incremental launching. Generally, cantilevering and incremental launching construction are utilized for large spans between 200-350 feet, and larger. For a span of 140 feet, the best option, as outlined by the Post-Tensioning Institute (PTI), is span-by-span segmental construction. Span-by-span requires a smaller labor crew, and can be completed from behind the structure rather than on top or underneath (Sward, 2012). **Figure 12** is a visual representation of segmental construction, in which beams are placed in sections, and are then cantilevered from permanent or temporary supports. Eventually, using welding or post-tensioning, these sections are joined to create a continuous span. The main purpose for segmental construction is to be able to build longer spans without having to transport or cast extremely long pieces on site (Muller, 1975).

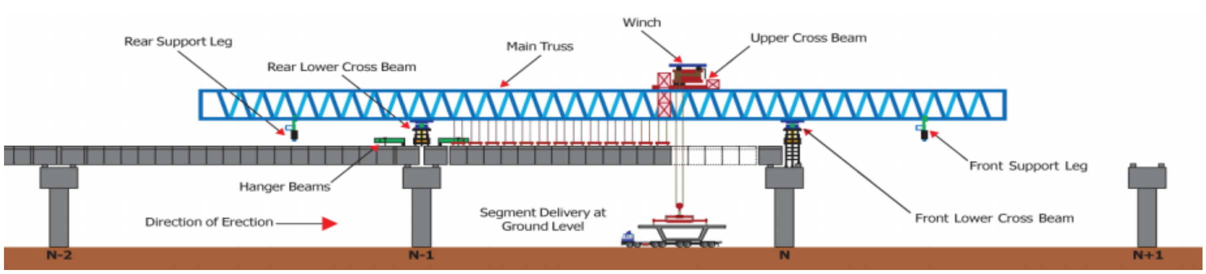


Figure 12: Span-by-span Segmental Construction (PTI, 2012).

2.3.2 Slide-In Bridge Construction (SIBC)

SIBC utilizes a method in which the replacement structure is built adjacent to the existing bridge and on temporary supports, so that during construction, traffic can still follow the same route. Once the new structure is ready, the road is then closed, the existing bridge is demolished, and the new bridge is slid into place (**Figure 13**). In terms of safety, SIBC reduces the probability of accidents by a significant amount as this process reduces the exposure of workers to live traffic (UDOT/FHWA, 2013). However, since this is a fairly new method, it requires qualified engineers for inspection and design. Additionally, traditional bridge construction generally consists of replacing one travel direction first and eventually the other one, which requires twice the mobilization time, concrete cure times and other inefficiencies. The use of SIBC not only allows for one installation process for the entire superstructure, but also allows for an overall faster project delivery. One of the biggest benefits of SIBC is the reduction of mobility[2] impacts from seven to 24 months to just hours or a week (UDOT/FHWA, 2013). Phased construction typically includes long-term lane closures, interstate crossovers and detours.

Figure 13: SIBC Construction Methods (UDOT/FHWA, 2013).

Furthermore, these traditional processes tend to increase the price of construction, create traffic delays, and cause distractions to drivers. The bridge sliding cost depends on the superstructure weight, width and distance moved (UDOT/FHWA, 2013). However, SIBC projects generally experience cost reductions in traffic detouring, project administration, mobilization, and temporary bridge materials. Finally, when constructed to the side, there is more room onsite for material placement and equipment access. Section 3.1 of the FHWA and UDOT *Slide-In Bridge Construction Implementation Guide* details the various techniques that address the challenges of building substructures under existing bridges.

[2] Mobility pertains to moving road users efficiently through or around a work zone area with a minimum delay compared to baseline travel when no work zone is present (FHWA, 2013).

3.0 Methodology

The purpose of this project was to provide a preliminary structural design, construction schedule, and traffic management plan for the Route 24 bridge replacement. This section includes the steps the MQP team took to develop the final recommendation for Stantec. The timeline consisted of four sequential objectives: evaluating the site conditions, developing a list of design options, creating and applying the evaluation criteria, and finally, presenting final recommendations to Stantec.

3.1 Project Specifications

Given the current conditions of the bridge, this interchange is undergoing improvements for the ramps on both routes and for bridge expansion. Specifically, the Taunton bridge project includes the following modifications and additions to the existing bridge structure:

- Accommodations to widen Route 24 Southbound to three lanes
- Lane additions to Route 140 Northbound and Southbound
- Vertical clearance increase of the Route 24 bridge from 14.5 feet to 16.5 feet, which is the upper bound of the recommended range for a highway, and accounts for any future development (FHWA, 2014).

To meet these specifications, the goal of this project was to increase the width and the vertical clearance of the Route 24 and 140 interchange to accommodate for traffic flow and structural requirements through redesign. Specifically, the current bridge geometry was assessed and two new bridge design options were provided. The staging process as well as the estimated labor and material costs were considered when evaluating both options. In order to achieve the project goal, the following objectives were defined:

3.2 Project Objectives

1. **Evaluated the current site conditions.**

   First, information about the site and the bridge was gathered from the geotechnical report, traffic studies, and existing AutoCAD drawings. The drawings included site plans, which detailed utility work, wetland regions, and elevation markings. During the site visit, the team drove through the interchange, noted possible construction staging areas, and took pictures of the bridge to capture the current conditions. Finally, a meeting with Stantec's structural engineer and traffic engineer involved in the project helped to further define the scope. From the information gathered, a solution path was developed to solve the problem.

2. **Developed the bridge structural design options, based on geometric requirements and constraints.**

   The original bridge plans, Stantec's initial proposal and the 2015 traffic mitigation report provided key information in determining preliminary ideas for the new cross-section. These reports, in conjunction with *AASHTO Bridge Design Specifications* (AASHTO, 2013), as well as MassDOT and FHWA requirements (MassDOT, 2013), helped to establish bridge options. Both single span and two-span structures made of steel and/or concrete were investigated. Additionally, the geotechnical report included a recommended foundation design with center piers. However, in order to evaluate the best design for the intersection, another foundation option without center piers was also considered by the MQP team. After this research, four bridge designs were evaluated for the team's final recommendation.

   The footings, girder system, and bridge deck were the three main structural components considered for each design option. Dead and live loads on the bridge were analyzed, considering effects from moving vehicles, snow, utilities, and seismic forces. Based on standard AASHTO highway design, an HL-93 design vehicle loading was used to design the concrete deck. Based on MassDOT requirements, the minimum thickness for the concrete deck is 7 inches. In order to calculate the beam system, two different loading conditions were considered. The single span cases were modeled as simply supported beams, while the two-span cases were modeled with a fixed end at the center pier and a roller at the abutment side. This support structure was used to emulate the fixed support at the center pier and the bearing support on the abutment side of the bridge for the two-span, and a bearing support on either end for the single span. Steel and concrete beam sections were chosen based on strength and serviceability, in accordance with PCI and ASTM standards. All hand calculations completed can be found in Appendix F.

3. **Defined evaluation criteria to determine feasibility, and subsequently, the best design, through comparative qualitative and quantitative analyses.**
   The team's evaluation criteria were developed based on background research, and project goals, which were then reviewed by Stantec. Criteria in **Table 1** were obtained from MassDOT's *LRFD Bridge Manual*, as a part of their preliminary bridge type selection section, as well as recommendations from Stantec. The evaluation criteria was split into two parts: negative factors and positive factors.

   The MQP team provided a brief description for each criterion to indicate the scope of analysis. Within each criterion, an option was given a score of 0 or 1, depending on how well the design satisfies the goals. Additionally, the team applied an importance factor to each criterion, whose value was based on input and feedback from Stantec about the importance of certain criterion over others. The four cases were all evaluated, and the final recommendation was chosen based on the highest score.

Table 1: Evaluation Chart.

No.	Negative Factors	Description	Analysis	Case #1	Case #2	Case #4	Case #6
1	**Beam Height**	*To allow for easier construction to meet the needed vertical clearance*	A shorter beam height was preferred, since it would simplify construction and reduce vertical jacking required to lift the new bridge.				
2	**Maintenance and Inspection of Structure**	*Consider costs for upkeep, repairs, or procedure preservation of bridge strength.*	A project could be economical at the initial construction, but long-term, produce large expenses in maintenance. Therefore, the option that required less maintenance procedures was preferred.				
3	**Inspection Requirements**	*Provide a structure that allows for adequate hands on inspection access.*	FHWA requires routine bridge inspections; designing a structure easily accessible for inspection increases safety for inspectors, and leads to good quality inspections.				
4	**Cost of Materials**	*What is the preliminary estimated cost for the suggested design?*	A preliminary cost estimate breakdown was completed for all four cases. Table 5 outlines a summary of the cost totals for each case. The table indicated that Case #1, Case #3, and Case #4 were lowest in cost and closest in value to each other. Throughout the design process, it was emphasized that cost was the biggest concern for the project. Therefore, the team decided that multiplying this score by an factor of 1.5 would best illustrate the importance of the criterion.				
5	**Labor Cost**	*Are specialized workers necessary for the type of construction involved? How large is the worker group? Consider police detail, working overtime, etc.*	Through the assessment of different bridge construction practices, effective project completion time was found to be an important factor. An extended period of construction would represent higher costs in terms of traffic management and labor, as well as an increased disruption to motorists in the area. The team established that utilizing prefabricated components in all cases would improve the project timeline. When the different cases were compared, it was found that the single span cases could be completed faster than the double span cases.				
6	**Time of Construction**	*About how long will the entire construction take?*	For this project, the project team selected SIBC methods for construction. Based on information and processes described in FHWA and UDOT's SIBC Implementation Guide, erection of all the selected prefabricated designs are similar enough for effects due to these three factors to be negligible. Consequently, they were not included in the team's preliminary evaluation criteria.				
7	**Traffic Management**	*Provide the traffic detouring during the construction phase.*					
8	**Minimize Safety Hazards During Construction**	*Are there elements that could be a hazard to traffic or that would make traffic harder to manage?*					
		SUBTOTAL SCORE					

No.	Positive Factors	Description	Analysis	Case #1	Case #2	Case #4	Case #6
1	**Possibility for Future Improvement**	*Future lane widening or increased traffic loads*	This criterion was included to take into account any potential lane widening or improvements due to a higher traffic volume in the future.				
2	**Aesthetics**	*Provide a type of structure that is architecturally and contextually aesthetic to the location.*	This factor was not of extreme relevance for the team and for Stantec, since the project purpose was to make the most efficient and cost-effective bridge. As a result, all options received the same value of zero.				
3	**Minimize Environmental Impacts**	*What are the potential impacts to the wetland regions?*	Besides having the general importance of environmental considerations as any other project, this project is located in a wetlands area which increases the relevance of this factor.				
		What are the potential impacts to the environment (construction, structure, transportation, etc.)					
4	**Specialized Machinery and Simplicity of Construction**	*Is there complex falsework or construction methods that require more care? Consider safety of construction, quality assurance, etc. throughout the phase.*	After research, it was determined that steel box girders require additional detailing for interior lateral bracing and framework within the shape that may require more experienced workers, and/or more engineers onsite for quality assurance.				
		TOTAL SCORE					

4. **Presented recommendations in the form of a final design and management plan.** The option that minimized negative impacts and had a design that best satisfied project constraints was considered to be the most efficient design strategy. In order to assess the feasibility of implementation, the team outlined a construction staging schedule using SIBC methods, as well as a traffic detour plan for the bridge closure. The final design and construction traffic management plan is outlined in the Results section of this report. These recommendations for Stantec were delivered in the form of a final report, poster, presentation, drawings, and mapped detour paths.

4.0 Results

4.1 Evaluation of Site Conditions

The procurement of the initial information was essential for the success of subsequent steps in the MQP. The observations at the site visit provided an important perspective to really understand what was mentioned in the traffic reports as well as factors that were unknown previously. For example, the team was unaware of the additional signage that was noted around the interchange, such as “Expect Backup on Next Exit,” and signals at the on/off ramps prior to the visit. Due to this traffic buildup, loading due to queuing on the bridge became another consideration to focus on the traffic management plan.

Site plans were key in establishing appropriate dimensions for the structural design. The team was able to determine possible design layouts that fit within site restrictions. Furthermore, these plans outlined wetland regions, which became a factor during the selection of the final design. However, Stantec clarified that this was not a deciding factor, but rather, a consideration for the team. Finally, meetings with Stantec engineers allowed the team to narrow the project scope and prioritize different criteria in the evaluation stage. From this background research, the following key concepts were established:

- Design for bridge replacement rather than rehabilitation
- Consider that the project is time and cost-sensitive, and is in need of replacement rather than rehabilitation
- Investigate both one-span and two-span bridges, along with an evaluation of both steel and concrete superstructures
- Implement the use of prefabricated elements and Accelerated Bridge Construction (ABC) Methods
- Address detouring and traffic management during the construction process in a congested area

The site constraints and the complexity with bridge closure dictated the initial decision to use prefabricated components and partial lane closure during construction as part of the final design. In order to begin developing a construction plan, the team utilized the preliminary decision value chart provided in MassDOT's *LRFD Bridge Design Specifications*. Although some factors were unknown, the team inputted known site conditions, and combined them with "worst case scenarios" for other factors. This resulted in final Preliminary Decision Value greater than 7, highlighting the complexity of the interchange. Following the path shown in **Figure 14**, this led to the final determination to "Strongly Consider Prefabrication and/or Accelerated Procurement Methods."

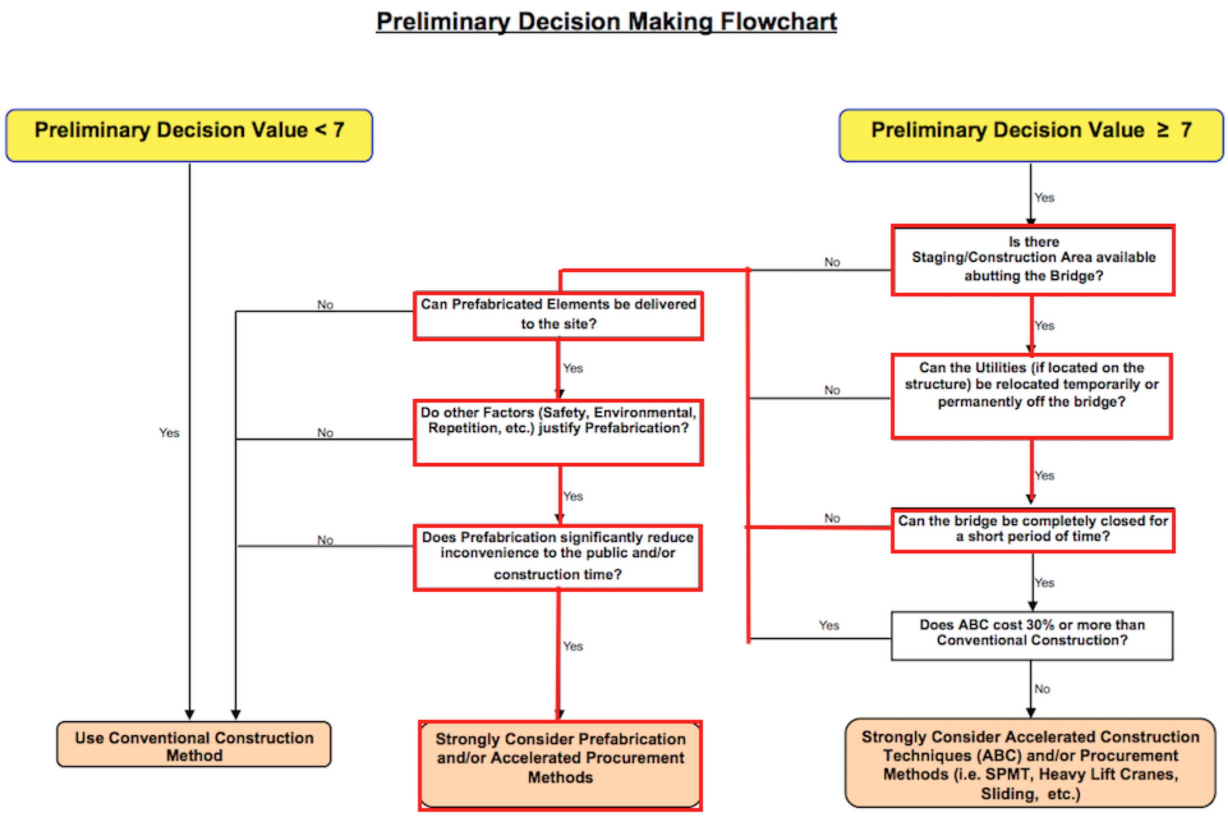


Figure 14: Preliminary Decision Making Chart Trial 1 (MassDOT, 2013).

First, the team considered Phased Construction for the installation process. However, after research and discussion of options, it became clear that segmental construction with partial lane closure would not only disrupt traffic for an extended period of time, but would also be complex due to the abutments and substructure of the existing bridge. The current abutments would have to be completely removed in order to install the larger substructure, and there would be additional police detail and signaling required for detouring to the temporary bridge. Therefore, the team considered the possibility of a short-term complete closure during night hours or off-peak hours for SIBC. This would allow traffic to continue to use the existing bridge during construction, and reduce labor/traffic detail associated with a temporary bridge. Following the MassDOT decision making chart again, a new recommendation to use “ABC and/or Procurement Methods” was found (**Figure 15**).

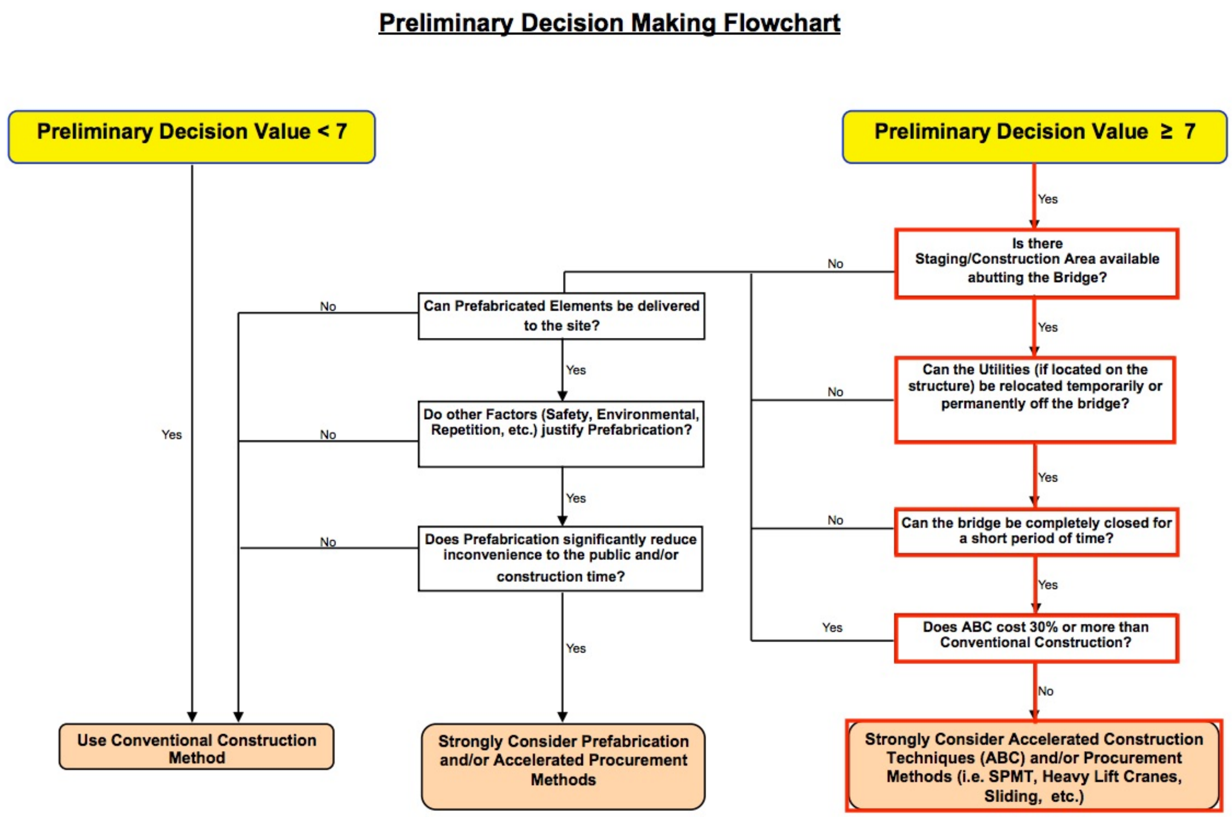


Figure 15: Preliminary Decision Making Chart Trial 2 (MassDOT, 2013).

4.2 Development of the Bridge’s Structural Design

MassDOT’s *LRFD Bridge Manual*, Chapter 3 provided recommendations for bridge types based on the expected clear span length. This chapter suggested three types of bridges for both two-span and single-span bridges for a total of six cases. The specifications also recommended a composite concrete decking, which was assumed for all six cases. Additionally, each option includes footings made of reinforced concrete. The six cases are shown in **Table 2**, and specify the section size and shape, beam spacing, and the expected footing size. Section shapes were chosen based on MassDOT *LRFD Bridge Manual* and the intended clear span length, and the beam spacing values are PCI recommendations for required maximum span. The final footing sizes for each case were developed based on shear values at the beam supports, and soil properties provided in the geotechnical report.

Table 2: Preliminary Bridge Design Selection.

	Span	Recommended Beam Shape	Design Beam Shape	Center-to-Center Spacing (Ft.)	Beam Material	Footing Size	Footing Material
Case #1	Single, Pin-Roller	Plate Girders	W40x235	6-feet Interior 6-feet Exterior	Steel	B = 11 ft	Reinforced Concrete
Case #2	Single, Pin-Roller	Box Girders	W=120" h=33+1.5"=41"	Continuous	Steel	B = 11 ft	Reinforced Concrete
Case #3	Single, Pin-Roller	NeBT Beams	AASHTO-PCI Bulb-Tees BT-72	6-feet Interior 6-feet Exterior	Prestressed Concrete	B = 11 ft	Reinforced Concrete
Case #4	Double, Fixed End-Roller	Stringers	W24x117	6-feet Interior 6-feet Exterior	Steel	B = 6 ft, B = 8 ft. for center pier	Reinforced Concrete
Case #5	Double, Fixed End-Roller	NeXT Beams	AASHTO-PCI NeXT 32Fx96	Continuous	Prestressed Concrete	B = 6 ft, B = 8 ft. for center pier	Reinforced Concrete
Case #6	Double, Fixed End-Roller	Spread Box Beams	AASHTO-PCI Box Beam BII-36	6-feet Interior 6-feet Exterior	Prestressed Concrete	B = 6 ft, B = 8 ft. for center pier	Reinforced Concrete

In order to verify the structural feasibility of the beams chosen in each case, the MQP team developed a simplified loading case. The dead loading used to calculate the maximum moment and shear was a combination of the beam's self weight, the weight of the concrete slab and future wearing surface, as well as weight from future utilities. Live loading was based on a HL-93 design vehicle loading, with point loads and a uniform load positioned to create the maximum moment on the span (AASHTO, 2015). The dead loading was reduced based on allowable distribution methods as outlined by MassDOT. Similar to the dead load, the live loads were also distributed based on reduction factors as provided in Table 4.6.2.2.1 of AASHTO's *Bridge Design Specifications*. The geometry and loading were logged into a computer analysis software, IBeams Pro (Version 2.2, Schuster 2010), and the final results were recorded in **Table 3**. As shown, cases #1, 2, 4, and 6 are the lowest in weight, which could translate to a lower cost per unit weight for materials. Additionally, these four cases had the smaller maximum moments and shear values due to the loading.

Case #1 (single span) and Case #4 (double span) results are shown in Figures 16 and 17, respectively. These diagrams illustrate the maximum moment and shear values for each support system. For the single span, the maximum moment occurs at the center, while the maximum moment for the two-span occurs at the fixed end. The shear values at the beam supports were used as the normal force when completing the foundation design. The shear-moment diagrams for the remaining cases can be found in **Appendix B**.

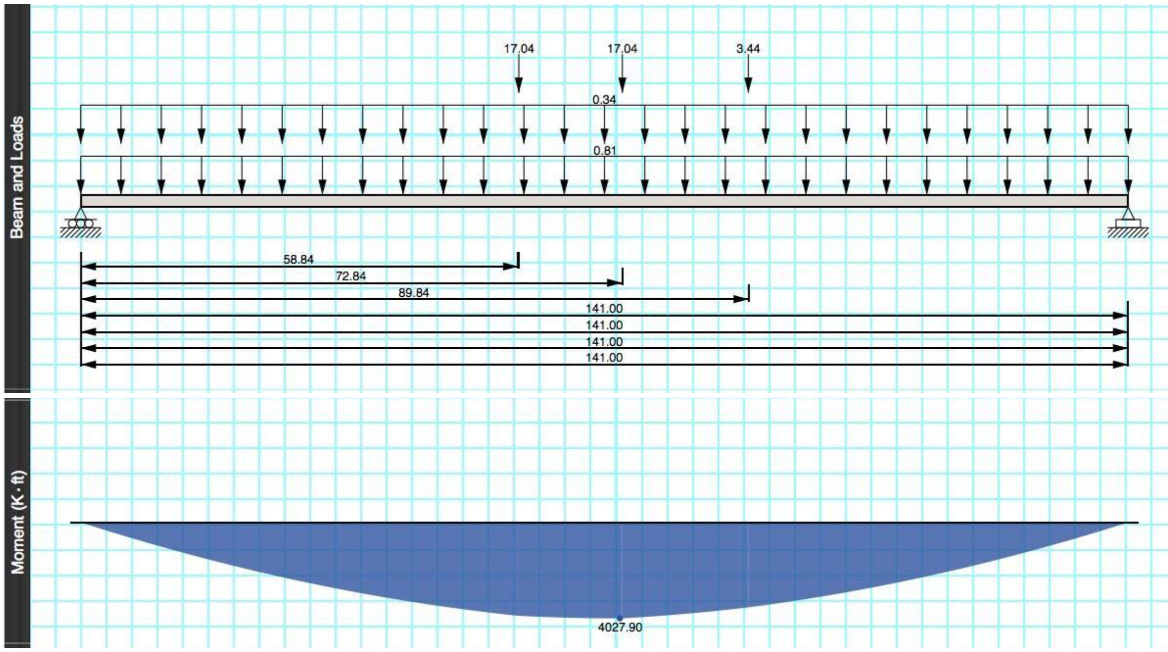


Figure 16: Single Span, Steel Plate Girder Bridge Moment Results.

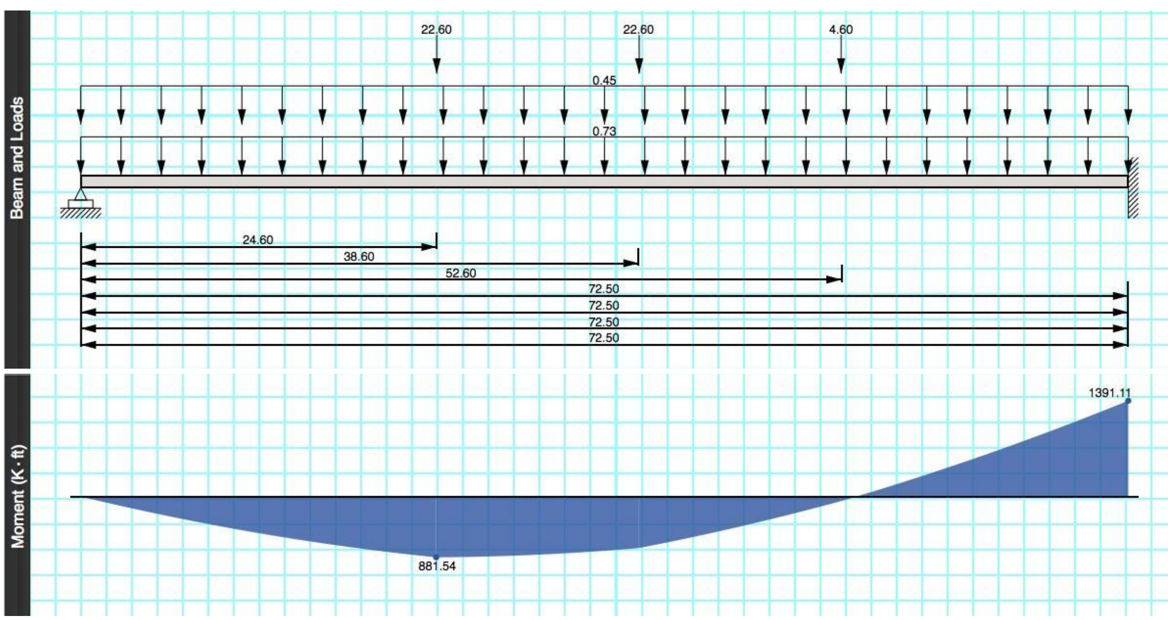


Figure 17: Double Span, Steel Stringer Bridge Moment Results.

Table 3: Preliminary Bridge Design Calculations.

	Span	Mmax(+) (ft-K)	Mmax(-) (ft-K)	Vmax(-) (K)	Vmax(+) (K)	Beam Self Weight (klf)	Overall Weight of Superstructure (kips)	Beam Height (in)	Overall Height Ground to Top of Slab (ft)
Case #1	Steel, Single, Pin-Roller	0	4027.90	99.11	100.42	0.24	65	38.67	20.72
Case #2	Concrete, Single, Pin-Roller	0	4639.45	114.98	116.06	0.59	70	41.00	20.92
Case #3	Single, Pin-Roller	0	5520.61	141.48	142.79	0.80	73	72.00	23.50
Case #4	Stringer, Double, Fixed End-Roller	1391.11	581.54	85.09	50.35	0.12	63	24.30	19.53
Case #5	Double, Fixed End-Roller	1404.25	588.85	85.91	50.89	1.23	80	32.00	20.17
Case #6	Box Girder, Double, Fixed End-Roller	1518.59	916.44	97.30	57.65	0.65	71	33.00	20.25

4.3 Establishing Bridge Cases Based on the Evaluation Criteria

During this project, both single and double-span designs, comprised of either a concrete or steel superstructure, were assessed. The four cases highlighted in green in **Tables 2 and 3** were the top options chosen by the team based on structural feasibility. In these four cases, one superstructure is composed of concrete, and the remaining cases are composed of steel. In order to obtain an evaluation that encompassed the many factors involved, the team developed a combined qualitative and quantitative analysis based on the established evaluation criteria. The following drawings are schematics, showing principal member and foundation sizes for the four selected cases (**Figures 18-21)**.

Figure 18: Single span, steel plate girder bridge (Case #1).

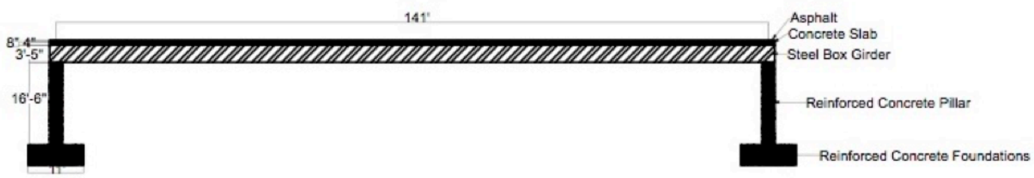
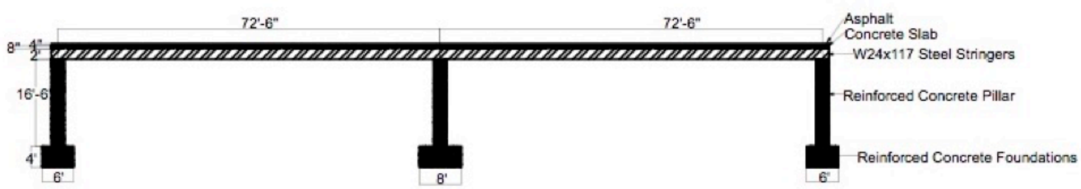


Figure 19: Single span, steel box girder bridge (Case #2).



Figures 20: Double span, steel stringer bridge (Case #4).

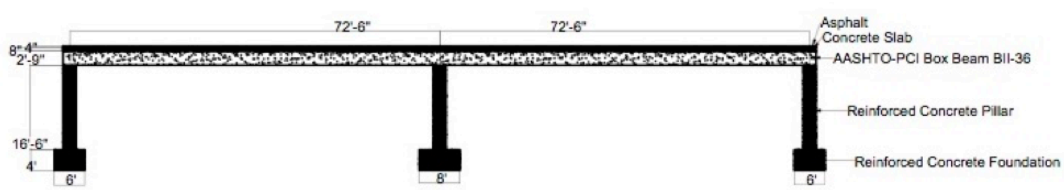


Figure 21: Double span, prestressed concrete spread box beam bridge (Case #6).

4.3.1 Evaluation Criteria Factors

The twelve factors outlined in **Table 4** were chosen based on guiding questions provided in MassDOT's *LRFD Bridge Manual* (MassDOT, 2013). For each factor, the team developed a description that defined the scope of the criterion, and what was considered within each factor. The evaluation process was reviewed by Stantec, and was approved to encompass the key considerations for the project site. The "analysis" section indicates the decision making process the team took to determine the final solution. A comparison amongst all cases was conducted; the cases that had more advantages, and had minimized negative impacts received a score of 1. Otherwise, a score of 0 was assigned. The asterisks in the **Table 4** indicate that these factors were similar in all four cases, and thus, were considered negligible in the evaluation. A score of 1.5 was used in the "Cost of Materials" criterion because a lower cost project was desirable by Stantec.

Table 4: Evaluation Chart.

No.	Negative Factors	Description	Analysis	Case #1	Case #2	Case #4	Case #6
1	**Beam Height**	*To allow for easier construction to meet the needed vertical clearance*	A shorter beam height was preferred, since it would simplify construction and reduce vertical jacking required to lift the new bridge.	1	0	0	0
2	**Maintenance and Inspection of Structure**	*Consider costs for upkeep, repairs, or procedure preservation of bridge strength.*	A project could be economical at the initial construction, but long-term, produce large expenses in maintenance. Therefore, the option that required less maintenance procedures was preferred.	0	0	0	1
3	**Inspection Requirements**	*Provide a structure that allows for adequate hands on inspection access.*	FHWA requires routine bridge inspections; designing a structure easily accessible for inspection increases safety for inspectors, and leads to good quality inspections.	1	1	1	0
4	**Cost of Materials**	*What is the preliminary estimated cost for the suggested design?*	A preliminary cost estimate breakdown was completed for all four cases. Table 5 outlines a summary of the cost totals for each case. The table indicated that Case #1, Case #3, and Case #4 were lowest in cost and closest in value to each other. Throughout the design process, it was emphasized that cost was the biggest concern for the project. Therefore, the team decided that multiplying this score by a factor of 1.5 would best illustrate the importance of the criterion.	1.5	0	1.5	1.5
5	**Time of Construction**	*Are specialized workers necessary for the type of construction involved? How large is the worker group? Consider police detail, working overtime, etc.*	Through the assessment of different bridge construction practices, effective project completion time was found to be an important factor. An extended period of construction would represent higher costs in terms of traffic management and labor, as well as an increased disruption to motorists in the area. The team established that utilizing prefabricated components in all cases would improve the project timeline. When the different cases were compared, it was found that the single span cases could be completed faster than the double span cases.	1	1	0	0
6	**Labor Cost**	*About how long will the entire construction take?*	For this project, the project team selected SIBC methods for construction. Based on information and processes described in FHWA and UDOT's SIBC Implementation Guide, erection of all the selected prefabricated designs are similar enough for effects due to these three factors to be negligible. Consequently, they were not included in the team's preliminary evaluation criteria.	*	*	*	*
7	**Traffic Management**	*Provide the traffic detouring during the construction phase.*		*	*	*	*
8	**Minimize Safety Hazards During Construction**	*Are there elements that could be a hazard to traffic or that would make traffic harder to manage?*		*	*	*	*
		SUBTOTAL SCORE		**4.5**	**2**	**2.5**	**2.5**

No.	Positive Factors	Description	Analysis	Case #1	Case #2	Case #4	Case #6
1	**Possibility for Future Improvement**	*Future lane widening or increased traffic loads*	This criterion was included to take into account any potential lane widening or improvements due to a higher traffic volume in the future.	1	1	1	0
2	**Aesthetics**	*Provide a type of structure that is architecturally and contextually aesthetic to the location.*	This factor was not of extreme relevance for the team and for Stantec, since the project purpose was to make the most efficient and cost-effective bridge. As a result, all options received the same value of zero.	0	0	0	0
3	**Minimize Environmental Impacts**	*What are the potential impacts to the wetland regions?*	Besides having the general importance of environmental considerations as any other project, this project is located in a wetlands area which increases the relevance of this factor.	0	0	1	1
		What are the potential impacts to the environment (construction, structure, transportation, etc.)		1	1	1	0
4	**Specialized Machinery and Simplicity of Construction**	*Is there complex falsework or construction methods that require more care? Consider safety of construction, quality assurance, etc. throughout the phase.*	After research, it was determined that steel box girders require additional detailing for interior lateral bracing and framework within the shape that may require more experienced workers, and/or more engineers onsite for quality assurance.	1	0	1	1
		TOTAL SCORE		**7.5**	**4**	**6.5**	**4.5**

4.4 Final Design

4.4.1 Bridge Cost Estimate Breakdown

Scores from the evaluation criteria revealed that the one-span plate girder bridge with a composite concrete deck, and 11-ft spread footings on either end with abutments (Case #1) best met the project requirement. **Table 5** summarizes the cost estimates for the four cases. Although the table outlines that Case #1 is not the lowest cost option, it proved to be the design that best met project requirements. The cost breakdown of Case #1 is detailed in **Table 6**. **Appendix C** details the cost estimate breakdown for the remaining three cases.

Table 5: Cost Estimate Summary.

	Bridge Type	Project Cost
Case #1	Steel Plate Girder	**$13,000,000.00**
Case #2	Steel Box Girder	**$16,100,000.00**
Case #3	Steel Stringer	**$11,500,000.00**
Case #4	Concrete Box Beams	**$11,500,000.00**

Table 6: One-Span Plate Girder Bridge Cost Estimate.

One Span Plate Girder Bridge Cost Estimate

Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
114.1	Demolition of Superstructure of Bridge	LS	1	$190,000.00	$190,000.00
114.2	Demolition of Substructure of Bridge	LS	1	$344,000.00	$344,000.00
140	Bridge Excavation	CY	29,740	$34.00	$1,011,160.00
151.1	Gravel Borrow for Bridge foundation	CY	250	$40.00	$10,000.00
151.2	Gravel borrow for backfilling structures and pipes	CY	790	$35.00	$27,650.00
	Additional Fill for approach roadway	CY	29,160	$34.00	$991,440.00
995.01	Bridge Structure	LS	1	$5,300,000.00	$5,300,000.00
	Additional Items	EA	1	$73,000.00	$73,000.00
	SIBC	EA	1	$2,210,000.00	$2,210,000.00
				Total Cost of Project	$10,157,250.00
				25% Contingency	$12,696,562.50
				Call	$13,000,000.00

Breakdown of item 995.01 "Bridge Structure"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
460	Hot Mix Asphalt	TON	99	$200.00	$19,857.50
460.1	Hot Mix Asphalt Dense Binder	TON	200	$225.00	$44,904.38
901	4000 PSI, 1 1/2 in, 565 Cement Concrete	CY	249	$700.00	$174,637.04
910.1	Steel Reinforcement for Structures, Epoxy Coated	LB	696,000	$2.00	$1,392,000.00
911.1	Shear Connectors	EA	20,300	$15.00	$304,500.00
922.1	Laminated Elastometric Bearing W/P Anchor Bolts	EA	38	$650.00	$24,700.00
936.3	Prefabricated Retaining Walls	SF	4,455	$80.00	$356,400.00
952.1	Steel Sheeting	SF	1,480	$35.00	$51,800.00
960	Structural Steel (Plate Girder)	LB	497,025	$3.50	$1,739,587.50
965.2	Membrane Waterproofing for Bridge Deck Spray Applied	SY	19,035	$9.00	$171,315.00
970	Bituminous Damp-proofing	SY	2,115	$12.00	$25,380.00
972	Strip Seal Bridge Joint System	FT	405	$400.00	$162,000.00
975.6	Snow Fence	LF	2,902	$200.00	$580,400.00
994.1	Temporary Protective Shielding	SF	18,850	$12.00	$226,200.00
				Total Cost of Bridge Structure	$5,273,681.41
				Call	$5,300,000.00

Breakdown of item "Additional Items"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
976	Temporary concrete bridge barrier	LF	270	$119.05	$32,143.50
977	Temporary concrete bridge barrier remove and reset	LF	270	$107.15	$28,930.50
992.32	Temporary supports for piping	LS	1	$11,905.11	$11,905.11
				Total Cost of Additional Items	$72,979.11
				Call	$73,000.00

Breakdown of item 993.1 "Temporary Bridge"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
140	Bridge Excavation	CY	1,452	$119.05	$172,860.60
901	4000 PSI, 1 1/2" 565 Cement Concrete	CY	543	$107.15	$58,194.36
904.4	4000 PSI, 3.4" 585 HP Cement Concrete	CY	31	$800.00	$25,066.67
910.1	Steel Reinforcement for Structures, Epoxy Coated	LB	174,000	$2.50	$435,000.00
	Bridge Cost	LS	1	$1,903,500.00	$1,903,500.00
996.3	Mobilization/Demobilization -3%	LS	1	$420,100.00	$420,100.00
				Total Cost of Additional Items	$3,014,721.62
				Call	$3,100,000.00

Breakdown of item 993.1 "SIBC"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
	Bridge Cost	LS	1	$1,903,500.00	$1,903,500.00
	Bridge Slide Cost	LS	1	$306,000.00	$306,000.00
				Total Cost of Additional Items	$2,209,500.00
				Call	$2,210,000.00

The cost estimate breakdown (**Table 6**) was completed based on values given by MassDOT average unit prices for 2016, and by estimates previously completed by Stantec. Values such as structural steel reinforcement, gravel borrow fill for foundation excavation, and others marked in orange were values copied from previous Stantec estimates from this same project, since these details were not estimated as part of the preliminary design. Using these values provided a more accurate estimate, although these values can change closer to a 75% submittal proposal.

For all four cases, the highest cost items were the bridge structure cost and the construction cost. This influenced the decision to choose designs that could lower these costs. After completing the cost estimates, it was found that construction costs were similar for all four cases (see **Appendix C**). Therefore, the team evaluated a design with a lower bridge structure cost. Case #1 had bridge structure cost of $5,300,000, which can be compared to the lowest structure cost of $4,000,000.

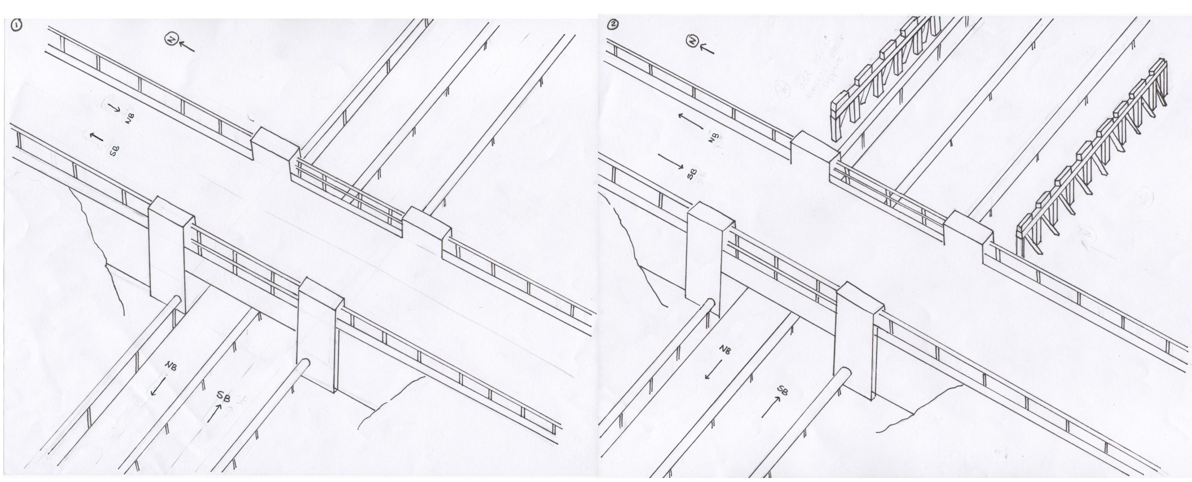
The team then completed a cost estimate for a temporary bridge, which is also detailed in **Table 6.** As shown, a temporary bridge with supports, excavation, and mobilization/demobilization costs would sum to a $3 million cost. Due to the high cost of phased construction, a cost estimate of SIBC methods for comparison was also completed. The final SIBC cost is a combination of the total bridge material cost multiplied with reduction factors (Site Complexity Factor, Slide Cost Adjustment Factor, etc.), an added contingency percentage, and any additional costs (administration costs, incentives/disincentives) that can be subtracted from the final estimate. Another benefit of using SIBC methods is the elimination of additional construction costs. The SIBC cost, as calculated from the procedure outlined above, is the total cost of construction, including costs from labor, schedule, and materials. The detailed procedure to determine SIBC costs was provided by FHWA, and is shown in **Appendix D**. This caused a reduction in construction costs, by approximately $900,000. This is due to the elimination of mobilization costs, as well as the costs for structural components for a temporary bridge. Since this is a preliminary estimate, and FHWA outlines that the accelerated schedule and reduced labor required for SIBC can continue to reduce the cost of construction, the team decided that these methods were optimal for the bridge replacement. The project cost with SIBC methods resulted in an overall value of $13 million.

4.4.2 Recommended Construction Staging

According to Stantec site plans, there are wetland regions west of the bridge, in between the on/off ramps for Route 24 southbound. Therefore, in order to reduce wetland impacts, it would be best to complete erection of the slide-in bridge east of the existing structure. Based on FHWA's *SIBC Implementation Guide*, the team estimated three to four days of complete closure of the existing bridge, as well as closure of Route 140 under Route 24, for the demolition and installation of the substructure, the slide-in of the new bridge, and final approach roadway work. After the lateral sliding process, pavement markings and final roadway work will cause partial closures on the bridge for an additional two days. **Figures 22-30** illustrate the planned SIBC construction site, just east of the existing bridge and over Route 140. The figures are hand-sketched drawings (not to scale) of the proposed staging schedule, from excavation of the substructure and construction of the slide-in bridge, to the lateral sliding process and the final positioning of the new bridge. The three-week estimated time frame was split into a staged timeline, based on research conducted on prefabricated bridge construction and previous nationwide ABC projects.

Stage 1 (1 week)

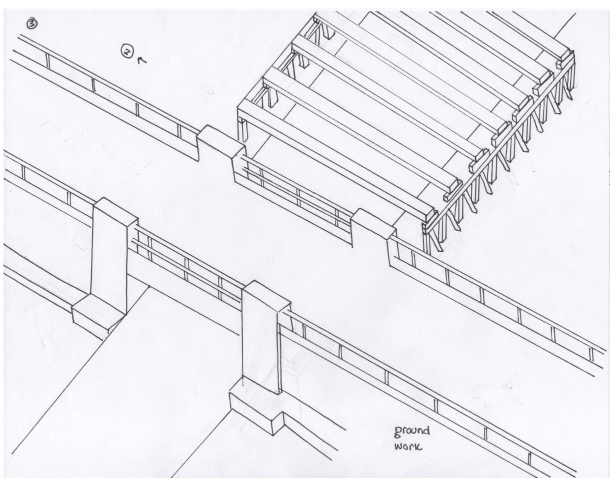
Preparation for the construction schedule begins. Any signage necessary to indicate the dates of completion and partial shutdown is posted, along with transportation of required machinery. Temporary supports are built in preparation for construction of the new bridge, adjacent to the existing bridge. Traffic can continue to flow through the interchange in all directions.

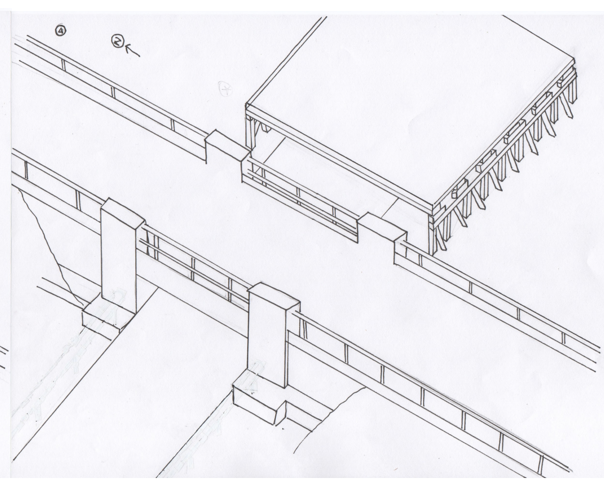


Figures 22 and 23: Stage 1 bridge construction.

Stage 2 (2 weeks)

Groundwork is started in order to begin the excavation process and to expose the foundations. This allows the opportunity to accelerate the new substructure work, and install parts of the prefabricated retaining wall, and footings. Micropiles can be used for additional support for parts of the existing substructure during adjacent excavation (ICEUSA, 2017). Also during this time, work for the new superstructure work is also started; the prefabricated steel beams and composite concrete deck are transported to the site, and then placed onto the temporary supports. Occupational Safety and Health Administration (OSHA) requires that barricades and hand/mechanical signals are used where necessary, and soil is graded away from excavation to assist in vehicle control, and avoid hazards of vehicular accidents (OSHA, 2016). Therefore, during the process of excavation, it would be best to close one lane in either direction of Route 140 under the bridge to accommodate the space required for the soil grading. The best path would be to merge lanes under the bridge, and then to expand into the normal lane configuration after clearing the construction area.

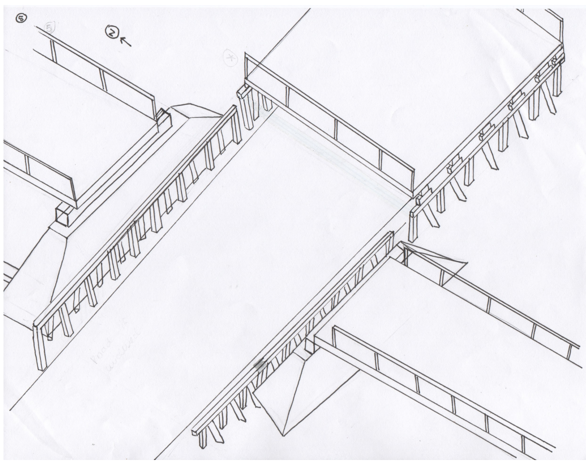


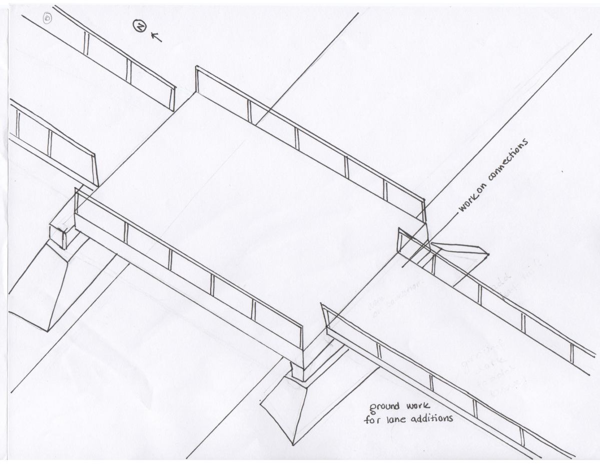


Figures 24 and 25: Stage 2 bridge construction.

Stage 3 (3-4 days)

Once the new bridge superstructure is complete, the interchange is shutdown, and demolition of the old bridge begins. The new foundations are completely installed, along with any guardrails and safety barriers. The new bridge is then slid into place, using a hydraulic jack for lateral sliding.

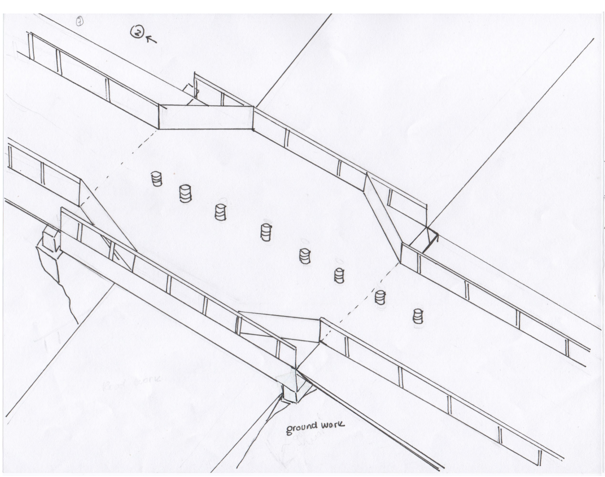


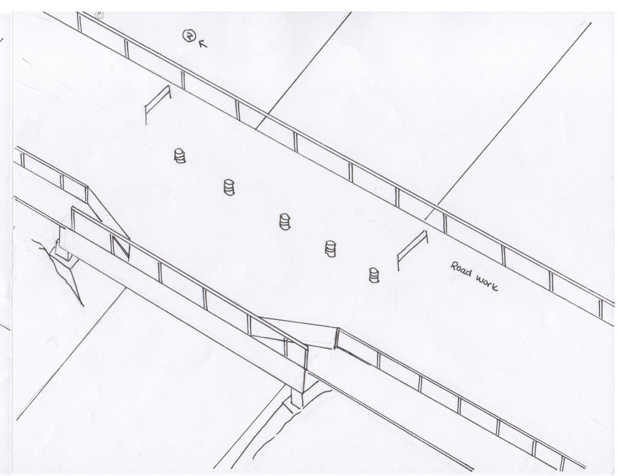


Figures 26 and 27: Stage 3 bridge construction.

Stage 4 (2 days)

Once the new bridge is in place, concrete is poured on the approach roadway, in order to accommodate the new bridge width. Grading and backfill is completed to allow for the new vertical clearance. The bridge is then reopened, with partial closure, and roadwork on Route 140 can also begin underneath. Temporary barriers are placed to detour traffic, while pavement markings and lane demarcations are added to the Route 24 bridge.





Figures 28 and 29: Stage 4 bridge construction.

Stage 5

The interchange is then fully open to all traffic, with the new lane configurations and added capacity.

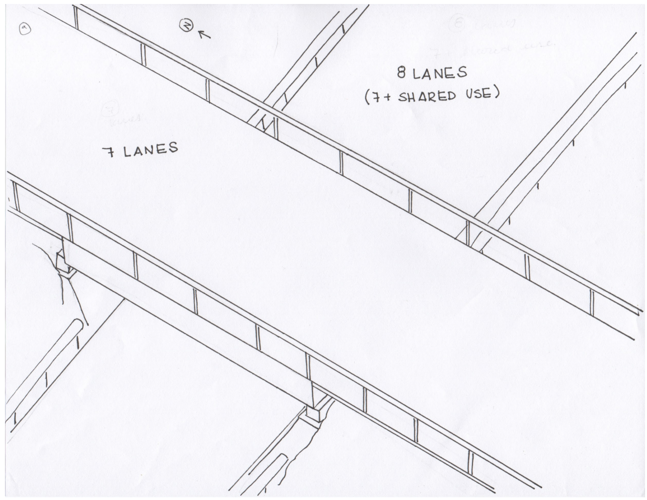


Figure 30: Stage 5 final bridge.

4.4.3 Recommended Traffic Management Plan

The planned 3-4 days of bridge closure required the team to develop a Traffic Management Plan for construction. **Table 7** outlines the 12 paths that are disrupted by a complete closure of the bridge. In order to make sure a closure was feasible, it was necessary to locate a detour solution for each of the following paths.

Table 7: Paths disrupted by bridge closure.

From	Onto	From	Onto
Route 140 NB	Route 140 NB**	Route 24 NB	Route 24 NB**
	Route 24 SB**		Route 140 SB***
	Route 24 NB***		Route 140 NB**
Route 140 SB	Route 140 SB**	Route 24 SB	Route 24 SB*
	Route 24 SB***		Route 140 SB*
	Route 24 NB**		Route 140 NB*

* Detours using proposed temporary ramp/planned ramp configurations.
**Detours using existing ramps.
*** Detours not needed.

The team utilized Google Maps and site plans to identify potential exits, interchanges, or empty lots for potential on/off ramps. In order to determine the "best fit" path, the team listed all viable local detours for each direction, and then assessed them based on the following requirements:

- Reduced (if any) additional temporary construction costs
- Efficiently used the existing interchange configurations
- Minimized delay time for motorists
- Minimized effects on the LOS of surrounding roads, with added traffic volume

Based on Google Maps, the team located detours for motorists travelling through Taunton. Motorists could utilize paths like Route 79 instead of Route 24, or Interstate 495 or Route 138 instead of using Route 140. If motorists are notified far enough in advance, these paths can further mitigate traffic congestion problems during construction. Additionally, the team found local detours, such as Hart Street, Stevens Street, Route 79, and Route 44 as alternatives for motorists with destinations closer to the interchange. **Figures 31-34** are four maps that outline the paths around the bridge closure that motorists could take, and are grouped based on similar routes, or require temporary ramps. During the time of closure, the team assumed that on/off ramps for both Route 24 and Route 140 would remain open. Details of each individual path can be seen in **Appendix E**.

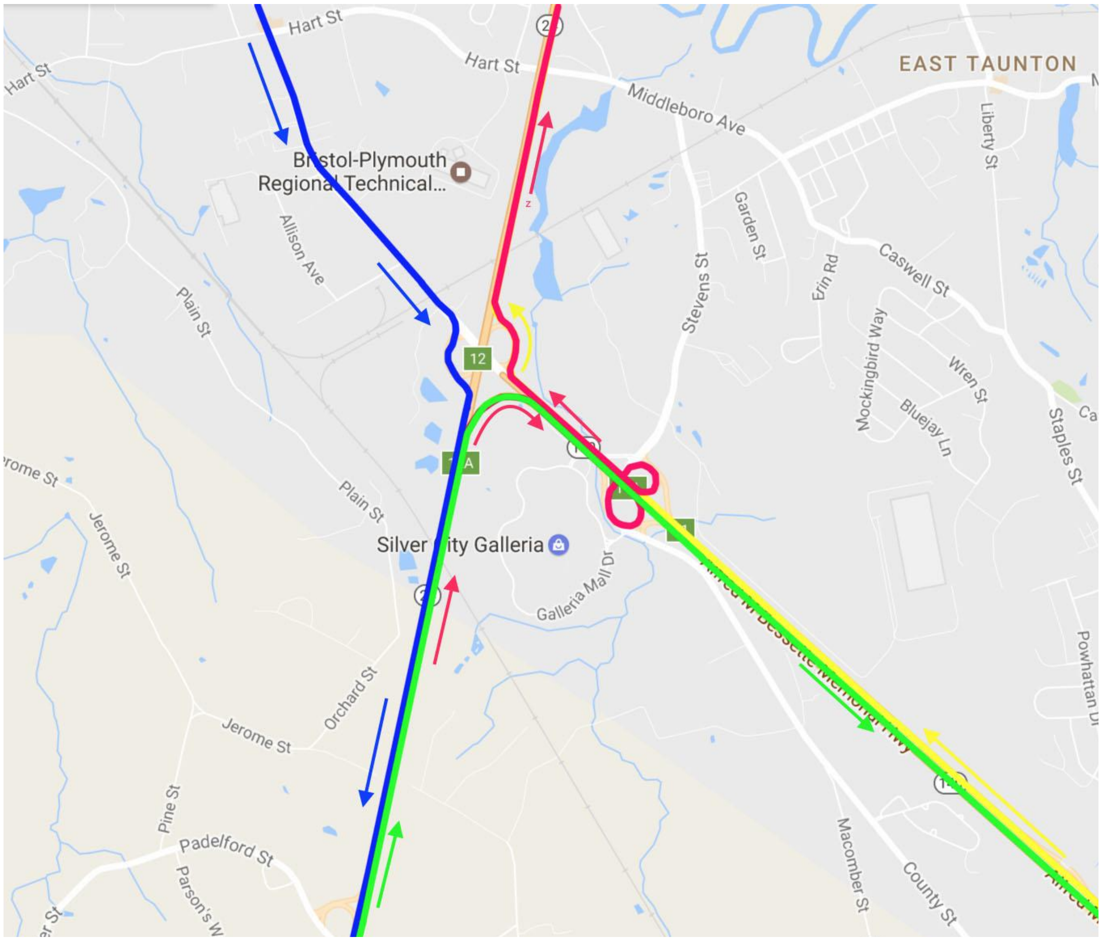


Figure 31: Paths using existing on/off ramps (Google Maps, 2017k).

From	Onto	
Route 24 NB	Route 140 SB	
Route 140 NB	Route 24 NB	
Route 140 SB	Route 24 SB	
Route 24 NB	Route 24 NB	

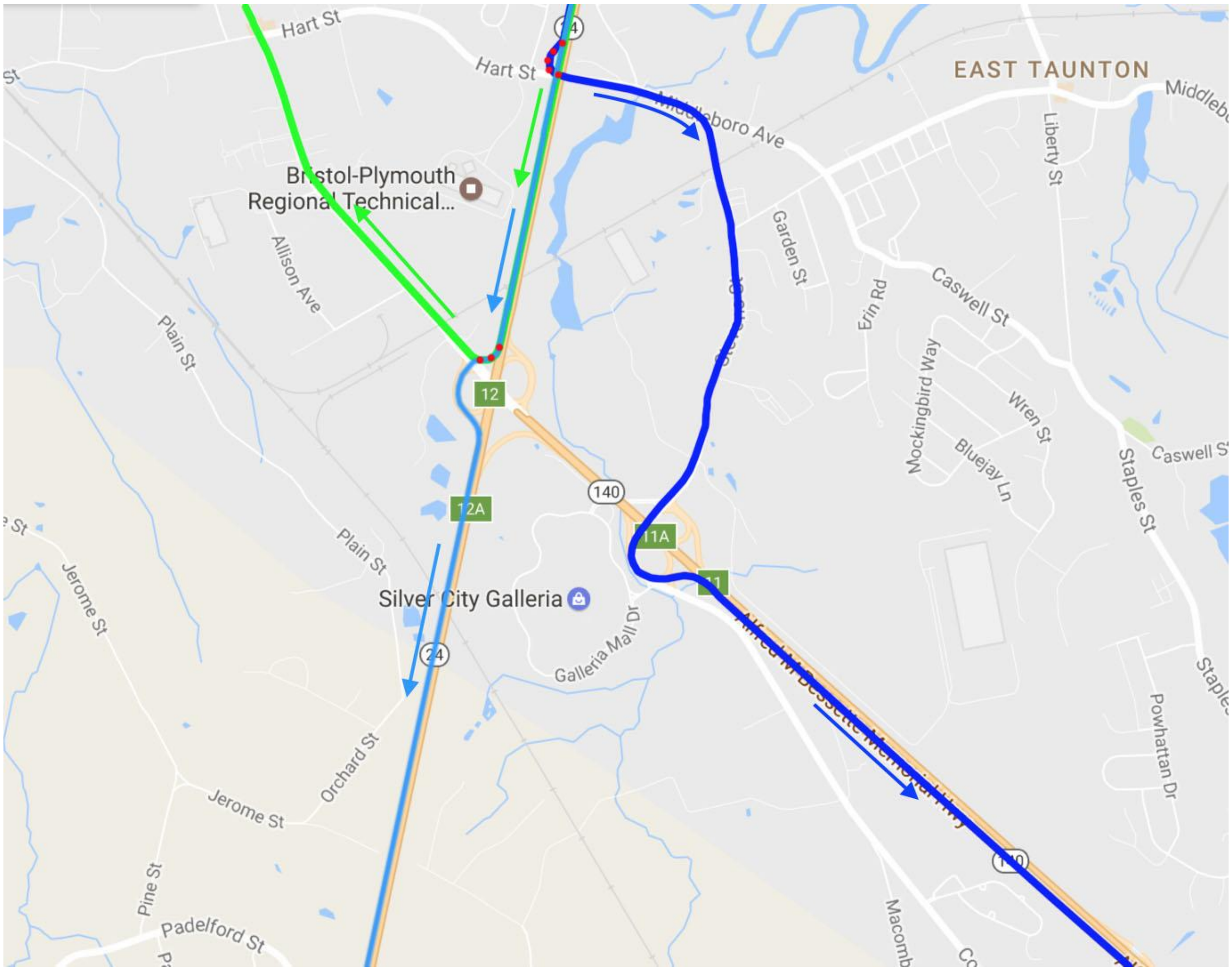


Figure 32: Detours using temporary/proposed ramps (Google Maps, 2017k).

From	Onto	
Route 24 SB	Route 140 SB	
Route 24 SB	Route 24 SB	
Route 24 SB	Route 140 NB	

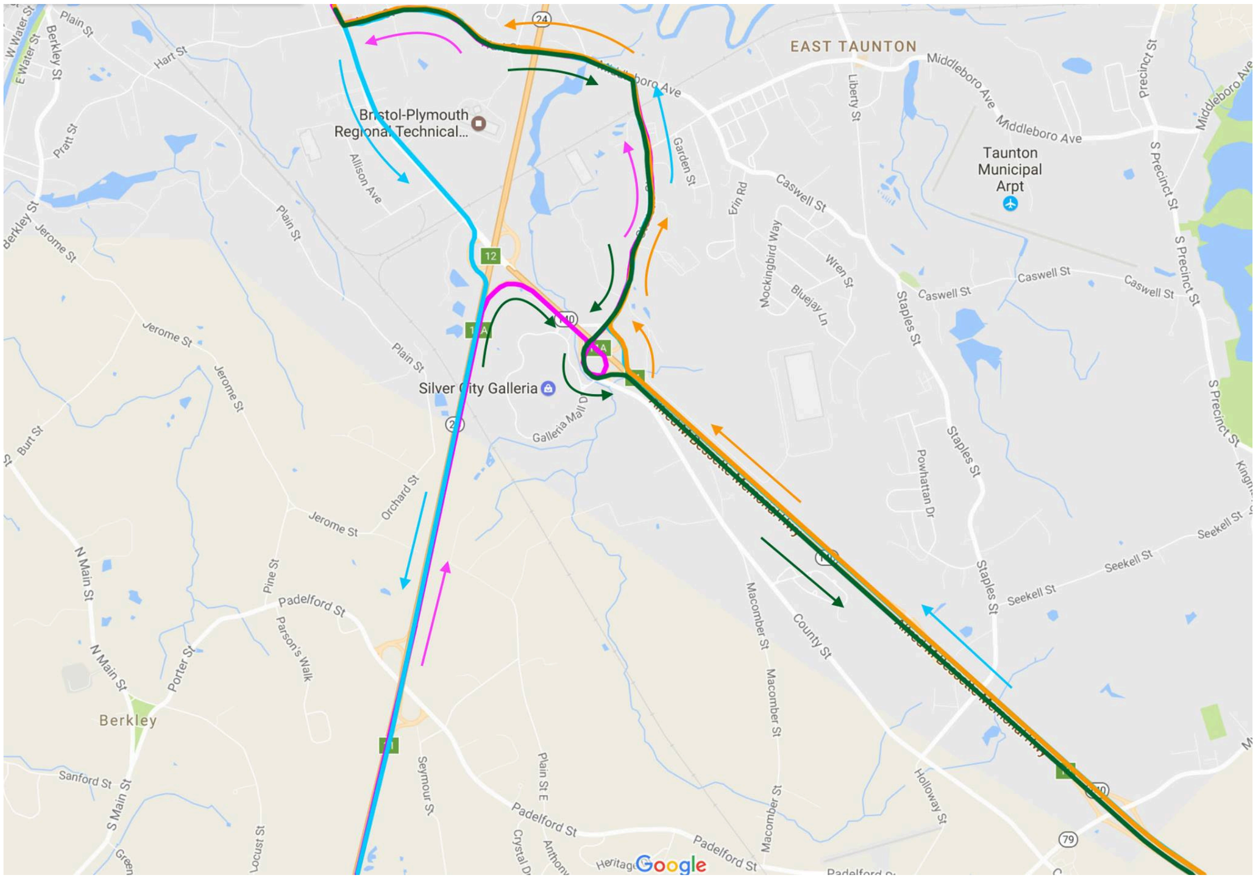


Figure 33: Detours using Stevens Street (Google Maps, 2017k).

From	Onto	
Route 140 SB	Route 140 SB	
Route 24 NB	Route 140 NB	
Route 140 SB	Route 24 SB	
Route 140 NB	Route 140 NB	

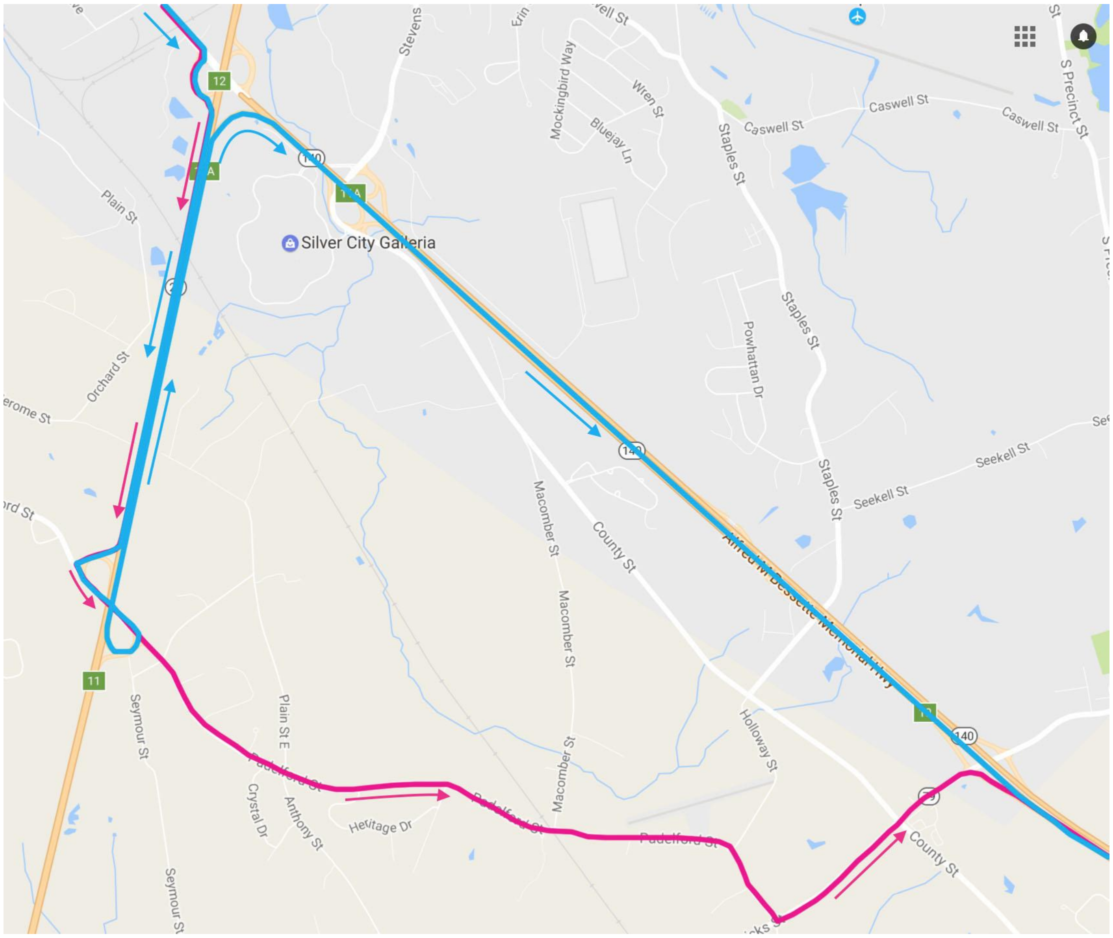


Figure 34: Detours using Exit 11 on Route 24 (Google Maps, 2017k).

From	Onto	
Route 140 SB (Option 1)	Route 140 SB	
Route 140 SB (Option 2)	Route 140 SB	

Once the new bridge is installed, there will be a total width to accommodate 7 lanes (see **Figure 7**). In order to complete the required approach grading and pavement markings, one side of the bridge will be closed, and then the other side, for about 2-3 days. **Table 8** outlines the peak hour traffic volumes northbound and southbound on the Route 24 bridge. **Table 9** provides the MassDOT standard for the capacity of lanes during construction work.

Table 8: Peak hour traffic volumes for the 24/140 interchange.

	Peak Hour Traffic Volumes (Number of Vehicles)		
	Weekday AM	*Weekday PM*	*Saturday Midday*
Route 24 NB	**1,876**	**3,792**	**2,256**
Route 24 SB	**2,716**	**2,144**	**1,578**

Table 9: Measured work zone capacity versus lanes open during construction (MassDOT, 2006).[3]

Number of Lanes		Estimated Capacity	
Normally Open	**During Construction**	**Vehicles/hour/lane**	**Total vehicle/hour**
2	1	1,340	1,340
3	2	1,490	2,980
3	1	1,170	1,170
4	3	1,520	4,560
4	2	1,480	2,980
4	1	1,170	1,170

[3] "Source: Adapted from Notes on Work Zone Capacity and Level of Service" (MassDOT, 2006).

Table 10: Peak hour traffic volumes for the 24/140 interchange.

	Necessary Number of Lanes During Construction		
	Weekday AM	***Weekday PM***	***Saturday Midday***
Route 24 NB	**2**	**3**	**2**
Route 24 SB	**2**	**2**	**2**

Based on the total volume and MassDOT standards, **Table 10** outlines how many lanes should be open in each direction during partial closures at peak hours. Based on the required lanes, it may be best to begin the pavement work with 5 lanes open on weekday PM, and then work through the night into weekday AM, ensuring that there are enough lanes open during peak hours to carry the capacity of motorists. If completed during the day, motorists can be detoured with traffic signaling and barriers to shift lanes while roadway and markings are finished.

5.0 Conclusion and Final Recommendations

In this project, the team developed a preliminary bridge design, construction, and traffic management plan for a two-way highway overpass. The design complied with MassDOT, FHWA, and AASHTO requirements. The team used I-Beam Pro to model HL-93 loading on the selected beams. Construction methods and traffic detours were selected based on site constraints, as well as suggestions provided in FHWA's *SIBC Implementation Guide*. After a full analysis of the interchange, the team has the following recommendations for Stantec in regards to the design and construction of this project:

5.1 Structural Design

The team determined that the best design for the bridge would be a one-span, steel girder bridge with reinforced concrete footings. Steel beams allow for easy inspection, and for potential future improvements to the bridge. In addition, a single-span bridge increases site visibility for motorists using Route 140 since it does not use center pillars. Finally, the team recommends using prefabricated components in the bridge, due to their benefits specific to the project location and time frame. The components can be fabricated off site in a controlled environment, transported and installed onsite, without additional impact to the wetland environment.

5.2 Construction Methods

The team recommends Stantec to use SIBC methods for construction. SIBC has been proven to accelerate the project schedule due to its adaptability to a short period of complete closure rather than requiring an extended partial closure (UDOT/FHWA, 2013). This construction method eliminates labor and time delays associated with the construction of a temporary bridge. The cost estimates showed that SIBC methods reduce construction costs, since there are no additional costs associated with the construction and demolition of a temporary bridge. The accelerated time schedule is also expected to reduce construction costs and traffic control costs. Finally, the team recommends recycling the demolished steel and concrete, to further reduce environmental impacts.

5.3 Traffic Management

The team developed a traffic management plan for three days of complete closure, and two additional days of partial closure. Detours for 13 paths were identified and routed using Google Maps. The team evaluated the paths that would minimize the need for additional temporary construction and utilized existing roads to reduce the cost and complexity of the project. Since the interchange and nearby roads will be highly congested due to construction detours, it is advisable to warn motorists to take alternative routes to Route 24 and Route 140, since traffic delays are expected near the intersection.

5.4 Final Recommendations

If Stantec chooses to pursue the recommendation to use a single-span bridge with SIBC methods, the team recommends further analysis and investigation on a more detailed construction timeline. The timeline provided in this report is preliminary, and can vary based on the final structural design, and on any unexpected site conditions that are found during construction. Once more details about the replacement are confirmed, it is recommended to reassess the construction timeline, as well as the overall project cost. Additionally, the team recommends an analysis of costs due to any temporary ramps for detours, which can increase the project cost. Finally, since this complete closure is proposed for three days, the MQP team recommends starting and finishing Construction Stage 3 during a long weekend.

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Appendices

Appendix A: Initial Proposal

Investigation of the Route 140/24 Interchange in Taunton, MA

A Major Qualifying Project Proposal Submitted to the Faculty
Of
Worcester Polytechnic Institute
In Partial Fulfillment of the requirements for the Bachelor of Science Degree
By

Anjali Kuchibhatla
Carolina Leguizamón
Maitane Sesma

December 15, 2016

Advisors:
Leonard Albano
Suzanne LePage

Table of Contents

Introduction

According to the Federal Highway Administration (FHWA), there are over two hundred million trips taken in metropolitan areas over structurally deficient bridges. As defined by the Massachusetts Department of Transportation (MassDOT), “structurally deficient bridges are those in need of extensive repair in order to address deficiencies (MassDOT, 2010). In efforts to improve the highway system, MassDOT initiated the Accelerated Bridge Program (ABP), whose goal is to reduce the number of structurally deficient bridges and increase the overall Bridge Health Index in the state by designing innovative and sustainable bridges (MassDOT, 2008).

One of the bridges in need of replacement is situated at the interchange between Route 140 and Route 24 in Taunton, Massachusetts; this bridge has four travel lanes with an approximate span of 100 feet. The goal of this project is to increase the width and the vertical clearance of the Route 24 and 140 interchange to accommodate for traffic flow and structural requirements, by considering bridge rehabilitation or redesign.

Background

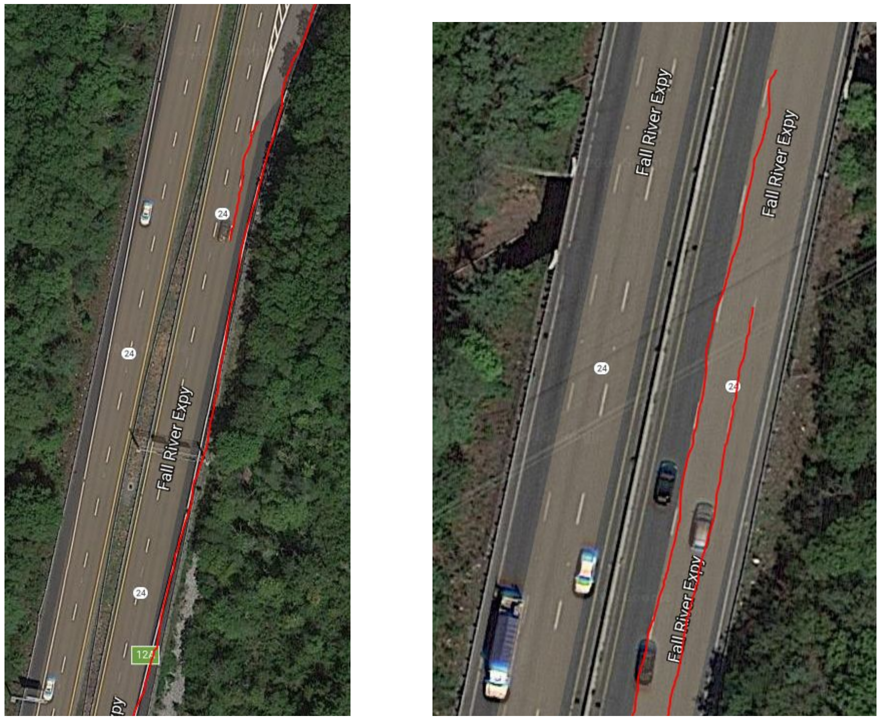
This chapter provides an overview of the characteristics of Route 24/Route 140 interchange in the city of Taunton, Massachusetts. We investigated the existing conditions of the interchange and surrounding area, such as current traffic flow, crash rates, and structural issues of the bridge.

Existing Site Conditions

Existing Interchange and Bridge Layout

An interchange is an intersection where one road passes over another one (OhDOT, 2015). This interchange of Route 24 over Route 140 has a five-ramp partial cloverleaf configuration, and is located on Exit 12 (**Figure 1**). In the vicinity of the interchange, both ramp locations are controlled by traffic signals (Hudson, 2016). Route 24 has four operating lanes, and provides a major link between the greater Boston area and communities to the Southeast of Taunton. Route 140 is a state highway that passes through parts of Southeastern and Central Massachusetts. 2,700 feet "north in advance of Exit 12", the lane was widened by MassDOT. The acceleration lane on Route 24 northbound was also lengthened by 2,000 feet (Fay, Spofford, & Thorndike, 2015). An aerial view of these additions are shown in **Figure 2** and **Figure 3**.

Figure 1: Route 140/Route 24 Interchange Existing Conditions.



Figures 2 and 3: Deceleration lane off Route 24 northbound and acceleration lane on Route 24 northbound (Google Maps).

The Route 24 bridge is a four-lane, composite steel I-beam girder bridge with two lanes going in each respective direction (**Figure 4**). An approximation of 100 feet for the end-to-end bridge span was made from **Figure 5**, a lateral view of the interchange at Route 24 and 140. This is considered a short to medium span sized bridge.

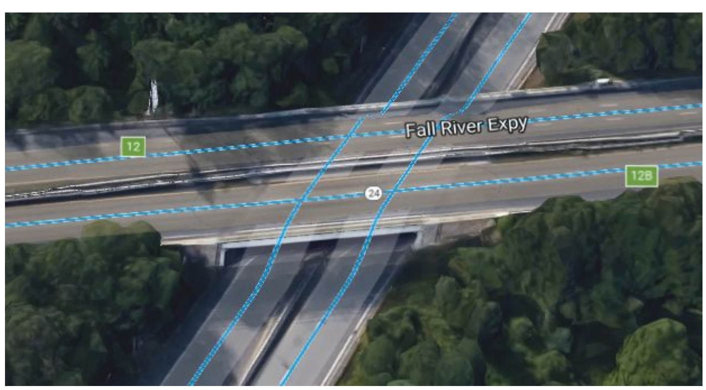


Figure 4: Aerial view of Rte. 24 bridge (Google Maps).

Figure 5: Route 24/140 Interchange (Google Maps).

Structural Considerations

As previously stated, this bridge is considered “structurally deficient.” This means that the bridge’s deck, substructure, and superstructure has received a rating between “0-4” on the National Bridge Inventory (NBI) Rating Scale. Although the bridge can remain in service, it does require immediate attention (MDOT, 2015). Additionally, due to its deficiencies, there must be signage before entering the bridge indicating the permissible vehicle weight, since it is lower than the state’s gross weight limit for trucks.

Existing Traffic Conditions

According to a study conducted in 2009 by Fay, Spofford, & Thorndike, Route 140 carried 22,600 vehicles per average day (Fay, Spofford, & Thorndike, 2015). Comparatively, in a traffic study completed in 2012, MassDOT recorded an average of 43,400 vehicles per day in the area near the interchange. Over 3 years, this is approximately a 200% increase in the number of vehicles that use the route. Route 24 carried between 53,600 - 72,000 vehicles per day, which is also an increase from the average values in 2009. The interchange has been identified by the MassDOT as a “crash cluster,” meaning that it is part of the top 5% of high crash locations, as defined by the Southeastern Regional Planning and Economic Development District (SRPEDD) (MassDOT, 2015). This indicates that changes are necessary to improve driving conditions at the interchange, and to accommodate a growing number of vehicles.

A safety audit prepared by Fay, Spofford & Thorndike in 2015 analyzed operations, geometry, and crash history for both roads. Route 24 “operated poorly due to heavy afternoon volumes with significant queuing occurring on the main line," creating a driving environment prone to rear end accidents. The audit found maintenance issues due to the deterioration of signage and pavement markings, as well as issues with the ramp that increase the possibility for off-ramp accidents. Additionally, ramps on routes 140 and 24 face similar issues, having an excessive amount of signage in a short distance, missing lane delineations, and overall geometry limitations that increase the possibility of sideswipe crashes, off-ramp accidents and queues from the intersection that routinely back up onto Route 24 during rush hours (Fay, Spofford, & Thorndike, 2015).

Bridge Structural Components

A general understanding of bridge components is necessary for effective design. Through research, it was concluded that bridges can be separated into two sections: the superstructure and substructure (**Figure 6**). The superstructure consists of the deck and deck components, slab, and the girders underneath the bridge deck. The substructure is comprised of the abutments, piers, footings, and foundation (MoDOT, 2010). These two sections will need to be assessed and designed for structural integrity. Factors such as mobilization/construction, project schedule, serviceability, and cost will also be considered when assessing bridge rehabilitation and redesign.

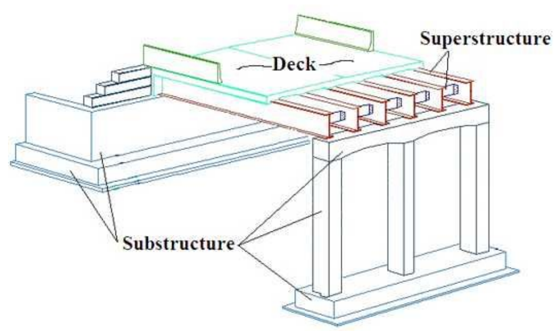


Figure 6: Superstructure and substructure (Michigan Dept. of Transportation, 2016).

Methodology

Project Specifications

Given the current conditions of the bridge, this interchange is currently undergoing improvements for the ramps on both routes and for bridge expansion. The Taunton bridge rehabilitation project outlines the following modifications and additions to the existing bridge structure:

- Accommodation to the future widening of Route 24 to three lanes
- Wider cross-section of Route 140
- Vertical clearance increase

To meet these specifications, the goal of this project is to increase the width and the vertical clearance of the Route 24 and 140 interchange to accommodate for traffic flow and structural requirements, by considering bridge rehabilitation or redesign. Specifically, we intend to assess the current conditions of the bridge, provide alternative designs for rehabilitation, and to deliver a schedule and cost estimate for the project will be done. In order to achieve our goal, we shall complete the following objectives:

1. **Evaluate the current site conditions.**
   The first task is to gather information about the site from environmental impact reports, traffic studies, and soil investigations. Then, existing drawings, bridge inspection reports, and load rating reports that Stantec may have will be reviewed. This will aid to establish the geometric characteristics of the existing interchange.

2a. Determine the feasibility of bridge rehabilitation.
After reviewing the bridge inspection and loading rating reports, analysis of certain members will be completed to determine structural deficiencies of the existing bridge. Then, computer software analysis programs, such as RISA or RAM, will be utilized to model the existing bridge and to model various rehabilitation ideas, taking into consideration AASHTO Bridge Design Specifications and MassDOT requirements.

These improvement options will be evaluated to determine if it is feasible to preserve the core structure, with adjustments (steel girder additions, lane widening, etc). This will entail reviewing case studies of previous projects that have implemented a similar approach. If improvements on the existing structure is adequate, then a cost estimate and schedule will be developed.

2b. If updates are not feasible, research alternative design options and develop a preliminary strategy for a new structure.

However, if it is determined that the existing structure should be replaced, strategies for new bridge construction will be developed by completing analysis techniques used in Objective 2a. Design will be based on the application of AASHTO Bridge Design Specifications and MassDOT requirements. Then, an overall cost and project schedule will be created by utilizing available load ratings and project constraints.

3. Present recommendations and final design.

In order to assess the best design options, the evaluation criteria will be defined, considering factors such as cost and schedule estimates,as well as other factors deemed necessary by Stantec. Then, a comparative analysis between the different design approaches will be conducted to determine advantages and drawbacks. Finally, recommendations for Stantec will be delivered in the form of a final report and presentation.

These objectives and respective tasks are further outlined in our Project Timeline, as illustrated below:

Task Name	Start	Finish
Evaluate the current site conditions.	Thu 1/12/17	Tue 1/24/17
Review EIS, traffic studies, and soil investigation report	Thu 1/12/17	Mon 1/16/17
Review existing drawings and bridge inspection reports	Thu 1/12/17	Wed 1/18/17
Determine geometric characteristics	Wed 1/18/17	Tue 1/24/17
Determine the feasibility of bridge rehabilitation.	Tue 1/24/17	Mon 2/6/17
Model existing bridge using RISA or RAM	Tue 1/24/17	Fri 1/27/17
Research improvement options	Fri 1/27/17	Mon 2/6/17
Research alternative design options and develop a preliminary strategy for a new structure.	Mon 2/6/17	Wed 2/15/17
Research bridge design options	Mon 2/6/17	Fri 2/10/17
Develop cost and schedule estimate for all options	Wed 2/8/17	Wed 2/15/17
Present recommendations and final design.	Wed 2/15/17	Fri 3/3/17
Compare benefits and drawbacks of design alternatives	Wed 2/15/17	Tue 2/21/17
Prepare final report and presentation	Tue 2/21/17	Fri 3/3/17

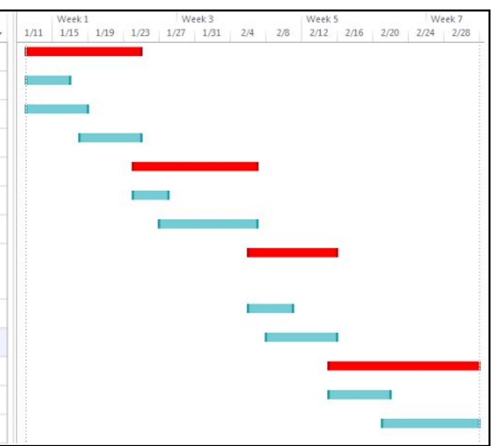


Figure 7: Estimated project timeline.

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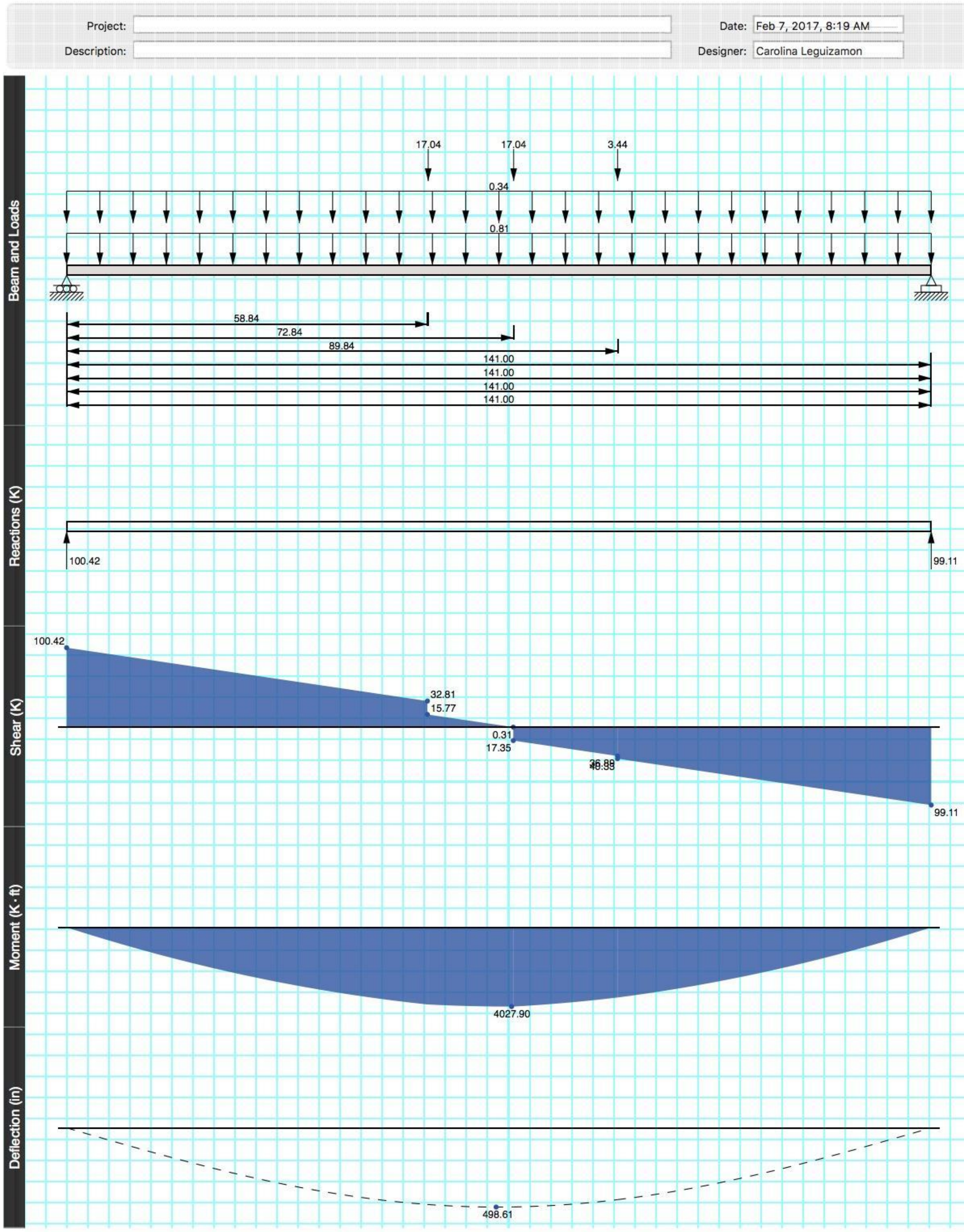
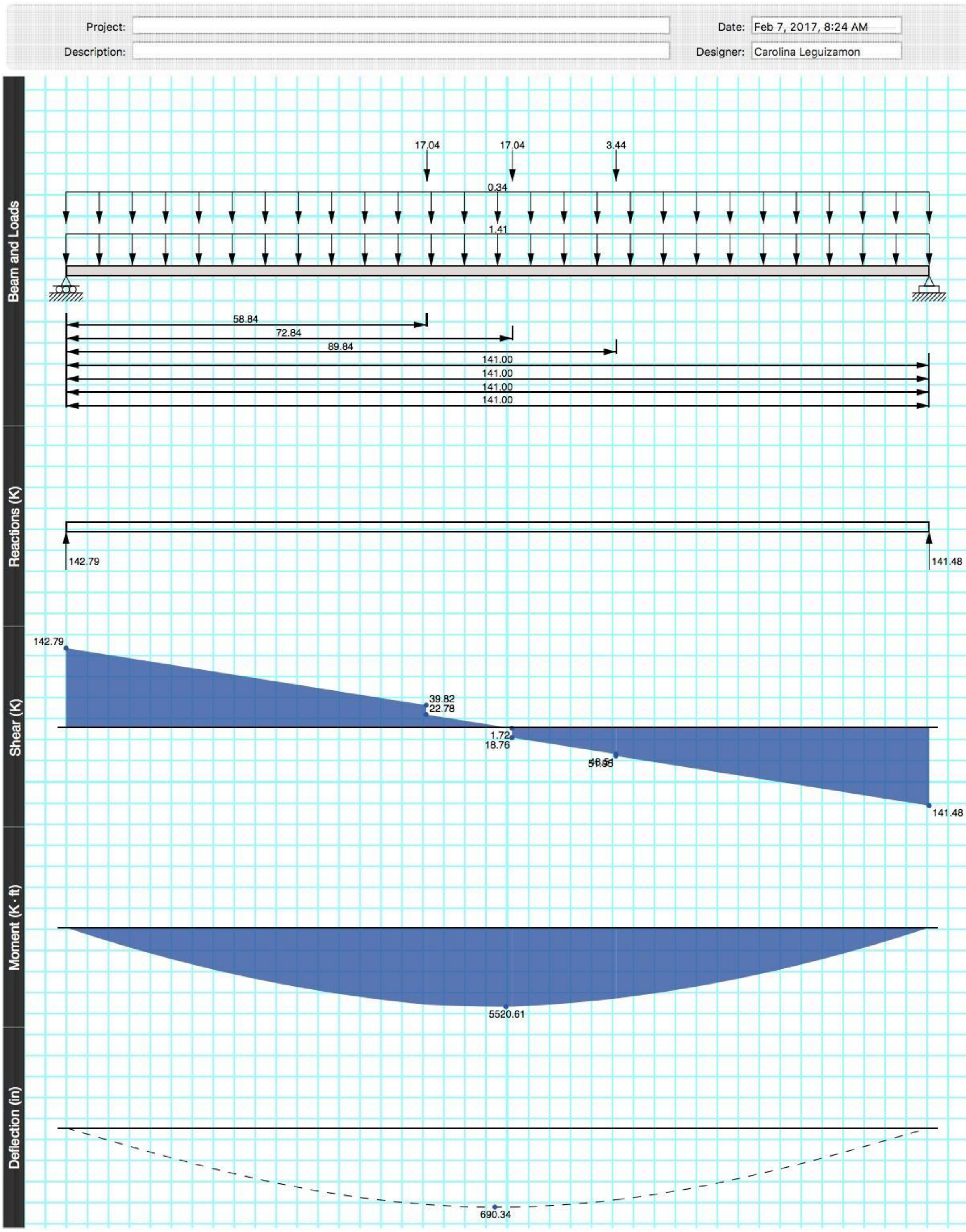
Appendix B: Shear Moment Diagrams

Case #1



Case #2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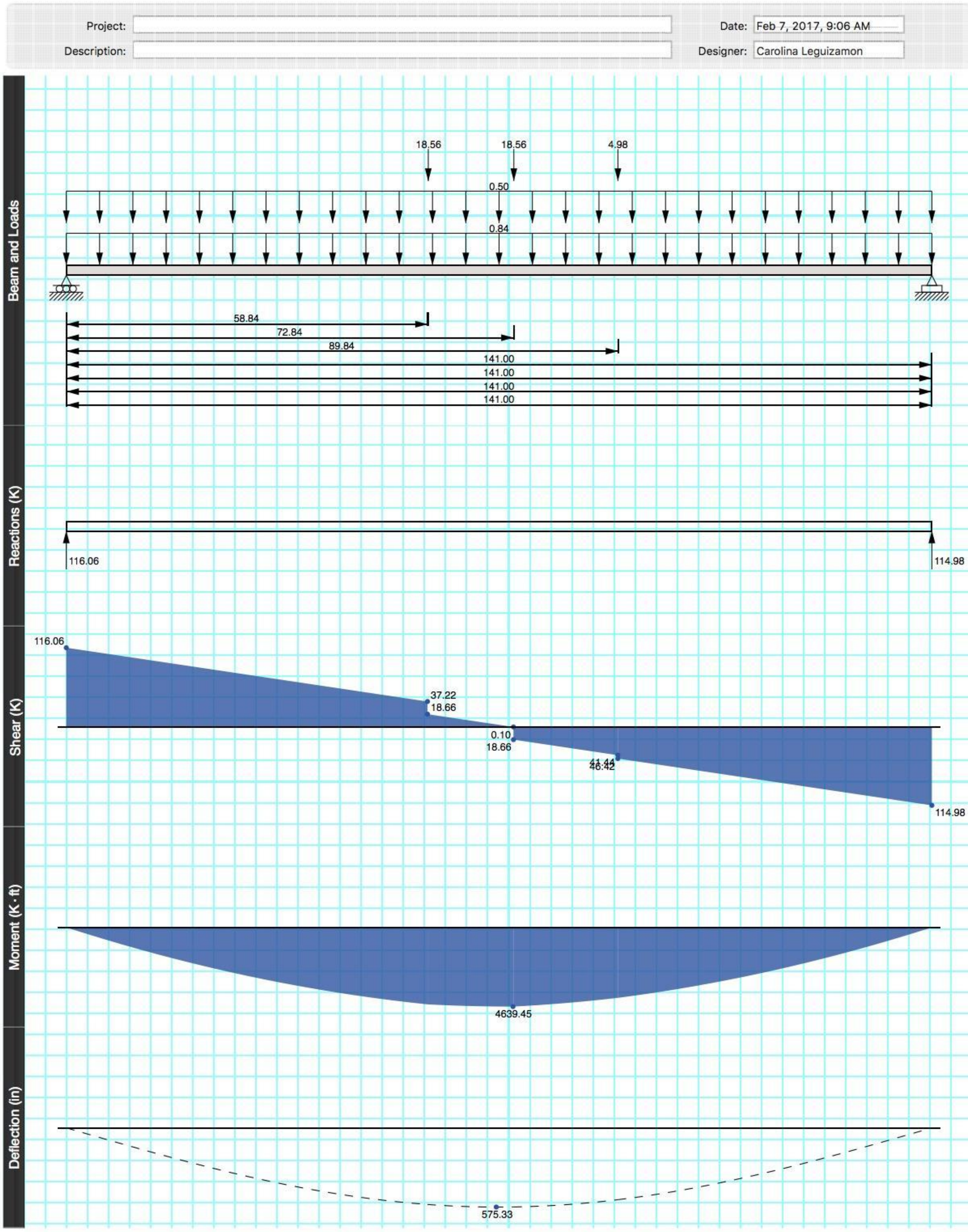
Description:
Date: Feb 7, 2017, 8:24 AM
Designer: Carolina Leguizamon
Beam and Loads
17.04
17.04
3.44
0.34
1.41
58.84
72.84
89.84
141.00
141.00
141.00
141.00
Reactions (K)
142.79
141.48
Shear (K)
142.79
39.82
22.78
1.72
18.76
141.48
Moment (K · ft)
5520.61
Deflection (in)
690.34

Case #3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Designer: Carolina Leguizamon
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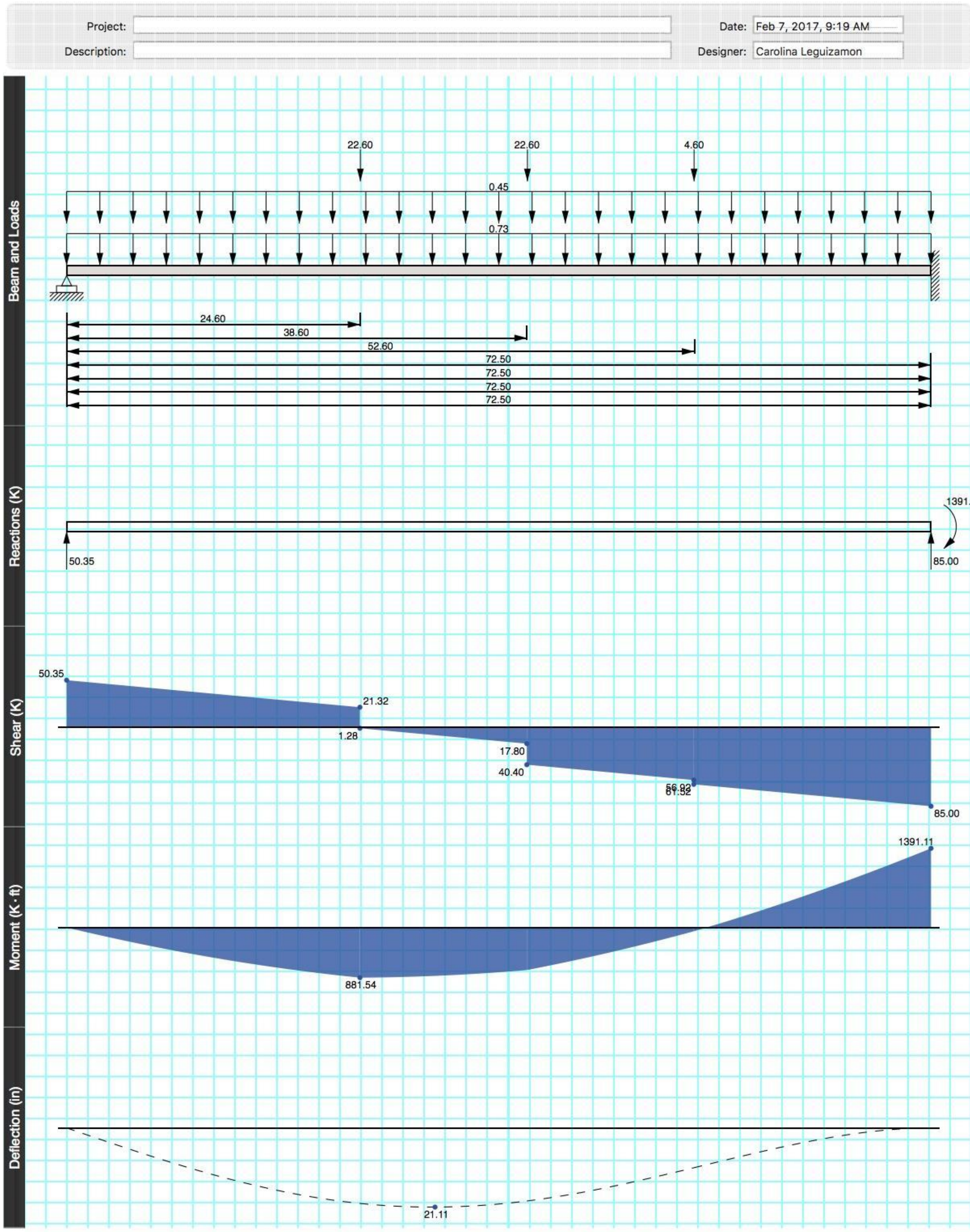
18.56
4.98
0.50
0.84
58.84
72.84
89.84
141.00
141.00
141.00
141.00
Reactions (K)
116.06
114.98
Shear (K)
116.06
37.22
18.66
0.10
18.66
41.44
46.42
114.98
Moment (K · ft)
4639.45
Deflection (in)
575.33

Case #4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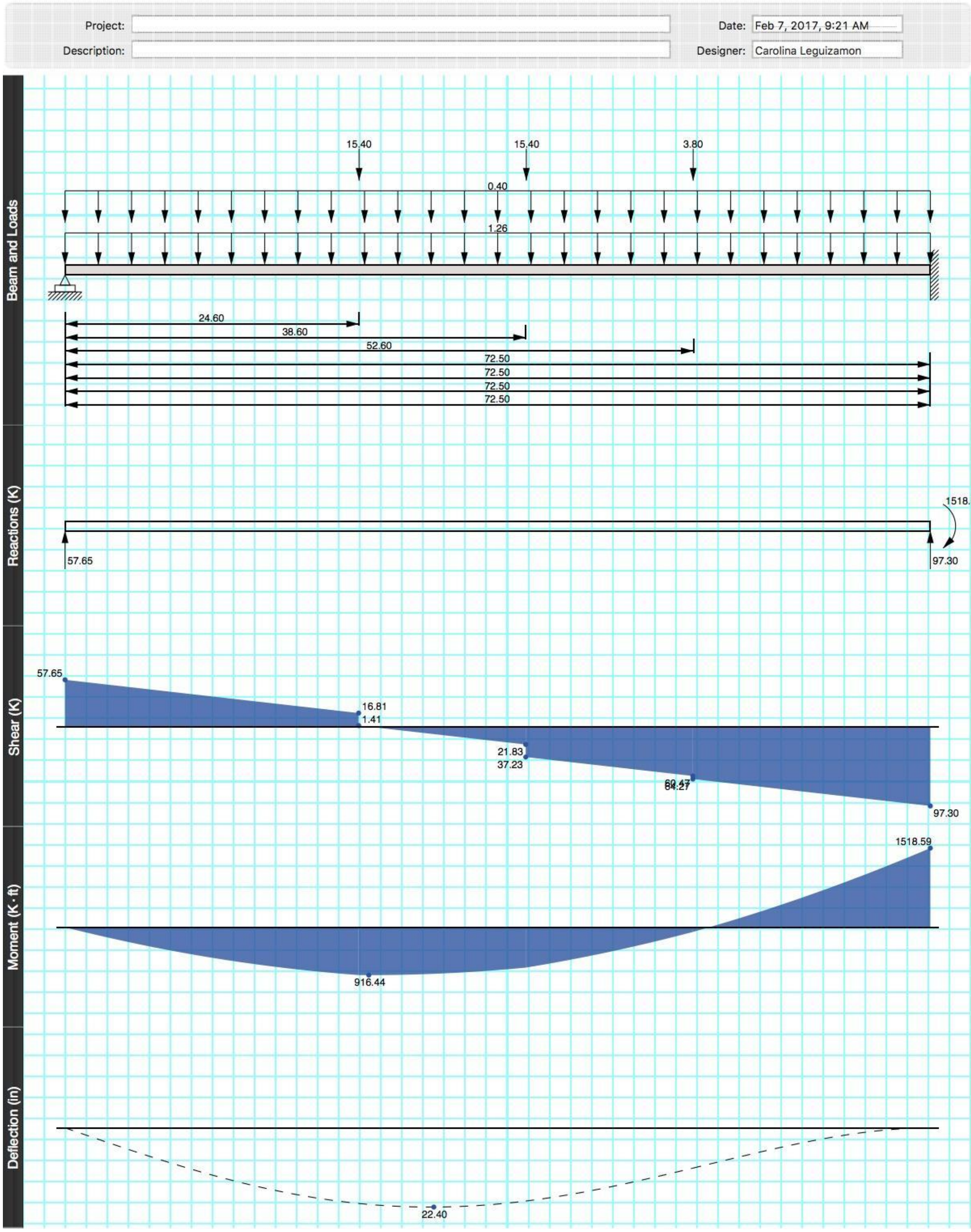
22.60
4.60
0.45
0.73
24.60
38.60
52.60
72.50
72.50
72.50
72.50
Reactions (K)
50.35
85.00
Shear (K)
50.35
21.32
1.28
17.80
40.40
85.00
Moment (K · ft)
1391.11
881.54
Deflection (in)
21.11

Case #5



Project:
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Designer: Carolina Leguizamon
Beam and Loads
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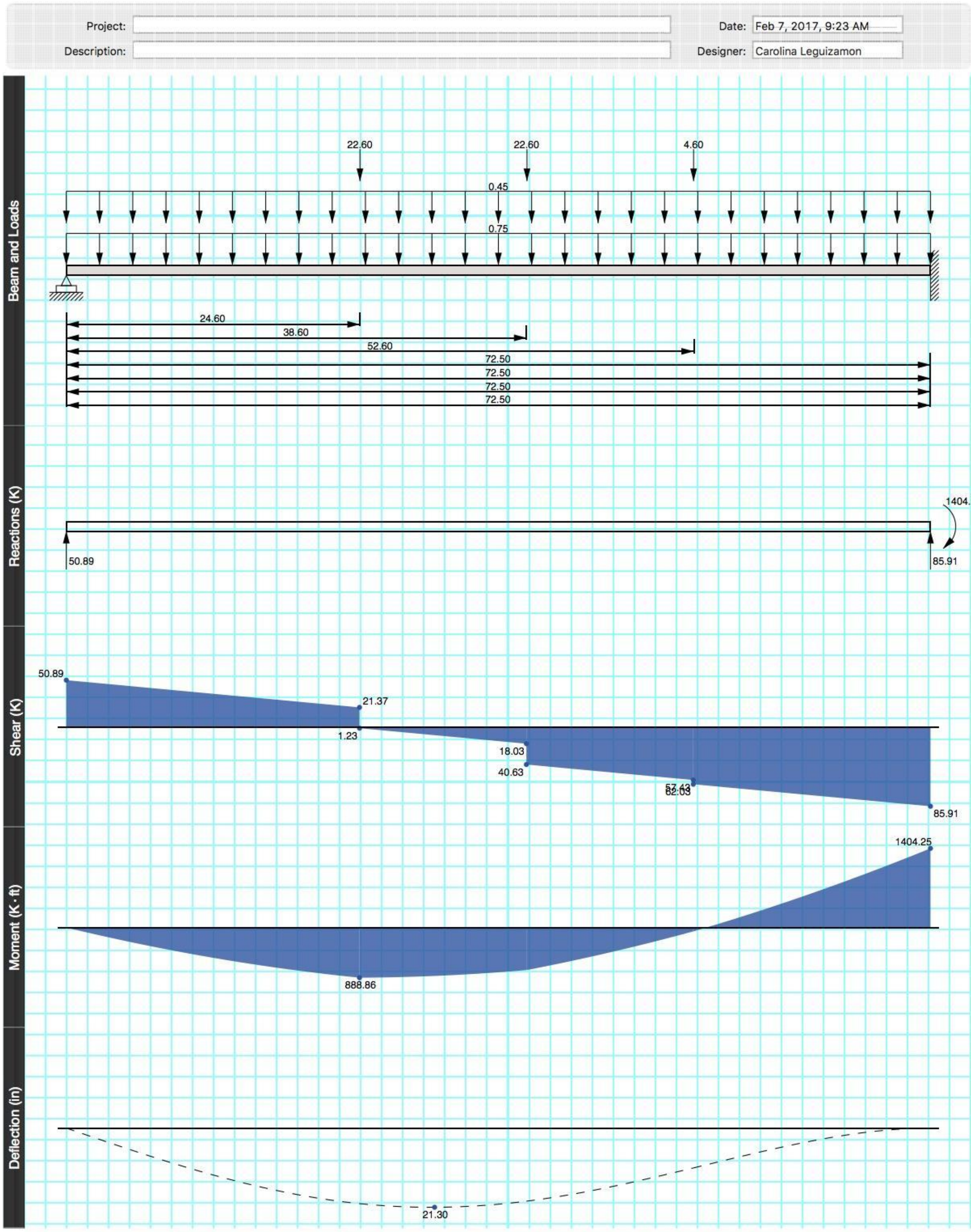
15.40
3.80
0.40
1.26
24.60
38.60
52.60
72.50
72.50
72.50
72.50
Reactions (K)
57.65
97.30
Shear (K)
57.65
16.81
1.41
21.83
37.23
97.30
Moment (K · ft)
1518.59
916.44
Deflection (in)
22.40

Case #6



Project:
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Designer: Carolina Leguizamon
Beam and Loads
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22.60
4.60
0.45
0.75
24.60
38.60
52.60
72.50
72.50
72.50
72.50
Reactions (K)
50.89
85.91
Shear (K)
50.89
21.37
1.23
18.03
40.63
85.91
Moment (K · ft)
1404.25
888.86
Deflection (in)
21.30

Appendix C: Preliminary Cost Estimate Breakdown

One Span Box Girder Bridge Cost Estimate

Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
114.1	Demolition of Superstructure of Bridge	LS	1	$190,000.00	$190,000.00
114.2	Demolition of Substructure of Bridge	LS	1	$344,000.00	$344,000.00
140	Bridge Excavation	CY	29,740	$34.00	$1,011,160.00
151.1	Gravel Borrow for Bridge Foundation	CY	250	$40.00	$10,000.00
151.2	Gravel borrow for backfilling structures and pipes	CY	790	$35.00	$27,650.00
	Additional Fill for approach roadway	CY	29,160	$34.00	$991,440.00
995.01	Bridge Structure	LS	1	$8,000,000.00	$8,000,000.00
	Additional Items	EA	1	$73,000.00	$73,000.00
	SIBC	EA	1	$2,210,000.00	$2,210,000.00
				Total Cost of Project	$12,857,250.00
				25% Contingency	$16,071,562.50
				Call	$16,100,000.00

Breakdown of item 995.01 "Bridge Structure"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
460	Hot Mix Asphalt	TON	99	$200.00	$19,857.50
460.1	Hot Mix Asphalt Dense Binder	TON	200	$225.00	$44,904.38
901	4000 PSI, 1 1/2 in, 565 Cement Concrete	CY	249	$700.00	$174,637.04
910.1	Steel Reinforcement for Structures, Epoxy Coated	LB	696,000	$2.00	$1,392,000.00
911.1	Shear Connectors	EA	20,300	$15.00	$304,500.00
922.1	Laminated Elastometric Bearing W/P Anchor Bolts	EA	38	$650.00	$24,700.00
936.3	Prefabricated Retaining Walls	SF	4,455	$80.00	$356,400.00
952.1	Steel Sheeting	SF	1,480	$35.00	$51,800.00
960	Structural Steel (Box Girder)	LB	1,247,850	$3.50	$4,367,475.00
965.2	Membrane Waterproofing for Bridge Deck Spray Applied	SY	19,035	$9.00	$171,315.00
970	Bituminous Damp-proofing	SY	2,115	$12.00	$25,380.00
972	Strip Seal Bridge Joint System	FT	405	$400.00	$162,000.00
975.6	Snow Fence	LF	2,902	$200.00	$580,400.00
994.1	Temporary Protective Shielding	SF	18,850	$12.00	$226,200.00
				Total Cost of Bridge Structure	$7,901,568.91
				Call	$8,000,000.00

Breakdown of item "Additional Items"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
976	Temporary concrete bridge barrier	LF	270	$119.05	$32,143.50
977	Temporary concrete bridge barrier remove and reset	LF	270	$107.15	$28,930.50
992.32	Temporary supports for piping	LS	1	$11,905.11	$11,905.11
				Total Cost of Additional Items	$72,979.11
				Call	$73,000.00

Breakdown of item 993.1 "Temporary Bridge"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
140	Bridge Excavation	CY	1,452	$119.05	$172,860.60
901	4000 PSI, 1 1/2" 565 Cement Concrete	CY	543	$107.15	$58,194.36
904.4	4000 PSI, 3.4" 585 HP Cement Concrete	CY	31	$800.00	$25,066.67
910.1	Steel Reinforcement for Structures, Epoxy Coated	LB	174,000	$2.50	$435,000.00
	Bridge Cost	LS	1	$1,903,500.00	$1,903,500.00
996.3	Mobilization/Demobilization -3%	LS	1	$420,100.00	$420,100.00
				Total Cost of Additional Items	$3,014,721.62
				Call	$3,100,000.00

Breakdown of item "SIBC"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
	Bridge Cost	LS	1	$1,903,500.00	$1,903,500.00
	Bridge Slide Cost	LS	1	$306,000.00	$306,000.00
				Total Cost of Additional Items	$2,209,500.00
				Call	$2,210,000.00

Two Span Steel Bridge Cost Estimate

Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
114.1	Demolition of Superstructure of Bridge	LS	1	$190,000.00	$190,000.00
114.2	Demolition of Substructure of Bridge	LS	1	$344,000.00	$344,000.00
140	Bridge Excavation	CY	29,740	$34.00	$1,011,160.00
151.1	Gravel Borrow for Bridge foundation	CY	250	$40.00	$10,000.00
151.2	Gravel borrow for backfilling structures and pipes	CY	790	$35.00	$27,650.00
	Additional Fill for approach roadway	CY	29,160	$34.00	$991,440.00
995.01	Bridge Structure	LS	1	$4,000,000.00	$4,000,000.00
	Additional Items	EA	1	$73,000.00	$73,000.00
	SIBC	EA	1	$2,300,000.00	$2,300,000.00
				Total Cost of Project	$8,947,250.00
				25% Contingency	$11,184,062.50
				Call	$11,500,000.00

Breakdown of item 995.01 "Bridge Structure"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
460	Hot Mix Asphalt	TON	102	$200.00	$20,420.83
460.1	Hot Mix Asphalt Dense Binder	TON	205	$225.00	$46,171.88
901	4000 PSI, 1 1/2 in, 565 Cement Concrete	CY	249	$700.00	$174,637.04
910.1	Steel Reinforcement for Structures, Epoxy Coated	LB	696,000	$2.00	$1,392,000.00
911.1	Shear Connectors	EA	20,300	$15.00	$304,500.00
922.1	Laminated Elastometric Bearing W/P Anchor Bolts	EA	38	$650.00	$24,700.00
936.3	Prefabricated Retaining Walls	SF	4,455	$80.00	$356,400.00
952.1	Steel Sheeting	SF	1,480	$35.00	$51,800.00
960	Structural Steel (Stringers)	LB	254,475	$3.50	$890,662.50
965.2	Membrane Waterproofing for Bridge Deck Spray Applied	SY	19,575	$9.00	$176,175.00
970	Bituminous Damp-proofing	SY	2,175	$12.00	$26,100.00
972	Strip Seal Bridge Joint System	FT	405	$400.00	$162,000.00
975.6	Snow Fence	LF	290	$200.00	$58,000.00
994.1	Temporary Protective Shielding	SF	18,850	$12.00	$226,200.00
				Total Cost of Bridge Structure	$3,909,767.25
				Call	$4,000,000.00

Breakdown of item "Additional Items"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
976	Temporary concrete bridge barrier	LF	270	$119.05	$32,143.50
977	Temporary concrete bridge barrier remove and reset	LF	270	$107.15	$28,930.50
992.32	Temporary supports for piping	LS	1	$11,905.11	$11,905.11
				Total Cost of Additional Items	$72,979.11
				Call	$73,000.00

Breakdown of item 993.1 "Temporary Bridge"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
140	Bridge Excavation	CY	1,452	$119.05	$172,860.60
901	4000 PSI, 1 1/2" 565 Cement Concrete	CY	559	$107.15	$59,845.26
904.4	4000 PSI, 3.4" 585 HP Cement Concrete	CY	32	$800.00	$25,777.78
910.1	Steel Reinforcement for Structures, Epoxy Coated	LB	174,000	$2.50	$435,000.00
	Bridge Cost	LS	1	$1,957,500.00	$1,957,500.00
996.3	Mobilization/Demobilization -3%	LS	1	$420,100.00	$420,100.00
				Total Cost of Additional Items	$3,071,083.64
				Call	$3,100,000.00

Breakdown of item "SIBC"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
	Bridge Cost	LS	1	$1,957,500.00	$1,957,500.00
	Bridge Slide Cost	LS	1	$317,000.00	$317,000.00
				Total Cost of Additional Items	$2,274,500.00
				Call	$2,300,000.00

Two Span Concrete Bridge Cost Estimate

Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
114.1	Demolition of Superstructure of Bridge	LS	1	$190,000.00	$190,000.00
114.2	Demolition of Substructure of Bridge	LS	1	$344,000.00	$344,000.00
140	Bridge Excavation	CY	29,740	$34.00	$1,011,160.00
151.1	Gravel Borrow for Bridge foundation	CY	250	$40.00	$10,000.00
151.2	Gravel borrow for backfilling structures and pipes	CY	790	$35.00	$27,650.00
	Additional Fill for approach roadway	CY	29,160	$34.00	$991,440.00
995.01	Bridge Structure	LS	1	$4,000,000.00	$4,000,000.00
	Additional Items	EA	1	$73,000.00	$73,000.00
	SIBC	EA	1	$2,300,000.00	$2,300,000.00
				Total Cost of Project	$8,947,250.00
				25% Contingency	$11,184,062.50
				Call	$11,500,000.00

Breakdown of item 995.01 "Bridge Structure"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
460	Hot Mix Asphalt	TON	102	$200.00	$20,420.83
460.1	Hot Mix Asphalt Dense Binder	TON	205	$225.00	$46,171.88
901	4000 PSI, 1 1/2 in, 565 Cement Concrete	CY	249	$700.00	$174,637.04
910.1	Steel Reinforcement for Structures, Epoxy Coated	LB	696,000	$2.00	$1,392,000.00
911.1	Shear Connectors	EA	20,300	$15.00	$304,500.00
922.1	Laminated Elastometric Bearing W/P Anchor Bolts	EA	38	$650.00	$24,700.00
936.3	Prefabricated Retaining Walls	SF	4,455	$80.00	$356,400.00
952.1	Steel Sheeting	SF	1,480	$35.00	$51,800.00
960	Prestressed Concrete (NeXT Beams)	LF	1,740	$450.00	$783,000.00
965.2	Membrane Waterproofing for Bridge Deck Spray Applied	SY	19,575	$9.00	$176,175.00
970	Bituminous Damp-proofing	SY	2,175	$12.00	$26,100.00
972	Strip Seal Bridge Joint System	FT	405	$400.00	$162,000.00
975.6	Snow Fence	LF	290	$200.00	$58,000.00
994.1	Temporary Protective Shielding	SF	18,850	$12.00	$226,200.00
				Total Cost of Bridge Structure	$3,802,104.75
				Call	$4,000,000.00

Breakdown of item "Additional Items"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
976	Temporary concrete bridge barrier	LF	270	$119.05	$32,143.50
977	Temporary concrete bridge barrier remove and reset	LF	270	$107.15	$28,930.50
992.32	Temporary supports for piping	LS	1	$11,905.11	$11,905.11
				Total Cost of Additional Items	$72,979.11
				Call	$73,000.00

Breakdown of item 993.1 "Temporary Bridge"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
140	Bridge Excavation	CY	1,452	$119.05	$172,860.60
901	4000 PSI, 1 1/2" 565 Cement Concrete	CY	559	$107.15	$59,845.26
904.4	4000 PSI, 3.4" 585 HP Cement Concrete	CY	32	$800.00	$25,777.78
910.1	Steel Reinforcement for Structures, Epoxy Coated	LB	174,000	$2.50	$435,000.00
	Bridge Cost	LS	1	$1,957,500.00	$1,957,500.00
996.3	Mobilization/Demobilization -3%	LS	1	$420,100.00	$420,100.00
				Total Cost of Additional Items	$3,071,083.64
				Call	$3,100,000.00

Breakdown of item "SIBC"

Sub-Item	Item Description	Unit	Quantity	Unit Price (2016)	Subtotal
	Bridge Cost	LS	1	$1,957,500.00	$1,957,500.00
	SIBC Cost	LS	1	$317,000.00	$317,000.00
				Total Cost of Additional Items	$2,274,500.00
				Call	$2,300,000.00

Appendix D: SIBC Methods Construction Cost Breakdown

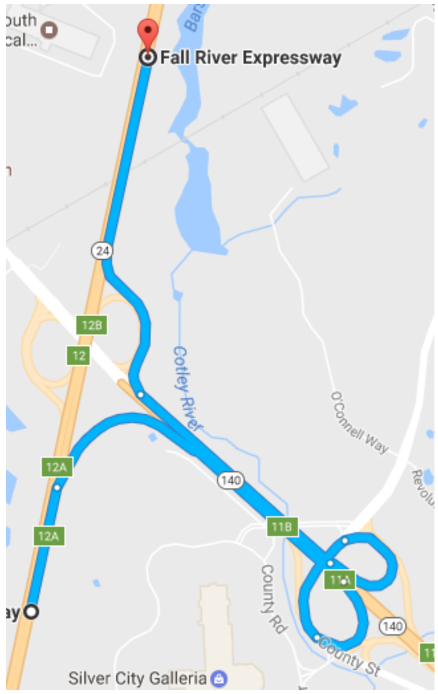
SIBC Cost (One-Span)

Bridge cost (SF)	19,035	$100.00	$1,903,500.00
Base Cost Slide Total (LS)	1	$380,700.00	$380,700.00
Slide Cost Adjustment Factors	Little or No Combined Experience	1.05	
Site Complexity Factor	Average Site Complexities	1	
Shoring Factor	Average Quantity of Shoring using Reusable Materials	0.8	
Vertical Jacking Factor	Additional Vertical Jacking Factor	1	
AADT Factor	Bridge over Roadway (AADT 10,000-100,000)	0.99	
Modified Base Slide Ratio		0.8316	
Cost Savings	Additional Site Costs	-$90,000.00	
Project Contingency		25%	
Total Estimated Slide Cost		**$395,737.65**	
SIBC Cost		**$305,737.65**	

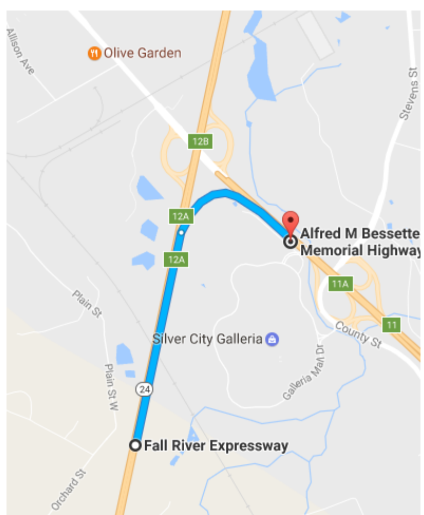
SIBC Cost (Two-Span)

Bridge cost (SF)	19,575	$100.00	$1,957,500.00
Base Cost Slide Total (LS)	1	$391,500.00	$391,500.00
Slide Cost Adjustment Factors	Little or No Combined Experience	1.05	
Site Complexity Factor	Average Site Complexities	1	
Shoring Factor	Average Quantity of Shoring using Reusable Materials	0.8	
Vertical Jacking Factor	Additional Vertical Jacking Factor	1	
AADT Factor	Bridge over Roadway (AADT 10,000-100,000)	0.99	
Modified Base Slide Ratio		0.8316	
Cost Savings	Additional Site Costs	-$90,000.00	
Project Contingency		25%	
Total Estimated Slide Cost		**$406,964.25**	
SIBC Cost		**$316,964.25**	

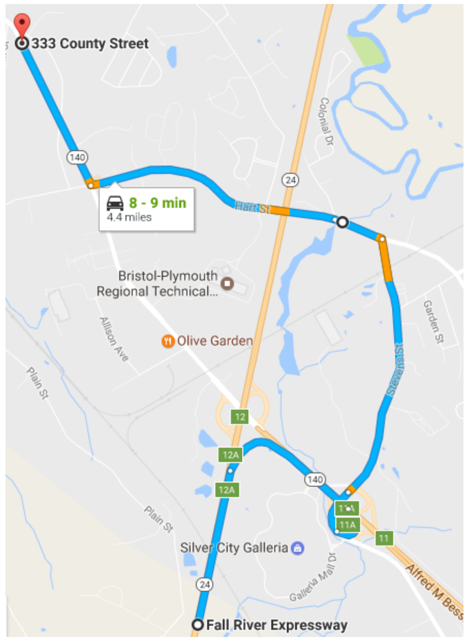
Appendix E: Detour Paths



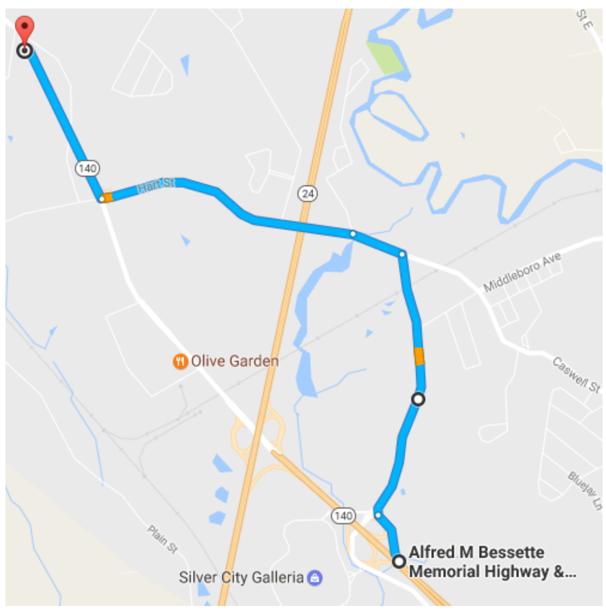
Route 24 NB to Route 24 NB (Google Maps, 2017a).



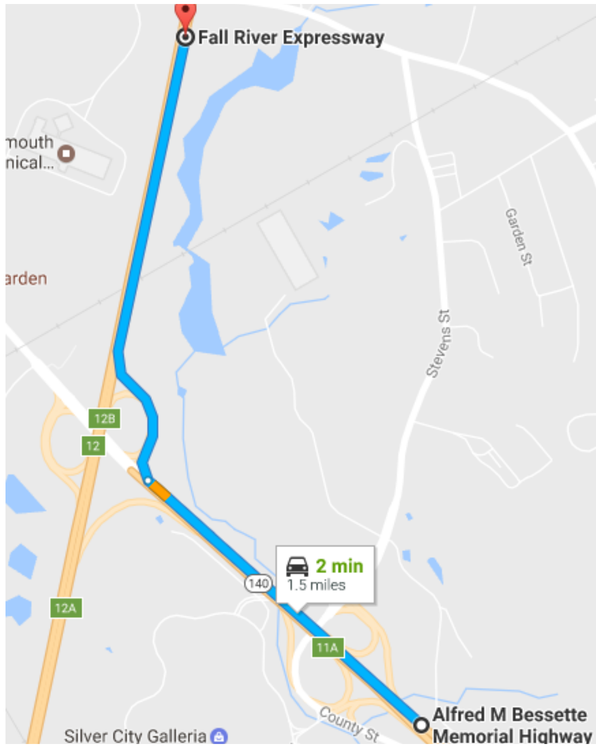
Route 24 NB to Route 140 SB (Google Maps, 2017b)



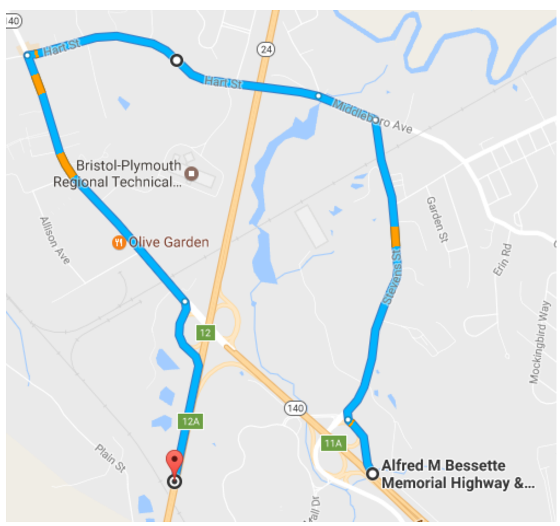
Route 24 NB to Route 140 NB (Google Maps, 2017c).



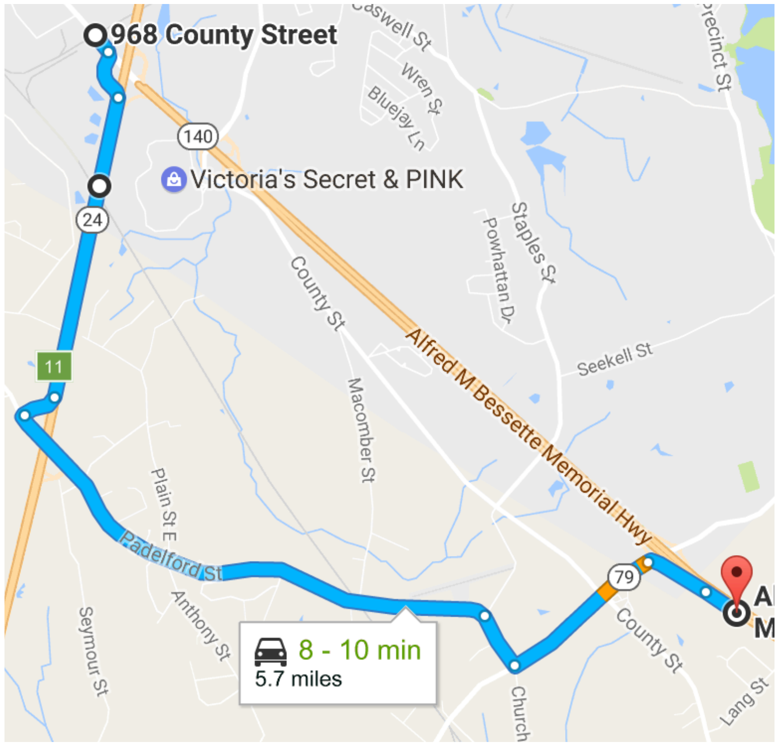
Route 140 NB to Route 140 NB (Google Maps, 2017d).



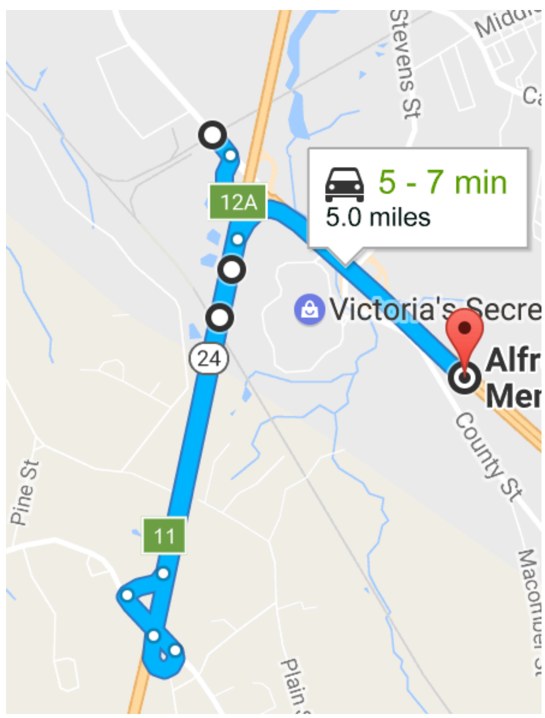
Route 140 NB to Route 24 NB (Google Maps, 2017e).



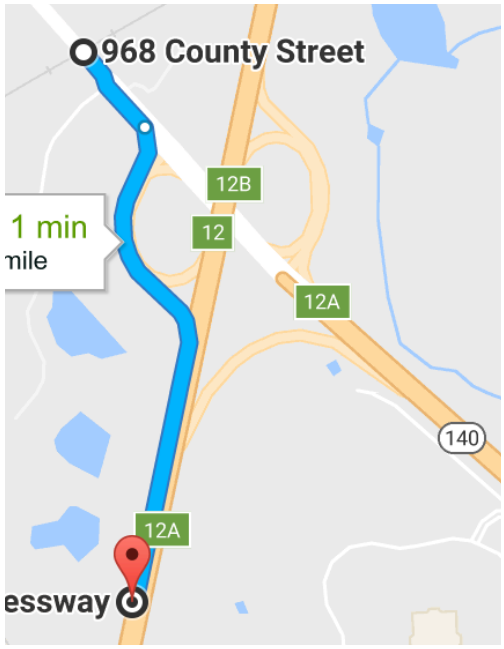
Route 140 NB to Route 24 SB (Google Maps, 2017f).



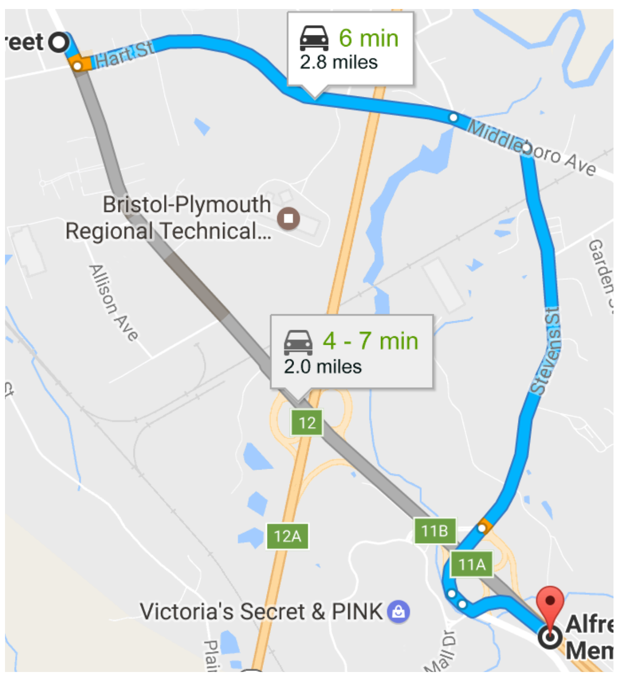
Route 140 SB to Route 140 SB (Path 1) (Google Maps, 2017g).



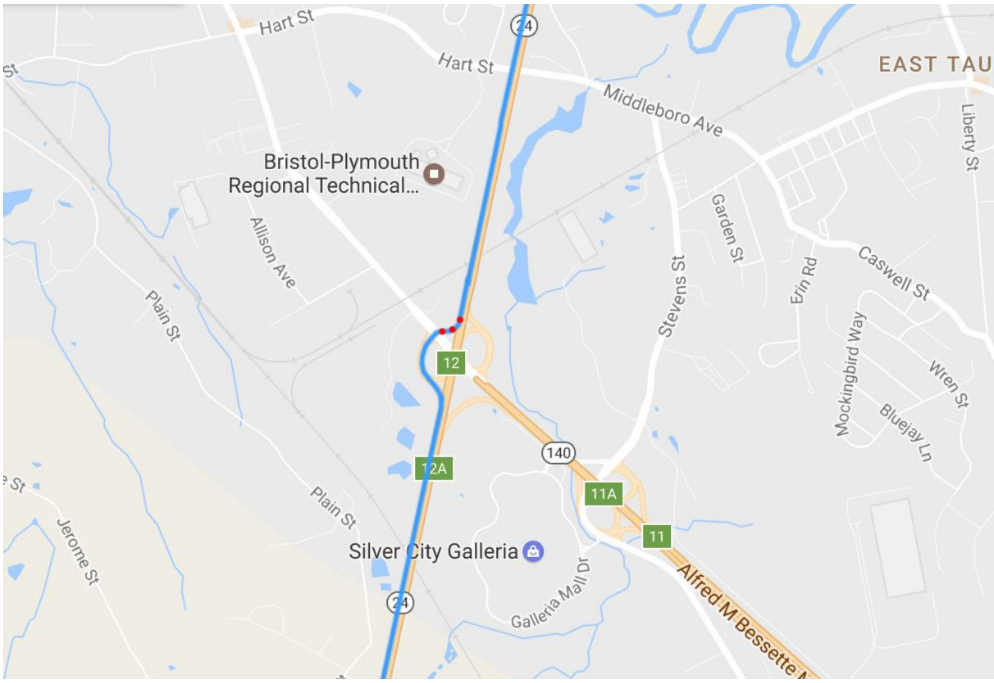
Route 140 SB to Route 140 SB (Path 2) (Google Maps, 2017h).



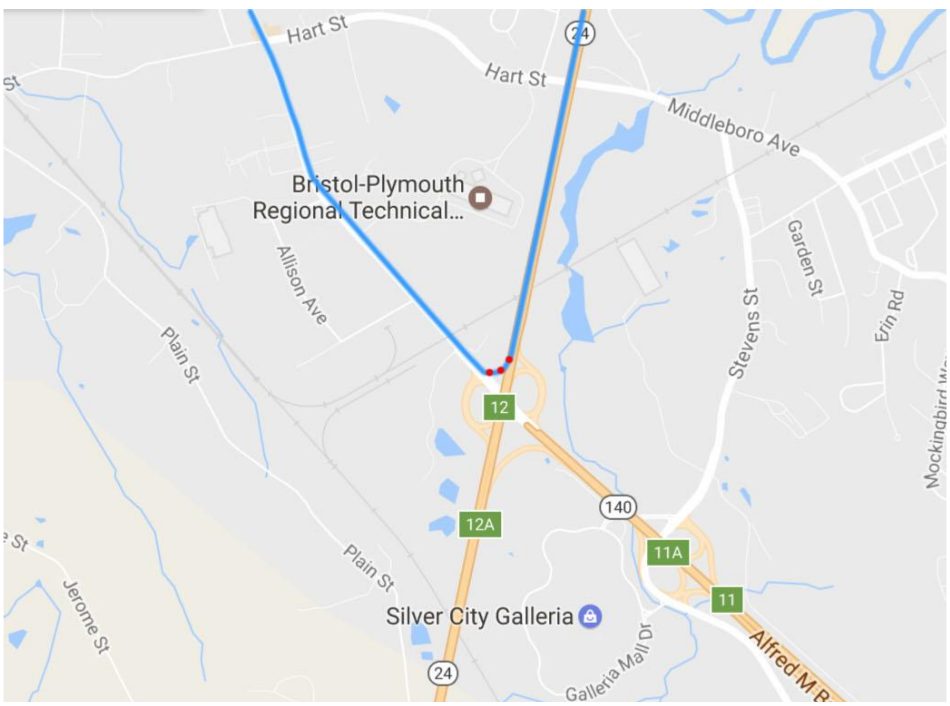
Route 140 SB to Route 24 SB (Google Maps, 2017i).



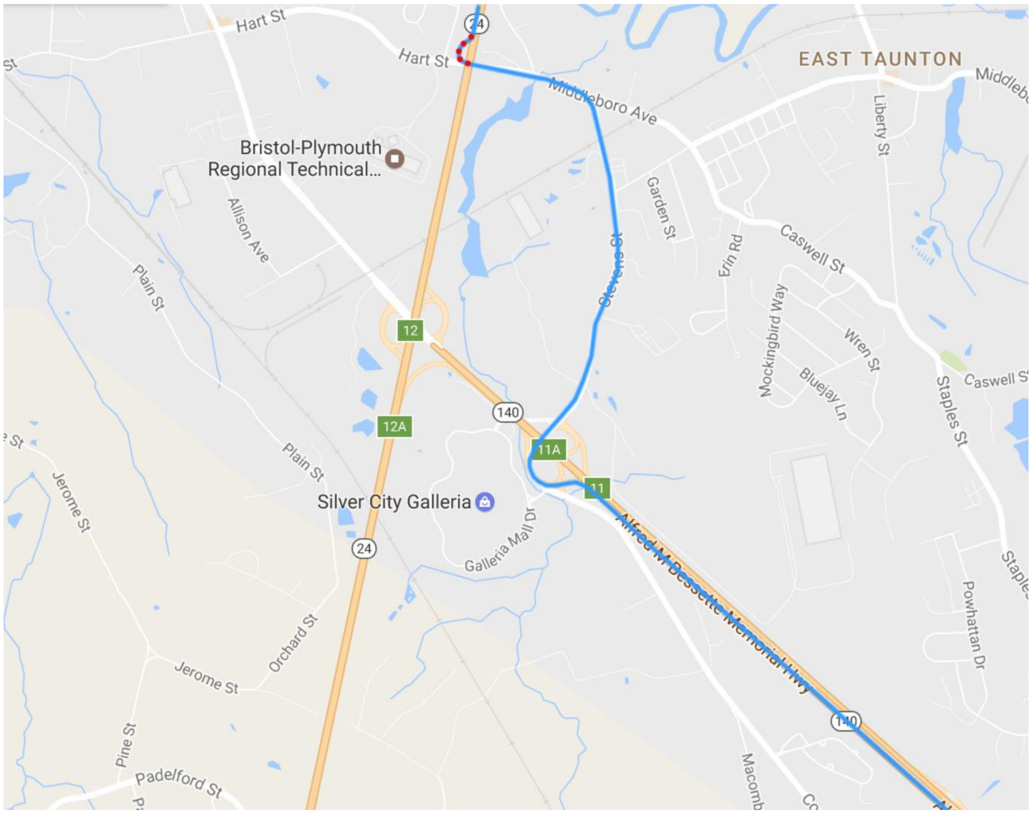
Route 140 SB to Route 24 NB (Google Maps, 2017j).



Route 24 SB to Route 24 SB (Google Maps, 2017k).



Route 24 SB to Route 140 NB (Google Maps, 2017k).



Route 24 SB to Route 140 SB (Google Maps, 2017k).

Affected traffic routes due to bridge closure (Route 24).

From	Onto	Proposed Detour
Route 24 NB	Route 24 NB	Utilizing the existing ramp onto Route 140 SB and take Exit 11-B to loop around and get onto Route 140 NB. Then, take Exit 12-A to re-enter Route 24 NB.
	Route 140 SB	Taking the existing exit ramp at Exit 12-A to connect to Route 140 SB.
	Route 140 NB	Taking Exit 11 towards Route 140 SB to loop around at Stevens St exit (Exit 11) to connect to Route 140 NB. If the user is trying to get to the other side of the bridge, the motorist can take Stevens St. towards Hart St. and connect back to Route 140 NB.
Route 24 SB	Route 24 SB	The proposed ramp on Route 24 SB could be temporarily widened to allow for an additional lane. This way, there is space for cars to turn right on Route 24 and to cross-over Route 140 (using signaling) and to take Exit 12-A towards Route 24 SB.
	Route 140 SB	A temporary ramp could be built from Route 24 onto Hart St. and then taking a detour through Stevens towards Route 140 SB.
	Route 140 NB	Taking the proposed ramp connecting Route 24 SB with Route 140 SB can be used. Therefore, this portion of the project needs to be completed before the bridge closure.

Affected traffic routes due to bridge closure (Route 140).

From	Onto	Proposed Detour
Route 140 NB	Route 140 NB	Taking Exit 11 towards Stevens St. and detouring towards Hart St. all the way until it intersects Route 140 NB.
	Route 24 SB	Taking Exit 10 towards Route 79 until it intersects with Route 24 SB. Smaller roads such as Padelford St. and Bryant St. can be utilized by locals and residents. Overall, this path represents a longer detour, but it would alleviate traffic at the intersection.
	Route 24 NB	To alleviate traffic, proposed ramp for Route 140 NB- Route 24 NB needs to be completed before bridge closure to serve as traffic detour.
Route 140 SB	Route 140 SB	There are two different detour paths. Initially, both paths include taking Exit 12-A connecting Route 140 SB to Route 24 SB. Then taking Exit 11 on Route 24 SB. At this point drivers can either: 1- Take Padelford St. towards Route 79 and finally reach Route 140 SB. (Class D vehicles). 2-Loop around the interchange at Exit 11, enter Route 24 NB, then take Exit 12-A towards Route 140 SB. (Class B vehicles).
	Route 24 SB	The proposed ramp widening on Exit 12-A can be utilized to get on Route 140 SB. Since there will be an increase in traffic on this ramp during the detour stage, signaling and coordination will be required.
	Route 24 NB	Taking Hart St. before reaching the interchange and driving towards Stevens St. and then taking Exit 11 to Route 24 NB.

Appendix F: Structural Beam Analysis Calculations

1/2

RTE 24/140 INTERCHANGE LOADING | WPI-STANTEC

Determine simplified loading (per beam): AASHTO 4.6.2.2

Dead Loading (applicable for all materials):

0.15 kcf · 6' · 8"/12" = 0.6 klf (slab wt./tributary area)
0.14 kcf · 4"/12" = 0.047 klf (FWS/21 beams) = 0.0022 klf
0.125 klf/21 beams = 0.006 klf (future utilities)

HL-93 Live Loading

Case #1 Loading:

DL(W40×199) = 0.199 klf

$$DF = 0.075 + \left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{Kg}{12Lt_s^3}\right)^{0.1}$$

S = 6 ft.
L = 141 ft.
t_s = 8 in.

$Kg = n(I + Ae_g^2)$

$$n = \frac{E_s}{E_{c\,slab}} = \frac{29 \cdot 10^6}{(57000\sqrt{4000})} = 8$$

Assumed cross-section (W40×235)
$A = 69\ in^2$
$I = 17{,}400\ in^4$
$e_g = C_t + C_{b\,slab} = 20 + 4 = 24"$

$kg = 8(17400 + 69(24^2)) = 457152.6$

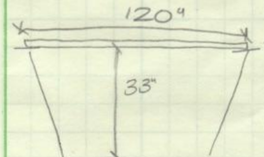
$$DF = 0.075 + \left(\frac{6}{9.5}\right)^{0.6}\left(\frac{457152.6}{12 \cdot 141 \cdot 8^3}\right)^{0.1}\left(\frac{6}{141}\right)^{0.2} = 0.38 \rightarrow 0.4$$

LL + Dynamic Allowance (IM) =
0.64 + 0.33(0.64) = 0.85 klf → 0.4(0.85 klf) = 0.34 klf
32 + 0.33(32 k) = 42.6 k → 0.4(42.6 k) = 17.04 k
8 + 0.33(8 k) = 8.6 k → 0.4(8.6 k) = 3.44 k

− Mmax = 4027.9 ft·k   + Vmax = 100.42 k
− Vmax = 99.11 k

Case #2 Loading:

DL = 0.59 klf



$$DF = 0.05 + 0.85\left(\frac{N_L}{N_b}\right) + \frac{0.425}{N_L}$$

$$DF = 0.05 + 0.85(0.5) + \frac{.425}{4}$$

DF = 0.58

$N_L = 4$
$N_b = 9$
$N_L/N_b = 0.41$
use 0.5

LL + IM =
.58 (0.85 klf) = .493 klf
.58 (42.6 k) = 24.7 k
.58 (8.6 k) = 5.0 k

2/2 | RTE 24/140 INTERCHANGE | LOADING | WPI - STANTEC

−Mmax = 4639.5 ft·k +Vmax = 116.06 k
−Vmax = 114.98 k

Case #3 Loading:

DL = 0.799 klf . (same as case #1)

DF = 0.38

LL + IM =
0.34 klf
17.04 k
3.44 k

−Mmax = 5520.61 ft·k
−Vmax = 141.48 k
+Vmax = 142.79 k

Case #4 Loading =

DL = 0.117 klf

$$DF = 0.075 + \left(\frac{6}{9.5}\right)^{0.6}\left(\frac{6}{72.5}\right)^{0.2}\left(\frac{457152.6}{12 \cdot 72.5 \cdot 8^3}\right)^{0.1}$$

DF = 0.53

LL + IM =
0.53(0.85 klf) = 0.45 klf
0.53(42.6 k) = 22.6 k
0.53(8.6 k) = 4.6 k

−Mmax = 581.54 ft·k −Vmax = 85.1 k
+Mmax = 1391.11 ft·k +Vmax = 50.4 k

Case #5 Loading:

DL = 0.143 klf DF = 0.53 (same as case #4)

LL + IM =
0.45 klf
22.6 k
4.6 k

−Mmax = 588.85 ft·k −Vmax = 85.1 k
+Mmax = 1404.25 ft·k +Vmax = 50.4 k

Case #6 Loading:

DL = 0.646 klf

$$DF = \left(\frac{S}{6.3}\right)^{0.6}\left(\frac{Sd}{12L^2}\right)^{0.125}$$

S = 6 ft
d = 33 in
L = 72.5 ft

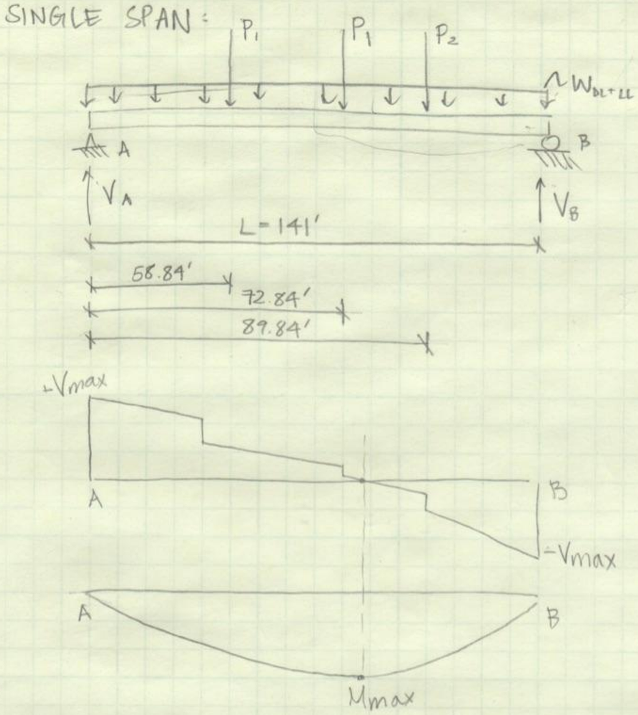
$$DF = \left(\frac{6}{6.3}\right)^{0.6}\left(\frac{6 \cdot 33}{12(72.5^2)}\right)^{0.125} = 0.47$$

LL + IM =
0.47(0.85 klf) = 0.4 klf
0.47(42.6 k) = 15.6 k
0.47(8.6 k) = 3.8 k

−Mmax = 916.44 ft·k −Vmax = 97.3 k
+Mmax = 1518.6 ft·k +Vmax = 57.7 k

1/1 | RTE 24 / I140 INTERCHANGE | MOMENT CALCS | WPI - STANTEC

SINGLE SPAN:



$\circlearrowleft + \Sigma M_B = 141 V_A - 70.5 W_{DL+LL}(141) - 82.16P_1 - 68.16P_1 - 51.16P_2$

$V_A = 70.5 W_{DL+LL} + 1.07P_1 + 0.36P_2$

$V_B = 2P_1 + P_2 - V_A + W_{DL+LL}(141)$

2-SPAN: