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Comparative Structural Bridge Design

A Major Qualifying Project Report
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WORCESTER POLYTECHNIC INSTITUTE
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By

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Report Submitted to:

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Abstract

This project focused on creating the structural vehicular bridge design for a highway overpass. The design followed the *AASHTO LRFD Bridge Specifications* and the MassDOT and FHWA requirements. To support hand calculations, computer modeling programs, like Risa-3D, were used as tools. Along with the design of the superstructure and substructure, alternative girder designs were investigated and evaluated based on a set of established criteria. The proposed bridge design included a completed superstructure design, three alternative girder options, substructure evaluation and a cost analysis.

Acknowledgement

Many individuals helped with this Major Qualifying Project. I would like to thank them for their contributions. The success and completion of the project would not have been possible without the following individuals:

- Professor Leonard D. Albano, the advisor of the project, who provided me with helpful feedback and guidance on my design project and writing.
- Jessica A. Rosewitz for the guidance and information provided to me in order to create an analysis for different components of the design using computer software.

Capstone Design Statement

The Major Qualifying Project satisfied the Capstone Design requirements for the Civil Engineering major. The capstone design requirement followed the Accreditation Board for Engineering and Technology (ABET) guidelines to show the ability to be able to design a structural system that incorporates engineering standards and real-world constraints. The design constraints that were considered within this project included constructability, economic, sustainability, health and safety, and ethics. By meeting these constraints, the design project satisfied the requirements for the Capstone Design Experience.

1. Constructability

Constructability was considered throughout the design of the project to compare the three alternative designs. Two designs used steel while the other used precast concrete. The bridge design relied on the use of standard structural steel and concrete members. Constructability was addressed in this aspect by using readily available cross-sections for the members. In addition, in regards to construction, standard construction materials and practices were utilized to promote efficient construction.

2. Economic

Economic factors were considered when developing the design in order to determine the more financially affordable alternative. Although there was not a specific budget, the cost of the designs were a consideration to help determine the more favorable option. Cost-effective bridge designs and construction methods tend to be more favorable. This is because bridge construction tends to be completed with public funds. The project consisted of conducting a cost analysis for the members of each bridge design. The construction cost of the three alternative designs were then compared, and the most cost-effective design was identified. To provide representative values for material, labor, and equipment costs, the *R.S. Means Heavy Construction Cost Data* prices were used to prepare the cost estimates.

3. Health and Safety

Health and safety is a priority, especially during construction. This bridge was developed by following the American Association of State Highway and Transportation Officials AASHTO LRFD design process. The safety of the design was ensured by abiding to these requirements. This document uses load and resistance factors to ensure the design of a stable bridge with ample strength is met. The design accounted for worst-case scenario loading cases to ensure there is no bridge failure during its design life that may endanger the public. By abiding to these specifications, the resulting design alternatives did not impose a high level of threat to human life.

4. Sustainability

Sustainability requires the design to meet the needs of the present without jeopardizing the future needs (International Institute of Sustainable Development 2019). Once the structure is built and in use, the goal is to reduce maintenance. The bridge design was created with the intent to withstand a long service life and with the purpose that the design could be implemented in many locations over a six-lane highway. When designing a civil infrastructure, the goal is to try to optimize the system. The optimization of the system is in respect to analyzing the structural design, utilized material, and impacts on the society. These aspects of optimization made the bridge design more resilient and sustainable towards the environment.

5. Ethics

Ethics play an important role in the responsibility to abide by governing standards. These standards guide engineers to follow the design process in a certain way. The American Society of

Civil Engineers (ASCE) Code of Ethics was followed throughout the entirety of this project. This code of ethics is a model used for professional conduct and was referred to when designing the bridge structure to make sure everything was done properly. This code makes sure that the designers conduct each design step methodically, ensuring that no shortcuts are taken to save time and money. This design process upholds professional honor and provided adequate designs. There are many ethical factors that were considered when developing the bridge designs. The most applicable and highly important guide from the Code of Ethics is "Hold Safety Paramount". This code of ethics ensures that the design of each alternative places the health, safety, and welfare of the users of this bridge infrastructure as a top priority **(**Code of Ethics**)**.

Professional Licensure Statement

The practice of obtaining professional licensure in civil engineering in the United States is governed by the state an individual pertains to because licensing laws and requirements are regulated by state.

The National Council of Examiners for Engineering and Surveying (NCEES) is a non-profit organization of engineering and land surveying licensing boards representing all of the U.S states and territories (American Society of Civil Engineers). According to the NCEES, Professional Licensure is a standard that restricts engineering practice to specific individuals who must be certified. The Professional Licensure protects the public by ensuring that the engineer completing a job has met "specific qualifications in education, work experience, and exams" (NCEES, 2017).

In the United States, all of the states have laws that govern the practice of engineering. The purpose of this is to protect the safety, health, and welfare of the public of that specific state. Having a Professional Engineering Licensure means to accept both the technical and the ethical obligations of the engineering profession. A Professional Engineer can take pride in being officially recognized by the state and by the public as an official engineer. The Professional Engineer License grants individuals the opportunity to perform engineering services for the public. This license also gives individuals the privilege of applying a state-authorized engineering seal to their engineering work. This privilege and licensure requires individuals to take responsibility for their designs, reports, professional opinions, and more (ASCE's Committee on Licensure and Ethics, 2001).

In order to become a licensed Professional Engineer, there are a variety of requirements that must be completed in order to obtain and maintain this license. There are different factors to obtaining a license for some states in regards to experience and educational requirements. The general Professional Engineering Licensure requirements are as follows:

1. Graduating from an ABET-accredited engineering program or an ABET-accredited engineering technology program
2. Passing the national Fundamentals of Engineering exam offered by the NCEES
3. Obtaining four years (or three years past a masters degree) of acceptable engineering experience under the guidance of licensed engineers
4. Submitting an application documenting a progressive increase in professional experience and professional and character references
5. Passing the Principles and Practice of Engineering exam offered by the NCEES

(ASCE's Committee on Licensure and Ethics, 2001).

Civil engineers are strongly encouraged to become licensed engineers because their work often involves engineering services directed for the public. There are many reasons to become a licensed engineer some of them include having public recognition, being able to take personal responsibility for engineering work performed for the public and private clients, aiding an individual in important areas of ethics, etc. (ASCE's Committee on Licensure and Ethics, 2001).

Over the years it has become increasingly important to be certified as a Professional Engineer. The state provides professional licensing to engineers to certify that only qualified individuals practice engineering. This ensures the safety of the public by holding all engineers to the same standard of education and experience. This certification is an indication of an engineer's ability to take on responsibilities while ensuring that the quality of work is held at a high standard of ethical practice (NCEES, 2017).

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1.0 Introduction

Bridges play a crucial role within the highway and transportation systems in the United States. There are over 590,000 highway bridges in the United States, most being owned by state or local government institutions. According to the Federal Highway Administration, there are over 200 million trips taken in metropolitan areas over structurally deficient bridges. In the US, about 25 percent of bridges are 20 years old. Bridges are an expensive, major and growing investment that must be carefully designed, especially for a transportation system. Bridge structures must be designed properly to withstand the loadings they're subject to in order for them to have a long service life. Bridges do not just appear. These structures must be planned and engineered before constructed. Bridges must first be designed properly, later the structure is built, and then the bridge has to be maintained for its entire service life **(**Memmott, 2017**)**.

Bridges provide a means for easy travel and are important structures in any society. Bridges provide direct links and connections across natural obstacles, neighboring towns, and passages over highways. Therefore, bridges are key elements in highway and transportation networks. Because of this, it is important that they are structurally sound, and that they do not collapse or go out of service for any reason. This would not only threaten human life due to the danger associated with a collapse, but it would also have severe financial implications. The financial implications are in regards to both the bridge itself and the loss of an important travel route to product distributors and travelers. To assure the quality of bridges, engineers have studied their behavior and developed specifications for designing and structurally constructing them. These specifications have been made available by the American Association of State Highway and Transportation Officials (AASHTO) (Barker & Puckett, 2013).

For this project, three alternative designs were analyzed and compared. The project compared the designs of a steel and concrete girder bridge systems and their components while fulfilling the Capstone Design Experience. These bridge systems were evaluated based on a set of established evaluation criteria. These criteria include an engineer's analysis of cost estimates and constructability for economical design. The criteria mentioned are to be analyzed to bring conclusive results for the alternative designs.

This project studied the basic design of a bridge, particularly a highway overpass. This type of bridge is one of the simplest to design and was a good starting point for a young bridge engineer. To complete the design of a highway overpass required extensive background research. This research provided me with the tools necessary to get an education on bridges and the opportunity to gain hands-on experience with bridge design. Specifically, the ability to learn and research bridges to make informed decisions following proper standards and limit states. The proper standards and limit states were met through the use of *AASHTO LRFD Bridge Design Specifications* and a series of bridge engineering handbooks and manuals.

The goal was to create a structural vehicular bridge design for a highway. The bridge overpass design spanned over a 6-lane highway. The design consisted of a standard bridge overpass providing access between two levels. For example, the work consisted of a number of elements, including the design of the bridge section, the design of alternative girders, a deck design, the evaluation of alternatives, selection of the best alternative, discussion of the substructure and alternative foundations, and finally recommendations. To support hand calculations, computer modeling programs, like Risa (3D), were used as tools. The tools were used to calculate design loadings, forces, and stresses. Computer modeling was used as an aid to calculate live, vehicular, and dead loads for the bridge. The bridge was designed using three different member options: W-shape I-beams, built-up girders, and precast concrete girders. These different options for design were then compared using the material steel or concrete. The steel and concrete designs for each different member design options were compared and evaluated based on different criteria. This system was developed in order to evaluate the three alternative bridge designs. The evaluation criteria used were economic factors, sustainability, and constructability. In addition to the different member design options the designs of the bridge's deck was made.

2.0 Background

Bridges affect people: without them travel routes would not be as direct and traveling within a region would become tedious. In addition, without them there would also be economical and environmental factors. Bridges are used every day and have an effect on people whether they use them to get to work or travel. Bridges are very important structures to everyday life and society. It is important that they are structurally stable, and that they do not collapse or go out of service. If bridges are not designed properly, safety for the people becomes a problem. Without proper design, bridges threaten human life due to the danger associated with a collapse.

2.1 Design of Highway Overpass

In order to start the design process for a bridge, prior research and identification of different components of a typical highway overpass must be completed beforehand. Along with the components of a highway overpass, investigation of the site design, constructability, and cost all influence the design process. Factors such as serviceability were also considered when assessing bridge options (American Association of State Highway and Transportation Officials, 2004).

The function of the bridge also plays an important role in how the structure will be designed. The function, a highway bridge overpass, will determine the design loads and provide an idea of how much support the bridge will require. In the design process, strength is always a major consideration followed by measures to prevent deterioration. Bridge preservation is used to slow down and prevent deterioration. Some prevention measures include preventive maintenance (PM) and cyclical maintenance activities. PM prevents deterioration for highway bridges by applying a cost-effective treatment to various bridge elements, whereas cyclical maintenance performs various activities in intervals that aim to preserve highway bridge elements. Some examples of cyclical maintenance activities include bridge cleaning, or washing of the substructure and superstructure elements and applying deck sealers (Ailaney, 2018).

Another important aspect of bridge design is the span length. Bridges are generally classified by span type such as simple span, rigid frame, cantilever, and so on. Once the bridge is classified by span type, it can also be classified by length. A small-span bridge will be less than 50ft (15m), a medium-span bridge goes up to 250ft (75m), and a large-span bridge ranges from 150ft to 500ft (50m-150m). Any bridge structure with a span over 500ft (150m) is classified as having an extra-large span length. Depending on the required loading and moment, different materials and shapes can be used to design the bridge. For example, a simple span bridge will have different requirements than a continuous span bridge. Therefore, different materials and shapes are used depending on the type. The *PCI Design Manual* and *AISC Steel Manual* have design charts to aid in the selection of beam shapes that satisfy loading requirements (Barker & Puckett, 2013).

2.2 Girder-Bridges

The selection of a bridge type involves the consideration of a number of different factors. In general, the factors are related to function, economy, safety, construction experience, traffic control, soil conditions, seismicity, and aesthetics. The type of bridge selected often depends on the horizontal and vertical alignment of the highway route and on the clearances above and below the roadway. In the selection of a bridge type, there is no unique or “right” decision. For each span length range, more than one bridge type will satisfy the design criteria. Factors that help determine bridge selection stem from regional differences and preferences. Regional differences and preferences will help determine a bridge selection because of available materials and resources, skilled workers and knowledgeable contractors, economy, and safety (Haskins, 2015).

Girder bridges, in the United States, are generally the most common type of highway bridges. Girder bridge's contribution to the transportation system often goes unrecognized. These bridges can be found on almost any interstate highway and are important structures because they are used so frequently. In addition, girder bridges have great stiffness and are less subject to vibrations. Girder bridges are most commonly used for straight bridges that are 33-650 feet (10-200m) long, such as light rail bridges, and pedestrian and highway overpasses. However, the spans of girder bridges seldom exceed 500 ft (150 m), with a majority of them being less than 170 ft (50m). When selecting bridge types, for short and medium spans the difference in material weight is small, therefore, girder bridges are a competitive selection when it comes to these span lengths. Some of the early girder bridges, with multiple short spans and deep girders, were not very attractive or aesthetically pleasing. However, with the arrival of prestressed concrete and the development of segmental construction, the spans of girder bridges have become longer and girders more slender. In the construction of the interstate highway system, girder bridges have been and continue to be built adding to the growth of the transportation system (Haskins, 2015).

2.3 Bridge Structural Components

An understanding of a bridge's components is necessary for an effective design. Bridges can be separated into two structural components: the superstructure and substructure. These two sections need to be assessed and designed for structural purposes. The superstructure comprises all portions of the bridge above the substructure, as modeled in Figure 1. The substructure supports the superstructure. Each of these components is dependent upon the other in terms of loading and geometry. When designing each of the structural components, the other must be taken into account.

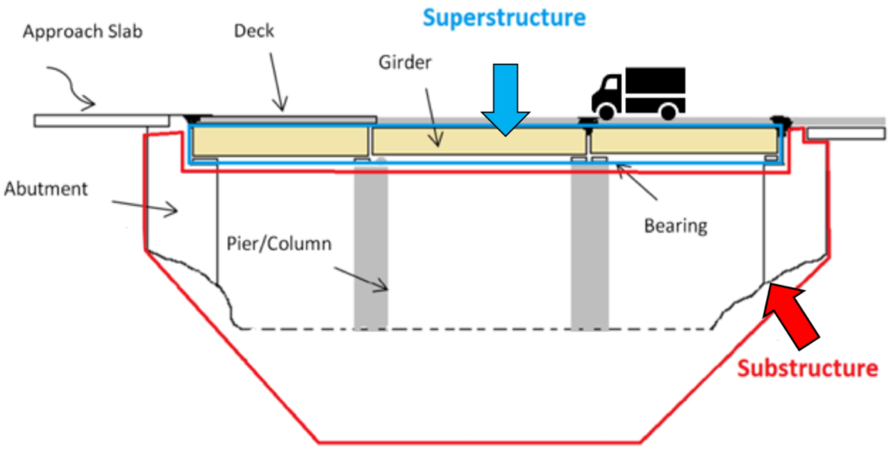

Figure 1. Major Bridge Components (Bektas, Carriquiry, & Smadi, 2013)

2.3.1 Superstructure Elements

The function of the superstructure is to collect live and traffic loads and transfer them into the substructure. The main components of the superstructure are the deck, girders, the primary members, and the secondary members. The purpose of primary members is to carry the principle live loads from trucks, whereas for secondary members its purpose is not to carry the traffic loads. Typically, primary members consist of girders, stringers, trusses, etc., and secondary members can be diaphragms, lateral bracing, pin and hanger assemblies, etc. These elements are the most visible part of the bridge structure and are located above all the supports. When designing one aspect the other elements of the superstructure must be considered.

2.3.1.1 Deck

Bridge decking provides a riding surface for the traffic utilizing the bridge. The deck is responsible for transferring the live and dead loads of the deck to the underlying bridge components. Decks are generally designed using reinforced concrete. The advantages a concrete deck provides is strength and it allows for the bridge to have a smooth riding surface. The deck of a bridge must be designed to satisfy the following limit state requirements: service, strength, fatigue, and extreme events. The requirements specified for these limit states are to meet specifications found in the AASHTO LRFD sections. The traditional design method of deck design is based on flexure. Therefore, in the design method the mode of failure is due to flexural failure. In the design method, the reinforcing steel normal to the supporting girders is considered to be the primary reinforcement. The areas of the primary reinforcement are computed based on the design moments. The reinforcing steel in the other direction are the distribution reinforcements. The areas of the distribution reinforcement are computed based on a specified percentage of the primary reinforcement area. The purpose of distribution reinforcements is to control cracking. Distribution reinforcements are used to hold the slabs to resist cracks and shear stress from developing at the top (Baker & Puckett, 2013).

In accordance with the *AASHTO LRFD Bridge Design Specifications* all decks must be made composite with supporting components. The only exception to this specification being wood and open grid decks. Composite action is beneficial because it enhances the stiffness of the superstructure, improves the economy of the bridge, and prevents vertical separation between the deck and its supporting components. A primary function of the deck is to provide a safe and supportive riding surface; therefore, deck drainage has to be considered during the design of the deck (U.S. Department of Transportation, 2015).

Deck drainage is an important aspect that should be designed with care and detail. If it is not, the deck joint regions can be affected by the insufficient deck drainage causing deterioration due to excessive water. In addition, it is important to consider deck appurtenances in design. Appurtenances are located along the edges of the bridge and are generally made of concrete. They are utilized primarily to safely direct traffic through the bridge. The deck appurtenances should be considered for service and fatigue limit states, and be disregarded for strength or extreme event limit states. This is because of the damage inflicted on the deck appurtenances due to vehicular collisions (U.S. Department of Transportation, 2015).

When designing concrete deck slabs and appurtenances, reinforcement is required generally in the form of steel reinforcement bars. When using steel reinforcement bars it is important to consider methods of corrosion resistance because steel reinforcement degradation is one of the main causes of poor deck performance. The minimum concrete depth and cover for deck design is specified in the AASHTO LRFD. Additionally, edge supports must be provided along the edges of the deck. The edge support may be either an edge beam or an integral part of the deck, such as a structurally continuous barrier. The deck haunch is another factor considered in the design of the deck. The deck haunch is generally the area between the girder and the bottom of the concrete deck. In the case of steel girder bridges, the haunch is typically the distance from the top of the girder web to the bottom of the concrete deck. For concrete girder bridges, the haunch is the distance between the top of the girder and the bottom of the deck. When setting the haunch depth, it is important to consider all variations in the flange thicknesses, deck cross slope, and forming method (U.S. Department of Transportation, 2015).

2.3.1.2 Primary Members

The primary members of the bridge are responsible for distributing the loads from the bridge deck longitudinally to the supporting piers and abutments. The primary members are designed to resist flexure. These members are the most noticeable element of a highway overpass. The primary members are the girders that run below the bridge deck. These girders are typically made of structural steel or concrete. The most common type of steel girder is the rolled beam. A stringer is a horizontal member used to connect upright members. There are many different types of stringers starting with the difference between steel and concrete stringer. Both steel and concrete have many different designs of stringers that are used for specific purposes depending on span length (Tonias, 1995).

2.3.1.2.1 Girder

A girder bridge is a common type of bridge where the bridge deck is built on top of supporting beams. The supporting beams are placed on piers and abutments that support the span of the bridge. The types of beams used for girder bridges are usually either I-beam girders or box girder beams that are made of steel or concrete. There are four types of girder bridges each classified depending on the construction material and type of girders used. A rolled steel girder bridge is built using I-beams made from prefabricated steel, while a plate girder bridge is constructed by welding flat pieces of steel together on-site to make the I-beams. A concrete girder bridge is constructed using concrete I-beam girders that can be made from various kinds of reinforced concrete. The various types of reinforced concrete include pre-stressed concrete and post-tensioned concrete. The last type of girder bridge is known as a box girder bridge. Box girder bridges can be made from either steel or concrete, and they’re used to support the bridge deck (Haskins, 2015).

Whether an I-beam girder or box girder is used to construct a girder bridge depends on various factors. It is easier and inexpensive to build and maintain a girder bridge using I-beam girders. However, these girders do not always offer sufficient structural strength and stability if the bridge is very long or the bridge span curves. The span of the girder bridge, if long or curved, is subjected to sensitive twisting forces or torque. Box girders are preferred for bridges with more lengthier and curvy spans. The concern with box girders is corrosion. Concerns have been raised about this because if rain water seeps into the open space inside the girders, corrosion is a possibility (Haskins, 2015).

2.3.1.2.2 Prestressed Concrete Girder

Prestressed concrete bridges have become a popular structural system for bridge design because they offer additional structural advantages of durability, fire resistance, deflection control, and other redundancies. The prestressed concrete girder is generally a popular choice for a highway overpass design. Prestressed concrete is favorable due to economic reasons, the ease of construction, their high strength, efficient assembly, and physical properties. Prestressed concrete girders are able to span long, continuous spans while not giving up much depth. These girders come in two different shapes, an I-girder and a T-girder. The design of prestressed concrete, which are AASHTO standards, depending on the size needed, have specified locations and numbers for pre-stressing strands (Tonias, 1995).

There are two main types of prestressing systems for concrete girders. The first is a pre-tensioning system where steel strands are subjected to tension before the concrete is placed. The second type is a post-tensioning system. In this case, the steel is not put through tension until after the concrete has been placed and has gained sufficient strength. Prestressed concrete has both high tensile and compressive strengths because of the combination of concrete and steel in the member (Tonias, 1995).

2.3.1.2.3 Rolled Beam

The rolled beam is a type of steel beam formed when hot steel is sent through a series of rollers to give the beams the distinct I-shape. These beams are referred to as I-beams because of the geometry the beam forms. The most common rolled steel beam for primary members is the wide-flange beam. Wide-flange beams come in a wide variety of sizes with known physical properties. When utilizing rolled beams a cover plate is generally added to the bottom flange of the beam to increase the flexural capacity of the member, allowing for a smaller, more economical beam to be used in the design process. The disadvantage of adding a cover plate is they put a large amount of stress on the ends of the plate, which could eventually lead to damage due to fatigue (Tonias, 1995).

A type of rolled beam is a hot rolled steel I-beam. This type of beam requires that the steel be rolled to its size while still hot, at a temperature over 1700 °F (926.7 °C). Because of this, the size of the steel isn’t always as precise as with cold rolled steel. However, hot rolled steel still has many advantages over cold rolled steel. Hot rolled beams are commonly used in highway overpass bridge designs and are less expensive compared to cold rolled steel I- beams. Hot rolled steel members come in a variety of different sizes and shapes, are easily assembled on site by either welding or bolting, and are very strong in tension. However, there are disadvantages in using hot rolled steel. A major drawback is that hot rolled steel, like all steel beams are susceptible to rust. Rust proofing coatings can be used to prevent rusting, but this has to be maintained otherwise the service-life of the bridge will shorten. Another disadvantage of using steel girders is site design and storage. The steel girders have to be shipped to the site from a fabrication plant and because of this there has to be space on site. The space is needed in order to work on the members before they are put in place (Tonias, 1995). In the case of structural steel members, there are many uncertainties. These uncertainties exist in the material properties, cross-sectional dimensions, fabrication tolerances, workmanship, and the equations used to calculate the resistance (Baker & Puckett, 2013).

2.3.2 Substructure Elements

The substructure is the foundation section of the bridge. The substructure of a bridge supports all the elements of the superstructure. It allows loads from the superstructure to be transferred to the underlying soil or rock. The design of the substructure is greatly influenced by the superstructure elements. The substructure consists of different elements. The elements found in this section are the bearings, piers, abutments, and the foundation (Rossow, 2005).

2.3.2.1 Bearing

Bearings may be small but are an important element in design. The bearings allow for translational and rotational movement in both the longitudinal and transverse directions. Bridge bearings provide an interface between its superstructure and substructure. The primary function of a bearing is to transmit loads from the superstructure to the substructure. The loads from the superstructure are transferred to the bearing plates which then transfer the loads to the foundations (Chen & Duan, 1999).

Bearings connect the girders to the piers and abutments to transmit loads. Bearings are subjected to a variety of forces such as the superstructure self-weight, traffic loads, and environmental loads. Translational movements are caused by shrinkage, creep, and temperature effects, while rotational movements are caused by traffic loads and uneven settlement of the foundations. When selecting a bearing, it is important to consider the maximum load capacity in addition to the bearings' ability to resist translational and rotational forces (Rossow, 2005).

There are two primary categories of bearings, fixed and expansion bearings. The principle difference between the two is fixed bearings restrict translational movements whereas expansion bearings allow for both translational and rotational movements. These different types of bearings have comparatively different loading capacities, therefore bearings need to be routinely inspected to ensure they still work for their intended purpose (Rossow, 2005).

Within the two categories of bearings, there are several different types of bearings. These types can be classified as rocker bearings, roller bearings, sliding plate bearings, pot bearings, spherical bearings, elastomeric bearings, and lead rubber bearings, etc. Rocker bearings consist of a pin at its top to allow rotational movement and a curved surface at its bottom to allow translational movement of the bridge. Roller bearings are composed of one or more cylindrical rollers between two parallel steel plates. Singular roller bearings accommodate both translational and rotational movements whereas multiple rollers work only with translational movements. Single roller bearings have a low manufacturing cost but at the same time have a small vertical loading capacity. In contrast, multiple roller bearings can support large loads but in comparison are more expensive. Sliding plate bearings typically provide longitudinal movement on bridges with spans of 15 meters or less. Pot bearings are comprised of a plain elastomeric disk that is confined in a steel "pot" ring that is able to transmit translational loads. Finally, elastomeric bearings transmit both types of movement. Elastomeric bearings are made of a natural or synthetic rubber called elastomer. They accommodate translational and rotational movements through the deformation of this rubber. Elastomeric bearings are more commonly used because they are inexpensive and almost maintenance free, while still being tolerant with respect to loads and movements greater than the design values (Chen & Duan, 1999).

2.3.2.2 Piers

A pier is a structural element of a bridge located between the ends of a bridge span. The basic function of piers is to provide support to the bridge span at intermediate points between the end supports known as abutments. Piers generally consist of footings, columns or stems, and caps. Some main functions of the piers are to carry their self-weight, support the dead loads and live loads provided by the superstructure, and to transmit all loads to the foundation of the bridge (Tonias, 1995).

A pier is designed to support the bridge at intermediate intervals with minimal interference to the roadway or water traffic passing under. A pier is generally constructed with only one column and supported by one footing (Rossow, 2005). They carry vertical loads from the superstructure to the foundation and resist any horizontal loads acting on the bridge. Piers are responsible for providing support for the girders at intermediate points along the bridge, and transferring the load from the superstructure to the foundation. Even though piers are commonly designed to resist vertical loads, design precautions are often taken even further to resist lateral wind loads (Chen & Duan, 1999). The connection between the pier and superstructure is usually a fixed or expansion bearing. This allows rotation in the longitudinal direction of the superstructure eliminating longitudinal moment transfer between the pier and superstructure (Wisconsin Department of Transportation, 2019b).

Piers are generally made of reinforced concrete. However, steel tubing filled with concrete is a growing commodity. It is important to distinguish the difference between a pier and a column. Columns are utilized to resist lateral forces by flexural action whereas piers use shear action to resist the lateral forces (Chen & Duan, 1999). All piers and abutment walls should be designed to have a suitable offset from the traveled way, with proper proportions in place between a pier and its superstructure. Piers can be designed in many different possible styles and shapes. The more favorable piers are those that have a flare, taper, texture, or other features that improve the visual aesthetics of the users who pass by. The key to pier design is that they be designed proportional with the superstructure and its surroundings (Barker & Puckett, 2013).

There are a number of different types of piers. Selection of which type of pier to use is based on aesthetics, shape of the superstructure, and how they provide limited interference to the passing traffic. The use of each type of pier is used based on different criteria (Tonias, 1995). Additionally, piers can be classified as either monolithic or cantilevered. This classification is defined by how they connect to the superstructure. A pier can also be distinguished by its column shape whether they be considered round, octagonal, hexagonal, or rectangular. Each column type has the option to be either solid or hollow. The shape of the column affects the area in which the load is distributed, and the column contributes to the aesthetic variability of the substructure. Lastly, a pier can be distinguished by its frame, single column, bent, hammerhead or pier wall (Chen & Duan, 1999).

There are many different types of piers and the selection of a specific one depends on what the bridge will be constructed of and the bridge's purpose. For concrete bridges, the typical pier types used are bents, and can be utilized for the design of precast girders and cast-in-place girders.

The type of pier differs depending upon the material used for the girders because of the difference in the weights. For piers, many factors are considered when selecting a type and configuration. The engineer designing this structural element should consider the superstructure type, span lengths, bridge width, bearing type and width, skew, required vertical and horizontal clearance, required pier height, aesthetics, and economic factors (Wisconsin Department of Transportation, 2019b).

2.3.2.3 Abutment

Abutments structures are the elements in bridge structure that provide vertical and lateral support at the bridge's end supports. The vertical support is for the bridge while the lateral support is for the soil and the ends of the roadway or stream. There are a variety of abutments that can be used for bridge design. Abutments are either constructed with plain concrete, reinforced concrete, stone masonry or a combination of concrete and stone masonry. The foundation soils found at a site will determine whether abutments and piers can be found on spread footings, driven piles, or drilled shafts. Large abutments may be needed to anchor a suspension bridge, but they are not needed for medium and short-span bridges. The preferred abutment is generally placed near the top of the bank, away from the traffic below. This abutment type is often referred to as a stub abutment. If the abutment is supported on columns or piling it is known as a spill-through abutment. This is because the embankment material spills through the piling. For a given length of an abutment, the flatter the slope of the embankment, the smaller the abutment appears to be. The preferred slope of the bank has a ratio of 1:2 or less. Proper selection of slope protection materials will give the bridge a neatly defined and finished appearance (Barker & Puckett, 2013).

There are two categories of abutments. Bridge abutments can be classified as either open-ended or close-ended. Open-ended abutments have a slope that goes from the abutment to the roadway or the river canal beneath. The bridge crosses over these and with their slopes leave space to widen the passing road below. On the other hand, close-ended abutments are constructed on the edge of the roadways or stream and are typically high vertical walls that have no slope. In comparison, open-ended abutments are generally more economical, flexible and aesthetically pleasing. Construction costs for close-ended abutments tend to run higher due to their higher walls and larger backfill area (Chen & Duan, 1999).

Abutments can also be categorized based on the connection to the bridge superstructure. The connection between the abutment is classified as either monolithic or seat-type. The monolithic abutment is usually reserved for shorter bridges. The monolithic abutment is built with the bridge superstructure leaving no displacement between the abutment and the superstructure. For this type of abutment deformations of the superstructure, such as thermal movements, must be considered in the abutment design in order to prevent cracking. Its greatest advantage in design is its lower construction costs, but it is important to consider the potential maintenance and rehabilitation costs. The seat-type abutment is constructed separate from the superstructure. For the seat-type abutments, the superstructure rests on the abutment stem through bearing pads, rock bearings, or other devices. These bearings enable the designer to control bridge displacement. This aspect makes seat-type abutments popular for longer bridges, especially those with concrete or steel girders. Although this type of abutment has a higher initial cost it has a relatively lower cost in maintenance (Chen & Duan, 1999).

The design of abutments depends upon the soil conditions at the project site. If the site is mostly hard bedrock, a vertical, close-end abutment will most likely be considered. Meanwhile, if the soil is softer, a sloped, open-end abutment will most likely be sufficient in helping counteract settlement. However, the use of sloped abutments are typically for long-span bridges and requires extra earthwork which could increase bridge construction cost (Chen & Duan, 1999).

2.3.2.4 Foundation

A foundation is constructed under the pier and abutment and over the underlying soil or rock. The loads transmitted by the foundation to the underlying soil or rock must not cause soil shear failure or excessive settlement of the superstructure. The foundations of bridges are critical. Foundations must support the entire bridge weight and traffic loads that the bridge will carry throughout its service life. The purpose of the foundation is to distribute the loads of a bridge over a large bearing area. This will provide stability to the bridge against settlement and tilting. All foundation designs must meet certain requirements in order to be designed properly. Foundations must provide adequate safety against any structural failures, provide sufficient bearing capacity to the soil beneath the foundation with a factor of safety design, and must achieve acceptable total or differential settlements under the working load (Wisconsin Department of Transportation, 2019a).

There are two types of foundations, shallow and deep. To determine the foundation type suitable to satisfy the site-specific needs, assessments are made based on the requirements for the type of foundation. A shallow foundation can be determined as one in which the depth to the bottom of the footing is usually less than or equal to twice the smallest dimension of the footing (Wisconsin Department of Transportation, 2019a).

Shallow foundations generally consist of spread footings but may also include rafts that support multiple columns. Shallow foundations are typically the most economical foundation alternative, and this foundation type provides support entirely from its bases. Shallow foundations transfer loads to the ground through the use of bearing at the bottom of the foundation. The design of a shallow foundation must provide adequate resistance against geotechnical and structural failure. The design must also limit deformations within the tolerable values. Suitable soil conditions exist for this foundation type within a depth of approximately 0 to 15 feet below the base of the proposed foundation (Wisconsin Department of Transportation, 2019a).

When shallow foundations are not satisfactory, deep foundations must then be considered. Deep foundations transfer foundation loads through shallow deposits to underlying deposits of deeper bearing material. These foundation types transmit the weight of the abutment to the supporting soil or rock. Deep foundations classifications include piles, drilled shafts, caissons, micro-piles, and anchors. Deep foundations have a variety of functions. A primary function is to transmit the loads of the structure through a stratum of poor bearing capacity to one of adequate bearing capacity. Additionally, the purpose of this foundation type is to eliminate objectionable settlement, transfer loads from a structure through erodible soil in a scour zone, and resist lateral loads from earth pressures, as well as external forces (Wisconsin Department of Transportation, 2019a).

All possible structural and geotechnical failure modes for foundations present during the design life of the bridge are grouped into three distinct limit states. The three limit states are service, strength and extreme events. These limit states should be checked during the foundation design (U.S. Department of Transportation, 2011).

2.4 Design Requirements and Computer Aids

The function of a design process is to produce a bridge configuration that can be justified and described to others. Computers can help aid with the analysis, design calculations, and the drawings. Drawings include computer drawn images of cross-sections, elevations, and graphics. Computer software packages can perform calculations of loads and internal forces but must be checked using hand calculations.

2.4.1 AASHTO LRFD Specification

To assure the quality of bridges, engineers have studied bridge behaviors and developed specific specifications. The specifications are for the purpose of designing and constructing bridges in a structurally safe manner. These specifications have been made available by the American Association of State Highway and Transportation Officials (AASHTO). In order for an engineer to safely design a bridge, all factors of bridge design must be taken into account. The factors and the loads must be accurately determined, the materials must be carefully chosen, and the geometry of the bridge must be set. The specifications published by AASHTO were created to design various key components of the bridge, such as the substructure and superstructure elements (American Association of State Highway and Transportation Official, 2004).

Load and Resistance Factor Design (LRFD) accounts for both load factors and resistance factors. LRFD compares the required strength to the actual strength. The purpose of these factors is to decrease the load carrying capacity calculated from the design. By using these factors, the results have a low probability of surpassing the critical level. There are many advantages and disadvantages of using this approach. One advantage that this method of design provides is that it is compatible with other design specifications such as those of the American Concrete Institution

(ACI) and the American Institution of Steel Construction (AISC), and these methods are familiar to engineers and new graduates. In addition, the LRFD method provides uniform levels of safety for different limit states and bridge types. One disadvantage found when using the LRFD method is that it required a change in design philosophy, in regards to previous AASHTO methods. Additionally, using this method requires an understanding of probability and statistics in order to make adjustments to resistance factors (Barker & Puckett, 2013).

2.4.2 Geometry Requirements

The typical lane width for a freeway overpass is 12ft (3.6m). In urban settings, a barrier must be placed in order to separate the traffic for a two-way elevated freeway. The width of the barrier is generally 2ft (0.6m). The minimum median, a reserved area that separates contrasting lanes of traffic on a divided highway, is determined by adding two left shoulder widths. Left shoulder widths are usually 4ft (1.2 m). However, the median of a four-lane highway is 10ft (0.3m) and is 22ft (6.6m) for a six or eight lane freeway (American Association of State Highway and Transportation Official, 2004).

On interstate highways, the vertical clearance of bridge structures cannot be less than 16ft (4.9m). The 16ft height clearance should span over the entire roadway width. On other urban interstate routes, the clear height cannot be designed to be less than 14 feet (4.3 meters). If these standard requirements are not met, a design exception is required. A formal design exception is required whenever these criteria are not met for the applicable functional classification. If there is a need for a design exception for an interstate highway, it must be coordinated with the Military Surface Deployment and Distribution Command Transportation Engineering Agency of the Department of Defense (U.S. Department of Transportation, 2015).

2.4.3 Design Loads and Limit States

AASHTO provides a variety of different types of loads to be considered in bridge design. These loads can be classified into two categories: permanent loads and temporary loads. Permanent loads and temporary loads are also known as dead load and live load respectively. Live loads can be divided into two categories: vehicular live loads and environmental live loads. Vehicular live loads include traffic passing over the bridge. Environmental live loads include aspects like wind loads and earthquake loads. In order to design a bridge, none of its components must fail. Therefore, it is important to determine the acceptable level of risk or the probability of failure in the design. During the design process, an important goal is to prevent a limit state from being reached. This is because once a particular loading condition reaches its limit state, failure is the only assumed result. The loading condition that caused this failure to occur becomes the failure mode. Limit states for girder bridges include: deflection, cracking, fatigue, flexure, shear, torsion, buckling, settlement, bearing, and sliding (Barker & Puckett, 2013).

2.4.3.1 Limit States

The basic design expression in the *AASHTO LRFD Bridge Specifications* that must be satisfied for all limit states, both global and local, is given as service, fatigue and fracture, strength, and extreme event limit states (Barker & Puckett, 2013).

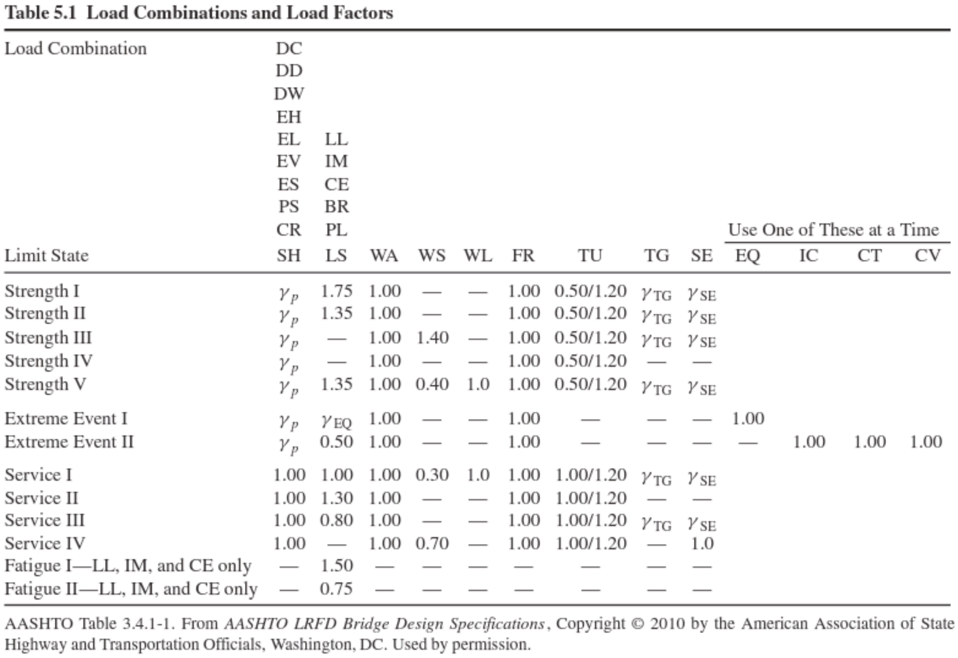

Table 5.1 Load Combinations and Load Factors

Load Combination	DC DD DW EH EL EV ES PS CR	LL IM CE BR PL								Use One of These at a Time			
Limit State	SH	LS	WA	WS	WL	FR	TU	TG	SE	EQ	IC	CT	CV
Strength I	γ_p	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}				
Strength II	γ_p	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}				
Strength III	γ_p	—	1.00	1.40	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}				
Strength IV	γ_p	—	1.00	—	—	1.00	0.50/1.20	—	—				
Strength V	γ_p	1.35	1.00	0.40	1.0	1.00	0.50/1.20	γ_{TG}	γ_{SE}				
Extreme Event I	γ_p	γ_{EQ}	1.00	—	—	1.00	—	—	—	1.00			
Extreme Event II	γ_p	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00
Service I	1.00	1.00	1.00	0.30	1.0	1.00	1.00/1.20	γ_{TG}	γ_{SE}				
Service II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—				
Service III	1.00	0.80	1.00	—	—	1.00	1.00/1.20	γ_{TG}	γ_{SE}				
Service IV	1.00	—	1.00	0.70	—	1.00	1.00/1.20	—	1.0				
Fatigue I—LL, IM, and CE only	—	1.50	—	—	—	—	—	—	—				
Fatigue II—LL, IM, and CE only	—	0.75	—	—	—	—	—	—	—				

AASHTO Table 3.4.1-1. From *AASHTO LRFD Bridge Design Specifications*, Copyright © 2010 by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission.

Figure 2. Load Combinations and Load Factors Addressing Design Situations (Barker & Puckett, 2013)

2.4.3.2 Service

The service limit state refers to restrictions on stresses, deflections, and crack widths of bridge components that occur under regular service conditions. Failure modes are related to the function and performance of the bridge under regular operating conditions. For the service limit state, the resistance factors are 1.0 and nearly all of the load factors are equal to 1.0. There are four different service limit state load combinations that address different design situations (Barker & Puckett, 2013).

2.4.3.3 Fatigue and Fracture

The fatigue and fracture limit state refers to a set of restrictions on stress range caused by a single design truck. The restrictions depend on the number of stress–range excursions expected to occur during the design life of the bridge. This limit state is intended to limit crack growth under repetitive loads and to prevent fracture due to cumulative stress effects in steel elements, components, and connections (Barker & Puckett, 2013).

2.4.3.4 Strength

The strength limit state refers to providing sufficient strength or resistance to satisfy the inequality for the statistically significant load combinations that a bridge is expected to experience in its design life. Failure modes are the collapse or damage of the bridge or its foundation under loads applied continuously or frequently during its design life. Strength limit states include the evaluation of resistance to bending, shear, torsion, and axial load. The statistically determined resistance factor will usually be less than 1.0 and will have different values for different materials and strength limit states (Barker & Puckett, 2013).

2.4.3.5 Extreme Event

The extreme event limit state refers to the structural survival of a bridge during a major event. Failure modes are the collapse of the bridge or its foundation due to events that have a return period greater than the design life. These events include a major earthquake or flood or when collided by a vessel, vehicle, or ice floe, possibly under scoured conditions. The probability of these events occurring simultaneously is extremely low; therefore, they are specified to be applied separately. The recurrence interval of extreme events may be significantly greater than the design life of the bridge. Under these extreme conditions, the structure is expected to undergo considerable inelastic deformation (Barker & Puckett, 2013).

2.4.4 Risa (3D)

RISA-3D is a powerful design tool that can be applied when analyzing structures. This computer aid program allows the engineer designing the structure to be in control of the design due to its many included features. This computer-aided design software can analyze anything from a simple beam and truss to shear walls. RISA-3D includes within the program the most current steel, concrete, cold-formed steel, and timber design codes. The loads applied are specified by the *AASHTO LRFD Design Specifications*. The results from the design can be viewed graphically through shear and moment diagrams, or viewed in more detail through the member details reports. The member details reports display the analysis and design calculation results for each member. In addition, RISA-3D is known for its ease of use and convenience. Loads can be easily adjusted for different loading case scenarios and coefficients can be assigned to specific loads to create multiple load cases (RISA Tech, Inc).

2.4.5 AutoCAD

AutoCAD is a computer-aided design (CAD) program commonly used for 2D and 3D drawings and drafts. AutoCAD has a variety of applications in many different fields. The software assists in the creation, modification, and optimization of designs. AutoCAD is a software that engineers and designers can use to create many different types of precise and complex drawings. This program helps create these drafts faster and more accurate than doing it by hand. These drawings can be drafted with the many included features the software provides. Drafting and designs can be customized by adding solids, surfaces, and mesh features. These features allow the engineer to make accurate drawings using real world elements and behaviors. Design drawings can also be drafted using detailed components and keynoting tools. These tools AutoCAD offers aid with the annotation of drawings through the use of text, dimensions, tables, and leaders. Additionally, by using these tools, properties such as size, shape, and location can also be manipulated and changed in a quick and easy manner (AutoCAD For Mac & Windows).

2.5 Cost Estimate

In determining the cost of any bridge project the initial cost of construction should be considered. The success of a project is built on being able to provide an accurate preliminary estimate for the proposed structure. A preliminary estimate includes the unit price for each item needed for a specific project. The initial cost is an essential component in comparative analysis for potential bridge design options. This is because it is important to know how much a project will cost because more economic bridge structures tend to be more favorable. The main purpose of a cost estimate is to evaluate the different design alternatives by seeing if any of them are significantly less expensive. The initial cost is something that gets bid on by different contractors. Contractors submit different price estimates per unit cost of construction items whether they be labor, material, or construction equipment. To obtain initial cost prices, one must research and gather unit prices from a number of sources. The *R.S. Means Heavy Construction Cost Data* is a useful tool to find unit prices for bridge components and materials. These cost values are needed to estimate the initial cost of the bridge. When using cost data from past years, it is crucial to adjust all prices based on inflation rates and location to have the valid prices for labor work, materials used, construction equipment costs, etc. for the current year and locale.

The *R.S. Means Heavy Construction Cost Data* book is a powerful construction tool that can be used for any structural civil project. This tool presents information on the necessary factors that go into cost estimates with quick and readily accessible key costs. The book is a comprehensive, reliable source of current construction costs and productivity rates. The prices in the construction industry are continuously monitored to ensure that accurate and up-to-date cost information is represented in the book. This tool provides a variety of useful references in order to get more accurate unit prices and results when conducting a project estimate. These references include equipment rental cost, crew listings, historical cost indexes, city cost indexes, location factors, etc. All cost values are U.S. national averages and are given in U.S. dollars. The costs in *R.S. Means Heavy Construction Cost Data* are divided by material, labor, equipment, general conditions (bare cost), and overhead and profit. The bare cost is the cost that is of most importance to my project. The total bare costs consist of adding up the labor cost, equipment cost and material cost. Neither overhead nor profit are included in the bare cost (RSMeans, 2011).

3.0 Methods

The purpose of this section is to provide an overview with key information to understand the steps taken to develop this Major Qualifying Project. The focus of this project was to provide a preliminary structural design for a highway bridge with three alternative girder designs, two using steel and one using concrete. From these different alternative girders, the best choice among the design options for the proposed bridge was selected. Throughout the design there were five major areas of work: geometry, deck design, girder designs, evaluation of alternatives, and the substructures/ foundation. A brief overview of the objectives, key aspects, and steps taken to complete each element to obtain the final design recommendation is contained within this chapter.

1. Geometry

The geometry of the bridge was the first step completed for the bridge design. The geometry of the bridge was the bases used for the rest of the design process. Specifications were used in order to develop the design of the bridge's general section. The bridge was designed to carry vehicular interstate traffic over a highway; therefore, the bridge's roadway width, span, and vertical clearance were highway specified. These dimensions had to abide to regulations set by bridge standards and the state. Once the dimension of the bridge was set, preliminary drawings and views of the bridge were made.

2. Deck Design

The deck was designed to be compatible when coupled with the three different alternative girders types. The appropriate design method and assumptions made were determined prior to starting the calculations. Parameters such as girder spacing, overhang width, yield and compressive strengths, as well as the densities of the applicable materials were identified. The deck thickness depth was then selected based on the deck span length (*S*) in order to control deflection. The sacrificial surface and overhang thicknesses were also considered while adhering to the specifications. The weight of the barrier, future wearing surface, slab, and cantilever overhang components for a 1-ft-wide strip of concrete were calculated. These calculations were then used for the analysis for the deck's bending moment force effects. A moment distribution for the deck slab was conducted to find the loading factors as well as the extreme positive and negative moments at different location for the various components of the deck.

3. Girder Design

The primary members were separated into three categories, one for each girder alternative. Each material and girder type had very different characteristics and was looked at separately. Standard design sizes for each alternative were selected to reduce cost and contribute to constructability. The design of the girders started with computing the live load force effects and the governing maximum moment and shear load effects the bridge would be experience. This was completed using both hand calculations and computer software. Once these design loads were calculated the governing values were used to design all three alternative girders options.

The design of the girders started with the steel rolled W-shape alternative. Using the design-required maximum loads, a trial section for the W-shape was calculated, and from the result, a girder that met the requirements was selected from the *AISC Steel Manual*. The W-shape selected was then checked for flexure, shear, and deflection.

The next girder investigated was a steel Built-up structure. The Built-up girder was designed following the process outlined in various reference books. From the process, a spreadsheet was developed in order to find the dimensions of the plates that would be welded together to create the Built-up girder. The spreadsheet input critical design steps and checks in order to find a trial size for the web and flange. The design process for the Built-up girder was an iterative process. The goal was to find a size that could carry the maximum design loads and pass the required checks outlined by the specifications and textbooks used. From the selected plate sizes, a drawing was created to depict the cross-sectional view of the girder.

The last alternative investigated was a concrete bulb-tee girder. To design this girder type, an Excel sheet for the primary design of precast/ prestressed concrete girders was used. The spreadsheet required the input of critical factors. Some of these design factors include material, geometric, and loading properties. Another iterative process was conducted and the final bulb-tee selected passed all the required code checks. A drawing of the cross-section was then designed using the dimensions of the bulb-tee selected.

4. Evaluation of Alternatives

Once all the alternative girder designs were created a comparison amongst all of the options was conducted to select the final design. A cost analysis for each girder was preformed and this was used as one of the evaluation criteria. The three evaluation criteria used were: economic, constructability, and sustainability. A scale was then created and each design was rated according to the criteria. The design with the highest total score was selected as the final design.

5. Substructure/ Foundation

This portion included an analysis as to how the design process for an abutment and pier would follow. The two sections highlight key design elements for each part of the substructure along with a thorough description of the fundamental factors that need to be considered. Images were developed for the abutment and pier in order to depict the main components involved for the design of the structures.

Table 1. Bridge Design Process Overview

Area of Work	**Key Topics**	**References**
Geometry	• Lane Width • Vertical Clearance • Curb Width • Bridge Elevation and Drawing Views	• *AASHTO Green Book, A policy on Geometric Design of Highway and Streets* • *AASHTO LRFD Bridge Design Specifications* • Federal Highway Association • Massachusetts Department of Transportation
Deck Design	• Load Factors • Minimum Deck Thickness Properties • Bending Moment Force Effects • Maximum Positive and Negative Moments	• *AASHTO LRFD Bridge Design Specifications* • *Design of Highway Bridges: An LRFD Approach* • Federal Highway Association • Massachusetts Department of Transportation
Girder Design	• Governing Moment and Shear • Load Modifiers • Load Factors • Selection of Girder Type and Size • Design Checks for Selected Girder • Cross-Sectional View Drawings	• *AASHTO LRFD Bridge Design Specifications* • *Precast/Prestressed Concrete Institute Manual* • *American Institute of Steel Construction Manual* • *Structural Steel Design* • *Design of Highway Bridges: An LRFD Approach* • PSGSimple_demo.xls
Evaluation of Alternatives	• Bare Cost for Selected Girder	• *R.S. Means Heavy Construction Cost Data*
Substructure/ Foundation	• Fundamental Design Factors • Design Considerations	• *AASHTO LRFD Bridge Design Specifications* • *WisDOT Bridge Manual*

Table 1 shows a breakdown of the five major areas of work followed throughout the bridge design project. Attached to each area of work are the key elements with the corresponding references used to complete the work. The references are taken from the manuals, specifications, and books used throughout the design process. The development of the design for the bridge structure used appropriate methods that align with standard engineering practices. Each bridge component was properly designed according to certain specifications, regulations and codes.

4.0 Bridge Geometry and Deck Design

The first step in designing the composite deck was to obtain the dimensions of the bridge and collect the general specifications. These dimensions and general information on the bridge geometry can be found in Table 1. The AutoCAD drawings for the top view of the bridge and the jersey barrier used can be found in section 4.2 (Geometry Design). The drawings elevation of the overpass design and the cross-sectional view can be seen in Appendix E.

These drawings are based on a structural vehicular bridge design intended to span over a six-lane highway. The design drawings consist of modeling a standard bridge overpass providing access between two levels.

4.1 Geometry Design

The information and numbers gathered in Table 1 originated from a number of resources such as bridge manuals and specifications. These resources had controlling conditions that the bridge design had to abide to in order to be constructed and to ensure safety.

The highway bridge overpass was designed to carry interstate traffic over a six-lane highway. The design of the highway has two lanes and the roadway width was highway specified. Table 1 includes the geometry of the bridge design structure. The information provided by Table 1 was used for all of the alternative designs and was needed to produce drawings on AutoCAD. The values were used to create drawings for the elevation of the overpass, the top view of the bridge design, and the plan and cross-sectional views. These values had to abide to the following standards and codes as stated by: *AASHTO LRFD Bridge Design Specifications, A Policy on Geometric Design of Highway and Streets,* the Federal Highway Association, and the

Massachusetts Department of Transportation (MassDOT). The design's intended span length, beam spacing, vertical clearance, lane and curb width had to be checked against the codes specified and highway bridge standards found within these references.

Table 2. General Bridge Information Used for all Alternative Design Options

Roadway Width (curb-curb)	32ft
Curb Width	4ft (on each side)
Lane Width	12ft
Number of Lanes	2 Lanes
Total Width (includes overhang)	34.5ft
Span Arrangement for Design	55ft
Total Span	110ft
Bridge Vertical Clearance	20ft
Barrier Type	Jersey Barrier
Girder Spacing	7ft
Number of Girders	5 Girders

4.2 Geometry Design

The figures below display a variety of AutoCAD drawings for the final bridge designs. The different drawings of the bridge design are visual representations of all the calculations and collection of geometry regulations collected. The AutoCAD drawings were created to display the different aspects and section views of the bridge. In addition, the final bridge designs drawings are present to show and compare the superstructures of the three alternative designs. The following figures are a representation of different elements and views of a proposed two lane highway overpass.

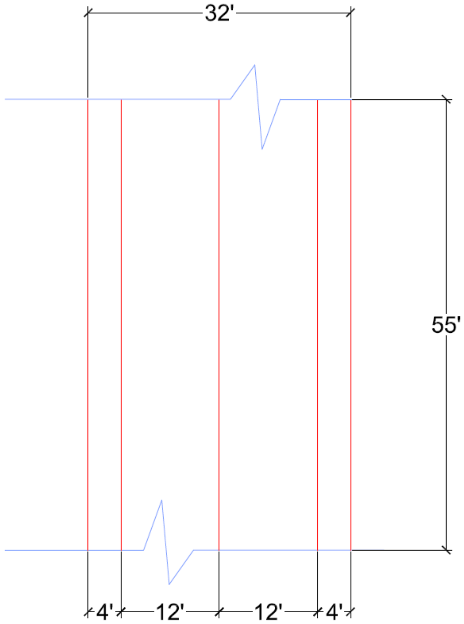

Figure 3. Top Sectional View

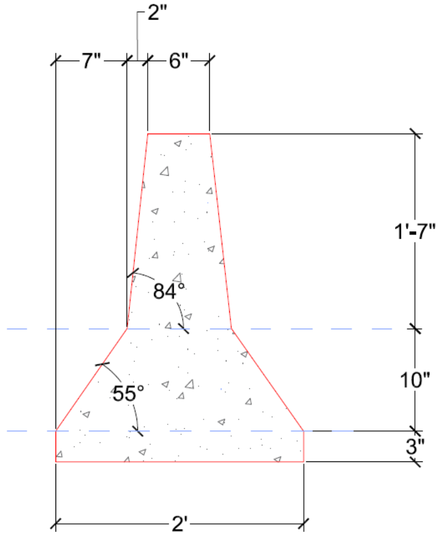

Figure 4. Jersey Barrier Design

4.3 Deck Design

Once the geometry of the bridge was set, the next step was to design the deck. The first step in designing a concrete deck that would be compatible with the alternative girder designs was to obtain the design criteria. A composite concrete deck was used because the *AASHTO LRFD Bridge Design Specifications* recommended this type of deck for a highway overpass. The design criteria outline the known values that were used in subsequent steps through the entire deck design process. The design criteria used for the composite deck design can be found in Table 1. When designing the deck, design factors for both live load and dead load moments had to be calculated to use in different loading combinations. These factors were obtained using the loading factors and combinations specified in the *AASHTO Specifications Manual.*

Table 3. Material and Selection Properties for Deck Design

Structural Type	Concrete Deck
Overall Deck Width	34.5ft
Bridge Length	110ft
Girder Spacing	7.0ft
Concrete Top Cover	2.5in
Concrete Bottom Cover	1.0in
Wearing Surface	3.0in
Concrete Strength	4.5ksi
Reinforcement Strength	60ksi
Concrete Density	0.150kcf
Deck Overlay (Wearing Surface) Density	0.140kcf

Design criteria for this specific deck design included a variety of deck properties. Some of them include girder spacing, number of girders, concrete deck top and bottom cover, density of concrete, reinforcing steel strength, density of the future wearing surface, etc. All these numbers came from either the design geometry of the bridge or from the *AASHTO LRFD Bridge Design Specifications.*

Table 4. Deck Thicknesses

Minimal Deck Thickness (H_{min})	6.8in
Structural Thickness of Deck (H_s)	7.5in
Additional Thickness for Sacrificial Surface (H)	8.0in
Deck Overhang (H_o)	9.0in

According to AASHTO, S9.7.1.1 and the MassDOT requirements, the minimum slab thickness for a concrete deck is 7.5-inches but this minimum thickness can be pushed to as low as 6.8-inches. In order to be conservative and abide by these specifications, a slab thickness of 8-inches was chosen for the design process. The deck thickness of 8 inches takes into consideration additional thickness to account for more support. The deck incorporates extra thickness compared to the minimum requirement for structural thickness and wearing surface. The overhang thickness of the deck also had to be selected. This is an essential part as the overhang is the portion of the deck that supports the parapets, therefore the thickness must be greater than the slab. The minimum overhang thickness denoted by AASHTO was 8-in; therefore, a thickness of 9-in. was selected for the design. A partial drawing of the deck section for the bridge can be seen in Figure 5.

Table 5. Weight of Deck Components

Barrier (P_b)	0.435 k-ft
Future Wearing Surface (W_{DW})	0.035 ksf
Deck Slab (W_s)	0.100 ksf
Cantilever Overhang (W_o)	0.113 ksf

The weights of the deck components were calculated based on a one-foot wide section of the bridge slab. This was the first process taken in order to start the deck design process. In order to do out the hand calculations that support Table 5, an assumed weight of concrete was utilized. The assumed unit weight of the concrete used was 0.150kcf.

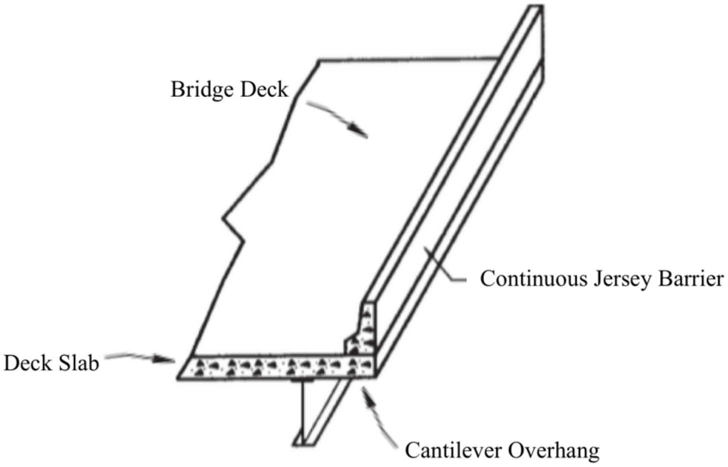

Figure 5. Resulting Bridge Deck Section

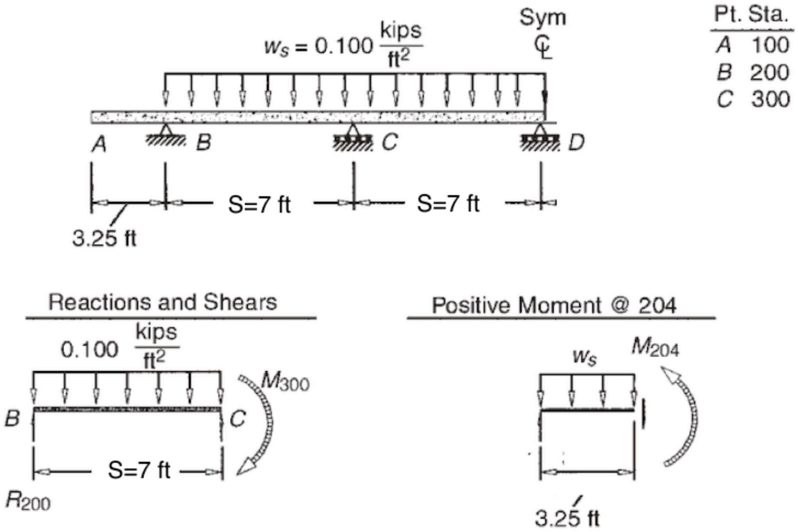

Figure 6. Moment Distribution for Deck

Figure 6 shows the placement of the deck slab dead load. This represent the results of a moment distribution analysis for negative and positive moments, specifically for a 1-ft-wide section. For calculations on a uniform load, the tabulated areas were multiplied by *S* for shears and by S^2 for moments. The results for the bending moment on the concrete deck can be found in Table 6.

Table 6. Bending Moment Force Effects

Component Type	**R_{200}**	**M_{200}**	**M_{204}**	**M_{300}**
Barrier (P_b)	0.658	-1.23	-0.606	0.332
Future Wearing Surface (W_{DW})	0.179	-0.070	0.098	-0.165
Deck Slab (W_s)	0.275	[redacted]	0.378	-0.523
Cantilever Overhang (W_o)	0.476	-0.597	-0.294	0.161

Table 6 is a summary table of the hand calculations used to determine the overall factored design moments for positive and negative moment areas for the proposed deck design. The hand calculations can be found in Appendix C. The table also provides results for the support reactions for the different components. The maximum negative bending moment effects occurred at the barrier at M200. The positive maximum bending moment occurred at the deck slab at the location of M204. The highest resultant reaction occurred at the barrier. All these values were calculated to determine the bending moment force effects the deck would experience during loading whether it be from the self-weight components or the maximum vehicular loads. This was a very important process as the deck must be designed for the loading condition that creates the most extreme effect whether it be from the truck, tandem, fatigue or the lane load.

When the maximum positive moments for the component types were added together, it resulted in a value of 2.418 k-ft. As for the negative maximum number, the total was 3.485 k-ft. In order to clarify, the maximum values for positive and moment and the reaction for the component types have been highlighted in Table 6. See Appendix B for partial calculations tabulated within this section (4.3 Deck Design).

5.0 Girder Design

This section of the report presents the final LRFD design results for the three alternative bridge designs and concludes with the final design chosen. In designing the members of the bridge the AASHTO specifications for the LRFD design method were followed. The principal document used for each design was *AASHTO LRFD Bridge Design Specifications*, which outlined a variety of specifications that were referenced in order to complete the required calculations. Once all calculations were completed, the results were placed into a series of tables and schematics. This chapter suggested three types of bridge members for the desired span (55ft). The three types of bridge members discussed are W-shape rolled beams, Built-up girders, and precast concrete girders. The designs were developed using the properties and dimensions specified in Table 1. The final designs for the alternative bridges were created to support the maximum loads applied to the bridge. An iterative process was conducted to determine the superstructure's maximum loading and design. The calculation for the dead load and live load were calculated by hand, while the maximum shear and maximum moments were calculated by hand and then checked using Risa-3D. The iterative process to calculate these values was done to ensure that both hand calculations and software results matched and were calculated correctly. In addition, this process helped to ensure that the bridges were designed to withstand and support the maximum loading.

5.1 Determining Governing Moment and Shear

The preliminary investigation to calculate the maximum moment and shear produced both steel and precast bridge designs options. These calculations served to determine the member type selected for preliminary design. In addition, a load study was conducted for AASHTO LRFD lane load, HS20-26 truck, HS20-30 fatigue, and tandem loads. These loads studies were performed on RISA-3D and were based on moving loads.

AASHTO provides various strength limit states to be considered when designing a bridge, but for the simplicity of the design, the standard LRFD load factors were used (1.2DL +1.6LL). The shear and moment values obtained from the studies were maximized by placing the axle loads at various locations along the span. The vehicle loads were placed as close to these critical moment locations as allowed under the *AASHTO LRFD Bridge Design Specification* using an iterative trial-and-error approach until the maximum moments were observed.

Table 7. Maximum Envelope Results for Moving Load Analysis

Moving Load Pattern	**Maximum Moment (k-ft)**	**Location of M_{max} (ft)**	**Maximum Shear (kips)**	**Location of V_{max} (ft)**
Truck (HS20-26)	719.449	25.208	58.75	0, 55
Fatigue (HS20-30)	500.359	21.198	47.113	0, 55
Tandem	641.828	26.927	48.004	0, 55
Lane Load	249.617	27.5	18.154	0, 55

Table 7 is a representation of the maximum results calculated for the moving loads investigated. The highlighted elements in the table are differentiated to show the maximum moment and shear values for the moving loads when all the loading patterns were compared. The table above provides at what specific locations the maximum moment and maximum shear occurred on the arranged span of the bridge design. RISA-3D was used to calculate and find the values listed in Table 6. The maximum values determined by this software were also evaluated and checked through hand calculations. For both cases, hand calculations and the RISA-3D model calculations, the arranged span used was 55ft. Under the column titled ‘Moving Load Pattern’, the characters bracketed by parentheses are the names given to that specific load pattern on RISA-3D. The specified load patterns come from standard AASHTO loads built into RISA’s moving loads database; the other two types of patterns shown were added and customized. The analysis of the load path for the moving loads was applied throughout the entire arranged span, and the path was set to move both ways. By specifying that the analysis goes both ways, the moving loads being investigated were applied in both directions of the load path. The figures below are the Risa-3D graphical results for the Truck (HS20-26) moving load pattern. See Appendix B for diagrams, graphs, and the full envelope reports for each moving load pattern.

Figure 7. Maximum Moment Diagram for the Truck (HS20-26) Moving Load Pattern

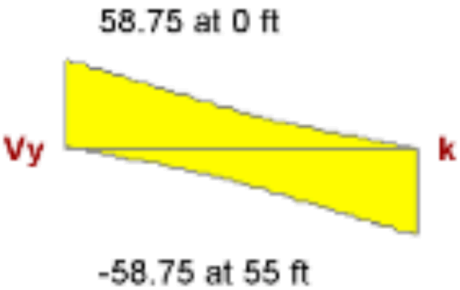

Figure 8. Maximum Shear Diagram for the Truck (HS20-26) Moving Load Pattern

The absolute maximum shear for simply supported beams occurred right next to where the supports are located. This can be seen in Table 7 and in Figure 8 as all of the maximum shears occurred at the beginning and end of the arranged beam length, where the supports were located in the design model. In a simply supported beam the maximum moment occurs under one of the concentrated forces. The midway point of the arranged span investigated is 27.5ft; in Table 6 and Figure 7 the maximum moments calculated tended to occur around this location. As shown in Table 7, the truck moving load pattern governed for both maximum shear and maximum moment. These maximum values have been distinguished differently for emphasis. The loads from the truck governed therefore the result values for moment and shear were used in the analysis and design process to calculate the loads on the exterior and interior beams.

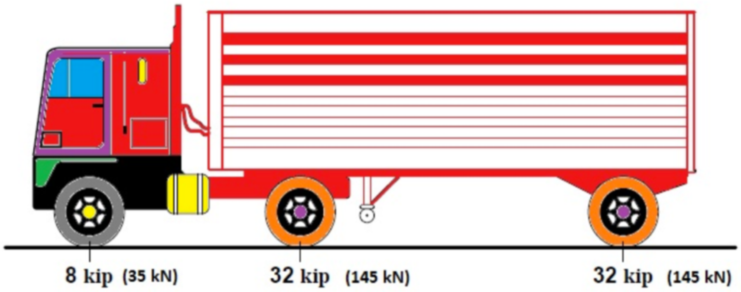

Figure 9. AASHTO HS20-26 Truck Design Moving Load (American Association of State Highway and Transportation Officials, 2015)

Figure 9 displays the standard AASHTO design for the moving load analysis. The truck moving load was the governing load pattern for the highway overpass. The computer model for the HS20-26 Truck consisted of one 8-kip axle load and two 32-kip axle loads. These loads represent a truck traveling over the bridge. The 32-kip axle loads represent the rear wheels of the AASHTO design truck while the 8-kip load represents the loading from the front wheel. The AASHTO distributed load was applied as a moving load which moved at one foot increments along the bridge arranged span. This was done in order to determine the critical location of the design truck. These calculations were done by hand and then double checked using Risa-3D.

Table 8. Calculated Unfactored Moments and Shears for Interior and Exterior Girders

	Load Type	Distributed Load (k/ft)	Moment (k-ft)	Shear (kips)
Interior Girder	DC	0.90	340.3	24.8
	DW	0.28	105.9	7.7
	LL + IM (distributed)		690.6	74.1
	Fatigue + IM (distributed)		22.4	28.9
Exterior Girder	DC	1.33	502.9	36.6
	DW	0.21	79.4	5.8
	LL + IM (distributed)		851.7	74.3
	Fatigue + IM (distributed)		370.2	34.9

The following abbreviations in Table 7 are defined below:

- DC = Dead Load of Structural Components and Nonstructural Attachments
- DW = Dead Load of Wearing Surfaces and Utilities
- LL = Vehicular Live Load
- IM = Vehicular Dynamic Load Allowance

For the results in Table 8, the unfactored moment for the interior girders governed when two or more design lanes were loaded. However, the exterior girders governed when one design lane was loaded. The interior girder's distributed load (w_{DC}) was calculated by adding the girder distributed load and DC deck slab weight. The exterior girder's distributed load (w_{DC}) was calculated by adding the distributed loads of the girder and barrier and the DC deck slab weight.

Calculations of the DW for both the interior and exterior girders depended on the bituminous paving selected.

For the calculations, a spacing value of 7-ft (consistent with deck design) between the girders was used and the length was driven by the arranged span which has a value of 55-ft. In both cases, the equations used to calculate these values came from the *AASHTO LRFD Bridge Design Specification.*

Table 9. Calculated Factored Moments and Shears for Interior and Exterior Girders

	Limit State	**Moment (Mu, k-ft)**	**Shear (Vu, kips)**
Interior Girder	*Strength I*	1792.83	172.30
	Service II	1344.02	128.88
	Fatigue I	336.62	43.34
	Fatigue II	168.31	21.67
	Construction Strength	425.38	31.00
Exterior Girder	*Strength I*	2238.22	184.55
	Service II	1689.52	139.04
	Fatigue I	555.27	52.28
	Fatigue II	277.64	26.14
	Construction Strength	628.63	45.75

Table 9 displays the results of the factored shear and moment for both the interior and exterior beams. For each limit state, the proper loading combination and load factors were used that followed the *AASHTO LRFD Bridge Design Specification.* Each limit state has its own unique equation in order to calculate the factored value. The limit states values for moment and shear were calculated by using the factors outlined for each equation and the DC, DW, LL, and IM values calculated in Table 8. The governing values for the factored moment and shear for the exterior girder and interior girder both came from the Strength I limit state. These absolute maximum values were used in all the subsequent design calculations. See Appendix C for calculations tabulated in Table 8 and Table 9.

5.2 Rolled W-Shape Girder Design

The dead load 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 the AASHTO HS20-26 truck design vehicle loading, with point loads and a uniform load positioned to create the maximum moment on the span. The total maximum factored moment calculated was 2238.22 k-ft, and this can be seen in Table 8. This loading was based on a 7-foot spacing between each girder. To resist this maximum moment, the *American Institute of Steel Construction* (AISC) *Manual* was used to select the appropriate rolled w-shape beam that could support the loading. An assumption that the compression flange is fully braced and the section is compact was made. The governing moment and shear, the grade of steel and the required z, were needed in order to find a trial section to satisfy these conditions. From the required z calculations, a value of z = 537in^3 was found, and a rolled w-shape member was selected that fit the requirements. A rolled beam size of W18x234 was determined to work at a spacing of 7-ft for a design span of 55ft with a total bridge span of 110ft after checking for beam moment capacity, deflection, and service live load deflection.

5.3 Built-Up Girder Design

In order to design a Built-up girder, the governing shear and moment must be used. The maximum moment calculated for the live load was due to the maximum vehicle load. The maximum moment calculated for the dead load incorporated the weight of the beam, superimposed loads, the deck, paving and sidewalk loads. The design of this type of girder followed the design example from both the *Structural Steel Design* by McCormac and Csernak and *Design of Highway Bridges: An LRFD Approach* by Barker and Puckett books. By following their approach to the process of designing Built-up girders, extensive spreadsheets were created that calculated the beam size, cover-plate size, and also included required design checks that the design needed to pass. The checks the spreadsheet includes are for $Z_{required}$, Z-section, b/t ratio for: plates, web, flanges, web compact (Case 15 AISC Table B4.1b), transverse stiffeners requirement (AISC Specification G2.3), and flange compactness (AISC Table B4.1b, Case11). In order to design the Built-up girder using the spreadsheet, an iterative process was conducted until a satisfactory girder was designed. The final built-up girder design drawing can be seen in Figure 9 along with the corresponding dimensions.

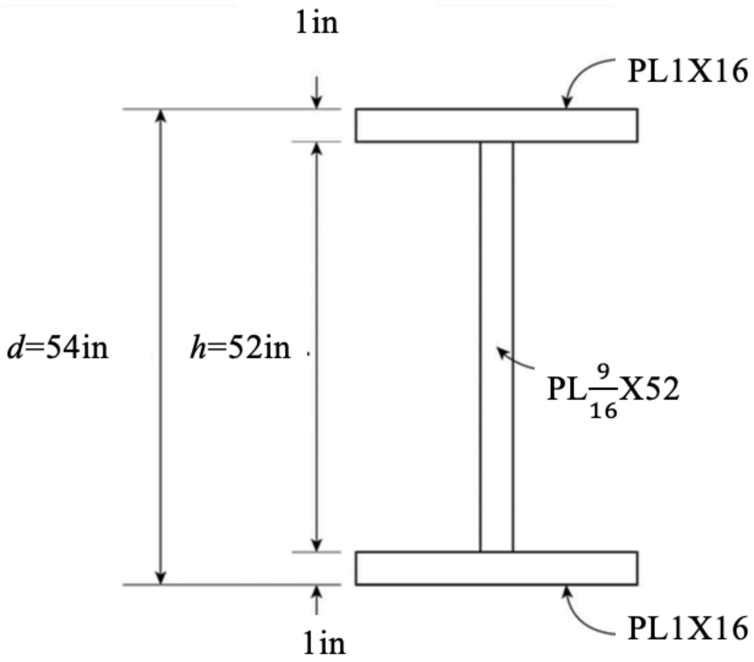

Figure 10. Built-Up Girder Design Drawing

Table 10. Girder Design Information

Height	52in
Total Height	54in
Flange Size (2)	PL1x16
Web Size	PL9/16x52
Total Area	61.25in^2
$Z_{required}$	840.84in^3
Z-section	1228.25in^3

The spreadsheet followed the LRFD method to produce the values calculated in Table 10. The Built-up girder will be welded together for construction. The design for this Built-up girder did not require stiffeners, the flanges were compact, and the Z-section value passed because it was greater than the $Z_{required}$.

5.4 Precast Concrete Girder Design

Along with the design of a compatible concrete deck for the alternative girder designs, a steel girder system, and a welded built-up girder, a precast concrete beam system was also investigated. The calculated moment and shear loads come from the loading that had the largest effect which corresponds to where the design truck was adjacent to an abutment right where the supports are located. A spreadsheet was used to aid the processes of the design of a precast concrete girder. The spreadsheet used complied with the AASHTO LRFD design criteria. It performed the stress analysis of a precast/prestressed bridge girder. By inputting the design values and data, the spreadsheet is able to size the girder and determine the amount of prestressing steel.

The design tab in the spreadsheet has a section “Preliminary Design of Prestressed Precast Concrete Bridge Girder with Cast-In-Place Concrete Composite Deck” that allows the user to input data values specific to the bridge design investigating. The values that can be input into the spreadsheet are for material properties, geometry, precast girder properties, loads, live load distribution factors, prestressing, and stress check. The input data values used in the spreadsheet were taken from the already developed and calculated general section, bridge information and geometry, and deck properties of the bridge design. The final design dimensions for the precast girder drawing can be seen in Figure 10 along with its corresponding dimensions.

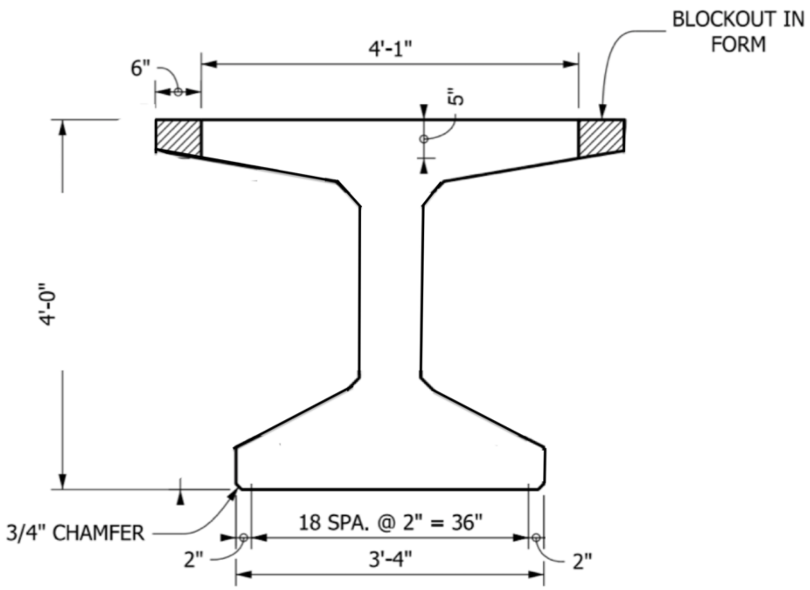

Figure 11. Precast Bulb-Tee 48 Girder Drawing

Table 11. Property Values for Selected Bulb-Tee (BTEE-48)

Section Properties for BTEE-48	**Values**
Height (in)	48
Area (in^2)	548
I_x (in^4)	173,198
Y_t (in)	24,450
Y_b (in)	23,550
S_t (in^3)	7,084
S_b (in^3)	7,354
B_{Top} (in)	49

Table 11 shows the section properties for the selected Bulb-Tee that passed all the required stress checks. When using the spreadsheet to find a Bulb- Tee section, the first step was to define a precast girder geometry. After this was completed, the next thing to do was to enter the properties of the bridge geometry and calculated properties in the spreadsheet data rows. Finally, the last step was to enter the required bridge parameters for the design on the data sheet. These steps became an iterative process in the design of the precast concrete girder.

The first attempt used a precast Bulb-Tee girder, BTEE-60 but this analysis did not satisfy all the design criteria. This selection failed because of extreme fiber stresses and the stresses at the top of the concrete girder were not acceptable. Because this selection failed, another precast girder section was proposed, a BTEE-48. The BTEE-48 selection was a lighter, more shallow girder than the BTEE-60 and it passed all the required stress checks.

5.5 Evaluation of Alternatives

Table 12. Alternative Bridge Design Selections

Bridge Design Alternatives	Material	Shape	Size Selected
Option 1	Steel	Rolled W-Beam	W18x234
Option 2	Steel	Built-up Girder	See Figure 9
Option 3	Concrete	Precast I-Beam	BTEE-48

Table 12 is a summary table for the three alternative designs highlighting some key parameters of each design option. The selection of the shape and sizes were chosen based on the Precast/Prestressed Concrete Institution (PCI) and the American Institute of Steel Construction (AISC) Manual. The three design options were then compared to one another based on a variety of factors to select the final design.

5.5.1 Cost Analysis

Table 13. Cost of Alternative Girders

Alternative Designs	Unit Price Value (US Dollars)	Total Price	Adjusted Prices
Option 1	$2,904.00 per ton	$187,000.00	$215,000.64
Option 2	$3,415.00 per ton	$235,000.00	$270,000.15
Option 3	$12,000 each	$120,000.00	$138,000.00

Table 13 shows the results for the cost analysis for each of the alternative options investigated. The bridge design had two arranged spans each of 55ft with five girders for each span; therefore, each girder cost was multiplied by 10. These calculations were performed in order to get the total price of girders needed for the entire bridge span. The unit price values found in the table came from the book *RSMeans Heavy Construction Cost Data 2011.* The price values had to be adjusted in order to get accurate numbers for the current year, 2020. The inflation rate from 2011 to 2020 is 14.7%; therefore, this adjustment factor had to be considered into the total price to get a price estimate for 2020. Overall the Precast concrete (Option 3) was the most economical design while the Built-up girder (Option 2) proved to be the most expensive design.

5.5.2 Evaluation Criteria Factors

The evaluation section indicates the decision-making process that took place in order to determine the final design solution for the superstructure of the bridge design.

Table 14. Description of Evaluation Criteria

Criteria	Definition
Economic	• Cost-effective bridge designs and construction methods • Cost analysis for the three alternative designs compared • *R.S. Means Heavy Construction Cost Data* prices were used to prepare the cost estimates. o Provided representative values for material, labor, and equipment cost • Emphasis on cost being the biggest concern
Constructability	• Readily available cross-section • Standard construction Materials and practice utilized o Allows for efficient Construction • Effective project completion time • Weight of components • Fabrication Difficulties
Sustainability	• Goal is to reduce maintenance • Withstand a long service life preferred • Optimize the bridge in respect to: o analyzing the structural design, utilized material, and impacts on the society. • More favorable when resilient and sustainable towards the environment • Design with less maintenance

Table 15. Evaluation Comparison Between Girder Options

	Rolled W-Shape	Built-up Girder	Precast Bulb-Tee
Economic	0	0	1.5
Constructability	0	0	1
Sustainability	1	1	0
	1	**1**	**2.5**

For each evaluation factor, a description was developed that defined the scope and what was considered of the criterion. Definitions for each criterion can be found in Table 14. 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. A score of 1.5 was used in the “Economic” criterion section because a lower cost design tends to be more desirable.

A preliminary cost estimate breakdown was completed for all three cases. Table 13 outlines a summary of the total prices for each case. The table indicated that Option 3, the precast bulb-tee was the design lowest in cost. Throughout the design process, it had been emphasized that cost was a big concern for the project. Therefore, the decision to multiply this score by a factor of 1.5 illustrated the high importance of the criterion.

Through the assessment of different bridge construction practices, efficient project completion time was found to be an important factor. Construction is a factor that can also contribute to cost because an extended period of construction leads to higher costs in traffic management and labor, as well as an increased disruption to vehicles in the area. Prefabricated and readily available cross-sections for the member components were utilized in all cases to improve this concern. Although there was not a substantial distinction between the advantage to using a rolled beam versus a built-up girder, there was an overwhelming amount of support towards the advantages of concrete construction. Therefore, the concrete alternative, a Precast Bulb-Tee received a score of 1.

As for the sustainability criterion, steel, when compared to concrete, is the more environmentally friendly material used in bridge construction. Rolled shapes are primarily made from reclaimed steel from scrap. In addition, steel allows for cost-effective longer spans that may minimize environmental impact. Therefore, both the steel alternatives received a score of 1.

5.5.3 Final Recommended Selection

The choice of the final design, considering the above considerations, was the precast bulb-tee girder (BTEE-48). Scores from the evaluation criteria revealed that the one-span precast bulb-tee with a composite concrete deck would best meet the design project requirement and therefore be solely used for the superstructure design.

6.0 Substructure and Foundations

The substructure and foundation would be finalized after the design live and dead loads are established from the superstructure and the final design alternative is selected. The elements of the substructure include the design of an abutment and piers. This section provides a discussion of the design considerations for these elements.

6.1 Abutment Design

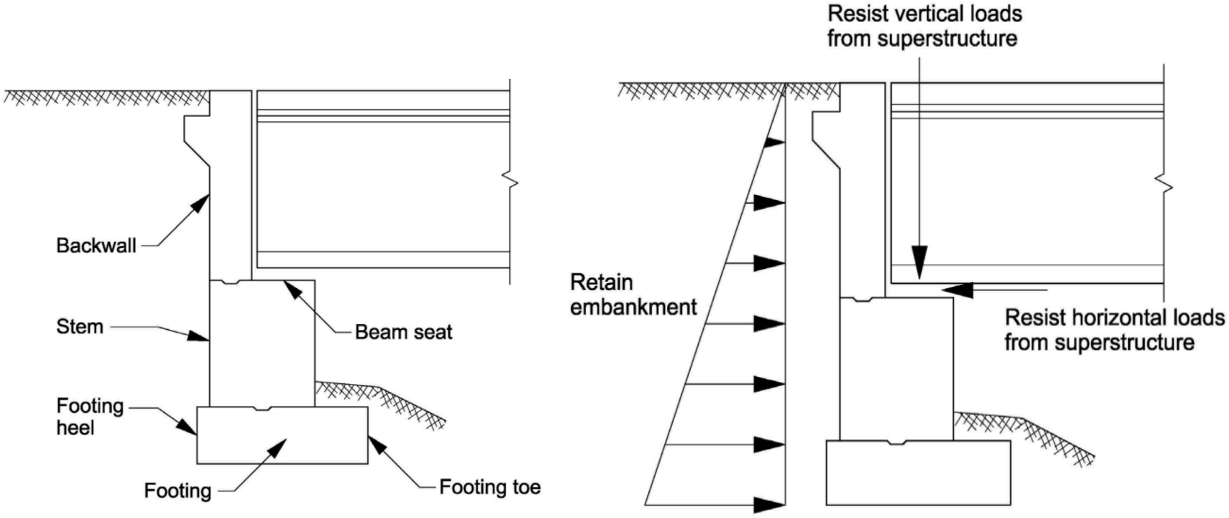

Figure 12. Abutment Components and Primary Functions (Wisconsin Department of Transportation, 2019c)

The image to the left in Figure 12 shows a breakdown of the six different elements that make up an abutment for bridge construction. To the right of Figure 12 is an image of the same abutment that displays the main loading applied to the abutment while describing some of the functions an abutment is design against. The abutment design incorporates all the components listed and must be designed to resist embankment, vertical, and horizontal loadings.

Table 16. Design Considerations for Abutments on Highway Bridges

Key Aspects	**Description**
Support	• Piles or Drilled Shafts • Spread Footings
Wing Walls	• Length • Slope • Loads • Parapets
Drainage and Backfill	• Prevention of Undesirable Loads
Design Loads	• Load Modifiers • Load Factors • Live Load Surcharge • Unit Weight of Soils • Horizontal Pile Resistance
Body Details	• Construction Joints • Beam Seats

Table 16 provides the main elements that need to be considered for an abutment design on a highway overpass bridge. The description column refers to the fundamental factors that need to be investigated when addressing the key aspect. Piles, drilled shafts and spread footings are the most common types of abutment support. The geotechnical and structural design of the abutment supports shall be designed in accordance with the *AASHTO LRFD Bridge Design Specifications*.

For wing walls, they must be designed long enough to retain the roadway embankment which are based on the allowable slopes at the abutment. The preferred slope ratio used at the abutments is 2:1. In order to design for wing wall load, they are treated and designed as if they were retaining walls. The earth loads and surcharge loads applied to the stem of the retaining wall are similarly applied to wing walls. Wing walls are evaluated like cantilevers that extend from the abutment body. At the bridge approaches a steel plate beam is typically used. In order to resist high-tension forces on the guard rail, it is important that there is enough longitudinal parapet steel provided (Wisconsin Department of Transportation, 2019c).

When analyzing the drainage and backfill, there are additional design considerations that must be applied in order to prevent undesirable loading from being directed on the abutment. Abutment drainage is necessary to prevent pressures associated with frost and hydrostatic conditions. In order to facilitate drainage within the abutment, all abutments and wing walls must utilize a backfill structure (Wisconsin Department of Transportation, 2019c).

An abutment is subjected to both horizontal and vertical loads from the superstructure. In addition, the abutment resists lateral loads coming from the backfill material plus any water that may be present. Although vertical and horizontal reactions from the superstructure are represented as concentrated loads, during the design they are distributed over the entire length of the abutment wall. Live load effects are determined by maximizing the force on the structure and multiplying it by their respective factors. The primary load factors presented in abutment design are Strength I and Service I limit states. Soil conditions like unit weight, soil properties, and friction angle determine whether a shallow or deep foundation will be adequate. If piles are used, the horizontal resistance of the piles must be verified (Wisconsin Department of Transportation, 2019c).

When designing the body sections of the abutment, it is ill-advised to use small and highly reinforced sections. In general, it is better to use more concrete and less reinforcing steel to create massive, stiff parts. Sufficient horizontal reinforcement and vertical contraction joints are essential to prevent cracking within the abutment bodies (Wisconsin Department of Transportation, 2019c).

6.2 Pier Design

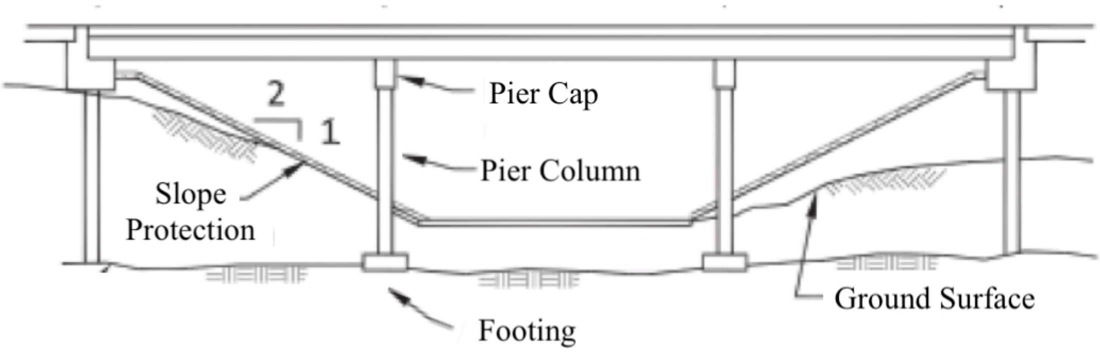

Figure 13. Pier Components (American Association of State Highway and Transportation Officials, 2015)

Table 17. Design Considerations for Piers on Highway Bridges

Key Aspects	Description
Location	• Placement of Piers Within Structure
Loads	• Dead Loads • Live Loads • Vehicular Braking Force • Wind Loads o From the Superstructure o Applied Directly to Substructure o On Vehicles o Vertical Forces • Uniform Temperature Forces • Extreme Event Collision Loads
Load Application	• Loading Combinations • Expansion Piers • Fixed Piers
Multi-Column Pier and Cap Design	• Designed Using Conventional Beam Theory
Column/ Shaft Design	• Identify Controlling Loads for Design • Column-to-Cap Connection • Column- to- Footing Connection • Cracking Control
Footing Design	• Footing Considerations for Design • Isolated Spread Footings vs Continuous Footings

Table 17 provides the major components that need to be considered for a pier design on a bridge. The description column refers to the fundamental factors considered when addressing the key aspects. Piers are an essential part of the load path between the superstructure and the foundation. Piers are designed to resist the vertical loads from the superstructure and the loads not resisted by the abutments. The piers of a bridge are designed to provide adequate bearing capacity for maximum axial loads transferred through the columns and for settlement due to sustained loads from the columns. Pier designs shall satisfy the requirements set by the LRFD method and the *AASHTO LRFD Bridge Design Specifications* (Wisconsin Department of Transportation, 2019b).

For highway structures, the spacing and location of the pier is usually controlled by the minimum horizontal and vertical clearances required for the roadway. In regards to pier loads the following should be considered in the design: dead loads, live, loads, vehicular braking force, wind loads, uniform temperature forces, and extreme event collision loads. The dead loads acting on the piers come from the reactions of the superstructure. For girder type superstructures, the live loads are transmitted to the pier through the girders. The vehicular braking force is a longitudinal force acting on the bridge. The vehicular braking force represents the forces induced by vehicles braking and can act on all design lanes. The load combinations associated with the design of wind loads on the piers are Strength III, Strength V, and Service I. Wind loads for a pier are divided into the following four types: wind load from the superstructure, wind load applied directly to substructure, wind load on vehicles, and vertical wind load. With all of these forces, the appropriate load combinations for each limit state must be applied. When determining the pier design forces, an understanding of the load paths for each load is critical. Piers are designed for the Strength I, Strength III, Strength V and Extreme Event II load combinations as specified by the LRFD method (Wisconsin Department of Transportation, 2019b).

Multi-column pier caps shall be designed using conventional beam theory. A multi-columned pier is a horizontal member supported by columns. Each of the components should be sized for function, economy and lastly aesthetics. The maximum column spacing on pier frames is 25ft. Column height is determined using the bearing elevations, the bottom of footing elevation, and the required footing depth (Wisconsin Department of Transportation, 2019b).

For the design of the Column/ Shaft an analysis procedure must determine the axial loads as well as the longitudinal and transverse moments acting on the column. These forces tend to be the largest at the top and bottom of the column. The column-to-cap and the column-to-footing connection are designed as rigid joints and must consider axial and bending stresses. All pier columns designs are required to be considered for cracking control (Wisconsin Department of Transportation, 2019b).

When designing the footing for a multi-columned pier there are a variety of important concepts that need to be considered. For multi-columned piers, each footing for a given pier should be the same dimension along the length of the bridge and should be the same thickness. However, each footing for a given pier does not need to be the same width, have the same reinforcement, or same number of piles. The design of footings requires a critical section to be determined and then the loads are applied. The transverse and longitudinal faces of the footing are analyzed to determine the proper amount of reinforcement. Spread footings and pile footing are designed using the LRFD strength limit state loads and to resist for moment and shear. The spread footing is proportioned and designed so that the foundation bearing capacity is not surpassed, whereas the pile footing is proportioned so that when the footing is loaded with the strength limit state loads, the factored pile resistance does not become exceeded (Wisconsin Department of Transportation, 2019b).

7.0 Conclusion

Throughout the design of the vehicular bridge, many considerations were kept in mind during the design such as: ethical, economic, sustainability and constructability concerns. Any ethical considerations were addressed by referring to ACI, ASCE Code of Ethics, and AASHTO requirements for bridge design. Economic considerations involved different approaches that minimized the amount of material needed and finding the most cost-effective girder design. Constructability was considered primarily through the dimensioning of the substructures. This incorporated designing the substructure to the nearest 0.5 foot and using readily available cross-sections for the girders. The design was governed by *AASHTO LRFD Bridge Design Specifications* and complied with the MassDOT and FHWA, which was consistent with all of the design components. The design of the proposed bridge included a completed deck design analysis, beam design analysis to determine the governing moment and shear, three alternative girder design options, an evaluation of the designs, an initial cost analysis, and finally a substructure assessment.

7.1 Summary and Recommendation

In this project a preliminary bridge design plan for a two-way highway overpass, which would be placed over a six-lane highway, was developed. It was determined that a concrete bridge, a precast Bulb-Tee 48, would satisfy the purpose of this project. The final design of the superstructure was established to support the design dead loads and live loads described by the *AASHTO LRFD Bridge Design Specifications*. The initial investigation to calculate the maximum moment and shear formed both steel and precast bridge designs options. In addition, a load study was conducted for AASHTO LRFD lane load, HS20-26 truck, HS20-30 fatigue, and tandem loads. These loads studies were performed on RISA-3D and were based on moving loads. The truck moving load was determined to be the governing load pattern for the highway overpass. The dead load 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 the AASHTO HS20-26 truck design vehicle loading, with point loads and a uniform load positioned to create the maximum moment on the span. The total maximum factored moment calculated was 2238.22 k-ft.

The completed superstructure design includes size and spacing recommendations for the proposed concrete bridge. The design of the superstructure was accomplished through an iterative process using Risa-3D and Microsoft Excel spreadsheets to investigate multiple cross-section dimensions for the different girder selections (W-shape, Built-up, Bub-Tee). The different girder options were evaluated to determine the final design solution for the superstructure of the bridge. A preliminary cost estimate breakdown was completed for all three cases to be used as an additional measure. The main evaluation criteria were based on: economics, constructability, and sustainability. For each evaluation criteria factor, a description was developed that defined the scope and what was considered of the criterion. A comparison amongst all cases was conducted and a girder option was determined. The final design was evaluated based on a set of established criteria and a cost analysis.

The overall purpose of this report was to compare three different alternative girder designs on the bases of constructability, sustainability, and economics. Extensive background research was developed for each bridge component in addition to the mentioned comparative measures. Ultimately the most appropriate, cost-effective cross-section was selected and used to develop the rest of the superstructure and substructure design. The bridge design chosen was the one with the precast bulb-tee girder (BTEE-48), estimating a total girder cost of $130,000.00. The evaluation criteria revealed that the one-span precast bulb-tee with a concrete deck would best meet the project requirement and therefore be exclusively used for the design of the superstructure.

7.2 Future Work

Following the completed design of this highway bridge overpass, there are some additional factors that could be studied to advance the analysis of the bridge design. One aspect is to consider the study of the stringer loads as a function of the bridge design. The deck is generally connected to the supporting stringers or girders. Stringers carry the load from the deck slab, and distribute the loads that act on the bridge along the bridge's cross-section (Tonias, 1995). The stringers then transfer the loads to the substructure. This distribution of load transfer allows for extra load-carrying capacity. Throughout the design, girder options were analyzed as individual members. A more accurate analysis of the load distribution would consider the stiffness of the various superstructure components, including the slab, the girders, and cross-frame members (diaphragms).

In addition, one might consider assessing the construction timeline for the bridge, as well as the overall project cost. For the project cost, a fully developed cost analysis should be reassessed for the entire bridge structure to get a gage of the total cost of the proposed design. For future applications, Accelerated Bridge Construction (ABC) is one of the fastest growing divisions of bridge construction. Any method of improving construction at slight minor cost must be considered. The application of ABC construction is a significant consideration for any bridge design or bridge construction and replacement that provides adequate space on a major highway overpass crossing.

Additionally, an analysis on the center joint could be performed as there are numerous problems associated with them such as drainage and expansion concerns. Bridge joints play a crucial role in design. They allow the superstructure to expand and contract as it experiences repeated variations in thermal energy. These types of “joints notoriously suffer wear and tear as a result of being subjected to thermal movements, traffic impacts, freeze thaw cycles and various weather conditions” (Civjan, 2016). If for any reason the joints stop functioning properly this causes the elements below the joints to become exposed to water and salts. The damage cause by the exposure can lead to costly repairs and replacements of the superstructure and substructure elements. Because of this, analyzing and understanding the effects of bridge joints is important to prevent failure, additional maintenance problems and cost, and education in the bridge’s service life.

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Appendix

Appendix A: Proposal

Comparative Structural Bridge Design

A Major Qualifying Project Proposal
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the
degree of Bachelor of Science

By

Alejandra Santos Olivarez

Date:
06 December 2019

Report Submitted to:

Professor Leonard D. Albano
Worcester Polytechnic Institute

Capstone Design Statement

The Major Qualifying Project will satisfy the Capstone Design requirements for the Civil Engineering major. The capstone design requirement will follow the Accreditation Board for Engineering and Technology (ABET) guidelines to show the ability to be able to design a structural system that incorporates engineering standards and realistic, real world constraints. The design constraints that will be considered within this project include constructability, economic, sustainability, health and safety, and ethics. By meeting these constraints, the design project will satisfy the requirements for the Capstone Design Experience.

1. Constructability

Constructability will be considered throughout the design of the project to compare the three alternative designs. Two designs will use steel while the other will use precast concrete. The bridge design will rely on the use of standard structural steel and concrete members. Constructability will be addressed in this aspect by using readily available cross-sections for the members. In addition, in regards to construction, standard construction materials and practices will be utilized to promote efficient construction.

2. Economic

Economic factors will be considered when developing the design in order to determine the more financially affordable alternative. Although there is not a specific budget, the cost of the designs will be a consideration to help determine the more favorable option. Cost-effective bridge designs and construction methods tend to be more favorable. The project will consist of conducting a cost analysis for the members of each bridge design. The construction cost of the three alternative designs will then be compared, and the most cost-effective designed will be identified. To provide representative values for material, labor, and equipment cost the *R.S. Means heavy Construction Cost Data* prices will be used to prepare the cost estimates.

3. Health and Safety

Health and safety is a priority, especially during construction. This bridge is going to be developed by following the American Association of State Highway and Transportation Officials AASHTO LRFD design process. The safety of the design will be ensured by abiding to these guidelines. This guide uses load and resistance factors to ensure the design of a stable bridge with ample strength is met. The design will account for worst-case scenario loading cases to ensure there is no bridge failure during its design life that may endanger the public. By abiding to these specifications, the resulting design alternatives will not impose a high level of threat to human life.

4. Sustainability

Sustainability requires the design to meet the needs of the present without jeopardizing the future needs (International Institute of Sustainable Development 2019). Once the structure is built and in use, the goal is to reduce maintenance. The designs will be created with the intent to withstand a long service life and to be adaptable to changes. The bridge design will be created with the purpose that the design could be implemented in many locations over a highway. When designing a civil infrastructure the goal is to try to optimize the system. The optimization of the system is in respect to analyzing the structural design, utilized material, and impacts on the society. These aspects make the bridge design more resilient and sustainable towards the environment.

5. Ethics

Ethics play an important role in the responsibility to abide by governing standards. These standards guide engineers to follow the design process in a certain way. The American Society of Civil Engineers (ASCE) Code of Ethics will be followed throughout the project. This code of ethics is a model used for professional conduct and will be referred to when designing to make sure everything is done properly. This code makes sure that the designers conduct each design step methodically, ensuring that no shortcuts are taken to save time and money. This design process will uphold professional honor and provide adequate designs. There are many ethical factors that are going to be considered when developing the bridge designs. The most applicable and highly important guide from the Code of Ethics is "Hold Safety Paramount". This code of ethics ensures that the design of each alternative places the health, safety, and welfare of the users of this bridge infrastructure as a top priority **(**Code of Ethics**)**.

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1.0 Introduction

Bridges play a crucial role within the highway and transportation systems in the United States. There are over 590,000 highway bridges in the United States, most being owned by state or local government institutions. According to the Federal Highway Administration , there are over 200 million trips taken in metropolitan areas over structurally deficient bridges. In the US, about 25 percent of bridges are 20 years old. Bridges are an expensive, major and growing investment that must be carefully designed, especially for a transportation system. Bridge structures must be designed properly to withstand the loadings they're subject to in order for them to have a long service life. Bridges do not just appear. These structures must be planned and engineered before constructed. Bridges must first be designed properly, later the structure is built, and then the bridge has to be maintained for its entire service life **(**Memmott, 2017**)**.

Bridges provide a means for easy travel and are important structures in any society. Bridges provide direct links and connections across natural obstacles, neighboring towns, and passages over highways. Therefore, bridges are key elements in highway and transportation networks. Because of this, it is important that they are structurally sound, and that they do not collapse or go out of service for any reason. This would not only threaten human life due to the danger associated with a collapse, but it would also have severe financial implications. The financial implications are in regards to both the bridge itself and the loss of an important travel route to product distributors and travelers. To assure the quality of bridges, engineers have studied their behavior and developed guidelines for designing and structurally constructing them. These guidelines have been made available by the American Association of State Highway and Transportation Officials (AASHTO) (Barker & Puckett, 2013).

Highway bridges are essential components of modern infrastructure. With the growing industries of bridge infrastructures and the need for bridge upgrades and maintenance, engineers are in demand. For this project, three alternative designs were analyzed and compared. The project will compare the designs of a steel and concrete girder bridge system and their components while fulfilling the Capstone Design Experience. These bridge systems were evaluated based on a set of established evaluation criteria. These criteria include an engineer's analysis of cost estimates and constructability for ethical design. The criteria mentioned are to be analyzed to bring conclusive results for the alternative designs.

This project will study the basic design of a bridge, particularly a highway overpass. This type of bridge is one of the simplest to design and was a good starting point for a young bridge engineer. To complete the design of a highway overpass requires extensive background research. This research provides one with the tools necessary to get an education on bridges and the opportunity to gain hands-on experience with bridge design. Specifically the ability to learn and research bridges to make informed decisions following proper standards and limit states. The proper standards and limit states are to be met through the use of *AASHTO LRFD Bridge Design Specifications* and a series of bridge engineering handbooks and manuals.

The goal is to create a structural vehicular bridge design for a highway. The bridge overpass design will span over a 6-lane highway. The design will consist of a standard bridge overpass providing access between two levels. To support hand calculations, computer modeling programs, like Risa (3D), will be used as tools. The tools will be used to calculate design loadings, forces, and stresses. Computer modeling will also aid to calculate live, moving, and dead loads for the bridge. The bridge will be designed using three different member options:

W-shape I-beams, built-up girders, and precast girder. These different options for design will then be compared using the material steel or concrete. The steel and concrete designs for each different member design options will be compared and evaluated based on different criteria. This system will be developed in order to evaluate the three alternative bridge designs. The criteria used in the system are economic factors, sustainability, and constructability. In addition to the different member design options, designs of the bridge's deck, piers, abutments, and foundation will be made.

2.0 Background

Bridges affect people: without them travel routes would not be as direct and traveling within a region would become tedious. Bridges are used every day and have an effect on people whether they use them to get to work or travel. Bridges are very important structures to everyday life and society. It is important that they are structurally stable, and that they do not collapse or go out of service. If bridges are not designed properly, safety for the people becomes a problem. Without proper design, bridges threaten human life due to the danger associated with a collapse.

2.1 Design of Highway Overpass

In order to start the design process for a bridge, prior research and identification of different components of a typical highway overpass must be completed beforehand. Along with the components of a highway overpass, investigation of the site design, constructability, and cost all influence the design process. Factors such as serviceability will also be considered when assessing bridge options (American Association of State Highway and Transportation Officials, 2004) .

The function of the bridge also plays an important role in how the structure will be designed. The function, a highway bridge overpass, will determine the design loads and provide an idea of how much support the bridge will require. In the design process, strength is always a major consideration followed by measures to prevent deterioration. Bridge preservation is used to slow down and prevent deterioration. Some prevention measures include preventive maintenance (PM) and cyclical maintenance activities. PM prevents deterioration for highway bridges by applying a cost-effective treatment to various bridge elements, whereas cyclical maintenance performs various activities in intervals that aim to preserve highway bridge elements. Some examples of cyclical maintenance activities include bridge cleaning and or washing of the substructure and superstructure elements and applying deck sealers (Ailaney, 2018).

Another important aspect of bridge design is the span length. Bridges are generally classified by span type such as simple span, rigid frame, cantilever, and so on. Once the bridge is classified by span type, it can also be classified by length. A small-span bridge will be less than 50ft (15m), a medium-span bridge goes up to 250ft (75m), and a large-span bridge ranges from 150ft to 500ft (50m-150m). Any bridge structure with a span over 500ft (150m) is classified as having an extra large span length. Depending on the required loading and moment, different materials and shapes can be used to design the bridge. For example, a simple span bridge will have different requirements than a continuous span bridge. Therefore, different materials and shapes are used depending on the type. The *PCI Design Manual* and *AISC Steel Manual* have design charts to aid in the selection of beam shapes that satisfy loading requirements (Barker & Puckett, 2013).

2.2 Girder-Bridges

The selection of a bridge type involves the consideration of a number of different factors. In general, the factors are related to function, economy, safety, construction experience, traffic control, soil conditions, seismicity, and aesthetics. The type of bridge selected often depends on the horizontal and vertical alignment of the highway route and on the clearances above and below the roadway. In the selection of a bridge type, there is no unique or “right” decision. For each span length range, more than one bridge type will satisfy the design criteria. Factors that help determine bridge selection stem from regional differences and preferences. Regional differences and preferences will help determine a bridge selection because of available materials and resources, skilled workers and knowledgeable contractors, economy, and safety (Haskins, 2015).

Girder bridges, in the United States, are generally the most common type of highway bridges. Girder bridge's contribution to the transportation system often goes unrecognized. These bridges can be found on almost any interstate highway and are important structures because they are used so frequently. In addition, girder bridges have great stiffness and are less subject to vibrations. Girder bridges are most commonly used for straight bridges that are 33-650 feet (10-200m) long, such as light rail bridges, and pedestrian and highway overpasses. However, the spans of girder bridges seldom exceed 500 ft (150 m), with a majority of them being less than 170 ft (50m). When selecting bridge types, for short and medium spans the difference in material weight is small, therefore, girder bridges are a competitive selection when it comes to these span lengths. Some of the early girder bridges, with multiple short spans and deep girders, were not very attractive or aesthetically pleasing. However, with the arrival of prestressed concrete and the development of segmental construction, the spans of girder bridges have become longer and girders more slender. In the construction of the interstate highway system, girder bridges have been and continue to be built adding to the growth of the transportation system (Haskins, 2015).

2.3 Bridge Structural Components

An understanding of a bridge's components is necessary for an effective design. Bridges can be separated into two structural components: the superstructure and substructure. These two sections need to be assessed and designed for structural purposes. The superstructure is comprised of all portions of the bridge above the substructure, as modeled in Figure 1. The substructure supports the superstructure. Each of these components is dependent upon the other in terms of loading and geometry. When designing each of the structural components, the other must be taken into account.

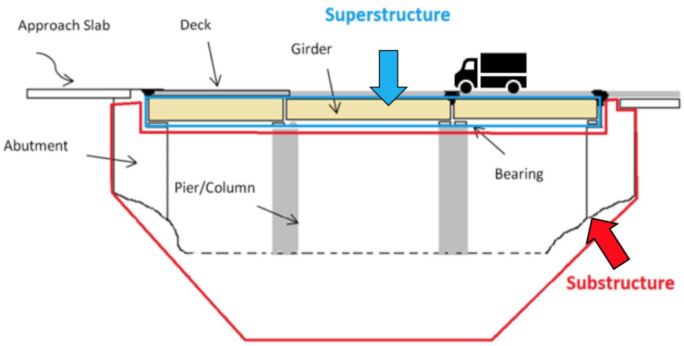


Figure 1. Major Bridge Components (Bektas, Carriquiry, & Smadi, 2013)

2.3.1 Superstructure Elements

The function of the superstructure is to collect live and traffic loads and transfer them into the substructure. The main components of the superstructure are the deck, girders, the primary members, and the secondary members. The purpose of primary members are to carry the principle live loads from trucks, whereas for secondary members its purpose is not to carry the traffic loads. Typically primary members consist of girders, stringers, trusses, etc. and secondary members can be diaphragms, lateral bracing, pin and hanger assemblies, etc. These elements are the most visible part of the bridge structure and are located above all the supports. When designing one aspect the other elements of the superstructure must be considered.

2.3.1.1 Deck

Bridge decking provides a riding surface for the traffic utilizing the bridge. The deck is responsible for transferring the live and dead loads of the deck to the underlying bridge components. Decks are generally designed using reinforced concrete. The advantages a concrete deck provides is strength and it allows for the bridge to have a smooth riding surface. The deck of a bridge must be designed to satisfy the following limit state requirements: service, strength, fatigue, and extreme events. The requirements specified for these limit states are to meet specifications found in the AASHTO LRFD sections. The traditional design method of deck design is based on flexure. Therefore, in the design method the mode of failure is due to flexural failure. In the design method, the reinforcing steel normal to the supporting girders is considered to be the primary reinforcement. The areas of the primary reinforcement are computed based on the design moments. The reinforcing steel in the other direction are the distribution reinforcements. The areas of the distribution reinforcement are computed based on a specified percentage of the primary reinforcement area (Baker & Puckett, 2013).

In accordance with the *AASHTO LRFD Bridge Design Specifications* all decks must be made composite with supporting components. The only exception to this specification being wood and open grid decks. Composite action is beneficial because it enhances the stiffness of the superstructure, improves the economy of the bridge, and prevents vertical separation between the deck and its supporting components. A primary function of the deck is to provide a safe and supportive riding surface, therefore, deck drainage has to be considered during the design of the deck (U.S. Department of Transportation, 2015).

Deck drainage is an important aspect that should be designed with care and detail. If it is not, the deck joint regions can be affected by the insufficient deck drainage causing deterioration due to excessive water. In addition, it is important to consider deck appurtenances in design. Appurtenances are located along the edges of the bridge and are generally made of concrete. They are utilized primarily to safely direct traffic through the bridge. The deck appurtenances should be considered for service and fatigue limit states, and be disregarded for strength or extreme event limit states. This is because of the damage inflicted on the deck appurtenances due to vehicular collisions (U.S. Department of Transportation, 2015).

When designing concrete deck slabs and appurtenances, reinforcement is required generally in the form of steel reinforcement bars. When using steel reinforcement bars it is important to consider methods of corrosion resistance because steel reinforcement degradation is one of the main causes of poor deck performance. The minimum concrete depth and cover for deck design is specified in the AASHTO LRFD. Additionally, edge supports must be provided along the edges of the deck. The edge support may be either an edge beam or an integral part of the deck, such as a structurally continuous barrier. The deck haunch is another factor considered in the design of the deck. The deck haunch is generally the area between the girder and the bottom of the concrete deck. In the case of steel girder bridges, the haunch is typically the distance from the top of the girder web to the bottom of the concrete deck. For concrete girder bridges, the haunch is the distance between the top of the girder and the bottom of the deck. When setting the haunch depth, it is important to consider all variations in the flange thicknesses, deck cross slope, and forming method (U.S. Department of Transportation, 2015).

2.3.1.2 Primary Members

The primary members of the bridge are responsible for distributing the loads from the bridge deck longitudinally to the supporting piers and abutments. The primary members are designed to resist flexure. These members are the most noticeable element of a highway overpass. The primary members are the girders that run below the bridge deck. These girders are typically made of structural steel or concrete. The most common type of steel girder is the rolled beam. A stringer is a horizontal member used to connect upright members. There are many different types of stringers starting with the difference between steel and concrete stringer. Both steel and concrete have many different designs of stringers that are used for specific purposes depending on span length (Tonias, 1995).

2.3.1.2.1 Girder

A girder bridge is a common type of bridge where the bridge deck is built on top of supporting beams. The supporting beams are placed on piers and abutments that support the span of the bridge. The types of beams used for girder bridges are usually either I-beam girders or box girder beams that are made of steel or concrete. There are four types of girder bridges each classified depending on the construction material and type of girders used. A rolled steel girder bridge is built using I-beams made from prefabricated steel, while a plate girder bridge is constructed by welding flat pieces of steel together on-site to make the I-beams. A concrete girder bridge is constructed using concrete I-beam girders that can be made from various kinds of reinforced concrete. The various types of reinforced concrete include pre-stressed concrete and post-tensioned concrete. The last type of girder bridges is known as a box girder bridge. Box girder bridges can be made from either steel or concrete, and they're used to support the bridge deck (Haskins, 2015).

Whether an I-beam girder or box girder is used to construct a girder bridge depends on various factors. It is easier and inexpensive to build and maintain a girder bridge using I-beam girders. However, these girders do not always offer sufficient structural strength and stability if the bridge is very long or the bridge span curves. The span of the girder bridge, if long or curved, is subjected to sensitive twisting forces or torque. Box girders are preferred for bridges with more lengthier and curvy spans. The concern with box girders is corrosion. Concerns have been raised about this because if rain water seeps into the open space inside the girders, corrosion is a possibility (Haskins, 2015).

2.3.1.2.2 Prestressed Concrete Girder

Prestressed concrete bridges have become popular structural system for bridge design because they offer additional structural advantages of durability, fire resistance, deflection control, and other redundancies. The prestressed concrete girder is generally a popular choice for a highway overpass design. Prestressed concrete is favorable due to economical reasons, the ease of construction, their high strength, efficient assembly, and physical properties. Prestressed concrete girders are able to span long, continuous spans while not giving up much depth. These girders come in two different shapes, an I‐girder and a T‐girder. The design of prestressed concrete, which are AASHTO standards, depending on the size needed, have specified locations and numbers for pre‐stressing strands (Tonias, 1995).

There are two main types of prestressing systems for concrete girders. The first is a pre-tensioning system where steel strands are subjected to tension before the concrete is placed. The second type is a post-tensioning system. In this case, the steel is not put through tension until after the concrete has been placed and has gained sufficient strength. Prestressed concrete has both high tensile and compressive strengths because of the combination of concrete and steel in the member (Tonias, 1995).

2.3.1.2.3 Rolled Beam

The rolled beam is a type of steel beam formed when hot steel is sent through a series of rollers to give the beams the distinct I-shape. These beams are referred to as I-beams because of the geometry the beam forms. The most common rolled steel beam for primary members is the wide‑flange beam. Wide‑flange beams come in a wide variety of sizes with known physical properties. When utilizing rolled beams a cover plate is generally added to the bottom flange of the beam to increase the flexural capacity of the member, allowing for a smaller, more economical beam to be used in the design process. The disadvantage of adding a cover plate is they put a large amount of stress on the ends of the plate, which could eventually lead to damage due to fatigue (Tonias, 1995).

A type of rolled beam is a hot rolled steel I-beam. This type of beam requires that the steel be rolled to its size while still hot, at a temperature over 1700 °F (926.7 °C). Because of this, the size of the steel isn’t always as precise as with cold rolled steel. However, hot rolled steel still has many advantages over colled rolled steel. Hot rolled beams are commonly used in highway overpass bridge designs and are less expensive compared to cold rolled steel I- beams. Hot rolled steel members come in a variety of different sizes and shapes, are easily assembled on site by either welding or bolting, and are very strong in tension. However, there are disadvantages in using hot rolled steel. A major drawback is that hot rolled steel, like all steel beams are susceptible to rust. Rust proofing coatings can be used to prevent rusting, but this has to be maintained otherwise the service-life of the bridge will shorten. Another disadvantage of using steel girders is site design and storage. The steel girders have to be shipped to the site from a fabrication plant and because of this there has to be space on site. The space is needed in order to work on the members before they are put in place (Tonias, 1995). In the case of structural steel members, there are many uncertainties. These uncertainties exist in the material properties, cross-sectional dimensions, fabrication tolerances, workmanship, and the equations used to calculate the resistance (Baker & Puckett, 2013).

2.3.2 Substructure Elements

The substructure is the foundation section of the bridge. The substructure of a bridge supports all the elements of the superstructure. It allows loads from the superstructure to be transferred to the underlying soil or rock. The design of the substructure is greatly influenced by the superstructure elements. The substructure consists of different elements. The elements found in this section are the bearings, piers, abutments, and the foundation (Rossow, 2005).

2.3.2.1 Bearing

Bearings may be small but are an important element in design. The bearings allow for translational and rotational movement in both the longitudinal and transverse directions. Bridge bearings provide an interface between its superstructure and substructure. The primary function of a bearing is to transmit loads from the superstructure to the substructure. The loads from the superstructure are transferred to the bearing plates which then transfer the loads to the foundations (Chen & Duan, 1999).

Bearings connect the girders to the piers and abutments to transmit loads. Bearings are subjected to a variety of forces such as the superstructure self-weight, traffic loads, and environmental loads. Translational movements are caused by shrinkage, creep, and temperature effects, while rotational movements are caused by traffic loads and uneven settlement of the foundations. When selecting a bearing it is important to consider the maximum load capacity in addition to the bearings' ability to resist translational and rotational forces (Rossow, 2005).

There are two primary categories of bearings, fixed and expansion bearings. The principle difference between the two is fixed bearings restrict translational movements whereas expansion bearings allow for both translational and rotational movements. These different types of bearings have comparatively different loading capacities, therefore bearings need to be routinely inspected to ensure they still work for their intended purpose (Rossow, 2005).

Within the two categories of bearings, there are several different types of bearings. These types can be classified as rocker bearings, roller bearings, sliding plate bearings, pot bearings, spherical bearings, elastomeric bearings, and lead rubber bearings, etc. Rocker bearings consist of a pin at its top to allow rotational movement and a curved surface at its bottom to allow translational movement of the bridge. Roller bearings are composed of one or more cylindrical rollers between two parallel steel plates. Singular roller bearings accommodate both translational and rotational movements whereas multiple rollers work only with translational movements. Single roller bearings have a low manufacturing cost but at the same time have a small vertical loading capacity. In contrast, multiple roller bearings can support large loads but in comparison are more expensive. Sliding plate bearings typically provide longitudinal movement on bridges with spans of 15 meters or less. Pot bearings are comprised of a plain elastomeric disk that is confined in a steel "pot" ring that is able to transmit translational loads. Finally, elastomeric bearings transmit both types of movement. Elastomeric bearings are made of a natural or synthetic rubber called elastomer. They accommodate translational and rotational movements through the deformation of this rubber. Elastomeric bearings are more commonly used because they are inexpensive and almost maintenance free, while still being tolerant with respect to loads and movements greater than the design values (Chen & Duan, 1999).

2.3.2.2 Piers

A pier is a structural element of a bridge located between the ends of a bridge span. The basic function of piers are to provide support to the bridge span at intermediate points between the end supports known as abutments. Piers generally consist of footings, columns or stems, and caps. Some main functions of the piers are to carry their self-weight, support the dead loads and live loads provided by the superstructure, and to transmit all loads to the foundation of the bridge (Tonias, 1995).

A pier is designed to support the bridge at intermediate intervals with minimal interference to the roadway or water traffic passing under. A pier is generally constructed with only one column and supported by one footing (Rossow, 2005). They carry vertical loads from the superstructure to the foundation and resist any horizontal loads acting on the bridge. Piers are responsible for providing support for the girders at intermediate points along the bridge, and transferring the load from the superstructure to the foundation. Even though piers are commonly designed to resist vertical loads, design precautions are often taken even further to resist lateral wind loads (Chen & Duan, 1999). The connection between the pier and superstructure is usually a fixed or expansion bearing. This allows rotation in the longitudinal direction of the superstructure eliminating longitudinal moment transfer between the pier and superstructure (Wisconsin Department of Transportation, 2019b).

Piers are generally made of reinforced concrete. However, steel tubing filled with concrete is a growing commodity. It is important to distinguish the difference between a pier and a column. Columns are utilized to resist lateral forces by flexural action whereas piers use shear action to resist the forces (Chen & Duan, 1999). All piers and abutment walls should be designed to have a suitable offset from the traveled way, with proper proportions in place between a pier and its superstructure. Piers can be designed in many different possible styles and shapes. The more favorable piers are those that have a flare, taper, texture, or other features that improve the visual aesthetics of the users who pass by. The key to pier design is that they be designed proportional with the superstructure and its surroundings (Barker & Puckett, 2013).

There are a number of different types of piers. Selection of which type of pier to use is based on aesthetics, shape of the superstructure, and how they provide limited interference to the passing traffic. The use of each type of pier is used based on different criteria (Tonias, 1995). Additionally, piers can be classified as either monolithic or cantilevered. This classification is defined by how they connect to the superstructure. A pier can also be distinguished by its column shape whether they be considered round, octagonal, hexagonal, or rectangular. Each column type having the option to be either solid or hollow. The shape of the column affects the area in which the load is distributed, and the column contributes to the aesthetic variability of the substructure. Lastly, a pier can be distinguished by its frame, single column, bent, hammerhead or pier wall (Chen & Duan, 1999).

There are many different types of piers and the selection of a specific one depends on what the bridge will be constructed of and the bridge's purpose. For concrete bridges, the typical pier types used are bents, and can be utilized for the design of precast girders and cast-in-place girders. The type of pier differs depending upon the material used for the girders because of the difference in the weights. For piers many factors are considered when selecting a type and configuration. The engineer designing this structural element should consider the superstructure type, span lengths, bridge width, bearing type and width, skew, required vertical and horizontal clearance, required pier height, aesthetics, and economic factors (Wisconsin Department of Transportation, 2019b).

2.3.2.3 Abutment

Abutments structures are the elements in bridge structure that provide vertical and lateral support at the bridge's ends supports. The vertical support is for the bridge while the lateral support is for the soil and the ends of the roadway or stream. There are a variety of abutments that can be used for bridge design. Abutments are either constructed with plain concrete, reinforced concrete, stone masonry or a combination of concrete and stone masonry. The foundation soils found at a site will determine whether abutments and piers can be founded on spread footings, driven piles, or drilled shafts. Large abutments may be needed to anchor a suspension bridge, but they are not needed for medium and short-span bridges. The preferred abutment is generally placed near the top of the bank, away from the traffic below. This abutment type is often referred to as a stub abutment. If the abutment is supported on columns or piling it is known as a spill-through abutment. This is because the embankment material spills through the piling. For a given length of an abutment, the flatter the slope of the embankment, the smaller the abutment appears to be. The preferred slope of the bank has a ratio of 1:2 or less. Proper selection of slope protection materials will give the bridge a neatly defined and finished appearance (Barker & Puckett, 2013).

There are two categories of abutments. Bridge abutments can be classified as either open-ended or close-ended. Open-ended abutments have a slope that goes from the abutment to the roadway or the river canal beneath. The bridge crosses over these and with their slopes leave space to widen the passing road below. On the other hand, close-ended abutments are constructed on the edge of the roadways or stream and are typically high vertical walls that have no slope. In comparison, open-ended abutments are generally more economical, flexible and aesthetically pleasing. Construction costs for close-ended abutments tend to run higher due to their higher walls and larger backfill area (Chen & Duan, 1999).

Abutments can also be categorized based on the connection to the bridge superstructure. The connection between the abutment is classified as either monolithic or seat-type. The monolithic abutment is usually reserved for shorter bridges. The monolithic abutment is built with the bridge superstructure leaving no displacement between the abutment and the superstructure. For this type of abutment deformations of the superstructure, such as thermal movements, must be considered in the abutment design in order to prevent cracking. Its greatest advantage in design is its lower construction costs, but it is important to consider the potential maintenance and rehabilitation costs. The seat-type abutment is constructed separate from the superstructure. For the seat-type abutments, the superstructure rests on the abutment stem through bearing pads, rock bearings, or other devices. These bearings enable the designer to control bridge displacement. This aspect makes seat-type abutments popular for longer bridges, especially those with concrete or steel girders. Although this type of abutment has a higher initial cost it has a relatively lower cost in maintenance (Chen & Duan, 1999).

The design of abutments depends upon the soil conditions at the project site. If the site is mostly hard bedrock, a vertical, close-end abutment will most likely be considered. Meanwhile, if the soil is softer, a sloped, open-end abutment will most likely be sufficient in helping counteract settlement. However, the use of sloped abutments are typically for long-span bridges and requires extra earthwork which could increase bridge construction cost (Chen & Duan, 1999).

2.3.2.4 Foundation

A foundation is constructed under the pier and abutment and over the underlying soil or rock. The loads transmitted by the foundation to the underlying soil or rock must not cause soil shear failure or excessive settlement of the superstructure. The foundations of bridges are critical. Foundations must support the entire bridge weight and traffic loads that the bridge will carry throughout its service life. The purpose of the foundation is to distribute the loads of a bridge over a large bearing area. This will provide stability to the bridge against settlement and tilting. All foundation designs must meet certain requirements in order to be designed properly. Foundations must provide adequate safety against any structural failures, provide sufficient bearing capacity to the soil beneath the foundation with a factor of safety design, and must achieve acceptable total or differential settlements under the working load (Wisconsin Department of Transportation, 2019a).

There are two types of foundations, shallow and deep. To determine the foundation type suitable to satisfy the site specific needs, assessments are made based on the requirements for the type of foundation. A shallow foundation can be determined as one in which the depth to the bottom of the footing is usually less than or equal to twice the smallest dimension of the footing (Wisconsin Department of Transportation, 2019a).

Shallow foundations generally consist of spread footings but may also include rafts that support multiple columns. Shallow foundations are typically the most economical foundation alternative, and this foundation type provides support entirely from its bases. Shallow foundations transfer loads to the ground through the use of bearing at the bottom of the foundation. The design of a shallow foundation must provide adequate resistance against geotechnical and structural failure. The design must also limit deformations within the tolerable values. Suitable soil conditions exist for this foundation type within a depth of approximately 0 to 15 feet below the base of the proposed foundation (Wisconsin Department of Transportation, 2019a).

When shallow foundations are not satisfactory, deep foundations must then be considered. Deep foundations transfer foundation loads through shallow deposits to underlying deposits of deeper bearing material. These foundation types transmit the weight of the abutment to the supporting soil or rock. Deep foundations classifications include piles, drilled shafts, caissons, micropiles, and anchors. Deep foundations have a variety of functions. A primary function is to transmit the loads of the structure through a stratum of poor bearing capacity to one of adequate bearing capacity. Additionally, the purpose of this foundation type is to eliminate objectionable settlement, transfer loads from a structure through erodible soil in a scour zone, and resist lateral loads from earth pressures, as well as external forces (Wisconsin Department of Transportation, 2019a).

All possible structural and geotechnical failure modes for foundations present during the design life of the bridge are grouped into three distinct limit states. The three limit states are service, strength and extreme events. These limit states should be checked during the foundation design (U.S. Department of Transportation, 2011).

2.4 Design Requirements and Computer Aids

The function of a design process is to produce a bridge configuration that can be justified and described to others. Computers can help aid with the analysis, design calculations, and the drawings. Drawings include computer drawn images of cross-sections, elevations, and graphics. Computer software packages can perform calculations of loads and internal forces but must be checked using hand calculations.

2.4.1 AASHTO LRFD Specification

To assure the quality of bridges, engineers have studied bridge behaviors and developed specific guidelines. The guidelines are for the purpose of designing and constructing bridges in a structurally safe manner. These guidelines have been made available by the American Association of State Highway and Transportation Officials (AASHTO). In order for an engineer to safely design a bridge, all factors of bridge design must be taken into account. The factors and the loads must be accurately determined, the materials must be carefully chosen, and the geometry of the bridge must be set. The guidelines published by AASHTO were created to design various key components of the bridge, such as the substructure and superstructure elements (American Association of State Highway and Transportation Official, 2004).

Load and Resistance Factor Design (LRFD) accounts for both load factors and resistance factors. LRFD compares the required strength to the actual strength. The purpose of these factors is to decrease the load carrying capacity calculated from the design. By using these factors, the results have a low probability of surpassing the critical level. There are many advantages and disadvantages of using this approach. Some advantages this method of design provides is that it is compatible with other design specifications such as those of the American Concrete Institution (ACI) and the American Institution of Steel Construction (AISC), and these methods are familiar to engineers and new graduates. In addition, this method provides uniform levels of safety for different limit states and bridge types. Some disadvantages found when using the LRFD method is that it required a change in design philosophy, in regards to previous AASHTO methods. Additionally, using this method requires an understanding of probability and statistics in order to make adjustments to resistance factors (Barker & Puckett, 2013).

2.4.2 Geometry Requirements

The typical lane width for a freeway overpass is 12ft (3.6m). In urban settings, a barrier must be placed in order to separate the traffic for a two-way elevated freeway. The width of the barrier is generally 2ft (0.6m). The minimum median, a reserved area that separates contrasting lanes of traffic on a divided highway, is determined by adding two left shoulder widths. Left shoulder widths are usually 4ft (1.2 m). However, the median of a four-lane highway is 10ft

(0.3m) and is 22ft (6.6m) for a six or eight lane freeway (American Association of State Highway and Transportation Official, 2004).

On interstate highways, the vertical clearance of bridge structures can not be less than 16ft (4.9m). The 16ft height clearance should span over the entire roadway width. On other urban interstate routes, the clear height cannot be designed to be less than 14 feet (4.3 meters). If these standard requirements are not met, a design exception is required. A formal design exception is required whenever these criteria are not met for the applicable functional classification. If there is a need for a design exception for an interstate highway, it must be coordinated with the Military Surface Deployment and Distribution Command Transportation Engineering Agency of the Department of Defense (U.S. Department of Transportation, 2015).

2.4.3 Design Loads and Limit States

AASHTO provides a variety of different types of loads to be considered in bridge design. These loads can be classified into two categories: permanent loads and temporary loads. Permanent loads and temporary loads are also known as dead load and live load respectively. Live loads can be divided into two categories: vehicular live loads and environmental live loads. Vehicular live loads include traffic passing over the bridge. Environmental live loads include aspects like wind loads and earthquake loads. In order to design a bridge, none of its components must fail. Therefore it is important to determine the acceptable level of risk or the probability of failure in the design. During the design process, an important goal is to prevent a limit state from being reached. This is because once a particular loading condition reaches its limit state, failure is the only assumed result. The loading condition that caused this failure to occur becomes the failure mode. Limit states for girder bridges include: deflection, cracking, fatigue, flexure, shear, torsion, buckling, settlement, bearing, and sliding (Barker & Puckett, 2013).

2.4.3.1 Limit States

The basic design expression in the *AASHTO LRFD Bridge Specifications* that must be satisfied for all limit states, both global and local, is given as service, fatigue and fracture, strength, and extreme event limit states (Barker & Puckett, 2013).

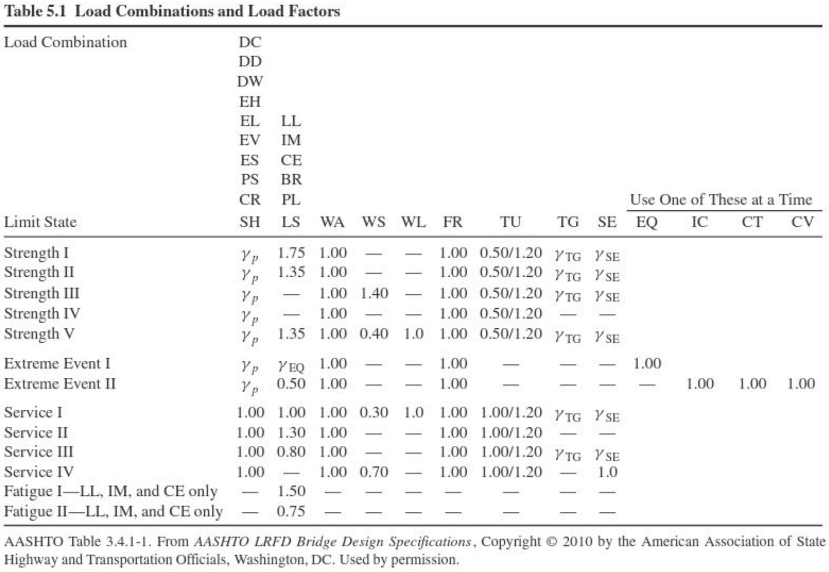


Table 5.1 Load Combinations and Load Factors

Load Combination	DC DD DW EH EL EV ES PS CR	LL IM CE BR PL								Use One of These at a Time			
Limit State	SH	LS	WA	WS	WL	FR	TU	TG	SE	EQ	IC	CT	CV
Strength I	γ_p	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}				
Strength II	γ_p	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}				
Strength III	γ_p	—	1.00	1.40	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}				
Strength IV	γ_p	—	1.00	—	—	1.00	0.50/1.20	—	—				
Strength V	γ_p	1.35	1.00	0.40	1.0	1.00	0.50/1.20	γ_{TG}	γ_{SE}				
Extreme Event I	γ_p	γ_{EQ}	1.00	—	—	1.00	—	—	—	1.00			
Extreme Event II	γ_p	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00
Service I	1.00	1.00	1.00	0.30	1.0	1.00	1.00/1.20	γ_{TG}	γ_{SE}				
Service II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—				
Service III	1.00	0.80	1.00	—	—	1.00	1.00/1.20	γ_{TG}	γ_{SE}				
Service IV	1.00	—	1.00	0.70	—	1.00	1.00/1.20	—	1.0				
Fatigue I—LL, IM, and CE only	—	1.50	—	—	—	—	—	—	—				
Fatigue II—LL, IM, and CE only	—	0.75	—	—	—	—	—	—	—				

AASHTO Table 3.4.1-1. From *AASHTO LRFD Bridge Design Specifications*, Copyright © 2010 by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission.

Figure 2. Load Combinations and Load Factors Addressing Design Situations (Barker & Puckett, 2013)

2.4.3.2 Service

The service limit state refers to restrictions on stresses, deflections, and crack widths of bridge components that occur under regular service conditions. Failure modes are related to the function and performance of the bridge under regular operating conditions. For the service limit state, the resistance factors are 1.0 and nearly all of the load factors are equal to 1.0. There are four different service limit state load combinations that address different design situations (Barker & Puckett, 2013).

2.4.3.3 Fatigue and Fracture

The fatigue and fracture limit state refers to a set of restrictions on stress range caused by a single design truck. The restrictions depend on the number of stress–range excursions expected to occur during the design life of the bridge. This limit state is intended to limit crack growth under repetitive loads and to prevent fracture due to cumulative stress effects in steel elements, components, and connections (Barker & Puckett, 2013).

2.4.3.4 Strength

The strength limit state refers to providing sufficient strength or resistance to satisfy the inequality for the statistically significant load combinations that a bridge is expected to experience in its design life. Failure modes are the collapse or damage of the bridge or its foundation under loads applied continuously or frequently during its design life. Strength limit states include the evaluation of resistance to bending, shear, torsion, and axial load. The statistically determined resistance factor will usually be less than 1.0 and will have different values for different materials and strength limit states (Barker & Puckett, 2013).

2.4.3.5 Extreme Event

The extreme event limit state refers to the structural survival of a bridge during a major event. Failure modes are the collapse of the bridge or its foundation due to events that have a return period greater than the design life. These events include a major earthquake or flood or when collided by a vessel, vehicle, or ice floe, possibly under scoured conditions. The probability of these events occurring simultaneously is extremely low; therefore, they are specified to be applied separately. The recurrence interval of extreme events may be significantly greater than the design life of the bridge. Under these extreme conditions, the structure is expected to undergo considerable inelastic deformation (Barker & Puckett, 2013).

2.4.4 Risa (3D)

RISA-3D is a powerful design tool that can be applied when analyzing structures. This computer aid program allows the engineer designing the structure to be in control of the design due to its many included features. This computer aided design software can analyze anything from a simple beam and truss to shear walls. RISA-3D includes within the program the most current steel, concrete, cold-formed steel, and timber design codes. The loads applied are specified by the *AASHTO LRFD Design Specifications*. The results from the design can be viewed graphically through shear and moment diagrams or viewed in more detail through the member details reports. The member details reports display the analysis and design calculation results for each member. In addition, RISA-3D is known for its ease of use and convenience. Loads can be easily adjusted for different loading case scenarios and coefficients can be assigned to specific loads to create multiple load cases (RISA Tech, Inc).

2.4.5 AutoCAD

AutoCAD is a computer-aided design (CAD) program commonly used for 2D and 3D drawings and drafts. AutoCAD has a variety of applications in many different fields. The software assists in the creation, modification, and optimization of designs. AutoCAD is a software that engineers and designers can use to create many different types of precise and complex drawings. This program helps create these drafts faster and more accurate than doing it by hand. These drawings can be drafted with the many included features the software provides. Drafting and designs can be customized by adding solids, surfaces, and mesh features. These features allow the engineer to make accurate drawings using real world elements and behaviors. Design drawings can also be drafted using detail components and keynoting tools. These tools AutoCAD offers aid with the annotation of drawings through the use of text, dimensions, tables, and leaders. Additionally by using these tools, properties such as size, shape, and location can also be manipulated and changed in a quick and easy manner (AutoCAD For Mac & Windows).

2.5 Cost Estimate

In determining the cost of any bridge project the initial cost of construction should be considered. The success of a project is built on being able to provide an accurate preliminary estimate for the proposed structure. A preliminary estimate includes the unit price for each item needed for a specific project. The initial cost is an essential component in comparative analysis for potential bridge design options. This is because it is important to know how much a project will cost because more economic bridge structures tend to be more favorable. The main purpose of a cost estimate is to evaluate the different design alternatives by seeing if any of them are significantly less expensive. The initial cost is something that gets bid on by different contractors. Contractors submit different price estimates per unit cost of construction items whether they be labor, material, or construction equipment. To obtain initial cost prices, one must research and gather unit prices from a number of sources. The *R.S. Means Heavy Construction Cost Data* is a useful tool to find unit prices for bridge components and materials. These cost values are needed to estimate the initial cost of the bridge. When using cost data from past years, it is crucial to adjust all prices based on inflation rates and location to have the valid prices for labor work, materials used, construction equipment costs, etc. for the current year and locale.

The *R.S. Means Heavy Construction Cost Data* book is a powerful construction tool that can be used for any structural civil project. This tool presents information on the necessary factors that go into cost estimates with quick and readily accessible key costs. The book is a comprehensive, reliable source of current construction costs and productivity rates. The prices in the construction industry are continuously monitored to ensure that accurate and up-to-date cost information is represented in the book. This tool provides a variety of useful references in order to get more accurate unit prices and results when conducting a project estimate. These references include equipment rental cost, crew listings, historical cost indexes, city cost indexes, location factors, etc. All cost values are U.S. national averages and are given in U.S. dollars. The costs in *R.S. Means heavy Construction Cost Data* are divided by material, labor, equipment, general conditions (bare cost), and overhead and profit. The bare cost is the cost that is of most importance to my project. The total bare costs consists of adding up the labor cost, equipment cost and material cost. The bare cost does not include neither overhead nor profit (RSMeans, 2011).

3.0 Methods

The purpose of this project is to provide a preliminary structural design for a highway bridge overpass. The focus will be to develop a bridge design for three different alternatives, two using the material steel and one using concrete. The development of the design for the bridge structure must use appropriate methods that align with standard engineering practices. Each bridge component must be properly designed according to certain specifications, regulations and codes. The structural calculations for the bridge components will follow the LRFD method in addition to abiding by the *AASHTO LRFD Design Specifications*. The bridge design will be compliant with these factors along with specifications regulated by the state.

Table 1 below is divided into three categories: Activity, Reference, and Comments. The activity column encompasses the necessary steps to begin the design process, the major bridge design elements, and ultimately the method that will be used to compare the alternative design options. The activities listed in Table 1 are in chronological order (Top - Bottom) based on the steps that will be followed to complete the project. The reference column lists all the outside resources that will be used to complete a specific activity. The right-most column, Comments, represent the outputs for the activities which incorporate either analysis, presentation of the activity, or both. Table 1 can be divided into three phases. The initial phase consists of design studies for alternatives bridge options considering both structural steel and precast concrete. This phase will also consist of identifying the geometry configuration, spans, spacings, and clearance for the bridge design. The second phase will consist of further developing the design focusing on the major bridge elements and design loads. These elements consist of the alternative girder designs and the deck design. The final phase of the project takes the developed designs and creates a cost analysis in order to determine the most cost-effective bridge. The bridge selected will be based on cost and real world constraints, and this bridge would then be completed furthered in regards to design. The pier, abutment, and foundation system would be developed for the selected design. The selected bridge design option will then be used to complete a full cost analysis, divided by the superstructure and substructure components.

Table 1. Methodology Process for Bridge Design

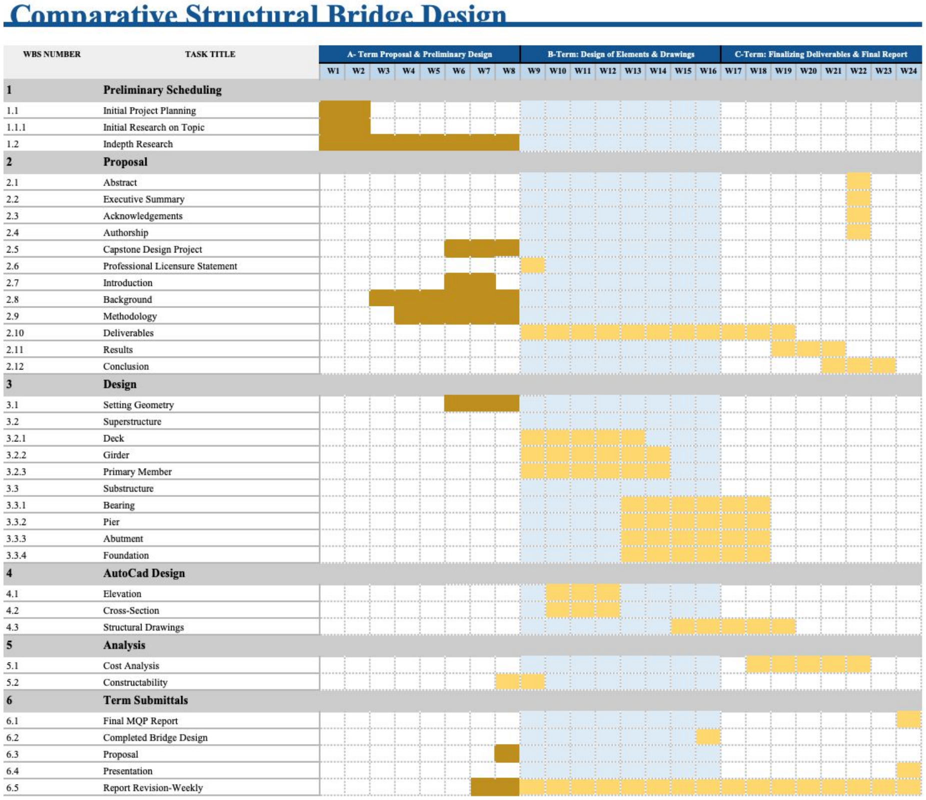
	Activity	**Reference**	**Comments**
Phase 1	**Setting Geometry**	-*AASHTO LRFD Bridge Design Specifications* -*A Policy on Geometric Design of Highway and Streets* -Massachusetts Department of Transportation (MassDOT)	-Elevation and Cross-sectional views -Top and Plain views
Phase 2	**Load Analysis** -For Key Girders	-*AASHTO LRFD Bridge Design Specification* -RISA Design Codes & Loads Applied -RISA Member Details	-Vehicle Loads -Dead Load, Live Load, Snow Loads, Wind Loads -Dynamic Loads -Load Paths -Limit States
Phase 2	**Girder Design**	-*AASHTO LRFD Bridge Design Specification* -*Structural Steel Design 6th Edition* by McCormac and Csernak	-AutoCAD Drawing -RISA moving loads to calculate and analyze for maximum moment and shear
	Concrete Girder	-Precast/Prestressed Concrete Institute (PCI)	-Precast Concrete I-Beam
	Steel Girder	-Steel Construction Manual American Institute of Steel Construction (AISC)	-Steel Built-up Girder -Rolled Steel Beam
Phase 2	**Deck Design**	-*AASHTO LRFD Bridge Design Specification*	-AutoCAD Drawing

Phase 3	**Pier Design**	-*AASHTO LRFD Bridge Design Specification* -Federal Highway Administration (FHWA)	-AutoCAD Drawing
Phase 3	**Abutment Design**	-*AASHTO LRFD Bridge Design Specification* -Federal Highway Administration (FHWA)	-AutoCAD Drawing
Phase 3	**Comparative Analysis**	*R.S. Means Heavy Construction Cost Data*	- The best, most affordable option out of the three superstructure design will be chosen -The substructure design will be based off of the substructure design chosen -Completed/Updated cost analysis for selected bridge design

4.0 Deliverables

The completion of this project will encompass a design of a highway bridge overpass. This entails a completed design of each component of the bridge's superstructure and substructure. All the design calculations for the elements will be completed by hand using the LRFD method and then reviewed by the application of RISA (3D), a computer aided design software. These design calculations will be accompanied by a series of structural drawings. The structural drawings will be of the entire bridge design and each of the components. Drawings of the bridge's cross-section and elevation will also be created. AutoCAD will be the software used to create these structural drawings. Along with this, a detailed evaluation of the alternative designs and analysis will be documented through tables. These tables involves a comparison of load types, constructability, and cost estimate for each design. These deliverables are what are expected to be submitted at the end with the inclusion of a final report and poster for project presentation day.

5.0 Schedule



Comparative Structural Bridge Design

WBS NUMBER	TASK TITLE	A- Term Proposal & Preliminary Design								B-Term: Design of Elements & Drawings								C-Term: Finalizing Deliverables & Final Report							
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24
1	**Preliminary Scheduling**																								
1.1	Initial Project Planning	🟫	🟫																						
1.1.1	Initial Research on Topic	🟫	🟫																						
1.2	Indepth Research	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫																
2	**Proposal**																								
2.1	Abstract																						🟨		
2.2	Executive Summary																						🟨		
2.3	Acknowledgements																						🟨		
2.4	Authorship																						🟨		
2.5	Capstone Design Project						🟫	🟫	🟫																
2.6	Professional Licensure Statement									🟨															
2.7	Introduction						🟫	🟫																	
2.8	Background			🟫	🟫	🟫	🟫	🟫	🟫																
2.9	Methodology				🟫	🟫	🟫	🟫	🟫																
2.10	Deliverables									🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨					
2.11	Results																			🟨	🟨	🟨			
2.12	Conclusion																					🟨	🟨	🟨	
3	**Design**																								
3.1	Setting Geometry						🟫	🟫	🟫																
3.2	Superstructure																								
3.2.1	Deck									🟨	🟨	🟨	🟨	🟨											
3.2.2	Girder									🟨	🟨	🟨	🟨	🟨	🟨										
3.2.3	Primary Member									🟨	🟨	🟨	🟨	🟨	🟨										
3.3	Substructure																								
3.3.1	Bearing													🟨	🟨	🟨	🟨	🟨	🟨						
3.3.2	Pier													🟨	🟨	🟨	🟨	🟨	🟨						
3.3.3	Abutment													🟨	🟨	🟨	🟨	🟨	🟨						
3.3.4	Foundation													🟨	🟨	🟨	🟨	🟨	🟨						
4	**AutoCad Design**																								
4.1	Elevation										🟨	🟨	🟨												
4.2	Cross-Section										🟨	🟨	🟨												
4.3	Structural Drawings															🟨	🟨	🟨	🟨	🟨					
5	**Analysis**																								
5.1	Cost Analysis																		🟨	🟨	🟨	🟨	🟨		
5.2	Constructability								🟨	🟨															
6	**Term Submittals**																								
6.1	Final MQP Report																								🟨
6.2	Completed Bridge Design																🟨								
6.3	Proposal								🟫																
6.4	Presentation																								🟨
6.5	Report Revision-Weekly							🟫	🟫	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨

Figure 3. Gantt Chart Outlining Completion of Major Project Activities

Figure 3 outlines the schedule that will be used throughout the three terms highlighting major events and end of the term submittals that must be completed. The objectives and their associated tasks are outlined to ensure the completion of each project deliverable. The Gantt Chart displays the proposed allocated time period for each task. Figure 3 points out that by the end of A-term the proposal and some elements of the design should be done, by the end of B-term most of the drawings and design aspects should be completed, and C-term will be finishing up the design aspects and writing the final report. By the fifth week in C-term, there should be no major aspect of the project being complete. At this point the project should consist of finishing and concluding the results and report.

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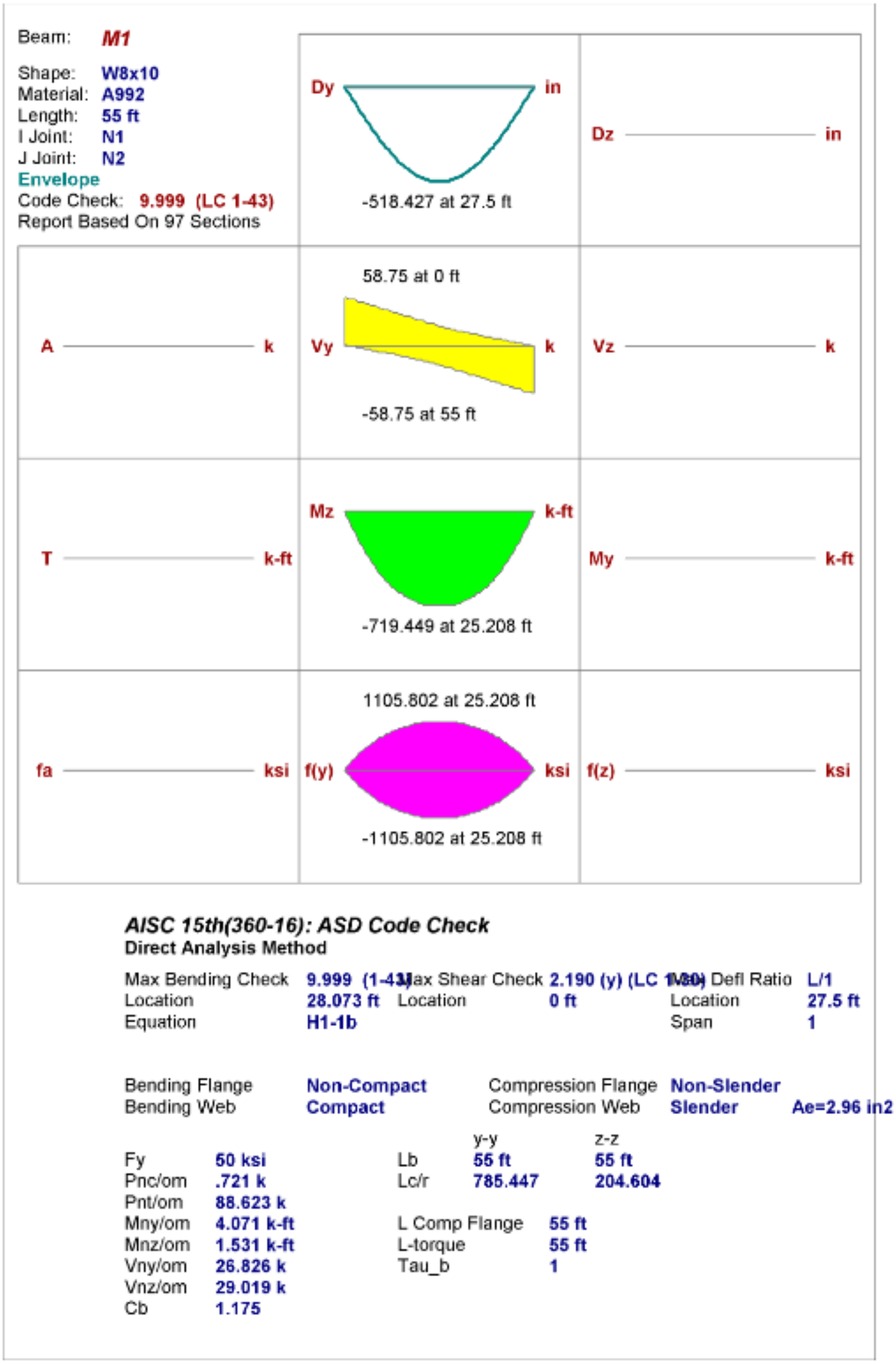
Appendix B: Envelope Results for Moving Load Analysis on RISA-3D

Truck Envelope Analysis Report



Beam:	*M1*
Shape:	W8x10
Material:	A992
Length:	55 ft
I Joint:	N1
J Joint:	N2

Envelope

Code Check: 9.999 (LC 1-43)

Report Based On 97 Sections

AISC 15th(360-16): ASD Code Check

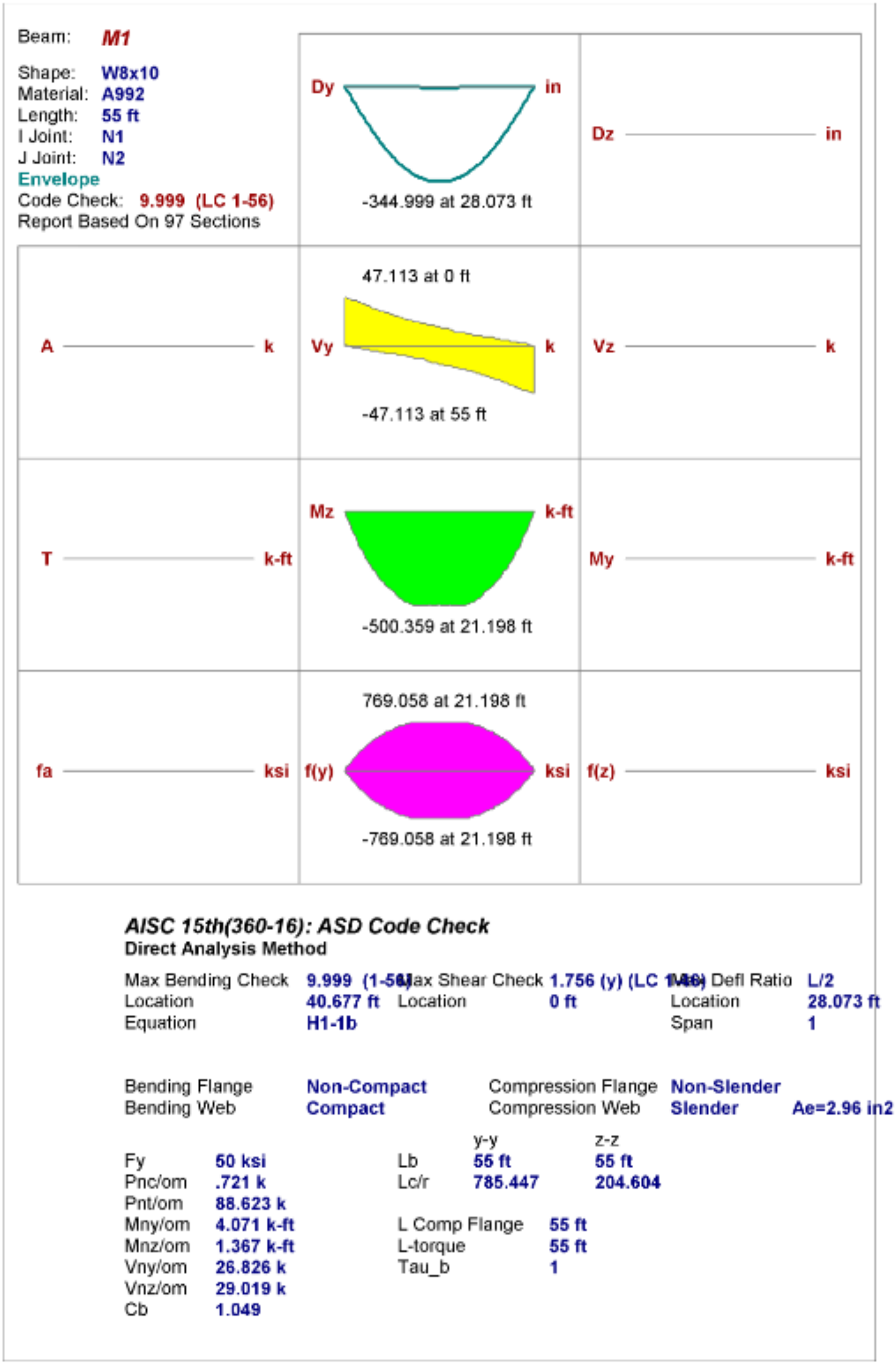
Direct Analysis Method

Max Bending Check	9.999 (1-43)	Max Shear Check	2.190 (y) (LC 1-30)	Max Defl Ratio	L/1
Location	28.073 ft	Location	0 ft	Location	27.5 ft
Equation	H1-1b			Span	1

Bending Flange	Non-Compact	Compression Flange	Non-Slender	
Bending Web	Compact	Compression Web	Slender	Ae=2.96 in2

			y-y	z-z
Fy	50 ksi	Lb	55 ft	55 ft
Pnc/om	.721 k	Lc/r	785.447	204.604
Pnt/om	88.623 k			
Mny/om	4.071 k-ft	L Comp Flange	55 ft	
Mnz/om	1.531 k-ft	L-torque	55 ft	
Vny/om	26.826 k	Tau_b	1	
Vnz/om	29.019 k			
Cb	1.175			

Fatigue Envelope Analysis Report



Beam: ***M1***

Shape: **W8x10**
Material: **A992**
Length: **55 ft**
I Joint: **N1**
J Joint: **N2**
Envelope
Code Check: **9.999 (LC 1-56)**
Report Based On 97 Sections

Dy in
-344.999 at 28.073 ft

Dz in

47.113 at 0 ft
A k
Vy k
Vz k
-47.113 at 55 ft

Mz k-ft
T k-ft
My k-ft
-500.359 at 21.198 ft

769.058 at 21.198 ft
fa ksi
f(y) ksi
f(z) ksi
-769.058 at 21.198 ft

AISC 15th(360-16): ASD Code Check

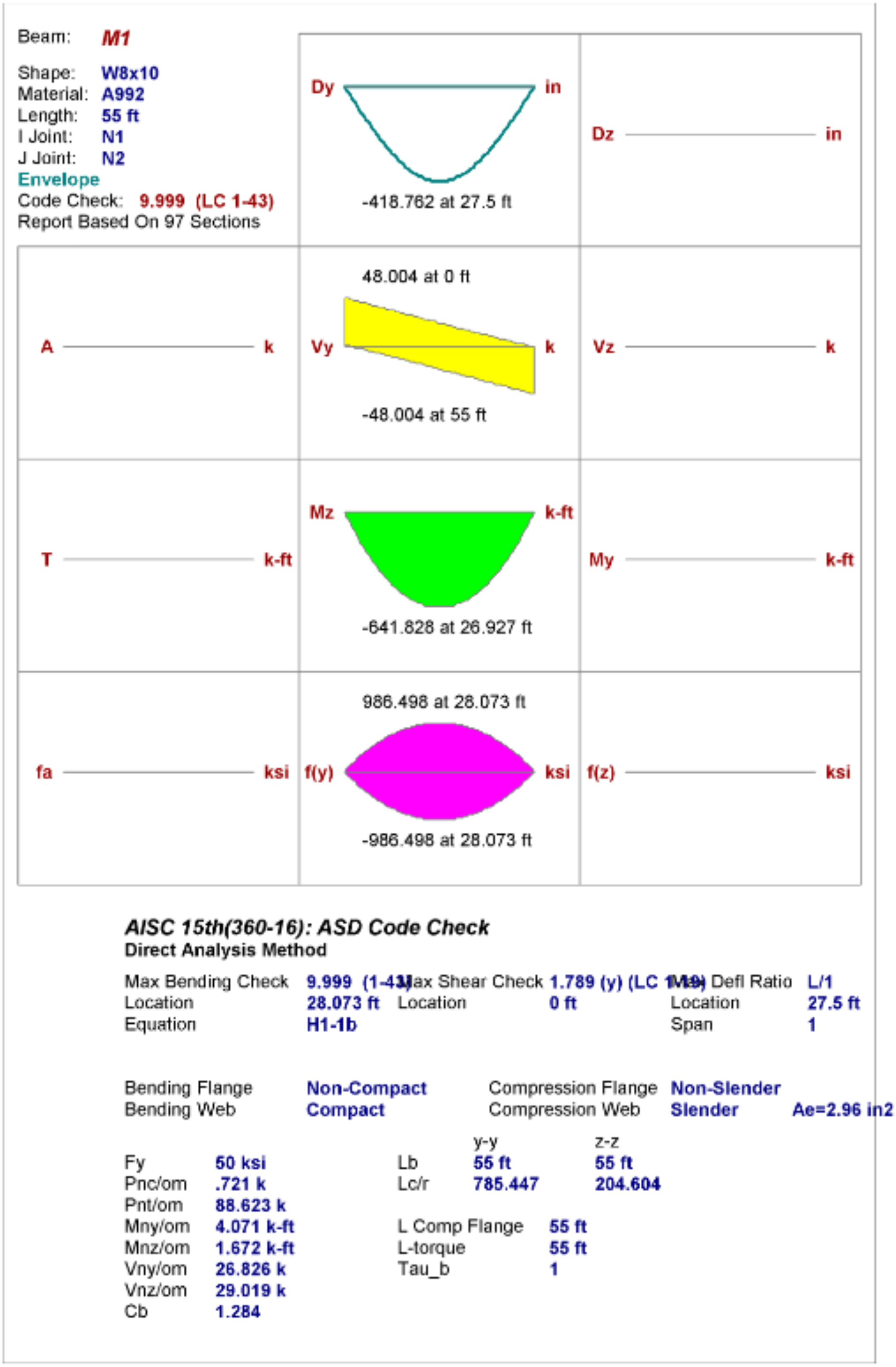
Direct Analysis Method

Max Bending Check	**9.999 (1-56)**	Max Shear Check	**1.756 (y) (LC 1-56)**	Max Defl Ratio	**L/2**
Location	**40.677 ft**	Location	**0 ft**	Location	**28.073 ft**
Equation	**H1-1b**			Span	**1**

Bending Flange	**Non-Compact**	Compression Flange	**Non-Slender**	
Bending Web	**Compact**	Compression Web	**Slender**	**Ae=2.96 in2**

			y-y	z-z
Fy	**50 ksi**	Lb	**55 ft**	**55 ft**
Pnc/om	**.721 k**	Lc/r	**785.447**	**204.604**
Pnt/om	**88.623 k**			
Mny/om	**4.071 k-ft**	L Comp Flange	**55 ft**	
Mnz/om	**1.367 k-ft**	L-torque	**55 ft**	
Vny/om	**26.826 k**	Tau_b	**1**	
Vnz/om	**29.019 k**			
Cb	**1.049**			

Tandem Envelope Analysis Report



Beam: **M1**

Shape: **W8x10**
Material: **A992**
Length: **55 ft**
I Joint: **N1**
J Joint: **N2**
Envelope
Code Check: **9.999 (LC 1-43)**
Report Based On 97 Sections

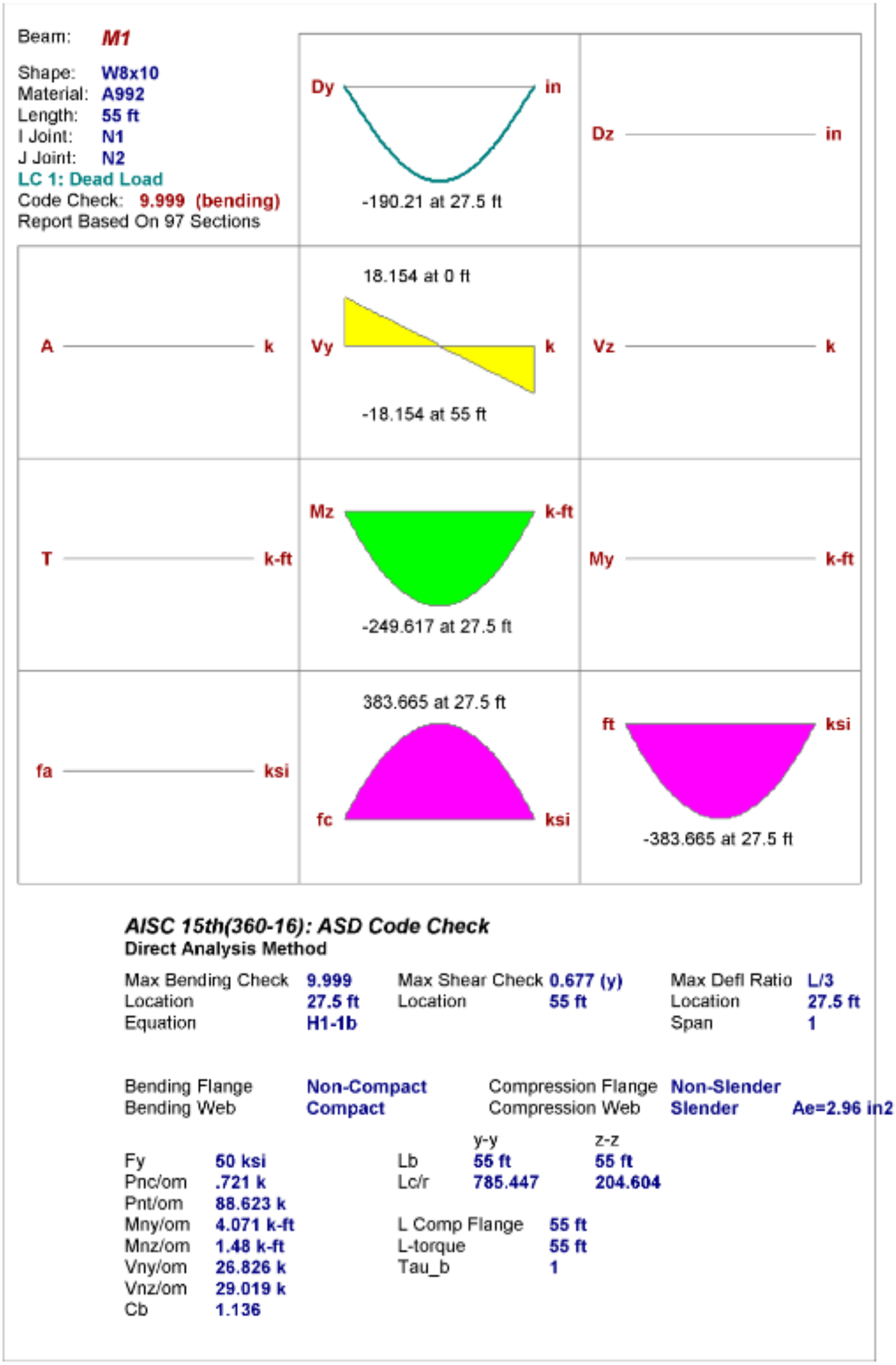
AISC 15th(360-16): ASD Code Check
Direct Analysis Method

Max Bending Check	9.999 (1-43)	Max Shear Check	1.789 (y) (LC 1-43)	Max Defl Ratio	L/1
Location	28.073 ft	Location	0 ft	Location	27.5 ft
Equation	H1-1b			Span	1

Bending Flange	Non-Compact	Compression Flange	Non-Slender	
Bending Web	Compact	Compression Web	Slender	Ae=2.96 in2

			y-y	z-z
Fy	50 ksi	Lb	55 ft	55 ft
Pnc/om	.721 k	Lc/r	785.447	204.604
Pnt/om	88.623 k			
Mny/om	4.071 k-ft	L Comp Flange	55 ft	
Mnz/om	1.672 k-ft	L-torque	55 ft	
Vny/om	26.826 k	Tau_b	1	
Vnz/om	29.019 k			
Cb	1.284			

Land Load Envelope Analysis Report



Beam: ***M1***

Shape:	**W8x10**
Material:	**A992**
Length:	**55 ft**
I Joint:	**N1**
J Joint:	**N2**

LC 1: Dead Load

Code Check: **9.999 (bending)**

Report Based On 97 Sections

AISC 15th(360-16): ASD Code Check

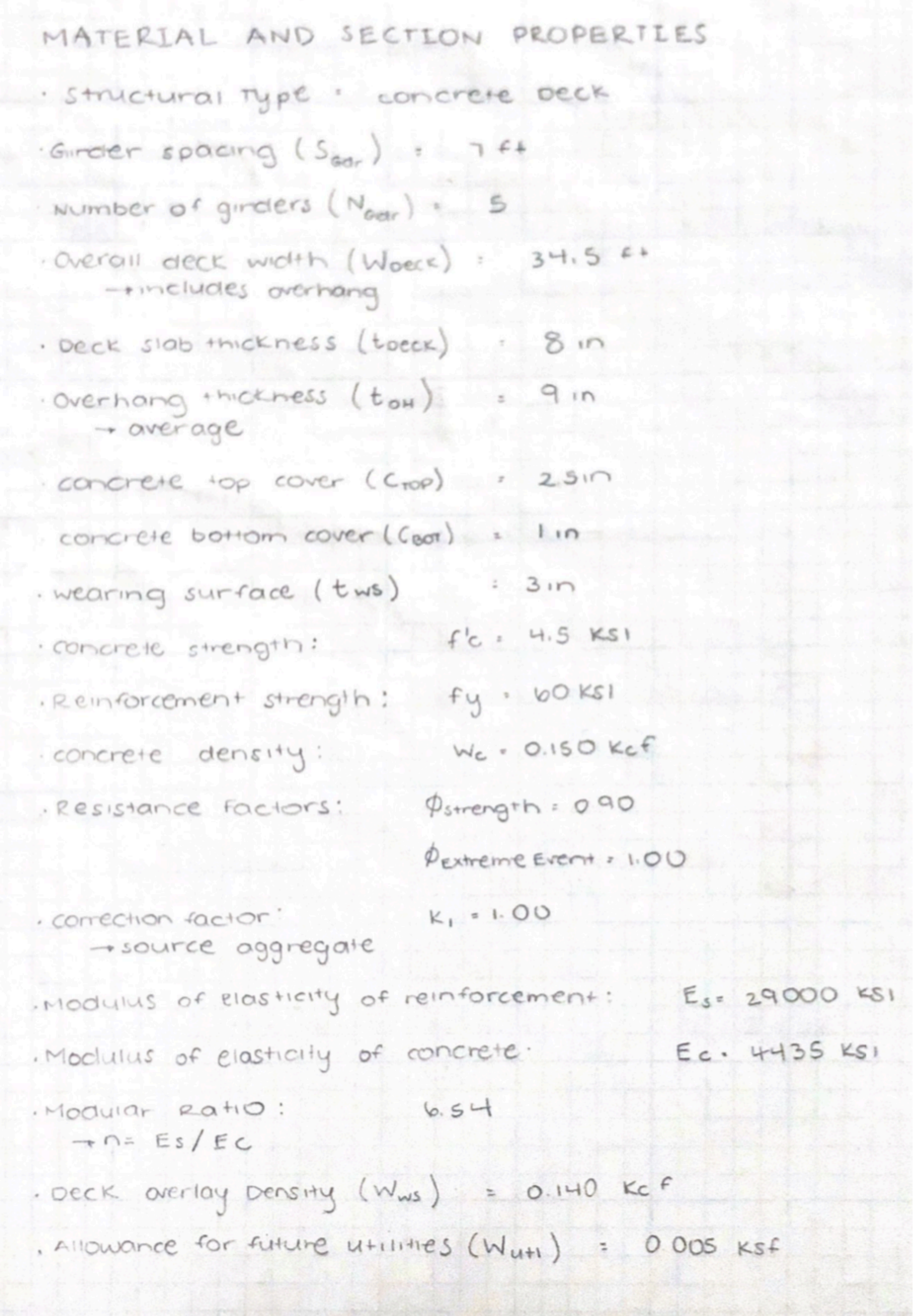
Direct Analysis Method

Max Bending Check	**9.999**	Max Shear Check	**0.677 (y)**	Max Defl Ratio	**L/3**
Location	**27.5 ft**	Location	**55 ft**	Location	**27.5 ft**
Equation	**H1-1b**			Span	**1**

Bending Flange	**Non-Compact**	Compression Flange	**Non-Slender**	
Bending Web	**Compact**	Compression Web	**Slender**	**Ae=2.96 in2**

Fy	**50 ksi**		y-y	z-z
Pnc/om	**.721 k**	Lb	**55 ft**	**55 ft**
Pnt/om	**88.623 k**	Lc/r	**785.447**	**204.604**
Mny/om	**4.071 k-ft**	L Comp Flange	**55 ft**	
Mnz/om	**1.48 k-ft**	L-torque	**55 ft**	
Vny/om	**26.826 k**	Tau_b	**1**	
Vnz/om	**29.019 k**			
Cb	**1.136**			

Appendix C: Deck Design Hand Calculations



MATERIAL AND SECTION PROPERTIES

- Structural Type : concrete Deck
- Girder spacing (S_{Gdr}) : 7 ft
- Number of girders (N_{Gdr}) : 5
- Overall deck width (W_{DECK}) : 34.5 ft
  - → includes overhang
- Deck slab thickness (t_{DECK}) : 8 in
- Overhang thickness (t_{OH}) : 9 in
  - → average
- concrete top cover (C_{TOP}) : 2.5 in
- concrete bottom cover (C_{BOT}) : 1 in
- wearing surface (t_{WS}) : 3 in
- Concrete strength: $f'c$: 4.5 KSI
- Reinforcement strength: fy : 60 KSI
- concrete density: W_c : 0.150 Kcf
- Resistance factors: $\phi_{strength}$: 0.90

  $\phi_{extreme\ Event}$: 1.00
- Correction factor: K_1 = 1.00
  - → source aggregate
- Modulus of elasticity of reinforcement: E_s = 29000 KSI
- Modulus of elasticity of concrete: E_c : 4435 KSI
- Modular Ratio: 6.54
  - → $n = Es/Ec$
- Deck overlay Density (W_{WS}) = 0.140 Kcf
- Allowance for future utilities (W_{util}) : 0.005 ksf

- Deck Thickness:

$\rightarrow h_{min} = \frac{S+10}{30} = \frac{7+10}{30} = 0.57ft = 6.8in$

- USE $h_s = 7.5in$ (For structural thickness of deck)
- USE $h = 8.0in$ (Addition for sacrificial surface)
- USE $h_0 = 9.0in$ (For portion of deck that overhang

- weight of components:

→ unit weight of concrete = 0.150 Kcf (ASSUME)
→ calculated for 1.00ft wide section of the bridge

- Barrier

$\rightarrow P_b = 0.150 Kcf \times 418in^2 \times \frac{1ft^2}{144in^2} = 0.435 kip/ft$

- Future wearing surface

$\rightarrow w_{DW} = 0.140 Kcf \times 3.0in \times \frac{1ft}{12in} = 0.035 Ksf$

- Slab 8.0in thick

$\rightarrow W_s = 0.150 Kcf \times 8.0in \times \frac{1ft}{12in} = 0.100 Ksf$

- Cantilever Overhang 9.0in thick

$\rightarrow W_0 = 0.150 Kcf \times 9.0in \times \frac{1ft}{12in} = 0.113 Ksf$

BENDING MOMENT FORCE EFFECTS

1. Deck slab

→ $h = 8.0\,\text{in}$, $W_s = 0.100\,\text{ksf}$, $S = 7.0\,\text{ft}$

· $\text{FEM} = \pm \dfrac{W_s S^2}{12} = \pm \dfrac{(0.100\,\text{ksf})(7.0\,\text{ft})^2}{12} = 0.4083\,\text{kips}$

· $R_{200} = W_s\,(\text{net Area w/o cantilever})\,S$

$= (0.100\,\text{ksf})(0.3928)7 = 0.275\,\text{kip/ft}$

· $M_{204} : W_s\,(\text{net Area w/o cantilever})\,S^2$

$= (0.100\,\text{ksf})(0.0772)7^2 : 0.378\,\text{kip-ft/ft}$

· $M_{300} = Ws\,(\text{net Area w/o cantilever})\,S^2$

$= (0.100\,\text{ksf})(-0.1071)7^2 = -0.523\,\text{kip-ft/ft}$

2. Overhang

→ $h = 9.0\,\text{in}$, $Wo = 0.113\,\text{ksf}$, $L = 3.25\,\text{ft}$

· $R_{200} = W_o\,(\text{net Area cantilever})\,L$

$= (0.113\,\text{ksf})\left(1.0 + 0.635\,\dfrac{3.25}{7}\right)3.25 : 0.476\,\text{kip/ft}$

· $M_{200} = W_o\,(\text{net Area cantilever})\,L^2$

$= (0.113\,\text{ksf})(-0.5000)\,3.25^2 = -0.597\,\text{kip-ft/ft}$

· $M_{204} = W_o\,(\text{net Area cantilever})\,L^2$

$= (0113\,\text{ksf})(-0.2460)\,3.25^2 = -0.294\,\text{kip-ft/ft}$

· $M_{300} = W_o\,(\text{net Area cantilever})\,L^2$

$= (0.113\,\text{ksf})(0.1350)\,3.25^2 = 0.161\,\text{kip-ft/ft}$

3 Barrier

→ $P_b = 0.435$ kip/ft, $L = 3.25 - 0.42 = 2.83$ ft

· $R_{200} = P_b$ (influence line ordinate)

$$= (0.435 \text{ kip/ft})\left(1.0 + 1.270\frac{2.83}{7}\right) = 0.658 \text{ kip/ft}$$

· $M_{200} = P_b$ (influence line ordinate) L

$$= (0.435 \text{ kip/ft})(-1.0000)(2.83) = -1.23 \text{ kip-ft/ft}$$

· $M_{204} = P_b$ (influence line ordinate) L

$$= (0.435 \text{ kip/ft})(-0.4920)(2.83) = -0.606 \text{ kip-ft/ft}$$

· $M_{300} = P_b$ (influence line ordinate) L

$$= (0.435 \text{ kip/ft})(0.2700)(2.83) = 0.332 \text{ kip-ft/ft}$$

4. Future wearing surface

→ $W_{DW} = 0.035$ ksf, $L = 3.25 - 1.25 = 2.0$ ft

· $R_{200} = W_{DW}\left[(\text{net area cantilever})L + (\text{net Area w/o cantilever})S\right]$

$$= 0.035\left[\left(1.0 + 0.635\frac{2.0}{7}\right)2.0 + (0.3928)7\right] = 0.179 \text{ kip/f}$$

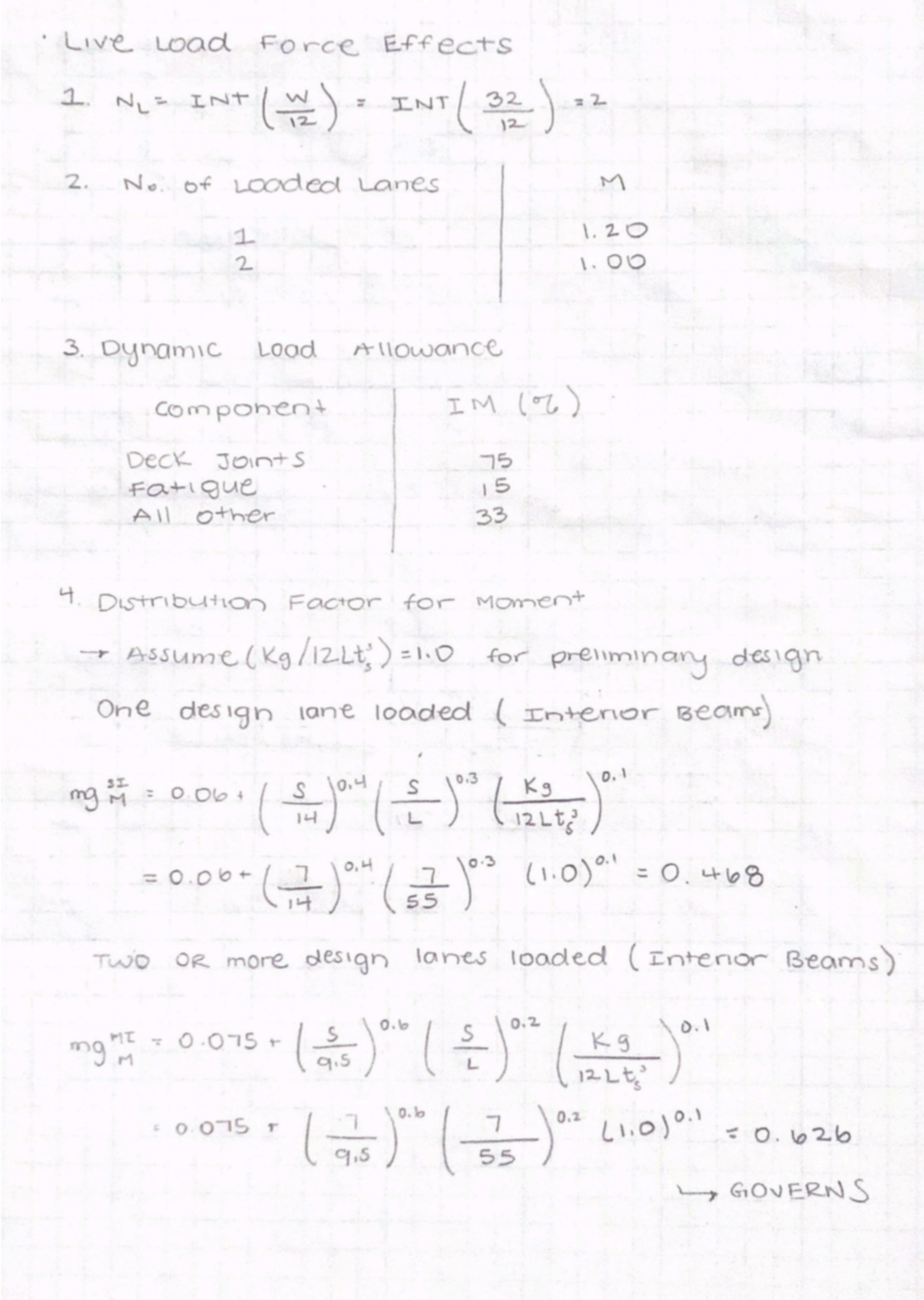
· $M_{200} = W_{DW}(\text{net area cantilever})L^2$

$$= (0.035 \text{ ksf})(-0.5000)2.0^2 = -0.070 \text{ kip-ft/ft}$$

· $M_{204} = W_{DW}\left[(\text{net Area cantilever})L^2 + (\text{net Area w/o cantilever})S^2\right]$

$$= (0.035 \text{ksf})\left[(-0.2460)2.0^2 + (0.0772)7^2\right] = 0.098 \text{ kip-ft/ft}$$

Appendix D: Girder Design Hand Calculations



· Live Load Force Effects

1. $N_L = INT\left(\frac{w}{12}\right) = INT\left(\frac{32}{12}\right) = 2$

2.

No. of Loaded Lanes	M
1	1.20
2	1.00

3. Dynamic Load Allowance

Component	IM (%)
Deck Joints	75
Fatigue	15
All other	33

4. Distribution Factor for Moment

→ Assume $(K_g/12Lt_s^3) = 1.0$ for preliminary design

One design lane loaded (Interior Beams)

$$mg_M^{SI} = 0.06 + \left(\frac{S}{14}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{12Lt_s^3}\right)^{0.1}$$

$$= 0.06 + \left(\frac{7}{14}\right)^{0.4}\left(\frac{7}{55}\right)^{0.3}(1.0)^{0.1} = 0.468$$

Two or more design lanes loaded (Interior Beams)

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

$$= 0.075 + \left(\frac{7}{9.5}\right)^{0.6}\left(\frac{7}{55}\right)^{0.2}(1.0)^{0.1} = 0.626$$

→ GOVERNS

One design lane loaded (Exterior Beams)
→ lever rule

$$R = \frac{P}{2}\left(\frac{2+7}{7}\right) = 0.643P$$

$$g^{SE}_{M} = 0.643$$

$$mg^{SE}_{M} = 1.2(0.643) = 0.772 \Rightarrow \text{GOVERNS}$$

Two or more design lanes loaded (Exterior Beams)

$$d_e = 3.25 - 1.25 = 2\ ft$$

$$e = 0.77 + \frac{de}{9.1} = 0.77 + \frac{2}{9.1} = 0.99$$

$$mg^{ME}_{M} = e \cdot mg^{MI}_{M} = (0.99)(0.772) = 0.764$$

Live-Load Moments

$$M_{LL+IM} = mg\left[(M_{Truck} \text{ or } M_{Tandem})\left(1 + \frac{IM}{100}\right) + M_{Lane}\right]$$

- M_{Truck} = 719.449 K-ft => GOVERNS
- M_{Tandem} = 641.828 K-ft
- $M_{Fatigue}$ = 500.359 K-ft
- M_{Lane} = 249.617 K-ft

Interior Beam

- $M_{LL+IM} = 0.626\left[(641.828)(1 + (33/100)) + 249.617\right]$
  $= 690.63$ K-ft

- $M_{Fatigue+IM} = (0.468/1.2)\left(500.359(1+15/100)\right)$
  $= 224.41$ K-ft

Exterior Beam

- $M_{LL+IM} = 0.772\left[(641.828)(1+(33/100)) + 249.617\right]$
  $= 851.71$ K-ft

- $M_{fatigue+IM} = (0.772/1.2)\left(500.359(1+15/100)\right)$
  $= 370.18$ K-ft

5. Distribution factor for shear

One design lane loaded (Interior Beams)

$$mg_{V}^{SI} = 0.36 + \frac{S}{25}$$

$$= 0.36 + \frac{7}{25} = 0.64$$

Two or more design lanes loaded (Interior Beams)

$$mg_{V}^{MI} = 0.2 + \frac{S}{12} - \left(\frac{S}{L}\right)^{2.0}$$

$$= 0.2 + \frac{7}{12} - \left(\frac{7}{55}\right)^{2.0} = 0.77 \quad \text{(GOVERNS)}$$

One design lane loaded (Exterior Beams)

$mg_{V}^{SE} = 0.772$ governs

Two or more design lanes loaded

$de = 2$ ft

$e = 0.6 + \frac{de}{10} = 0.6 + \frac{2}{10} = 0.80$

$mg_V^{ME} = e \cdot mg_V^{MI} = (0.80)(0.77) = 0.62$

Live-Load shears

$V_{LL+IM} = mg\left[(V_{Truck} \text{ or } V_{Tandem})\left(1 + \frac{IM}{100}\right) + V_{Lane}\right]$

- $V_{Truck} = 58.75$ K => GOVERNS
- $V_{Tandem} = 48.004$ K
- $V_{Fatigue} = 47.113$ K
- $V_{Lane} = 18.154$ K

Interior Beams

- $V_{LL+IM} = 0.77\,[58.75\ (1.33) + 18.154] = 74.144$ K
- $V_{Fatigue+IM} = (0.64/1.2)(47.113\ (1.15)) = 28.896$ K

Exterior Beams

- $V_{LL+IM} = 0.772\,[58.75\ (1.33) + 18.154] = 74.337$ K
- $V_{Fatigue+IM} = (0.772/1.2)(47.113\ (1.15)) = 34.856$ K

6 Stiffness

→ loads applied to the bare steel noncomposite section

7. Wind Effects

→ wind pressure on superstructure is 50 psf = 0.050 ksf
→ load is applied to girders, deck, and barriers

8. Reactions to substructure

→ reactions are per design lane without any distribution factors

$R_{100} = V_{100} = 1.33\,V_{Truck} + V_{Lane}$

$= 1.33(58.75) + 18.154 = 96.292$ kips/lane

· Calculate Force Effects from Other Loads

$M_{max} = M_{105} = \frac{wL^2}{8} = \frac{w(55)^2}{8} = 378.1 \times w$ kip·ft

$V_{max} = V_{100} = \frac{wL}{2} = \frac{w(55)}{2} = 27.5 \times w$ kip

→ Assume beam weight of 0.10 K/ft

1. Interior Girders

DC Deck slab = $(0.15)(8/12)(8) = 0.80$ K/ft

Girder = 0.10 K/ft

$\Rightarrow w_{DC} = 0.90$ K/ft

DW 75mm bituminous paving = $(0.140)(3/12)(8)$

$\Rightarrow w_{DW} = 0.28$ K/ft

2. Exterior Girders

→ barrier weight assigned to exterior girder

DC Deck slab = $(0.15)(8/12)(3.25+(8/2)) = 0.72$ K/f

Barrier = 0.50 K/ft

Girder = 0.10 K/ft

=> $w_{DC} = 1.33$ K/ft

DW 3 in bituminous paving =

=> $w_{DW} = (0.14)(3/12)(2+(8/2)) = 0.21$ K/ft

INTERIOR GIRDER

Load Type	w (K/ft)	Moment (K/ft) M_{105}	Shear (Kips) V_{100}
DC	0.90	340.3	24.8
DW	0.28	105.9	7.7
LL + IM (distributed)	—	690.63	74 144
Fatigue + IM (distributed)	—	224.41	28.896

=> unfactored moments and shears

EXTERIOR GIRDER

Load Type	w (K/ft)	Moment (K/ft) M_{105}	Shear (Kips) V_{100}
DC	1.33	502.9	36.6
DW	0.21	79.4	5.8
LL + IM (distributed)	–	851.71	74.337
Fatigue + IM (distributed)	—	370.18	34.856

=> unfactored moments and shears

·Design Required sections

Interior Beam (Factored Shear and Moment)

$U_{strength\ I} = \eta\left[1.25DC + 1.50DW + 1.75(LL + IM)\right]$

$\rightarrow V_u = 1.0[1.25(24.8) + 1.50(7.7) + 1.75(74.14)] = 172.30$

$\rightarrow M_u = 1.0[1.25(340.3) + 1.50(105.9) + 1.75(690.63)] = 1792.83$ K-f

$U_{service\ II} = \eta\left[1.0DC + 1.0DW + 1.30(LL + IM)\right]$

$\rightarrow V_u = 1.0[1.0(24.8) + 1.0(7.7) + 1.30(74.14)] = 128.88$ K

$\rightarrow M_u = 1.0[1.0(340.3) + 1.0(105.9) + 1.30(690.63)] = 1344.02$ K-f

$U_{Fatigue\ I} = \eta\left[1.5(\text{Range of } LL + IM)\right]$

$U_{Fatigue\ II} = \eta\left[0.75(\text{Range of } LL + IM)\right]$

$\rightarrow V_u = 1.0[1.5(28.896)] = 43.34$ K

$\rightarrow V_u = 1.0[0.75(28.896)] = 21.67$ K

$\rightarrow M_u = 1.0[1.5(224.41)] = 336.62$ K-ft

$\rightarrow M_u = 1.0[0.75(224.41)] = 168.31$ K-ft

$U_{construction} = \eta[1.25DC]$

$\rightarrow V_u = 1.0[1.25(24.8)] = 31$ K

$\rightarrow M_u = 1.0[1.25(340.3)] = 425.4$ K-ft

Exterior Beam (factored shear and Moment)

$U_{strength\ I} = \eta\left[1.25\,DC + 1.50\,DW + 1.75\,(LL + IM)\right]$

$\rightarrow V_u = 1.0\left[1.25\,(36.6) + 1.50(5.8) + 1.75(74.34)\right] = 184.55\ K$

$\rightarrow M_u = 1.0\left[1.25\,(502.9) + 1.50\,(79.4) + 1.75\,(851.71)\right] = 2238.22\ K\text{-}f$

$U_{service\ II} = \eta\left[1.0\,DC + 1.0\,DW + 1.30\,(LL + IM)\right]$

$\rightarrow V_u = 1.0\left[1.0\,(36.6) + 1.0\,(5.8) + 1.30\,(74.34)\right] = 139.04\ K$

$\rightarrow M_u = 1.0\left[1.0\,(502.9) + 1.0\,(79.4) + 1.30\,(851.71)\right] = 1689.52\ K\text{-}ft$

$U_{fatigue\ I} = \eta\left[1.5\ (LL + IM)\right]$

$U_{Fatigue\ II} = \eta\left[0.75\ (LL + IM)\right]$

$\rightarrow V_u = 1.0\left[1.5\,(34.856)\right] = 52.28\,K$

$\rightarrow V_u = 1.0\left[0.75\,(34.856)\right] = 26.14\ K$

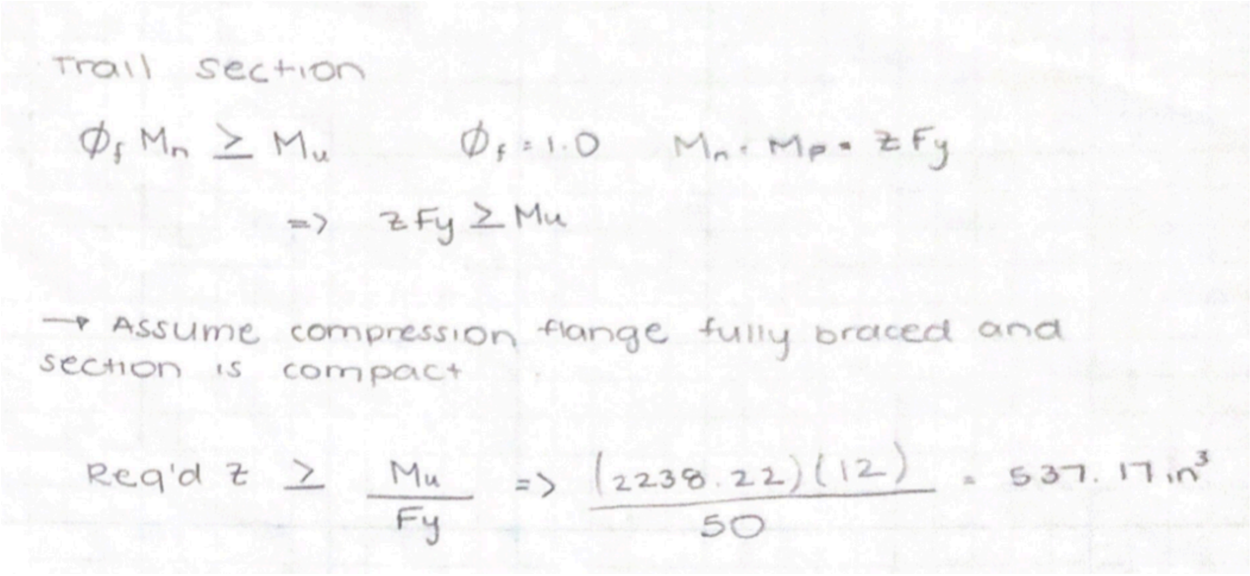
$\rightarrow M_u = 1.0\left[1.5\,(370.18)\right] = 555.27\ K\text{-}ft$

$\rightarrow M_u = 1.0\left[0.75\,(370.18)\right] = 277.64\ K\text{-}ft$

$U_{construction} = \eta\left[1.25\,DC\right]$

$\rightarrow V_u = 1.0\left[1.25\,(36.6)\right] = 45.8\ K$

$\rightarrow M_u = 1.0\left[1.25\,(502.9)\right] = 628.6\ K\text{-}ft$



Trail section

$\phi_f M_n \geq M_u \qquad \phi_f = 1.0 \qquad M_n = M_p = Z F_y$

$\Rightarrow \quad Z F_y \geq M_u$

→ Assume compression flange fully braced and section is compact

$$\text{Req'd } Z \geq \frac{M_u}{F_y} \Rightarrow \frac{(2238.22)(12)}{50} = 537.17 \, in^3$$

Appendix E: Preliminary Bridge Drawings