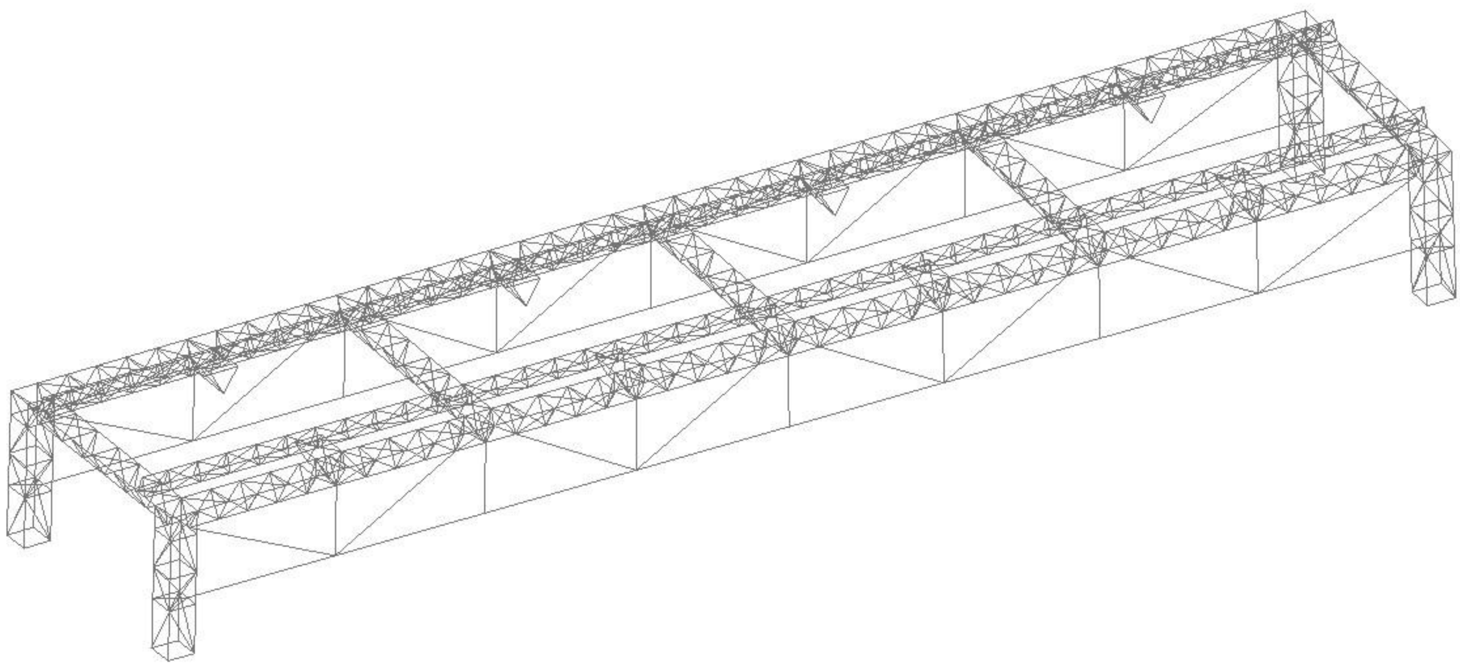
Design of a Steel Bridge for the ASCE 2010 Student Steel Bridge Competition



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We would also like to thank SLM and Associate for their financial contribution for this project. Without their financial contribution the construction of the project would be impossible. Their aid has assisted us in our process to educate ourselves for a better future as structural engineers.

Abstract

The ASCE student competition each year is part of a growing stepping stone for IPFW's civil engineering department. As seniors the three of us were requested to design, build, and test a steel bridge that could be used for the AISC/ASCE student steel bridge competition. This competition is a small measure of the quality of engineers that are develop at IPFW compared to that of other universities around the nation. In this report the process of designing, building, and testing will be elaborated on. This is the start of what will hopefully be an annual competition for IPFW and will be improve with each year to come.

Section I: Problem Statement

I.1. Problem Statement

A significant topic of debate in the world today, especially in the United States, is the use of fossil fuels. The most commonly thought of fossil fuel would be crude oil. Much debate about drilling for crude oil has been brought forth several restrictive laws. Therefore, Boreal Energy Corporation has obtained a parcel of land that permits them to drill for crude oil in the Arctic Tundra. This parcel has very limited access because there is a river and floodway adjacent to it. In order for the company to occupy this parcel and use it for profit they must build a bridge to cross over the river and flood way in order to transport their equipment and product.

Boreal Energy Corporation has posted a call of bidders to design them a bridge over the said floodway and river. They have several specifications that they have set forth for the designers to abide by. The specifications are set forth for purposes of climate, personal preference, functionality, and economical reasons.

The proposal presented by Boreal Energy Corporation has been fabricated by members of the American Institute of Steel Construction (AISC) and national leaders/members of the American Society of Civil Engineers (ASCE). They have made up a set of specification to challenge collegiate students with a structural problem that they would face after graduation while working for a structural engineering firm. To engage students competitively, the said organizations have required the competing students to build a model of their design so that I can be tested and judged.

I.2. Background

For several years now university students have presented there abilities to use their engineering education and apply it to a competition that challenges them similarly to that they may face outside of an educational facility. Each year the competition becomes more and more challenging to raise the bar for new classes of engineers. For example in previous years the vertical loading was applied directly to the bridge girders. This year's competition (2010) the load is applied to a separate top rail running the length of the bridge.

To grasp an idea of what is expected; last year's results were considered. For example the winning bridge built by SUNY Canton weighed 155.8 lbs., was built in 3.28 minutes, had an aggregate deflection of 0.42", and had an estimated cost of

$1,943,833. This bridge wasn't the winner of each individual category, but won the overall ranking with these results.

This year's national competition will be held at the Purdue University in Lafayette, Indiana.

I.3. Requirements, Specifications, and Given Parameters

I.3.1. Functionality

The most important design specification set forth in the project is the functional capabilities of the bridge. As stated previously the bridge will be located in the Artic Tundra. Given its location the bridge will be very secluded and on an oil drilling field. This means the aesthetics and pedestrian accessibility is the least of the owners concerns. The bridge that will be awarded the job is the bridge that can accommodate the owners needs the best at the lowest cost.

In oil refining large equipment is needed. In order for the workers to transport the equipment to and from the oil field the bridge must be able to accommodate for these equipments. Therefore, it was specified that by no means what so ever can there be structural members of the bridge above the bridge deck. This will allow very wide and tall vehicles and equipment to be transported of the river and floodway.

The owners have mapped out a location that they would prefer to locate the bridge. They have specified the size and location of the bridge based a geotechnical report and a cartograph of drilling locations. The owners have given the bidders pre-determined footing locations that will be pre-casted in place for the bridge construction. Based on environmental purposes the owners have laid out a perimeter for all of the construction to occur within.

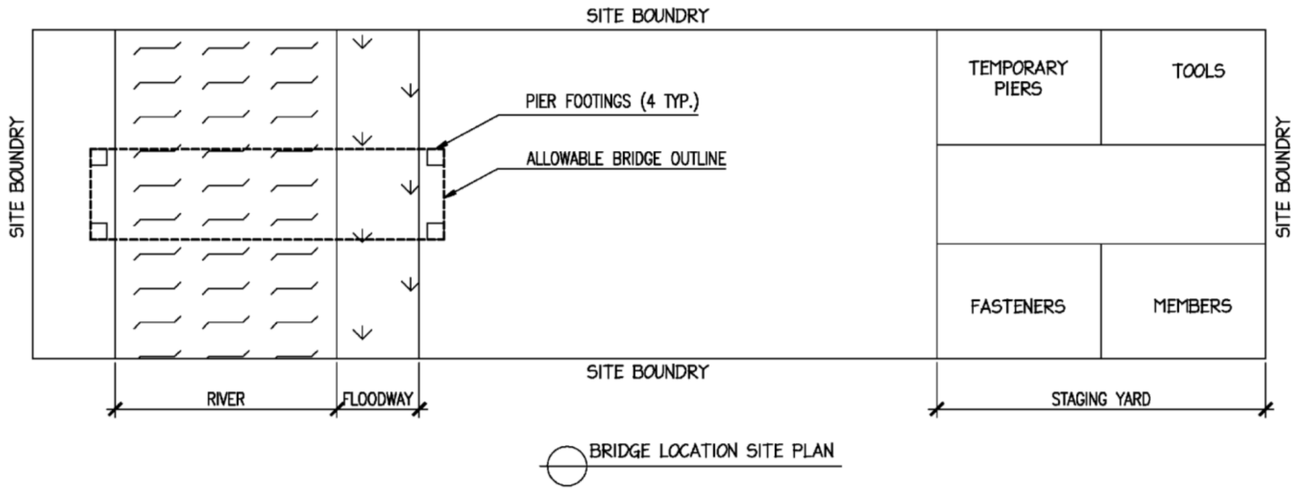


Figure I.3.1.A.

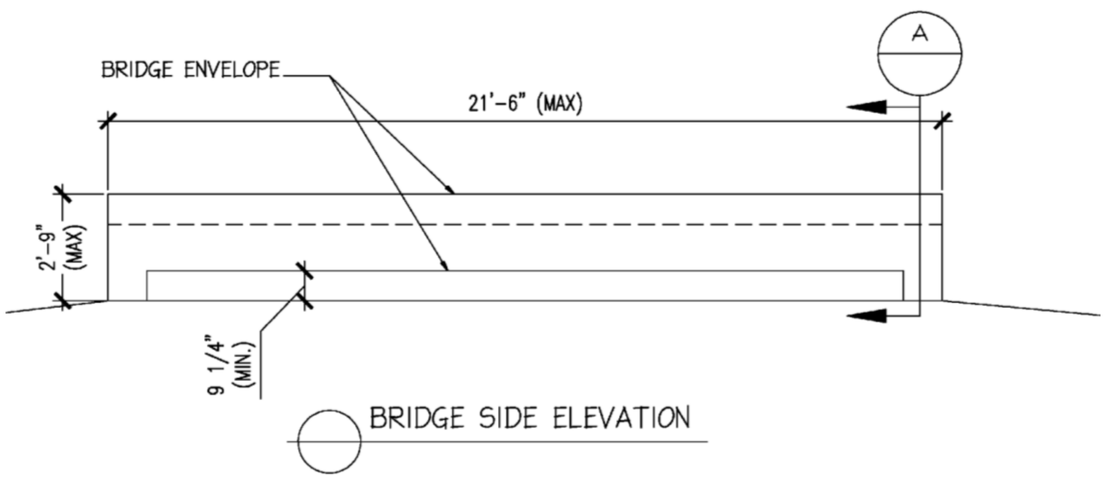


Figure I.3.1.B.

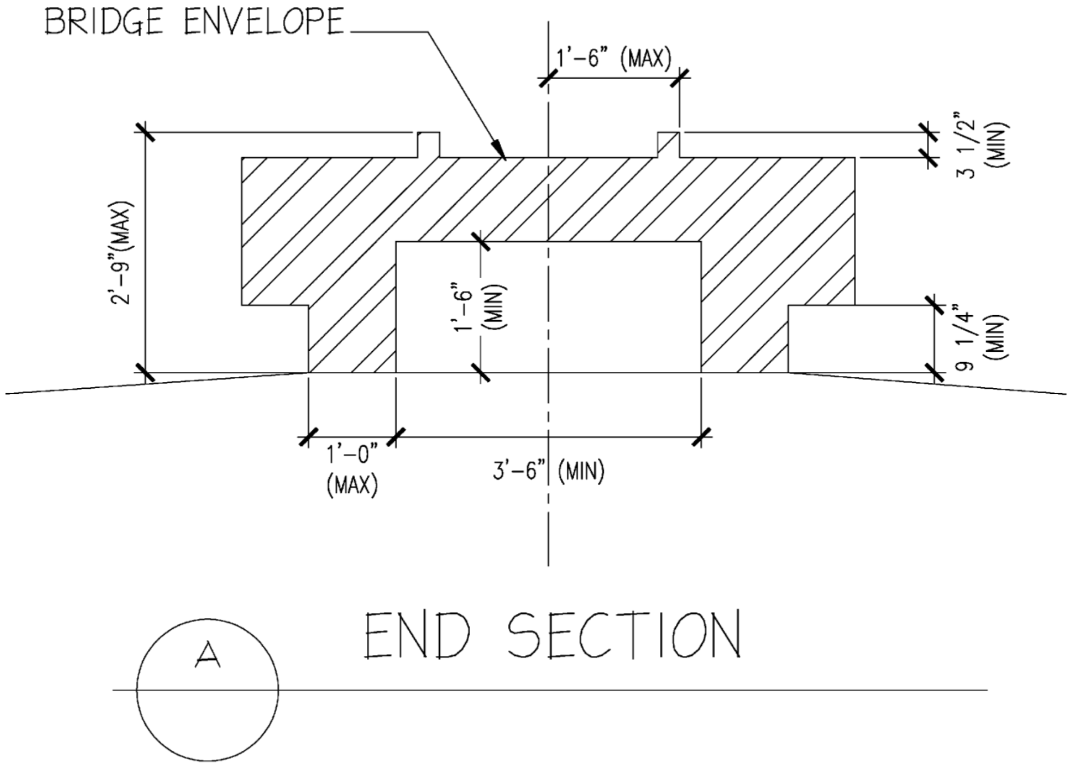


Figure I.3.1.C.

Along with the dimensions of equipment that will occupy the bridge they will also carry loads. The bridge must be able to with stand the loads created laterally by wind and vertically by equipment and produce. The owners have determined the maximum wind load that they desire to have the bridge with stand safely and the maximum load of their equipment to cross safely. It is an absolute must that the bridge can with stand the load of the owners equipment. This is of the highest priority of the designers, to ensure that the safety of the operators is guaranteed. This is the sole reason of contracting a structural engineer. If there were no consideration given to loading then an architect could complete this project. It is designers responsibility present a bridge to the owners that will serve their purposes safely.

I.3.2. Climate

Since the oil field is in the Artic Tundra several specifications have been placed upon the designers. The construction season in the Artic Tundra is very short. It is only about 3 months long. The owners want this project to be completed within in one year. This gives the construction crew about 3 months to build the bridge.

To prevent build up of ice and debris the bridge must clear span the river and floodway. This means that absolutely no permanent piers other than the pre determined footing locations. With the extremely cold temperatures the buildup of ice would drastically reduce the flow of the river, potentially causing damming. This damming could cause flooding and structural damage. If the bridge is designed for wind, seismic, dead, live loading, but not hydraulic pressure; the damming could create structural failure. Keeping structural members out of the water will also help reduce the corrosion of the structure. This will minimize the chemical and mechanical wear of the structure.

For construction purposes, temporary piers will be allowed during the construction duration only. These piers must not create damming within the flood way. Another climate specification for constructability is a pre-fabricated deck. The designed structure must be self sufficient; meaning that the load must be fully supported by the structure without help from the deck. The load includes the live load and the dead load of itself and the deck. This is specified to ensure that the project can be complete in a timely manner within the construction season. It was also specified to ensure adequate curing of the concrete deck, away from the harsh cold temperatures of the Arctic Tundra.

I.3.3. Owners Preference

The only preference that the owner has requested is that the structure be made of structural steel. The owner may have felt the steel was more economical, less corrosive, stronger, more aesthetic, or possibly some other reason. A logical reason that steel was requested was to help accelerate the construction process. A steel structure will cut out the time allotted for curing and forming.

I.3.4. Economy

Much like most projects budget is an issue. The owner has the right to choose the design they see most fit, but this is a call to bidders. This means that the designers need to be competitive in price. In most situations like this the lowest bidder wins. However, the lowest bidder will not win the project if their design doesn’t meet safety standards or the function purposes of the bridge. Therefore, and optimization curve will be need to create the most safety and functionality for the lowest dollar.

I.4. Design Variables

The bid proposals will be reviewed and chosen based on five variables of the designs. These variables are stiffness, construction speed, weight, efficiency, and aesthetics. Each design will have their own characteristics that will define how the owners will rank each bridge in these categories. The owners will use these variables to determine which bid proposal to accept.

I.4.1. Stiffness

Stiffness is better described as deflection. The stiffer the design the less the bridge will deflect under loading. The best design would be the design that has the least deflection.

The differences in the deflection from one design to another are difference in material and cross section of the primary support girders. Since steel was specified by the owner the material properties are fixed. In this case the material property of interest in the modulus of elasticity (E). If E is fixed, then the deflection differences from design are dependent fully on the moment of inertia about the x axis if the x axis is the axis parallel with the ground and perpendicular to the girder cross section. The moment of inertia is the second moment of area; therefore the dimensions of the cross section will control entirely the deflection differences from one design to another.

I.4.2. Construction Speed

Construction speed is a point of interest in this project because of the short construction season and like most projects the faster the project is constructed the cheaper.

Construction speed is dependent on three primary variables from one design to another. Those variables are the number of structural members, the ease of assembly created by the connection and member design, and finally the experience of the builders with construction of such a structure. This is where a lot of optimization will have to occur.

I.4.3. Weight

The weight of the bridge is of concern to reduce cost. The less material used in the design the less the material for the bridge will cost, since steel is sold by the pound. With that in mind it is important to use enough steel to maintain the minimal deflection as stated in I.4.1.

I.4.4. Efficiency

It is important that the design makes sense. The design needs to be efficient in many ways. The steel to load ratio should be as low as possible, creating the maximum usage of the steel used in the project. The bridge should be very easy and worry free to use. It should not be an obstacle for the owners to transport equipment across the bridge. The building process should utilize all the builders at all time without costing money for little to no results. The member connections should be simple and effective to support the bridge loads.

I.4.5. Aesthetics

Aesthetics are the least of design variable worries for the designers and owners. The owners wish to have an aesthetically pleasing design, but will only be considered if all other categories are equivalent.

I.5. Bringing it Down to Size

For the said river and floodway the bridge required would need to be about 200-210 feet long and about 40-42 feet wide. The owners want to be able to test, touch, and see a model version of the designed bridge. As stated earlier this is a fabricated bid proposal by ASCE/AISC; therefore to reasonably judge the design variables said in section I.4 a 1:10 scale model is being built. The dimensions seen in section I.3.1 are the scaled sizes. From this point forth all dimensions and specification will be referred to in the reduced size and the scoring and judging will be the student competition versus the theoretical bid proposal.

I.6. Limitations and Constraints

I.6.1. Pre-Fabricated Members

The first specification placed on the designers to ensure this project can be completed in the allotted time is all members must be pre-fabricated. All the welding, cutting, shaping, etc of the members must be done prior to the start of construction. The only construction assembly allowed in the construction field is bolted connection of the pre-fabricated steel sections.

However, for transportation purposes, there are restrictions on the prefabricated sections. No section can be of greater dimensions than 6"X6"X42". When these members are assembled at the competition each connection must contain at least one bolt. No of the members can be telescoping. The bolt must be fully engaged by the nut and must no exceed a length of 1.5". Along with the limitation on the structural members, the footings are in predetermined locations as well.

I.6.2. Construction Constraints

As stated previously the duration of the construction season is very limited and the faster the building time the lower the cost. Perhaps an even more difficult construction constrain is that all construction must occur from on bank and on barges. This means that builders will only be allowed to build from outside of the floodway and river on one side of the bridge. Builders are allowed to be in the river but not the floodway, but they act as barges. They can not leave the river and no one can enter the river during construction.

I.6.3. Budget Constraints

The competition winner will be decided on two primary categories: structural efficiency and construction cost. Each of the two categories are broken down into sub categories.

I.6.3.a. Structural Efficiency

Structural efficiency is measured best on two criteria: aggregate deflection (the sum of deflection measured at two locations under vertical loading conditions) and total bridge weight.

I.6.3.b. Construction Cost

Construction cost is measure on four criteria: number of labors (workers outside of the river on one bank), number of barges (workers within the river), number of temporary piers, and overall construction time.

Section II: Conceptual Design

II.1. Loading

The bridge must be able to accommodate 12 different vertical load combinations and one lateral load combination. The 12 vertical load combinations consist of 6 different cases from each end of the bridge. The bridge will be loading in two locations with a 3 foot wide load. The each of the two loads will consist of a one hundred pound steel deck followed by a 1150 lb live load. The location of these loads can be seen in the following equations and in Figure II.1.A.

$L1=97+8s$ $L2=13(s-1)$

Location of Loading

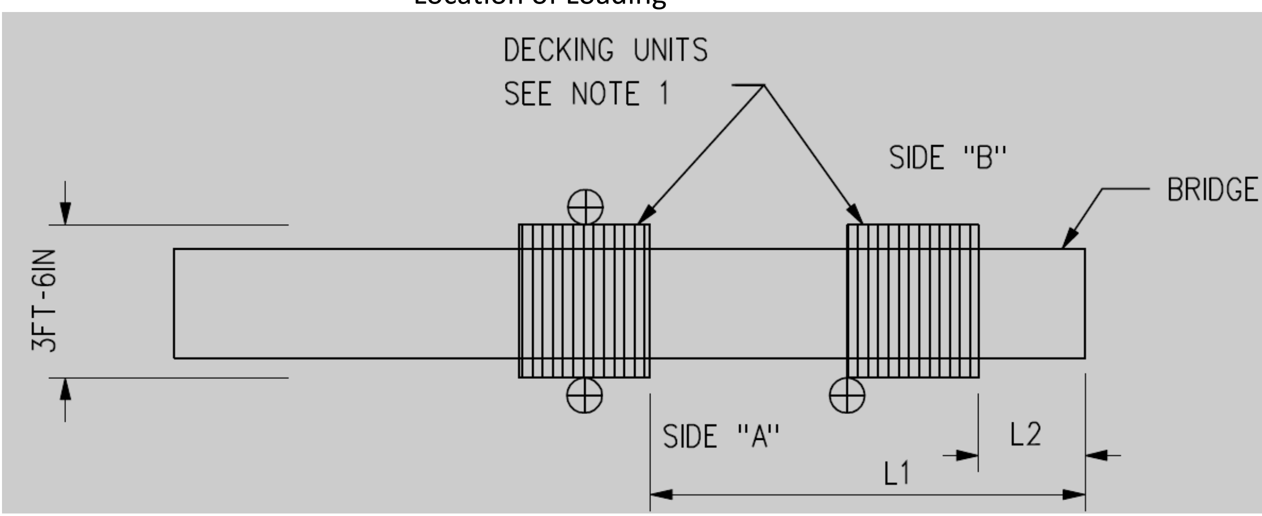


Figure II.1.A.

S in the above equations is the value rolled on a die. L1 and L2 are in inches. Understanding how the bridge is loaded can help determine the design parameters. The maximum design moment for the bridge is given when L1 is minimized and L2 is maximized.

Controlling Moment Case

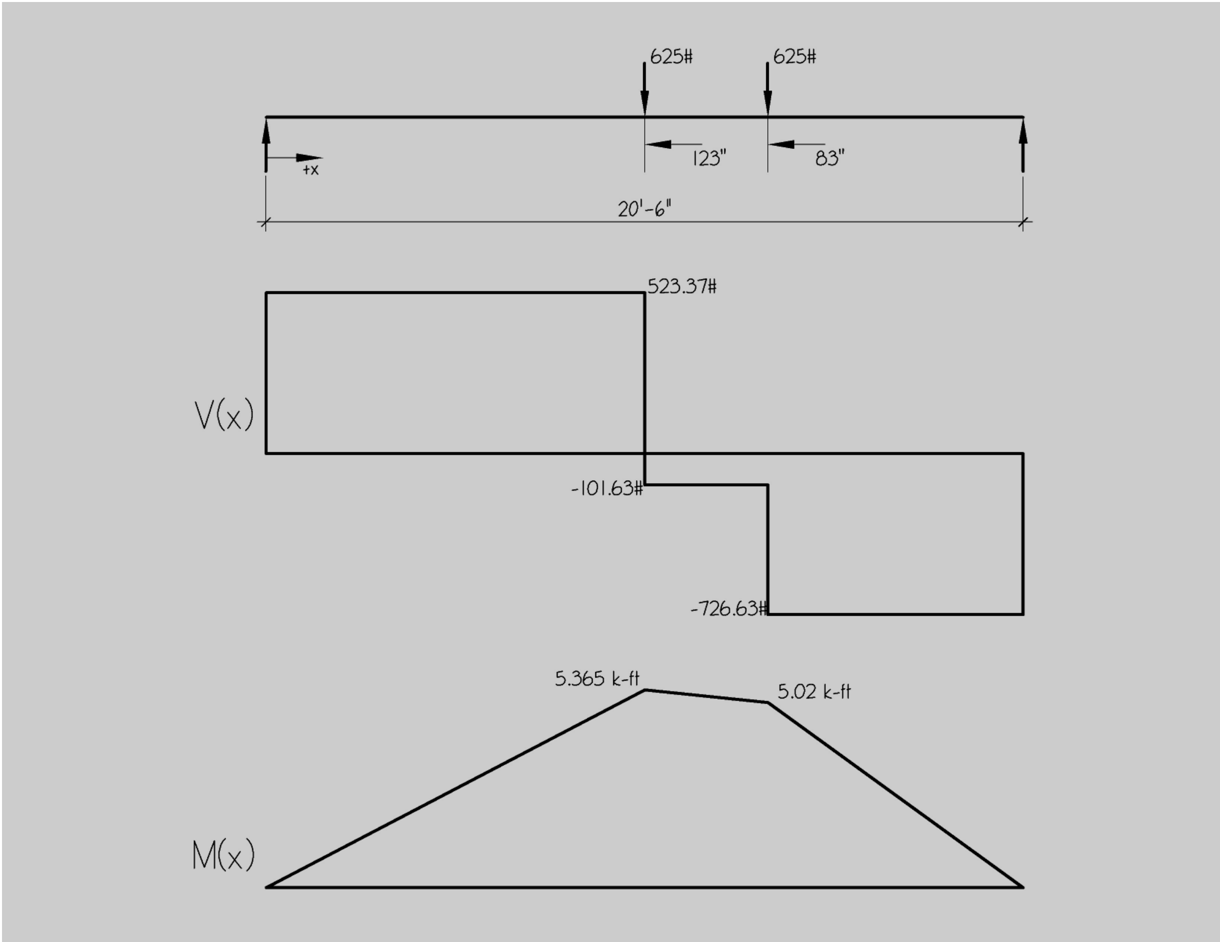


Figure II.1.B.

The controlling shear load occurs when L1 and L2 are both minimal.

Controlling Shear Case

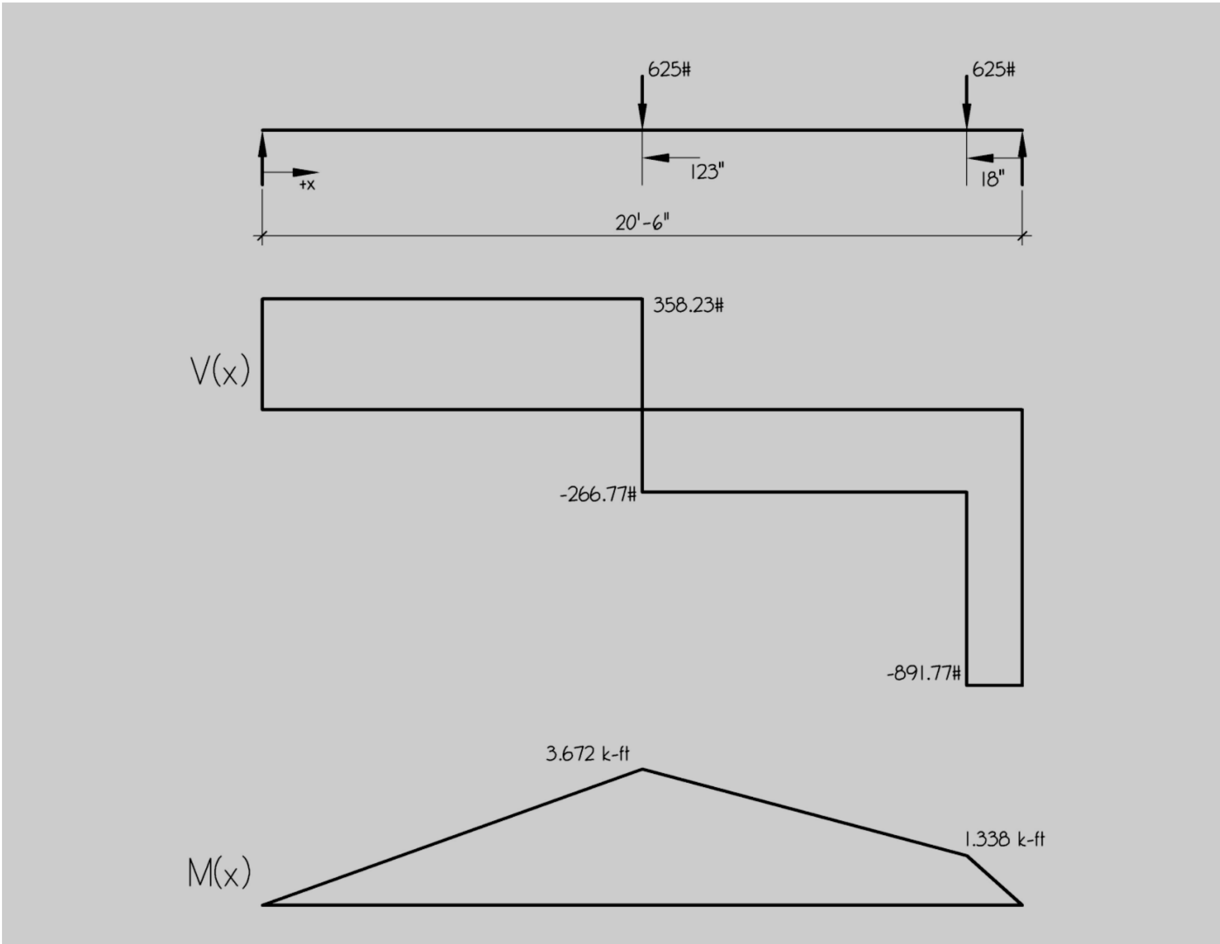


Figure II.1.C.

As can be seen in Figure II.1.B. & II.1.C. the primary girders are only designed for have of the load because there are two girders. These figures also show the resultant loads of each of the two three foot wide distributed load. This loading will be used to find the aggregate vertical deflection that will be discussed later in this report. The maximum allowable vertical deflection at any point is 2”.

The lateral load case is in place to ensure stability of the bridge. If it were a real life application the lateral load test would represent wind loading. In this case the lateral load can cause as much deflection up to one inch without be scored or judge for comparability to that of other bridges. This loading will only be 50 lbs laterally at the center of the bridge. The bridge will have 100 lb preloaded vertically on the bridge to keep the bridge from overturning.

Lateral Load Case

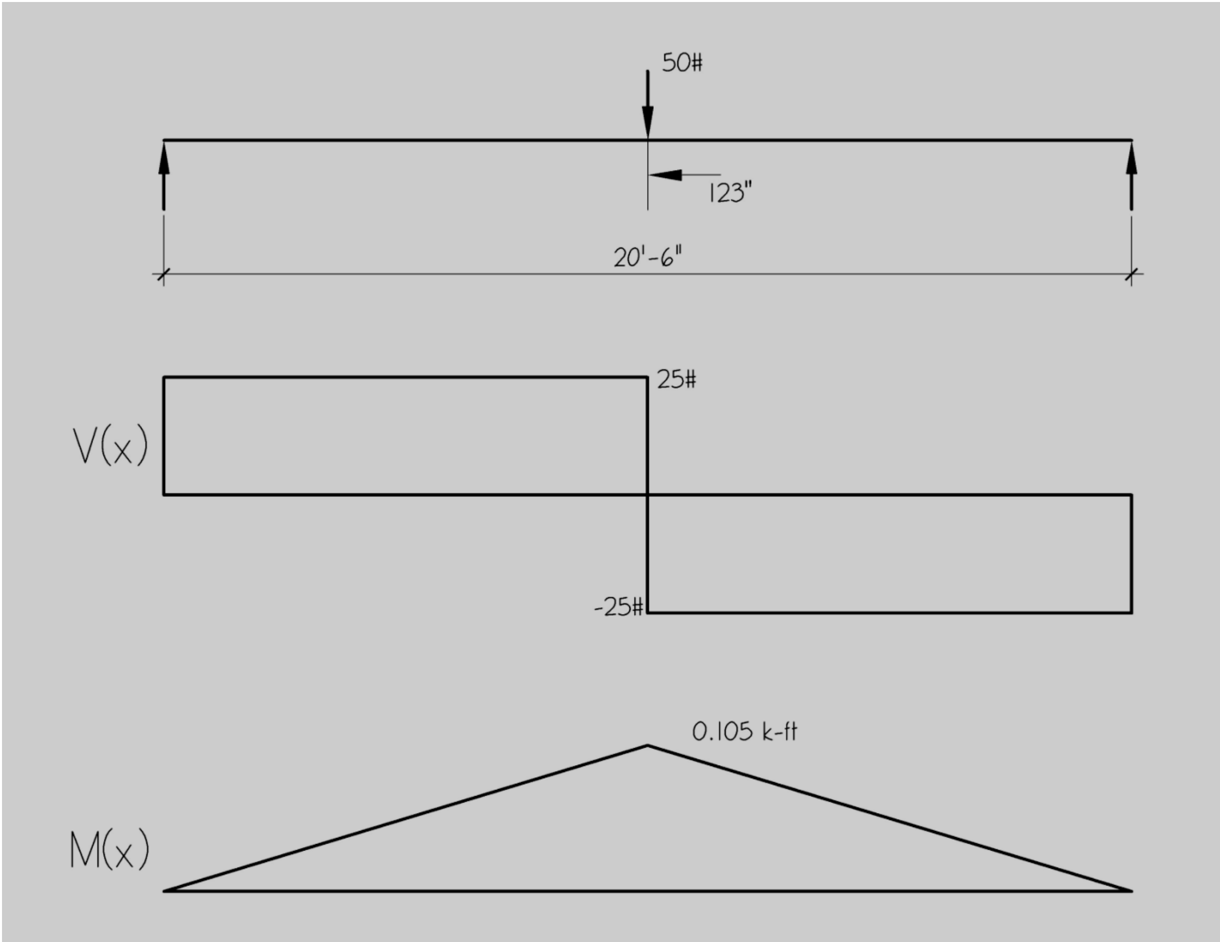


Figure II.1.D.

II.2. Design Philosophy

The primary design philosophy that will be used to design the bridge is that the members will act as trusses. Truss members will be much lighter than the use of solid members. Design and analysis of each member will be simplified with this approach because they will hold axial loads only.

Even though the members are trusses the beam theory can still be used. Meaning that the truss girders are under a positive bending moment. Since this is so, then the top chord will be under compression and the bottom chord will be in tension.

Both the top and bottom chords can be optimized independently of each other. The bottom chord can be optimized by minimizing the area of steel, thus reducing the weight. High grade structural steel with the highest yield strength can aid in this optimization.

The top chord will have to be designed for critical buckling. This can be optimized by producing a built up section for the top chord that will develop a large moment of inertia about both the x and y axis.

II.3. Chord Development Concepts

II.3.1. Top Chord

As stated in section II.2. Design Philosophy, the top chord of each girder must be designed for buckling and compressive strength. Each member of the top chord must be at maximum 6” x 6” x 42” including the connection. There were two different chord concepts to be considered.

Concept 1 consists of a rectangular cross-section developed by for steel components at the corners of the chord. These four components would act as one member by attaching them with webbing.

Concept 1

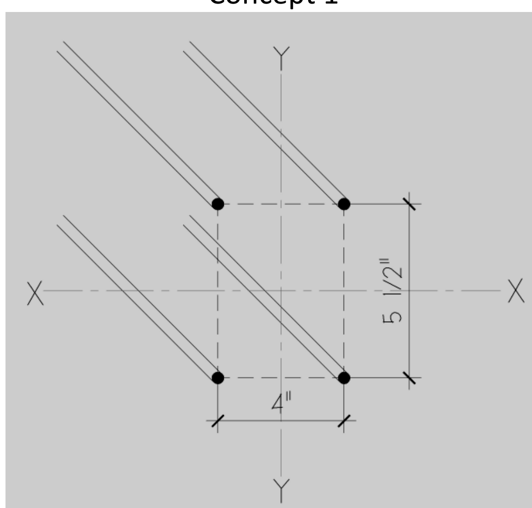


Figure II.3.1.A.

Concept 2 was developed similarly, but with a triangular cross-section.

Concept 2

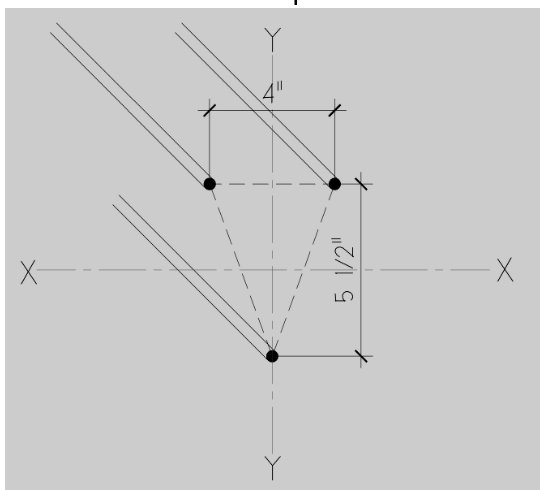


Figure II.3.1.B.

Concept 1 would provide a great moment of inertia about the YY axis and XX, but would be much heavier. To select a top chord an analysis of whether or not the added weight is worth the greater inertia.

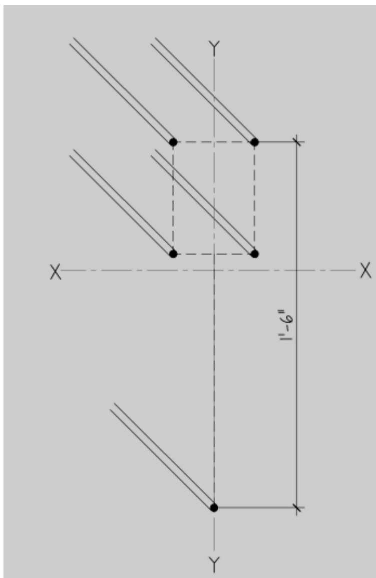
II.3.2. Bottom Chord

Since the bottom chord will be in tension a single component that similar to one of the components selected for the top chord can be use to hold the tensile axial load.

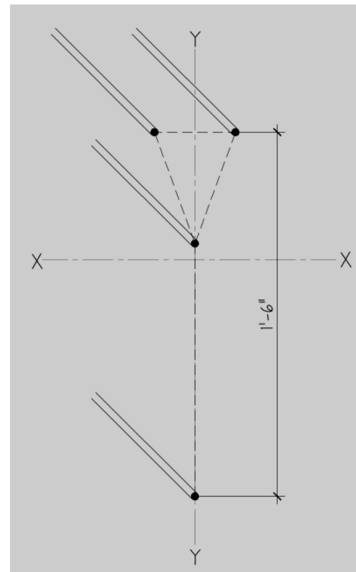
II.4. Girder Profile Concepts

Based on the two top chord design concepts the cross-section each girder will be as follows.

Girder Cross-section Comparison



Or



Figures II.4. A & B

Three different profiles where considered for the shape of the truss longitudinally with the bridge. A flat, slope, and curved bottom chord was considered. Based on the loading in Section II.1. the inertia required is not the same throughout the bridge to resist vertical deflection. Thus where the bending moment reduces the inertia can reduce. This allows the bottom chord structural depth relative to the top chord to reduce where the bending moment in the girder reduces. The following profiles were considered.

Girder Profiles

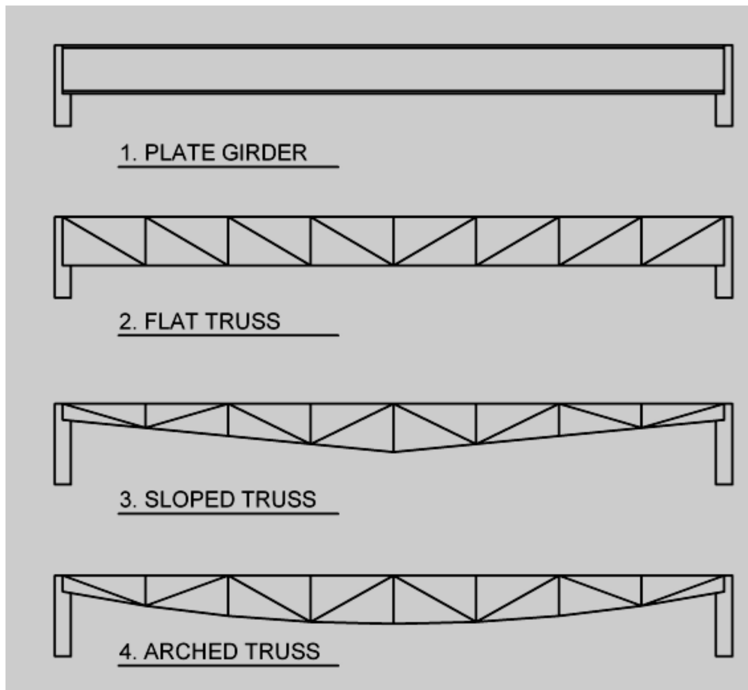


Figure II.4.C.

As stated in Section II.2 Design Philosophy, solid members would be less efficient than trussed section. Therefore, Profile 1 was immediately tossed out from consideration.

Section III: Concept Selection and Preliminary Design

III.1. Component Selection

In order to select chord sections the components cross-section would need to be selected. Several structural shapes were considered including, but not limited to: hollow square tubing, piping, angles, and plate. The selection from these structural shapes was conducted by analyzing the weight of each structural member per foot length. The most realistic and final considered sections can be seen in table II.3.1.A.

Weight Comparison

Structural Members	Weight (lb/ft)
.5” pipe	0.86
.75” pipe	1.15
.25” rod	0.167

Table II.3.1.A.

Based on the above table the use of solid rod was selected to reduce the weight of the bridge. 0.25” solid rod will have a cross-sectional area between that of a 0.5” and a 0.75” pipe.

III.2. Top Chord Selection

Now that the component selection was completed an analysis can be conducted to determine the diameter of the components and which concept will be best. The first step was to determine the required inertia for the loading discussed in Section II.1.

Required Inertia Given Deflection

Req. girder Ixx based on max moment case	
Deflection [in]	**Ixx [in^4]**
0.125	100
0.250	50
0.500	25
0.750	18.75
1.000	12.5

Table III.2.A.

With this now know, the inertia produce by each girder cross-section given various rod diameters.

Rectangular Top Chord

Truss girder made w/ rect top chord and rod bottom chord			
Bot. Rod ø [in]	**Top Rods ø [in]**	**Ixx [in^4]**	**Approx wt. [#/ft]**
0.25	0.25	10.62	0.835
0.375	0.25	17.92	1.044
0.5	0.25	23.6	1.336
0.25	0.375	10.8	1.671
0.375	0.375	23.02	1.88
0.5	0.375	32.12	2.172
0.25	0.5	12.52	2.839
0.375	0.5	26.1	3.048
0.5	0.5	37.09	3.34

Table III.2.B.

Triangular Top Chord

Truss girder made w/ trig. top chord and rod bottom chord			
Bot. Rod ø [in]	**Top Rods ø [in]**	**Ixx [in^4]**	**Approx wt. [#/ft]**
0.25	0.25	8.69	0.668
0.375	0.25	17.49	0.887
0.5	0.25	22.38	1.17
0.25	0.375	10.54	1.295
0.375	0.375	22.98	1.504
0.5	0.375	31.6	1.791
0.25	0.5	11.86	2.171
0.375	0.5	26.07	2.38
0.5	0.5	36.94	2.672

Table III.2.C.

With these three tables it was determine that a triangular top chord consisting of 0.25" diameter rods and a 0.375" diameter bottom chord would provide the least weight for the most stiffness. The inertia required and the inertia possible is based on the inertia in the center of each girder so that the structural depth of the girder is the same for the sloped, flat, and curved girder.

The lateral deflection shown in figure III.2.A. below also had to be considered. The selected section passed the required I_{yy}.

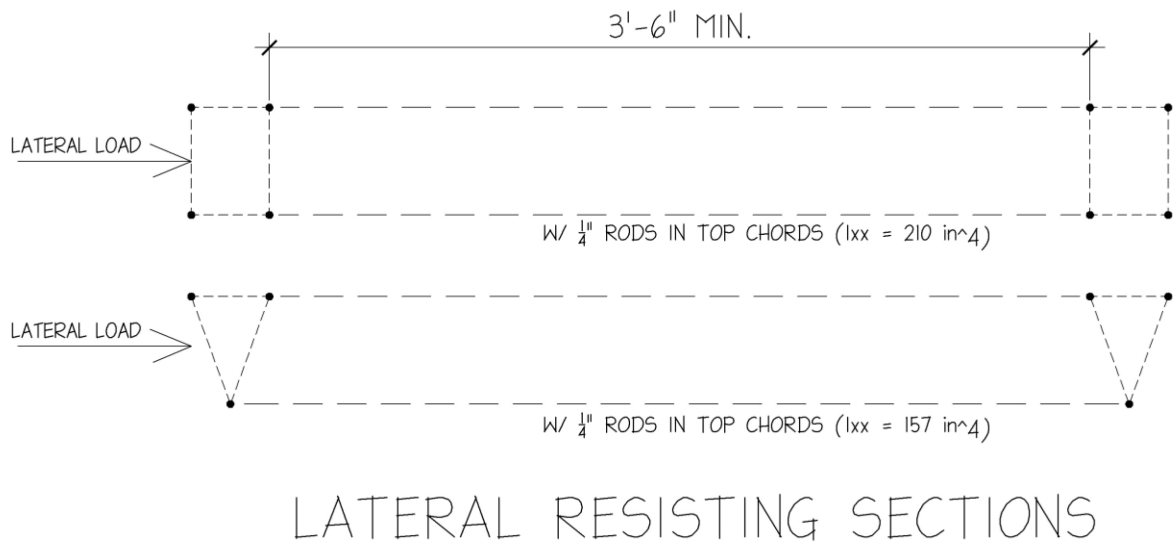


Figure III.2.A.

III.3. Girder Profile Selection

The purpose of the sloped and curved girder concepts was to reduce weight, however reducing the structural depth would sacrifice deflection. In order to select a section an optimization procedure was used. First the deflection of each girder profile using arbitrary structural shapes was determined.

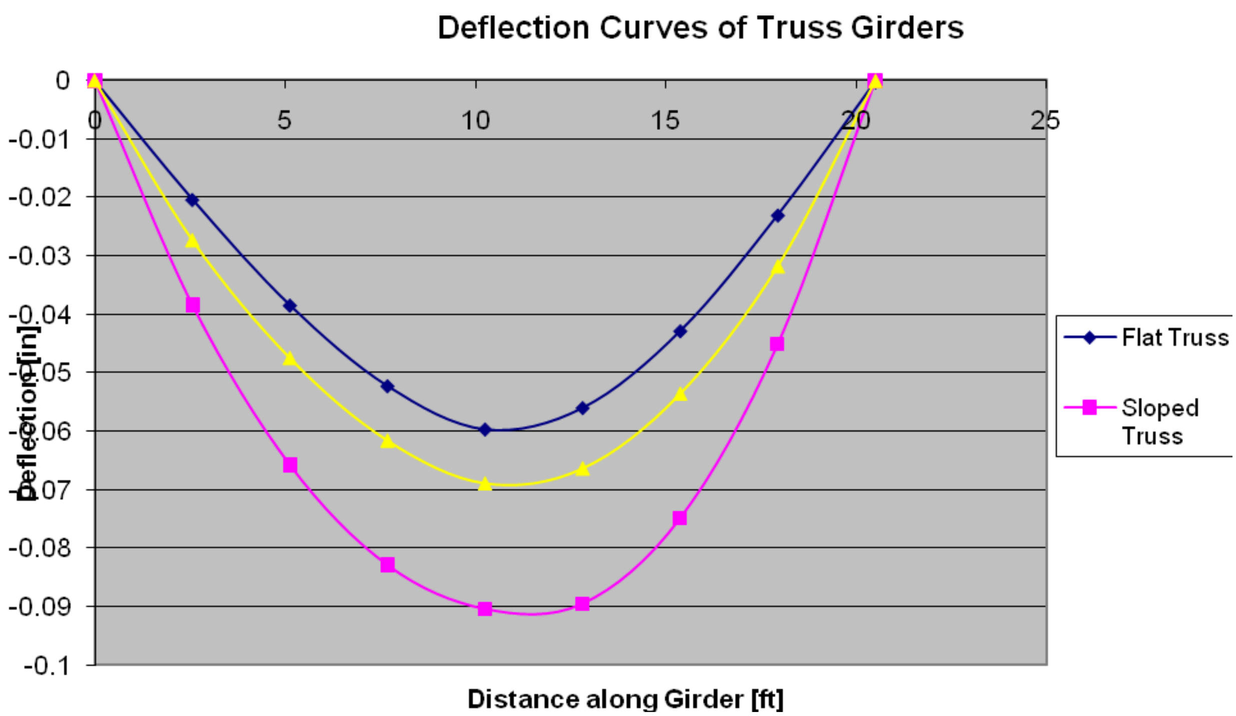


Figure III.3.A.

Then a normalized weight ratio was developed to determine the reduction in weight benefit.

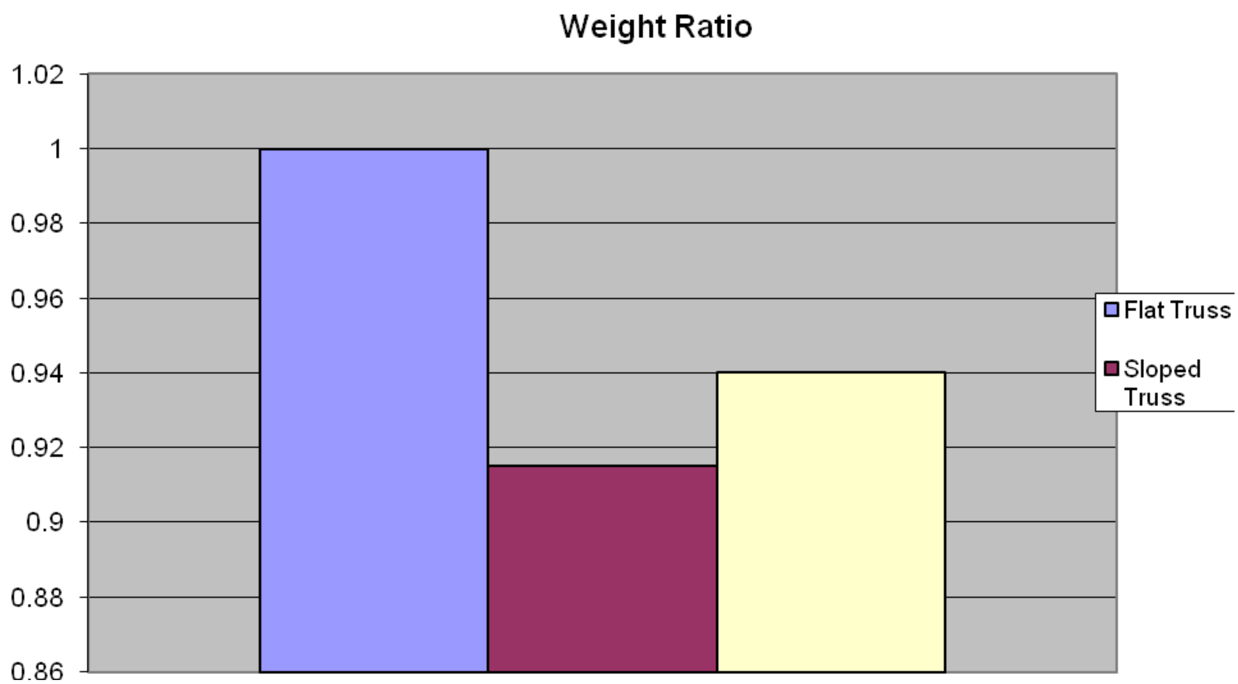


Figure III.3.A.

From these results the slope truss was selected because it adds little deflection to the flat truss and the little weight to the sloped truss. However, as will be seen later in this report, the slope truss does not allow for a solid moment connection at the columns of the bridge, but the flat truss does create a more rigid moment connection. The process was iterated using the selected structural shape.

Section IV: Final Design Process (Software Implementation)

IV.1. Modeling in Structural Analysis software

IV.1.1. Model building

A three dimensional model of the bridge was constructed in a cad software to the selected shapes and specifications stated in the preliminary girder development. Each member is modeled as a single line with the lines ending at each intersection. This will allow the analysis software to assign members to each line and nodes to each intersection. The 3d cad model can be seen in Fig. IV.1.A below.

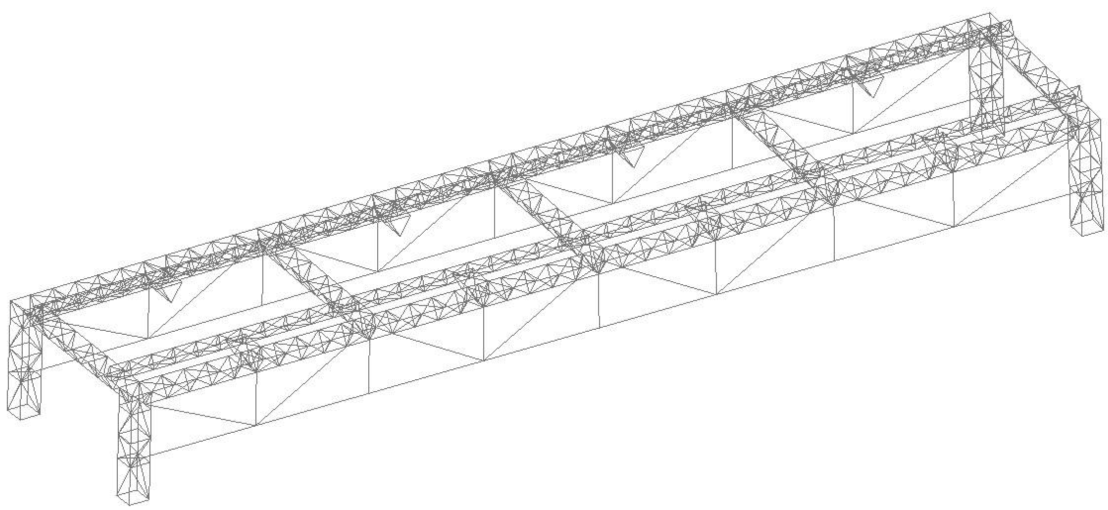


Figure IV.1.A. (3d CAD Model)

IV.1.2. Model Import to Analysis Software

The CAD model was directly imported into the analysis software were all of the lines become single members in the software and any intersect between lines becomes a node in the analysis software. The units/dimensions of the imported model are checked and the building of the structural model comences.

IV.1.3. Assignment of restraints, member sections and materials

The restraints for the bridge are added to the model. One of the bottom nodes on one leg is selected to be a pin restraint and rollers are assigned to the remaining leg bottom nodes. Additional roller supports where added on two legs to restrain the bridge during the lateral load application. Restraints are only added at one of the bottom nodes at each leg due to the fact that a roller support in the program can resist load in the upward and downward direction. This resistance to upward loading is not actually available in the constructed bridge so any resistance to deflection, overturning or bending capacity is that this upward resistance might offer is not favorable. The introduction of restraint at just one node insures that the roller will only support downward loading. The restraints that were used in the analysis can be seen in Figure IV.1.B.

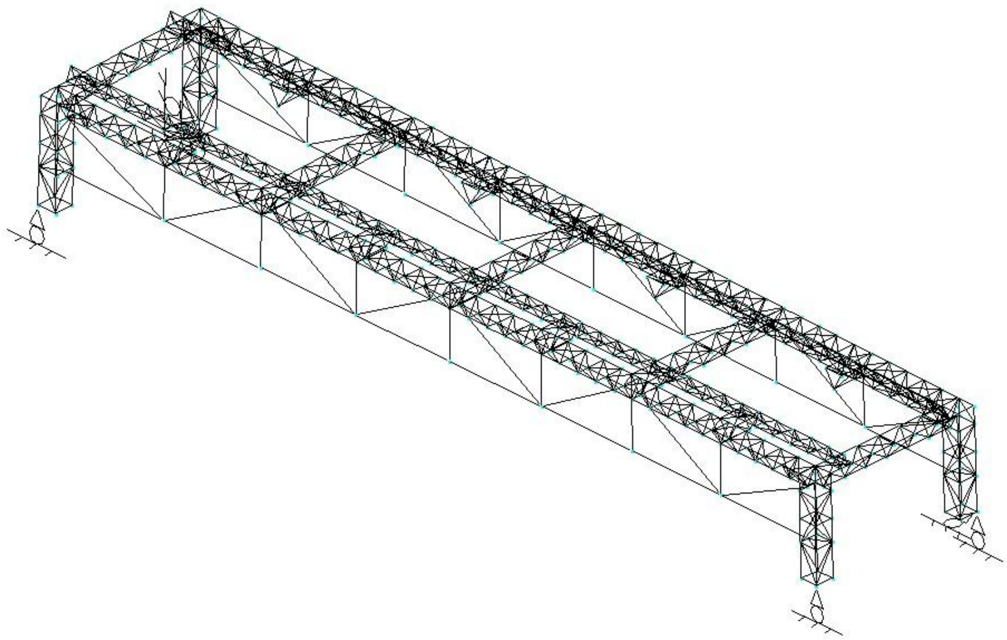


Figure IV.1.B. (Model Restraints)

The members of bridge are assigned a member cross-section and a material by selecting each member and assigning the sections and materials chosen from the preliminary design. Groups of like members are assigned group names to aid in member selection and design. All members were set to A36 steel at the beginning of the analysis process. Each members neutral axis orientation and end restraint conditions are assigned as each member is added to the model.

IV.1.4. Application of Loading to the Model

The loading of the bridge is discussed in section II.1 previously. There is one lateral load test and six possible vertical load test. The vertical loading consists of a 1250# load applied uniformly over a three foot length at two locations on the bridge. The vertical loading is applied to the model by dividing the load in half to the two top rails of the bridge and evenly distributing the each rails load over a three foot length. The lateral load is a single 50# point load applied to the side of the girder in the middle of the span. Load cases are developed for each of these loadings including one for the self weight of the bridge (i.e. Dead Load). Load combinations where then generated to combine each load case with the dead load case. The load cases are tabulated in the load data section below. Graphical representations of each load case are shown in figures Figure IV.1.C through IV.1.I.

Load Data

GLOSSARY

Comb: Indicates if load condition is a load combination (1= load combination. 0 = load case)

Load conditions

Condition	Description	Comb.	Category
DL	Dead Load	0	DL
lat	lateral load	0	lat
s1	roll of 1	0	s1
s2	roll of 2	0	s2
s3	roll of 3	0	s3
s4	roll of 4	0	s4
s5	roll of 5	0	s5
s6	roll of 6	0	s6
c1	1.0dl +1.0lat	1	
c2	1.0dl+1.0s1	1	
c3	1.0dl+1.0s2	1	
c4	1.0dl+1.0s3	1	

c5	1.0dl+1.0s4	1
c6	1.0dl+1.0s5	1
c7	1.0dl+1.0s6	1

Load on nodes

Condition		Node [Kip]	FX [Kip]	FY [Kip]	FZ [Kip*ft]	MX	MY [Kip*ft]	MZ	[Kip*ft]
lat	55	0.00	0.00	0.05	0.00	0.00	0.00		

Distributed force on members

Condition		Member	Dir1 [Kip/ft]	Val1 [Kip/ft]	Val2 [ft]		Dist1 [ft]	%		Dist2	%
lat	1912	Y	-0.0245		-0.0245		0.00	No		100.00	Yes
	1913	Y	-0.0245		-0.0245		0.00	No		100.00	Yes
	1914	Y	-0.0245		-0.0245		0.00	No		100.00	Yes
	1915	Y	-0.0245		-0.0245		0.00	No		100.00	Yes
	1916	Y	-0.0245		-0.0245		0.00	No		100.00	Yes
	1917	Y	-0.0245		-0.0245		0.00	No		100.00	Yes
s1	1533	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1534	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1535	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1536	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1537	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1538	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1550	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1551	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1552	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1553	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1554	Y	-0.2043		-0.2043		0.00	No		100.00	Yes
	1556	Y	-0.2043		-0.2043		0.00	No		100.00	Yes

	1913	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1914	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1915	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1916	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1917	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1918	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1930	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1931	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1932	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1933	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1934	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1936	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
s2	1531	Y	-0.2043	-0.2043	50.00	Yes	100.00	Yes
	1532	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1533	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1534	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1535	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1536	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1537	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes
	1548	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1549	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1550	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1551	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1552	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1553	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1911	Y	-0.2043	-0.2043	50.00	Yes	100.00	Yes
	1912	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1913	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1914	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1915	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1916	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1917	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes
	1928	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1929	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1930	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1931	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1932	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1933	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
s3	1530	Y	-0.2043	-0.2043	25.00	Yes	100.00	Yes
	1531	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1532	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1533	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1534	Y	-0.2043	-0.2043	0.00	No	100.00	Yes

	1535	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1536	Y	-0.2043	-0.2043	0.00	Yes	25.00	Yes
	1545	Y	-0.2043	-0.2043	75.00	Yes	100.00	Yes
	1546	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1547	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1548	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1549	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1550	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1551	Y	-0.2043	-0.2043	0.00	Yes	75.00	Yes
	1910	Y	-0.2043	-0.2043	25.00	Yes	100.00	Yes
	1911	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1912	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1913	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1914	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1915	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1916	Y	-0.2043	-0.2043	0.00	Yes	25.00	Yes
	1925	Y	-0.2043	-0.2043	75.00	Yes	100.00	Yes
	1926	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1927	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1928	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1929	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1930	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1931	Y	-0.2043	-0.2043	0.00	Yes	75.00	Yes
s4	1529	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1530	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1531	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1532	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1533	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1534	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1543	Y	-0.2043	-0.2043	75.00	Yes	100.00	Yes
	1544	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1545	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1546	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1547	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1548	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1549	Y	-0.2043	-0.2043	0.00	Yes	75.00	Yes
	1909	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1910	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1911	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1912	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1913	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1914	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1923	Y	-0.2043	-0.2043	75.00	Yes	100.00	Yes

	1924	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1925	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1926	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1927	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1928	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1929	Y	-0.2043	-0.2043	0.00	Yes	75.00	Yes
s5	1527	Y	-0.2043	-0.2043	66.00	Yes	100.00	Yes
	1528	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1529	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1530	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1531	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1532	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1533	Y	-0.2043	-0.2043	0.00	Yes	66.00	Yes
	1541	Y	-0.2043	-0.2043	50.00	Yes	100.00	Yes
	1542	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1543	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1544	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1545	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1546	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1547	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes
	1907	Y	-0.2043	-0.2043	66.00	Yes	100.00	Yes
	1908	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1909	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1910	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1911	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1912	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1913	Y	-0.2043	-0.2043	0.00	Yes	66.00	Yes
	1921	Y	-0.2043	-0.2043	50.00	Yes	100.00	Yes
	1922	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1923	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1924	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1925	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1926	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1927	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes
s6	1526	Y	-0.2043	-0.2043	33.00	Yes	100.00	Yes
	1527	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1528	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1529	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1530	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1531	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1532	Y	-0.2043	-0.2043	0.00	Yes	33.00	Yes
	1539	Y	-0.2043	-0.2043	66.00	Yes	100.00	Yes
	1540	Y	-0.2043	-0.2043	0.00	No	100.00	Yes

1541	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1542	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1543	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1544	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1545	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes
1906	Y	-0.2043	-0.2043	33.00	Yes	100.00	Yes
1907	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1908	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1909	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1910	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1911	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1912	Y	-0.2043	-0.2043	0.00	Yes	33.00	Yes
1919	Y	-0.2043	-0.2043	66.00	Yes	100.00	Yes
1920	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1921	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1922	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1923	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1924	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
1925	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes

Self weight multipliers for load conditions

Condition	Self weight multiplier Description	Comb.	MultX	MultY	MultZ
DL	Dead Load	0	0.00	-1.00	0.00
lat	lateral load	0	0.00	0.00	0.00
s1	roll of 1	0	0.00	0.00	0.00
s2	roll of 2	0	0.00	0.00	0.00
s3	roll of 3	0	0.00	0.00	0.00
s4	roll of 4	0	0.00	0.00	0.00
s5	roll of 5	0	0.00	0.00	0.00
s6	roll of 6	0	0.00	0.00	0.00
c1	1.0dl +1.0lat	1	0.00	0.00	0.00
c2	1.0dl+1.0s1	1	0.00	0.00	0.00
c3	1.0dl+1.0s2	1	0.00	0.00	0.00
c4	1.0dl+1.0s3	1	0.00	0.00	0.00
c5	1.0dl+1.0s4	1	0.00	0.00	0.00

c6	1.0dl+1.0s5	1	0.00	0.00	0.00
c7	1.0dl+1.0s6	1	0.00	0.00	0.00

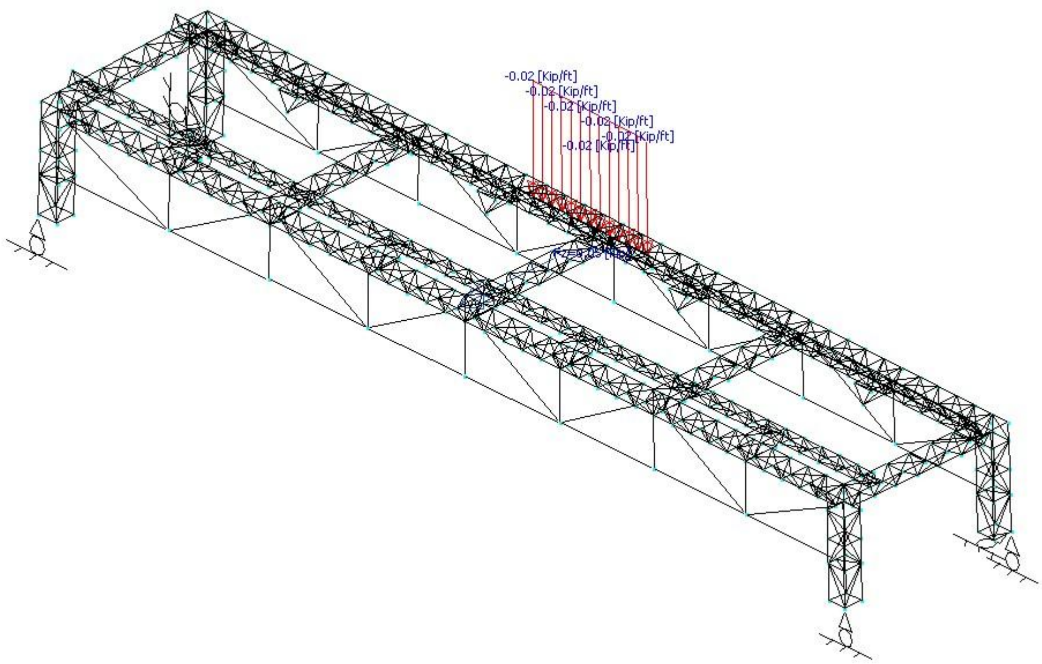


Figure IV.1.C. (Load Case C1)

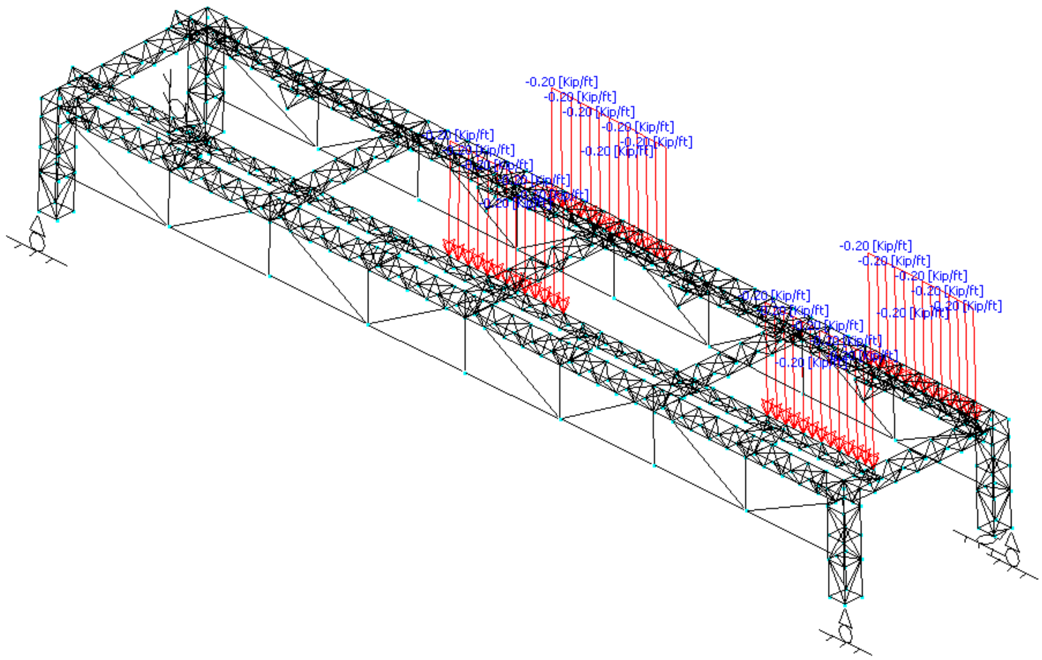


Figure IV.1.D. (Load Case C2)

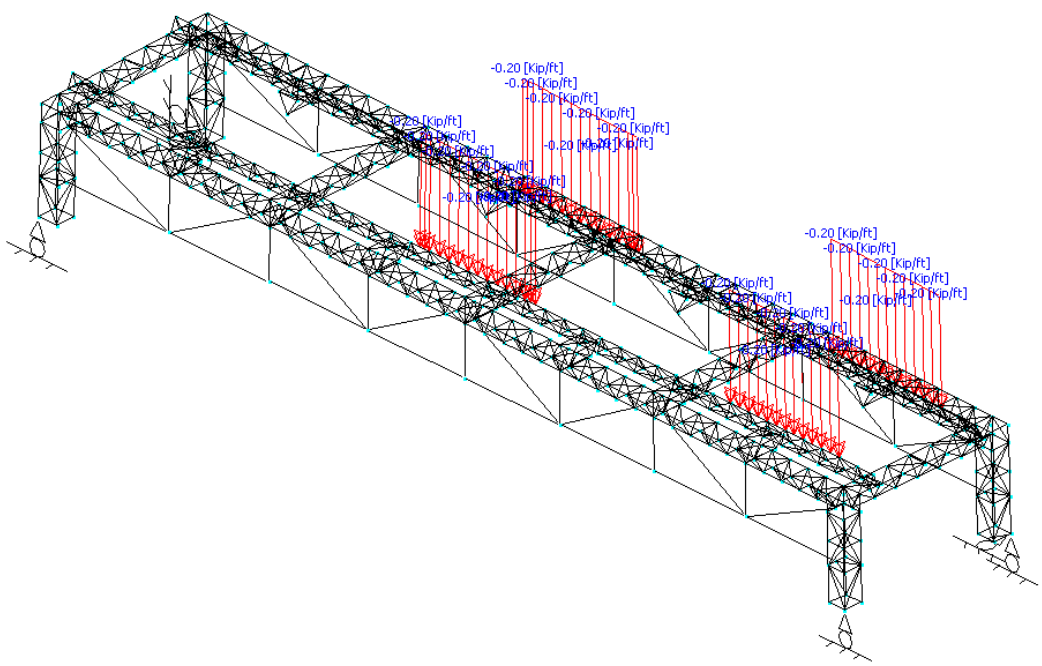


Figure IV.1.E. (Load Case C3)

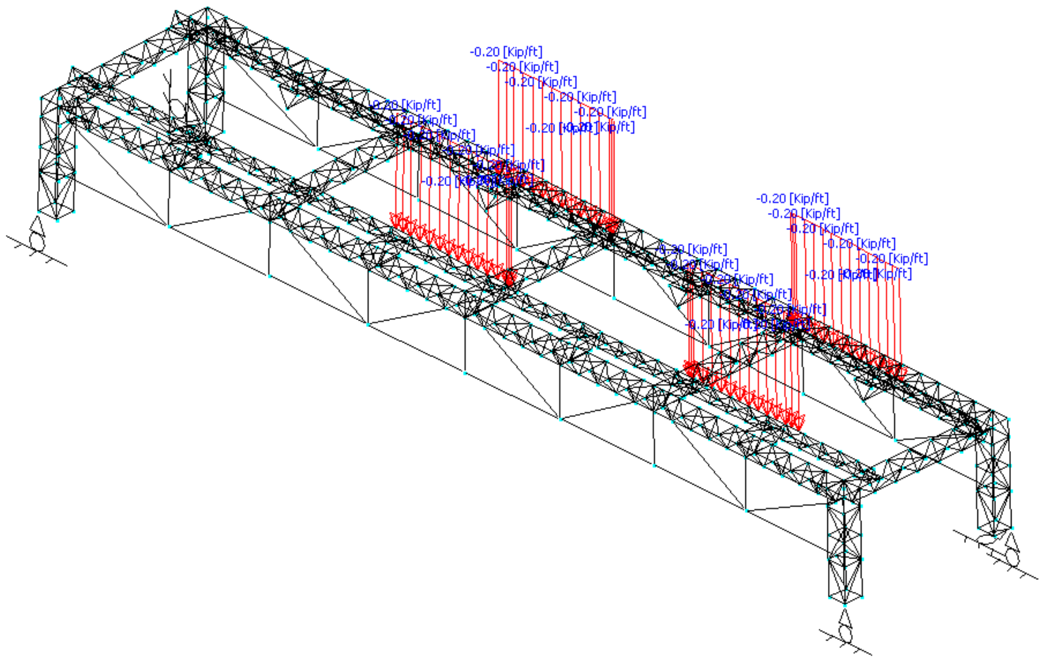


Figure IV.1.F. (Load Case C4)

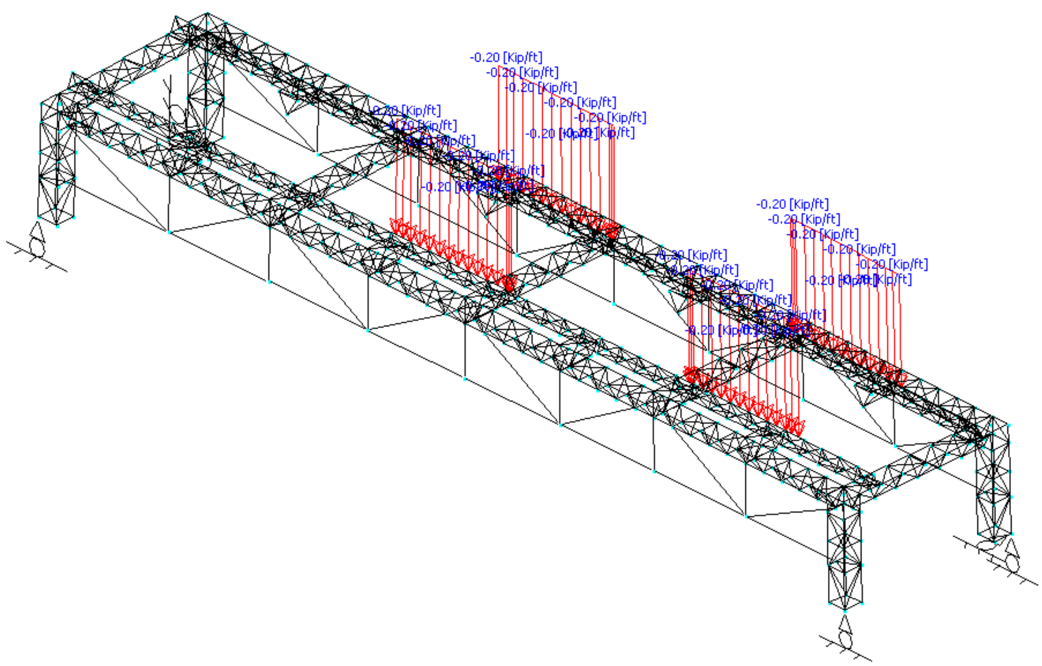


Figure IV.1.G. (Load Case C5)

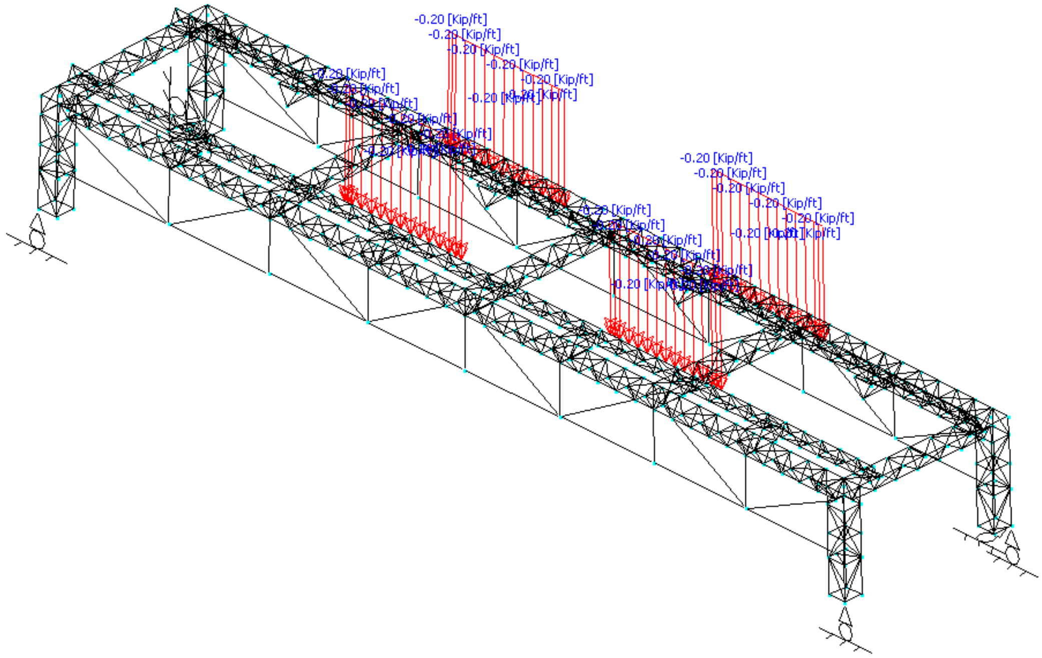


Figure IV.1.H. (Load Case C6)

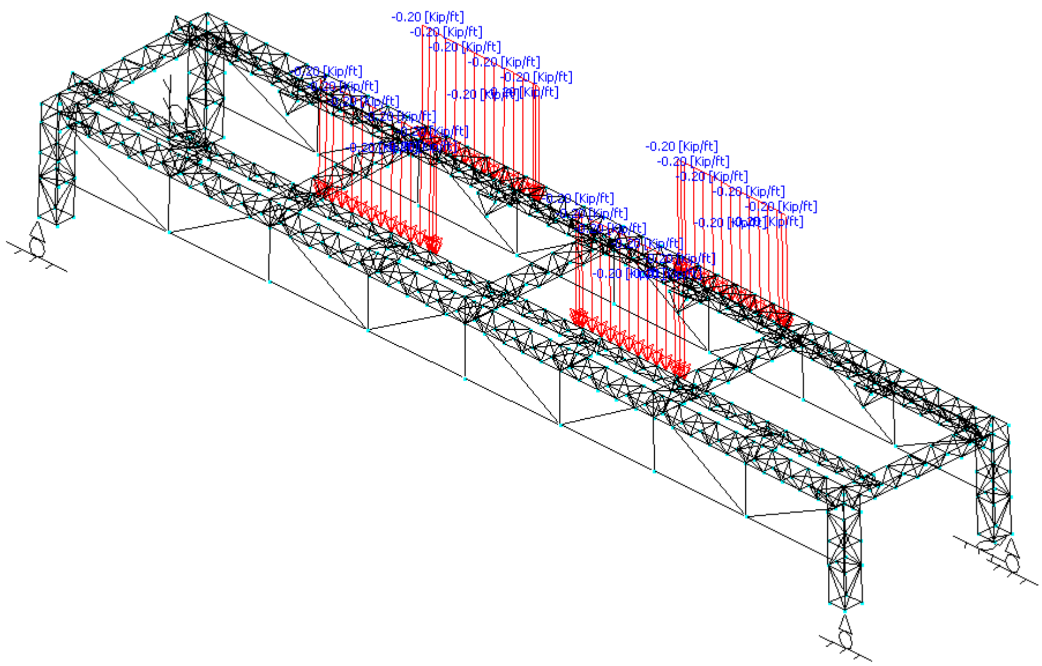


Figure IV.1.I. (Load Case C7)

IV.1.5. Completing Analysis Iterations

The model was than analysis using the software to find the principal stresses of each member and the deflection of the whole bridge. Several iterations of analysis were preformed with member cross-sections being optimized between each iteration. The design module in the software could not be utilized since it would design each member to a specific building code which would add excess weight to bridge through use of high factors of safety. The analysis iterations were preformed until each member was close to the yield strength of the material. Many of the highly stressed members where changed from A36 steel to 1018 steel to take advantage of the higher yield strength of the 1018 which in turn allowed small cross sections for the members. Compression members where designed using the ultimate force in each member given by the software and comparing it to calculations of critical buckling for several built up cross sections using the standard member cross sections.

Section V: Final Design Analysis (Theoretical Results)

V.1. Final Analysis and Design Results

V.1.1. Analysis results

The analysis software was used to find the ultimate stresses and forces in each member the deflection of the whole bridge and the approximate weight of the bridge. This data was used to design each member in the bridge either by use of the yield strength of the material or through critical bucking calculations using the ultimate compression force in the member. Members that are always in tension could be designed using the analysis software by simply providing the lightest section that was below the yield strength of the material. Compression members where studied individually using the ultimate force developed in the member. The buckling capacity of the member is highly dependent on the end restraints of the member so the buckling analysis for each member was studied for a pinned and fixed end restraint. The reinforcing of compression members was not completed until the bridge construction was finished. 1/8” webbing was provided in each trussed member in the bridge for ease of fabrication. Compression members that had forces well beyond the buckling capacity of one or two 1/8 rods were reinforced with one ¼” rod before any loading was applied to the bridge. Loading of the bridge and observation were used to find any additional members in need of reinforcement. A sample of the analysis software output is shown in the Analysis Report section below. Figure V.1.A shows the members that relate to the analysis. The deflection analysis is tabulated for each load case in the

Translations Section below. The data in the translation section is the deflection of a node from its original coordinates. The TY column of the data would be the vertical deflection of the nodes shown in figure V.1.B.

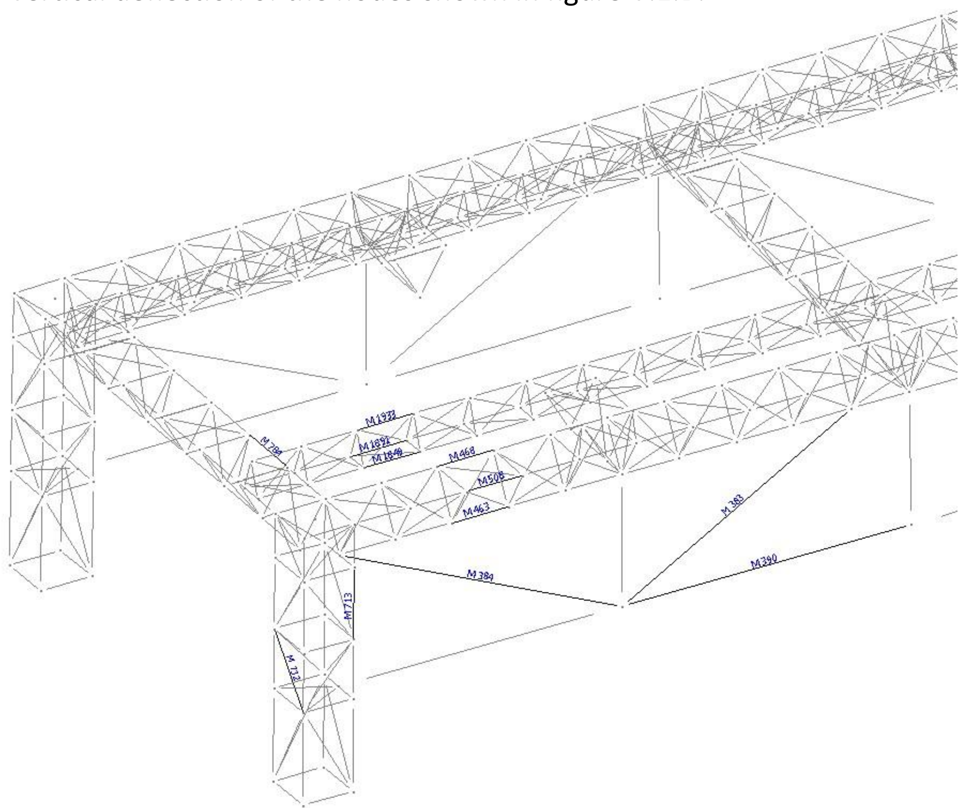


Figure V.1.A. (Members for sample results)

Analysis Results

Member stresses

Location of the fibers with maximum bending stresses

CONDITION : c1=1.0dl +1.0lat

		Bending					
Station	Axial	Shear V2	Shear V3	2-Pos	2-Neg	3-Pos	3-Neg
	[Kip/in2]	[Kip/in2]	[Kip/in2]	[Kip/in2]	[Kip/in2]	[Kip/in2]	[Kip/in2]

MEMBER 390

0%	1.72	0.01	0.00	0.47	-0.47	0.07	-0.07
50%	1.72	0.00	0.00	-0.34	0.34	0.06	-0.06
100%	1.72	0.01	0.00	0.31	-0.31	0.05	-0.05

MEMBER 383

0%	-1.94	0.01	0.00	0.00	0.00	0.13	-0.13
50%	-1.94	0.00	0.00	-0.81	0.81	0.07	-0.07
100%	-1.94	0.01	0.00	0.00	0.00	0.00	0.00

MEMBER 384

0%	2.20	0.01	0.00	0.00	0.00	0.04	-0.04
50%	2.20	0.00	0.00	-1.21	1.21	-0.05	0.05
100%	2.20	0.01	0.00	0.00	0.00	-0.13	0.13

MEMBER 713

0%	-1.95	0.01	0.01	-0.27	0.27	0.07	-0.07
50%	-1.95	0.01	0.01	0.08	-0.08	-0.17	0.17
100%	-1.94	0.01	0.01	0.43	-0.43	-0.40	0.40

MEMBER 732

0%	1.13	0.00	0.00	-0.04	0.04	0.03	-0.03
50%	1.13	0.00	0.00	-0.08	0.08	-0.01	0.01
100%	1.13	0.00	0.00	0.09	-0.09	-0.05	0.05

MEMBER 463

0%	-0.75	0.01	0.01	0.01	-0.01	0.14	-0.14
50%	-0.75	0.01	0.01	-0.01	0.01	0.00	0.00
100%	-0.75	0.01	0.01	0.06	-0.06	-0.14	0.14

MEMBER 508

0%	-0.73	0.00	0.00	-0.06	0.06	0.00	0.00
50%	-0.73	0.01	0.00	0.00	0.00	0.02	-0.02
100%	-0.73	0.01	0.00	0.16	-0.16	0.04	-0.04

MEMBER 468

0%	0.02	0.01	0.00	0.07	-0.07	-0.02	0.02
50%	0.02	0.00	0.00	-0.02	0.02	0.00	0.00
100%	0.02	0.00	0.00	-0.02	0.02	0.03	-0.03

MEMBER 1849

0%	0.14	0.01	0.01	0.07	-0.07	-0.12	0.12
50%	0.14	0.01	0.01	0.00	0.00	-0.08	0.08

100%	0.14	0.01	0.01	-0.01	0.01	-0.04	0.04

MEMBER 1933

0%	-0.07	0.00	0.01	-0.01	0.01	0.06	-0.06
50%	-0.07	0.00	0.01	0.00	0.00	-0.03	0.03
100%	-0.07	0.01	0.01	0.08	-0.08	-0.11	0.11

MEMBER 1891

0%	-0.78	0.00	0.01	-0.08	0.08	-0.21	0.21
50%	-0.78	0.00	0.01	0.00	0.00	0.05	-0.05
100%	-0.78	0.00	0.01	0.15	-0.15	0.31	-0.31

MEMBER 784

0%	-1.18	0.01	0.01	-0.31	0.31	0.10	-0.10
50%	-1.18	0.01	0.01	0.17	-0.17	-0.29	0.29
100%	-1.18	0.01	0.01	0.73	-0.73	-0.69	0.69

CONDITION : c2=1.0dl+1.0s1

		Bending						
Station	Axial	Shear V2		Shear V3		2-Pos	2-Neg 3-Pos	3-Neg
	[Kip/in2]		[Kip/in2]		[Kip/in2]		[Kip/in2]	[Kip/in2]
		[Kip/in2]		[Kip/in2]				

MEMBER 390

0%	14.90	0.03	0.02	-0.10	0.10	0.84	-0.84
50%	14.90	0.02	0.02	-0.64	0.64	0.10	-0.10
100%	14.90	0.03	0.02	0.29	-0.29	-0.63	0.63

MEMBER 383

0%	-14.39	0.02	0.02	0.00	0.00	1.48	-1.48
50%	-14.40	0.02	0.02	-0.81	0.81	0.17	-0.17
100%	-14.40	0.02	0.02	0.00	0.00	-1.13	1.13

MEMBER 384

0%	19.52	0.02	0.02	0.00	0.00	-1.51	1.51
50%	19.52	0.01	0.02	-1.21	1.21	0.12	-0.12
100%	19.53	0.02	0.02	0.00	0.00	1.75	-1.75

MEMBER 713

0%	-7.18	0.02	0.01	-1.74	1.74	0.15	-0.15
50%	-7.18	0.02	0.01	-0.05	0.05	-0.15	0.15
100%	-7.17	0.02	0.01	1.63	-1.63	-0.46	0.46

MEMBER 732

0%	-3.49	0.01	0.01	0.19	-0.19	0.86	-0.86
50%	-3.48	0.01	0.01	-0.14	0.14	0.27	-0.27
100%	-3.48	0.01	0.01	-0.25	0.25	-0.33	0.33

MEMBER 463

0%	-3.13	0.06	0.07	0.17	-0.17	0.92	-0.92
50%	-3.13	0.06	0.07	0.13	-0.13	0.14	-0.14
100%	-3.13	0.06	0.07	0.18	-0.18	-0.65	0.65

MEMBER 508

0%	-3.60	0.07	0.06	-0.51	0.51	-0.22	0.22
50%	-3.60	0.07	0.06	0.12	-0.12	0.01	-0.01
100%	-3.60	0.07	0.06	0.83	-0.83	0.25	-0.25

MEMBER 468

0%	0.21	0.06	0.06	-1.01	1.01	-0.84	0.84
50%	0.21	0.06	0.06	-0.49	0.49	-0.11	0.11
100%	0.21	0.06	0.06	0.11	-0.11	0.63	-0.63

MEMBER 1849

0%	2.11	0.03	0.03	-0.51	0.51	0.89	-0.89
50%	2.11	0.03	0.03	-1.54	1.54	-0.52	0.52
100%	2.11	0.03	0.03	-2.50	2.50	-1.93	1.93

MEMBER 1933

0%	-9.74	0.77	0.12	17.33	-17.33	3.31	-3.31
50%	-9.74	0.09	0.12	-10.47	10.47	0.48	-0.48
100%	-9.74	0.76	0.12	16.85	-16.85	-2.35	2.35

MEMBER 1891

0%	-0.88	0.21	0.22	-1.76	1.76	-0.16	0.16
50%	-0.88	0.21	0.22	-1.45	1.45	0.66	-0.66
100%	-0.88	0.21	0.22	-1.07	1.07	1.48	-1.48

MEMBER 784

0%	-9.91	0.27	0.12	-8.04	8.04	2.34	-2.34
50%	-9.91	0.27	0.12	9.25	-9.25	-3.66	3.66
100%	-9.91	0.27	0.12	26.61	-26.61	-9.66	9.66

CONDITION : c3=1.0dl+1.0s2

		Bending							
Station	Axial	Shear V2		Shear V3		2-Pos	2-Neg	3-Pos	3-Neg
	[Kip/in2]		[Kip/in2]		[Kip/in2]		[Kip/in2]		[Kip/in2]
		[Kip/in2]		[Kip/in2]					
MEMBER	390								
0%	16.74	0.02	0.02	-0.21	0.21	0.93	-0.93		
50%	16.74	0.02	0.02	-0.71	0.71	-0.08	0.08		
100%	16.74	0.02	0.02	0.27	-0.27	-1.09	1.09		
MEMBER	383								
0%	-15.71	0.02	0.02	0.00	0.00	2.03	-2.03		
50%	-15.71	0.02	0.02	-0.81	0.81	0.16	-0.16		
100%	-15.72	0.02	0.02	0.00	0.00	-1.70	1.70		
MEMBER	384								
0%	22.65	0.03	0.03	0.00	0.00	-2.46	2.46		
50%	22.65	0.02	0.03	-1.21	1.21	0.15	-0.15		
100%	22.65	0.03	0.03	0.00	0.00	2.75	-2.75		
MEMBER	713								
0%	-6.95	0.01	0.00	-1.65	1.65	0.19	-0.19		
50%	-6.95	0.01	0.00	-0.05	0.05	-0.16	0.16		
100%	-6.95	0.01	0.00	1.54	-1.54	-0.50	0.50		
MEMBER	732								
0%	-3.01	0.01	0.01	0.23	-0.23	0.83	-0.83		
50%	-3.01	0.01	0.01	-0.16	0.16	0.26	-0.26		
100%	-3.00	0.01	0.01	-0.34	0.34	-0.32	0.32		
MEMBER	463								
0%	-3.28	0.10	0.11	0.26	-0.26	0.96	-0.96		
50%	-3.28	0.10	0.11	0.18	-0.18	0.14	-0.14		
100%	-3.28	0.10	0.11	0.19	-0.19	-0.68	0.68		
MEMBER	508								
0%	-3.29	0.10	0.10	-0.56	0.56	-0.31	0.31		
50%	-3.29	0.11	0.10	0.11	-0.11	-0.05	0.05		
100%	-3.29	0.11	0.10	0.87	-0.87	0.21	-0.21		
MEMBER	468								
0%	0.79	0.11	0.11	-1.48	1.48	-0.93	0.93		
50%	0.79	0.11	0.11	-0.63	0.63	-0.15	0.15		

100%	0.79	0.11	0.11	0.30	-0.30	0.63	-0.63

MEMBER 1849

0%	2.01	0.09	0.09	-0.60	0.60	0.94	-0.94
50%	2.01	0.09	0.09	-1.44	1.44	-0.51	0.51
100%	2.01	0.08	0.09	-2.22	2.22	-1.96	1.96

MEMBER 1933

0%	-10.18	0.85	0.14	19.25	-19.25	3.52	-3.52
50%	-10.18	0.17	0.14	-13.38	13.38	0.73	-0.73
100%	-10.18	0.73	0.14	9.10	-9.10	-2.06	2.06

MEMBER 1891

0%	-1.87	0.24	0.25	-2.11	2.11	-0.21	0.21
50%	-1.87	0.24	0.25	-1.40	1.40	0.78	-0.78
100%	-1.87	0.24	0.25	-0.63	0.63	1.76	-1.76

MEMBER 784

0%	-9.89	0.27	0.15	-7.51	7.51	2.75	-2.75
50%	-9.89	0.27	0.15	8.44	-8.44	-4.04	4.04
100%	-9.89	0.27	0.15	24.47	-24.47	-10.83	10.83

CONDITION : c4=1.0dl+1.0s3

Station	Axial [Kip/in2]	Bending Shear V2 [Kip/in2]	[Kip/in2]	Shear V3 [Kip/in2]	[Kip/in2]	2-Pos	2-Neg [Kip/in2]	3-Pos	3-Neg [Kip/in2]

MEMBER 390

0%	18.73	0.02	0.02	-0.35	0.35	0.79	-0.79
50%	18.73	0.02	0.02	-0.78	0.78	-0.14	0.14
100%	18.73	0.02	0.02	0.27	-0.27	-1.07	1.07

MEMBER 383

0%	-18.21	0.02	0.02	0.00	0.00	1.95	-1.95
50%	-18.21	0.02	0.02	-0.81	0.81	0.12	-0.12
100%	-18.22	0.02	0.02	0.00	0.00	-1.70	1.70

MEMBER 384

0%	25.28	0.03	0.03	0.00	0.00	-2.50	2.50
50%	25.28	0.03	0.03	-1.21	1.21	0.19	-0.19
100%	25.29	0.03	0.03	0.00	0.00	2.89	-2.89

MEMBER 713

0%	-6.68	0.01	0.00	-1.55	1.55	0.23	-0.23
50%	-6.68	0.01	0.00	-0.05	0.05	-0.19	0.19
100%	-6.68	0.01	0.00	1.45	-1.45	-0.61	0.61

MEMBER 732

0%	-2.79	0.01	0.01	0.25	-0.25	0.78	-0.78
50%	-2.79	0.01	0.01	-0.17	0.17	0.24	-0.24
100%	-2.79	0.01	0.01	-0.38	0.38	-0.30	0.30

MEMBER 463

0%	-4.43	0.11	0.11	0.33	-0.33	1.04	-1.04
50%	-4.43	0.10	0.11	0.23	-0.23	0.09	-0.09
100%	-4.43	0.10	0.11	0.22	-0.22	-0.86	0.86

MEMBER 508

0%	-3.47	0.11	0.10	-0.59	0.59	-0.38	0.38
50%	-3.47	0.11	0.10	0.16	-0.16	-0.08	0.08
100%	-3.47	0.11	0.10	0.99	-0.99	0.21	-0.21

MEMBER 468

0%	0.71	0.11	0.12	-0.99	0.99	-1.07	1.07
50%	0.71	0.11	0.12	-0.46	0.46	-0.19	0.19
100%	0.71	0.11	0.12	0.16	-0.16	0.69	-0.69

MEMBER 1849

0%	-1.05	0.11	0.11	0.63	-0.63	0.32	-0.32
50%	-1.05	0.11	0.11	-0.51	0.51	-0.60	0.60
100%	-1.05	0.11	0.11	-1.59	1.59	-1.53	1.53

MEMBER 1933

0%	-5.56	0.11	0.12	-1.89	1.89	2.31	-2.31
50%	-5.56	0.11	0.12	-0.82	0.82	0.55	-0.55
100%	-5.56	0.11	0.12	0.32	-0.32	-1.22	1.22

MEMBER 1891

0%	-3.88	0.22	0.23	-0.98	0.98	-0.96	0.96
50%	-3.88	0.22	0.23	-0.53	0.53	0.75	-0.75
100%	-3.88	0.22	0.23	0.00	0.00	2.46	-2.46

MEMBER 784

0%	-8.98	0.21	0.14	-6.01	6.01	2.72	-2.72

50%	-8.98	0.22	0.14	6.41	-6.41	-3.99	3.99
100%	-8.98	0.22	0.14	18.90	-18.90	-10.70	10.70

CONDITION : c5=1.0dl+1.0s4

Bending
Station Axial Shear V2 Shear V3 2-Pos 2-Neg 3-Pos 3-Neg
[Kip/in2] [Kip/in2] [Kip/in2] [Kip/in2] [Kip/in2]
[Kip/in2] [Kip/in2]

MEMBER 390

0%	19.96	0.02	0.02	-0.45	0.45	0.50	-0.50
50%	19.96	0.02	0.02	-0.82	0.82	-0.07	0.07
100%	19.96	0.02	0.02	0.28	-0.28	-0.65	0.65

MEMBER 383

0%	-20.58	0.02	0.01	0.00	0.00	1.36	-1.36
50%	-20.59	0.01	0.01	-0.81	0.81	0.07	-0.07
100%	-20.59	0.02	0.01	0.00	0.00	-1.21	1.21

MEMBER 384

0%	26.27	0.03	0.03	0.00	0.00	-1.72	1.72
50%	26.27	0.02	0.03	-1.21	1.21	0.24	-0.24
100%	26.27	0.03	0.03	0.00	0.00	2.20	-2.20

MEMBER 713

0%	-6.45	0.01	0.01	-1.46	1.46	0.25	-0.25
50%	-6.45	0.01	0.01	-0.04	0.04	-0.21	0.21
100%	-6.45	0.01	0.01	1.37	-1.37	-0.68	0.68

MEMBER 732

0%	-2.79	0.01	0.01	0.25	-0.25	0.75	-0.75
50%	-2.79	0.01	0.01	-0.17	0.17	0.23	-0.23
100%	-2.79	0.01	0.01	-0.38	0.38	-0.29	0.29

MEMBER 463

0%	-5.76	0.08	0.09	0.32	-0.32	1.12	-1.12
50%	-5.76	0.08	0.09	0.25	-0.25	0.04	-0.04
100%	-5.76	0.08	0.09	0.26	-0.26	-1.05	1.05

MEMBER 508

0%	-4.01	0.08	0.07	-0.57	0.57	-0.38	0.38
50%	-4.01	0.08	0.07	0.23	-0.23	-0.07	0.07

100%	-4.01	0.08	0.07	1.11	-1.11	0.25	-0.25

MEMBER 468

0%	0.28	0.08	0.08	-0.03	0.03	-1.18	1.18
50%	0.28	0.07	0.08	-0.14	0.14	-0.21	0.21
100%	0.28	0.07	0.08	-0.16	0.16	0.75	-0.75

MEMBER 1849

0%	-2.67	0.09	0.09	0.85	-0.85	-0.20	0.20
50%	-2.67	0.09	0.09	-0.23	0.23	-0.71	0.71
100%	-2.67	0.09	0.09	-1.23	1.23	-1.22	1.22

MEMBER 1933

0%	-2.82	0.07	0.09	-0.22	0.22	1.69	-1.69
50%	-2.82	0.08	0.09	-0.11	0.11	0.35	-0.35
100%	-2.82	0.08	0.09	0.08	-0.08	-0.99	0.99

MEMBER 1891

0%	-4.50	0.17	0.19	-0.73	0.73	-1.45	1.45
50%	-4.50	0.17	0.19	-0.25	0.25	0.63	-0.63
100%	-4.50	0.17	0.19	0.29	-0.29	2.70	-2.70

MEMBER 784

0%	-7.83	0.16	0.12	-4.63	4.63	2.49	-2.49
50%	-7.83	0.16	0.12	4.62	-4.62	-3.73	3.73
100%	-7.83	0.16	0.12	13.95	-13.95	-9.95	9.95

CONDITION : c6=1.0dl+1.0s5

Bending
Station Axial Shear V2 Shear V3 2-Pos 2-Neg 3-Pos 3-Neg
[Kip/in2] [Kip/in2] [Kip/in2] [Kip/in2] [Kip/in2]
[Kip/in2] [Kip/in2]

MEMBER 390

0%	20.52	0.03	0.03	-0.47	0.47	0.30	-0.30
50%	20.52	0.03	0.03	-0.82	0.82	0.09	-0.09
100%	20.52	0.03	0.03	0.29	-0.29	-0.12	0.12

MEMBER 383

0%	-22.45	0.01	0.01	0.00	0.00	0.69	-0.69
50%	-22.46	0.01	0.01	-0.81	0.81	0.03	-0.03
100%	-22.46	0.01	0.01	0.00	0.00	-0.62	0.62

MEMBER 384

0%	26.15	0.02	0.02	0.00	0.00	-0.65	0.65
50%	26.15	0.02	0.02	-1.21	1.21	0.29	-0.29
100%	26.16	0.02	0.02	0.00	0.00	1.23	-1.23

MEMBER 713

0%	-6.15	0.01	0.01	-1.35	1.35	0.25	-0.25
50%	-6.15	0.01	0.01	-0.04	0.04	-0.23	0.23
100%	-6.15	0.01	0.01	1.27	-1.27	-0.71	0.71

MEMBER 732

0%	-2.81	0.01	0.01	0.24	-0.24	0.72	-0.72
50%	-2.81	0.01	0.01	-0.17	0.17	0.21	-0.21
100%	-2.81	0.01	0.01	-0.36	0.36	-0.29	0.29

MEMBER 463

0%	-6.84	0.04	0.05	0.27	-0.27	1.22	-1.22
50%	-6.84	0.04	0.05	0.24	-0.24	0.01	-0.01
100%	-6.84	0.04	0.05	0.30	-0.30	-1.21	1.21

MEMBER 508

0%	-4.56	0.04	0.03	-0.53	0.53	-0.31	0.31
50%	-4.56	0.04	0.03	0.29	-0.29	-0.02	0.02
100%	-4.56	0.04	0.03	1.20	-1.20	0.27	-0.27

MEMBER 468

0%	-0.14	0.04	0.04	0.74	-0.74	-1.22	1.22
50%	-0.14	0.04	0.04	0.12	-0.12	-0.21	0.21
100%	-0.14	0.04	0.04	-0.42	0.42	0.81	-0.81

MEMBER 1849

0%	-3.51	0.06	0.05	0.96	-0.96	-0.47	0.47
50%	-3.51	0.06	0.05	-0.04	0.04	-0.77	0.77
100%	-3.51	0.06	0.05	-0.96	0.96	-1.06	1.06

MEMBER 1933

0%	-1.11	0.04	0.06	0.02	-0.02	1.32	-1.32
50%	-1.11	0.04	0.06	0.04	-0.04	0.22	-0.22
100%	-1.11	0.05	0.06	0.14	-0.14	-0.88	0.88

MEMBER 1891

0%	-4.57	0.11	0.13	-0.57	0.57	-1.68	1.68

50% -4.57 0.11 0.13 -0.07 0.07 0.52 -0.52
100% -4.57 0.11 0.13 0.51 -0.51 2.72 -2.72

MEMBER 784
0% -6.66 0.11 0.10 -3.41 3.41 2.21 -2.21
50% -6.66 0.11 0.10 3.10 -3.10 -3.41 3.41
100% -6.66 0.11 0.10 9.69 -9.69 -9.04 9.04

CONDITION : c7=1.0dl+1.0s6

Station	Axial [Kip/in2]	Bending Shear V2 [Kip/in2]	Shear V3 [Kip/in2]	2-Pos [Kip/in2]	2-Neg [Kip/in2]	3-Pos [Kip/in2]	3-Neg [Kip/in2]
MEMBER 390							
0%	19.80	0.04	0.04	-0.38	0.38	0.33	-0.33
50%	19.80	0.04	0.04	-0.78	0.78	0.26	-0.26
100%	19.80	0.04	0.04	0.30	-0.30	0.19	-0.19
MEMBER 383							
0%	-22.41	0.02	0.01	0.00	0.00	0.36	-0.36
50%	-22.42	0.01	0.01	-0.81	0.81	0.03	-0.03
100%	-22.42	0.02	0.01	0.00	0.00	-0.29	0.29
MEMBER 384							
0%	24.73	0.02	0.01	0.00	0.00	-0.01	0.01
50%	24.73	0.01	0.01	-1.21	1.21	0.31	-0.31
100%	24.74	0.02	0.01	0.00	0.00	0.63	-0.63
MEMBER 713							
0%	-5.70	0.01	0.01	-1.23	1.23	0.24	-0.24
50%	-5.70	0.01	0.01	-0.04	0.04	-0.23	0.23
100%	-5.70	0.01	0.01	1.16	-1.16	-0.69	0.69
MEMBER 732							
0%	-2.70	0.01	0.01	0.23	-0.23	0.67	-0.67
50%	-2.70	0.01	0.01	-0.16	0.16	0.20	-0.20
100%	-2.70	0.01	0.01	-0.33	0.33	-0.27	0.27
MEMBER 463							
0%	-6.99	0.01	0.02	0.23	-0.23	1.21	-1.21
50%	-6.99	0.01	0.02	0.23	-0.23	-0.01	0.01

100%	-6.99	0.01	0.02	0.31	-0.31	-1.22	1.22

MEMBER 508

0%	-4.58	0.01	0.01	-0.47	0.47	-0.25	0.25
50%	-4.58	0.01	0.01	0.31	-0.31	0.01	-0.01
100%	-4.58	0.01	0.01	1.17	-1.17	0.26	-0.26

MEMBER 468

0%	-0.29	0.02	0.02	1.06	-1.06	-1.19	1.19
50%	-0.29	0.02	0.02	0.23	-0.23	-0.20	0.20
100%	-0.29	0.01	0.02	-0.51	0.51	0.80	-0.80

MEMBER 1849

0%	-3.67	0.04	0.03	0.96	-0.96	-0.55	0.55
50%	-3.67	0.04	0.03	0.04	-0.04	-0.76	0.76
100%	-3.67	0.03	0.03	-0.80	0.80	-0.97	0.97

MEMBER 1933

0%	-0.42	0.03	0.04	0.07	-0.07	1.12	-1.12
50%	-0.42	0.03	0.04	0.09	-0.09	0.15	-0.15
100%	-0.42	0.03	0.04	0.17	-0.17	-0.82	0.82

MEMBER 1891

0%	-4.35	0.07	0.09	-0.49	0.49	-1.69	1.69
50%	-4.35	0.07	0.09	0.02	-0.02	0.45	-0.45
100%	-4.35	0.08	0.09	0.59	-0.59	2.59	-2.59

MEMBER 784

0%	-5.81	0.08	0.09	-2.69	2.69	1.99	-1.99
50%	-5.81	0.09	0.09	2.24	-2.24	-3.13	3.13
100%	-5.81	0.09	0.09	7.24	-7.24	-8.24	8.24

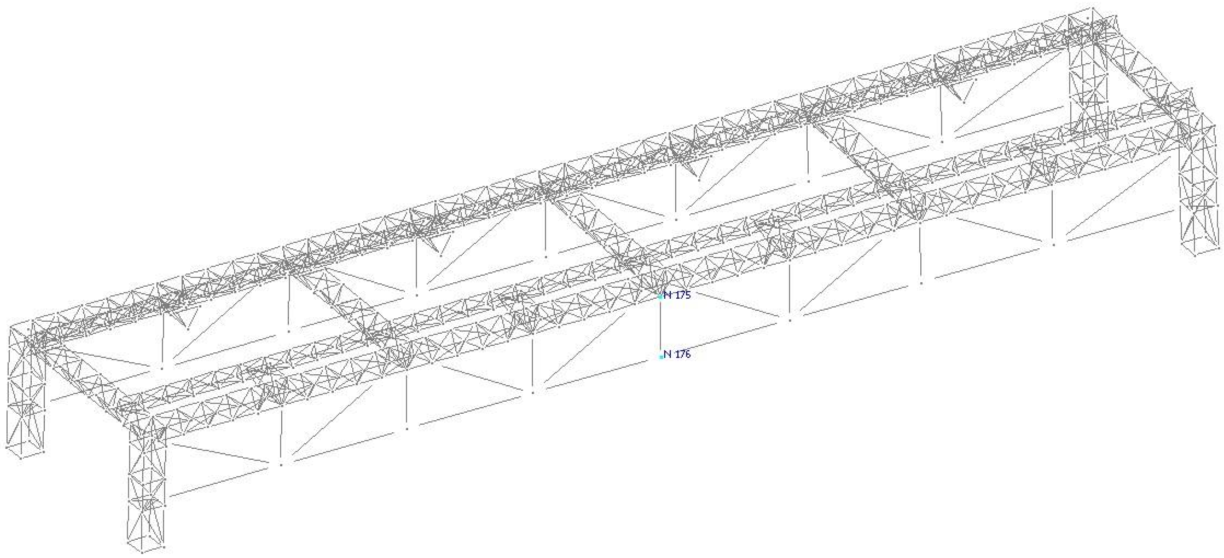


Figure V.1.B. (Nodes used for deflection analysis)

Translations

	Translations [in]			Rotations [Rad]		
Node	TX	TY	TZ	RX	RY	RZ
Condition c1=1.0dl +1.0lat						
175	-0.01513	-0.07213	0.08000	-0.00055	-0.00003	0.00000
176	-0.01513	-0.07214	0.08293	-0.00018	0.00001	0.00000
Condition c2=1.0dl+1.0s1						
175	-0.09769	-0.47605	0.06234	0.00419	0.00007	0.00061
176	-0.09548	-0.47606	-0.01495	0.00511	-0.00065	0.00047

Condition c3=1.0dl+1.0s2

175	-0.10991	-0.52358	0.05813	0.00427	-0.00012
	0.00047				
176	-0.10747	-0.52358	-0.02153	0.00540	0.00040
	0.00039				

Condition c4=1.0dl+1.0s3

175	-0.12212	-0.57104	0.05264	0.00424	-0.00027
	0.00041				
176	-0.11941	-0.57105	-0.03413	0.00600	0.00107
	0.00036				

Condition c5=1.0dl+1.0s4

175	-0.13222	-0.60631	0.04843	0.00420	-0.00035
	0.00032				
176	-0.12960	-0.60631	-0.04953	0.00682	0.00146
	0.00030				

Condition c6=1.0dl+1.0s5

175	-0.14206	-0.63876	0.04460	0.00433	-0.00035
	0.00022				
176	-0.14013	-0.63876	-0.07128	0.00806	0.00117
	0.00021				

Condition c7=1.0dl+1.0s6

175	-0.14754	-0.64878	0.04199	0.00448	-0.00033
	0.00004				
176	-0.14680	-0.64879	-0.08760	0.00900	0.00051
	0.00007				

V.1.2. Model Weight Analysis

The analysis software was used to monitor the total weight of the bridge. The software can easily generate material list for all of the members in the model. The weight represented by the material list generated by the software takes into account all of the member weight but neglects and fastner or connection weight. The final amount of material required and weight of the bridge is shown in the List of Material below.

List of materials

Members:

Profile	Material	Uweight [Kip/ft]	Length [ft]	Weight [Kip]
RNDBAR 1_4	A36	1.67E-04	344.515	0.058
RNDBAR 1_8	A36	4.18E-05	657.766	0.027
RNDBAR 3_8	A36	3.76E-04	81.750	0.031
RNDBAR 5_16	A36	2.61E-04	128.500	0.034
Total weight [Kip]				0.149

Section VI: Manufacturing

Since the specifications ask that the bridge is constructed from prefabricated members, it was necessary to come up with a quick and easy way to fabricate each of these members uniformly. The bridge was designed with over 2000 individual components in the main chords and webbing, which would prove to be very difficult to weld together individually. Because of this, it was decided that, for ease of fabrication, the main longitudinal rods could be continuous through the entire length of each prefabricated member, while the webbing of each member would be bent so that each side of the member would contain one continuous rod.

In order to expedite the fabrication of the webbing, two devices were made that would be able to mechanically bend the rods to a predetermined shape, which would be extremely difficult to do by hand. One of these devices was created by cutting out a piece of plate steel in a triangular shape and welding it to a bench vice. This would prove to be a very time consuming method of bending the triangular shaped rods for the top chord members of the bridge. Therefore another device was constructed for the production of the smaller triangular formed shapes that would be needed to make the members for the top rail (decking supports) of the bridge. This apparatus made use of a stationary steel plate triangle and three lever arms that would be used in order to press the steel rods around the triangle. With this piece of equipment, the triangular shaped rods were bent more consistently and they were much easier to work with than the larger triangular member components.

Device Made to Manufacture Smaller Triangles

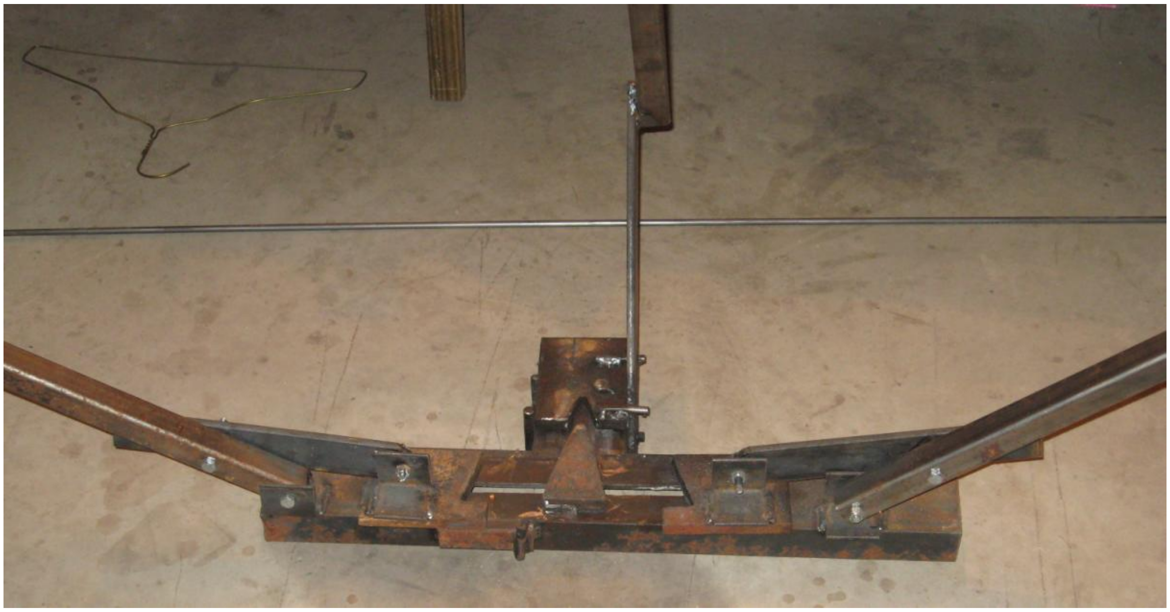


Figure VI.A.

Close UP

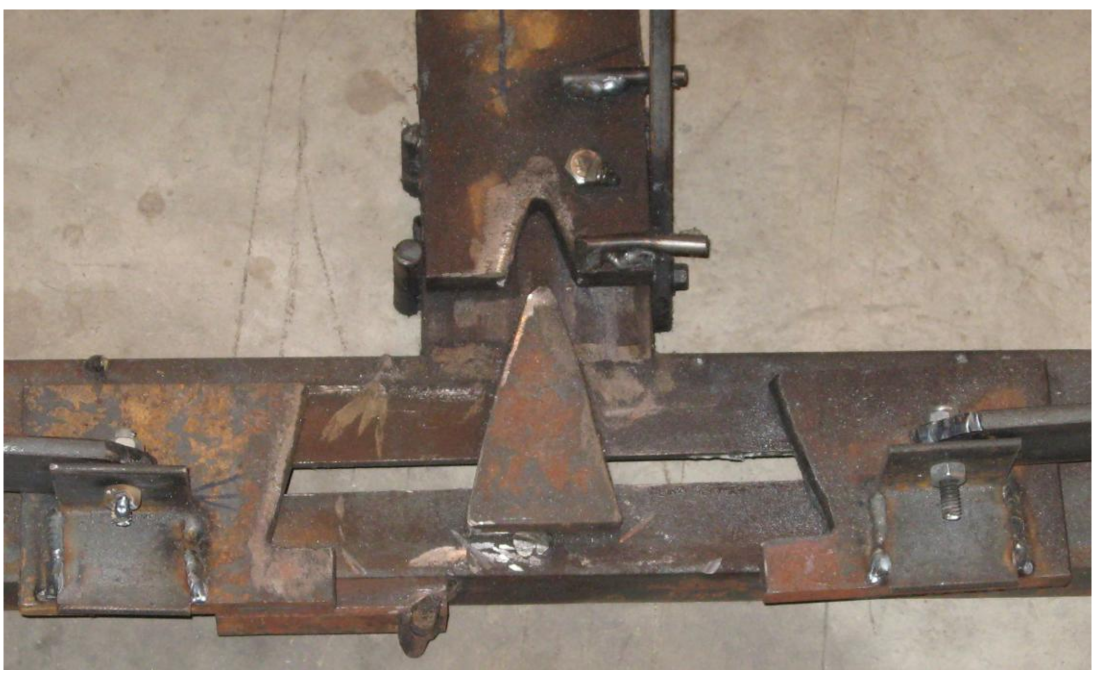


Figure VI.B.

Press Used to Bend Webbing

Figure VI.C.

Once the components were cut and bent to the correct shape, they were then welded together. In order to keep the prefabricated members as uniform with one another as possible, a jig was made from wood to keep them from twisting while they were being welded. This proved to be a satisfactory method for constructing each of the members. They turned out to be straight and the ends of the members lined up with one another in a way that the compression members would bear on one another at the ends and thus cleanly transfer the load from member to member without eccentricity. This is important because, if the bars are loaded eccentrically, it may cause them to buckle under the maximum loading condition.

The next step in the fabrication process was to add the connections so that the members would easily go together during the timed construction. These connections were created by using steel pins, plates, and washers rigidly welded to the ends of each of the prefabricated bridge members. Since there were obvious irregularities in each of the members (due to the crude nature in which the fabrication was preformed) each of the connections was custom made to fit each of the individual members. Because of this, all of the members had to be labeled before they were taken apart so that they would not get switched with one another and thus create confusion during the timed construction.

Once the top components of the bridge were finished, the webbing on the bottom of the girders needed to be fabricated. The tension members in the bottom chord of the bridge would need to be connected to one another with the use of gusset plates. These would be created from plate steel. The tension rods were then cut to length and steel plates were welded to the ends. Once this was completed they were aligned and the bolt holes were drilled in place in order to ensure that they would neatly line up during construction of the bridge.

Once the connections were aligned and the main fabrication process was completed, the analysis program was then checked in order to find components that made be pushed past critical buckling during the load testing. Stiffeners were then added to these locations so that the bridge would not fail when loaded for the maximum load case scenario described in the specifications. The bridge was then ready for load testing and timed construction.

Section VII: Assembly

For Assembly, or timed construction, the process had to be optimized so that the prefabricated bridge components could be assembled in the least amount of time possible with the lowest number of builders and temporary piers. It was decided that the construction would be attempted with the minimum number of builders, barges, and piers that are to be charged during the competition. That is: two barges, two builders, and one temporary pier. After several trials, the timed construction was completed in less than 25 minutes, which fell below the maximum time limit of 30 minutes that would be allowed in competition. These results proved to be satisfactory and thus no additional builders, barges or piers would be necessary for the construction of the bridge.

The process was set up so that the prefabricated members were all arranged in the order that they would be assembled, starting from the far end of the bridge opposite the floodway. Assembly was done on one side of the bridge at a time starting with the two top chords, and then moving on to the bottom tension members. The temporary pier was used to hold the bridge off of the ground and create a camber in the bridge while the bottom was being assembled. This made the ends of the tension members much easier to assemble.
During the timed construction of the bridge, there were two “barges” that began the assembly over the river, and the two “builders” would carry the members from the staging yard to the barges for assembly. Once the floodway was reached, one of the builders would begin to assemble the end of the bridge over the floodway from the bank, where the barges could not reach. The other builder continued carrying the components to the barges until the assembly was completed.

Section VIII: Actual Results

VIII.1. Deflection

The actual deflection of the bridge was measured on the outer most surface of the girder at the center of the bridge. The results are as follows.

Load Testing Deflection Results

End	Load Case	Deflection
Right	Roll of 1	7/8”
Right	Roll of 3	1 1/8”
Right	Roll of 6	1 5/8”
Left	Roll of 1	7/8”
Left	Roll of 3	1 3/16”
Left	Roll of 6	1 ¾”

Table VIII.1.A.

Load Testing 1

Figure VIII.1.A.

Load Testing 2

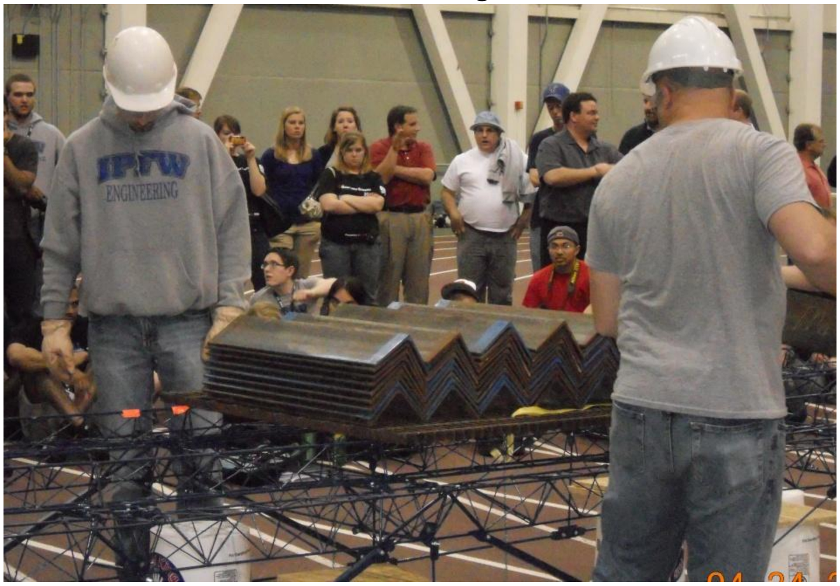


Figure VIII.1.B.

VIII.2. Weight

The final weight of the bridge was 187lbs. This weight includes bolts, paint, and logos.

VIII.3. Construction and Dimensions

All of the dimensional requirements were meet while the bridge required for labors to assemble in 24 minutes.

Section IX: Theoretical Results vs. Actual Results

The theoretical results for nearly every category were much different than the actual results. This is for several reasons.

IX.1. Deflection

The actual deflection was much more than the theoretical deflection. There are four main reasons for these results. The first is that in the software model all members are perfectly aligned so that they will distribute the load ideally. In actuality the members are not perfectly aligned so that is creates high stress concentrations in some points in the bridge and low stress concentration in other parts of the bridge.

Secondly, in the model the connections are perfect. Where in reality the connection have some degree of deflection and slack. When the bridge is load the slack is pulled from the connection and they start to deflect causing the entire bridge to deflect.

Third of all is that the slenderness ratio is unknown for the model and in reality. The end conditions for the webbing in the top chord are difficult to predict. It can be assume that it is fixed or pinned creating a very different slenderness ratio, thus change the value for critical buckling. Therefore, some webbing may have been elastically buckling. All of the webbing that was plastically buckling was searched for and reinforced.

Sample hand Calculations of Critical Buckling Load

Design of small compression webs in top chord section:

Critical buckling of 1/8" rod.

(1) 1/8" rod w/ pin-pin end conn.

$$A = 0.0123 in^2$$
$$I = 0.000012 in^2$$
$$r = 0.0312 in^3$$
$$l = 8.28 in$$
$$k = 1.00$$
$$\frac{kl}{r} = 265.4$$
$$F_e = \frac{\pi^2 E}{\left(\frac{kl}{r}\right)^2} = 4.064 ksi$$
$$F_{cr} = 0.877(F_e) = 3.56 ksi$$
$$P_{cr} = 44\#$$

(1) 1/8" rod w/ fix-fix end conn.

$$A = 0.0123 in^2$$
$$I = 0.000012 in^2$$
$$r = 0.0312 in^3$$
$$l = 8.28 in$$
$$k = 0.65$$
$$\frac{kl}{r} = 172.5$$
$$F_e = \frac{\pi^2 E}{\left(\frac{kl}{r}\right)^2} = 9.62 ksi$$
$$F_{cr} = 0.877(F_e) = 8.44 ksi$$
$$P_{cr} = 103\#$$

Figure IX.1.A.

Finally, when building with 1/8” rod it is difficult to keep the member from bending during manufacturing. Even the slightest bend in the rod would create eccentricity within the component when it was load. This would throw critical buckling way down. Thus member may have been elastically buckling.

IX.2. Weight

The overall weight was 187 lbs compare to the theoretical weight of 158 lbs. This is because the weight of the connections, paint, webbing reinforcing, and welds was not considered within the model.

Section X: Conclusion

This project was a success. All of the requirements and specification were met and within all of the constraints. The final solution was a 21’6” x 4’6” bridge that weighed 187 lbs and was able to hold 2500 lbs while deflecting a maximum of 1.75”. That’s impressive!

Figure X.A.

Section XI: Appendices

XI.1. Presentations

XI.1.1. Problem Statement

Design of a Steel Bridge for the ASCE 2010 Student Steel Bridge Competition

Group: Martin Duffy, Seannan Mettert, Devin Webster

Advisor: Dr. Mohammad Alhassan

October 7, 2009

Requirements and Specifications

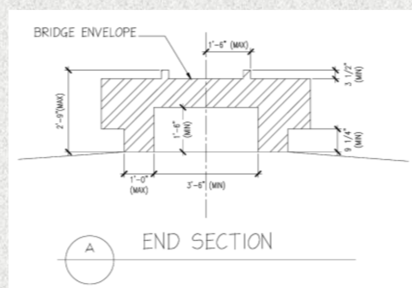
- Accommodates tall and wide vehicles/equipment
- No permanent piers (clear span)
- Dead, live, and lateral loading
- Pre-fabricated deck
- Steel structure is requested

Design Reasoning

- Boreal Energy Corporation is developing a new oil field and requesting engineering design proposals for a bridge over the river and floodway.
  - Seeking optimal design
    - Based on stiffness, cost, construction speed, durability, weight, and aesthetics.

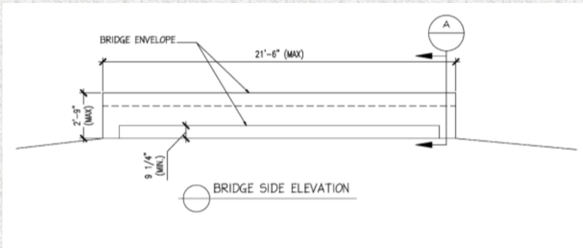
Requirements and Specifications

- Dimensions



Requirements and Specifications

- Dimensions cont.

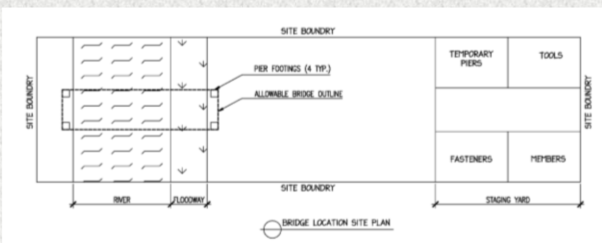


Limitations and Constraints

- Construction Constraints
  - Short Construction Season
  - Pre-fabricated Steel Members
    - Limit the size of each member.
      - 6" x 6" x 42"
  - Equipment and Material only allowed on one bank and barges.
- Predetermined footing locations

Requirements and Specifications

- Dimensions cont.



Limitations and Constraints

- Budget Constraints
  - The design with the lowest construction cost and highest structural efficiency will be awarded the project
    - Construction cost
      - Labors
      - Barges
      - Time
      - Temporary piers
    - Structural efficiency
      - Total weight
      - Aggregate Deflection

Design Variables

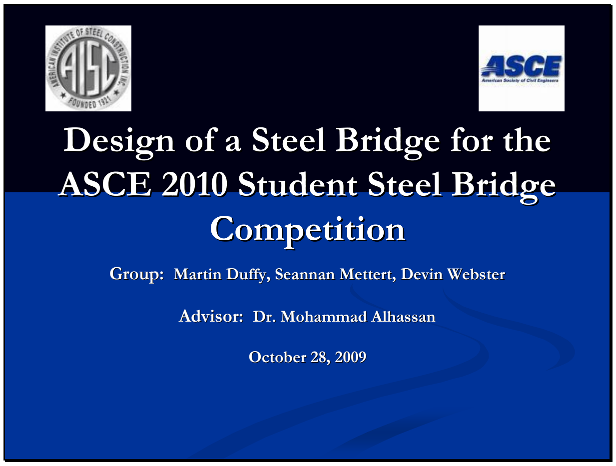
- Stiffness
- Lightness
- Construction Speed
- Aesthetic
- Efficiency

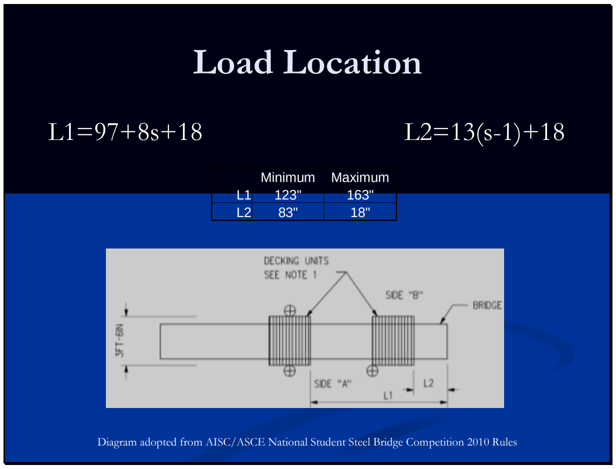
Questions?

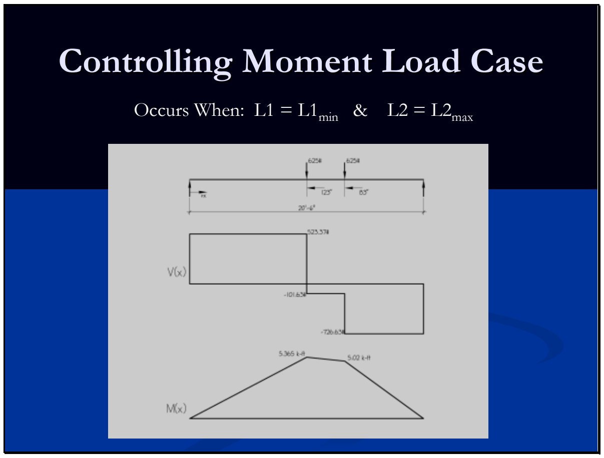
&

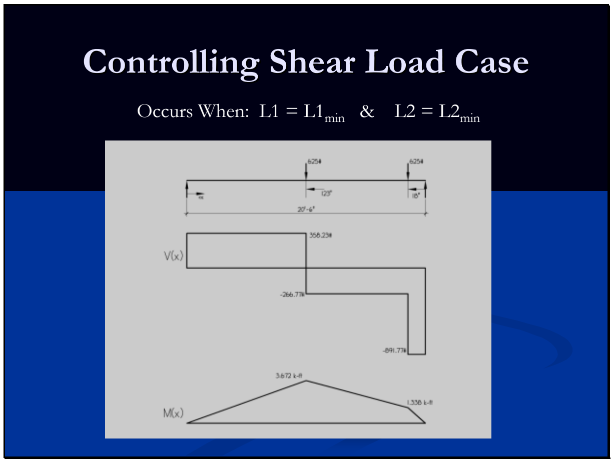
Suggestions!

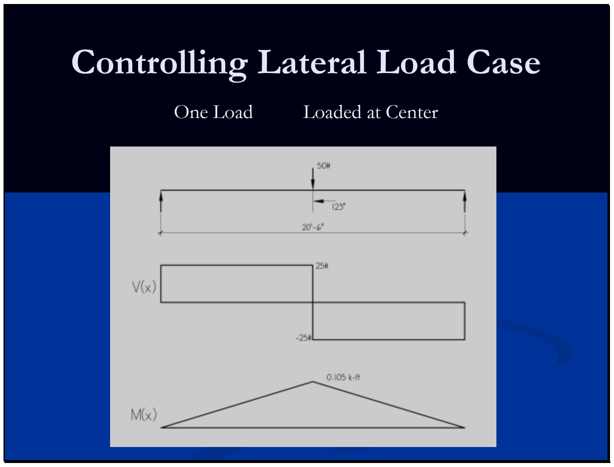
XI.1.2. Design Concepts









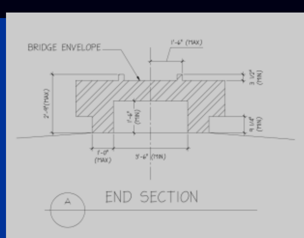


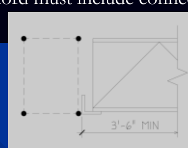
Design Philosophy

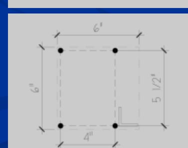
- Trussed girders will be much more economical than solid members.
- Optimization of Beam Theory
  - Positive Bending Moment
    - Top chord is under compressive axial forces
      - Optimize by increasing I_{xx} and I_{yy}
    - Bottom member is under tensile axial forces
      - Optimize by providing minimal area

Top Chord Member Development

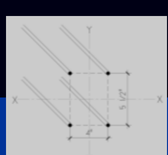
- Constraints
  1. Max. member dimension = 6" x 6" x 42"
  2. Must provide 42" min between girders
  3. One piece cross member => top chord must include connection



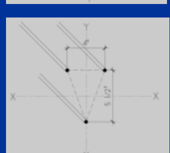




Top Chord Section Development



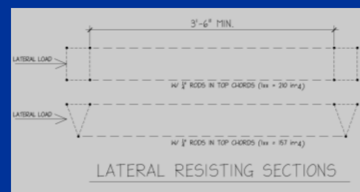
Possible Ixx w/ rect top chord		
Rod ø [in]	Ixx [in^4]	Iyy [in^4]
0.25	1.4875	0.7862
0.375	2.974	1.5746
0.5	4.4662	2.3677



Possible Ixx w/ Trig. top chord		
Rod ø [in]	Ixx [in^4]	Iyy [in^4]
0.25	0.9905	0.3933
0.375	1.9827	0.7883
0.5	2.9784	1.1867

Lateral Load Resistance

- Constraint
  1. Max lateral deflection = 1"
- Required I_{xx} based on maximum lateral load case
  - ¼" deflection ……..I_{xx}=2in^4
  - ½" deflection ……..I_{xx} = 1 in^4

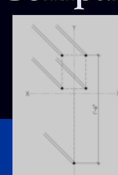


Preliminary Side Girder Design

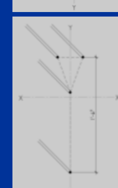
- Maximum moment case will develop maximum deflection
  - Deflection as a function of I_{xx}

Req. girder Ixx based on max moment case	
Deflection [in]	Ixx [in^4]
0.125	100
0.250	50
0.500	25
0.750	18.75
1.000	12.5

Comparison of girder sections



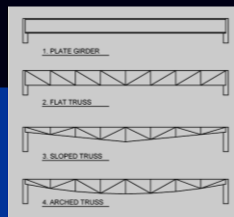
Truss girder made w/ rect top chord and rod bottom chord			
Bot. Rod ø [in]	Top Rods ø [in]	Ixx [in^4]	Approx wt. [#/ft]
0.25	0.25	10.62	0.835
0.375	0.25	17.92	1.044
0.5	0.25	23.6	1.336
0.25	0.375	10.8	1.671
0.375	0.375	23.02	1.88
0.5	0.375	32.12	2.172
0.25	0.5	12.52	2.839
0.375	0.5	26.1	3.048
0.5	0.5	37.09	3.34



Truss girder made w/ trig. top chord and rod bottom chord			
Bot. Rod ø [in]	Top Rods ø [in]	Ixx [in^4]	Approx wt. [#/ft]
0.25	0.25	8.69	0.668
0.375	0.25	17.49	0.887
0.5	0.25	22.38	1.17
0.25	0.375	10.54	1.295
0.375	0.375	22.98	1.504
0.5	0.375	31.6	1.791
0.25	0.5	11.86	2.171
0.375	0.5	26.07	2.38
0.5	0.5	36.94	2.672

Proceeding Steps

- Choose girder type



- Optimize constructability
  - Optimize girder design
  - Optimize connections

Questions?

&

Suggestions!

XI.1.3. Semester 1 Final Presentation

Design of a Steel Bridge for the ASCE 2010 Student Steel Bridge Competition

Group: Martin Duffy, Seannan Mettert, Devin Webster

Advisor: Dr. Mohammad Alhassan

December 8, 2009

Design Reasoning

- Boreal Energy Corporation is developing a new oil field and requesting engineering design proposals for a bridge over the river and floodway.
  - Seeking optimal design
    - Based on stiffness, cost, construction speed, durability, weight, and aesthetics.

Overview

- Problem Analysis
- Design Philosophy
- Location of Loading
- Girder Selection
- Girder Development
- Lateral Loading
- Final Bridge Proposal
- Design Analysis
- Typical Connections
- Constructability
- Question and Answers

Requirements and Specifications

- Accommodates tall and wide vehicles/equipment (no structural members above deck level)
- No permanent piers (clear span)
- Dead, live, and lateral loading
- Pre-fabricated deck
- Steel structure is requested

Limitations and Constraints

- Construction Constraints
  - Short Construction Season
  - Pre-fabricated Steel Members
    - Limit the size of each member.
      - 6” x 6” x 42”
  - Equipment and Material only allowed on one bank and barges.
- Predetermined footing locations

Design Philosophy

- Trussed girders will be much more economical than solid members.
- Optimization of Beam Theory
  - Positive Bending Moment
    - Top chord is under compressive axial forces
      - Optimize by increasing I_{xx} and I_{yy}
    - Bottom member is under tensile axial forces
      - Optimize by providing minimal area

Limitations and Constraints

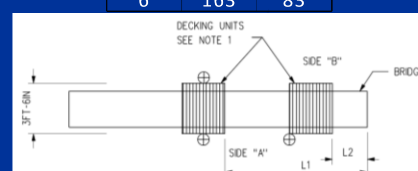
- Budget Constraints
  - The design with the lowest construction cost and highest structural efficiency will be awarded the project
    - Construction cost
      - Labor
      - Barges
      - Time
      - Temporary piers
    - Structural efficiency
      - Total weight
      - Aggregate Deflection

Location of Loading

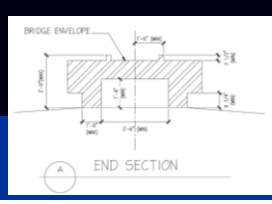
L1=97+8s+18
L2=13(s-1)+18

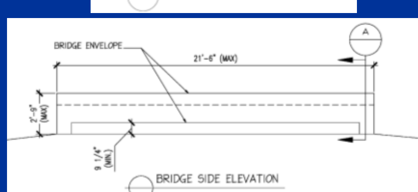
S= the value of the die roll

Load Combinations		
Die	L1	L2
1	123	18
2	131	31
3	139	44
4	147	57
5	155	70
6	163	83



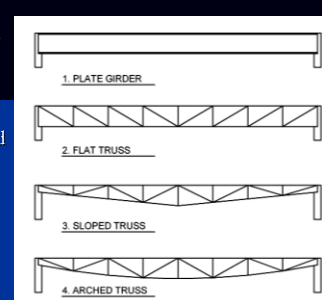
Required Bridge Envelope





Girder Section

- Plate Girder was eliminated based on engineering sense tell us that it would be extremely heavy
- Option 2-4 compared based on weight and deflection.



Deflection Analysis

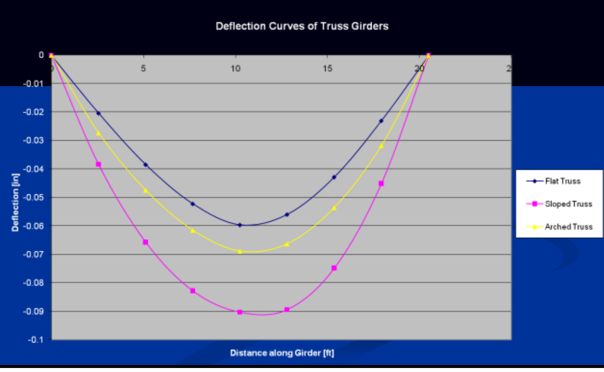
- Arbitrary structural section selected to compare deflection and weight of each design concept.
- Ram Advance structural analysis software was used to develop deflection results and weight calculations.

Preliminary Side Girder Design

- Maximum moment case will develop maximum deflection
  - Deflection as a function of I_{xx}

Req. girder Ixx based on max moment case	
Deflection [in]	Ixx [in^4]
0.125	100
0.250	50
0.500	25
0.750	18.75
1.000	12.5

Deflection Curve

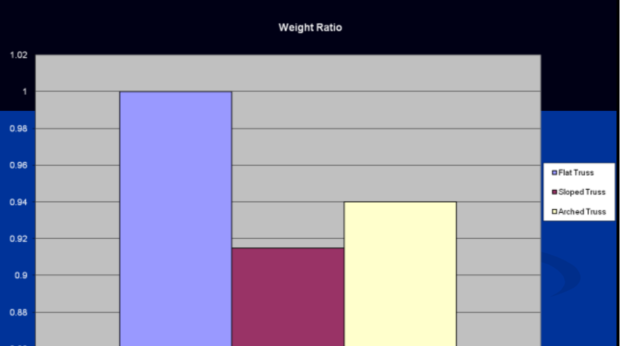


Member development

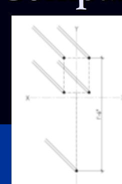
- Several different structural shapes considered
  - WT, Rod, HSS, Pipe
- Sections were eliminated by weight.

Structural Members	Weight (lb/ft)
.5" pipe	0.86
.75" pipe	1.15
.25" rod	0.167

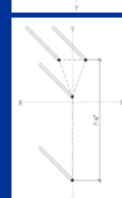
Weight Ratio Comparison



Comparison of girder sections



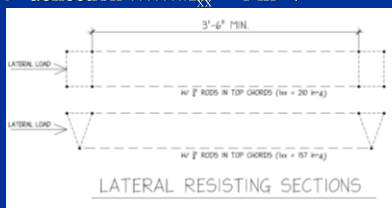
Truss girder made w/ rect top chord and rod bottom chord			
Bot. Rod ø [in]	Top Rods ø [in]	Ixx [in^4]	Approx wt. [#/ft]
0.25	0.25	10.62	0.835
0.375	0.25	17.92	1.044
0.5	0.25	23.6	1.336
0.25	0.375	10.8	1.671
0.375	0.375	23.02	1.88
0.5	0.375	32.12	2.172
0.25	0.5	12.52	2.839
0.375	0.5	26.1	3.048
0.5	0.5	37.09	3.34



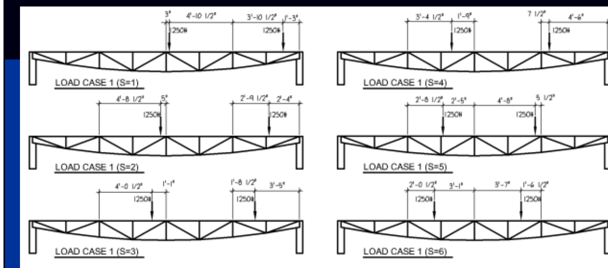
Truss girder made w/ trig. top chord and rod bottom chord			
Bot. Rod ø [in]	Top Rods ø [in]	Ixx [in^4]	Approx wt. [#/ft]
0.25	0.25	8.69	0.668
0.375	0.25	17.49	0.887
0.5	0.25	22.38	1.17
0.25	0.375	10.54	1.295
0.375	0.375	22.98	1.504
0.5	0.375	31.6	1.791
0.25	0.5	11.86	2.171
0.375	0.5	26.07	2.38
0.5	0.5	36.94	2.672

Lateral Load Resistance

- Constraint
  1. Max lateral deflection = 1”
- Required I_{xx} based on maximum lateral load case
  - ¼” deflection ……..I_{xx}=2in^4
  - ½” deflection ……..I_{xx} = 1 in^4



Load Combinations



Final Proposed Bridge

- Used Arched girder based on optimization
- Triangular top Chord
  - Provides needed section properties with less weight than rectangular.
  - Provides for easier connections

Analysis Results

- All members below 36 ksi yield stress

Analysis Results

Translations

	Translations [in]			Rotations [Rad]		
Node	**TX**	**TY**	**TZ**	**RX**	**RY**	**RZ**
Condition **C1=1.0DL+1.0s1+1.0lat**						
184	-0.00326	-0.48777	0.11292	0.00165	0.00019	-0.00032
Condition **c2=1.0dl+1.0s2+1.0lat**						
184	-0.00401	-0.54013	0.11038	0.00187	0.00025	-0.00041
Condition **c3=1.0dl+1.0s3+1.0lat**						
184	-0.00479	-0.58030	0.11058	0.00210	0.00031	-0.00049
Condition **c4=1.0dl+1.0s4+1.0LAT**						
184	-0.00554	-0.62047	0.11079	0.00232	0.00037	-0.00057
Condition **c5=1.0dl+1.0s5+1.0lat**						
184	-0.00482	-0.64805	0.11014	0.00245	0.00030	-0.00047
Condition **c6=1.0dl+1.0s6+1.0lat**						
184	-0.00208	-0.65848	0.10837	0.00245	0.00007	-0.00010

Analysis Results

- Weight results to determine structural cost

List of materials

Note.- Only the graphically selected members and shells are listed

Members:

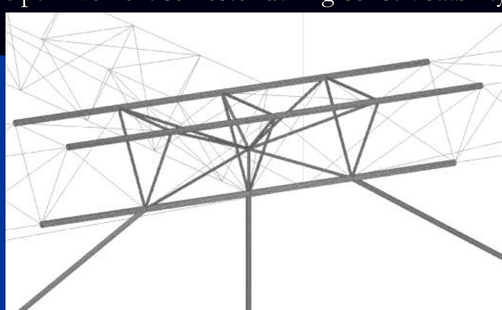
Profile	Material	Uweight [Kip/ft]	Length [ft]	Weight [Kip]
RNDBAR 1_2	A36	6.69E-04	11.667	0.008
RNDBAR 1_4	A36	1.67E-04	114.636	0.019
RNDBAR 1_8	A36	4.18E-05	518.790	0.022
RNDBAR 3_8	A36	3.76E-04	70.015	0.026
RNDBAR 5_16	A36	2.61E-04	123.000	0.032
Total weight [Kip]				0.107

Constructability

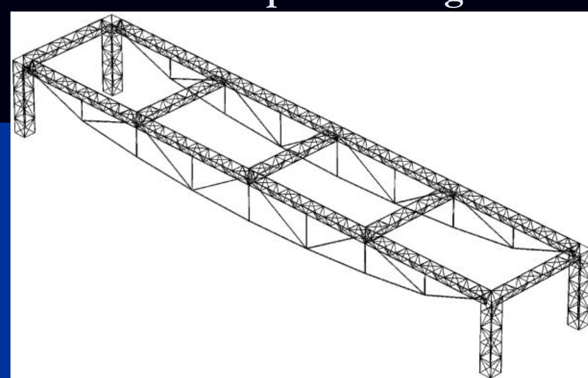
- Measure by speed of construction
- Optimization
  - Minimum number of connections
  - Simple connections (Type of connections)
  - Practice
  - Minimal Number of temporary piers

Typical Connections

- Optimize next semester during constructability.



Final Proposed Bridge



Questions?

&

Suggestions!

XI.1.4 Semester 2 Final Presentation

Design of a Steel Bridge for the ASCE 2010 Student Steel Bridge Competition

Group: Martin Duffy, Seannan Mettert, Devin Webster

Advisor: Dr. Mohammad Alhassan

April 29, 2010

Design Reasoning

- Boreal Energy Corporation is developing a new oil field and requesting engineering design proposals for a bridge over the river and floodway.
  - Seeking optimal design
    - Based on stiffness, cost, construction speed, durability, weight, and aesthetics.

Overview

- Problem Analysis
- Design Philosophy
- Location of Loading
- Girder Selection
- Girder Development
- Lateral Loading
- Design Analysis
- Connection Design
- Constructability
- Manufacturing Process
- Loading/Assembly Results
- Question and Answers

Requirements and Specifications

- Accommodates tall and wide vehicles/equipment (no structural members above deck level)
- No permanent piers (clear span)
- Dead, live, and lateral loading
- Pre-fabricated deck
- Steel structure is requested

Limitations and Constraints

- Construction Constraints
  - Short Construction Season
  - Pre-fabricated Steel Members
    - Limit the size of each member.
      - 6" x 6" x 42"
  - Equipment and Material only allowed on one bank and barges.
- Predetermined footing locations

Design Philosophy

- Trussed girders will be much more economical than solid members.
- Optimization of Beam Theory
  - Positive Bending Moment
    - Top chord is under compressive axial forces
      - Optimize by increasing I_{xx} and I_{yy}
    - Bottom member is under tensile axial forces
      - Optimize by providing minimal area

Limitations and Constraints

- Budget Constraints
  - The design with the lowest construction cost and highest structural efficiency will be awarded the project
    - Construction cost
      - Labor
      - Barges
      - Time
      - Temporary piers
    - Structural efficiency
      - Total weight
      - Aggregate Deflection

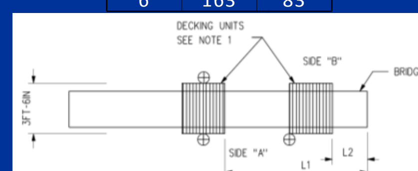
Location of Loading

L1=97+8s+18

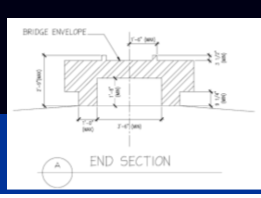
L2=13(s-1)+18

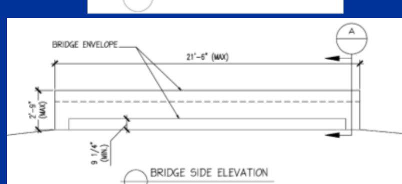
S= the value of the die roll

Load Combinations		
Die	L1	L2
1	123	18
2	131	31
3	139	44
4	147	57
5	155	70
6	163	83



Required Bridge Envelope





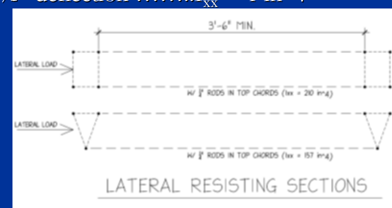
Preliminary Side Girder Design

- Maximum moment case will develop maximum deflection
  - Deflection as a function of I_{xx}

Req. girder Ixx based on max moment case	
Deflection [in]	Ixx [in^4]
0.125	100
0.250	50
0.500	25
0.750	18.75
1.000	12.5

Lateral Load Resistance

- Constraint
  1. Max lateral deflection = 1”
- Required I_{xx} based on maximum lateral load case
  - ¼” deflection ……..I_{xx}=2in^4
  - ½” deflection ……..I_{xx} = 1 in^4

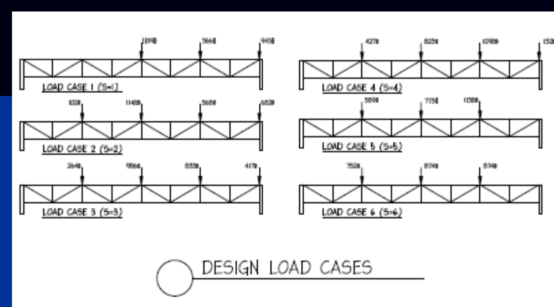


Member development

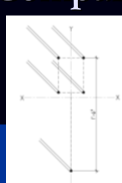
- Several different structural shapes considered
  - WT, Rod, HSS, Pipe
- Sections were eliminated by weight.

Structural Members	Weight (lb/ft)
.5" pipe	0.86
.75" pipe	1.15
.25" rod	0.167

Load Combinations



Comparison of girder sections



Truss girder made w/ rect top chord and rod bottom chord			
Bot. Rod ø [in]	Top Rods ø [in]	Ixx [in^4]	Approx wt. [#/ft]
0.25	0.25	10.62	0.835
0.375	0.25	17.92	1.044
0.5	0.25	23.6	1.336
0.25	0.375	10.8	1.671
0.375	0.375	23.02	1.88
0.5	0.375	32.12	2.172
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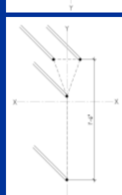
0.5	0.5	37.09	3.34



Truss girder made w/ trig. top chord and rod bottom chord			
Bot. Rod ø [in]	Top Rods ø [in]	Ixx [in^4]	Approx wt. [#/ft]
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0.375	0.25	17.49	0.887
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0.25	0.375	10.54	1.295
0.375	0.375	22.98	1.504
0.5	0.375	31.6	1.791
0.25	0.5	11.86	2.171
0.375	0.5	26.07	2.38
0.5	0.5	36.94	2.672

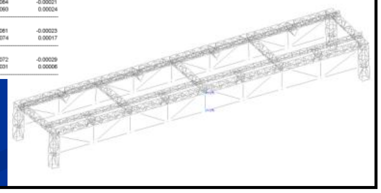
Analysis Results

- All members below 57 ksi yield stress

Analysis Results

Translations

Node	Translations [in] TX	TY	TZ	Rotations [Rad] RX	RY	RZ
Condition **c1=1.0dl +1.0lat**						
175	-0.01540	-0.07109	0.08812	-0.00052	-0.00007	-0.00004
176	-0.01540	-0.07110	0.09111	-0.00022	0.00000	0.00000
Condition **c2=1.0dl+1.0s1**						
175	-0.10081	-0.46647	0.06239	0.00416	0.00041	0.00036
176	-0.09742	-0.46648	-0.01093	0.00510	-0.00056	0.00035
Condition **c3=1.0dl+1.0s2**						
175	-0.11291	-0.51336	0.05823	0.00428	-0.00019	0.00008
176	-0.10959	-0.51337	-0.01788	0.00533	0.00019	0.00031
Condition **c4=1.0dl+1.0s3**						
175	-0.12515	-0.56000	0.05273	0.00436	-0.00058	-0.00007
176	-0.12166	-0.56001	-0.02907	0.00580	0.00065	0.00029
Condition **c5=1.0dl+1.0s4**						
175	-0.13514	-0.59458	0.04849	0.00444	-0.00084	-0.00021
176	-0.13195	-0.59458	-0.04135	0.00646	0.00093	0.00024
Condition **c6=1.0dl+1.0s5**						
175	-0.14491	-0.62653	0.04471	0.00471	-0.00081	-0.00023
176	-0.14262	-0.62653	-0.05809	0.00747	0.00074	0.00017
Condition **c7=1.0dl+1.0s6**						
175	-0.15028	-0.63663	0.04221	0.00495	-0.00072	-0.00029
176	-0.14941	-0.63664	-0.07032	0.00822	0.00031	0.00006



Sample Design Calculation

Design of small compression webs in top chord section:

Critical buckling of 1/8" rod.

(1) 1/8" rod w/ pin-pin end conn.

$A = 0.0123 in^2$

$I = 0.00012 in^2$

$r = 0.0312 in^3$

$l = 8.28 in$

$k = 1.00$

$\frac{kl}{r} = 265.4$

$F_e = \frac{\pi^2 E}{\left(\frac{kl}{r}\right)^2} = 4.064 ksi$

$F_{cr} = 0.877(F_e) = 3.56 ksi$

$P_{cr} = 44\#$

(1) 1/8" rod w/ fix-fix end conn.

$A = 0.0123 in^2$

$I = 0.00012 in^2$

$r = 0.0312 in^3$

$l = 8.28 in$

$k = 0.65$

$\frac{kl}{r} = 172.5$

$F_e = \frac{\pi^2 E}{\left(\frac{kl}{r}\right)^2} = 9.62 ksi$

$F_{cr} = 0.877(F_e) = 8.44 ksi$

$P_{cr} = 103\#$

Analysis Results

- Weight results to determine structural cost

List of materials

Note.- Only the graphically selected members and shells are listed

Members:

Profile	Material	Uweight [Kip/ft]	Length [ft]	Weight [Kip]
RNDBAR 1_4	1018	1.67E-04	257.626	0.043
RNDBAR 1_8	1018	4.18E-05	738.809	0.031
RNDBAR 3_8	1018	3.76E-04	81.750	0.031
RNDBAR 5_16	1018	2.61E-04	128.500	0.034
STUBE .75X.75	A500 GRB RECTANGULAR	1.06E-03	18.951	0.020
Total weight [Kip]				0.158

Constructability

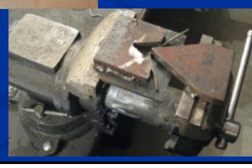
- Measure by speed of construction
- Optimization
  - Minimum number of connections
  - Simple connections (Type of connections)
  - Practice
  - Minimal Number of temporary piers

Connection Design

- Tension members were designed for yield stress
- Compression members design criteria was critical buckling

Bridge Construction

- Jigs and presses were developed to help the manufacturing process of common components



Completed Bridge

400 Man Hours Later

Manufacturing Process

- Form triangular vertical webbing
- Add main chord components
- Form and add webbing
- Cut tension members
- Align and develop connections
- Develop gusset plates for bottom chord
- Paint

Load Testing Results

End	Load Case	Deflection
Right	Roll of 1	7/8"
Right	Roll of 3	1 1/8"
Right	Roll of 6	1 5/8"
Left	Roll of 1	7/8"
Left	Roll of 3	1 3/16"
Left	Roll of 6	1 3/4"

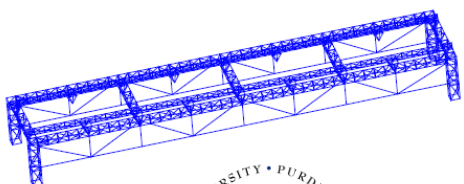
Lateral Deflection: 1/8”

Bridge Components

Assembly Results

- Construction time: 24 minutes
  - Four builders
  - One temporary pier
- Weight: 187 lbs
- Achieved all dimensional requirements

Questions?



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XI.2. Example of Geometric Data

Current Date: 4/25/2010 9:26 PM
Units system: English
File name: F:\Senior Design 1\final flat bridge with top rail 1018 pinned top rails.adv

Geometry data

GLOSSARY

Cb22, Cb33	: Moment gradient coefficients
Cm22, Cm33	: Coefficients applied to bending term in interaction formula
d0	: Tapered member section depth at J end of member
DJX	: Rigid end offset distance measured from J node in axis X
DJY	: Rigid end offset distance measured from J node in axis Y
DJZ	: Rigid end offset distance measured from J node in axis Z
DKX	: Rigid end offset distance measured from K node in axis X
DKY	: Rigid end offset distance measured from K node in axis Y
DKZ	: Rigid end offset distance measured from K node in axis Z
dL	: Tapered member section depth at K end of member
Ig factor	: Inertia reduction factor (Effective Inertia/Gross Inertia) for reinforced concrete members
K22	: Effective length factor about axis 2
K33	: Effective length factor about axis 3
L22	: Member length for calculation of axial capacity
L33	: Member length for calculation of axial capacity
LB pos	: Lateral unbraced length of the compression flange in the positive side of local axis 2
LB neg	: Lateral unbraced length of the compression flange in the negative side of local axis 2
RX	: Rotation about X
RY	: Rotation about Y
RZ	: Rotation about Z
TO	: 1 = Tension only member 0 = Normal member
TX	: Translation in X
TY	: Translation in Y
TZ	: Translation in Z

Nodes

Node	X [ft]	Y [ft]	Z [ft]	Rigid Floor
1	-10.7083	2.0203	4.1875	0
2	-10.7083	0.8333	4.1875	0
3	-8.1458	2.0203	4.1875	0
4	-8.1458	0.8333	4.1875	0
5	-5.5833	2.0203	4.1875	0
6	-5.5833	0.8333	4.1875	0
7	-3.0208	2.0203	4.1875	0
8	-3.0208	0.8333	4.1875	0
9	-10.1958	2.0203	4.1875	0

10	-6.0958	2.0203	4.1875	0
11	-5.0708	2.0203	4.1875	0
12	-0.4583	2.0203	4.1875	1
13	-13.2708	2.0203	4.1875	0
14	-13.2708	0.8333	4.1875	0
15	-15.8333	2.0203	4.1875	0
16	-15.8333	0.8333	4.1875	0
17	-18.3958	2.0203	4.1875	0
18	-18.3958	0.8333	4.1875	0
19	-11.2208	2.0203	4.1875	0
20	-16.3458	2.0203	4.1875	0
21	-20.9583	2.0203	4.1875	2
22	-0.4583	2.4172	4.4167	0
23	-0.9708	2.4172	4.4167	0
24	-1.4833	2.4172	4.4167	0
25	-1.9958	2.4172	4.4167	0
26	-2.5083	2.4172	4.4167	0
27	-3.0208	2.4172	4.4167	0
28	-0.9708	2.0203	4.1875	0
29	-1.4833	2.0203	4.1875	0
30	-1.9958	2.0203	4.1875	0
31	-2.5083	2.0203	4.1875	0
32	-3.5333	2.0203	4.1875	0
33	-4.0458	2.0203	4.1875	0
34	-4.5583	2.0203	4.1875	0
35	-3.5333	2.4172	4.4167	0
36	-4.0458	2.4172	4.4167	0
37	-4.5583	2.4172	4.4167	0
38	-5.0708	2.4172	4.4167	0
39	-5.5833	2.4172	4.4167	0
40	-6.6083	2.0203	4.1875	0
41	-7.1208	2.0203	4.1875	0
42	-7.6333	2.0203	4.1875	0
43	-6.0958	2.4172	4.4167	0
44	-6.6083	2.4172	4.4167	0
45	-7.1208	2.4172	4.4167	0
46	-7.6333	2.4172	4.4167	0
47	-8.1458	2.4172	4.4167	0
48	-8.6583	2.0203	4.1875	0
49	-9.1708	2.0203	4.1875	0
50	-9.6833	2.0203	4.1875	0
51	-8.6583	2.4172	4.4167	0
52	-9.1708	2.4172	4.4167	0
53	-9.6833	2.4172	4.4167	0
54	-10.1958	2.4172	4.4167	0
55	-10.7083	2.4172	4.4167	0
56	-11.7333	2.0203	4.1875	0
57	-12.2458	2.0203	4.1875	0
58	-12.7583	2.0203	4.1875	0
59	-11.2208	2.4172	4.4167	0
60	-11.7333	2.4172	4.4167	0
61	-12.2458	2.4172	4.4167	0
62	-12.7583	2.4172	4.4167	0
63	-13.2708	2.4172	4.4167	0
64	-13.7833	2.0203	4.1875	0
65	-14.2958	2.0203	4.1875	0
66	-14.8083	2.0203	4.1875	0
67	-15.3208	2.0203	4.1875	0
68	-13.7833	2.4172	4.4167	0

69	-14.2958	2.4172	4.4167	0
70	-14.8083	2.4172	4.4167	0
71	-15.3208	2.4172	4.4167	0
72	-15.8333	2.4172	4.4167	0
73	-16.8583	2.0203	4.1875	0
74	-17.3708	2.0203	4.1875	0
75	-17.8833	2.0203	4.1875	0
76	-16.3458	2.4172	4.4167	0
77	-16.8583	2.4172	4.4167	0
78	-17.3708	2.4172	4.4167	0
79	-17.8833	2.4172	4.4167	0
80	-18.3958	2.4172	4.4167	0
81	-18.9083	2.0203	4.1875	0
82	-19.4208	2.0203	4.1875	0
83	-19.9333	2.0203	4.1875	0
84	-20.4458	2.0203	4.1875	0
85	-18.9083	2.4172	4.4167	0
86	-19.4208	2.4172	4.4167	0
87	-19.9333	2.4172	4.4167	0
88	-20.4458	2.4172	4.4167	0
89	-20.9583	2.4172	4.4167	0
90	-0.4583	2.4172	3.9583	0
91	-0.9708	2.4172	3.9583	0
92	-1.4833	2.4172	3.9583	0
93	-1.9958	2.4172	3.9583	0
94	-2.5083	2.4172	3.9583	0
95	-3.0208	2.4172	3.9583	0
96	-3.5333	2.4172	3.9583	0
97	-4.0458	2.4172	3.9583	0
98	-4.5583	2.4172	3.9583	0
99	-5.0708	2.4172	3.9583	0
100	-5.5833	2.4172	3.9583	0
101	-6.0958	2.4172	3.9583	0
102	-6.6083	2.4172	3.9583	0
103	-7.1208	2.4172	3.9583	0
104	-7.6333	2.4172	3.9583	0
105	-8.1458	2.4172	3.9583	0
106	-8.6583	2.4172	3.9583	0
107	-9.1708	2.4172	3.9583	0
108	-9.6833	2.4172	3.9583	0
109	-10.1958	2.4172	3.9583	0

XI.3. Load Data

BENTLEY

Current Date: 4/25/2010 9:32 PM
Units system: English
File name: F:\Senior Design 1\final flat bridge with top rail 1018 pinned top rails.adv

Load data

GLOSSARY

Comb : Indicates if load condition is a load combination (1= load combination. 0 = load case)

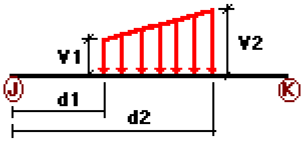
Load conditions

Condition	Description	Comb.	Category
DL	Dead Load	0	DL
lat	lateral load	0	lat
s1	roll of 1	0	s1
s2	roll of 2	0	s2
s3	roll of 3	0	s3
s4	roll of 4	0	s4
s5	roll of 5	0	s5
s6	roll of 6	0	s6
c1	1.0dl +1.0lat	1	
c2	1.0dl+1.0s1	1	
c3	1.0dl+1.0s2	1	
c4	1.0dl+1.0s3	1	
c5	1.0dl+1.0s4	1	
c6	1.0dl+1.0s5	1	
c7	1.0dl+1.0s6	1	

Load on nodes

Condition	Node	FX [Kip]	FY [Kip]	FZ [Kip]	MX [Kip*ft]	MY [Kip*ft]	MZ [Kip*ft]
lat	55	0.00	0.00	0.05	0.00	0.00	0.00

Distributed force on members



Condition	Member	Dir1	Val1 [Kip/ft]	Val2 [Kip/ft]	Dist1 [ft]	%	Dist2 [ft]	%
lat	1912	Y	-0.0245	-0.0245	0.00	No	100.00	Yes
	1913	Y	-0.0245	-0.0245	0.00	No	100.00	Yes
	1914	Y	-0.0245	-0.0245	0.00	No	100.00	Yes
	1915	Y	-0.0245	-0.0245	0.00	No	100.00	Yes
	1916	Y	-0.0245	-0.0245	0.00	No	100.00	Yes
	1917	Y	-0.0245	-0.0245	0.00	No	100.00	Yes
s1	1533	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1534	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1535	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1536	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1537	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1538	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1550	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1551	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1552	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1553	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1554	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1556	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1913	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1914	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1915	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1916	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1917	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1918	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1930	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1931	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1932	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1933	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1934	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1936	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
s2	1531	Y	-0.2043	-0.2043	50.00	Yes	100.00	Yes
	1532	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1533	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1534	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1535	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1536	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1537	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes
	1548	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1549	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1550	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1551	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1552	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1553	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1911	Y	-0.2043	-0.2043	50.00	Yes	100.00	Yes
	1912	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1913	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1914	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1915	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1916	Y	-0.2043	-0.2043	0.00	No	100.00	Yes

	1917	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes
	1928	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1929	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1930	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1931	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1932	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1933	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
s3	1530	Y	-0.2043	-0.2043	25.00	Yes	100.00	Yes
	1531	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1532	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1533	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1534	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1535	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1536	Y	-0.2043	-0.2043	0.00	Yes	25.00	Yes
	1545	Y	-0.2043	-0.2043	75.00	Yes	100.00	Yes
	1546	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1547	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1548	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1549	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1550	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1551	Y	-0.2043	-0.2043	0.00	Yes	75.00	Yes
	1910	Y	-0.2043	-0.2043	25.00	Yes	100.00	Yes
	1911	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1912	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1913	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1914	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1915	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1916	Y	-0.2043	-0.2043	0.00	Yes	25.00	Yes
	1925	Y	-0.2043	-0.2043	75.00	Yes	100.00	Yes
	1926	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1927	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1928	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1929	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1930	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1931	Y	-0.2043	-0.2043	0.00	Yes	75.00	Yes
s4	1529	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1530	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1531	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1532	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1533	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1534	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1543	Y	-0.2043	-0.2043	75.00	Yes	100.00	Yes
	1544	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1545	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1546	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1547	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1548	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1549	Y	-0.2043	-0.2043	0.00	Yes	75.00	Yes
	1909	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1910	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1911	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1912	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1913	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1914	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1923	Y	-0.2043	-0.2043	75.00	Yes	100.00	Yes
	1924	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1925	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1926	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1927	Y	-0.2043	-0.2043	0.00	No	100.00	Yes

	1928	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1929	Y	-0.2043	-0.2043	0.00	Yes	75.00	Yes
s5	1527	Y	-0.2043	-0.2043	66.00	Yes	100.00	Yes
	1528	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1529	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1530	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1531	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1532	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1533	Y	-0.2043	-0.2043	0.00	Yes	66.00	Yes
	1541	Y	-0.2043	-0.2043	50.00	Yes	100.00	Yes
	1542	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1543	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1544	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1545	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1546	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1547	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes
	1907	Y	-0.2043	-0.2043	66.00	Yes	100.00	Yes
	1908	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1909	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1910	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1911	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1912	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1913	Y	-0.2043	-0.2043	0.00	Yes	66.00	Yes
	1921	Y	-0.2043	-0.2043	50.00	Yes	100.00	Yes
	1922	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1923	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1924	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1925	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1926	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1927	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes
s6	1526	Y	-0.2043	-0.2043	33.00	Yes	100.00	Yes
	1527	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1528	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1529	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1530	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1531	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1532	Y	-0.2043	-0.2043	0.00	Yes	33.00	Yes
	1539	Y	-0.2043	-0.2043	66.00	Yes	100.00	Yes
	1540	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1541	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1542	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1543	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1544	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1545	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes
	1906	Y	-0.2043	-0.2043	33.00	Yes	100.00	Yes
	1907	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1908	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1909	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1910	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1911	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1912	Y	-0.2043	-0.2043	0.00	Yes	33.00	Yes
	1919	Y	-0.2043	-0.2043	66.00	Yes	100.00	Yes
	1920	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1921	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1922	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1923	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1924	Y	-0.2043	-0.2043	0.00	No	100.00	Yes
	1925	Y	-0.2043	-0.2043	0.00	Yes	50.00	Yes

Self weight multipliers for load conditions

Condition	Description	Self weight multiplier Comb.	MultX	MultY	MultZ
DL	Dead Load	0	0.00	-1.00	0.00
lat	lateral load	0	0.00	0.00	0.00
s1	roll of 1	0	0.00	0.00	0.00
s2	roll of 2	0	0.00	0.00	0.00
s3	roll of 3	0	0.00	0.00	0.00
s4	roll of 4	0	0.00	0.00	0.00
s5	roll of 5	0	0.00	0.00	0.00
s6	roll of 6	0	0.00	0.00	0.00
c1	1.0dl +1.0lat	1	0.00	0.00	0.00
c2	1.0dl+1.0s1	1	0.00	0.00	0.00
c3	1.0dl+1.0s2	1	0.00	0.00	0.00
c4	1.0dl+1.0s3	1	0.00	0.00	0.00
c5	1.0dl+1.0s4	1	0.00	0.00	0.00
c6	1.0dl+1.0s5	1	0.00	0.00	0.00
c7	1.0dl+1.0s6	1	0.00	0.00	0.00

Seismic (Dynamic analysis only)

Condition	a/g	Ang. [Deg]	Damp. [%]
DL	0.00	0.00	0.00
lat	0.00	0.00	0.00
s1	0.00	0.00	0.00
s2	0.00	0.00	0.00
s3	0.00	0.00	0.00
s4	0.00	0.00	0.00
s5	0.00	0.00	0.00
s6	0.00	0.00	0.00
c1	0.00	0.00	0.00
c2	0.00	0.00	0.00
c3	0.00	0.00	0.00
c4	0.00	0.00	0.00
c5	0.00	0.00	0.00
c6	0.00	0.00	0.00
c7	0.00	0.00	0.00

XI.4. Deflection Data

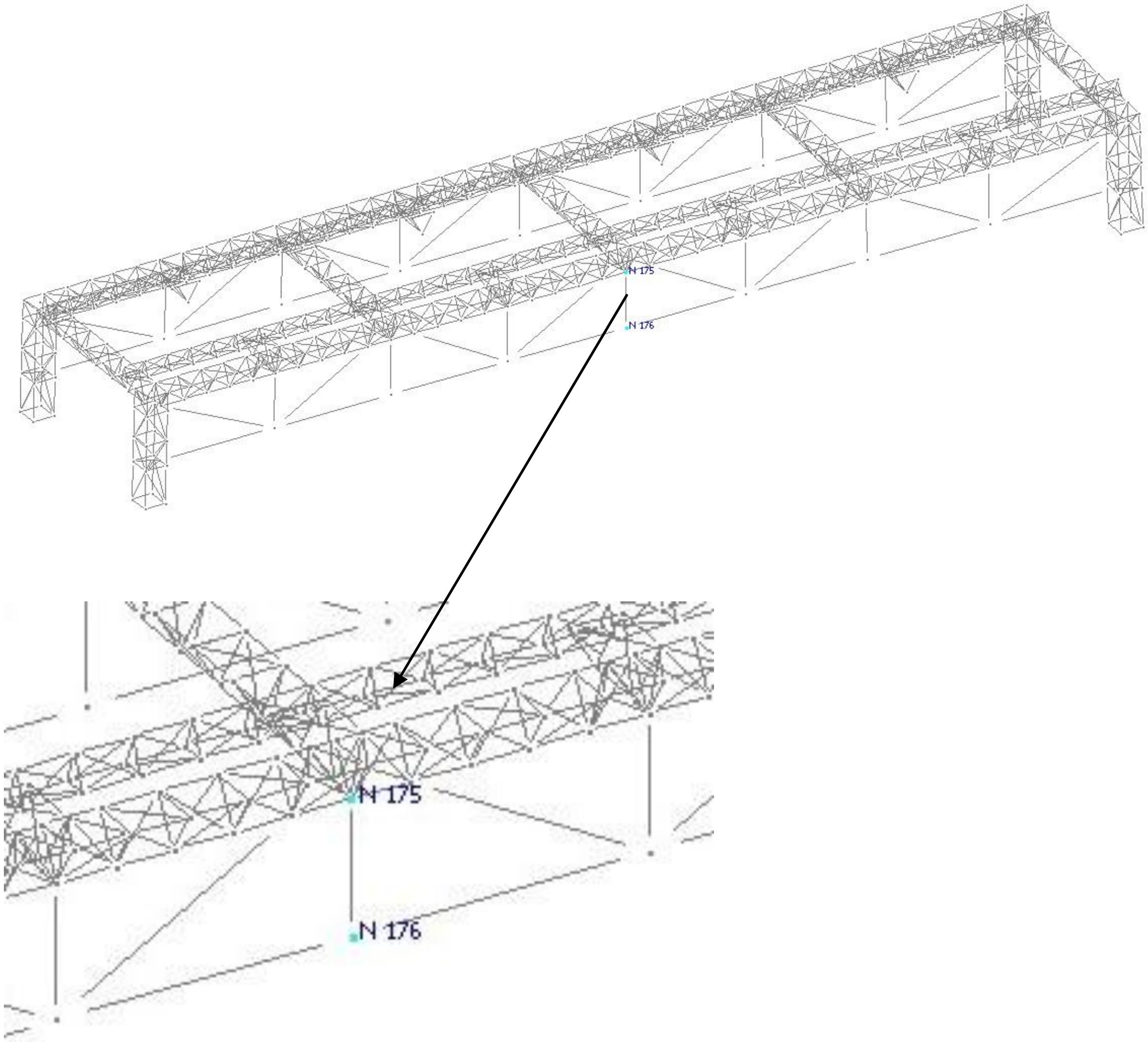
BENTLEY

Current Date: 4/25/2010 9:19 PM
Units system: English
File name: F:\Senior Design 1\final flat bridge with top rail 1018 pinned top rails.adv

Analysis Results

Translations

	Translations [in]			Rotations [Rad]		
Node	**TX**	**TY**	**TZ**	**RX**	**RY**	**RZ**
Condition **c1=1.0dl +1.0lat**						
175	-0.01540	-0.07109	0.08812	-0.00052	-0.00007	-0.00004
176	-0.01540	-0.07110	0.09111	-0.00022	0.00000	0.00000
Condition **c2=1.0dl+1.0s1**						
175	-0.10061	-0.46647	0.06239	0.00416	0.00041	0.00036
176	-0.09742	-0.46648	-0.01093	0.00510	-0.00056	0.00035
Condition **c3=1.0dl+1.0s2**						
175	-0.11291	-0.51336	0.05823	0.00428	-0.00019	0.00008
176	-0.10959	-0.51337	-0.01788	0.00533	0.00019	0.00031
Condition **c4=1.0dl+1.0s3**						
175	-0.12515	-0.56000	0.05273	0.00436	-0.00058	-0.00007
176	-0.12166	-0.56001	-0.02907	0.00580	0.00065	0.00029
Condition **c5=1.0dl+1.0s4**						
175	-0.13514	-0.59458	0.04849	0.00444	-0.00084	-0.00021
176	-0.13195	-0.59458	-0.04135	0.00646	0.00093	0.00024
Condition **c6=1.0dl+1.0s5**						
175	-0.14491	-0.62653	0.04471	0.00471	-0.00081	-0.00023
176	-0.14262	-0.62653	-0.05809	0.00747	0.00074	0.00017
Condition **c7=1.0dl+1.0s6**						
175	-0.15026	-0.63663	0.04221	0.00495	-0.00072	-0.00029
176	-0.14941	-0.63664	-0.07032	0.00822	0.00031	0.00006


N 175
N 176
N 175
N 176

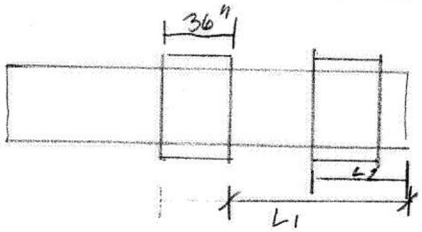
XI.5. Hand Calculations

ASCE BRIDGE CONTEST

LOADING

LATERAL
50# @ center

VERTICAL



PLAN VIEW

PLACEMENT (to center of Deck section)

L_1 max = 145" + 18" = 163"
L_1 min = 105 + 18" = 123"

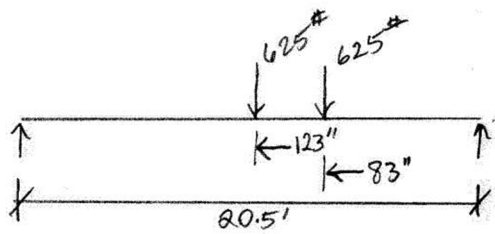
L_2 max = 65" + 18" = 83"
L_2 min = 0" + 18" = 18"

LOAD = 1250# @ EACH DECK SECTION
= 625#/GIRDER

Preliminary Design

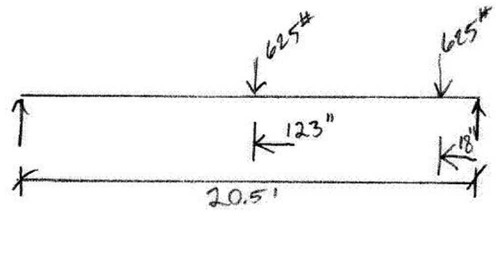
Max Moment Case when L_1 = 163" and L_2 = 83"
Max Shear Case when L_1 = 123" and L_2 = 18"

M_{max}

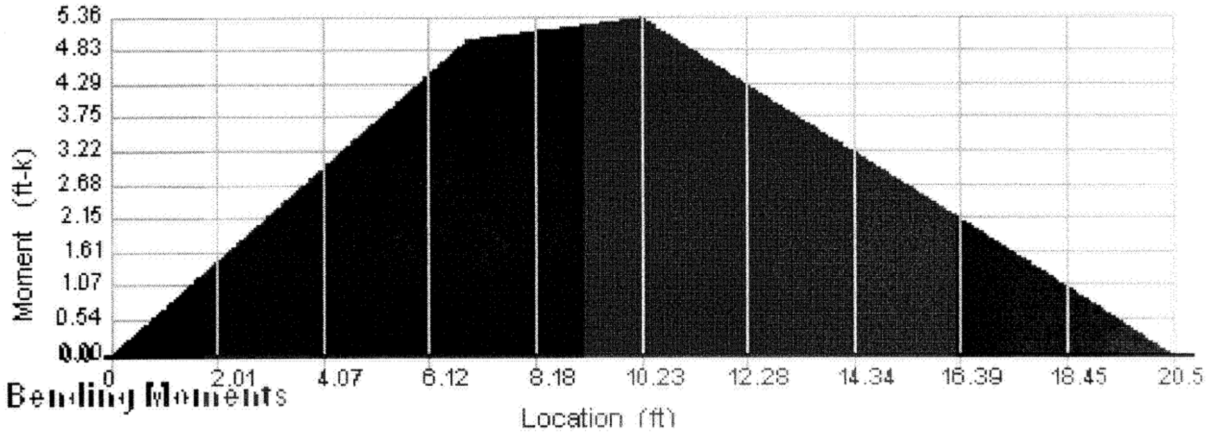


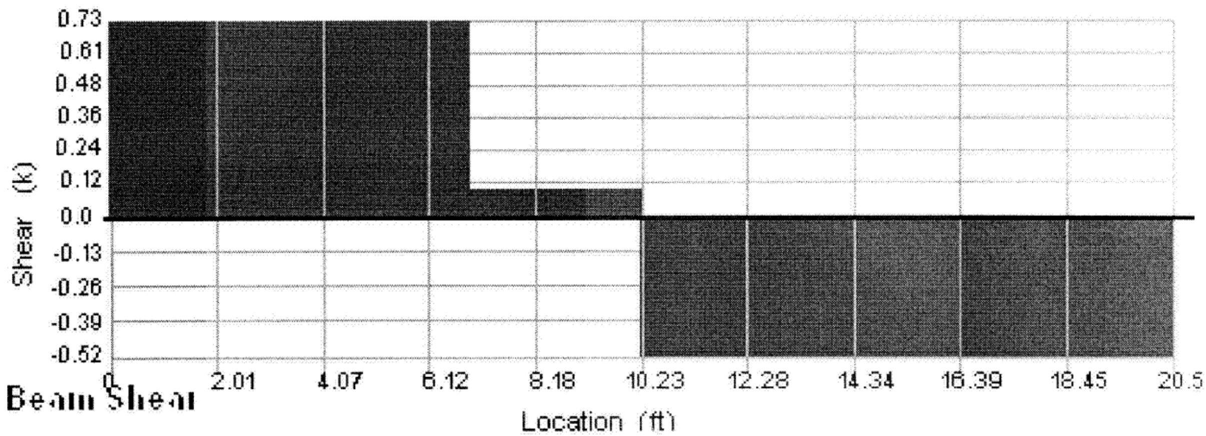
M_{max} = 5.36 K-ft
V_{max} = 0.727 K

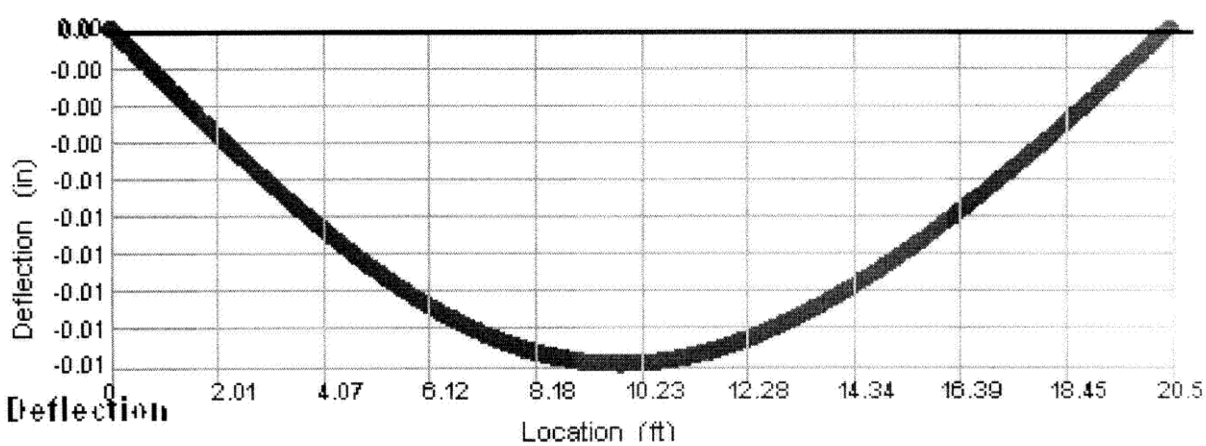
V_{max}

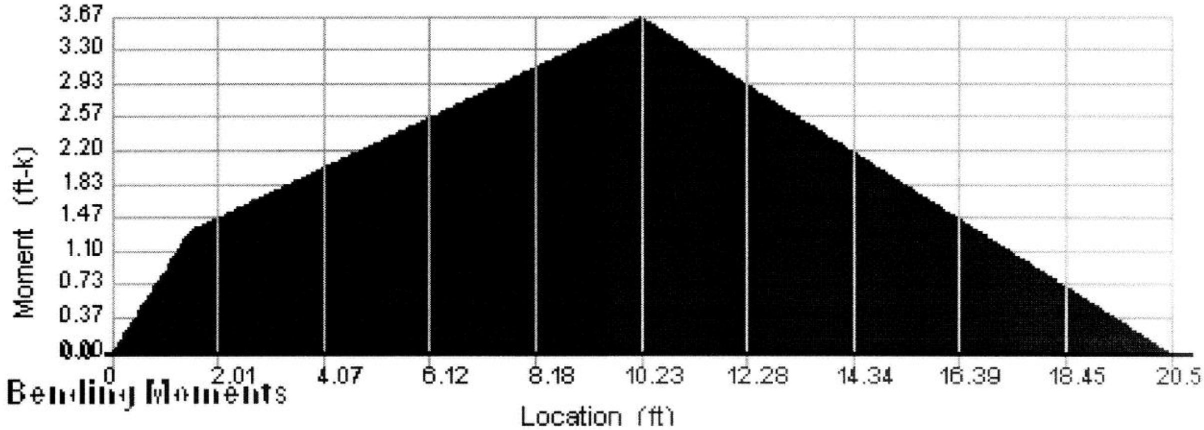


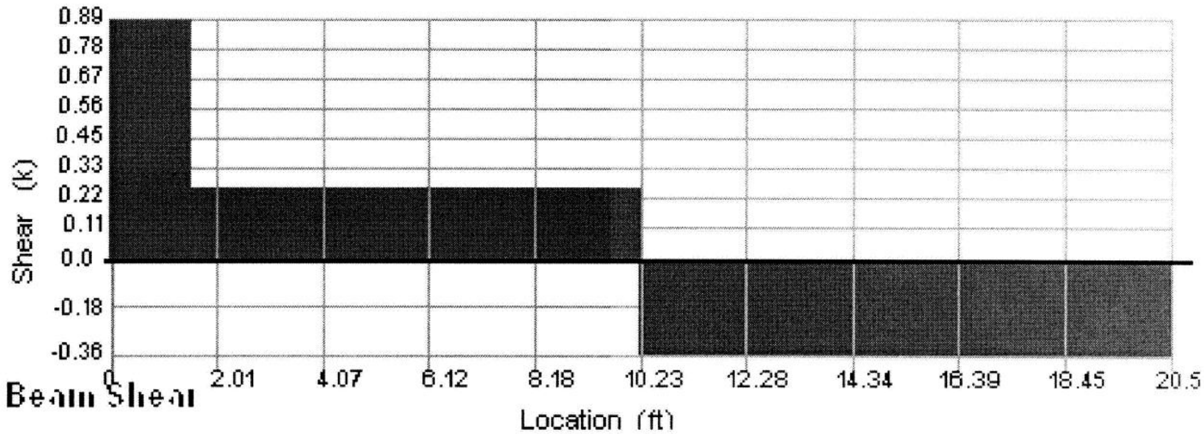
M_{max} = 3.67 K-ft
V_{max} = 0.892 K

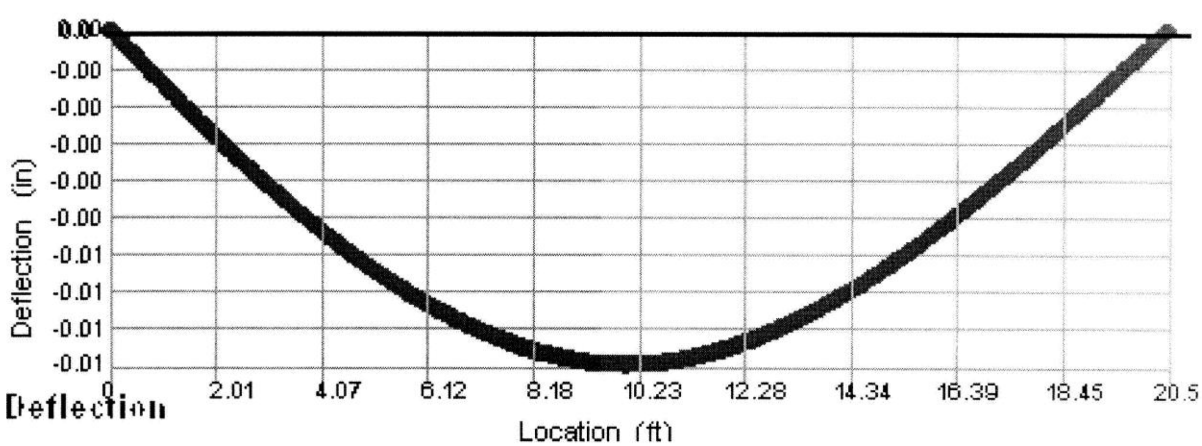

5.36
4.83
4.29
3.75
3.22
2.68
2.15
1.61
1.07
0.54
0.00
Moment (ft-k)
0
2.01
4.07
6.12
8.18
10.23
12.28
14.34
16.39
18.45
20.5
Bending Moments
Location (ft)


0.73
0.61
0.48
0.36
0.24
0.12
0.0
-0.13
-0.26
-0.39
-0.52
Shear (k)
0
2.01
4.07
6.12
8.18
10.23
12.28
14.34
16.39
18.45
20.5
Beam Shear
Location (ft)


0.00
-0.00
-0.00
-0.00
-0.01
-0.01
-0.01
-0.01
-0.01
-0.01
Deflection (in)
0
2.01
4.07
6.12
8.18
10.23
12.28
14.34
16.39
18.45
20.5
Deflection
Location (ft)


3.67
3.30
2.93
2.57
2.20
1.83
1.47
1.10
0.73
0.37
0.00
Moment (ft-k)
0
2.01
4.07
6.12
8.18
10.23
12.28
14.34
16.39
18.45
20.5
Bending Moments
Location (ft)

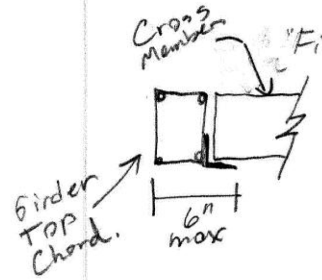

0.89
0.78
0.67
0.56
0.45
0.33
0.22
0.11
0.0
-0.18
-0.36
Shear (k)
0
2.01
4.07
6.12
8.18
10.23
12.28
14.34
16.39
18.45
20.5
Beam Shear
Location (ft)


0.00
-0.00
-0.00
-0.00
-0.00
-0.00
-0.01
-0.01
-0.01
-0.01
Deflection (in)
0
2.01
4.07
6.12
8.18
10.23
12.28
14.34
16.39
18.45
20.5
Deflection
Location (ft)

Preliminary Design Cont.

Notes:

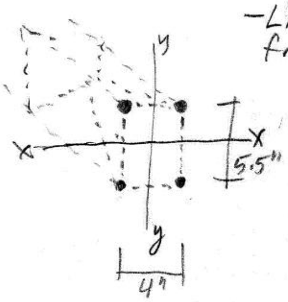
- Want large Comp member @ top of girder
- Use small solid tension member @ bottom
- max member dim. = 6"x 6" x 3'-6"



First design consideration:
3'-6" min between girders, which means if cross members are to be one peice, all connection materials must be part of top cord of girder.

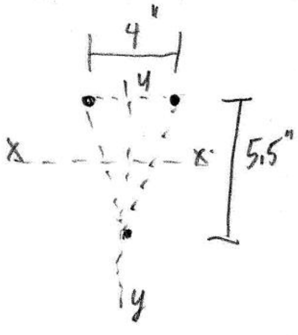
SAY, Max top chord dimension = 4"x 5½"

For comp. member we want to increase Ixx, Iyy
-Lightess way is to place mass at furthes points from c.g. (ie. use boxed truss members)



Possible I's

	Ixx (in⁴)	Iyy (in⁴)
4" x 5½" w/ ¼" bars	1.4857	0.7862
4 x 5½" w/ 3/8" bars	2.974	1.5746
4 x 5½" w/ ½" bars	4.4662	2.3677

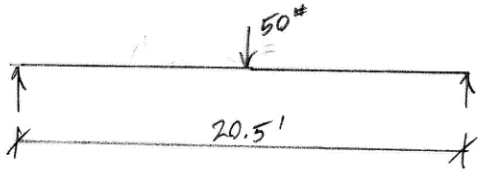


Possible I's

	Ixx (in⁴)	Iyy (in⁴)
4" x 5½" triangle ¼" bars	0.9905	0.3933
" 3/8"	1.9827	0.7883
½"	2.9784	1.1867

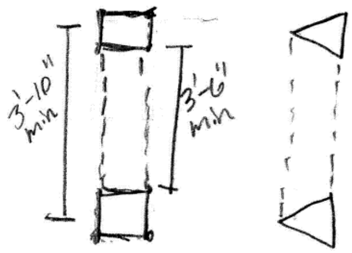
CHECK LATERAL DESIGN

LATERAL LOAD OF 50# @ CENTER



$M_{max} = .260^{k\text{-}ft}$
$V_{max} = 25^{\#}$

Resisting Section



1" Δ max allowed

1/4" Δ => I = 2 in^4
1/2" Δ => I = 1 in^4
3/4" Δ => I = N/A
1" Δ => I = N/A

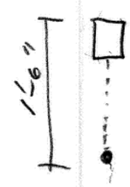
4"x5.5"x 1/4" w/3'-10 spread I = 210,709 in^4 OK
4x5.5 triangle 1/4 w/3'-10 spread I = 156.6 in^4 OK

GIRDER DESIGN

BASE REQ. I on Δ. based on Max Moment Case

Δ	Req Girder I (in^4)
1/8"	100
1/4"	50
1/2"	25
3/4"	17.5
1"	12.5

MAX ALLOWABLE GIRDER DEPTH = 1'-8 3/4"
=> USE 1'-6" TOTAL



Rod φ	(4) Top Rod φ	Ixx (in^4)	Approx (#/') Wt/ft
1/4	1/4"	10.62	.835
3/8	1/4"	17.92	1.044
1/2	1/4"	23.6	1.336
1/4	3/8"	10.80	1.671
3/8	3/8"	23.02	1.88
1/2	3/8"	32.12	2.172
1/4	1/2"	12.52	2.839
3/8	1/2"	26.1	3.048
1/2	1/2"	37.09	3.34

.25φ = .167#/ft
3/8φ = .376#/ft
1/2φ = .668#/ft

Bottom ROD Φ	(3) TOP ROD Φ	I_{xx} (in^4)	Appox. Wt/ft (#/')	
1/4	1/4	8.69	.668	25%
3/8	1/4	17.49	.887	
1/2	1/4	22.38	1.17	14%
1/4	3/8	10.54	1.295	
3/8	3/8	22.98	1.504	
1/2	3/8	31.60	1.791	
1/4	1/2	11.86	2.171	
3/8	1/2	26.07	2.38	
1/2	1/2	36.94	2.672	