SJSU SAN JOSÉ STATE UNIVERSITY

GUIDEWAY DESIGN AND FABRICATION METHOD FOR THE SPARTAN SUPERWAY

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Liwei Lu

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Liwei Lu

APPROVED BY THE DEPARTMENT OF MECHANICAL ENGINEERING

SAN JOSÉ STATE UNIVERSITY

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Burford Furman, Ph.D. (Chair)

Ron Swenson, International Institute of Sustainable Transportation

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James Mokri, Lecturer of ME Department, SJSU

ABSTRACT

The preliminary design for the guideway elements was undertaken throughout the semester. Straight guideway beam, curved guideway beam, supporting structure, and heat expansion joint has been modeled and analyzed. The current design for the guideway for SPARTAN Superway project followed the concept of SAFEGE (*__S__ociété __A__nonyme __F__rançaise d' __E__tude de __G__estion et d' __E__ntreprises, named after a French Company)* type guideway. It's a rectangular hollow steel beam with an open bottom, and outside of the hollow steel beams there are ribs that can hold the shape of the guideway from collapsing.

Finite element analysis (FEA) method is the main approach when designing the guideway. After the FEA design study, a 0.1-inch wall thickness and 48 inches rib spacing has been determined, which will give the guideway the best performance.

FEA study shows that all the guideways and support structures designed have a factor of safety 5.0 or above, and the maximum deflection of all the guideways and supporting structures are fulfilling the L/800 spec. It can also handle a magnitude 6.9 earthquake and a 115mph wind load.

ACKNOWLEDGMENT

I would like to thank Dr. Burford Furman for being my committee chair. I was guided and educated by Dr. Furman throughout the semester and we met weekly by either in-person meetings or Zoom meetings.

I would also like to thank my committee members Ron Swenson and James Mokri. They have been listening to my weekly progress report and have been giving me a lot of suggestions for improving the guideway design.

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INTRODUCTION

As residents in the San Francisco Bay Area, we experience heavy traffic every day during rush hour. According to a study, people spend approximately 4-7% of their time in traffic on average (Matz, 2017), which is about 1 to 1.7 hours. In San Francisco alone, 445,000 vehicles travel on the road every day (Muyi, 2018); you can imagine if all those vehicles operate 1 to 1.7 hours daily, how much pollution will be produced and how much fuel will need to be consumed. Here we are talking about three major difficulties with the current modes of transportation: heavy traffic, air pollution, and the impending fossil fuel crisis.

Fortunately, we have one solution to resolve all three problems: the SPARTAN Superway. SPARTAN stands for Solar Powered Automated Rapid Transit Ascendant Networks. The SPARTAN Superway project started in 2012 and has engaged more than 200 SJSU students across the disciplines of engineering, business, urban planning and industrial design to show what can be done with solar-powered automated transportation as a profound response to the difficulties we are facing (Furman, 2019). As the name of this project indicates, the SPARTAN Superway system is going to be operated by solar power. The goal for the project is to achieve 100% solar power operation, which means no fossil fuel is used and it does not produce air pollution. If this goal is achieved, then this project would significantly help to reduce air pollution and the fossil fuel crisis, and therefore slow down the climate change effect due to carbon emission. On the other hand, the SPARTAN Superway will be run on a suspended guideway system as shown in Figure 1, which will help to reduce the current traffic conditions in the Bay Area and beyond.

Figure 1. SPARTAN Superway Concept. *Relatively small vehicles traverse a network of exclusive guideways and utilize off-line stations to provide on-demand, non-stop, origin-to-destination mobility. Suspending the ATN vehicle below the guideway makes the upper surface available for PV panels that can power the system.*

The main reason for having heavy traffic in the Bay Area is because of the huge number of private vehicles due to poor public transportation; people have to drive their own cars to school or works since there is not enough public transportation to support their daily activity. By having SPARTAN Superway, we have a new option of public transportation, and at the same time, since the SPARTAN Superway used a suspended guideway system which is located above grade by about 20 feet, it won't interfere with existing traffic corridors we are having. This is extremely important in that vertical space, as opposed to additional horizontal space, can be utilized to situate an entirely new form of transit in an urban setting without needing additional land. The use of elevated guideways has an important advantage over the current transit paradigm in that transit machines are separated from humans that are not using them, i.e. pedestrians, bicyclists, etc. This results in vastly improved safety and quality of life for urban dwellers (Furman, 2016).

In this SPARTAN project, my focus will be to design the structural elements for the guideway, as well as to design the manufacturing process for the structural elements. The guideway is the most expensive part of a PRT system (Anderson, 2009), so the design of an appropriate shape and manufacturing process for the structural elements is extremely important. The goal will be to define the structural elements shape so that it will be strong enough to handle expected loads and also be easy enough to manufacture so that we can lower the cost of the guideway.

OBJECTIVES

1. Design the structural elements for the guideway for the SPARTAN Superway System, which meet the loading and safety requirements.
2. Define the manufacturing process required to manufacture the structural elements from goal #1.

METHODOLOGY

The approach to achieve the above objective will be:

1. Perform a literature review, evaluate the existing suspension railway design concepts, adopt the suitable design concepts to our SPARTAN Superway project.
2. Formulate the design requirement according to expected loading, safety requirements and manufacturability

3. Design and complete the model of the guideway structural elements using Solidworks
4. Perform Finite Element Analysis (FEA) to the solid model and ensure the stress and deflection level meets the design requirement
5. Define the manufacturing process for the structural element according to literature and manufacturer's recommendation.
6. Document the manufacturing process and all detailed drawings for the structural elements.

LITERATURE REVIEW

A Solar Powered Automated Transportation Network - Full Scale Guideway Team: (Bunker & Leyva, 2019)

Students from ME 195 Senior Design Project worked on the design of a guideway for a full-scale demonstration model. The idea in this guideway design is to have a strong piece of material hanging by a number of vertical supporting structures, then the actual running trackway will be held by vertical "ribs". This design has the disadvantage that most of the bending moment must be reacted by the top horizontal plate. To meet the loading requirement and deflection requirement in actual passenger service, the horizontal plate needs to be very thick, and this would add significantly to the mass of the suspended guideway and require more substantial support columns, hence higher costs.

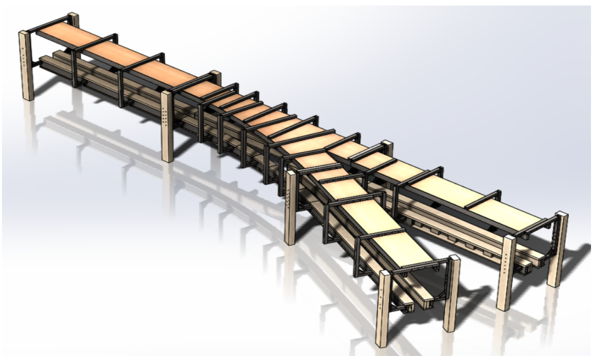


Figure 2. SPARTAN Guideway Design in 2019. *Demonstration model with wooden support and steel track (Bunker & Leyva, 2019)*

An Investigation Into The Deformation Properties Of Clamped Concrete Filled Steel Tubes: (Kishore, L. 2018)

An interesting study has been performed by previous SJSU MSME student Lalith Kishore about the concrete-filled steel tubes (CFST). The concrete-filled steel tubes are called Solomon's Knot crossbeams. The cross beam is unique in a way that they are formed by four pieces of sheet metal panels that are interlocked along their length as shown in Figure 3. The benefit of having the CFST comparing with the regular concrete or steel beam is that the CFST performs better against cracking and buckling. This type of structure could potentially be used in my guideway system as the vertical supporting structure

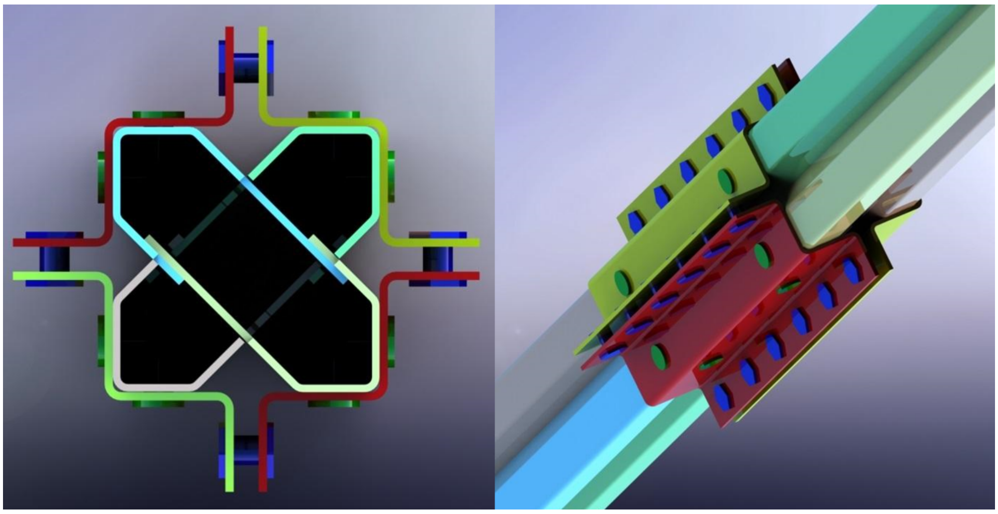


Figure 3.Cross-sectional View of Concrete Filled Steel Tube. Tube is form by four pieces of sheet metal panels that are interlocked. Four piece of sheet metal clamps are used as connection between tubes (Kishore, L. 2018)

Serviceability-Related Issue For Bridge Live Load Deflection And Construction Closure Pours: (Chung C. Fu, 2015)

One of the important design consideration for the guideway will be how much deflection will be allowed when the vehicles are in the middle of a guideway span. General design principles are detailed in chapter 2 of the AASHTO LRFD Bridge Design Specification. (AASHTO, 2017). Article 2.5.2.6.2 advise the maximum deformation of a bridge should not exceed 1/800 of the span length. The reason behind the 1/800 L is from a study by the Bureau of Public Road in the 1930s, they are trying to find a correlation between the vibration problems of bridges and bridge structural properties. The study concludes that structures having unacceptable vibration determined by subjective human response has deflection that exceeded L/800, and this is where the L/800 limit coming from. In our guideway design, we will use the same L/800 as the deflection requirement

American Society of Civil Engineers - Minimum Design Loads for Buildings and Other Structures (ASCE, 2010)

One of the design requirements for the guideway is that it needs to be strong enough to withstand a wind loading. This book has a very detailed description of how to calculate wind loading on a building-type of structure using a mathematical model and a lot of different factors. It also comes with a wind speed map that varies by risk category. However, since the guideway structure is too different from a regular building, the mathematical model described in the book might not be accurate, but we can still use the wind speed map to find the basic wind speed for the San Jose area, which is about 115 mph. We will use this wind speed and perform a CFD analysis on the guideway to estimate the wind load in this project.

Monorail Development and Application In Japan: (Shinya, 1988)

This article introduces the background of the monorail in Japan. A monorail is a transportation mode whose vehicles are guided and supported by a single rail or beam. There are two type of monorail as shown in Figure 4, for the first type of monorail, the vehicle is supported on top of the rail. For the second type, which is the suspended type, there are two variations, one with an arm extending from the vehicle " hooks" to the rail by wheel-rail contract (asymmetrical type), and the other with the vehicle suspended directly under the beam (symmetrical type).

Figure 4 Two Different Type of Monorail. *Straddle Form monorail, vehicle is supported on top of the rail (Left). Suspended Form monorail, vehicle is hooked below the rail (Right) (Shinya, 1988)*

The most popular type of system for the symmetrical type is called SAFEGE (Société Anonyme Française d' Etude de Gestion et d' Entreprises, English: French Limited Company for the Study of Management and Business), which was the names of the participating companies in the consortium (Wikipedia, 2020). The SAFEGE type of guideway is an open-bottom rectangular-shaped steel hollow beam as shown below in Figure 5. Because of this covered guideway, the adhesion between tires and the guideway is virtually unaffected by the weather. Furthermore, the noise level inside the vehicle is smaller than other regular railway systems due to the separation of the vehicle and the bogie.

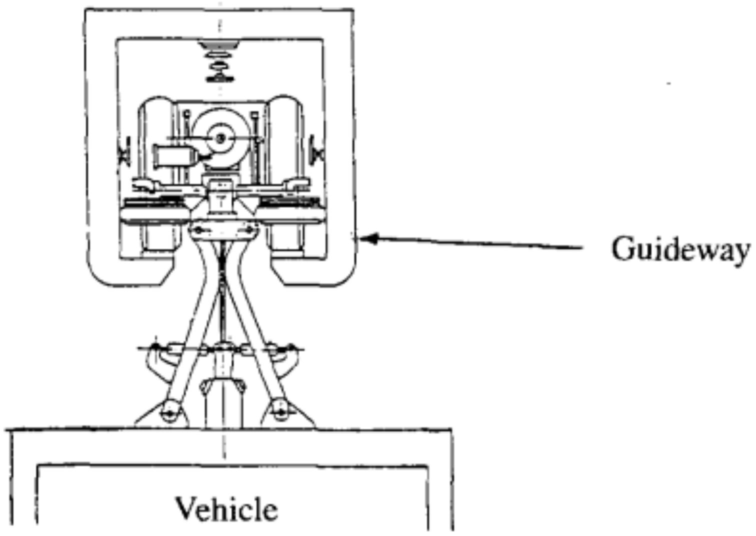


Figure 5. Cross-section of SAFEGE Monorail. *Bogie is running inside of the rectangular-shaped steel hollow beam with an open-bottom. (Shinya, 1988)*

Development / Deployment Investigation of Cabintaxi / Cabinlift Systems: (Hobbs, 1977)

The Cabintaxi/Cabinlift system is designed as a fully automated public transport system which is confined to a guideway. All system procedures and vehicle movements are carried out and controlled by a hierarchically structured electronic control system. The capability for both supported and suspended cabins permitting operation in opposite directions on a single guideway is a special design characteristic.

The guideway design is shown in Figure 6. It consists of an elevated double-track system. Top-mounted vehicles and suspended vehicles travel in opposite directions use the same beam. The guideway can also be constructed as a single track, according to the requirements of the city and other parameters regarding the transport situation.

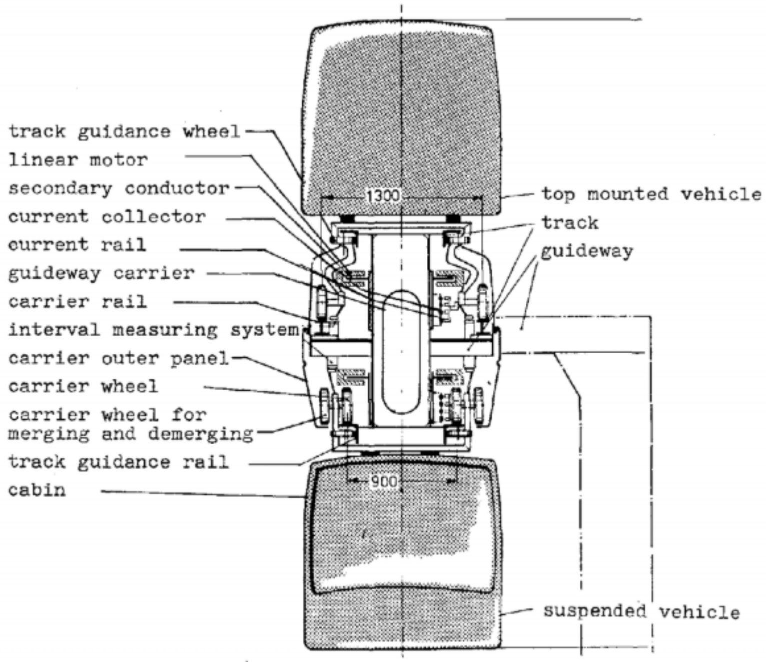


Figure 6. ***Bogie and Guideway Beam for Cabintaxi.*** Top vehicle is mounted on the guideway, and the bottom vehicle is suspended below the guideway, top and bottom vehicle travel in opposite directions (Hobbs, 1977).

H-Bahn: (Wikipedia, 2020)

The H-Bahn in Germany is a suspended, driverless passenger suspension railway system. The system was developed by Siemens in 1984. There are two existing routes currently, one at the Dortmund University campus, and the other at the Düsseldorf Airport. The design of H-Bahn is very similar to the SAFEGE system. The carrier is a hollow rectangular box girder with a slit in the bottom through which the cabin is suspended at the running gear, whose two axles carry the load with a rubber wheel on both sides providing both suspension and propulsion (see Figure 7). Two wheels run horizontally along the top and bottom of the interior sidewalls of the carrier box, providing horizontal guidance. All contact between the suspended cabin and the fixed system is enclosed in the interior of the carrier box, which is protected from inclement weather. Switching is done with the help of the horizontal guiding wheels, where short blades on both sides of the common section of the carrier move as a canal of the same width as the carrying box to the left or right, while a long blade between the two forking guideways moves right or left to provide the horizontal guidance into the intended direction. See Figure 7 for the switching mechanism.

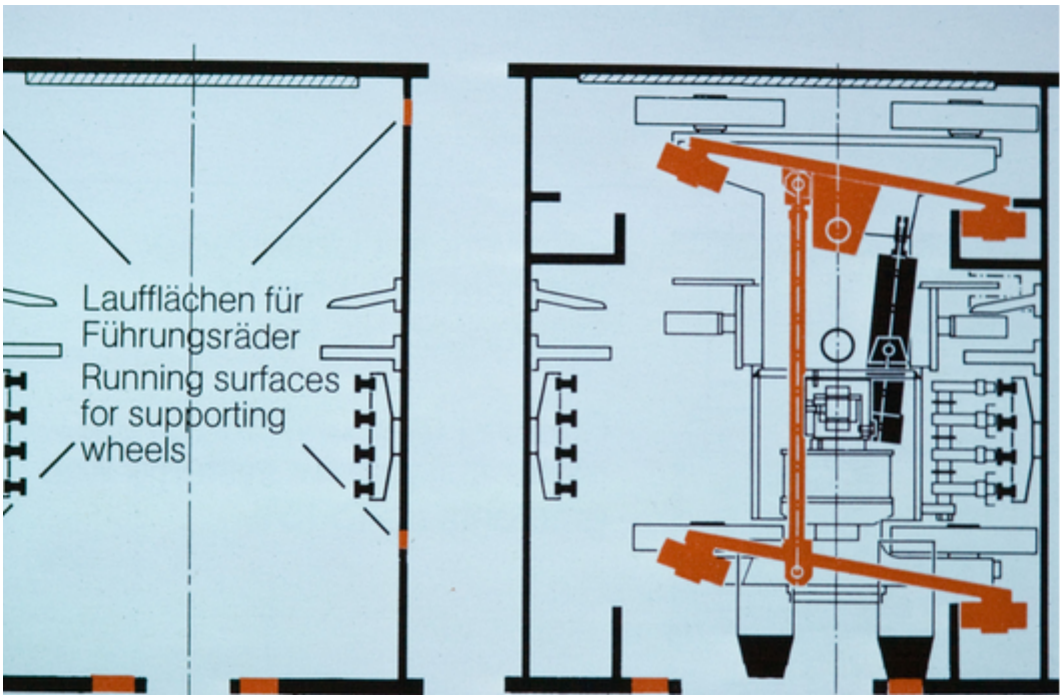


Figure 7. ***H-Bahn Switching Mechanism.*** *Left side shows the straight section of the guideway, no side-truck needed. Right side show the crosses-section of the guideway when turning, guiding wheels engage with side-truck to make a turn.*

Seismic Response Spectrum: (Jagadish, 2002)

One of the design factors we need to consider is earthquake. We need to make sure the guideway and supporting structure will not break down during an earthquake. To simulate the earthquake effect on structure, we usually use the response spectrum method. Response spectrum is an important tool in the seismic analysis and design of structures. It describes the maximum response of a damped single degree of freedom system to a particular input motion at deferment natural periods. The origin of this response spectrum method started back to 1971, with the occurrence of the San Fernando earthquake in California, the modern era of RSM was launched. This earthquake was recorded by 241 accelerographs, and by combining these data with all previous strong-motion records, it becomes possible to perform the first comprehensive empirical scaling analyses of response spectral amplitudes.

So as long as we can find some real spectrum data from an actual earthquake, we will be able to simulate how an earthquake will affect our guideway model.

The Transition Spiral: (Calvert, 2000)

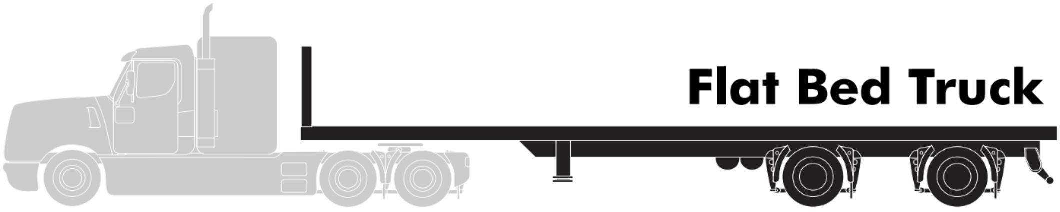
This article introduces what is transition spiral and how to calculate the transition spiral in general. In early railways design, it is unnecessary to superelevate the outer rail to make a comfortable passage of a curve due to the speed is low. However, when the speed increased to above 30 mph, the centrifugal force became uncomfortable to passengers. What we need is a gradual decrease in radius of curvature R concomitant with the elevation of the outer rail, so that the transition of the circular curve is smooth. This length of track in which the radius of curvature decrease from infinity to the radius of the circular curve is called transition spiral. A spiral in which the superelevation, and therefore the curvature, increases linearly with distance along the spiral has been found to be completely satisfactory. We will use this concept in the curved guideway design during the project.

Design of Steel Structures: Chapter 6 Weld Connections: (Varma, 2003)

Structural welding is a process by which the part that is to be connected is heated and fused, with supplementary molten metal at the joint. There are many different types of welding but the most common types are fillet weld and groove weld. For our guideway design project, the welding method we will use will probably fillet weld. For fillet weld, the weld sizes are specified in 1/16 in increments as a standard. This article also introduces and explain the basic functions of how to calculate the weld size needed according to the stress condition, which will be very helpful for our guideway design project.

DESIGN CONCEPT

There are several aspects we need to consider when designing the guideway. First, it's the modularity of the guideway. It's very difficult or even impossible to build the guideway in the field, so we will have to build the guideway in segments in a factory, transport them to the field, and assemble them into a complete guideway in the field. It would be costly to have a special truck just to transport guideway segments, so using information on standard freight truck sizes, a 48 feet length is determined to be the longest guideway segment recommended for transport by a regular freight truck.



Standards:
Common Lengths: 20, 40, 45, 48 feet
Width: 98 - 102 inches

Usage:

Designed to transport oversized cargo that won't normally fit into a standard sized trailer

Capacity:
Max Weight @ 40 ft length: 71,390 lbs

Common Flat Bed (Platform) Specifications

Overall		Max Weight
Length	Width	
26 ft	96"	55,000 lbs
40 ft	96"	55,000 lbs
45 ft	102"	55,000 lbs
48 ft	102"	55,000 lbs

Data provided for illustrative purposes only. Actual equipment in use varies by carrier and manufacturer.
This is only a guide and should not be used as a definitive reference for dock planning.

Figure 8. Freight Truck size chart. *Largest common flatbed truck is 48 feet long and 102 inches wide. (Cerasis 2015 Trailer Guide)*

The geometry of the guideway was chosen to be like that of the SAFEGE. It's basically a rectangular steel hollow beam with an open bottom as shown in Figure 9. Outside of the Rectangular beam, there are multiple "ribs" that are welded onto the outer surface to prevent the shape of the guideway from collapsing while the vehicle passes by. There are several advantages of having the SAFEGE type design, firstly, this design is simple and reliable, there are only two main components, the steel hollow beams and the ribs. The hollow steel hollow beams can be manufactured by welding up sheet metals, and the ribs are just standard rectangular tubes. They are easy to produce, and the welding process required is not too complicated. Secondly, due to its enclosed feature, radiated noise will be reduced compared to an open guideway, such as a monorail or train, this is a big win, since the first route planned for the SPARTAN Superway is going to be located in downtown San Jose, and it's going to pass by offices, libraries, schools, and neighborhoods. If the noise level is too high, it will significantly affect people's daily lives. Thirdly, since the bogie is using batteries and electric motors, it will be weather sensitive. By having this enclosed design, the weather effect on those electric components is minimized since sunlight or water will never reach the bogie.

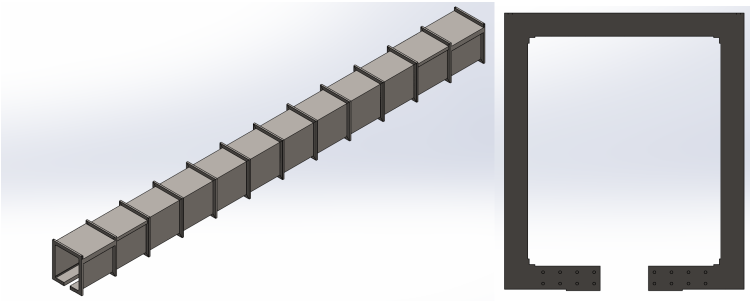


Figure 9. Guideway Straight Section. *Overall length is 48 feet, inner dimension of the crosses-section is 34 inches wide and 40.5 inches high. Ribs are 2x4'' rectangular tube with 0.25'' wall thickness.*

There are three types of supporting structures were designed to fulfill different needs. The L shape supporting structure is shown below in Figure 10. It was designed to support one route of the guideway only. It has a cylindrical tube with one end fixed to the ground. On the top side of the cylindrical tube, there is a rectangular holder welded onto the tube. There are a couple of blocks welded onto the rectangular holder as shown. The welded blocks are used for pulley installation.

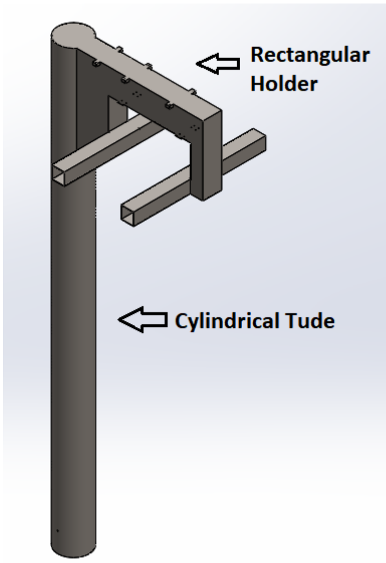


Figure 10. Supporting Structure. *Both cylindrical tube and rectangular holder are hollowed for weight reduction purpose.*

When the guideway needs to be assembled to the supporting structure, the pully system can be used to lift the guideway up. As shown in Figure 11, the top three pulleys can be used to adjust the height of the guide way as shown in blue lines, and the bottom two pulleys can be used to adjust the horizontal position of the guideway as shown in red lines. A 3-ton crane motor can be used with the pulley system to lift the guideway up. The motor can be mounted on a crane support to the bottom of the support structure as shown in Figure 12. The five horizontal bars of the crane support are removable, so we can remove the crane support easily after the guideway installation. When the guideway is in position, the operator in the field can place a guideway holder on each side of the guideway. The guideway holder is shown in figure 13, two guideway holders can be assembled with a thin metal plate and screws. After assembling, the guideway holder will be able to slide along the guideway to adjust the holder position as needed. The adjustable distance is about 40 inches, which means the support structure position can be moved along the guideway direction by about 80 inches (two adjustable guideways on one support structure). On the other hand, the guideway holder has an adjustable stand welded to the side. The adjustable stand is made with steel blocks and a 2-4.5 threaded steel shaft. By turning the steel shaft, the height of the stand can be adjusted. The adjustable height is about 4 inches. After all adjustments are done, we can use rail clips to fix the guideway on both sides. An example of the rail clip is shown in Figure 14. The reason for using rail clips instead of regular bolts and nuts is because of the heat expansion. We need the guideway to be able to move in some certain level in the direction along the guideway so that when the guideway expands, it doesn’t buckle.

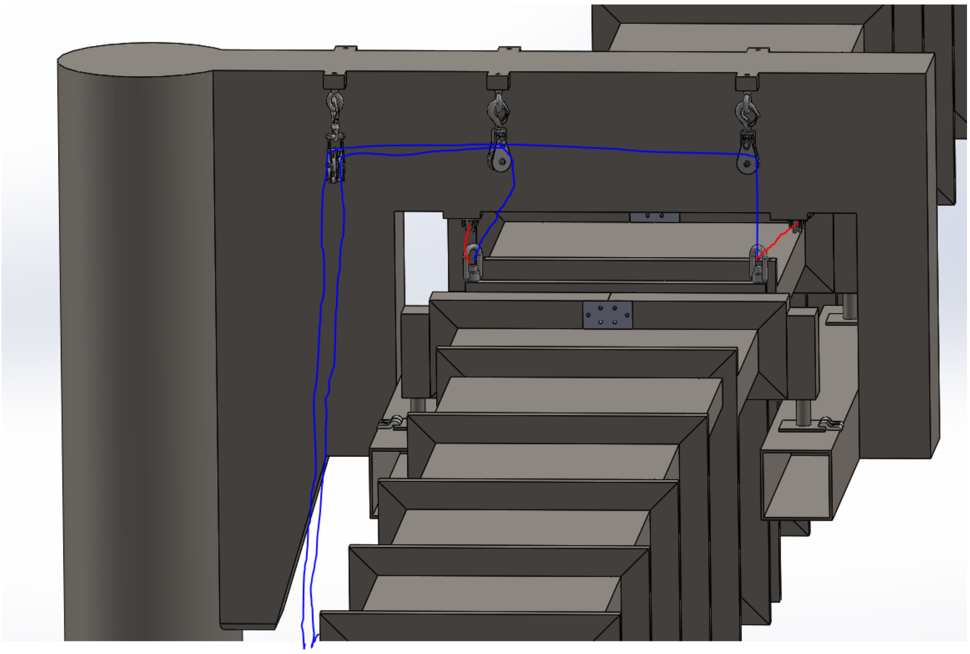


Figure 11. Guideway and Supporting Structure Assembly. *Guideways are sitting on the horizontal surface of the supporting structure, and they are fixed by rail clips on both sides.*

Figure 12. Crane Support. *A 3-ton crane motor can be mounted to the bottom of the support structure.*

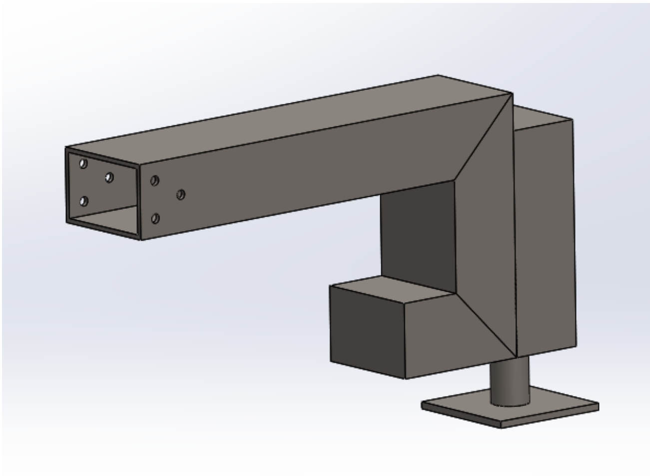


Figure 13. Guideway Holder. *Guideway holder is made with rectangular steel tubes with .25 inches wall thickness. An adjustable stand is welded to the side of the guideway holder*

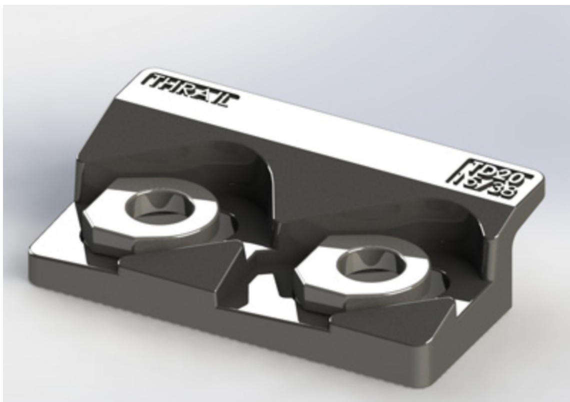


Figure 14. Rail Clip. *TD2015 Bolted rail fixing clips, 15mm horizontal rail adjustment and max side load of 250kN (THRAIL Bolted Fixing Catalog)*

By only having the rail clips are not enough for the heat expansion issue, we also need to leave a minimum of 0.38-inch space (See FEA result in the Discussion section) between each guideway segment for allowing the expansion. However, when having a big gap between each segment, it will create problems for the bogie. The bogie will hit hard to the edge of the gap, which will damage the bogie wheels significantly. To resolve this issue, we are adding a pair of heat expansion joints to each side of the guideway as shown in Figure 15. The heat expansion joints will be able to close the gaps between the guideway segments while still allowing the guideway for heat expansion. The heat expansion joint will be assembled to the guideway by using bolts and nuts.

The second type of support structure designed is the T shape support structure as shown in figure 16. It has the same design concept as the L shape support structure, except it can hold two guideway routes at the same time. Since the rectangular holders are welded on both sides of the cylindrical tube, the router direction will be fixed, hence this T shape support structure can only be used when the two guideway routes are parallel to each other.

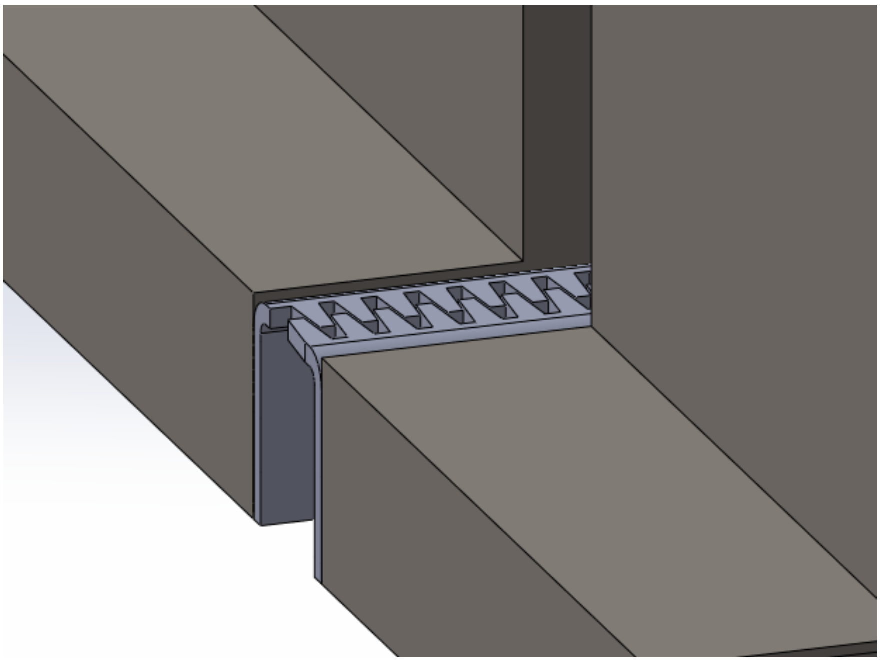


Figure 15. Heat Expansion Joint. *This joint is designed to allow continuous traffic between guideways while accommodating heat expansion due to temperature variation.*

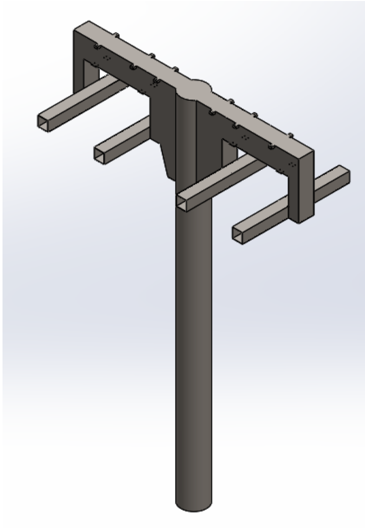


Figure 16.T Shape Support Structure. *T Shape Support structure is designed to support two guideway routes at the same time.*

When the guideway routes are not parallel, the third type of support structure will be needed. The third type of support structure is the support bridge as shown in Figure 17. The support bridge has a steel I beam sitting on top of two posts. On each side of the I beam there are two steel angles bolted together with the I beam and the post to secure the position of the I beam. A detailed view of the steel angle is shown in Figure 18. The steel angle has two slots on the bottom surface, which will allow minor adjustment when bolting it down on a pre-welded block on top of the post. The I beam will have a 15 inches slot on each end, which will allow bolts going through to connect the steel angles on both sides of the I beam. After the I beam is fixed, two or more hangers can be installed on to the I beam with angle beams and bolts. A detailed view of the hanger is shown in Figure 19. There are 12 threaded holes on each side of the hanger. When assembling it to the I beam, we need to install the 12 bolts on each side of the hanger first, then the hanger will be able to slide along the I beam, the position of the hangers will be determined by the guideway router, once the hanger is adjusted to the right position, simply install the 3 bolts on the top surface of each angle beam, and it will lock the position of the hanger.

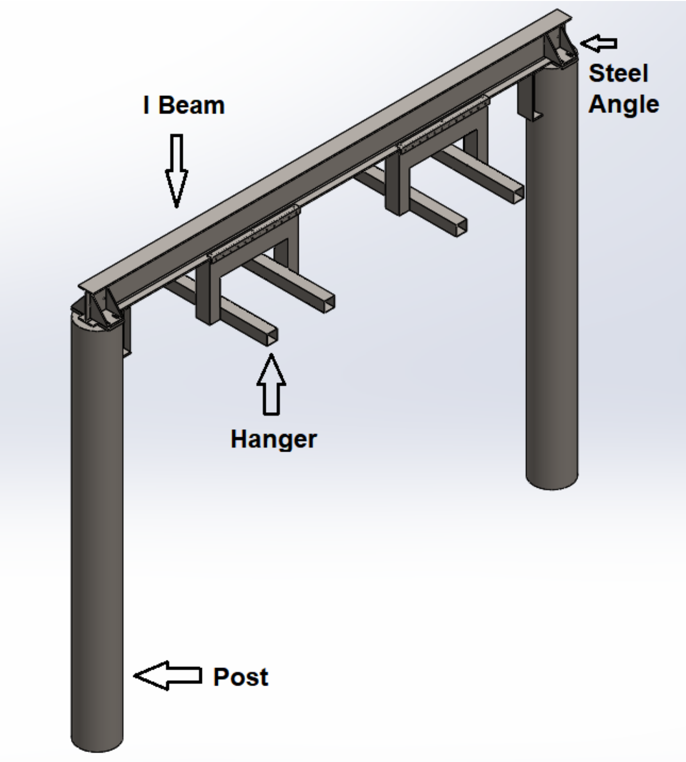


Figure 17. Support Bridge. *The support bridge with adjustable hanger will be able to support guideway routes that are not parallel.*

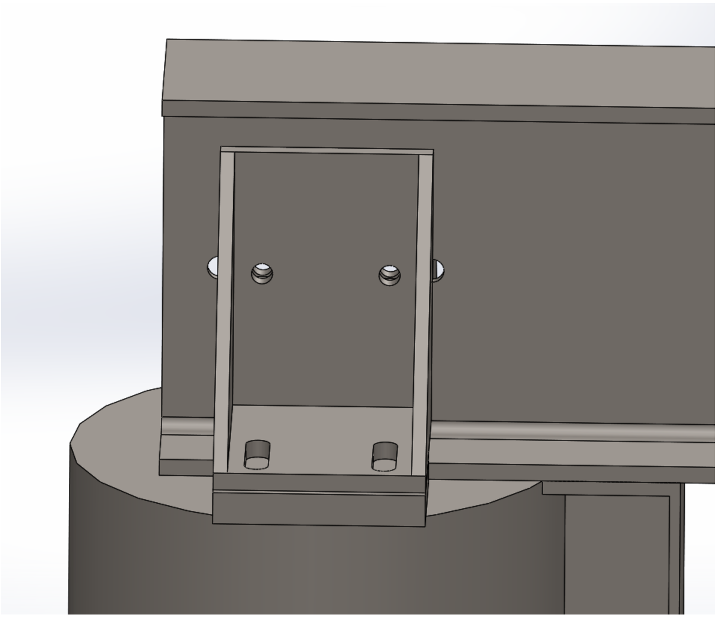


Figure 18. Steel Angle*. The steel angle can fix the position of the I beam while being adjustable during installation.*

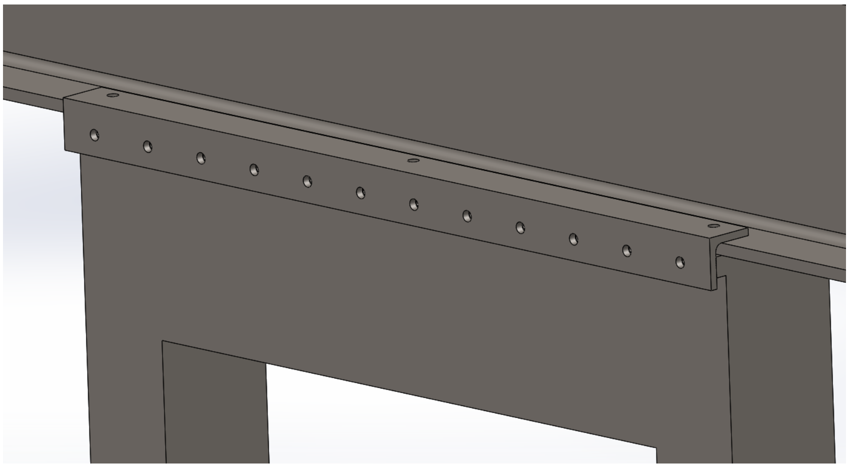


Figure 19. Detail view of hanger on support bridge*. Hanger and I beam are assembled with an angle beam and bolts.*

When the bogie needs to change directions, we will need a guideway segment that has a Y-joint. Figure 20 is a sample model for a Y-joint segment. The current design for the switching mechanism is shown in figure 21. There is an I beam welded on the inner vertical wall on each side, as well as two L beams welded on the ceiling of the guideway. When the bogie needs to turn right, the guide wheels on the bogie will slide to the right and engage with the I beam on the right side as well as the L beam on the right side, dragging the bogie to turn right. When the bogie needs to go straight, it's guiding wheels will need to slide to the left side instead.

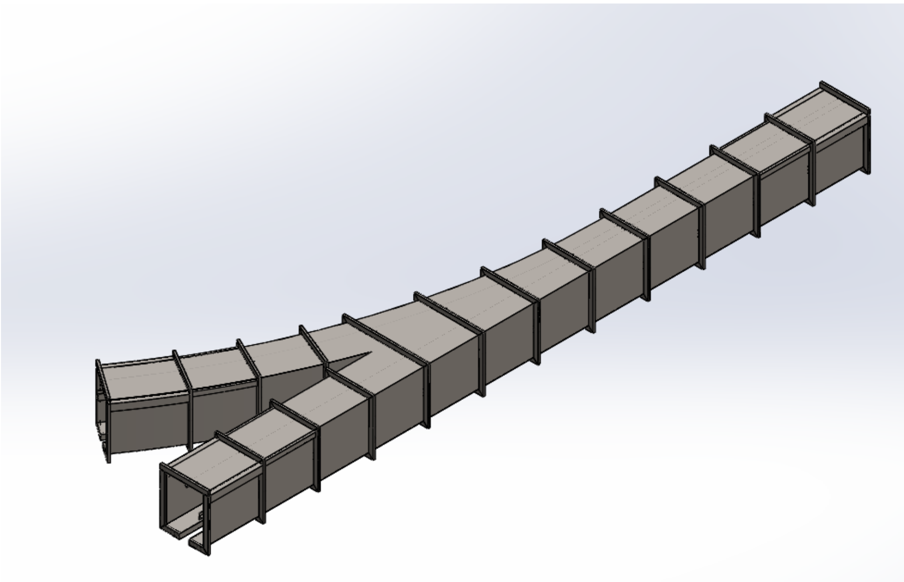


Figure 20. Y-Joint Guideway Segment. *Overall length of the straight section is 48 feet, the radius of the curved section is 49 feet (15m)*

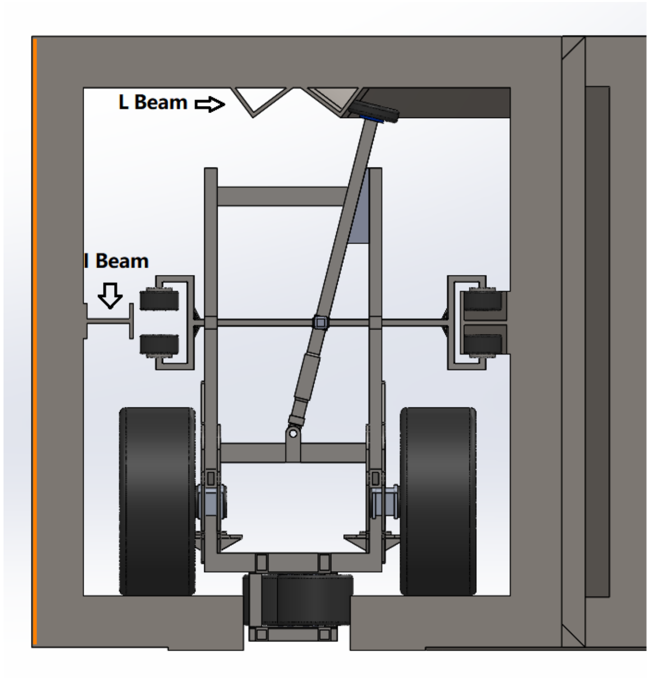


Figure 21. ***Cross Section of the Y-Joint Guideway Segment.*** *Guiding wheels will engage with the I beam and L beam on the right side when making right turns. If bogie need to go straight, the guiding wheels will engage with the I beam and L beam on the left side instead. (Bogie model is from Mohammed Owais Saiyed, team member of SPARTAN Superway, 2020)*

In the Y-split section of the guideway, there will be an area where the bogie is running through with no support on one side. Even we have the side track and upper track to keep the bogie in position, the position of the driving wheel will be lower due to the shock displacement. To prevent the driving wheel from hitting the guideway, we adjust the guiding track on the ceiling of the guideway so that the bogie will tilt up on one side during truing. As shown in Figure 22, the guiding track on the ceiling is shifted outward by 0.5 inches before the turning section, which will lift the bogie up slightly on one side, and it's just enough to avoid the driving wheel from hitting the bottom of the guideway. When the turning is completed, the guiding track of the ceiling will shift back inward by 0.5 inches to release the bogie back to the running surface of the guideway.

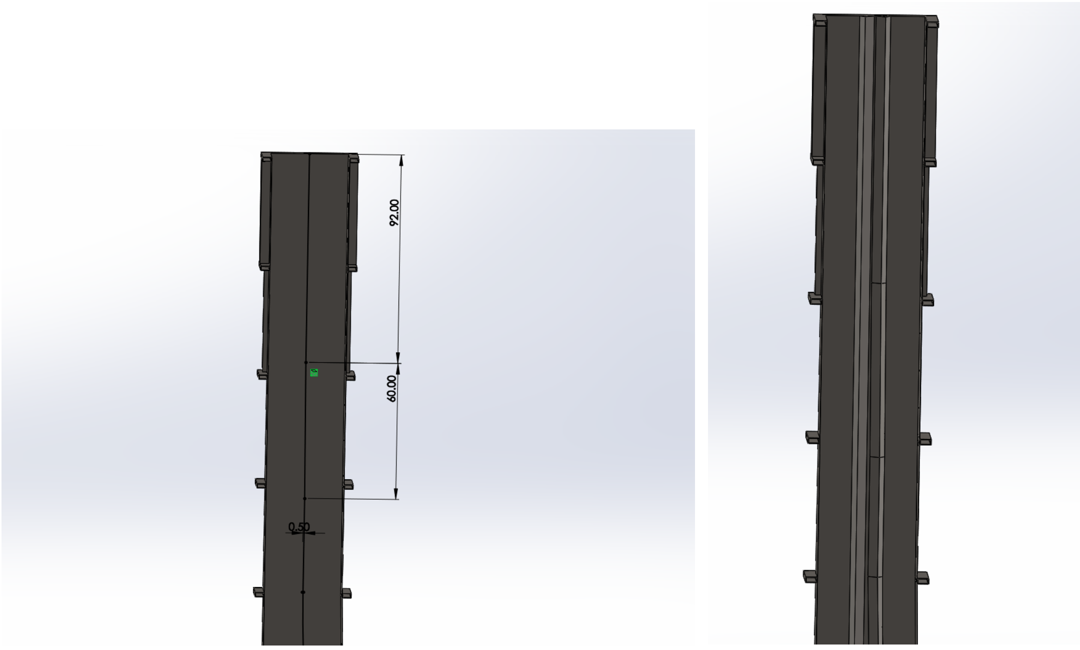


Figure 22. Transition Area of the Splitting Section.

When the route needs a wide turn, a curved guideway segment will be needed. The curved guideway segment is shown in Figure 23. The design concept of the curved guideway is the same as the straight guideway except it's curved. The cross section of the curved guideway is the same as the straight guideway, however, due to its curvature, the size of the outer ribs will need to be slightly wider in order to fit, therefore the guideway holder for the curved guideway need to be slightly wider as well. The radius of the curved guideway is set to be 600 inches currently; however, it should be changed in different situations. According to study, the lateral acceleration will affect the passenger's comfort level. The range of acceptable lateral acceleration will be 1.8 m/s^2 to 3.6 m/s^2. (Jin, X. & Kui, K., 2014) For a 600 inches radius, the maximum speed the bogie could have is about 7.5 m/s, which is about 16.5 mph. This speed is relatively low, if we need to increase the speed of the bogie, we will need to make the radius of the curved section to be larger. For the table of the relationship between guideway radius, bogie speed and acceleration, see Table 5 in the appendix.

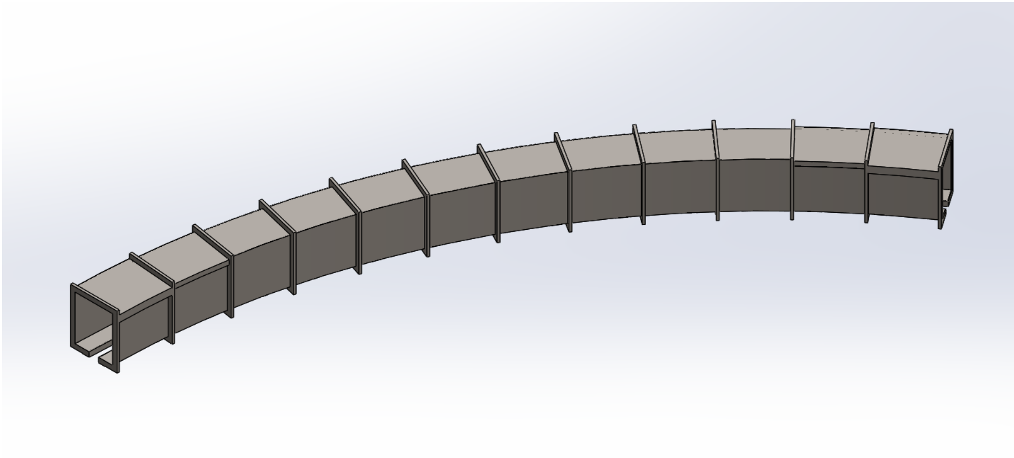


Figure 23. Curved Guideway Segment. Cross section of the curved guideway is the same as the straight guideway, the radius of the guideway is 600 inches (15.24 meters)

ANALYSIS AND DISCUSSION OF RESULTS

The most important feature for the guideway design is the wall thickness of the guideway and the number of ribs we need since those two numbers will determine the majority of the mass for the guideway. To find out the best optimal combination of those two variables, a design study was performed. The wall thickness and the number of ribs were set up as design variables, and the factor of safety against yield has been set as 5.0 minimum (See Table 1 for Typical Factor of Safety in Appendix). The goal of the study has been set as the total mass. The loading condition for the FEA has been set as shown in Figure 24. Since we don't have a final design for the bogie and carts at the moment of performing this study, we are using an estimated weight for the simulation. According to the spec sheet for a similar ATN system called Vectus (Furman, 2014), we get the maximum weight for the bogie and cart including passengers is about 2500kg. So in this design study, we add a 24517N of load at the center of the guideway. The weight of the solar racking was also considered in this study, a total force of 8589 N was applied to the ribs.

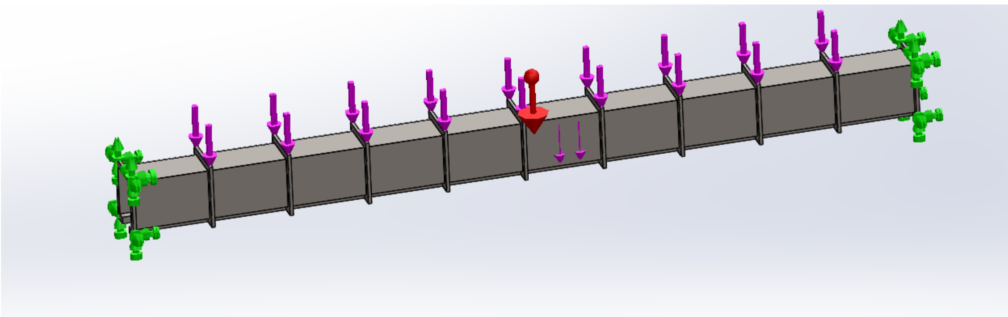


Figure 24. Loading Setup for Design Study. *Model is set to be fixed on both end, gravity is included, a 24517N of load is applied at the center of the guideway.*

The range for the two variables, wall thickness and the number of ribs are set as following: wall thickness varies from 0.1 to 0.3 inch, with a step of .1 inch. The number of ribs is set to be 8 - 13, with a step of 1. The guideway model will be modified automatically according to each combination of the two variables, which means 15 cases of FEA were performed in total. After running the simulation, the result is shown in Table 2 in the Appendix. The combination of .1-inch wall thickness and 13 ribs (which means the spacing between ribs is 48 inches) has the best performance of all the combinations.

The detail for the FEA analysis for the .1-inch wall thickness and 13 ribs guideway model is shown in Figure 25 and 26. The maximum stress is 3.245 x 10^7 N/m^2, the factor of safety against yield is about 8.7 and the maximum deflection of the guideway is about 3.068 mm. As one might expect, the highest stress is located in the middle where the 24571N loading. The region of maximum deflection area is also located where the force acts. According to the AASHTO LRFD Bridge Design Specification as mentioned above, the deflection allowed will be L /800. The guideway segment is about 576 inches long, so the deflection allowed will be about 0.72 inches, which is about 18mm. So, the 3.068 mm deflection is acceptable.

To verify the deflection from the FEA result, a simple hand calculation was performed. The detail of the hand calculation can be found in Appendix Figure 56. In the calculation, we treat the guideway as a beam with support on both ends. According to the equation for beam deflection, the maximum deflection of the guideway will be 3.17mm, which is very close to the FEA result. So, we confirmed that the FEA result is valid.

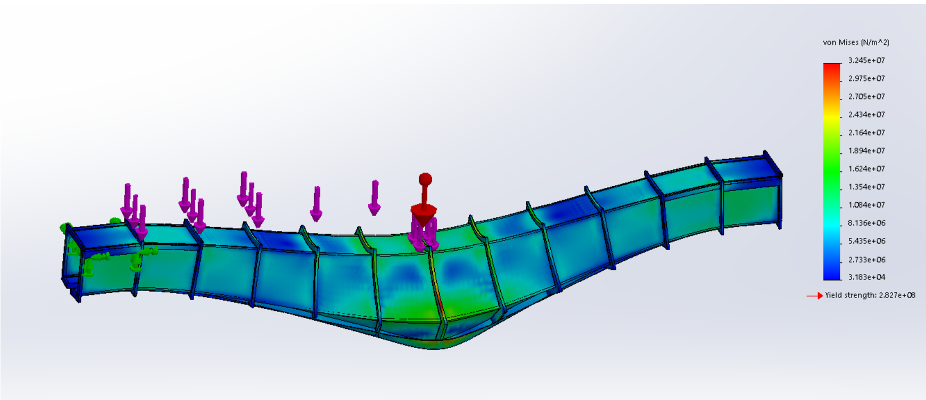


Figure 25. Stress Analysis for Guideway. *Maximum stress is 3.245 x 10^7 N/m^2 located at the middle of the guideway.*

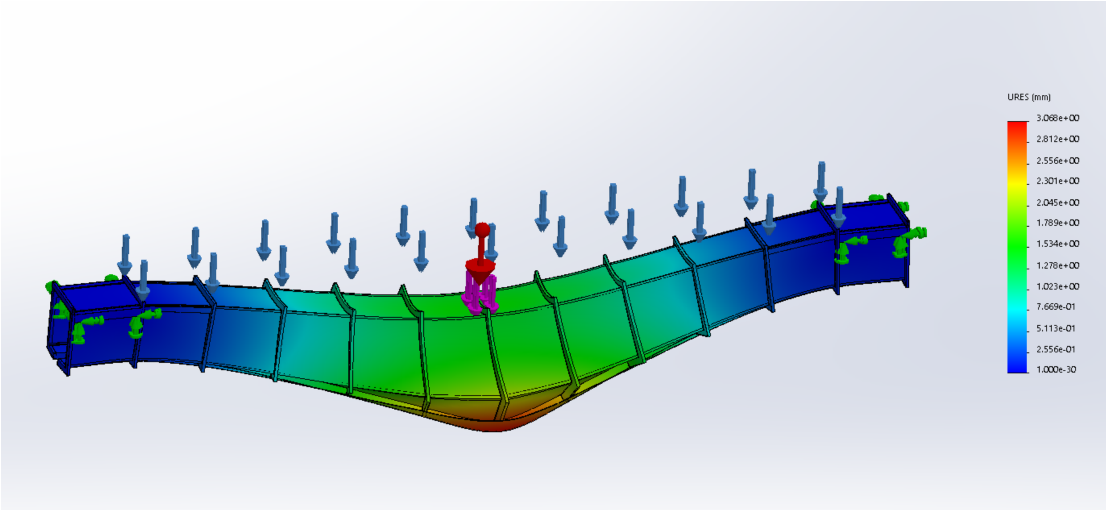


Figure 26. Displacement Analysis for Guideway. *Maximum deflection is 3.068 mm located at the middle of the guideway.*

The supporting structure needs to be able to hold the weight of the guideway, the bogie and passenger cabin, as well as the solar panel racking (See Figure 27 for solar panel racking). The combination of all those forces becomes a loading of about 47503 N total acting on the supporting surface. An FEA study has been performed to evaluate the performance of the supporting structure. As we can see from Figures 28 and 29, the maximum stress on an L shape support structure is about 5.47 x 10^7 N/m^2, which provides a factor of safety (against yield) of about 5.2. The maximum displacement is about 1.97mm.

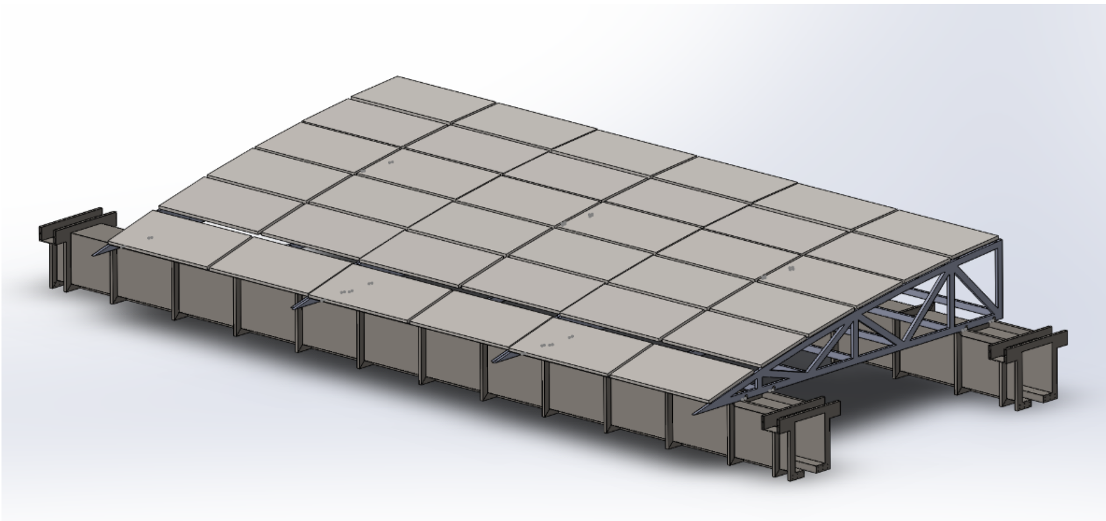


Figure 27. Solar Panel Racking. *(Solar Panel Racking model is from Sumeet Shastri, team member of SPARTAN Superway, 2020)*

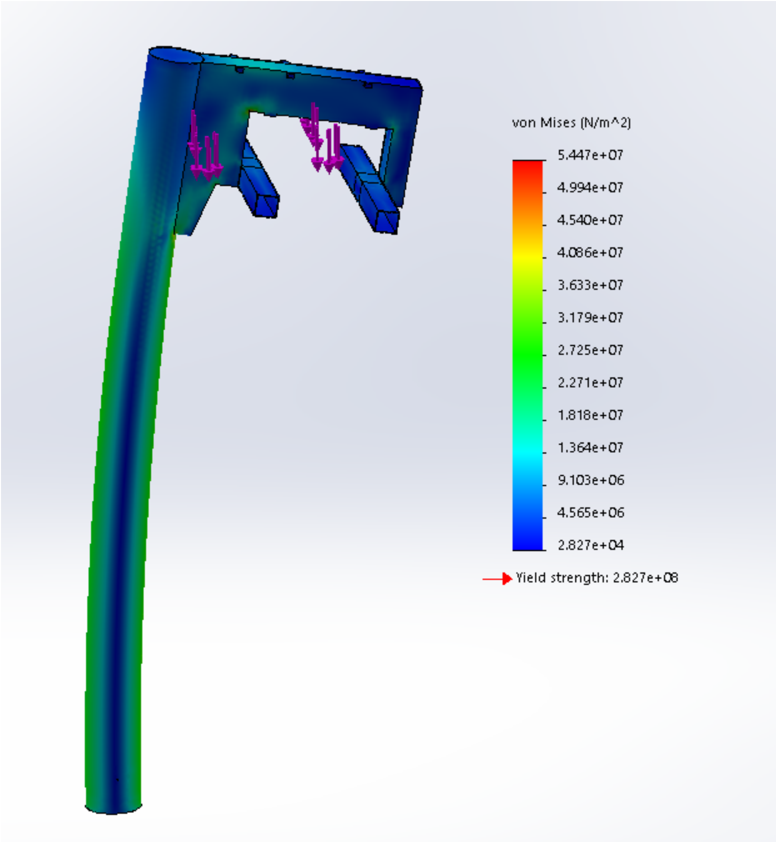


Figure 28. Stress Analysis for L Shape Supporting Structure. *Maximum Stress is 5.47 x 10^7 N/m^2*

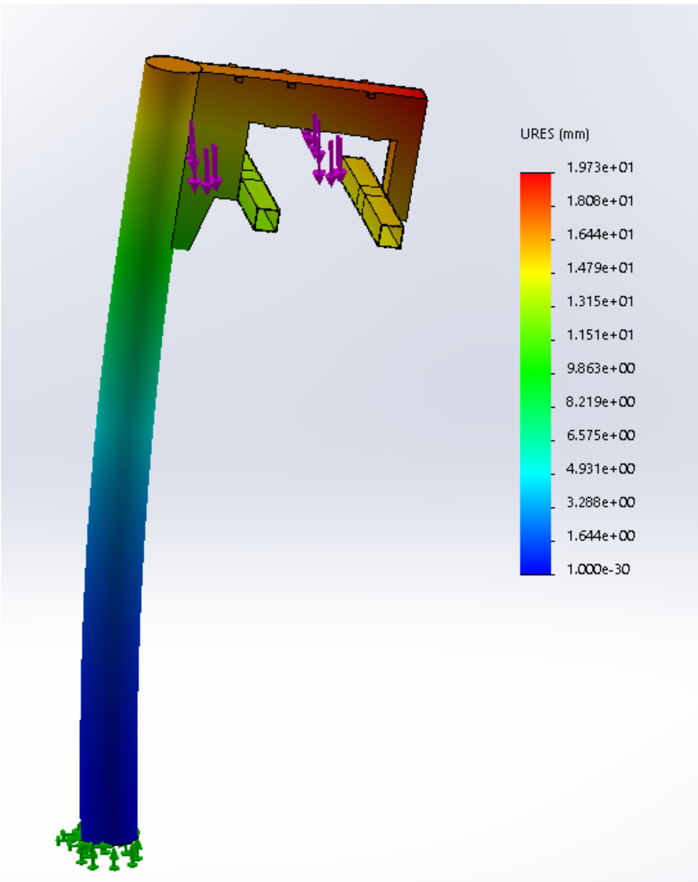


Figure 29. Displacement for L Shape Supporting Structure. *Maximum deflection is 1.97 mm*

The T shape support structure needs to withstand two times the loading compare to the L shape support structure since it needs to hold two guideway routes instead of one. So a 95006 N force is applied to the four support surfaces in total. The FEA result is shown in Figure 30 and Figure 31. The maximum stress on the T shape support structure is about 5.53 x 10^7 N/m^2 and the maximum displacement is about 1.4 mm. The maximum stress is located at the inner corner of the holder. The factor of safety against stress is about 5.1.

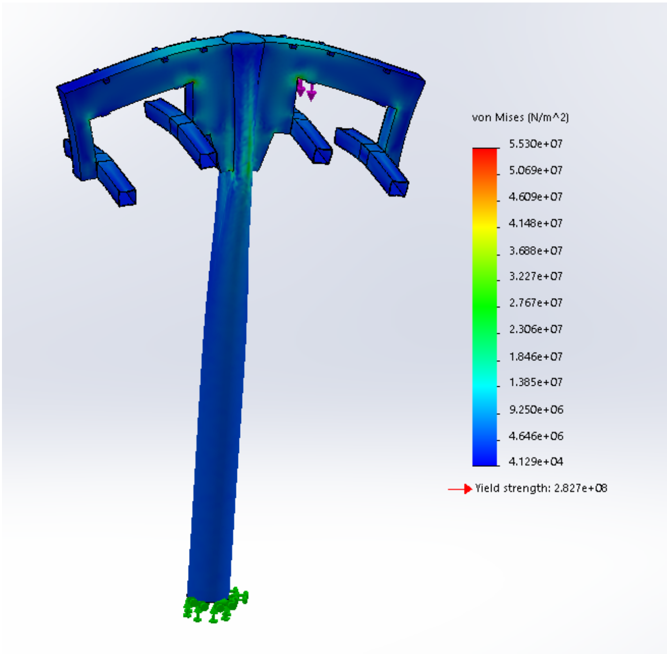


Figure 30. Stress Analysis for T Shape Support Structure. *Maximum stress is 5.53 x 10^7 N/m^2*

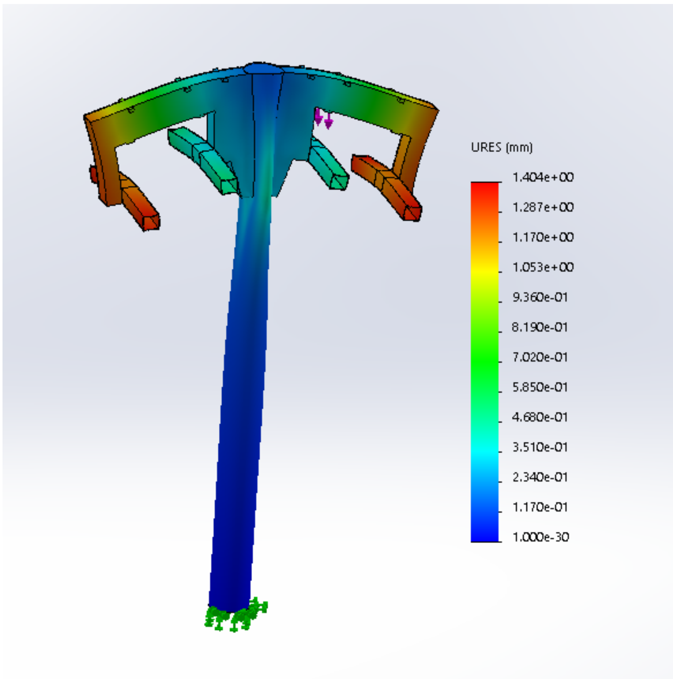


Figure 31. Displacement for T Shape Support Structure*. Maximum displacement is 1.40 mm*

The support bridge has the same loading condition as the T shape support structure. A total loading of 95006 N is applied to the support surface of the hanger. The FEA result is shown below in Figure 32 and Figure 33. The maximum stress on the support bridge is about 3.51 x 10^7 N/m^2, which provides a factor of safety against yield of about 8.0. The maximum displacement is about 2.4 mm.

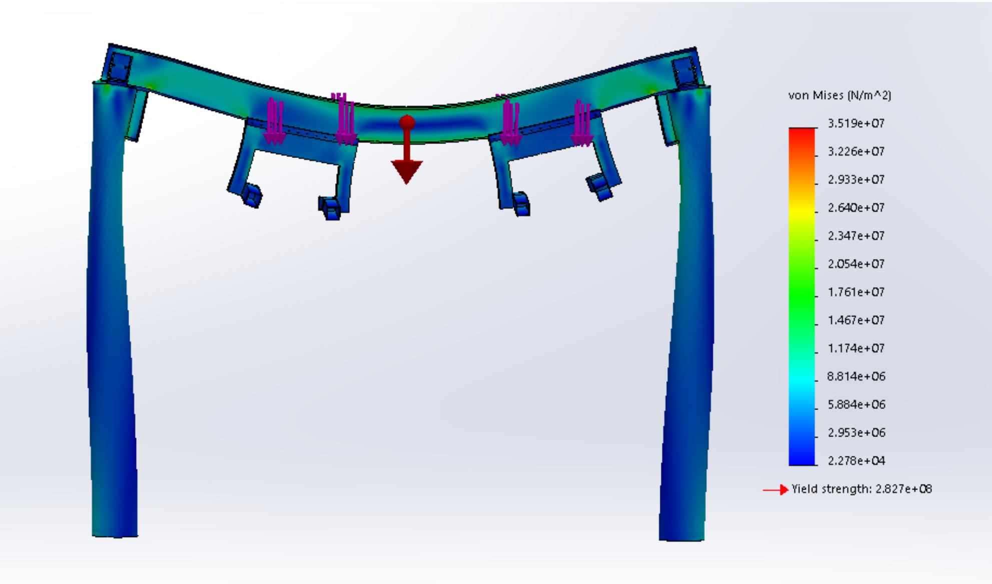


Figure 32. Stress Analysis for Support Bridge. *The maximum stress is 3.51 x 10^7 N/m^2*

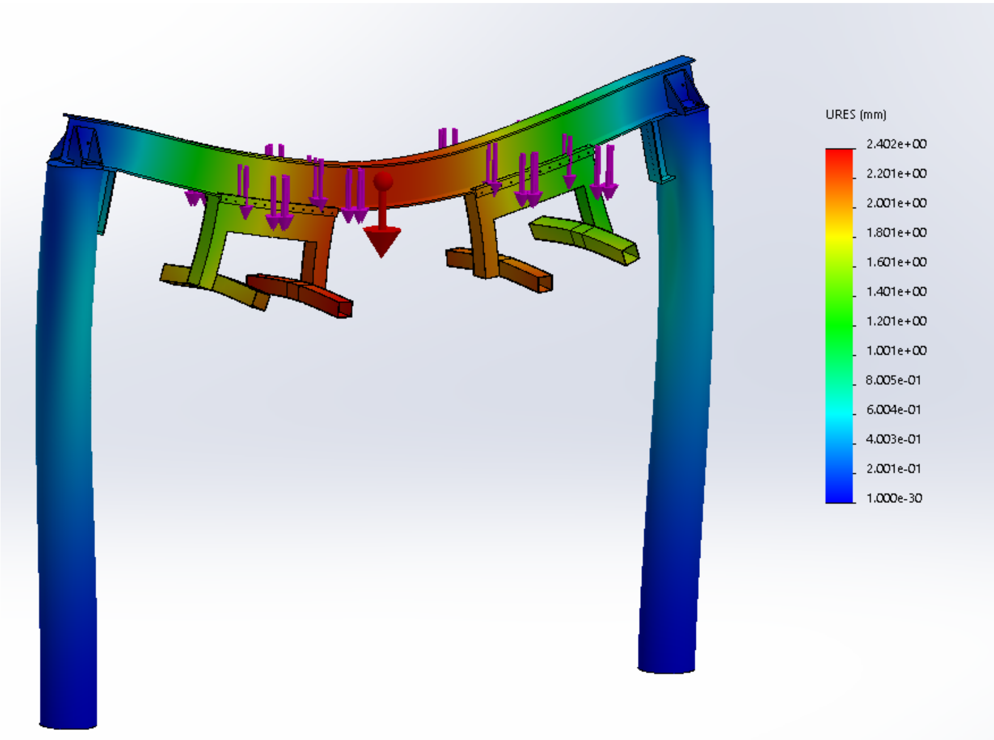


Figure 33. Displacement for Support Bridge. *The maximum displacement is 2.40 mm.*

Besides the static loading, we also need to evaluate how the supporting structure reacts to an earthquake. As mentioned in the literature review section, the seismic response spectrum method can be used to simulate the earthquake movement. I found the response spectrum data from an actual earthquake of Magnitude 6.9 (Tom, 2013) that happened in El Centro 1940 as shown in Appendix Table 2. The data has two columns, the first column is time, and the second column is the corresponding acceleration in g's, the acceleration due to gravity. With such data, Solidworks Dynamics Study can be used to simulate the earthquake. For the external loads setting, choose base excitation in the Solidworks program, and enter the raw data from the response spectrum, then we are getting a graph as shown in Figure 34.

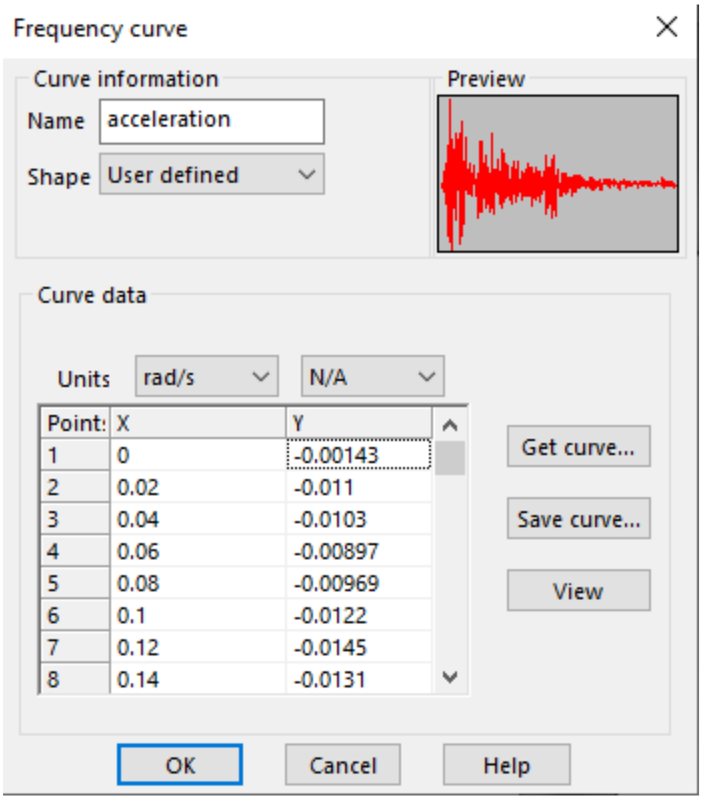


Figure 34. Seismic Response Spectrum Graph. *X indicates times in seconds, Y indicates acceleration in g's*

The result from running the simulation is shown in Figures 35 and 36. The maximum stress we have in the supporting structure is about 1.078 x 10^6N/m^2, and the maximum deflection during the earthquake is about 4.03 mm.

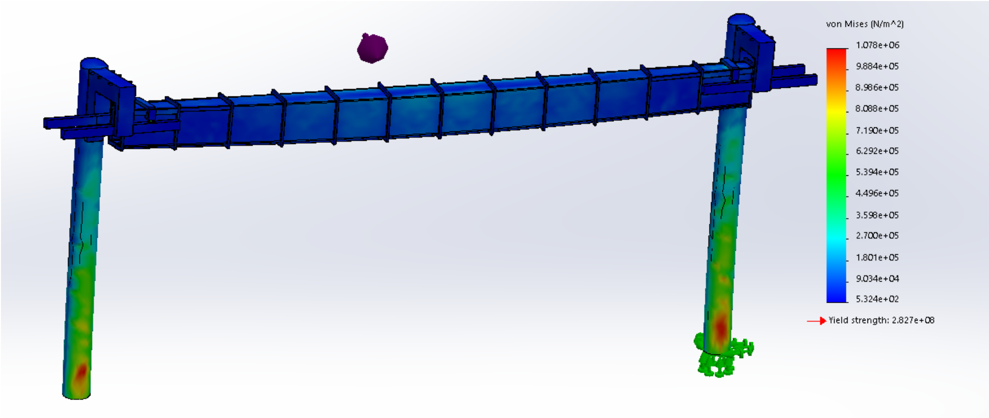


Figure 35. Earthquake Stress Analysis. *Maximum stress is 1.078x* $10^6 N/m^2$*, locates at the bottom side of the supporting structure.*

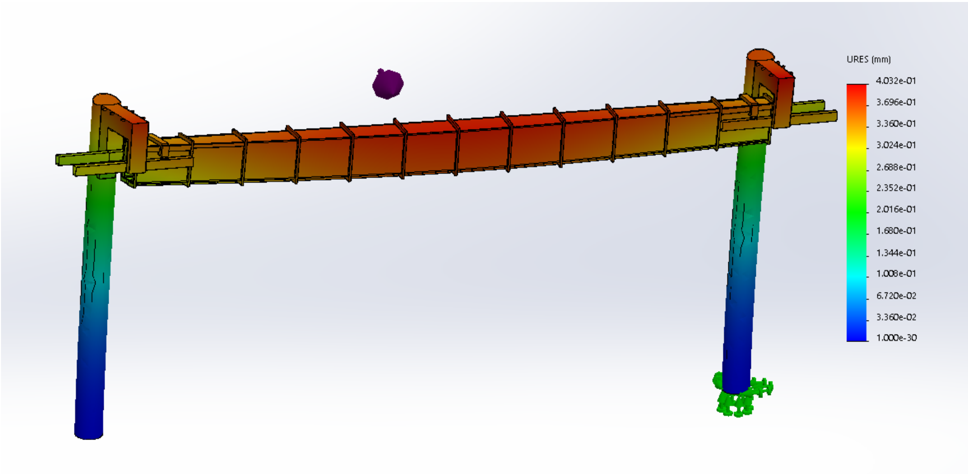


Figure 36. Deflection During Earthquake. *Maximum deflection is 4.03 mm, locates at the middle of the guideway.*

This simulation is not exactly how an actual earthquake is supposed to be, instead, it's a simplified version of an earthquake. An actual earthquake wave will have vertical movement as well as the horizontal moment. However, we know that most of the damage caused by an earthquake comes from the horizontal wave, which will make a building shake horizontally. That's why I choose to just use the horizontal acceleration as the input to simplify the simulation. So even though the maximum stress for the guideway is going to be a larger value during an actual earthquake, it should not be too much different from the simulation result. Hence, we can conclude that the current guideway design can survive a magnitude 6.9 earthquake. According to a study from USGS (Heidi, 2015), the likely hood of having an earthquake around magnitude 6.7 in the next 30 years in California is about 30%, and the likelihood of experiencing magnitude 8.0 or larger is about 7.0%. So even though the guideway can handle moderate earthquake of magnitude 6.9, a deeper study needs to be done in the future for a larger earthquake.

Another aspect we need to consider is the wind load on the guideway. According to the ASCE book (Minimum Design Loads for Buildings and Other Structures) mentioned above in the literature review, we are going to use a basic wind speed of 115mph in the simulation.

The model of the supporting structure has been simplified to speed up the simulation time. The wind is set to blow horizontally and perpendicular to the direction of the guideway. The simulation result is shown in Figures 37 and 38. The maximum stress caused by the wind load is about $1.02\text{x}10^7$ N/m^2, and the maximum deflection caused by wind load is about 2.75mm. The maximum stress that caused by wind load is relatively small compared to the yield strength of the material (Carbon steel), so the structure will be safe from wind loading.

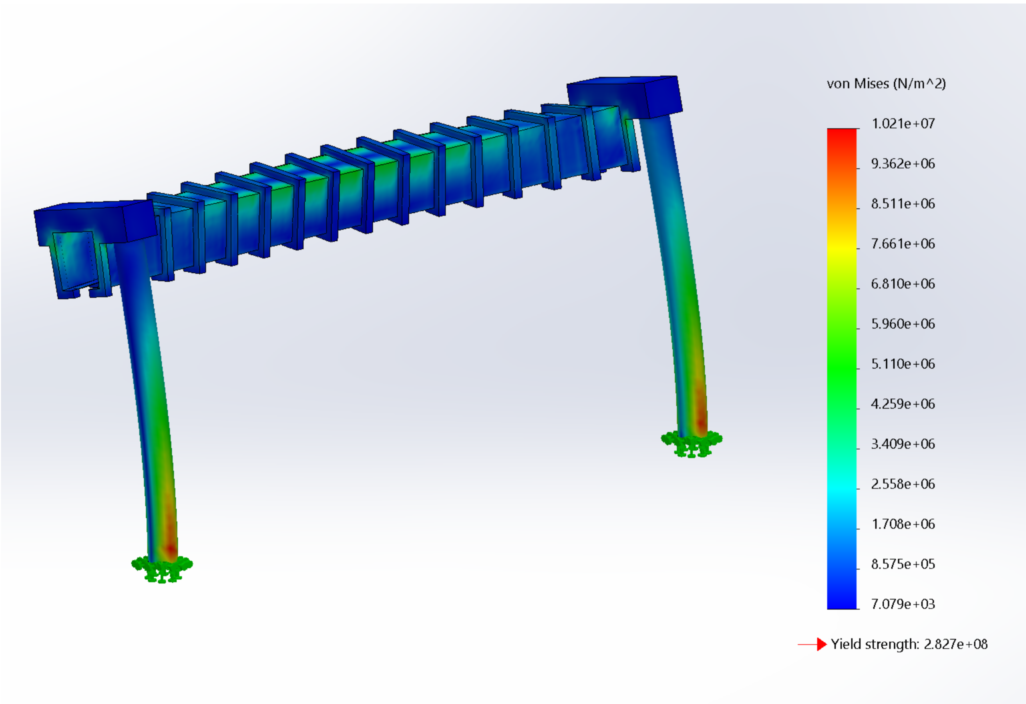


Figure 37. Stress Analysis for Wind Load. *Maximum stress is 1.02 x 10^7N/m^2, locates at the bottom side of the supporting structure.*

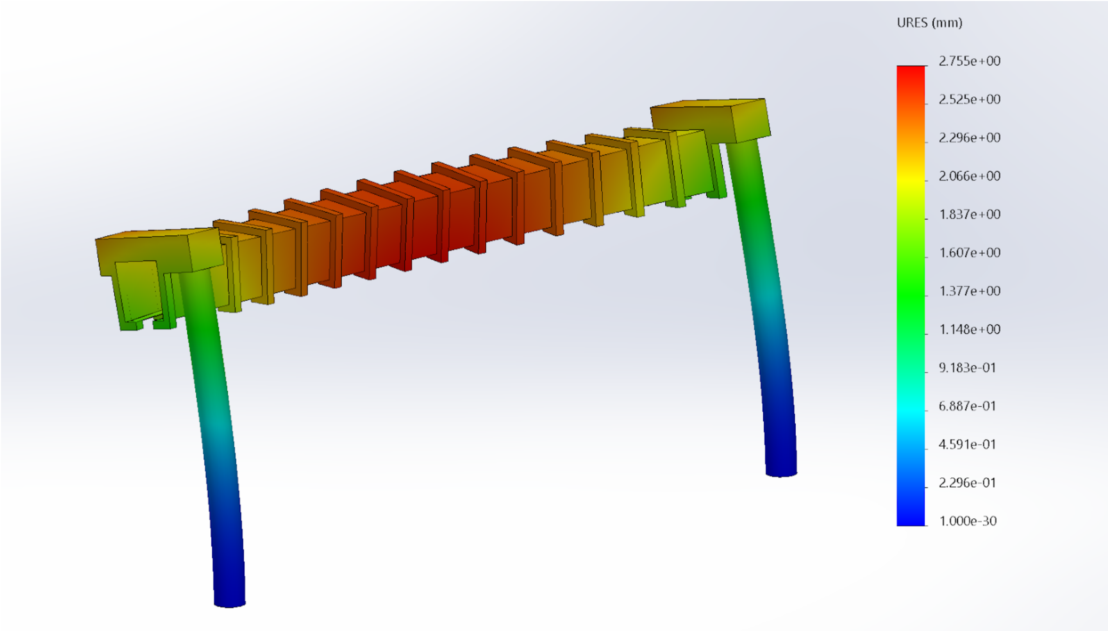


Figure 38. Deflection by Wind Load. *Maximum deflection is 2.75 mm, locates at the middle of the guideway.*

To prevent the guideway from buckling due to heat expansion, we will need to know how much the guideway can expand in extreme conditions. According to the Bridge Design Specification (AASHTO, 2017), in a moderate climate area as San Jose, a bridge needs to be able to handle temperature from 0 to 120 F as shown in Table 4. We will use the same specification for our guideway design. By setting the initial temperature to be 0 and the steady-state temperature to be 120°F, the simulation result shows that the guideway can expand by about 9.7 mm (See Figure 28), so we will leave a gap of 9.7 mm minimum in between the heat expansion joint.

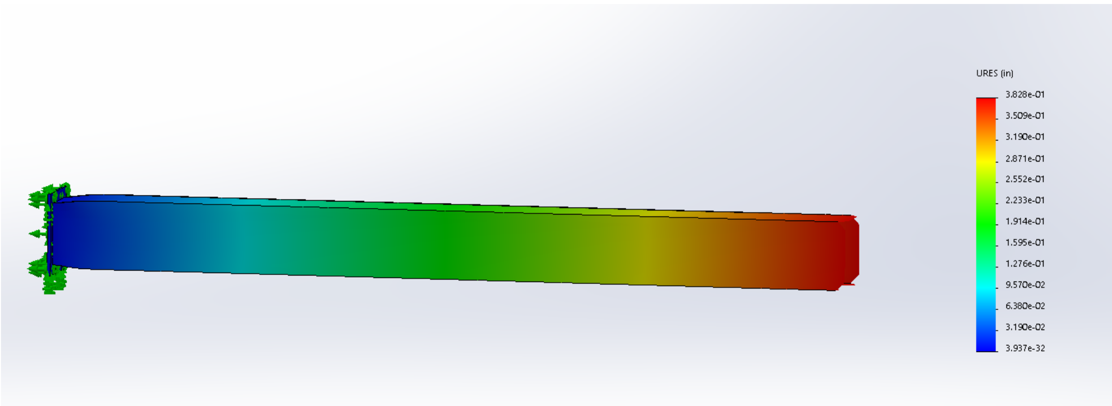


Figure 39. Heat Expansion Simulation. *Model is set to be fixed on the left end. Maximum expansion is about 9.7mm*

Since the bogie has four driving wheels, each of the wheels will contribute one-quarter of the weight to the heat expansion joint when the bogie travels past, which is about 6125N. The thickness of the heat expansion joint is about .375 inches, by setting a 6125N force acting downward and fixed geometry in the holes, the FEA result is shown in Figure 40. The maximum stress is seen to be about 5.10 x10^7 N/m^2, so the factor of safety against yield is about 5.5.

As we noticed that the maximum stress is located at the bending radius, which is due to the bending moment created by the downward force. To reduce the maximum stress, we can weld the outer radius near the top side of the expansion joint with the guideway, see Figure 41 for the welding area highlighted in red. By having the additional weld joint, it can reduce the maximum stress at the bending radius.

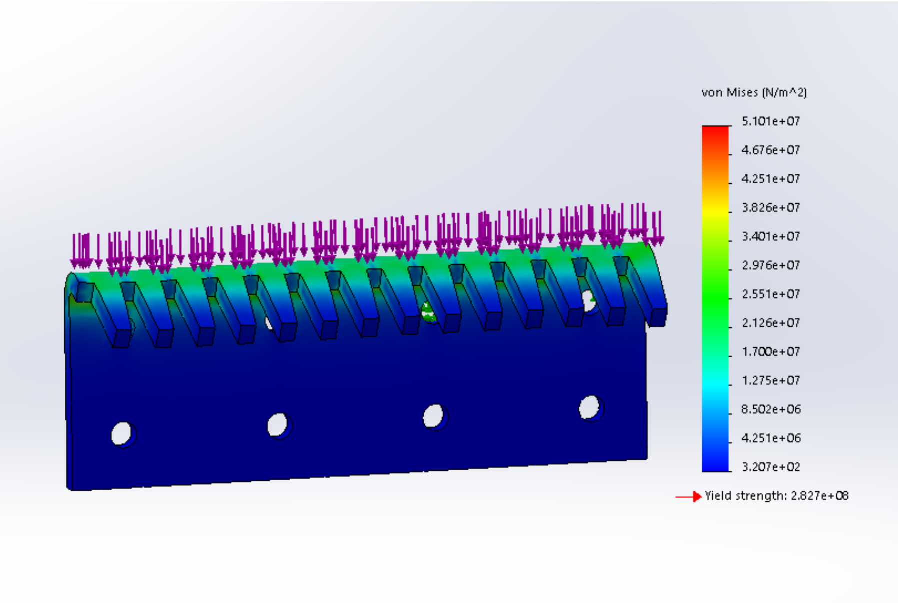


Figure 40. Stress Analysis for the Heat Expansion Joint. *Maximum stress is 5.1x10^7 N/m^2 located around the top three small holes.*

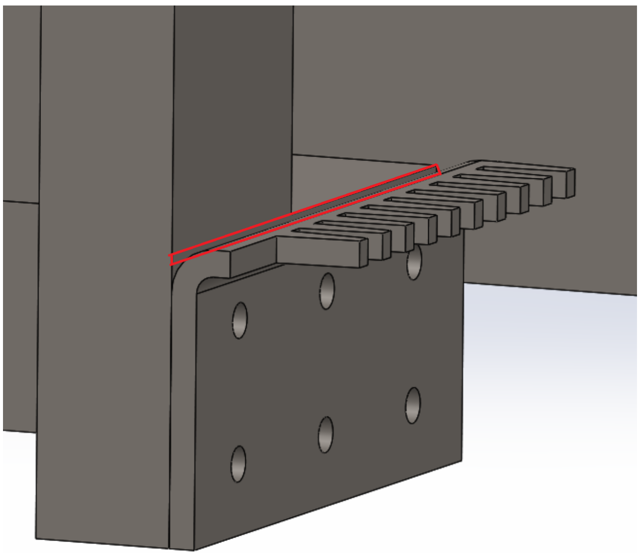


Figure 41. Welding Location for Heat Expansion Joint. *Area highlighted in read will be welded as an additional support.*

The static stress analysis for the "Y" joint guideway segment is shown in Figure 42 and Figure 43. There's a 14700N downward force is applied at the middle of the span length on the running surface, representing the normal weight of the bogie and passenger cabin. There's also an 8589N downward force is applied evenly on the top surface of the ribs, representing the weight of the solar panels and racking. The analysis is also taking the self-weight of the "Y" joint guideway into account, these combinations of forces result in a 2.48×10^7 N/m^2 maximum stress. The factor of safety against yield is about 11.34. The maximum deflection of the guideway under this loading condition is about 2.02 mm. In some special situations, there might be more than one bogie running within one single guideway segment. For example, during an earthquake or system malfunction, the bogies might stop running and all of them could be stuck in one guideway segment. Assuming the cart is about 2 meters long, and one guideway segment is about 15 meters long, the maximum number of bogies that could possibly be stuck in one guideway segment is about 7. We apply 7 times of the normal weight of bogies and passenger cabin to the guideway, the result of the FEA analysis is shown in Figure 44 and 45. The maximum stress on the guideway becomes 9.67×10^7 N/m^2, which is still far away from the 2.827×10^8 N/m^2 yield strength. The maximum deflection under this special loading is about 8.87 mm, which is also far away from the limit of the L/800 rule (18 mm). Therefore, we can conclude that the "Y" joint guideway will not fail due to any possible static loading condition.

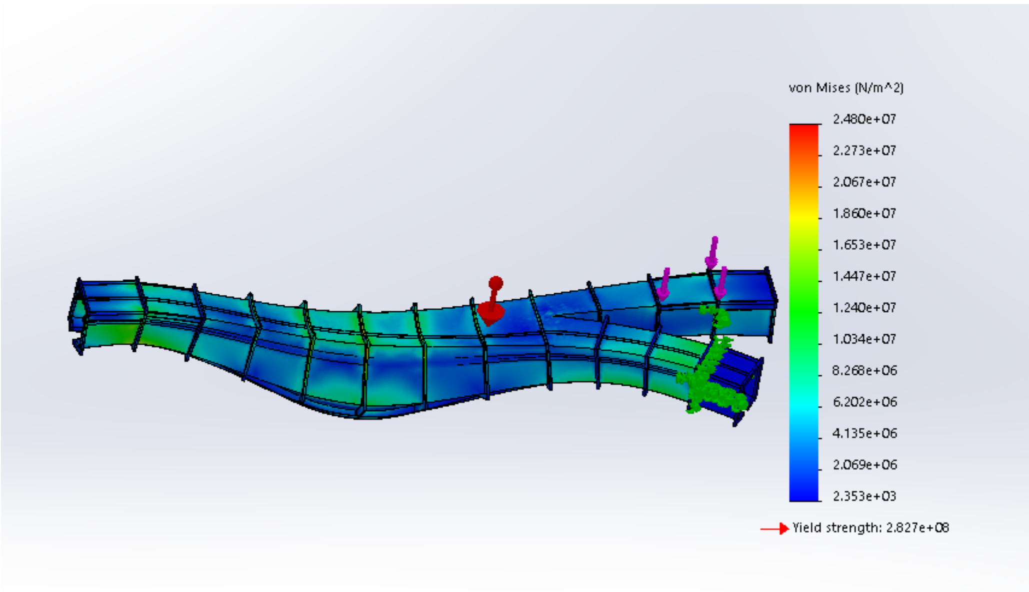


Figure 42. Stress Analysis For Y Joint Guideway Segment. *Maximum stress is $2.48 \times 10^7 N/m^2$*

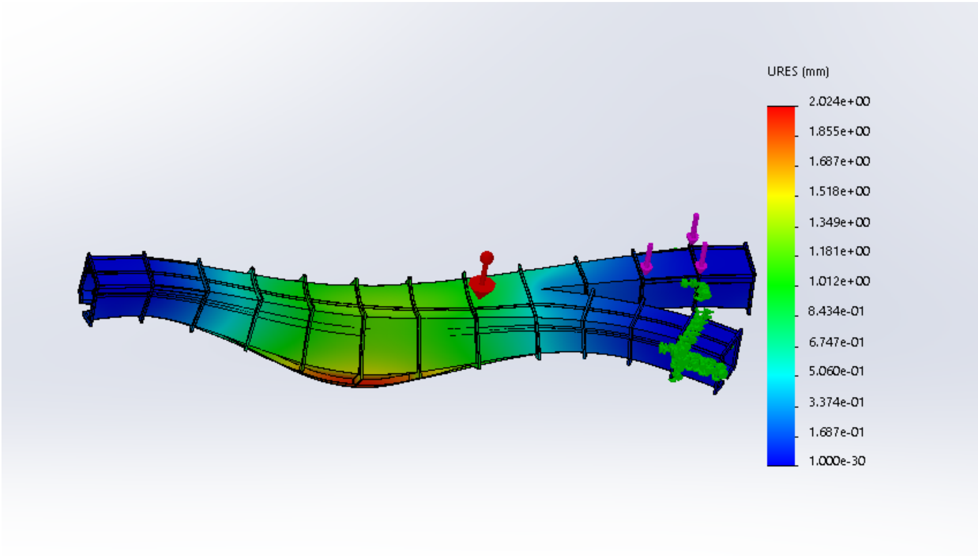


Figure 43. Deflection for Y Joint Guideway Segment. *The maximum deflection of the Y joint guideway is about 2.0 mm*

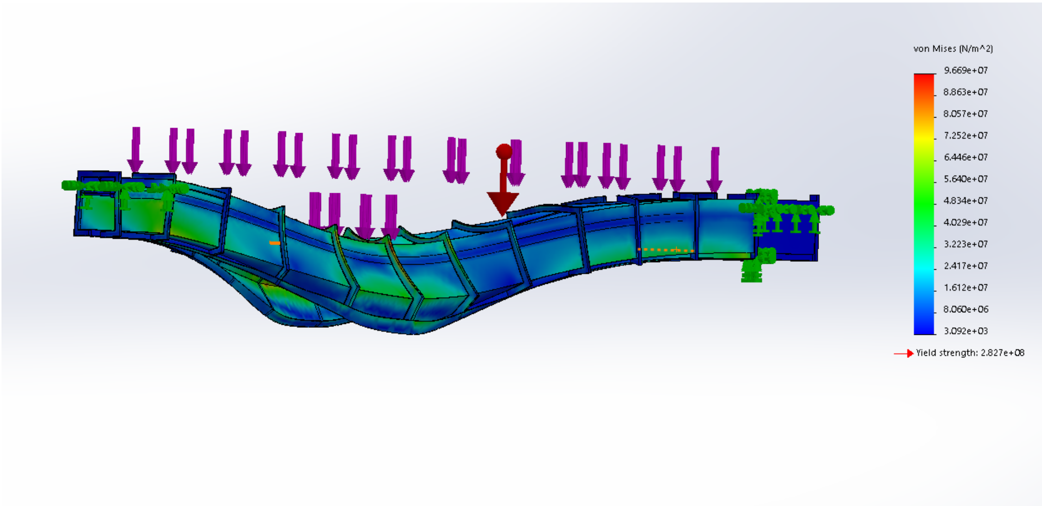


Figure 44. Stress Analysis for Y Joint Guideway Under Special Loading Condition. *Loading condition is 7 times of the regular loading condition, maximum stress is 9.76 x 10^7 N/m^2*

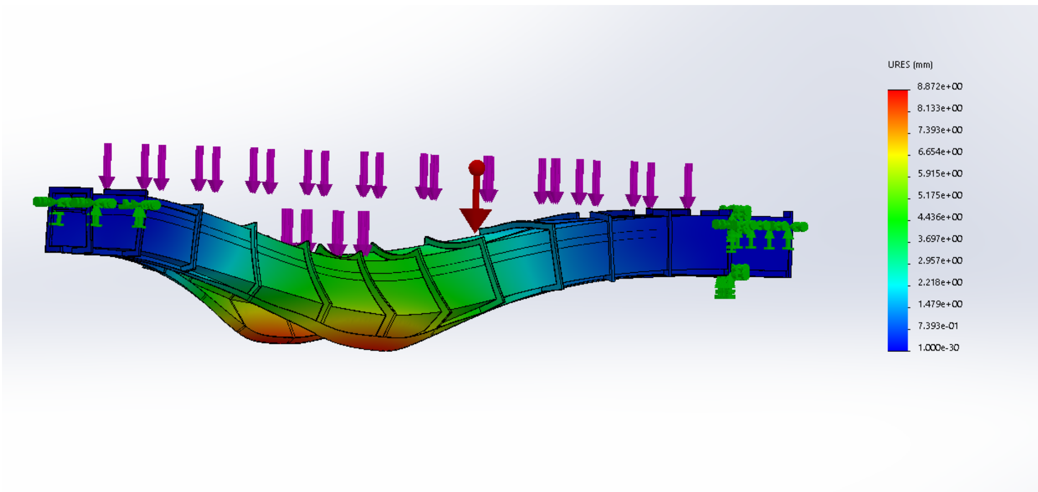


Figure 45. Deflection of Y Joint Guideway Under Special Loading Condition. *Loading condition is 7 times of the regular loading condition, maximum deflection is 8.87 mm.*

When the bogie is turning in the "Y" joint guideway, there will be an additional centrifugal force acting on the guiding track on the guideway's inner wall. In order to evaluate the centrifugal force, a motion analysis was performed. Due to the limitation of Solidworks, I can't get the maximum stress of the guiding track directly from this motion analysis, therefore this analysis is breaking into two steps. Firstly, we can get the reaction force of the guiding wheels on the bogie from the motion analysis, and then we can use that maximum reaction force to perform static stress analysis on the guideway to find the maximum stress of the guideway due to bogie turning. The main driving wheel of the bogie is set to be running at 150 RMP, also, there's a 14700N force adding downward on the bogie. The result of the motion analysis is shown in Figure 46 and Figure 47. From the reaction graphs, we can see the maximum reaction force from the side guiding wheels is about 4485 N, the maximum reaction force from the top guiding wheels is about 2565 N, and the maximum reaction force from the driving wheel is about 10302 N. Since there are four side wheels, two top wheels and 2 driving wheels are involved during the bogie turning, we assume each type of the wheels are having the same reaction force, by applying these loading conditions to the guideway in static stress analysis, we can estimate the maximum stress of the guideway during the bogie turning. The result of the static stress analysis is shown in Figure 49 and Figure 50. The maximum stress observed is 4.51×10^7 N/m^2, which provide a factor of safety of 6.28. The location of the maximum stress is located on the outer ribs of the guideway where the forces are applied. From the stress distribution plot, we can see the stress on the side guiding track and top guiding tracks are at the range of 1×10^7 N/m^2 to 2×10^7 N/m^2, which is showing the guiding tracks are strong enough to hold the centrifugal force due to turning, however, if we still want to increase the factor of safety of the guideway, we can improve the ribs design instead. The maximum deflection of the guideway due to bogie turning is about 1.78 mm, which is far away from the limit.

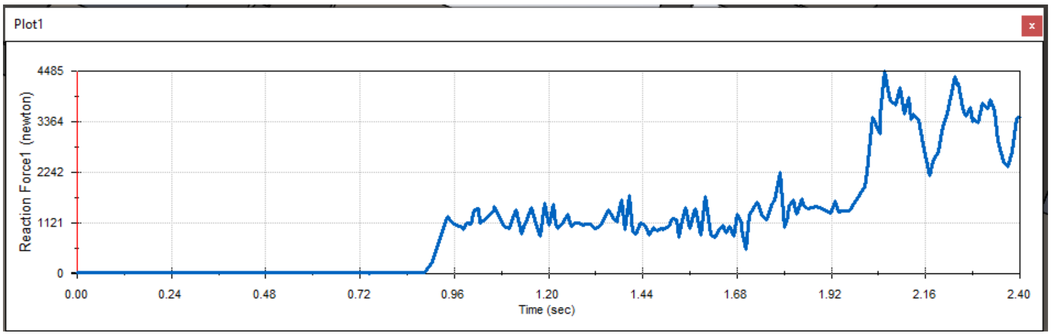


Figure 46. Reaction Force on Side Guiding Wheel During Bogie Turning. *Driving Wheel of the bogie is set to be 150 RPM, guideway turning radius is 600 inches (15.24 m), Maximum reaction force is 4485 N.*

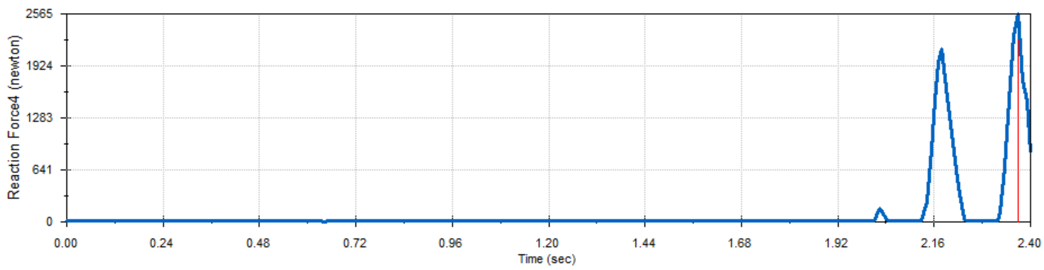


Figure 47. Reaction Force on Top Guiding Wheel During Bogie Turning. *Driving Wheel of the bogie is set to be 150 RPM, guideway turning radius is 600 inches (15.24 m), Maximum reaction force is 2565 N.*

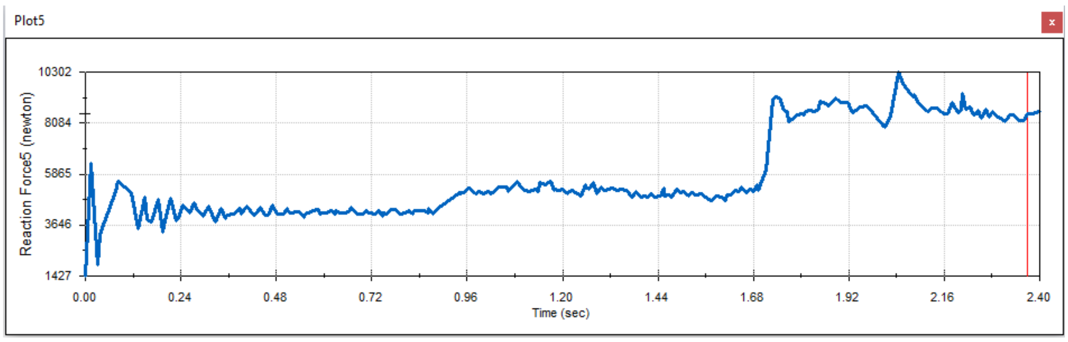


Figure 48. Reaction Force on The Driving Wheel During Turning. *Driving Wheel of the bogie is set to be 150 RPM, guideway turning radius is 600 inches (15.24 m), Maximum reaction force is 10302 N.*

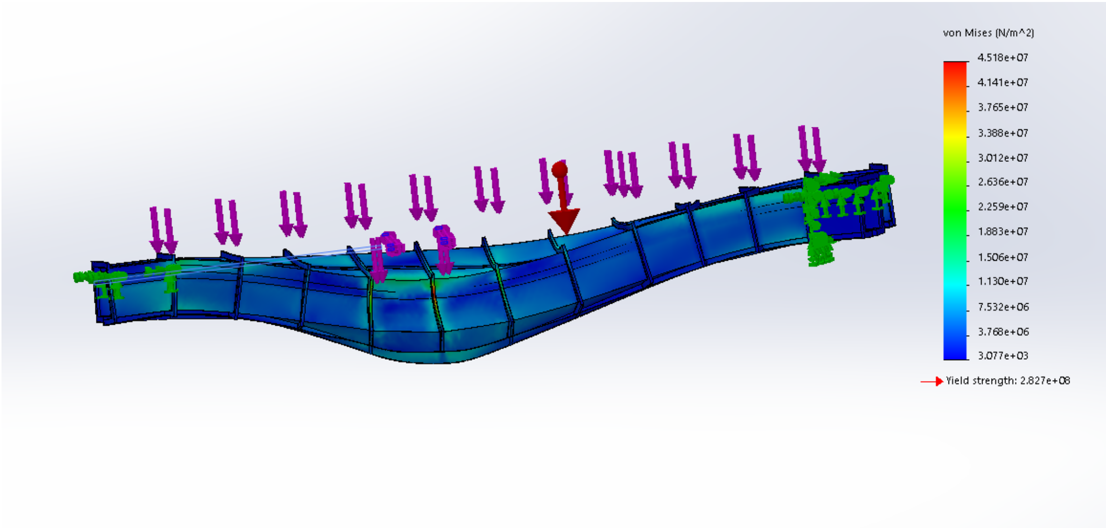


Figure 49. Stress Analysis for Bogie Turning. *Maximum Stress is at 4.51 x 10^7 N/m^2*

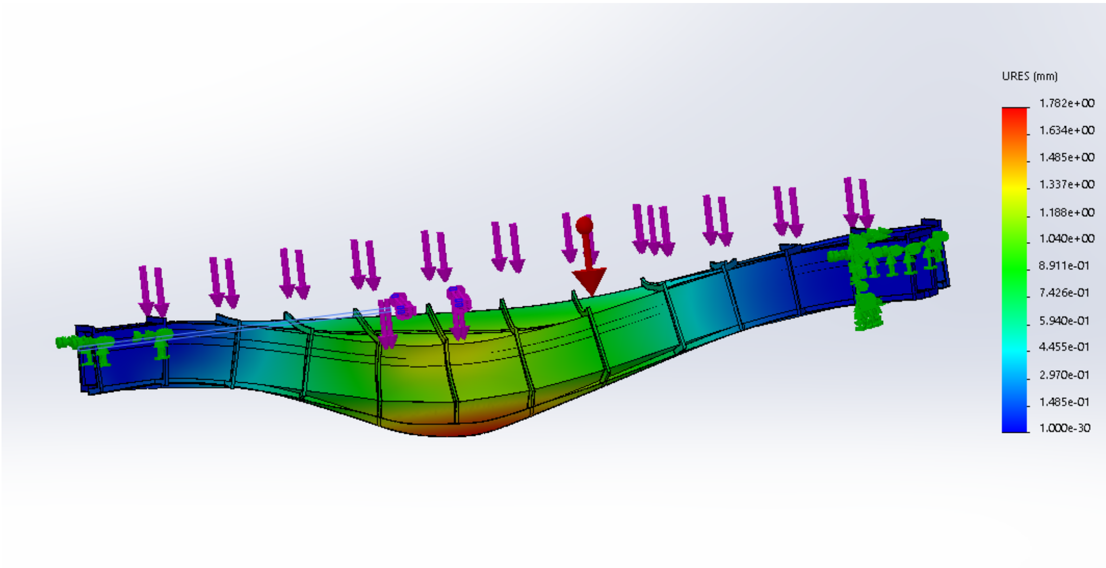


Figure 50. Deflection due to Bogie Turning. *Maximum Deflection due to bogie turning is at 1.78 mm.*

The stress analysis of the curved guideway is shown in Figure 50 and Figure 51. There’s 14700N of force acting downward at the middle of the span, which represents the weight of the bogie and passenger cabin. Also, there’s an 8589N force acting downward on the top surface of the ribs, which represents the weight of the solar panels and racking. The maximum stress on the curved guideway under this loading condition is 3.32 x 10^7 N/m^2, which provide a factor of safety of about 8.5. The maximum deflection under this loading condition is about 2.38 mm, which is acceptable.

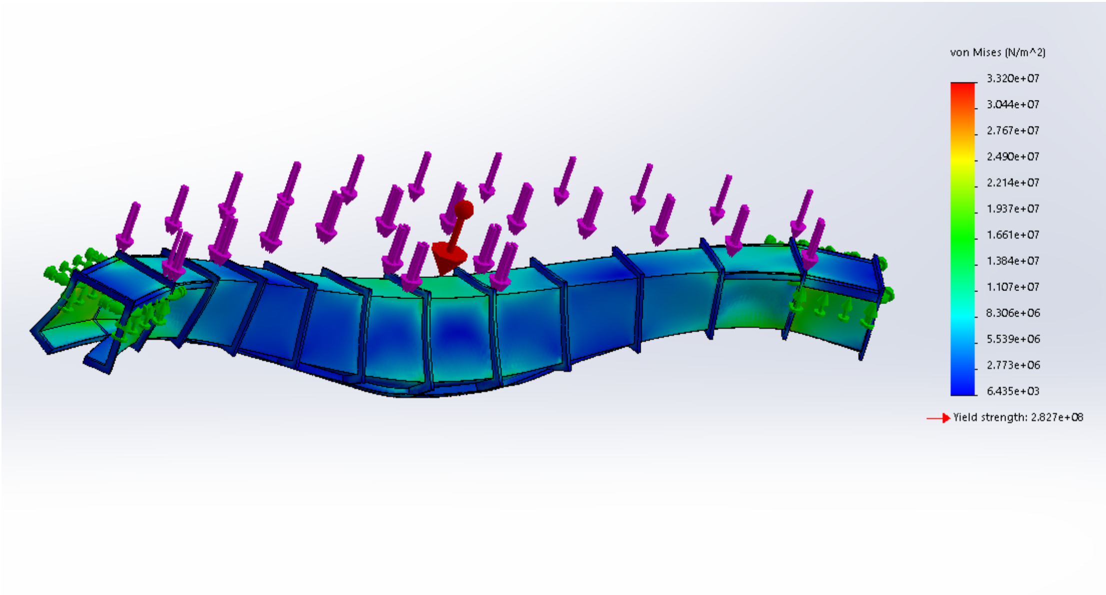


Figure 51. Stress Analysis for Curved Guideway Segment. *Maximum stress is about 3.32 x 10^7 N/m^2*

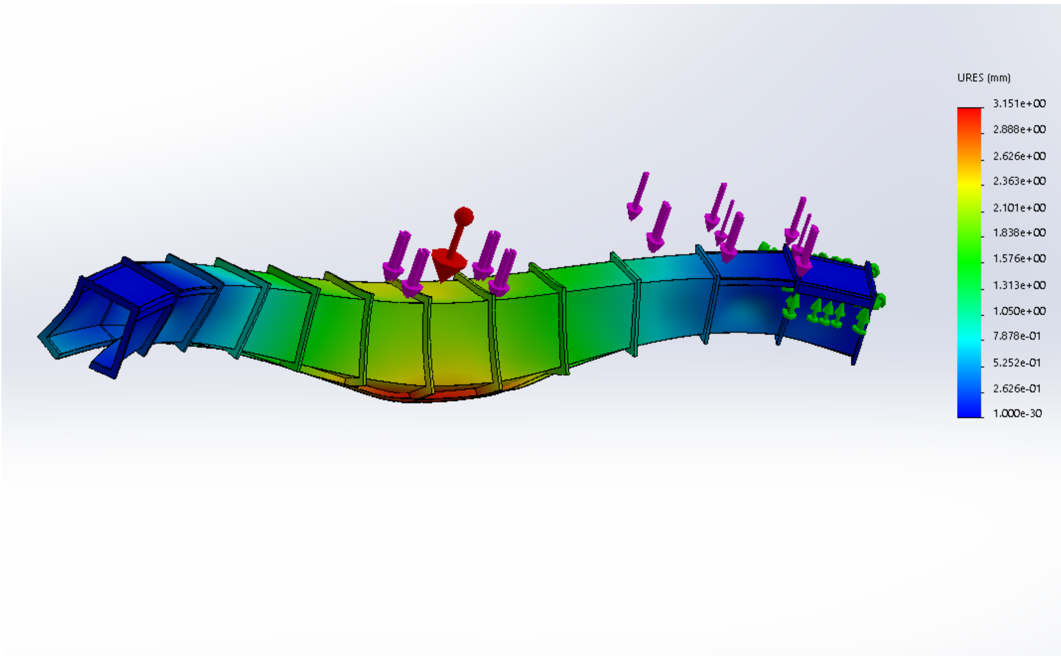


Figure 52. Deflection of Curved Guideway Segment. *Maximum deflection is about 2.38 mm.*

To hold each guideway segment on the support structure, a guideway holder is needed as mentions in the previous section. Since the guideway is about 2787.2 kg, the bogie plus cart and passengers weigh 1500 kg, and the solar panels and racking are weight 876 kg, so we are going to apply a 12725 N of force downward on the support surface of the guideway holder in this FEA. The result is shown in Figure 53 and Figure 54. The maximum stress on the guideway hanger is about 3.017 x 10^7 N/m^2, the factor of safety is about 9.37. The maximum deflection is about 5.77 mm.

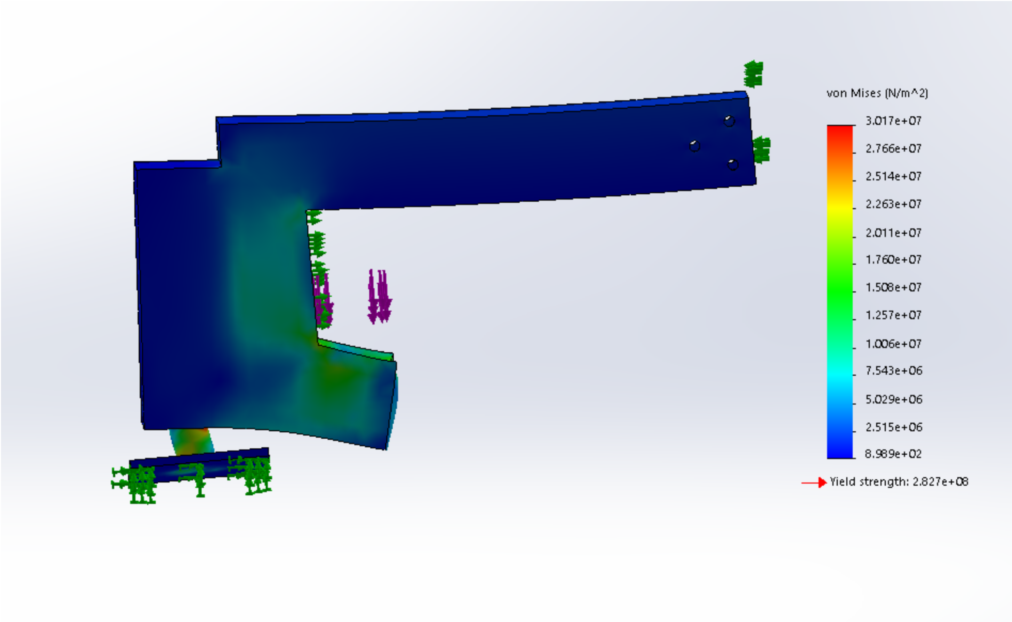


Figure 53. Stress Analysis for Guideway Holder. *Maximum Stress is 3.017 x 10^7 N/m^2*

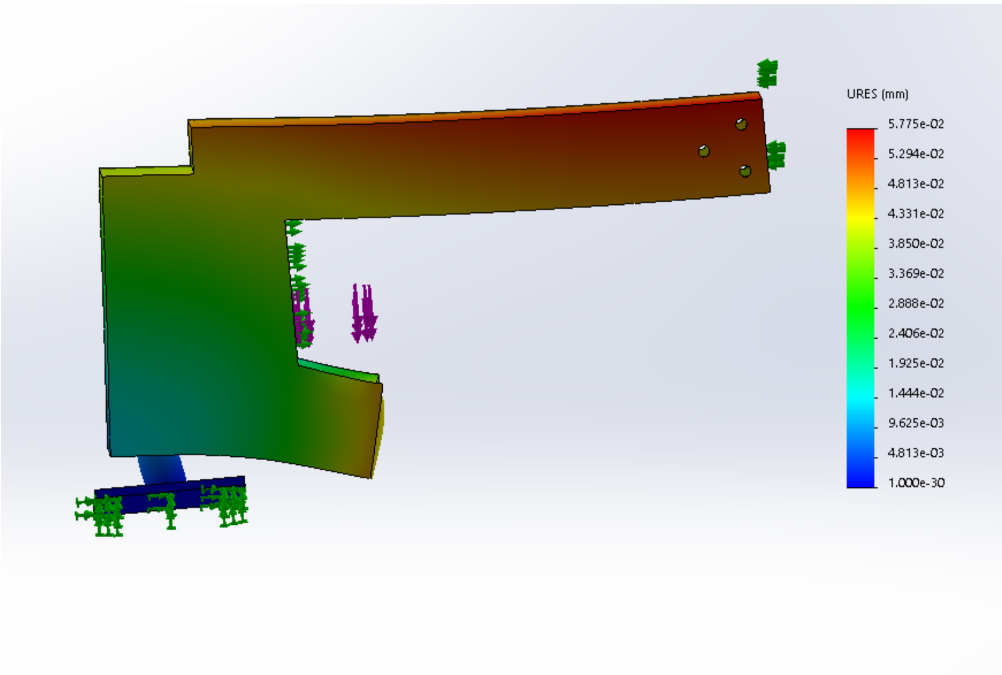


Figure 54. Deflection of Guideway Holder. *Maximum deflection is 5.77 mm*

DISCUSSION ABOUT MANUFACTURING ABILITY

Most of the guideway components that were designed in this project are going to be made of carbon steel. The detailed drawings and bill of materials can be found in the appendix. For the straight guideway segment, the enclosed steel tube is made by welding sheet metal together. The outer ribs on the guideway segment are simply made from standard rectangular steel beams that were precut to an appropriate shape and welded together. After the enclosed steel tube and outer ribs are ready, welded the outer ribs to the outer surface of the enclosed steel tube, then a straight guideway segment is completed. For the “Y” joint guideway and curved guideway, they can be made using the same method as the straight guideway segment. The only difference is some of the sheet metals need to be bent into the correct radius before welding. A sheet metal roller can be used to produce the curved sheet metal easily. A picture of a typical sheet metal roller is shown in Figure 55. For some of the sheet metal that needs to be cut into a special shape, there are three common types of cutting methods in the industry currently that we can consider. The three methods are Laser cutting, water jet cutting and plasma cutting. The water jet has the lowest cutting speed and plasma has the highest cutting speed. In terms of cutting quality, water jet produces the most accurate cut since no heat is involved during the process and therefore no material distortion. Among these three cutting methods, plasma cut has the lowest cutting accuracy, however, since we don’t need very high accuracy for our design, and most of the edges will be welded together anyway, therefore we will choose plasma cut for those parts that are required to be cut.

For manufacturing the support structures, it is also relatively simple. There are two main parts of the support structure, the post and the hanger. For the cylindrical hollow post, it could be made by metal extrusion directly and cut to the proper length. The hanger can be broken into multiple sheet metals, so we can use plasma cut to cut the sheet metal into a designed shape and simply weld them together.

Figure 55. Sheet Metal Roller. Mechanical hydraulic sheet metal steel roller bender rates 3-roller bending machine. Used for bending carbon steel sheet metal.

CONCLUSION AND RECOMMENDATION FOR FUTURE WORK

The current design for all three types of guideways and three types of supporting structure are all having a factor of safety 5.0 or above. The maximum deflection of all the guideways and supporting structures are fulfilling the L/800 spec. Also, the simulation result shows that the guideway and supporting structure can withstand a magnitude 6.9 earthquake and a 115mph wind load without failure.

The guideway design is far from finished at this moment, due to the limit of time, there are still a lot of works need to be done. Currently, we have only designed 3 types of guideway segment and 3 types of support structure, when the routes of the SPARTAN Superway are confirmed, there will be more different types of guideway and support structure are needed in the field. Also, the current design of the support structures are not including the underground portion, so the method of installing the support structure in the field is still needed to be designed.

Also, the earthquake analysis and wind load analysis are still preliminary, I only perform the analysis on one type of guideway and support structure, a deeper study will be needed for future work.

Finally, we need to analyze the cost of manufacturing the guideway, as well as the time we need for construction, to see if these designs are truly affordable. Also, it would be nice if we can have some different types of design concepts like trust and beam guideway to compare with, so we can have more options to consider.

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APPENDIX

Table 1. Typical overall Factors of Safety *Consider the guideway to be structural steel work in bridges, the general factor of safety requirement is 5-7 (www.engineeringtoolbox.com)*

Equipment	Factor of Safety *- FOS -*
Aircraft components	1.5 - 2.5
Boilers	3.5 - 6
Bolts	8.5
Cast-iron wheels	20
Engine components	6 - 8
Heavy duty shafting	10 - 12
Lifting equipment - hooks ..	8 - 9
Pressure vessels	3.5 - 6
Turbine components - static	6 - 8
Turbine components - rotating	2 - 3
Spring, large heavy-duty	4.5
Structural steel work in buildings	4 - 6
Structural steel work in bridges	5 - 7
Wire ropes	8 - 9

Table 2. Design Study Result. *15 combination has been analyzed by FEA, best combination is wall thickness 0.1 inches and 13 ribs (rib spacing 48 inches).*

Design Study 2																			
Scenarios/I	15																		
Parameter	Format	Unit	Initial Valu	Optimal Va	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15
					Calculated	Estimated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated
thk		N/A	0.1	0.1	0.1	0.2	0.3	0.1	0.2	0.3	0.1	0.2	0.3	0.1	0.2	0.3	0.1	0.2	0.3
num		N/A	8	8	9	9	9	10	10	10	11	11	11	12	12	12	13	13	13
Minimum F	> 5.000000		5.253088	5.253088	4.933308	Simulation	4.84744	5.126692	5.140132	4.828527	5.067845	5.116174	4.802596	5.115914	5.059571	4.842922	5.195065	5.063512	4.753703
Mass1	Minimize	lb	2654.1428	2654.1428	2827.456	Simulation	5898.3369	2914.1126	4456.0952	5984.9914	3000.7692	4542.751	6071.6459	3087.4258	4629.4068	6158.3004	3174.0824	4716.0626	6244.9548

Table 3. Respond Spectrum Raw Data *First column is times, unit is second, second column is acceleration in g's. (Data source: http://www.vibrationdata.com/elcentro.htm)*

	A	B
1	Time (s)	Accelation (g)
2	0.00E+00	-1.43E-03
3	2.00E-02	-1.10E-02
4	4.00E-02	-1.03E-02
5	6.00E-02	-8.97E-03
6	8.00E-02	-9.69E-03
7	1.00E-01	-1.22E-02
8	1.20E-01	-1.45E-02
9	1.40E-01	-1.31E-02
10	1.60E-01	-1.12E-02
11	1.80E-01	-8.67E-03
12	2.00E-01	-8.67E-03
13	2.20E-01	-1.34E-02
14	2.40E-01	-1.79E-02
15	2.60E-01	-1.98E-02
16	2.80E-01	-1.65E-02
17	3.00E-01	-1.47E-02
18	3.20E-01	-1.10E-02
19	3.40E-01	-8.36E-03
20	3.60E-01	-4.28E-03

Sheet1

Table 4. AASHTO Temperature Range Specification. *San Jose is moderate climate area, so we are using 0 to 120°F for the simulation.*

Table 3.7.2-1 Temperature Ranges
(Based on *AASHTO LRFD* Table 3.12.2.1-1)

Climate	Steel or Aluminum	Concrete	Wood
Moderate	0˚F to 120˚F	10˚F to 80˚F	10˚F to 75˚F
Cold	-30˚F to 120˚F	0˚F to 80˚F	0˚F to 75˚F

Table 5. Guideway Radius vs Bogie Speed vs Lateral Acceleration. *The lateral acceleration is calculated by the following equation: a=V^2 / R*

R (in)	R (m)	Speed (m/s)	Speed (mph)	KMH	Lateral Acce	g	Acceptable Lateral Acceleration (m/s^2)
400	10.16	5.00	11.19	17.90	2.46	0.25	1.8 - 3.6
500	12.70	5.00	11.19	17.90	1.97	0.20	
600	15.24	7.40	16.55	26.49	3.59	0.37	
700	17.78	5.00	11.19	17.90	1.41	0.14	
800	20.32	5.00	11.19	17.90	1.23	0.13	
2000	50.80	13.00	29.08	46.53	3.33	0.34	

Figure 56. Hand Calculation for Straight Guideway Deflection. *By treating the guideway as a beam, the hand calculation shows maximum deflection is about 3.17 mm.*

$$\delta_{max} = \frac{PL^3}{48EI}$$

P = weight of bogie + passenge carbin + weight of solar rack + weight of guideway $\approx$ 57488 N

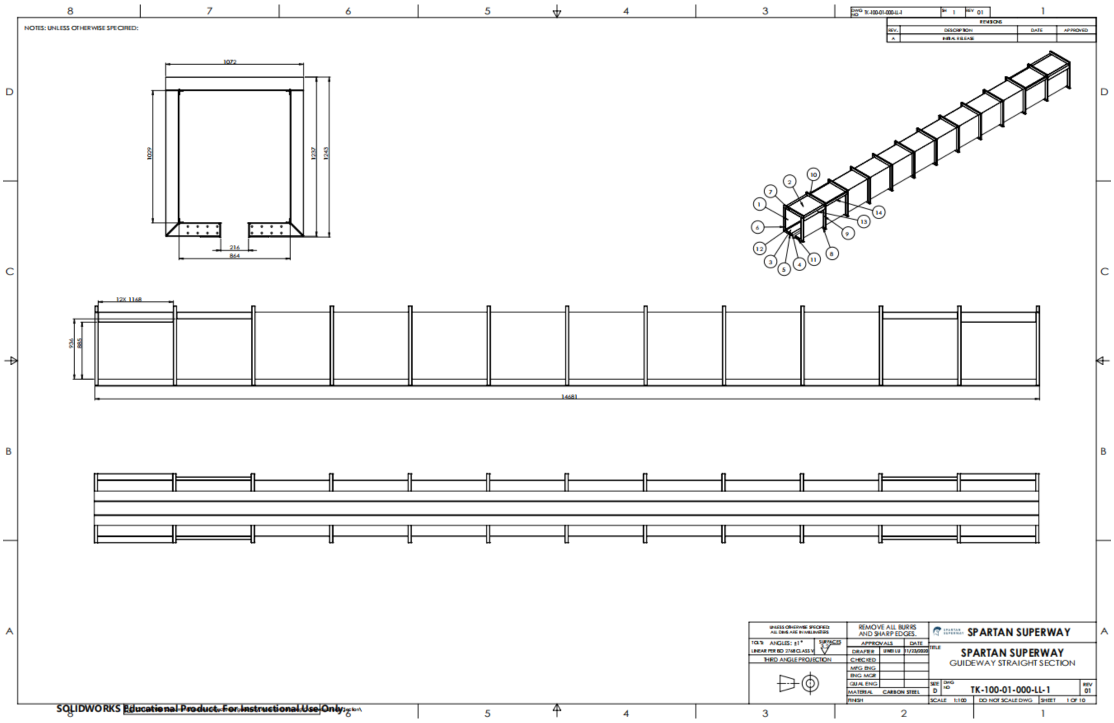
$L \approx 12.2$ m (distance between support)

$E = 2.45 \times 10^{11}$ N/m^2 (carbon steel)

$I \approx 2.8 \times 10^{-3}$ m^4

$$\Rightarrow \delta_{max} = \frac{57488 \times 12.2^3}{48 \times 2.45 \times 10^{11} \times 2.8 \times 10^{-3}} \approx .00317\text{m} = 3.17\text{mm}$$

Figure 57. Manufacturing Drawing for Guideway Straight Section. *Click the below icon for the complete drawings*

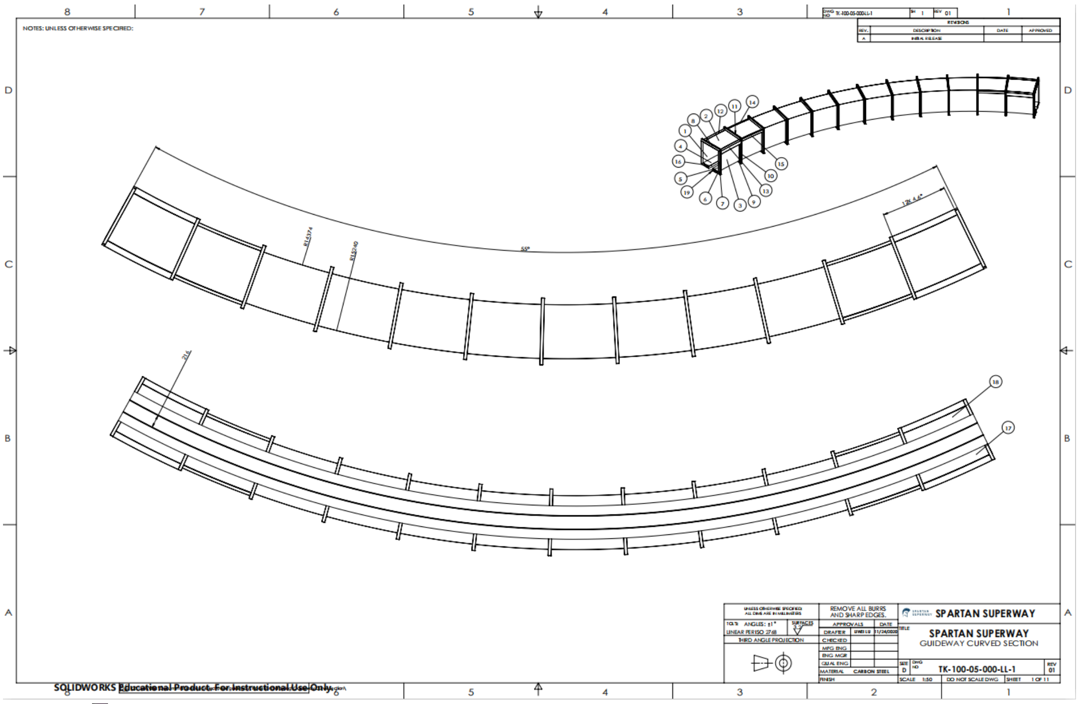


Guideway Straight Section

Table 6. Bill of Materials for Guideway Straight Section

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
0	TK-100-01-000-LL-1	GUIDEWAY STRAIGHT SECTION MANUFACTURING ASSEMBLY	1
1	TK-100-01-001	guideway straight section item 1	2
2	TK-100-01-002	guideway straight section item 2	1
3	TK-100-01-003	guideway straight section item 3	2
4	TK-100-01-004	guideway straight section item 4	2
5	TK-100-01-005	guideway straight section item 5	4
6	TK-100-01-006	guideway straight section item 6	4
7	TK-100-01-007	guideway straight section item 7	2
8	TK-100-01-008	guideway straight section item 8	22
9	TK-100-01-009	guideway straight section item 9	22
10	TK-100-01-010	guideway straight section item 10	11
11	TK-100-01-011	guideway straight section item 11	2
12	TK-100-01-012	guideway straight section item 12	4
13	TK-100-01-013	guideway straight section item 13	4
14	TK-100-01-014	guideway straight section item 14	4

Figure 58. Manufacturing Drawing for Curved Guideway. *Click the below icon for the complete drawings*



Guideway curve section assembly

Table 7. Bill of Materials for Curved Guideway Section.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
0	TK-100-05-000-LL-1	GUIDEWAY CURVE SECTION MANUFACTURING ASSEMBLY	1
1	TK-100-05-001	Guideway cruve section item 1	1
2	TK-100-05-002	Guideway cruve section item 2	1
3	TK-100-05-003	Guideway cruve section item 3	1
4	TK-100-05-004	Guideway cruve section item 4	1
5	TK-100-05-005	Guideway cruve section item 5	1
6	TK-100-05-006	Guideway cruve section item 6	4
7	TK-100-05-007	Guideway cruve section item 7	4
8	TK-100-05-008	Guideway cruve section item 8	2
9	TK-100-05-009	Guideway cruve section item 9	22
10	TK-100-05-010	Guideway cruve section item 10	22
11	TK-100-05-011	Guideway cruve section item 11	11
12	TK-100-05-012	Guideway cruve section item 12	2
13	TK-100-05-013	Guideway cruve section item 13	2
14	TK-100-05-014	Guideway cruve section item 14	2
15	TK-100-05-015	Guideway cruve section item 15	2
16	TK-100-05-016	Guideway cruve section item 16	1
17	TK-100-05-017	Guideway cruve section item 17	1
18	TK-100-05-018	Guideway cruve section item 18	1
19	TK-100-05-019	Guideway cruve section item 19	1

Figure 59. Manufacturing Drawing for "Y" Joint Guideway. *Click the below icon for the complete drawings*

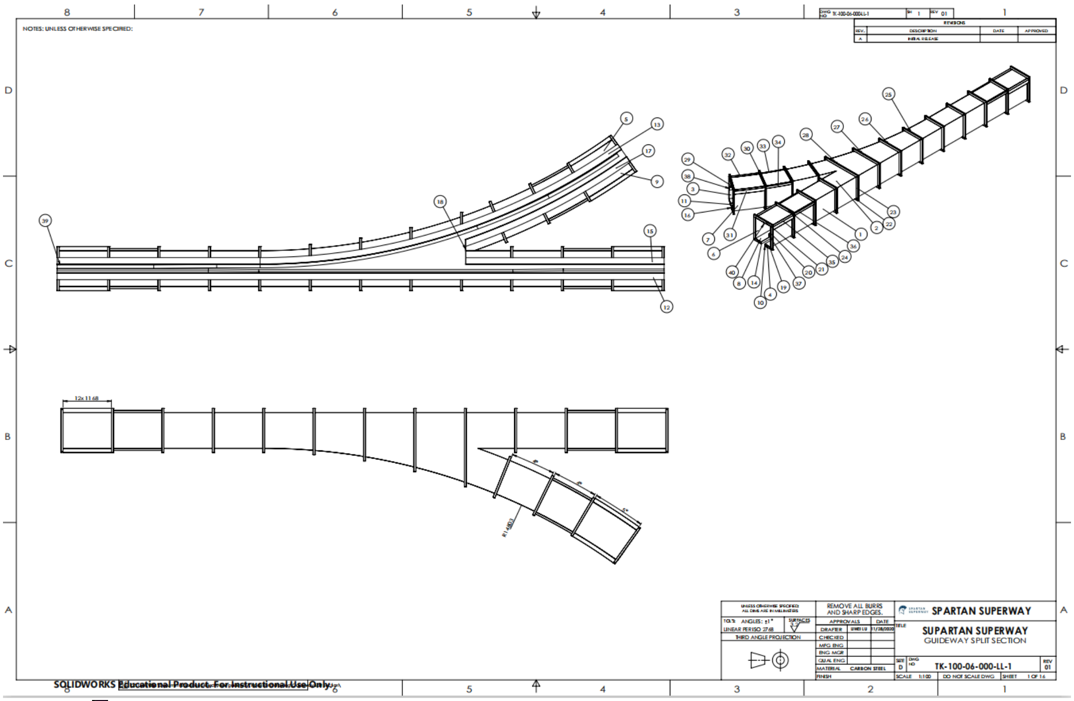


Table 8. Bill of Materials for "Y" Joint Guideway.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
0	TK-100-06-001-LL-1	GUIDEWAY SPLIT SECTION MANUFACTURING ASSEMBLY	1
1	TK-100-06-001	guideway split section item 1	1
2	TK-100-06-002	guideway split section item 2	1
3	TK-100-06-003	guideway split section item 3	1
4	TK-100-06-004	guideway split section item 4	1
5	TK-100-06-005	guideway split section item 5	1
6	TK-100-06-006	guideway split section item 6	1
7	TK-100-06-007	guideway split section item 7	1
8	TK-100-06-008	guideway split section item 8	1
9	TK-100-06-009	guideway split section item 9	1
10	TK-100-06-010	guideway split section item 10	1
11	TK-100-06-011	guideway split section item 11	1
12	TK-100-06-012	guideway split section item 12	1
13	TK-100-06-013	guideway split section item 13	1
14	TK-100-06-014	guideway split section item 14	1
15	TK-100-06-015	guideway split section item 15	1
16	TK-100-06-016	guideway split section item 16	1
17	TK-100-06-017	guideway split section item 17	1

18	TK-100-06-018	guideway split section item 18	1
19	TK-100-06-019	guideway split section item 19	6
20	TK-100-06-020	guideway split section item 20	6
21	TK-100-06-021	guideway split section item 21	2
22	TK-100-06-022	guideway split section item 22	28
23	TK-100-06-023	guideway split section item 23	28
24	TK-100-06-024	guideway split section item 24	7
25	TK-100-06-025	guideway split section item 25	1
26	TK-100-06-026	guideway split section item 26	1
27	TK-100-06-027	guideway split section item 27	1
28	TK-100-06-028	guideway split section item 28	1
29	TK-100-06-029	guideway split section item 29	1
30	TK-100-06-030	guideway split section item 30	3
31	TK-100-06-031	guideway split section item 31	1
32	TK-100-06-032	guideway split section item 32	1
33	TK-100-06-033	guideway split section item 33	1
34	TK-100-06-034	guideway split section item 34	1
35	TK-100-06-035	guideway split section item 35	4
36	TK-100-06-036	guideway split section item 36	4
37	TK-100-06-037	guideway split section item 37	1
38	TK-100-06-038	guideway split section item 38	1
39	TK-100-06-039	guideway split section item 39	1
40	TK-100-06-040	guideway split section item 40	1

Figure 60. Manufacturing Drawing for L Shape Support Structure. *Click the below icon for the complete drawings*

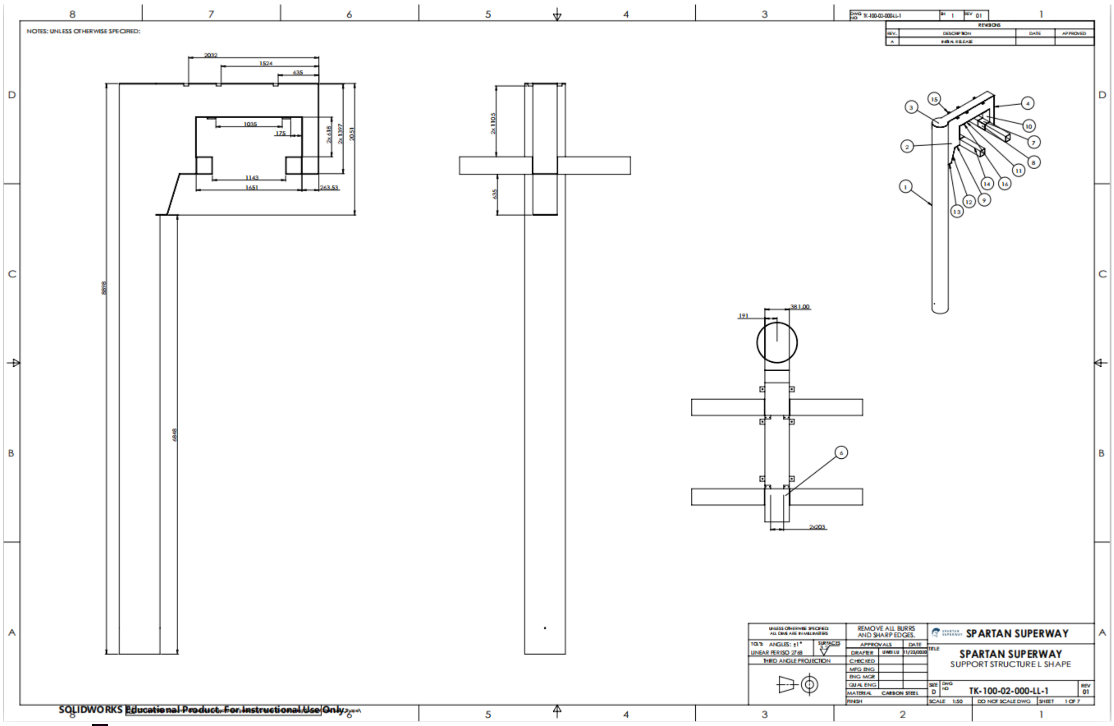


Table 9. Bill of Materials for L Shape Support Structure.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
0	TK-100-02-000-LL-1	SUPPORT STRUCTRUE L SHAPE MANUFACTURING ASSEMBLY	1
1	TK-100-02-001	support structure item 1	1
2	TK-100-02-002	support structure item 2	1
3	TK-100-02-003	support structure item 3	1
4	TK-100-02-004	support structure item 4	1
5	TK-100-02-005	support structure item 5	1
6	TK-100-02-006	support structure item 6	1
7	TK-100-02-007	support structure item 7	2
8	TK-100-02-008	support structure item 8	2
9	TK-100-02-009	support structure item 9	1
10	TK-100-02-010	support structure item 10	2
11	TK-100-02-011	support structure item 11	1
12	TK-100-02-012	support structure item 12	1
13	TK-100-02-013	support structure item 13	1
14	TK-100-02-014	support structure item 14	4
15	TK-100-02-015	support structure item 15	6
16	TK-100-02-016	support structure item 16	4

Figure 61. Manufacturing Drawing for T Shape Support Structure. *Click the below icon for the complete drawings*

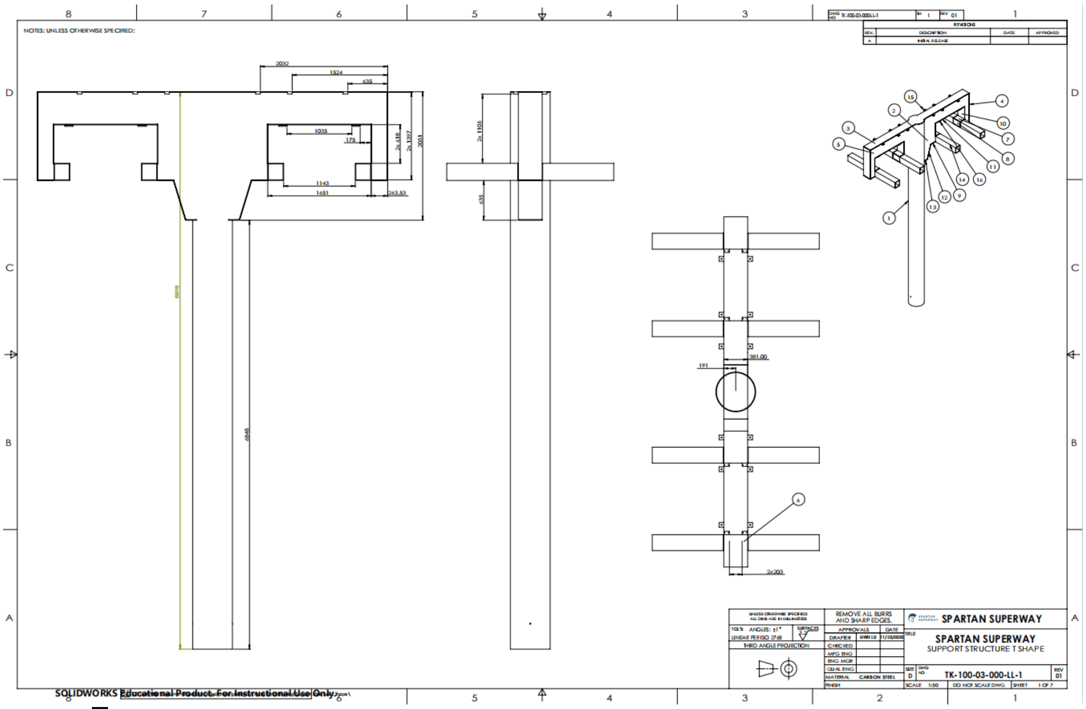


Table 10. Bill of Materials for T Shape Support Structure.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
0	TK-100-03-000-LL-1	SUPPORT STRUCTURE T SHAPE MANUFACTURING ASSEMBLY	1
1	TK-100-03-001	support structure T Shape item 1	1
2	TK-100-03-002	support structure T Shape item 2	2
3	TK-100-03-003	support structure T Shape item 3	1
4	TK-100-03-004	support structure T Shape item 4	2
5	TK-100-03-005	support structure T Shape item 5	2
6	TK-100-03-006	support structure T Shape item 6	2
7	TK-100-03-007	support structure T Shape item 7	4
8	TK-100-03-008	support structure T Shape item 8	4
9	TK-100-03-009	support structure T Shape item 9	2
10	TK-100-03-010	support structure T Shape item 10	4
11	TK-100-03-011	support structure T Shape item 11	2
12	TK-100-03-012	support structure T Shape item 12	2
13	TK-100-03-013	support structure T Shape item 13	2
14	TK-100-03-014	support structure T Shape item 14	8
15	TK-100-03-015	support structure T Shape item 15	12
16	TK-100-03-016	support structure T Shape item 16	8

Figure 62. Manufacturing Drawing for Support Bridge. *Click the below icon for the complete drawings*

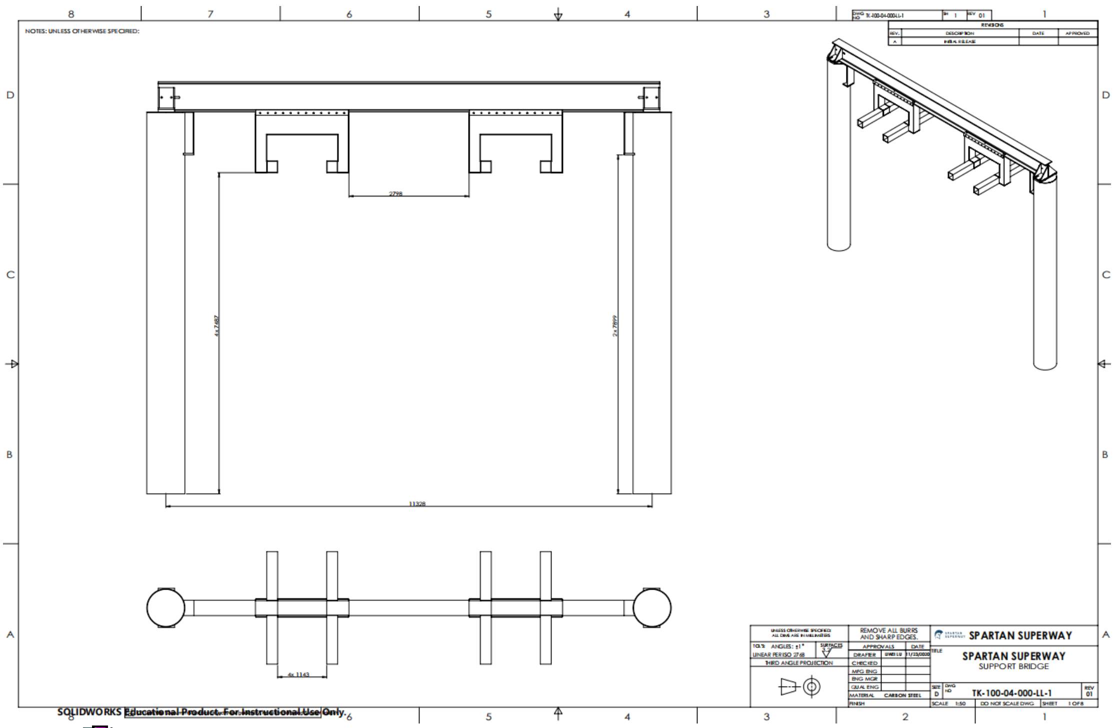


Table 11. Bill of Materials for Support Bridge.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
0	TK-100-04-000-LL-1	SUPPORT BRIDGE MANUFACTURING ASSEMBLY	1
1	TK-100-04-001	support bridge item 1	2
2	TK-100-04-002	support bridge item 2	2
3	TK-100-04-003	support bridge item 3	4
4	TK-100-04-004	support bridge item 4	2
5	TK-100-04-005	support bridge item 5	2
6	TK-100-04-006	support bridge item 6	2
7	TK-100-04-007	support bridge item 7	4
8	TK-100-04-008	support bridge item 8	4
9	TK-100-04-009	support bridge item 9	4
10	TK-100-04-010	support bridge item 10	4
11	TK-100-04-011	support bridge item 11	2
12	TK-100-04-012	support bridge item 12	4
13	TK-100-04-013	support bridge item 13	4
14	TK-100-04-014	support bridge item 14	2
15	TK-100-04-015	support bridge item 15	8
16	TK-100-04-016	support bridge item 16	1
17	TK-100-04-017	support bridge item 17	4
18	TK-100-04-018	support bridge item 18	4
19	TK-100-04-019	support bridge item 19	4