AE 212 Mechanics of Solids

Design Project

A Bridge for Bicycles

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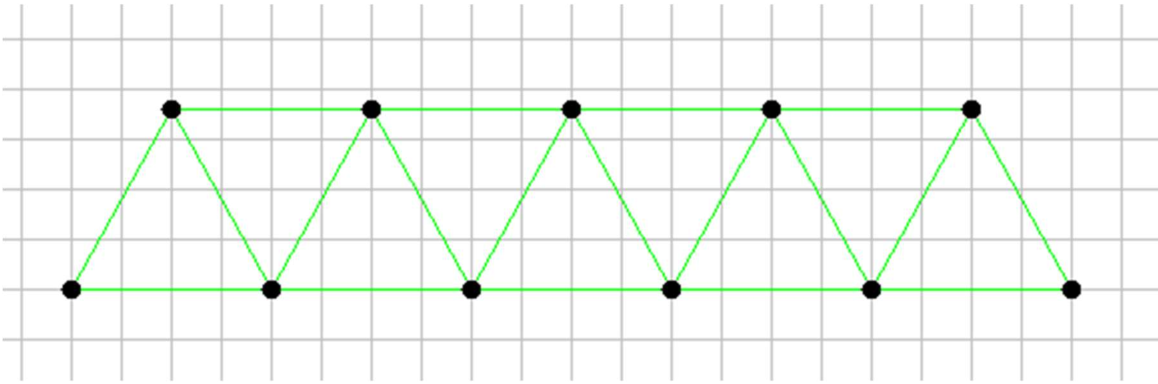
Introduction:

Warren Truss Bridges

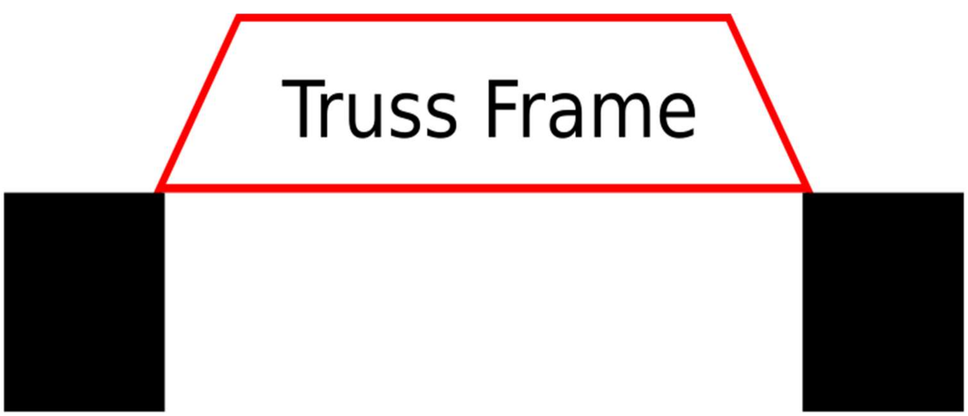


The Warren Truss is a quite common design for both real and model bridges. It is exact history and origination is a little muddled, however. James Warren patented a design in 1848 (in England), which many attributes the name “Warren Truss”.

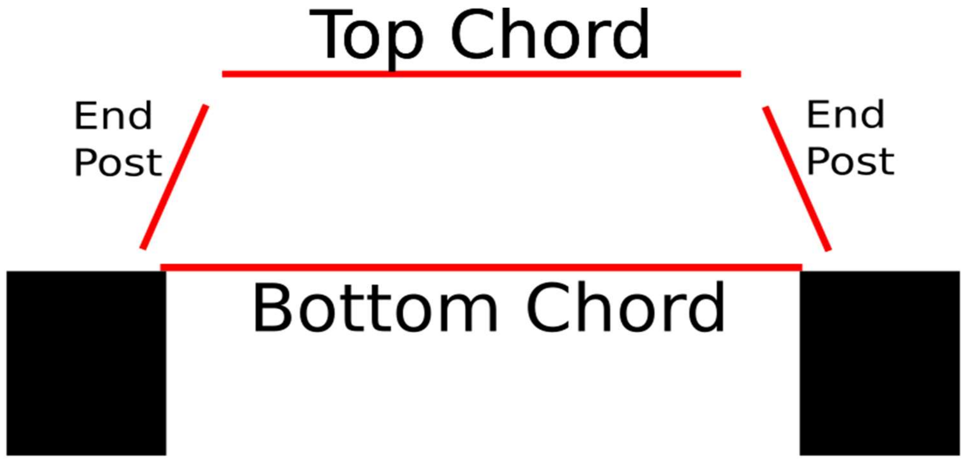
The Warren Truss uses equilateral triangles to spread out the loads on the bridge. This is opposed to the Neville Truss which used isosceles triangles. The equilateral triangles minimize the forces to only compression and tension. Interestingly, as a load (such as a car or train) moves across the bridge sometimes the forces for a member switch from compression to tension. This happens especially to the members near the centre of the bridge.

Brief Overview on Terminologies:

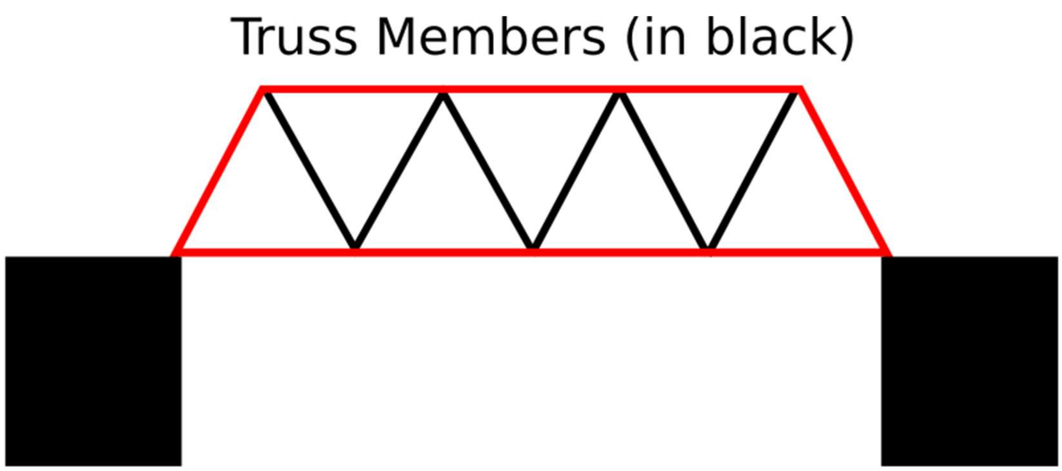
Let us define a couple terms to help you understand how to study truss design. Shown here in red is the Truss Frame. The frame is the outermost parts of the truss.



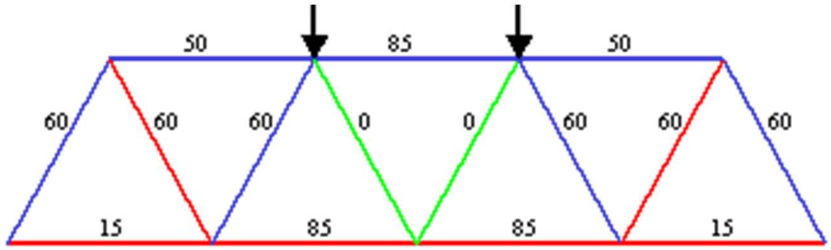
The frame is made up of several parts: Top chord, bottom chord, and two end posts. This diagram shows the frame in an expanded view so you can easily see each part. Practically, you might use different sizes or shapes of wood for each of these parts due to the force being put on each part is different.



Now we will add the truss members, which are shown in black in this diagram. The truss members are simply an arrangement of triangles (most of the time) that transfer the force/s put on the bridge to the ground. The way these triangles are arranged or shaped is the essence of truss design. You will see examples of the most common designs further on this page.



The tension and compression members are as shown.



- Blue: tension
- Red: compression
- Green: neutral (no load).

Brief History

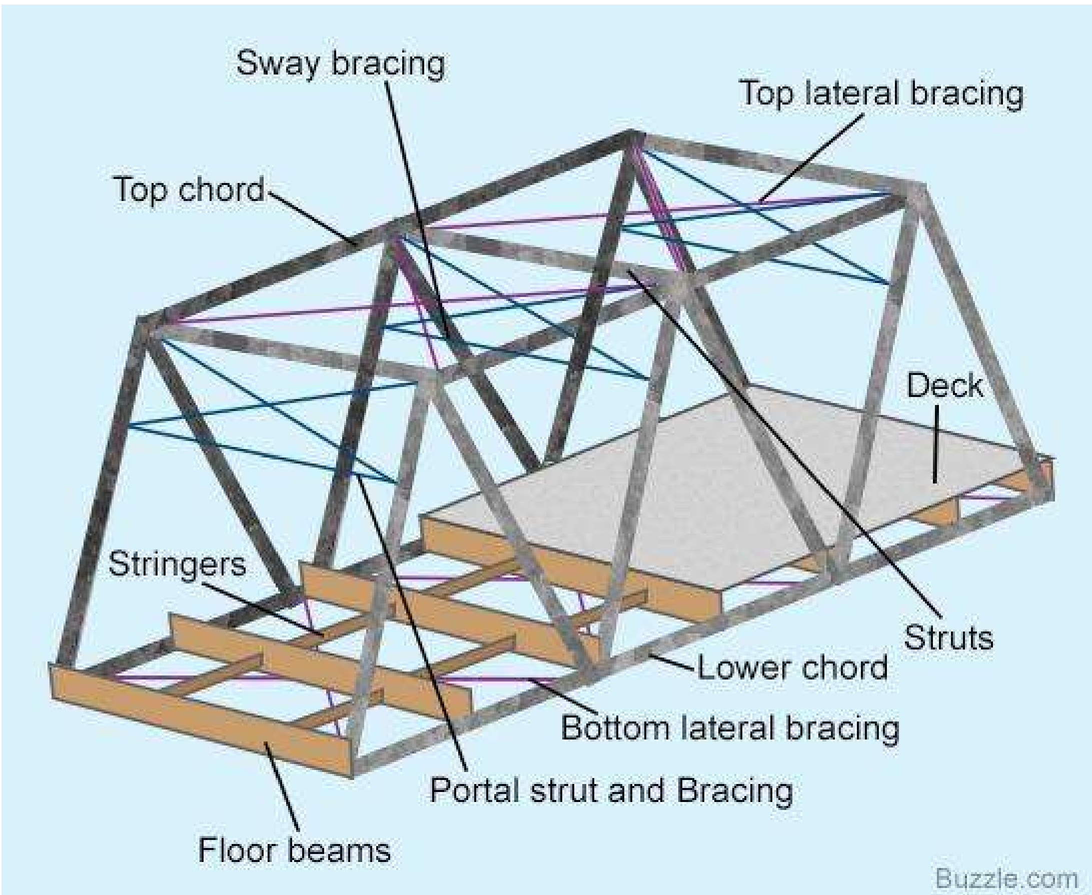
While trusses have been used for both roofs and bridges for many centuries, there was an explosion of truss advancement in the 19th century in America. The need for bridges to span longer distances in this era, as well as to hold increasingly heavy loads, brought about many creative solutions in the form of new truss designs.

Three names stand out as true pioneers in these early truss bridges: Timothy Palmer (1751-1821), Louis Wernwag (1770-1843), and Theodore Burr (1771-1822). These men, along with other bridge builders who followed them, designed, and built many bridges, especially in New England. Theodore Burr came up with a design that was used in many iconic covered bridges, and some are still standing today. These men came up with practical solutions for bridge building and did not know or have access to the theory behind their designs.

Interestingly, building bridges in the 18th and early 19th century was more about quality of construction. Skilled carpenters were needed, and most of the engineering was practical and not theoretical. Wood was the primary material available in these early years, but iron and then steel came along and changed everything.

With iron and steel, and the expansion of railroads that carried heavier and heavier loads, new bridge designs were needed. The Howe and Pratt trusses were designed to incorporate iron rods in the truss. These two designs, which you can see from the original patent images, do not look exactly like the truss designs that we associate with those names today. This is a bit of a mystery to me, but you can see semblances of the original designs in the modern depictions. Both the Pratt and Howe patents were very much concerned about methodology of construction more so than the actual design

Design of Warren Bridge:



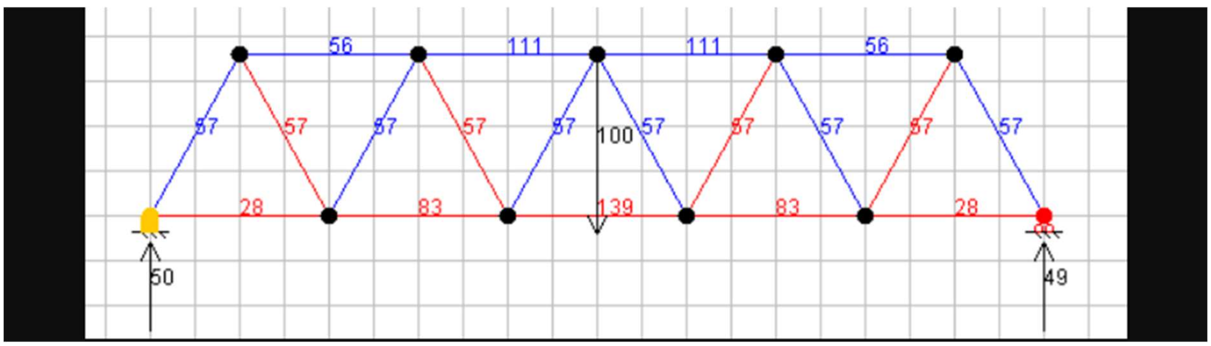
The Warren truss design uses equilateral triangles in the framework to spread out the load on the bridge. These triangles limit the force of the load to compression and tension of the bridge parts. The upper and lower horizontal parts are in tension, along with the diagonals in the centre, while the outer diagonals are compressed. Sometimes, when the upper portions of the bridge are not stiff enough, engineers may add vertical beams dividing each triangle in the centre. This prevents the bridge from buckling under pressure. Such a design is known as a subdivided Warren truss bridge. Other designs include the Double Warren, which has intersecting triangle parts, and give an appearance of diamond shapes; and the quadrangular Warren truss bridge, which has numerous diagonal ridges, giving it a netted appearance.

When a vehicle is moving across the bridge, the stress on the various parts of the bridge near the vehicle changes from compression to tension. The design of such bridges often depends upon the availability of machinery, and cost of materials and labour. These bridges can usually span to around 400 feet in length.

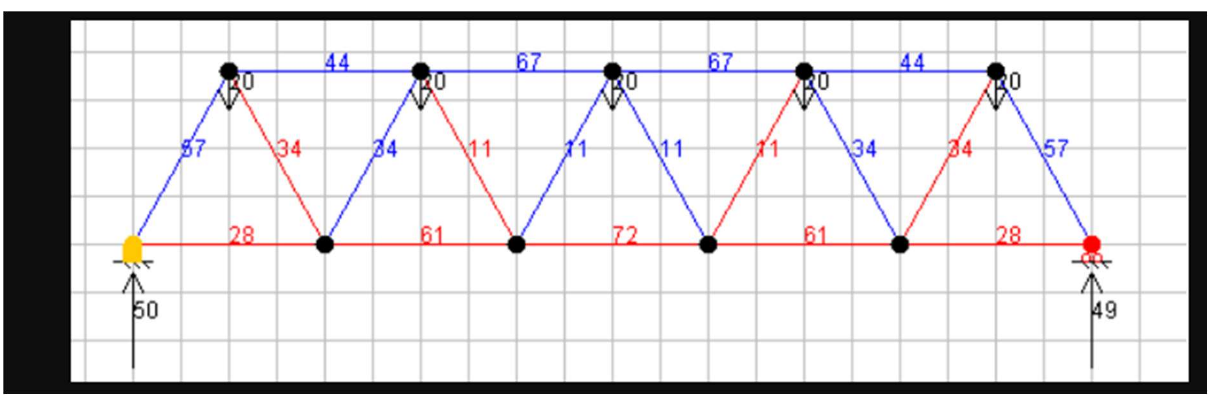
How the forces are spread out

Here are two diagrams showing how the forces are spread out when the warren truss is under a load. The first shows the load being applied across the entire top of the bridge. The second shows a localized load in the centre of the bridge. In both cases the total load = 100. Therefore, you can take the numbers as a percentage of the total load.

Centre Load



Spread Load



Interestingly, there is a significant difference. When the load is concentrated on the middle of the bridge, pretty much all the forces are larger. The top and bottom chord are under larger forces, even though the total load is the same. Thus, if you want your bridge to be able to hold more weight then try to spread out the force across the top of the bridge.

Advantages of Utilizing a Warren Truss Bridge

First and foremost, the design has an interior railing which is connected to the diagonal span which prevents people from falling from the edge of a bridge.

The truss utilizes Newton's laws of motion especially statics that forms an important part of the laws. The straight components meet at pin joints and the components of the truss will be involved in tension or compression.

A bridge built using this design is extraordinarily strong due to the use of triangles. The triangles are ridged which contributes to the strength of the structure.

A Warren truss bridge enables the distribution of forces in several ways. This has brought about a large variety in the ways a bridge can be built.

Disadvantages of Utilizing a Warren Truss Bridge

The joints and fittings of a Warren truss bridge need to be checked regularly, and maintenance can be expensive.

Bridges made over a long span may have many deflection flaws, which need to be corrected during the building process

If not designed in the correct manner it can cause a lot of wastage in terms of material because there can be members in the design that do not contribute in any way to the overall structure.

Famous Warren truss Bridges:

- Brookport Bridge (USA).
- Harteloire Bridge (France).
- Koblenz-Felsenau Footbridge (Switzerland).
- Nishiki Bridge (Japan).
- Pipeline Bridge No.6 (Germany).

A Case Study:


Vip Lounge
विप लाउंज
Bag shop
Sector 18, Noida...
आरबीएल बैंक
लिमिटेड।
Maharaja Agrasen Marg
Chumbak Pop Store
चुंबक पॉप स्टोर
Fashion accessories store
Bank of India
बैंक ऑफ इंडिया
Rolls King
Takeout · Delivery
Balsons jewellers
बल्सन्स ज्वैलर्स
Jewelry store
Indian Oil Petrol
Pump Sector 18 Noida
इंडियन ऑयल
पेट्रोल पम्प...
Foot Over Bridge
HAIRCRAFT
UNISEX SALON
हेयरक्राफ्ट
यूनिसेक्स सालों
24SEVEN
24सेवन
Takeout · Delivery
महाराजा अग्रसेन मार्ग
Ashok Marg
Hush Puppies
हुश पप्पीज
Shoe store
Helios Watch
Store - By Titan
Delivery
FOB, Nr. Centerstage Mall
Foot Over Bridge, Pocket J, Sector ...
28.567992, 77.324856

1. General information

- Pedestrian Bridge
- Construction company: PWD, Vanbros Construction India Limited
- Location- Noida Sector 18, Foot Over Bridge, India.
- Size: 40 X 40 | Area : 1600 sq. ft. sq. ft.
- Materials: Concrete, steel

2. Investment design

Pedestrian bridges are mainly used by pedestrians and cyclists and only occasionally by maintenance vehicles or ambulances.

Regarding appearance and to structure, open and covered bridges are distinguished as two main types of bridge. The choice of the best structural form of a bridge depends on several parameters:

- Topography and landscape.
- Span
- Loading
- Clearance and clear width
- Soil conditions
- Architectural features

3. Bearing system

For the bridge structure itself, many bearing systems are possible to be used. Most bridges consist of one of the following basic forms: beams on two or more supports, trussed systems, kings and queens post trusses, strut frame systems, frame systems, arch systems, suspended and cable-stayed systems, chainlike structure.

This pedestrian bridge is designed as chainlike structure.

4. Interesting construction details

It is based on warren truss, as equal panel lengths are shorter than the equal length diagonals or to say isometric truss.

The bridge is built with steel rods, inclined towards each other, and combined to form a series of Vandykes [V shapes]. They are bolted at top to horizontal compression rods, and at bottom to horizontal tension rods, and carry a roadway at top or at bottom, or at both.

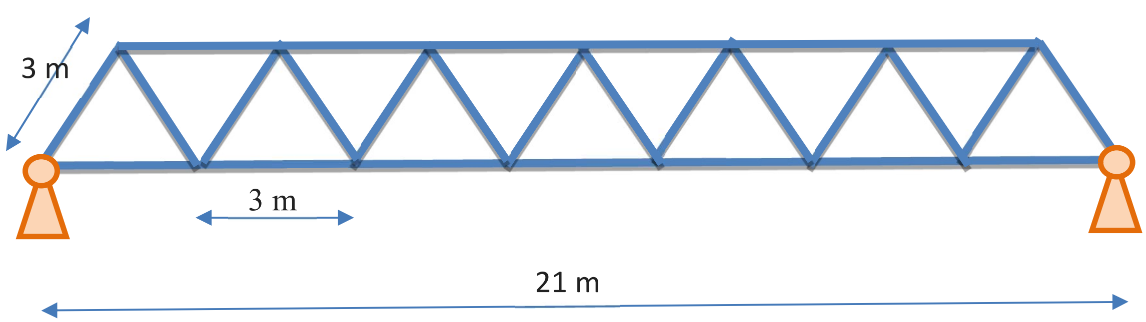
Inspirations:

- It gave as us a physical understanding about the structure and materials used in building a bridge.
- Geometry is of paramount importance in analysis of bridge.
- Symmetry is really a game changer, as nature loves symmetry. Majority of the structural problems can be solved by having the symmetry and the right geometry for e.g. an arch gives you more strength as compared to a straight beam on the roof.

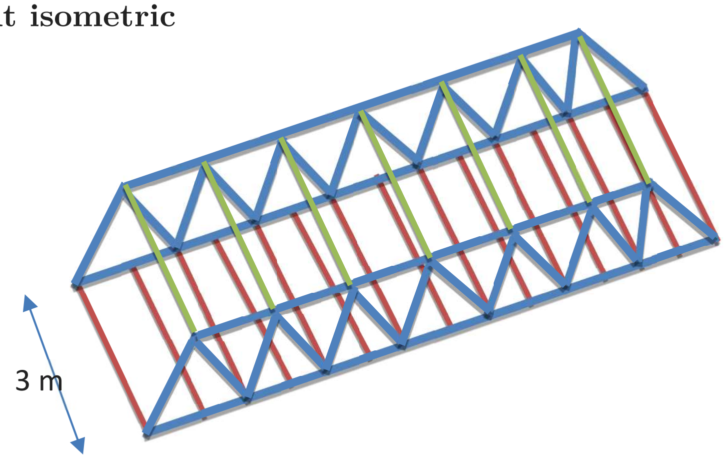
Our Warren Bridge Structure:

Basic Structure of Bridge:

Side View



Somewhat isometric



Dimensions

- Total length of the bridge is 21m.
- This 21m length is spanned by 7 equilateral triangle shaped members of 3m side on each side of the bridge.
- The width of the bridge is 3m.
- There are total 15 floor beams 1.5m apart. These floor beams start from the first member and go till the last.
- There are seven top beams of 3m length each.

Maximum Load condition

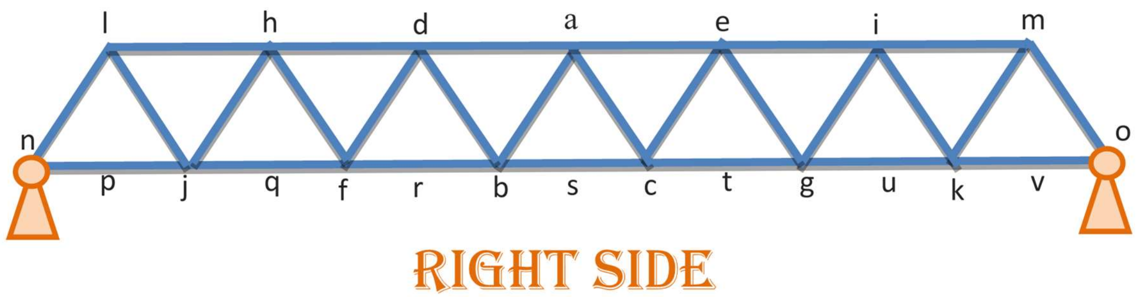
The maximum load condition is used for calculations. It is the worst-case scenario the whole bridge is lined up with two rows of bicycles. Length of each bicycle is assumed to be 1.5m. Which means 14 bicycles in each row and 28 in two rows in total. Weight of each bicycle is taken to be 100 kg. Which means total weight of bicycles is 2800 kg.

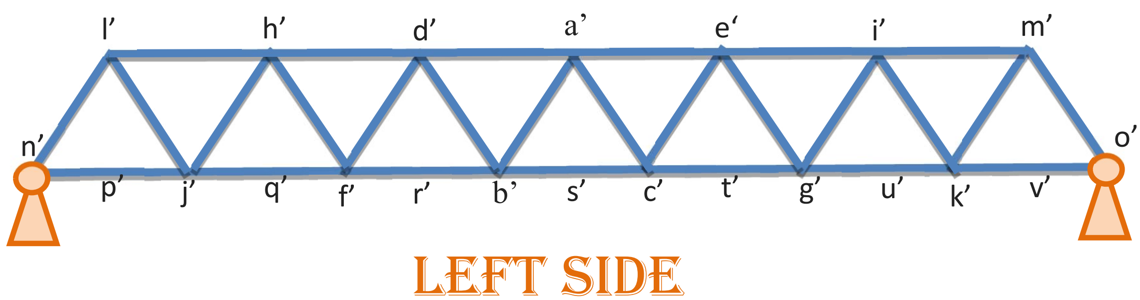
Assumptions

- All the joints are pin joints.
- Neglect the weight of members.
- Weight of deck is uniformly distributed.
- W = weight of bicycles + weight of deck
- This weight W is distributed equally among all the 15 floor beams.

- The floor beams will transfer this load to the vertical members.

Naming Scheme



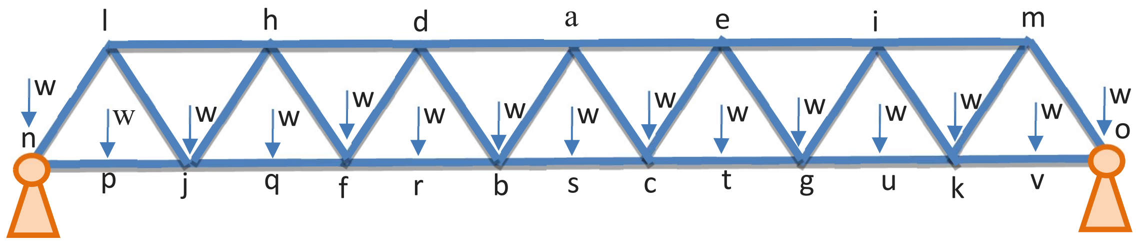


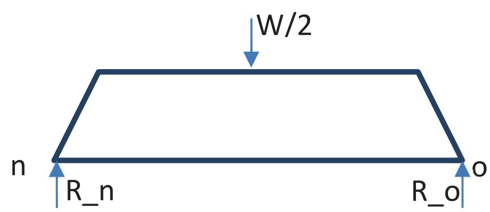
FBD:

- w = (W/15)/2 = W/30

Divided by 2 because this load is distributed between members on both sides of the bridge equally.

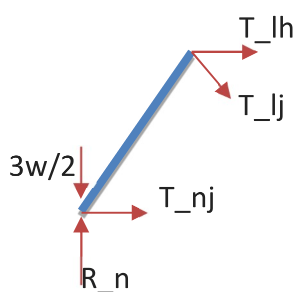
This weight w is acting on each floor beam. Which means that w/2 weight is acting on each pin-joint at n, p, j, q, f, etc. As in the below diagram:



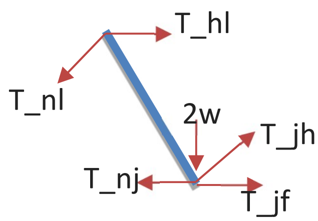
- 

FBD of the whole bridge

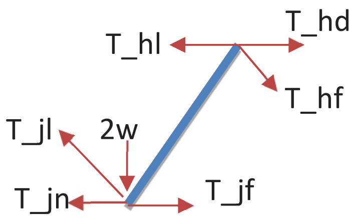
- FBD of member ln



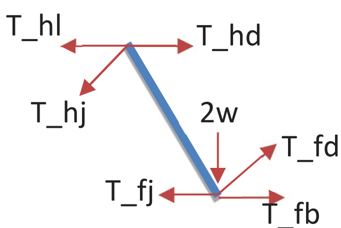
- FBD of member lj



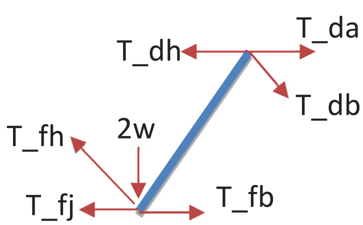
- FBD of member jh



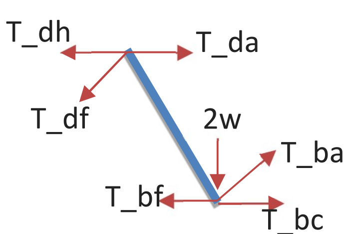
- FBD of member hf



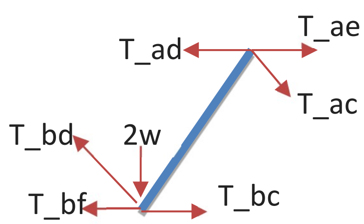
- FBD of member fd



- FBD of member db



- FBD of member ba



All the remaining members will have same FBD as the calculated ones due to symmetry.

Material:

Structural steel is a standard construction material made from specific grades of steel and formed in a range of industry-standard cross-sectional shapes (or 'Sections'). Structural steel grades are designed with specific chemical compositions and mechanical properties formulated for particular applications. It is widely used around the world for the construction of bridges from the very large to the very small. It is a versatile and effective material that provides efficient and sustainable solutions. This steel has long been recognised as the economic option for a range of bridges. It dominates the markets for long span bridges, railway bridges, footbridge, and medium span highway bridges. It is now increasingly the choice for shorter span highway structures as well. Society gains in many ways from the benefits delivered by steel bridge solutions. Landmark steel bridges embody good design, they are fast to build, and have stimulated the regeneration of many former industrial, dock and Canalside areas. Structural steelwork is used in the superstructures of bridges from the smallest to the greatest.

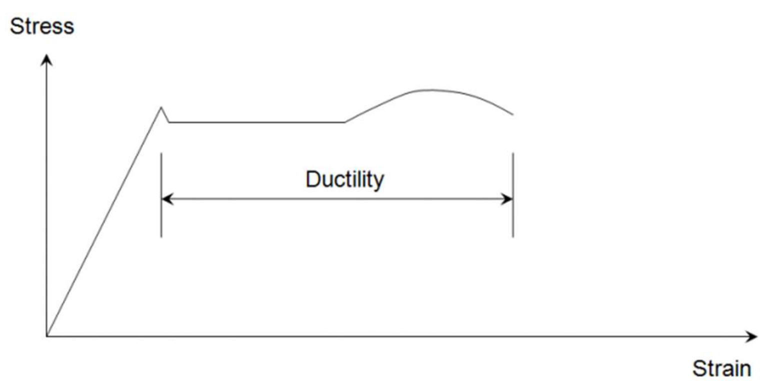
Steel material is supplied in two product forms – 'flat products' (steel plate and strip) and 'long products'(rolled sections, either open beams, angles, etc or hollow sections). For structural use in bridges these products are inevitably cut (to size and shape) and welded, one component to another. In the structure, the material is subject to tensile and compressive forces. Structural steel generally responds in a linear elastic manner, up to the 'yield point' and thereafter has a significant capacity for plastic straining before failure. All these aspects of steel material are utilised by the designer of a steel bridge.

Properties of Structural steel:

Steel derives its material properties from a combination of chemical composition, mechanical working and heat treatment. The chemical composition is fundamental to the mechanical properties of steel. Adding alloys such as Carbon, Manganese, Niobium and Vanadium can increase the strength. However, such alloy additions increase the cost of the steel, and can adversely affect other properties (i.e. ductility, toughness and weldability). Keeping the sulphur level low can enhance the ductility, and the toughness can be improved by the addition of Nickel. Hence, the chemical composition for each steel specification has been carefully chosen to achieve the required properties.

Yield strength is probably the most significant property that the designer will need to use or specify. The achievement of a suitable strength whilst maintaining other properties has been the driving force behind the development of modern steel making and rolling processes. yield strength for various structural steel varies between 200-400MPa and depend on thickness also. For eg. S275 of thickness 16mm has yield strength of 275MPa.

Ductility - it is of paramount importance to all steels in structural applications. It is a measure of the degree to which the material can strain or elongate between the onset of yield and eventual fracture under tensile loading. Whether it is realised or not, the designer relies on ductility for a number of aspects of design: redistribution of stress at the ultimate limit state; bolt group design; reduced risk of fatigue crack propagation; and in the fabrication process of welding, bending, and straightening, etc.



Toughness- the nature of steel material is that it contains some imperfections, albeit of very small size. When subject to tensile stress these imperfections tend to open. If the steel were insufficiently tough, the 'crack' would propagate rapidly, without plastic deformation, and failure would result. This is called 'brittle fracture' and is of particular concern because of the sudden nature of failure. The toughness of the steel, and its ability to resist this behaviour, decreases as the temperature decreases. This steel has good toughness as well.

Weldability – All structural steels are essentially weldable. However, welding involves laying down molten metal and local heating of the steel material. The weld metal cools quickly because the material offers a large 'heat sink' and the weld is relatively small. This can lead to hardening of the 'heat affected zone' of the material adjacent to the weld pool and to the reduced toughness (often called embrittlement).

Advantages of Structural steel:

- The high strength to weight ratio of steel minimizes substructures costs, which is particularly beneficial in poor ground conditions. Minimum self-weight is also an important factor in transporting and handling components.
- Steel is a high-quality material, which is readily available in different certified grades, shapes and sizes. Prefabrication in controlled shop conditions has benefits in terms of quality.
- Steel is the most recycled construction material and choosing it for bridges represent a sustainable management of natural resources.
- All structural steels, with the exception of weathering steel, have a similar resistance to corrosion. It will increase lifetime of bridge
- The prefabrication of components means that construction time on site in hostile environments is minimized which results into economic and safety benefits.
- Ductility and toughness of material to allow absorption of loading well above design values without catastrophic failures.

Hence, considering all above benefits, we have chosen structural steel as construction material for our bridge.

We have also chosen ISMC 200, which is a type of structural steel, for some special members in bridge like lower horizontal base bars, because these will bear heavy loads.

Simulation Results:

The simulation of the chosen bridge structure has been done in the Autodesk Inventor Professional software using its static frame analysis features to compare with the calculated data.

Material:

General	Mass Density	7.850 g/cm^3
	Yield Strength	207.000 MPa
	Ultimate Tensile Strength	345.000 MPa
Stress	Young's Modulus	220.000 GPa
	Poisson's Ratio	0.275 ul

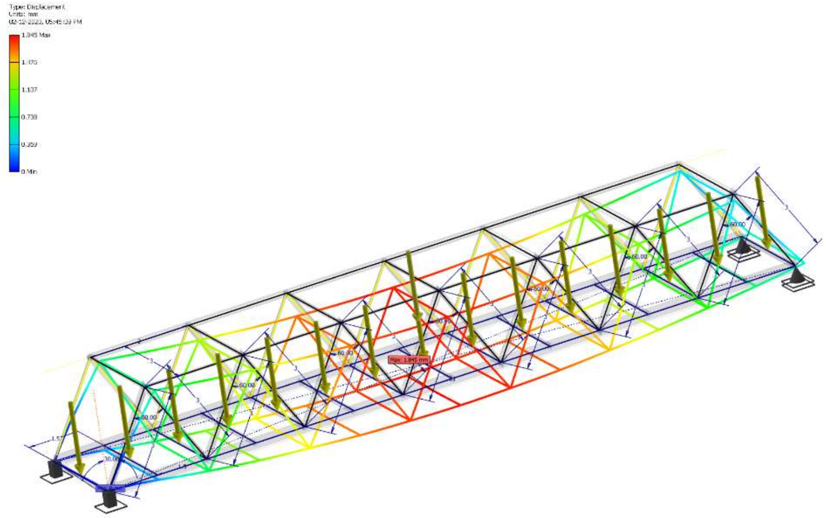
Cross Section:

Geometry Properties	Section Area (A)	17077.239 mm^2
	Section Width	300.000 mm
	Section Height	300.000 mm
	Section Centroid (x)	150.000 mm
	Section Centroid (y)	150.000 mm
Mechanical Properties	Moment of Inertia (I_x)	220759724.871 mm^4
	Moment of Inertia (I_y)	220759724.871 mm^4
	Torsional Rigidity Modulus (J)	364718208.586 mm^4
	Section Modulus (W_x)	1471731.499 mm^3
	Section Modulus (W_y)	1471731.499 mm^3
	Torsional Section Modulus (W_z)	0.000 mm^3
	Reduced Shear Area (A_x)	7965.012 mm^2
	Reduced Shear Area (A_y)	7965.012 mm^2

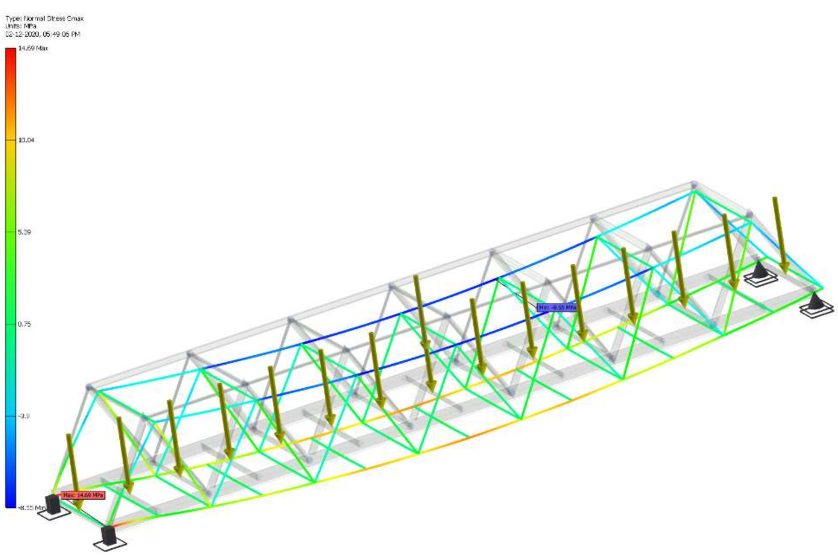
Loads:

Load Type	Gravity
Magnitude	9810.000 mm/s^2
Load Type	Force
Magnitude	1867.000 N

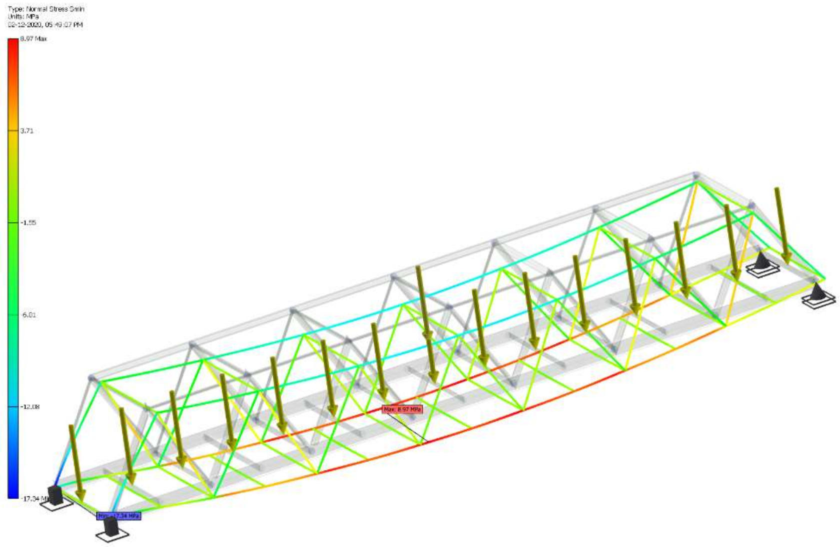
1. Displacement



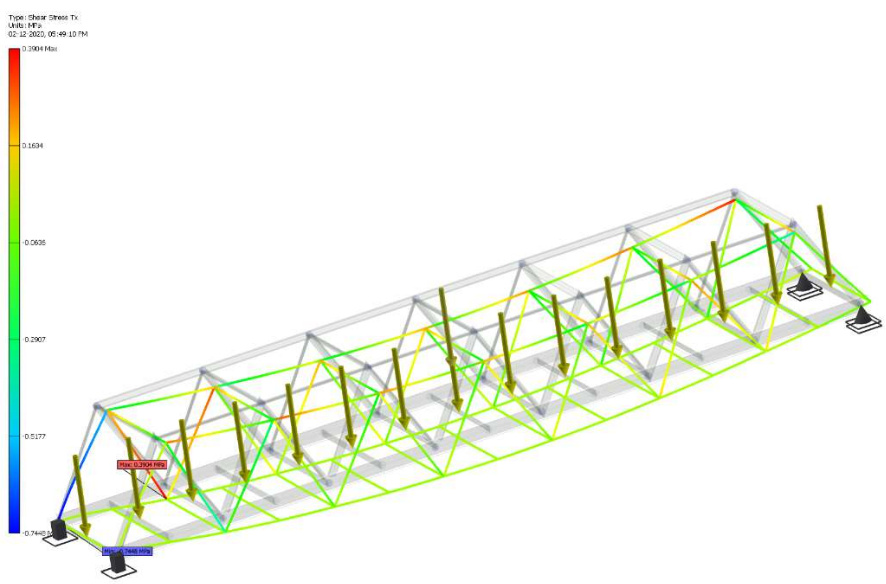
2. Maximum Normal stress in cross section



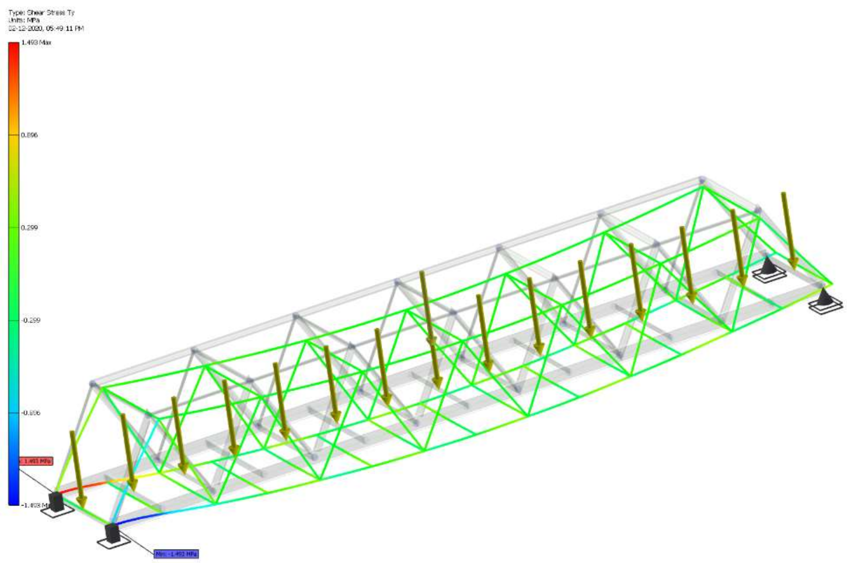
3. Minimum Normal stress in cross section:



4. Shear stress (T_x)



5. **Shear stress (T_y)**



Lifetime of the bridge

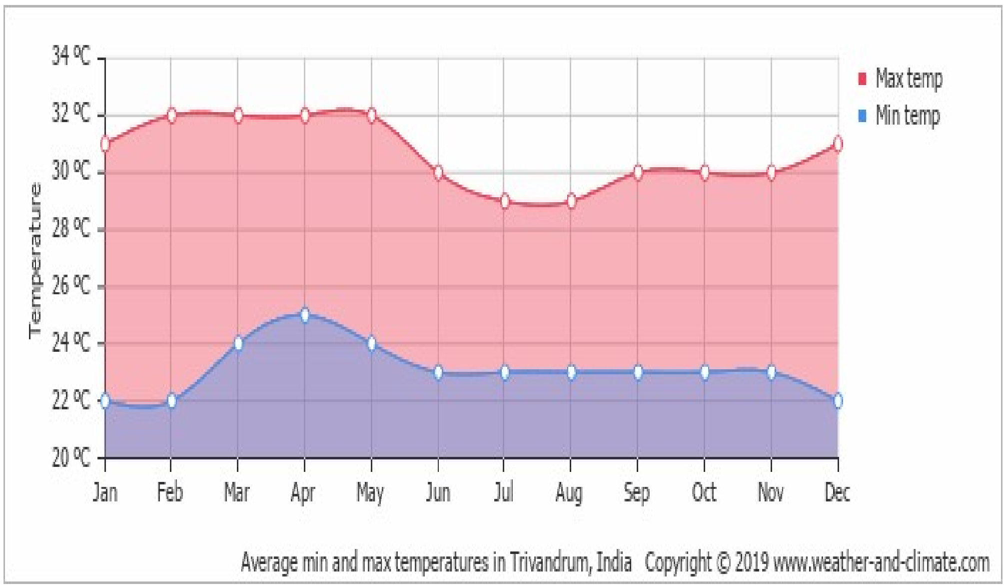
The average lifetime of a foot-over bridge is around 100 years with proper maintenance. The designed bridged is assumed to have a lifetime around the average value.

Environmental Factors affecting the Lifetime

Various environmental factors including temperature, air composition, etc. affect the lifetime of a bridge. The material used for the construction of the bridge is structural steel, the major constituent of which is iron. Now, iron profusely undergoes corrosion when the environmental conditions are favourable. The above-mentioned factors affect the corrosion rate of the iron present in the bridge, which in turn has a direct impact on the lifetime of the bridge. Let us consider each factor and the impact it has on the corrosion of the bridge's components.

Temperature

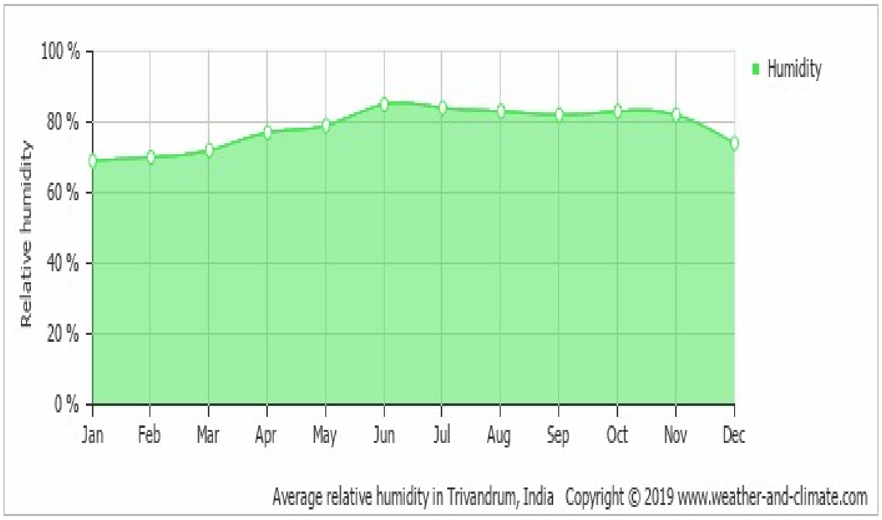
Corrosion rate depends on the temperature to a great extent. For any metal, the corrosion rate almost doubles for every 10°C rise in temperature. Now, the temperature of the region where the bridge is to be constructed is around 30°C, and it does not fluctuate much. Since there isn't a lot of variation in the ambient temperature of the region, the corrosion rate does not vary much but even then, since corrosion rate is



temperature dependent and the ambient temperature is moderately high, corrosion rate is also relatively high.

Humidity

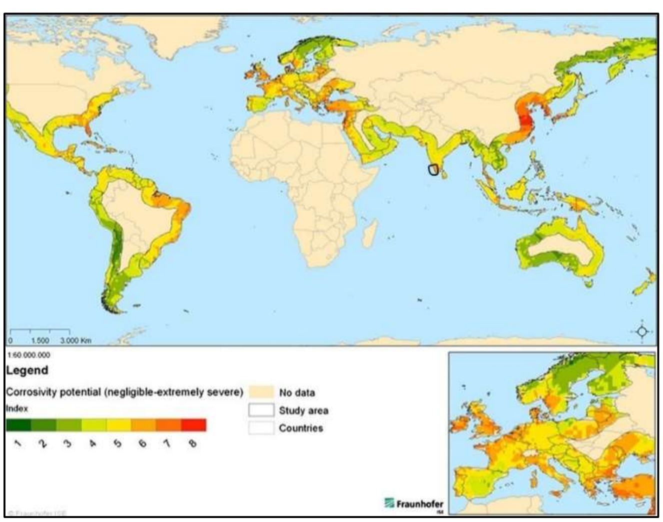
Humidity is another major factor that affects corrosion. The higher the humidity, higher is the possibility of occurrence of corrosion. In the region where the bridge is to be constructed, the average relative humidity of air is normally around 70%. Humidity content of 50% or higher is termed as extremely high humidity content. It can thus be said that there is a large possibility of corrosion in such a region where the humidity content is extremely high (around 70%), as in the case where the bridge is to be constructed.

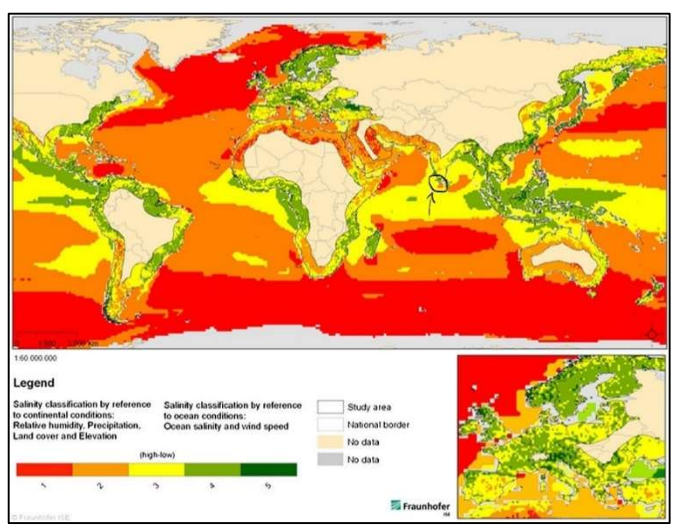


Other Factors

Some other factors which affect corrosion include the rainfall content of a region. IIST is located at a place where rainfall is a quite common phenomenon. Hence, it becomes even more important to consider the effect of rain on corrosion. Rainwater generally seeps into a structure via gaps, crevices and cracks and can cause corrosion to a great extent. The average annual rainfall around IIST is approximately 1800 mm as compared to the national average of around 400 mm. The above comparison shows that the rainfall content is extremely high compared to the national average, which in turn means that there is a high possibility of corrosion in such a region as compared to almost all the other regions in the country.

Following are a few statistics which highlight the importance of corrosion control for the bridge to be functioning for a long time.





The above images point out that the salinity as well as the corrosivity potential of the region under study lie in the severe region of the spectrum. Hence, it is quintessential to implement proper corrosion control strategies to increase the service life of the bridge in discussion.

Corrosion Control Strategies:

- Use of corrosion resistant stainless steels
- Regular application of paint coatings or galvanisation to further protect the material from corrosion.
- The structure must regularly be checked for cracks and all cracks mut be closed.
- The structure should be designed in such a way that it encourages the movement of air, dust and water do not get trapped in it.
- Corrosion inhibitors can also be used to inhibit or prevent corrosion by suppressing the electrochemical reactions that cause corrosion.

Budget:

Sl.	Material Description	Mass	Quantity	Total weight	Rs/kg	Cost	Position
1)	I Shape Beam, 400	61.60 kg/m	42m	2587.2 kg	40 Rs/kg	Rs.103488	Main support beam (21m)
2)	ISMC 200	22.10 kg/m	186m	4110.6 kg	34 Rs/kg	Rs.139760.4	Every 3m beam
3)	Checkered plate 6mm	49.74 kg/m sq	62m sq	3133.62 kg	205 Rs/kg	Rs.642392.1	decking
			Net weight	9831.42 kg	Total cost	Rs.885640.5	

Material Cost	Mix	Rs. 885640.5
Fabrication, Erection, and consumables	20 Rs/kg	Rs. 196628.4
Galvanization	28 Rs/kg	Rs. 275279.76
	Total	Rs. 1357548.66

GST	18%	Rs. 244358.7588
	TOTAL COST	Rs. 1601907.4188

Human Safety:

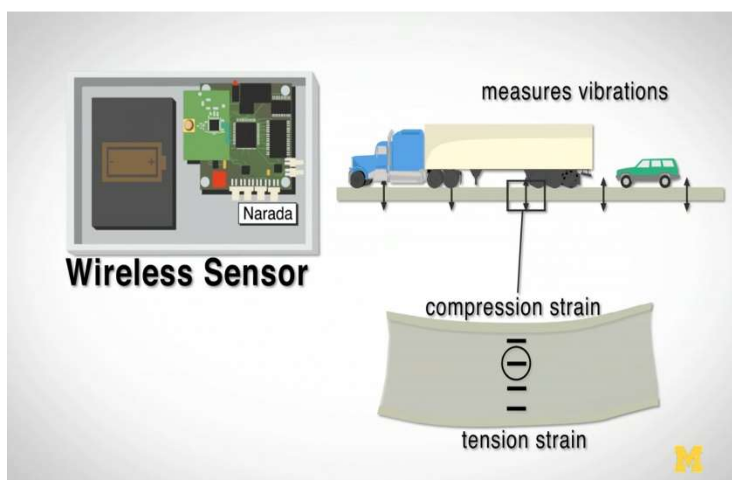
Human safety is important factor in bridge design so we must ensure that people will not jump from bridge for that we will put railing on both side of bridge. Considering average human height of person in India 5 feet 6 inch our railing should be minimum 2 feet 8-inch-long in our case we are taking it as 3 feet 6 inch to ensure safety of human beings.

Footpath:

We will make footpath on both side of bridge which is 1.2-meter-wide with stipple finish and border highlights. There is railing on right side of moving man direction of 3 feet to avoid people to go on road while walking.

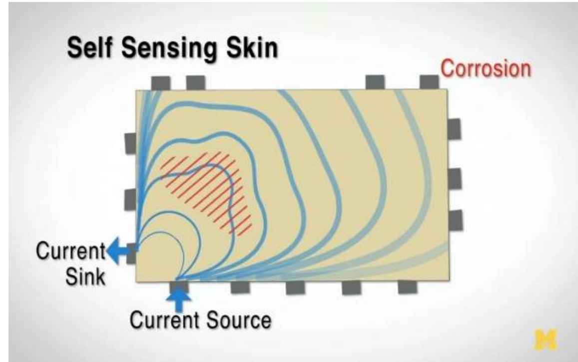
Wireless Sensor:

Wireless sensors are installed at different points of bridge to understand dynamic load on bridge. This data will be recorded and used for further inspection purpose this sensor will send data by mean of radio signal and stored in data center.

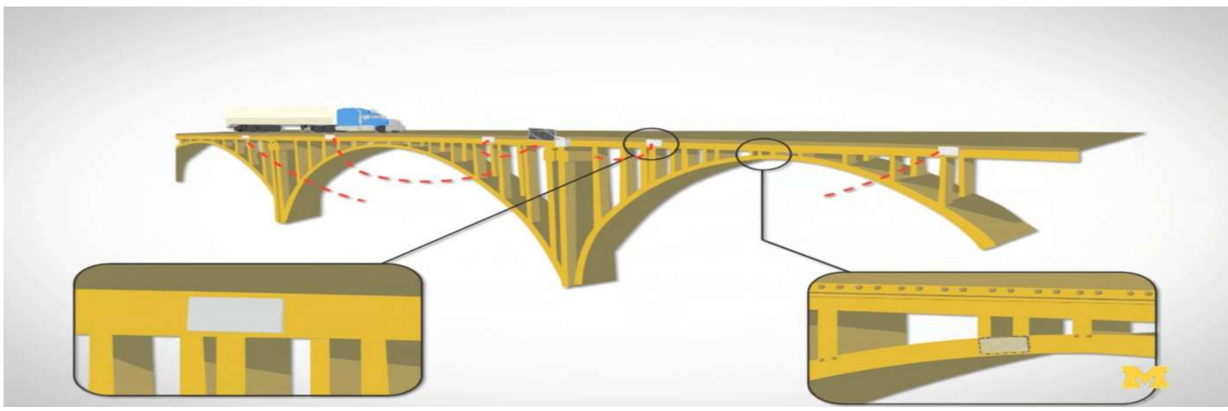


This will help in understanding steps which need to take to ensure safety of bridge.

Sensible Skin on Bridge:

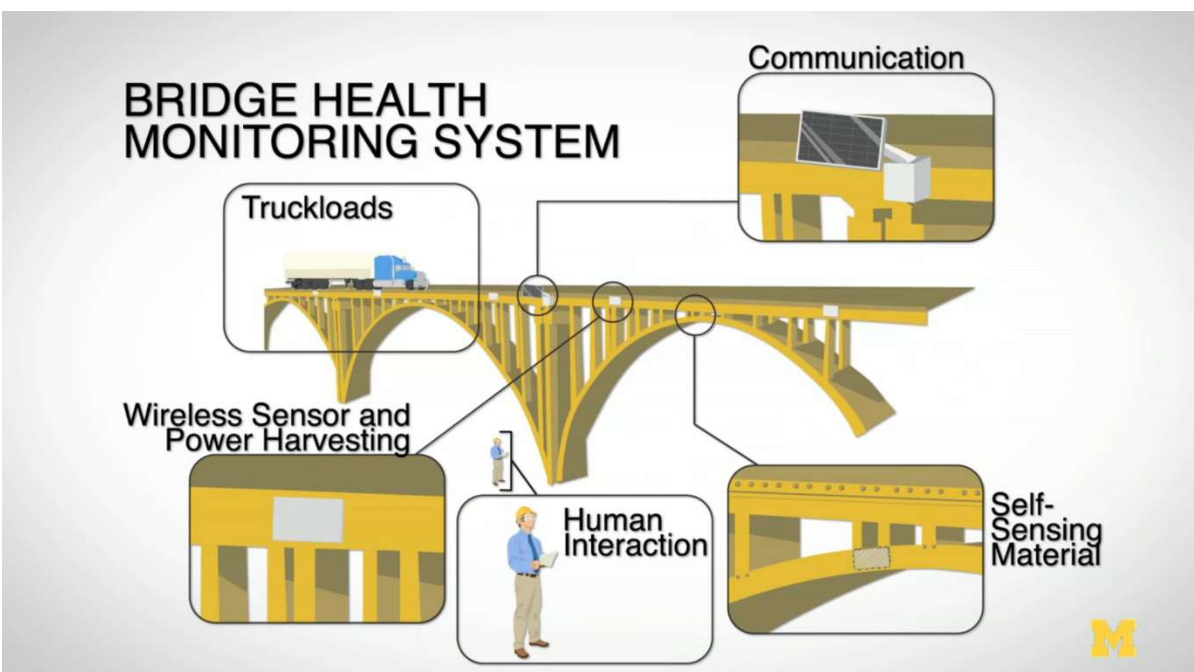


Sensible skin is installed on different point of bridge. This skin is self-sensing works on piezoelectric material concept. This will make current through according to load and then that data will be used to analyze places where corrosion can occur. This kind of skins ae especially useful because we cannot see inside the bridge this data will tell what is happening inside the bridge.



Positioning of sensors and skins on bridge.

Bridge Health Monitoring System:



Now we have bridge health monitoring system this system first collect data in sensors and sensible skins which is installed on bridges at different locations then t will transmit this to data center by mean of radio signal. At the data center this data will be analyzed and hand over to inspector on site who can check accordingly and rate the condition of bridge. This will ensure tracking of any failure before it happen.

Prevention From Expansion And Contraction Of Bridge:

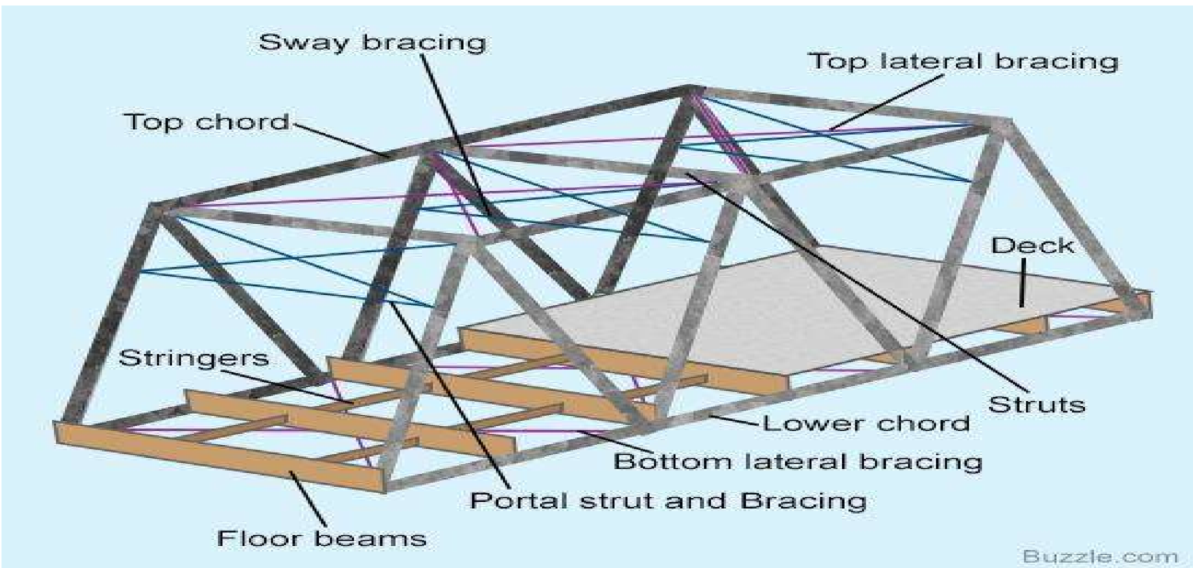
Temperature changes can occur expansion and contraction of bridge so bridge is divided in some parts and there is zig zag interlocking tooth are there which will provide gap for easy movement.

Roller Bearing:

To provide movement along bridge in case of compensation for expansion effect this kind of roller bearing are attached with the bridge.

Factor of Safety:

Factor of safety for our bridge is 4. All the material and design of bridge is selected accordingly to meet FOS 4.



FACTOR OF SAFETY = STRENGTH/ STRESS

- Stress which our bridge can withstand (strength) = 207Mpa
- Factor of safety = 4
- Stress which is permissible to put on bridge due to loads is = 207/4 =51.75Mpa.
- Base area of road portion of our bridge = 21m X 3m = 63m^2
- Average weight of human beings = 60 kg
- Average weight of bicycle = 15 kg
- Total combine weight = 75 kg
- Force which our bridge can with stand = 3.26E(9)
- Number of bicycles which can stand on bridge = 4.34E(7)
- Approx. 43 million bicycles.

Our bridge is quite strong, and its average life is between 10 to 15 years. With proper management it can reach even 20.