ENGR 111: Design Proposal

Section 068, Group 01

Group members

Michael Woo, mw3265@drexel.edu

Yelnur Abilakim, ya379@drexel.edu

Binh Dang, btd46@drexel.edu

Karl Jones, kjj56@drexel.edu

Abstract

A Report Card for America's Infrastructure is published to the American Society of Civil Engineering every four years. The report shows a grade for the bridge in the US base on its physical condition and the improvement necessary for different components. In 2017, the grade was C+ with 9.1% of the total number of brides that are under deflection. Significantly, 4506 bridges are insufficient which is around 19.8% of all deficient bridges in the US [1].

Both new and existing bridges benefited from the development of technology and new materials. The sensor is used to track the condition and gather all data of bridges, so engineers can use to calculate and provide solutions to improve conditions of bridges. New materials could increase the durability, strength, and lifetime of bridges. Therefore, the government is creating a plan for lowering the number of deficient bridges in order to improve traveling safety. Besides that, the government wants to consider the cost of building and maintaining infrastructure during bridge lifetime.

In addition, The Pennsylvania Department of Transportation has been contacting and hiring companies to design new truss bridges for replacing insufficient bridges within 10 miles away from Drexel which can span over railroad and roadway. The design model must be constructed by K'NEX and satisfy those factors: minimize cost, maximize strength, and in the range of deflection standard.

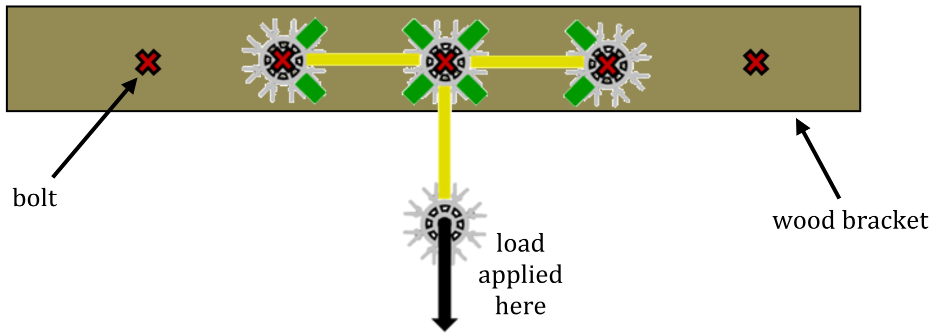
Introduction

The first ever bridge design was submitted in 1921 by Joseph B. Strauss for the Golden Gate strait. Structural engineers of that time only used a slide rule for calculations and pen and pencils for drafting. They tested their design on a steel tower model that was 56 times smaller than the actual tower [2].

Nowadays, engineers use far more complex tools such as 3D models for example. In this design report, several truss configurations were built in the Visual Analysis software and then tested to check the accuracy of the theoretical values.

Theory

Multiple K'NEX variations of the truss below were tested to determine how failure load is affected by adjacent green nodes. After testing different configurations, it was determined that green nodes adjacent on both sides of the vertical yellow rod strengthened the connection point(s). Placing a load at the bottom of this truss placed tension on the bottom 3 members (yellow rods). The higher amount of connection points produced a higher failure load. There are three possible connection types which were labeled as type 0, type 1, and type 2. Type 0 indicates it has 0 adjacent members, type 1 indicates it has 1, and type 2 indicates it has 2 adjacent members. The values of their failure loads are respectively 21, 27, and 35 lbs. The predicted failure load is calculated by dividing the 'w' value from the connection type's failure load. The member and node with the lowest failure load is the overall failure load of the structure. This is used later in calculating our bridge failure loads.



Experimental

The three truss designs, Pratt, Warren, and Howe were tested to determine the differences (strengths and weaknesses). Those results are shown below in table 1 – 3 (Visual representations of the trusses are shown above each table, Figures 4-6). The truss designs were each modeled in Visual Analysis in order to determine a predicted value shown in those tables below. All truss configurations were tested in 2D, by bolting the truss to the wood bracket and in 3D, creating a mock bridge and testing to failure with a load placed on top-center of bridge. The load was gradually applied through a pulley system with a force tracker which gave us our final failure load. This helped determine and finalize our design for the bridge. The first draft bridge design is shown below in figure 1 and the results can be found in the results section.

For the final design of the bridge, the goal was to decrease the cost per pound ratio by increasing the maximum failure load. We started by testing a different joint variation at the bottom edges of the bridge and added members to increase the failure load of those members. The joint orientation and overall bridge design can be seen in Figure 2. The method of testing the failure load was the same as all previous tests which incorporated the pulley system with a force tracker (the test results are shown in the results section in table 6**.** However, it had a hard time keeping the bridge from twisting and caving in compared to the previous design due to lack of horizontal supports in the center of the bridge. To finalize our design, we decided to strengthen the middle section of the bridge as the middle members kept failing. To do this we planned to increase the connection type and made sure each side of the member had the same connection type with an 'X' formation on certain sides of the bridge. In addition, a small truss pattern was added to the bottom of the bridge to further strengthen the bottom members. The final design can be seen in Figure 3 and the visual analysis of this design is in Figure 4.

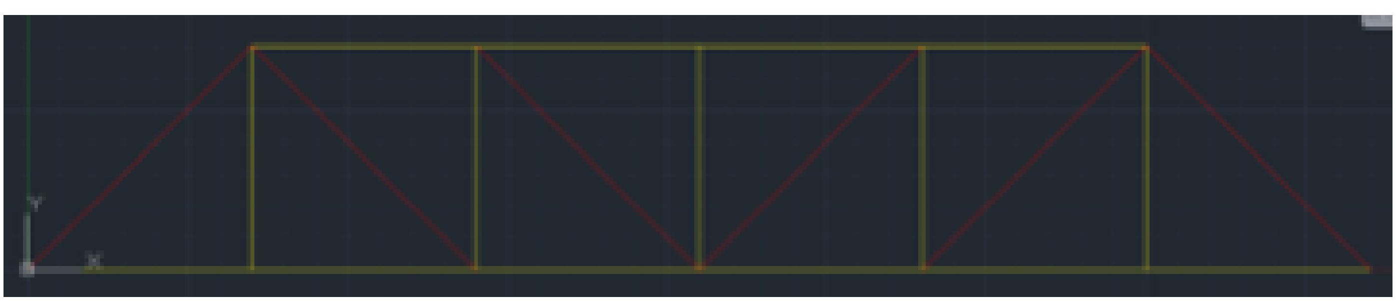


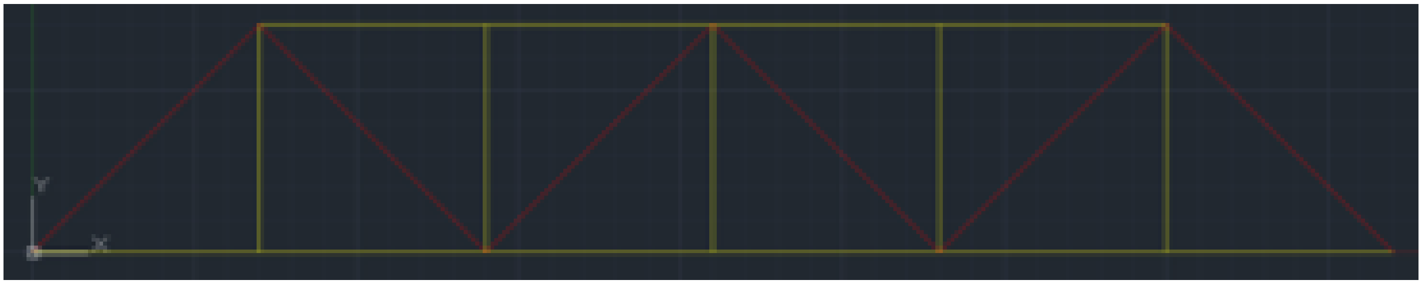
Figure 4

Pratt Truss Formation

Table 1 Pratt Truss

Member and Node	Type	Predicted W	Predicted Failure Load 2D, 3D	Actual Failure Load 2D, 3D
C2D2 ; C2	0	21	21, 42	18.2, 34.5
C2D2 ; C2	0	21	21, 42	14, 38.6
C2D2 ; C2	0	21	21, 42	16.5, 39.2

*experimental results for the Pratt Truss



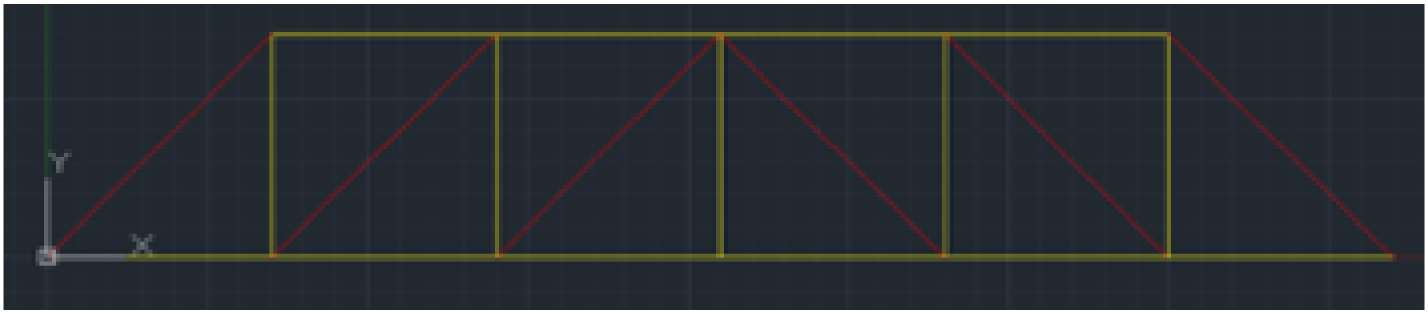
<u>Figure 5</u>

Warren Truss Formation

<u>Table 2 Warren Truss</u>

Member and Node	Type	Predicted W	Predicted Failure Load 2D, 3D	Actual Failure Load 2D, 3D
E2F2	1	27	18, 36	8.9, 16.5
F2E2	0	21	14, 28	10.2, 13.2
F2E2	0	21	14, 28	9.7, 19.3

*experimental results for the Warren Truss



<u>Figure 6</u>

Howe Truss Formation

<u>Table 3 Howe Truss</u>

Member and Node	Type	Predicted W	Predicted Failure Load 2D, 3D	Actual Failure Load 2D, 3D
D2E2 ; E2	1	27	13.5, 27	11.6, 28
D2E2 ; E2	1	27	13.5, 27	12.2, 32.3
D2E2 ; E2	1	27	13.5, 27	14.3. 31.4

*experimental results for the Howe Truss

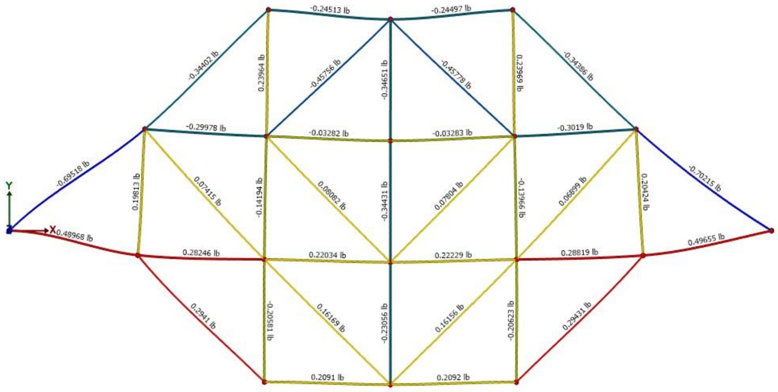


Figure 1

*draft design of bridge

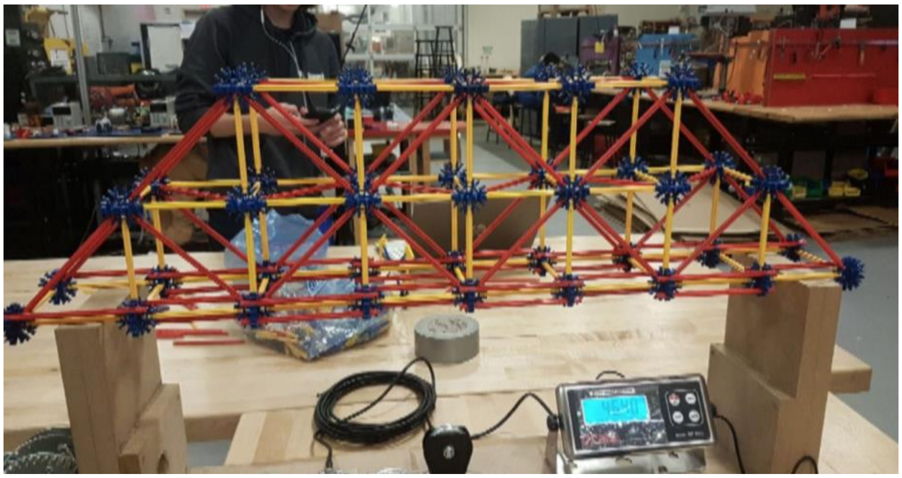


Figure 2

*first variation of bridge design with added members and different joint variation

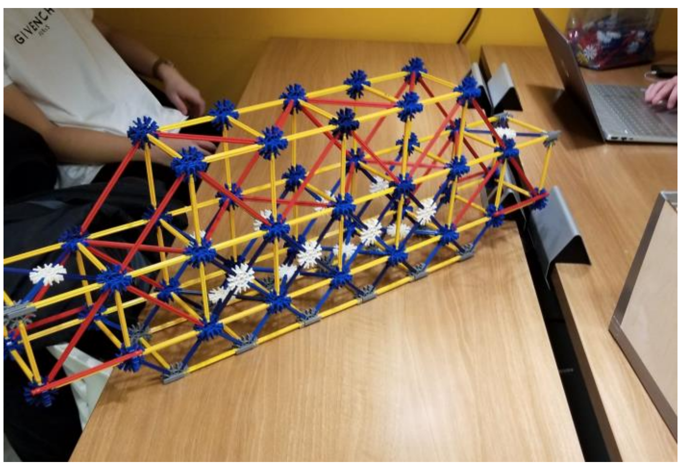


Figure 3

*final design of bridge

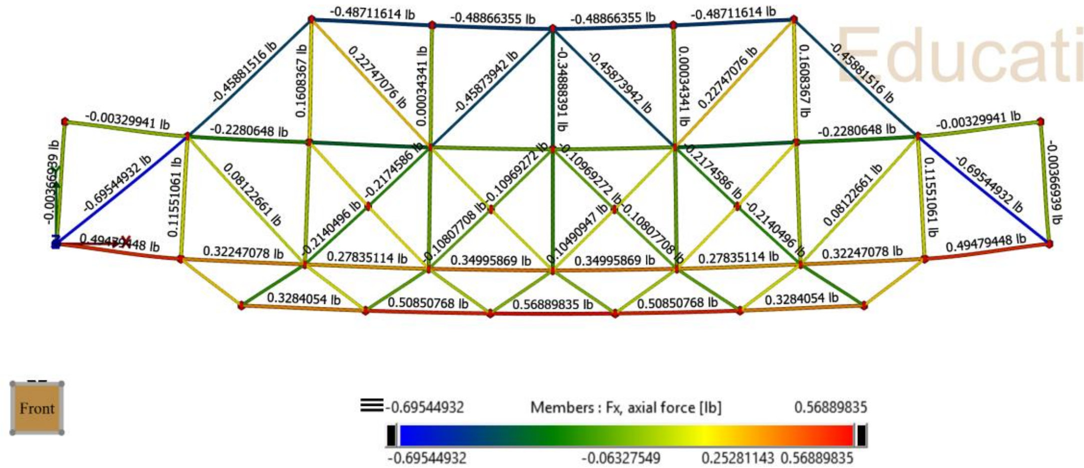


Figure 4

*Visual Analysis of Final design of bridge

Results

The first draft design of the bridge was tested to failure and the results are shown below in table 4 along with the predicted failure loads. The overall cost of this bridge is shown in table 5. Table 6 and 7 show the experimental results for our two bridge variation that were tested. Table 7 is also the results for our final bridge design and Table 8 shows the cost of the final bridge.

Table 4

Member and Node	Type	Predicted W	Predicted Failure	Experimental Load
A1B1 ; A1	1	27	54	60.2
F1G1 ; F1	0	21	42	68.3
F2G2 ; F2	0	21	42	65.2

*draft design bridge experimental results

42 pounds is the predicted failure load for a 2D model. For a 3D model, the predicted failure load is twice the amount for the 2D model, which is 2 × 42 pounds = 84 pounds.

Table 5

Parts	Quantity	Cost
Red Rods	42	$84000
Yellow Rods	68	$102000
Blue Rods	0	$0
Joint Connectors	36	$36000
Total:		$222000

*cost for draft design of bridge

Table 6

Member and Node	Type	Predicted W	Predicted Failure	Experimental Load
C1D1 ; C1	1	27	38.57	46.50
E1F1 ; E1	1	27	38.57	44.35
F2E2 ; F1	0	21	30	43.24

*experimental results for 1st variation with added members on joints (Figure 2)

Table 7

Member and Node	Type	Predicted W	Predicted Failure	Experimental Load
E1F1	2	35	100	98.6
E2F2	2	35	100	101.2
E1F1	2	35	100	97.6

*experimental results for final bridge design (Figure 3)

Table 8

Parts	Quantity	Cost
Red Rods	34	$68000
Yellow Rods	120	$180000
Blue Rods	80	$80000
Joint Connectors	72	$72000
Total:		$400000

*cost for final design of bridge

Some sources of error include: broken K'NEX joints, weaker than average connection points, nongradual load increase, weakened members after repeated testing.

Discussion

Overall, the initial draft bridge design behaved as expected. It was found that incorporating more type 2 or type 1 connections than type 0 connections resulted in configurations that could withstand higher loads. Additional green rods may be incorporated in the next design to strengthen the failure members and nodes in the experimental stage. This may lead to a higher failure load in a future test. However, it did not meet the requirement of spanning the length of the gap, so the design could not be used.

In addition, the visual analysis for the designs in Figure 2 and 3 were not exact prediction/representations of the designs due to the double-stacked members on the bottom as they could not be added in visual analysis.

In this experiment, several different designs have been tested. First, more green rods were incorporated to increase the maximum weight the bridge could sustain, and the weight has indeed gone up. However, due to high cost of green rods, the cost to strength ratio has increased as well. Then, red rods were added parallel to horizontal yellow rods to strengthen the joints. The weight has gone up, but the cost to price ratio still was not enough to compete. After that, parallel red rods were removed and blue rods were used in place of diagonal red rods in the middle part to strengthen the structure by creating more type 1 and type 2 connections. In addition, a couple of red rods were added to the sides of the bridge parallel to yellow rods to provide extra support.

To improve on this design in the future, we can reduce the cost of the bridge by replacing the 'X'-shaped supports with red ones and determine which ones are necessary and which ones are not. This would lower the ratio and possibly not affect the maximum failure load of the bridge. In addition, we can add more support to the members that failed most frequently by adding addition red rods horizontally on top of the yellow rods to add more support as it requires more force to then bend the yellow and red rods combined. This could potentially lead to a higher maximum failure load and lower ratio, but to determine the exact ratio would require further testing and experimentation.

References

[1] "ASCE's 2017 Infrastructure Report Card", *American Society of Civil Engineers*, 2017. [Online], Available https://www.infrastructurereportcard.org/cat-item/bridges/

[2] “History of the Design and Construction of the Bridge: Engineering the Design.” *Golden Gate Bridge, Highway and Transportation District.*
http://goldengate.org/exhibits/exhibitarea4_2.php