Investigating the Load Failure of Truss Skybridge Prototypes

Team WashPike

Helen Danielson, Kate Spencer

Advisor: Prof. Koh

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Executive Summary:

The goal of this assignment was to design a truss that could be incorporated into a skybridge to span across the busy intersection of Elm Street and College Lane to reduce crosswalk traffic and protect pedestrians. The truss, which was constructed from popsicle sticks, needed to be able to withstand a force to weight ratio of 5N:1g. We succeeded in creating a truss with a 5.09N:1g force to weight ratio. The truss failed due to warping because of a lack of strong support in the z-direction. The cross-beams connecting the two halves of the truss were what failed first. This failure was surprising because it represents a failure of assumptions made when analysing the truss in 2D to capture the full picture of the reality of testing the truss. Because of the nature of the failure, in future designs of our truss we would want to add additional or stronger supports spanning the z direction of the truss.

I. Motivation

The goal of this project was to design a truss bridge to span the intersection of College Lane and Elm Street. Currently, this intersection is just a crosswalk, and cars passing at 30mph often do not see or stop for students. Additionally, it can be hard to spot students in fall and spring, when the angle of the sun lowers drivers' visibility. Students often wear dark clothing that makes them much harder to spot at night as well. By implementing a skybridge, students could cross safely without interrupting the flow of traffic. Students and drivers would both benefit from this project, as everyone would be safer. The ability of our prototype to withstand a strength-to-weight ratio of 5N per gram would allow the college to build a safe skybridge for students to cross Elm Street while using only the necessary resources.

II. Test Methods & Materials

The truss was built using the smaller popsicle sticks. The smaller sticks were chosen due to the fact that they were thicker compared to their length than the larger popsicle sticks, giving them more rigidity. Prior to building the final design, a prototype was built using hot glue to visualize the dimensions and weak spots of the truss design. The sticks in the final design were glued together with wood glue and the connections were clamped until dry. Holes were drilled through the connections with a power drill, and then small nails were hammered through them to increase the stability and strength of the connections. Two identical 2D trusses were constructed, then connected by cross beams of half of a popsicle stick that were also glued on but not nailed. Within the 2D truss, some of the members, such as the ones along the bottom, were reinforced by layering a few popsicle sticks together, again with wood glue.

To test the loading the truss was tested in an Instron machine and a distributed load was applied over a 6 inch circle in the center. This load was centered above roller supports that were 13cm apart from each other. The truss was then tested in compression at a rate of 10mm per minute.

III. Failure Mode

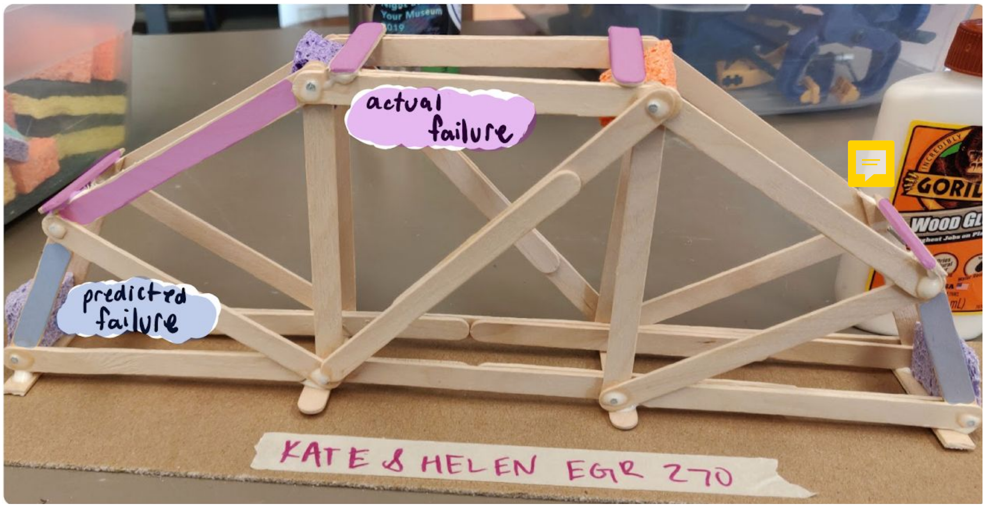


Figure 1: Failure Points
The above diagram illustrates the parts of the truss we predicted would fail in comparison to where it actually failed.

We predicted that our truss would fail along the small diagonal piece at the bottom, because we had to cut it, which caused the wood to splinter slightly. We thought that this shortened member would thus be weaker than the other members of the truss that were made from full-length popsicle sticks.

Our truss actually failed at the joint of the crossbeams, as well as along the higher diagonal piece. Both of these failures were due to the warping of the truss towards and away from us as the Instron load was applied.

Our truss did not fail in the way we expected it to. We have concluded that the truss failed by warping because we did not give a lot of added support in the z-direction - the cross beams were a weak point compared to the strength of the rest of our truss.

IV. Failure Load

We measured our truss to be 55g, and therefore calculated that it would need to hold 275N of force. Additionally, we found that the forces ranged from 10.62N - 91.66N.

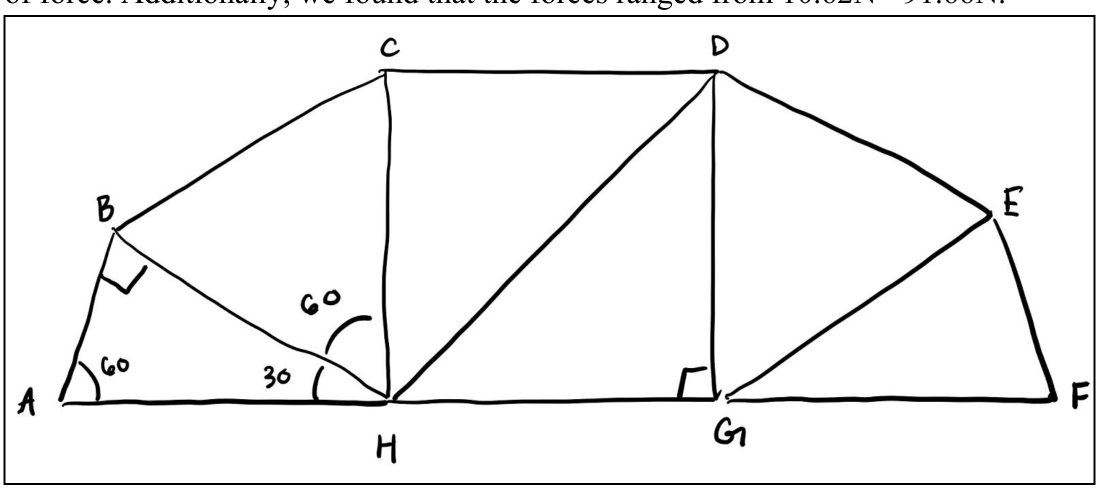


Figure 2: Point-Labelling Scheme

Truss	Force (N)	Truss	Force (N)
Truss AB	-79.38 N	Truss DE	91.66 N
Truss AH	39.69 N	Truss DG	-10.62 N
Truss BC	91.66 N	Truss EF	-79.38 N
Truss BH	-45.83 N	Truss EG	-45.83 N
Truss CD	-45.83 N	Truss FG	39.69 N
Truss CG	-47.45 N	Truss GH	-22.92 N
Truss CH	22.92 N		

Table 1: Forces in Individual Members
These are the calculated values for the forces in each member of the truss with an applied load of 275N. The calculations for these values are found in the Appendix.

Given that we calculated the maximum force the popsicle sticks are able to withstand to be 800N (See Appendix), and the maximum force in one popsicle stick was 91.66N, none of the popsicle sticks should fail in tension or compression. When the load was applied, the truss failed due to warping, validating our calculations.

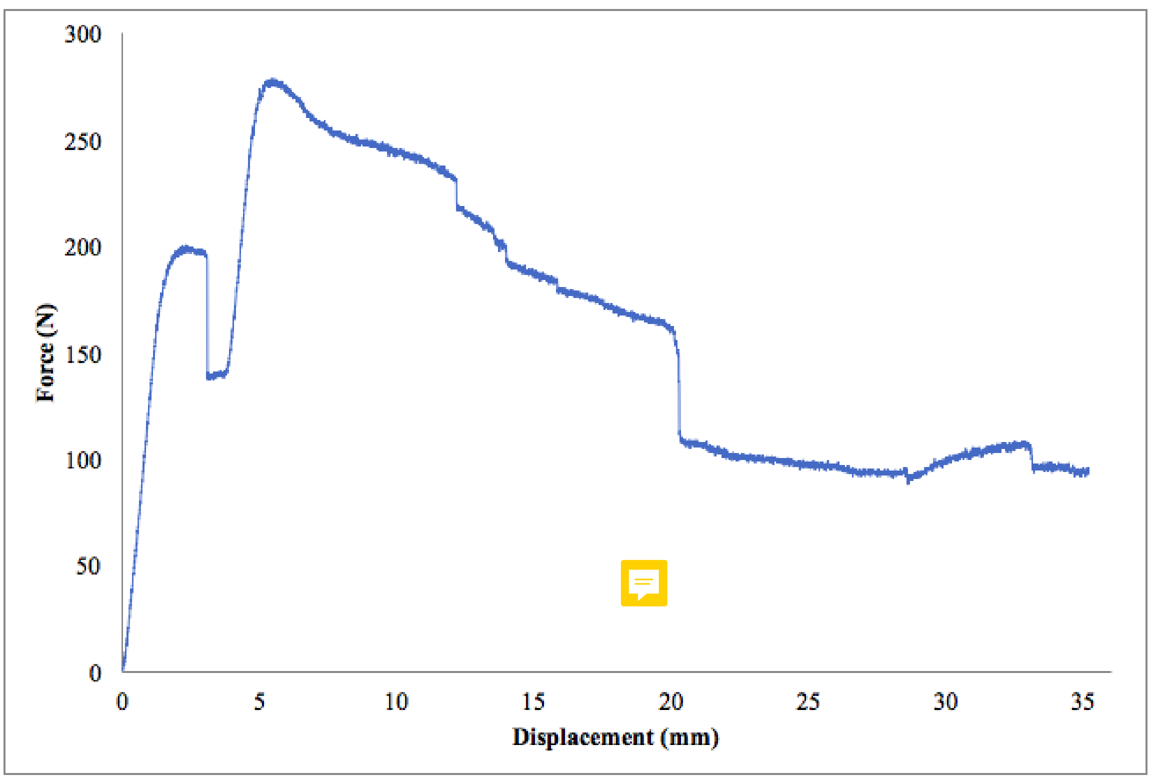


Figure 3: Force v. Displacement Curve of Truss
The above graph shows the force applied by the Instron machine to our truss over the machine's displacement.

Our truss held a maximum of 278.7N, which was above the 275N it needed to have a strength to weight ratio of 5N:1g. The sharp drops in the stress strain curve correspond to the cross beam supports of the truss failing, specifically along the top of the truss (Points B-E). Due to the statistical indeterminacy of the truss in cross section, there was little resistance to the truss warping in and out of the plane of the Instron machine. Despite this however, even after the first cross beam broke, the truss was still able to reload significantly.

V. Conclusions

We were surprised that even after a failure in the truss at about 4mm caused the force applied to drop by about 50N, the truss was still able to reload and gain an even higher max load. The failure at 4mm was one of the cross-beams snapping, so it was surprising that the bridge could support even more force after that failure had occurred.

If we were to build the truss again, the biggest change would be to support the truss more in the z direction. Because it was square in section, there was no moment resistance except for the wood glue connecting the cross pieces to the truss itself. We believe that more reinforcement on the cross beams would not add much more weight, but would greatly increase the maximum load because the structure would not be able to warp as significantly.

Additionally, we would reinforce members BC and DE which had the highest force in them. Because we were only able to complete the calculations of force after testing, we had to make an educated guess on which members to reinforce, meaning that some members were overdesigned, but some that held a lot of force were only one popsicle stick. This reinforcing would not make as much of a difference as the cross supports, but member BC did fail due to warping, and so reinforcing it should increase the overall load the truss is able to withstand.

VI. Appendix I

assume: σ_y is same in tension and compression

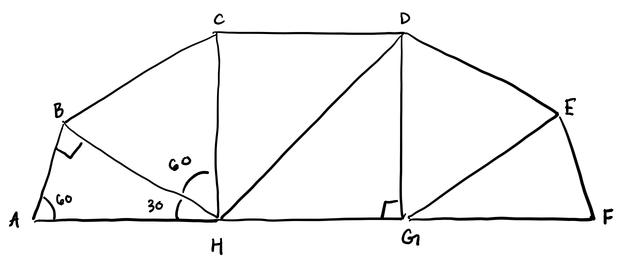
Yield Stress:

popsicle sticks are made from birch, so using Oak as an approximation as both are hard woods.

$\sigma_y = \frac{F}{a}$ $\sigma_y = 40$ mPA $a = 10\text{mm} \cdot 2\text{mm}$

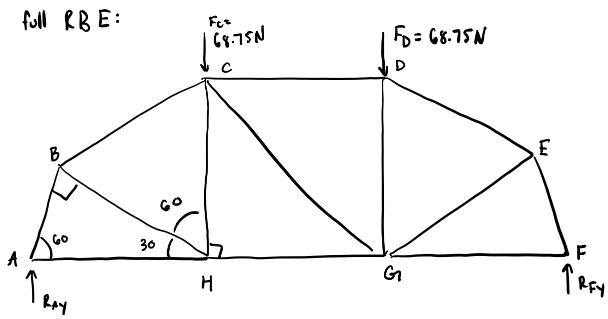
$F = \sigma A$ $a = 20\text{ mm}^2$

$40\text{mPA} \cdot 20\text{mm}^2 = 800\text{ N}$ ∴ should not fail in Tension or Compression



max force needed: 275 N. Approximate as 275/4 applied at C & D.

full RBE:



$\Sigma F_y = 137.5 + R_{Ay} + R_{Fy} = 0$

b/c symmetrical truss & even loading, $R_{Ay} = R_{AF}$

→ assume D-H doesn't affect loading at A & F

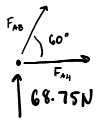
$R_{Ay} = 68.75\text{ N}$

$R_{AF} = 68.75\text{N}$

☆ Positive values are tension, negative are compression.

Method of Joints:

FBD A:



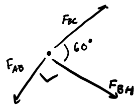
$\Sigma F_y = 68.75\,N + F_{AB} \sin 60 = 0$

$\boxed{F_{AB} = {}^{-}79.38N}$

$\Sigma F_x = F_{AB} \cos 60 + F_{AH} = 0$

$\boxed{F_{AH} = 39.69N}$

FBD B:

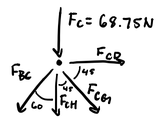


work below!

$\boxed{F_{BC} = 91.66\,N}$

$\boxed{F_{BH} = -45.83N}$

FBD C:

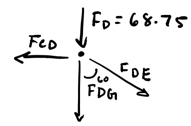


$\Sigma F_x = F_{BC} \sin 60 + F_{CG} \sin 45 + F_{CD} = 0$

$\frac{91.66 \sin 60 - 45.83}{\sin 45} = -F_{CG}$

$\boxed{F_{CG} = {}^{-}47.45}$

FBD D



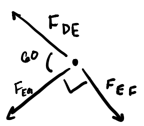
$\Sigma F_y = F_{DE} \sin 60 - 68.75 + F_{DG} = 0$

$\boxed{F_{DG} = -10.62N}$

$\Sigma F_x = F_{CD} + F_{DE} \cos 60 = 0$

$\boxed{F_{CD} = -45.83N}$

FBD E:

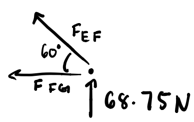


work below!

$\boxed{F_{DE} = 91.66\,N}$

$\boxed{F_{EG} = -45.83N}$

FBD F:



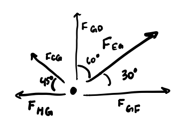
$\Sigma F_y = 68.75\,N + F_{AB} \sin 60 = 0$

$\boxed{F_{EF} = {}^{-}79.38N}$

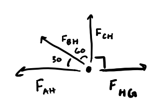
$\Sigma F_x = F_{AB} \cos 60 + F_{AH} = 0$

$\boxed{F_{FG} = 39.69N}$

FBD G:



FBD H



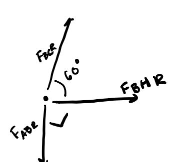
$\Sigma F_y = F_{BH} \sin 30 + F_{CH} = 0$

$\boxed{F_{CH} = 22.92\,N}$

$\Sigma F_x = F_{AH} + F_{CH} + F_{BH} \cos 30 + F_{GH} = 0$

$\boxed{F_{GH} = -22.92\,N}$

Rotated FBD of B



$F_{AB} = {}^{-}79.38N$

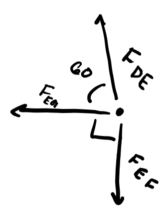
$\Sigma F_y = F_{AB} + F_{BC} \sin 60° = 0$

$\boxed{F_{BC} = 91.66\,N}$

$\Sigma F_x = F_{BC} \cos 60 + F_{BH} = 0$

$\boxed{F_{BH} = -45.83N}$

Rotated FBD of E



$\Sigma F_y = F_{EF} + F_{DE} \sin 60° = 0$

$\boxed{F_{DE} = 91.66\,N}$

$\Sigma F_x = F_{DE} \cos 60 + F_{EG} = 0$

$\boxed{F_{EG} = -45.83N}$