ENGS 33: Solid Mechanics - Final Report

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I. Introduction

Our design process began with preliminary sketching of concept designs, constrained by few, if any, design limitations. We strived as a group to create many *different* bridge configurations, and as such did not collaborate on our initial concepts, so as to promote individualized styles. As a result of these efforts, we produced a plethora of unique designs, some fantastical and some more realistic. Figures A, and B in the appendix refer to some of our early concept designs not selected for further development. Following several group meetings, we determined that Christian's sketch, shown in Figure C, was ideal largely due to its feasibility of construction, and some key improvements to the Grant Road design. Based off of the longest continuous truss bridge in the world, the Ikitsuki Bridge in Japan, the concept incorporates a Howe Truss design, further supported by "K" trusses in the center panels. Through outside research, we found that Howe Trusses in general distribute loads more effectively than a Pratt Truss[1] like the Grant Road Bridge. These general trends were confirmed for the most part during our initial by-hand force analyses. However, because the "K" trusses in the center panels constitute statically indeterminate members, full conclusive proof of stability was not obtained until computer simulation was employed. Figures D and E show some examples of quantitative analysis for an alternative design concept and an approximate model of our chosen Truss, removing the redundant "K" truss members for ease of calculation.

Following our decision to proceed with iterative development of the modified Howe Truss, we began construction of an initial CAD model, depicted in Figures F and G. Because Alex, Christian, and Youssef were situated locally this term, we agreed that Caitlin would handle

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[1] https://digitalcommons.murraystate.edu/cgi/viewcontent.cgi?article=1164&context=postersatthecapitol

a proportionally larger amount of the CAD design, as she would be unable to assist in the actual construction of the bridge. The CAD model of the side truss was completed using a basic extrusion with the gusset plates sketched and extruded directly on the part for ease of modification. Our original intention was to primarily use 30-60-90 triangles in the side truss. The final SolidWorks part included the side truss with the associated gusset plates and half the length of the deck members. Two of these parts were mated as a SolidWorks assembly to get the full bridge. One of our initial concerns included failure of the deck members. To combat this, we designed the bridge to be considerably taller than it is wide. The shorter members are less likely to break from the stress and the larger truss will better distribute the force from the deck.

It was also during this phase that computer simulations were undergone to confirm our hypothesis of added strength in our truss. Per the specifications of the rubric, we simulated the truss's response to several different load patterns. We modeled the bridge members as 1cm x 1cm square tubes of 0.5mm thickness for simplicity, and used paper property values adopted from Professor Snyder's source[2], and one of our own[3] for the coefficient of thermal expansion. We estimated this as the same value as pine wood. The results of our analyses, carried out in SAP2000 and Solidworks, are depicted in figures H, I, J, K, and L. The main takeaways from these analyses were that our bridge did seem to provide a stronger structure than the Grant Road Bridge, and that depending on the load, some members switched between compression and tension. This influenced our final design, as we ended up using tubes for each member for fear of slight deviations from the test loading buckling members designed only for tensile forces. We figured that the studiness that comes with tube members far outweighed the added weight. After the initial CAD drawing, we made small modifications to the scale, added cross members

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[2] *Materials and the Environment*, M. Ashby (2009)
[3] https://inspectapedia.com/exterior/Coefficients_of_Expansion.php

between the trusses, and streamlined a few of the gussets. From here on we fully committed to this design and began planning construction.

II. Predicted Quantitative Results vs. Actual Results

	Predicted Value	Recorded Value	% Error
Deflection at 5kg Load (mm)	0.3 downwards	2.5 downwards	733.33%
Failure Load (Kg)	14.5	19.5	34.48%
Failure Load (N)	142.2	191.23	34.48%
Failure to Weight Ratio	N/A	184	N/A
Deflection to Weight Ratio	N/A	266.8	N/A

*Our predicted failure points can be observed in Figure M

III. Post Testing Discussion/Analysis

Our bridge failed in the outermost panel, first on the outermost diagonal member, and then in the deck beam of that panel, once the model crashed into the testing apparatus. An image of the bridge after failure can be found in Figure N. Although we initially expected failure in the center of the bridge, as shown in Figure M, retrospectively, failure like that which actually occurred was similarly likely. Although the expected loading in the members which really failed was lower, these members were much longer, and thus more susceptible to buckling. Because each of our members were tubes, we were nearly certain that no tensile members would fail, and this assumption held true, but the two highest compressive loadings in the bridge were in two of the shortest and sturdiest members. The third highest compressive load was in the member that ultimately failed. These forces can all be observed in Figure H, the test loading condition. We suspect that our prediction being incorrect for the member that failed could also be the result of a small change that was made in the construction of the bridge. In the simulation the top slanted member was constructed as 3 different tubes connected by gussets. In the final construction of the bridge, these same members were fabricated as a single long member, still supported at multiple gussets, for both ease and stability. This small change in the design may have influenced some of the relationships and resulted in the bucking that we observed on testing day.

Our predictions for deflection and failure load were objectively fairly close, but proportionally quite inaccurate, as shown by our percent error values. Looking at the overarching trend of bridges out-performing their predicted failure loads, we think that this may be a result of underestimating some of the material properties in SAP2000 and Solidworks. We were advised to lean towards the lower end of the range of Young's modulus, compressive strength, yield strength and tensile strength when establishing our material properties for the simulations. Other groups in the course echoed this sentiment. Maybe choosing values from the middle to upper end of the range would yield more accurate estimates for failure loads.

Looking at our current scale model we think the main improvement would be specializing members in construction. Our scale model was constructed with all members being square tubes. We decided to do this because during some of our computer analysis we discovered that members, mainly in the K-truss, would alternate between tensile and compressive behavior depending on the location and distribution of the load. Keeping this in mind, most of the other members did not exhibit this behavior. Changing some of the square tubes to more narrow rectangular cutouts for members we know are going to be only experiencing tension may result in our design soaring in the "failure/weight" category. We could also add cross members between the connecting members of both the side truss and the deck members to increase lateral stability. Looking at how our bridge failed due to compressive buckling, adding compressive strength to the outer members would have increased our load limit. We can accomplish this through reducing the length of these members or reinforcing them with stringers.

IV. Final Construction and Engineering Drawings

Pictures of both the final engineering drawings and the finished physical bridge can be found in Figures O, P, and Q.

Appendix

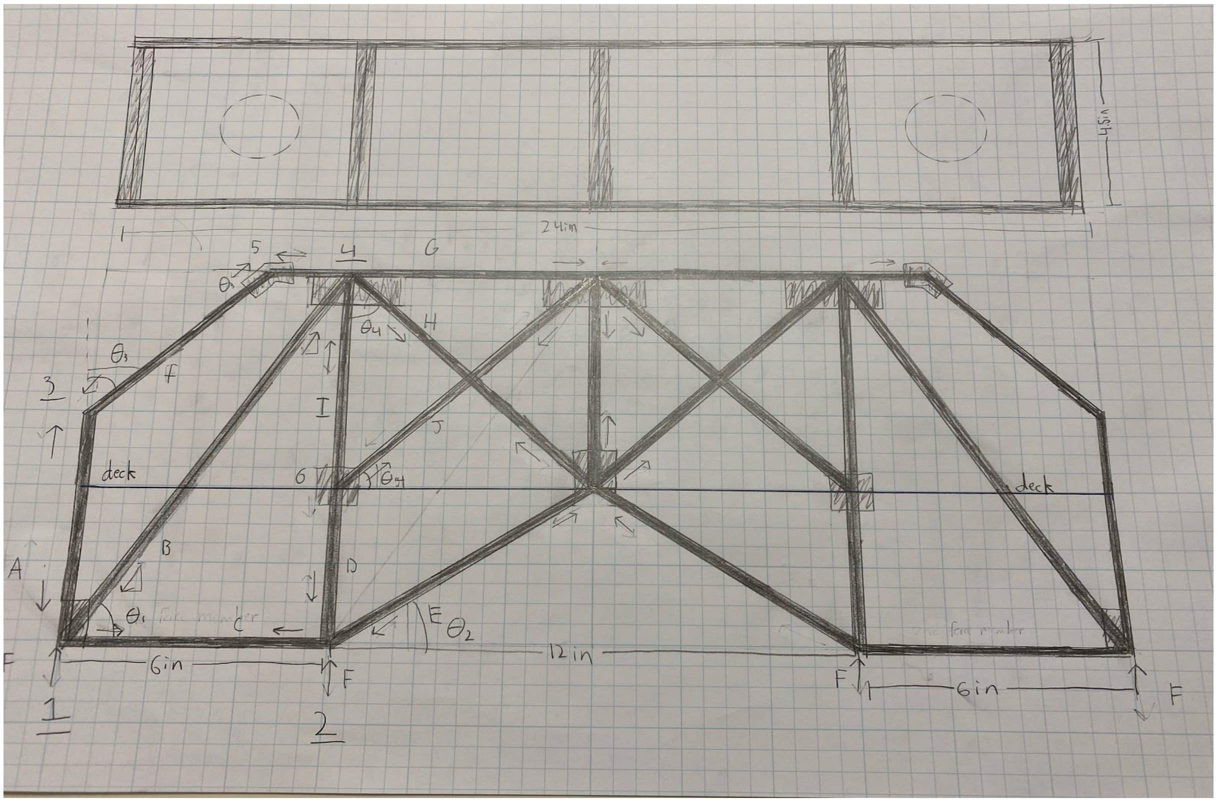


Figure A, Designed bed by Caitlin

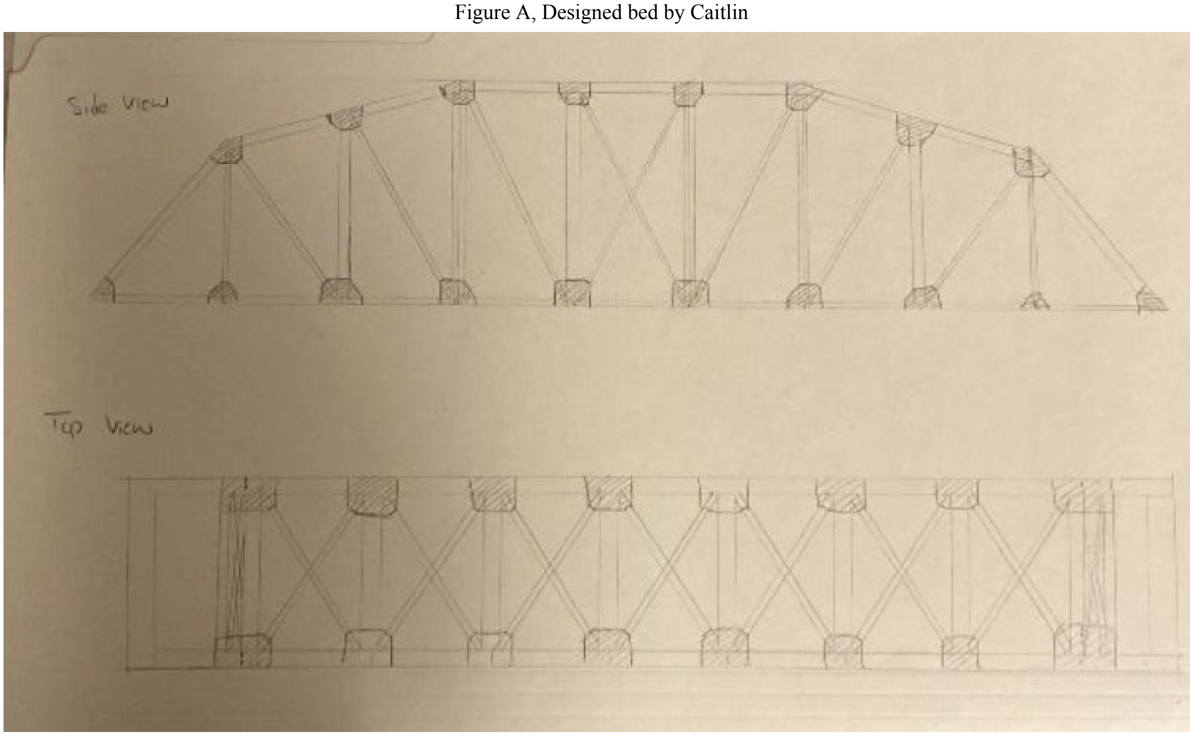


Figure B, Designed by Youssef

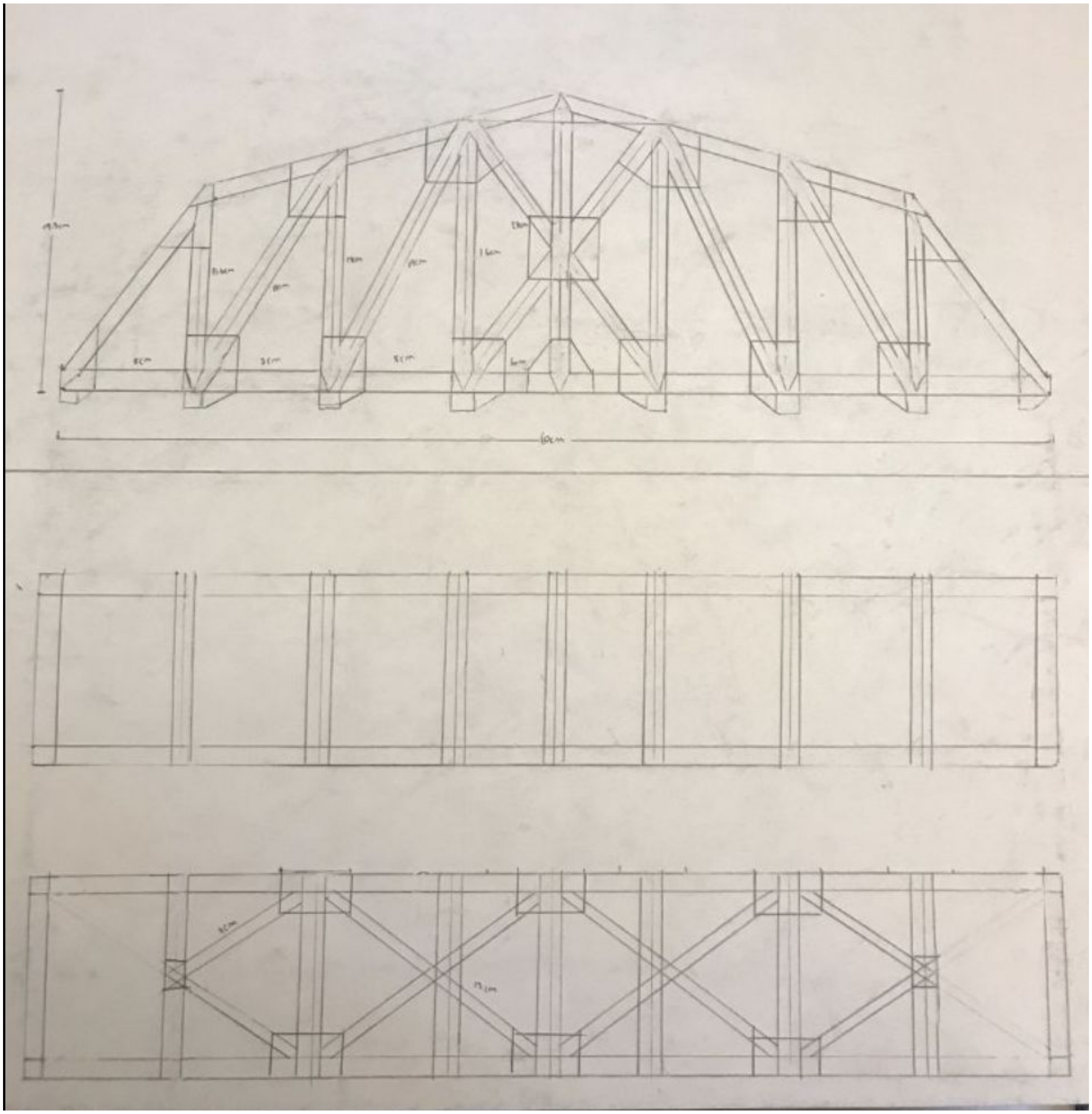
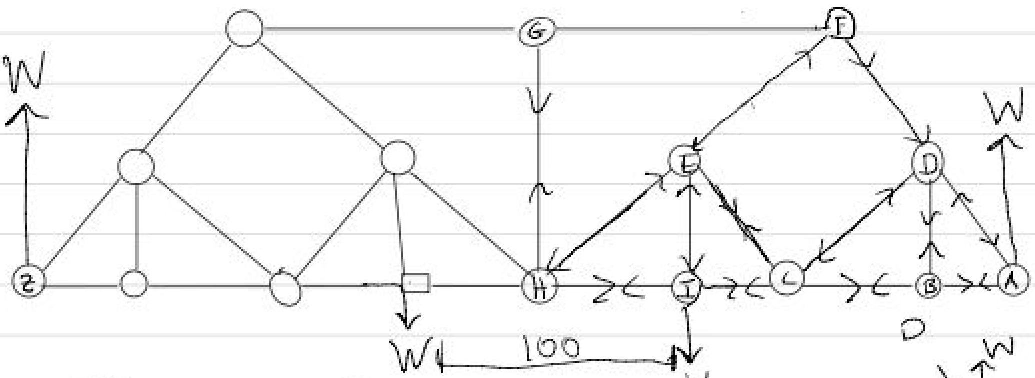
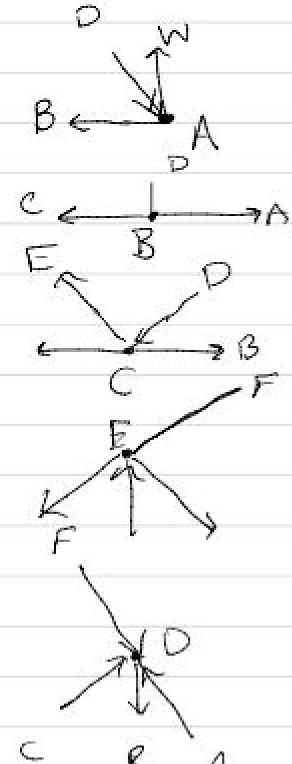


Figure C, chosen concept design by Christian

(2)





$F_Z = F_A = \boxed{W}$ (by symmetry)

$F_{DA} = \frac{W}{\sin(45)} = \boxed{1.41W}$

$F_{BA} = \cos(45) F_{DA} = \boxed{0.997W}$

$F_{CB} = -F_{BA} = \boxed{0.997W}$

$F_{EI} = \boxed{W}$

$F_{FD} = F_{DA} - \cos(45) F_{DC} \simeq \boxed{0.955W} = F_{EF}$

$F_{DB} = \sin(45) \cdot DA = \boxed{0.997W}$

$F_{EH} = F_{EC} = \boxed{W/2}$

$F_{CD} = F_{DB} - \cos(45) \cdot F_{EC} = \boxed{0.643W}$

$F_{HG} = \sin(45) F_{EH} = \boxed{0.354W}$

$F_{HI} = F_{IC} = \boxed{0.997W}$

Figure D, force analysis of alternative designs (Alex)

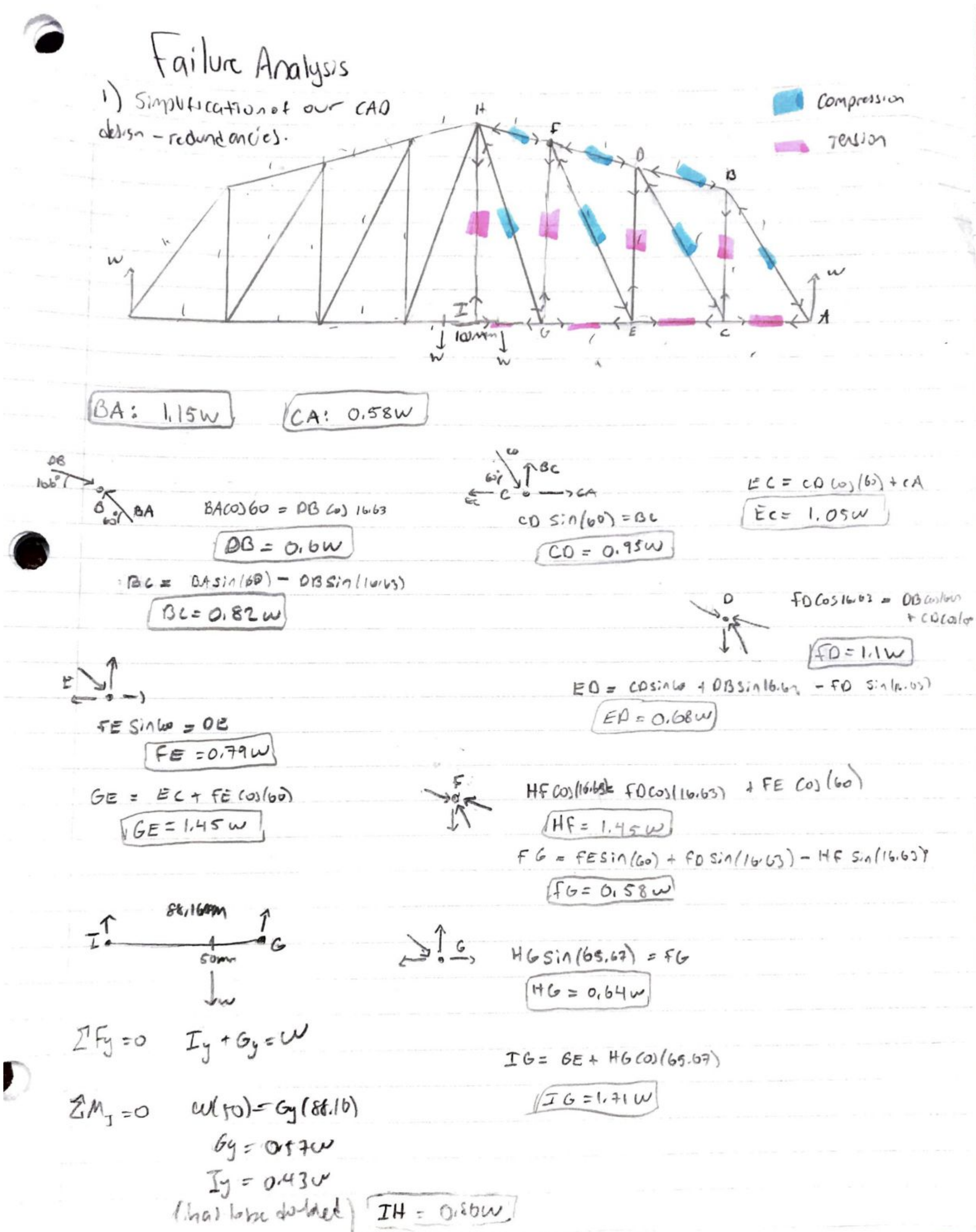


Figure E, force analysis of simplified design, (without redundancies) (from Christian's work)

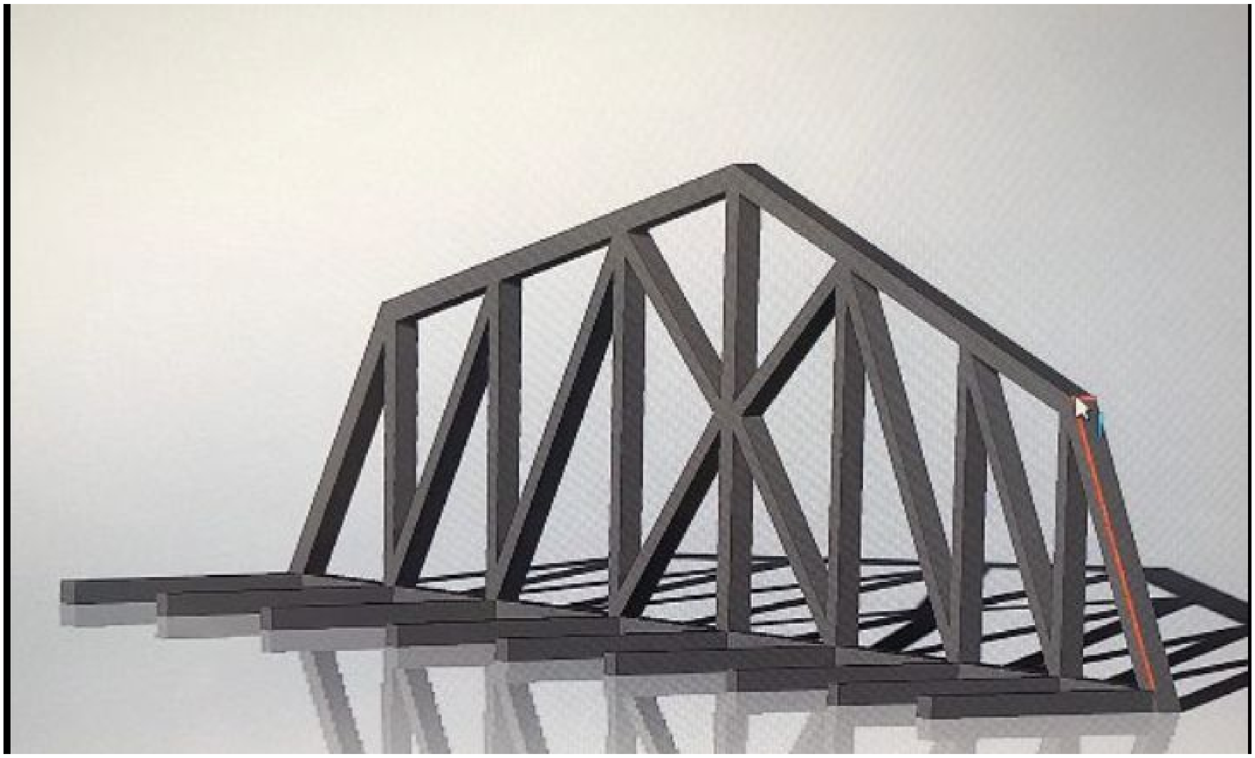


Figure F, initial CAD design developed by Caitlin

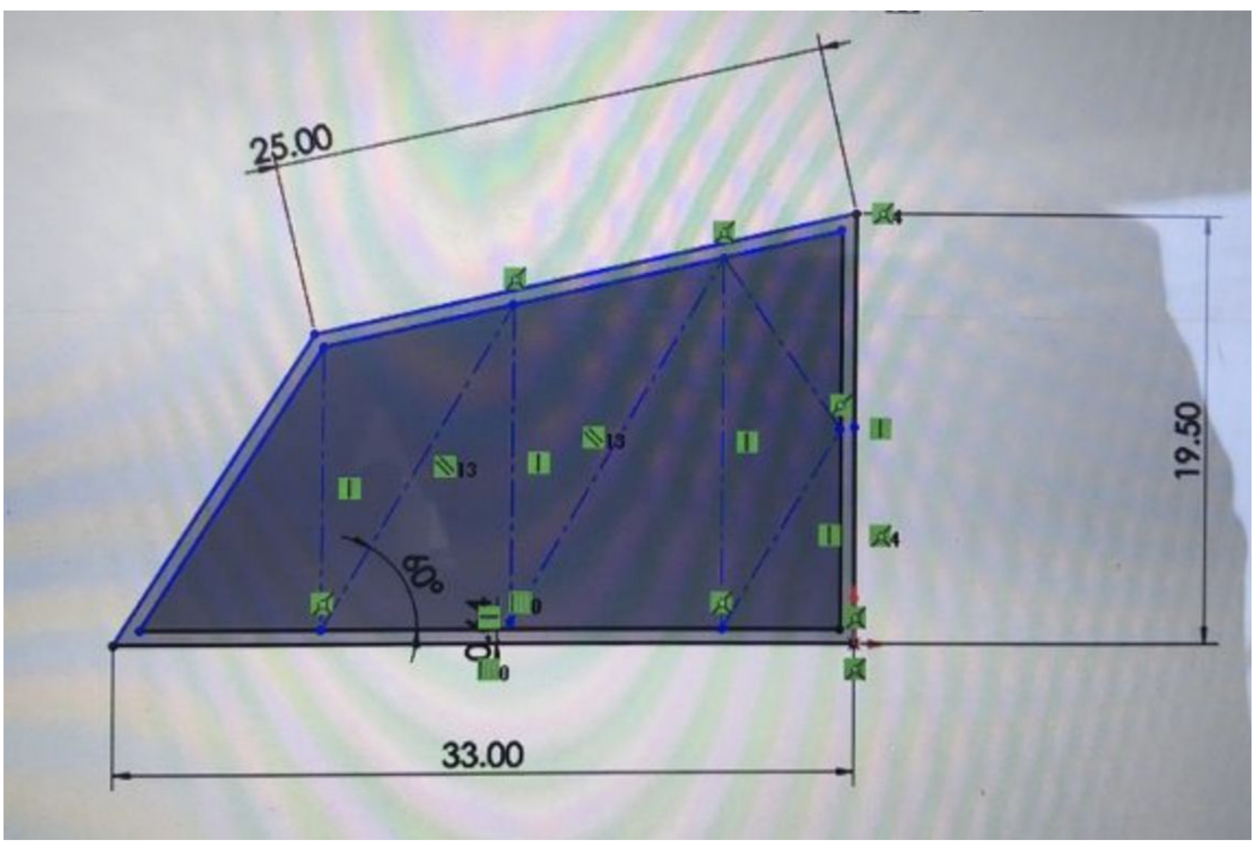


Figure G, further specs of initial CAD models by Caitlin

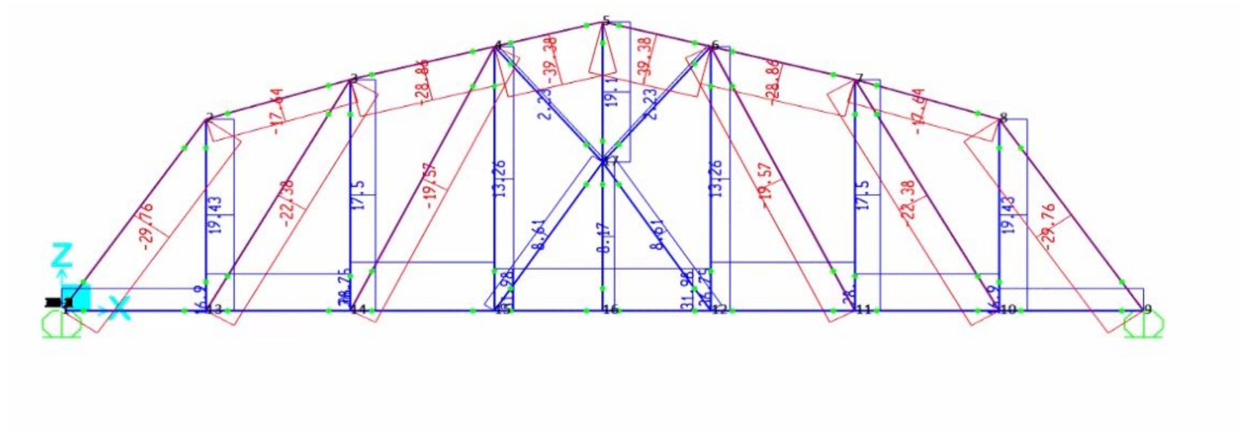


Figure H: Test loading condition, two downward forces about the center of the truss, separated by 100mm with a combined force of 49N (from a mass of 5kg) (Entire Group)

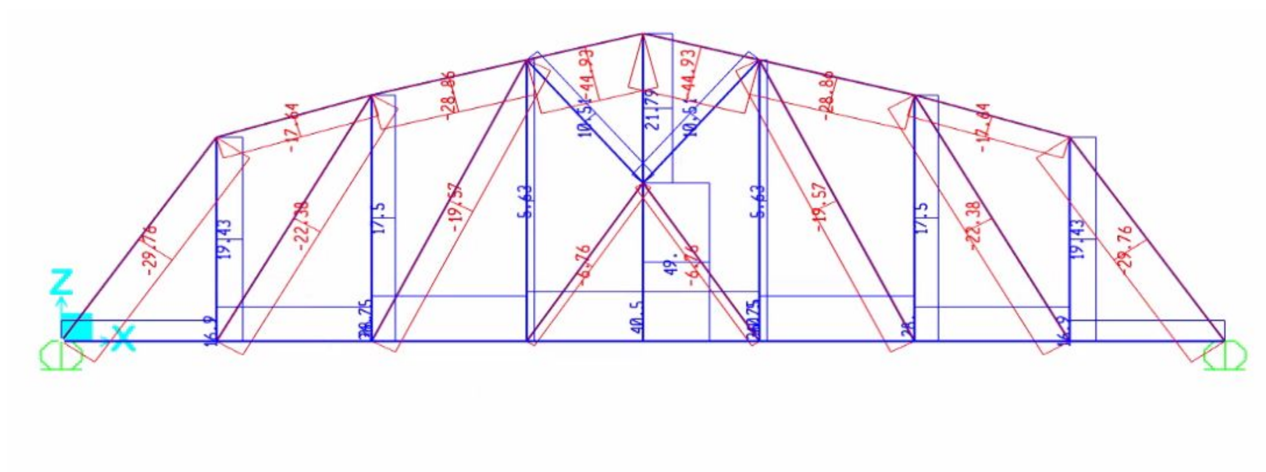


Figure I: Single load at center point of the deck of the truss, with force 49N (from mass of 5kg) (Christian)

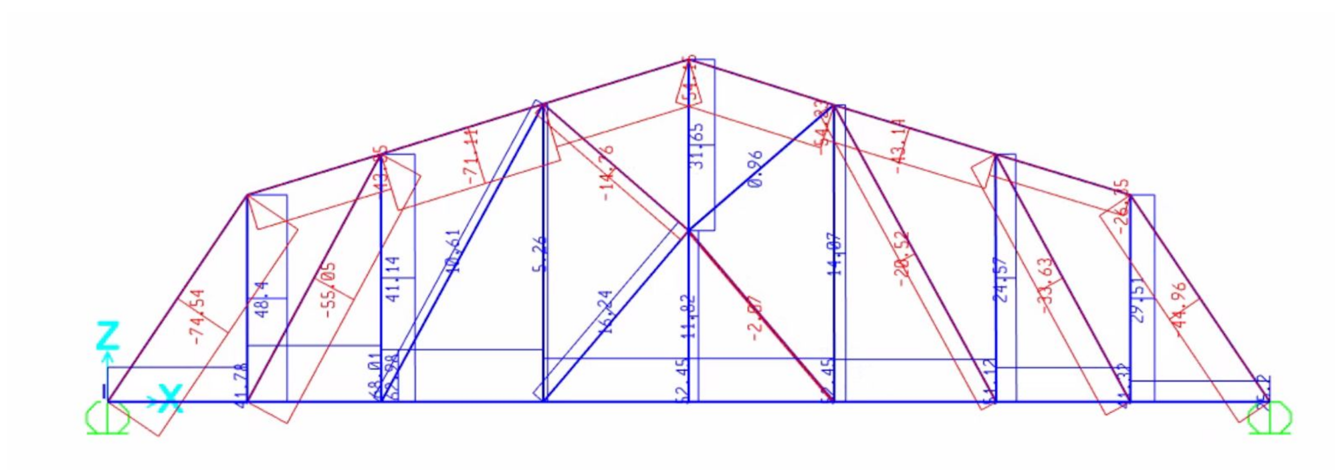


Figure J: One point load at the left quarter point, with force 49N(from a mass of 5kg) (Alex)

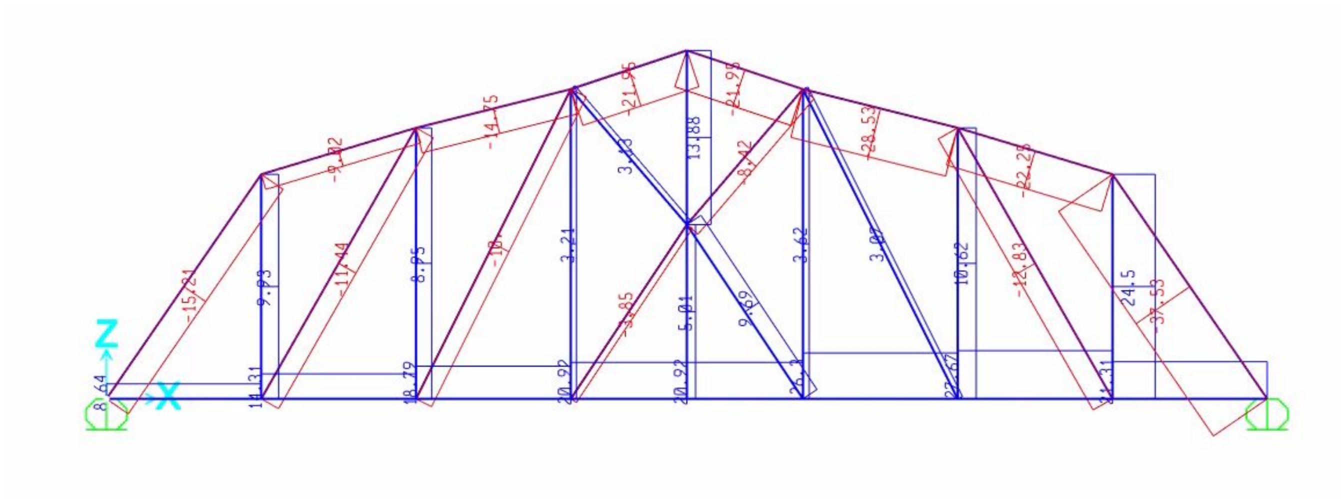


Figure K: Uniformly distributed force on the right side, with magnitude of .167N/mm. Resultant force of 49N(from a mass of 5kg) (Youssef)

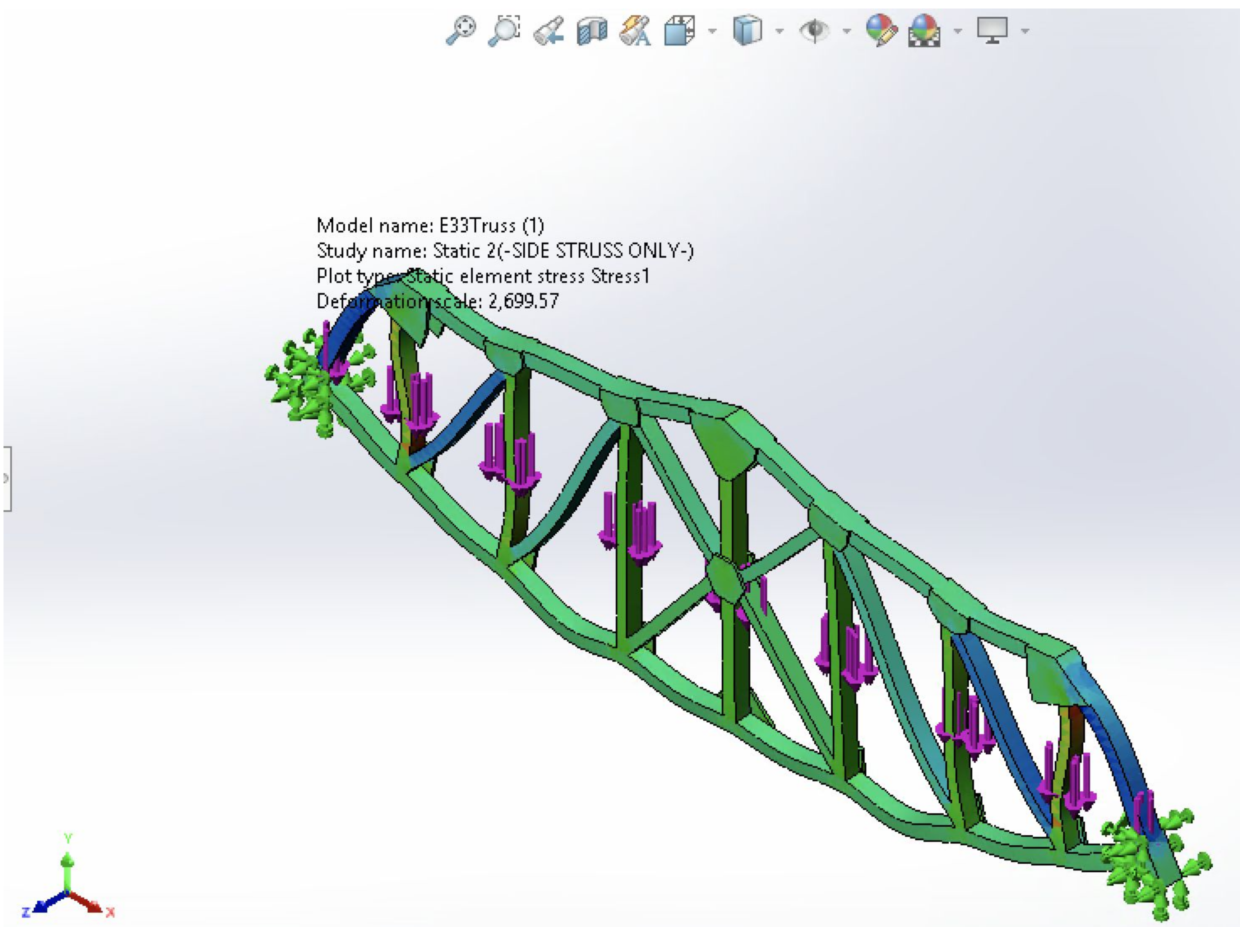


Figure L, Uniformly distributed load along the length of the bridge (Caitlin)

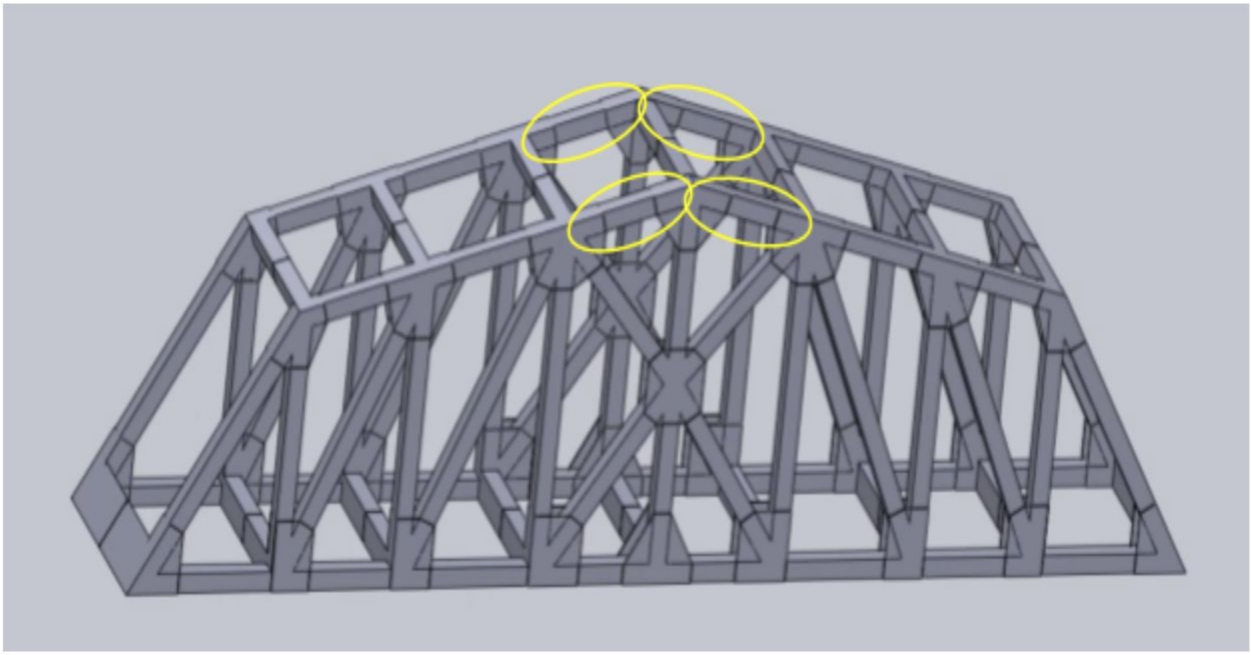


Figure M, predicted failure points on final CAD model

Figure N, Bridge post-testing, with apparent buckling in outermost diagonal member

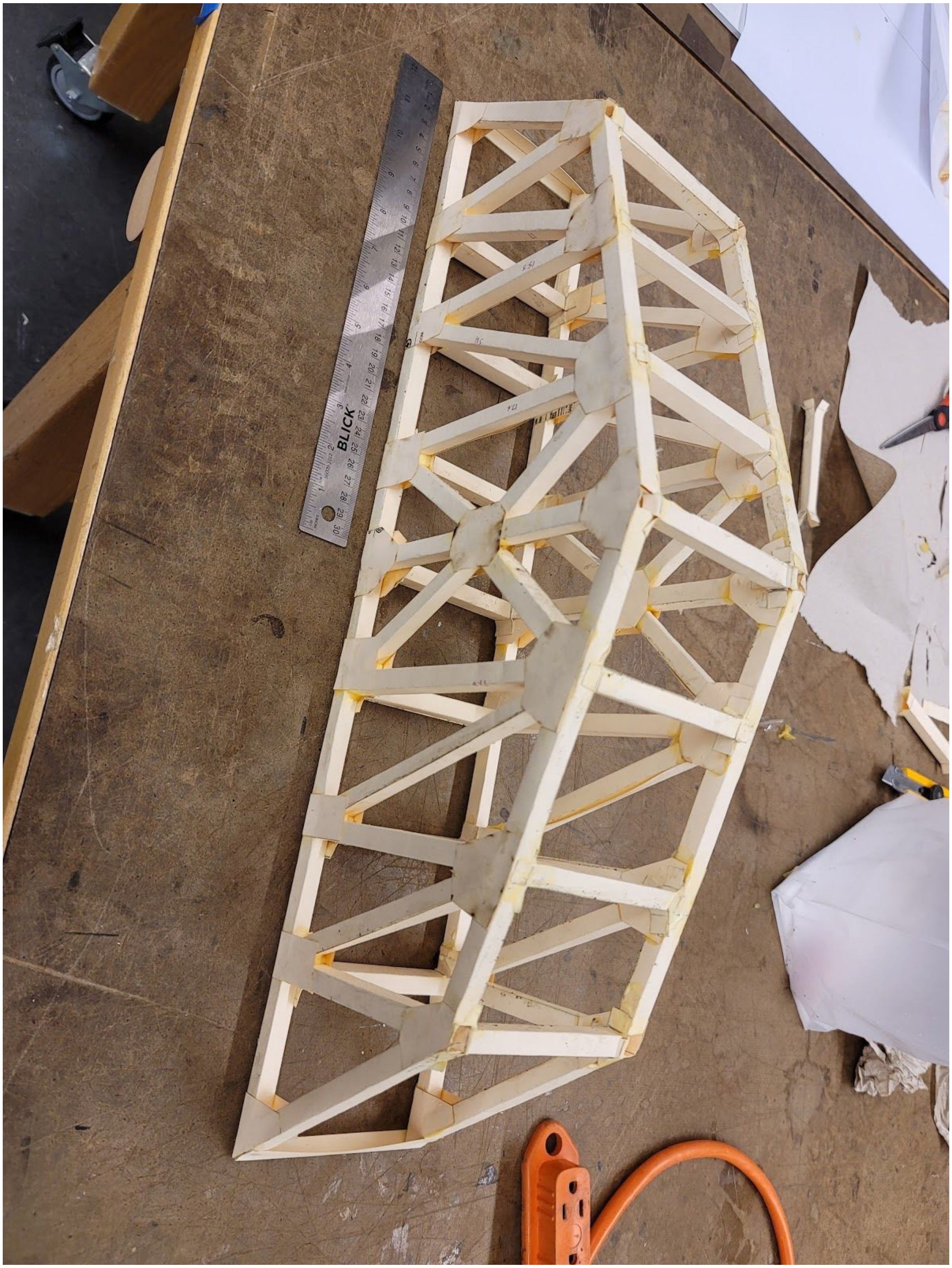


Figure O, final constructed bridge (Alex, Christian, Youssef)

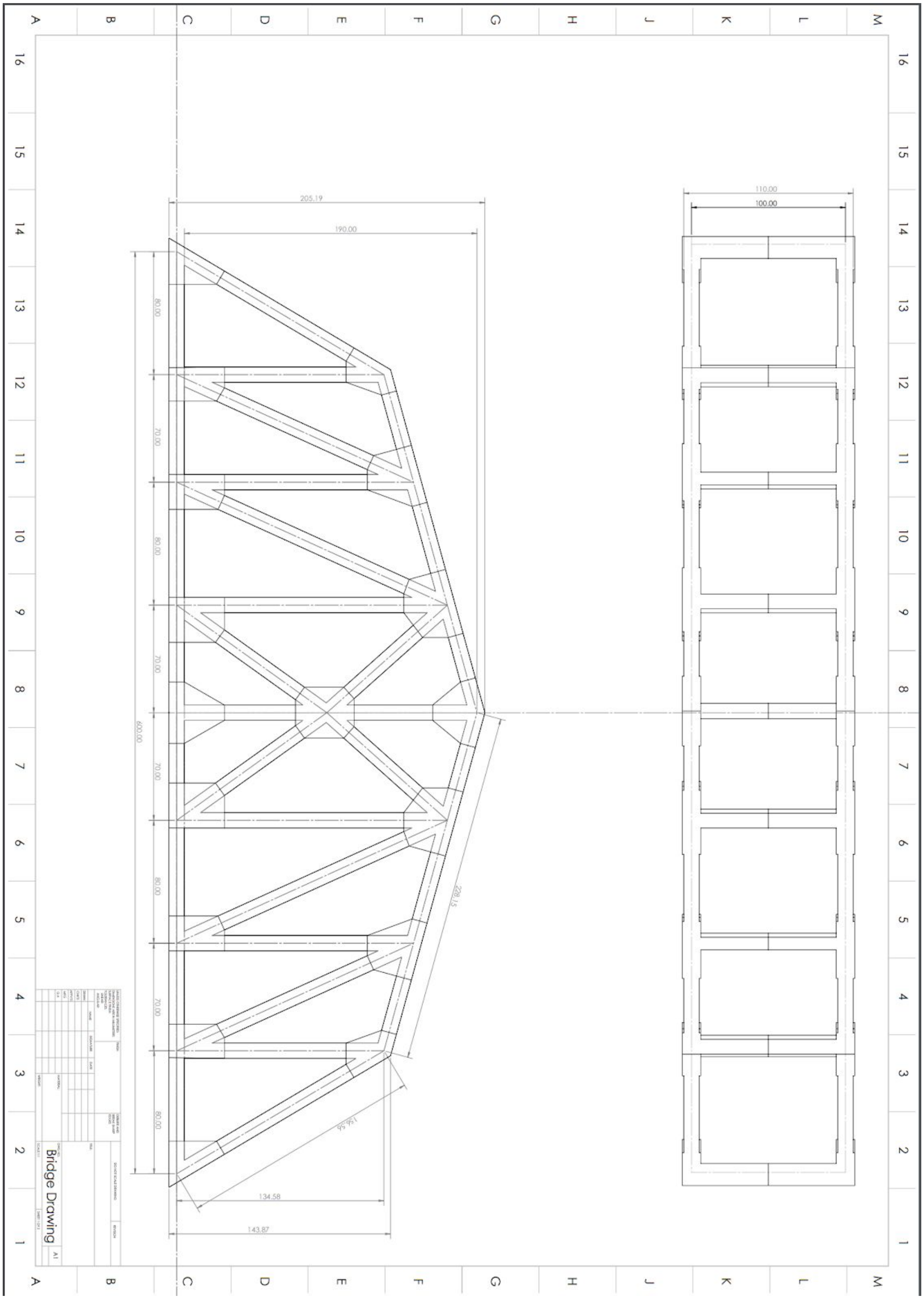


Figure P, final engineering drawing, side and top views (developed and printed by Caitlin and Youssef)

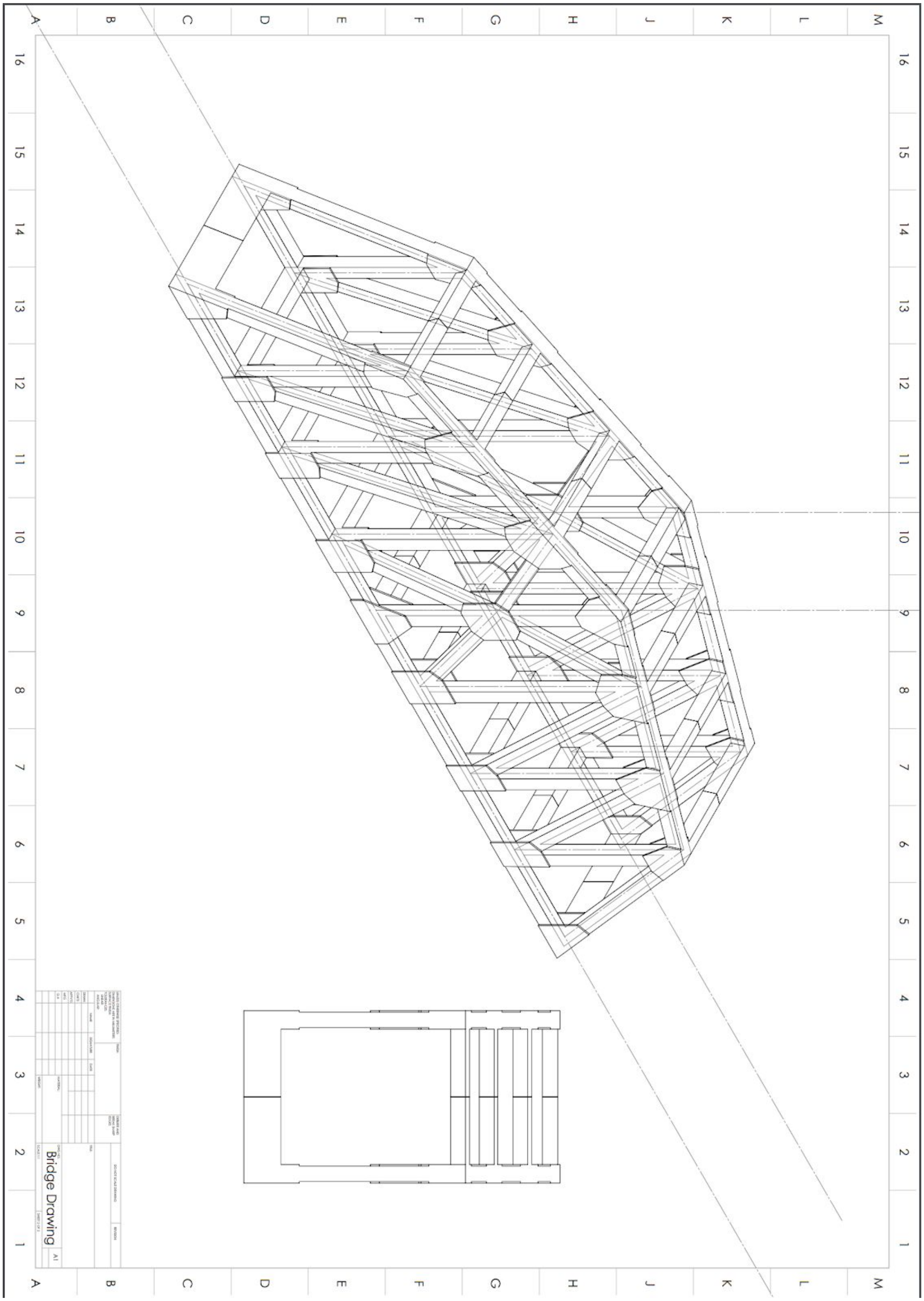


Figure Q, final engineering drawing, orthographic and front views, (developed and printed by Caitlin and Youssef)

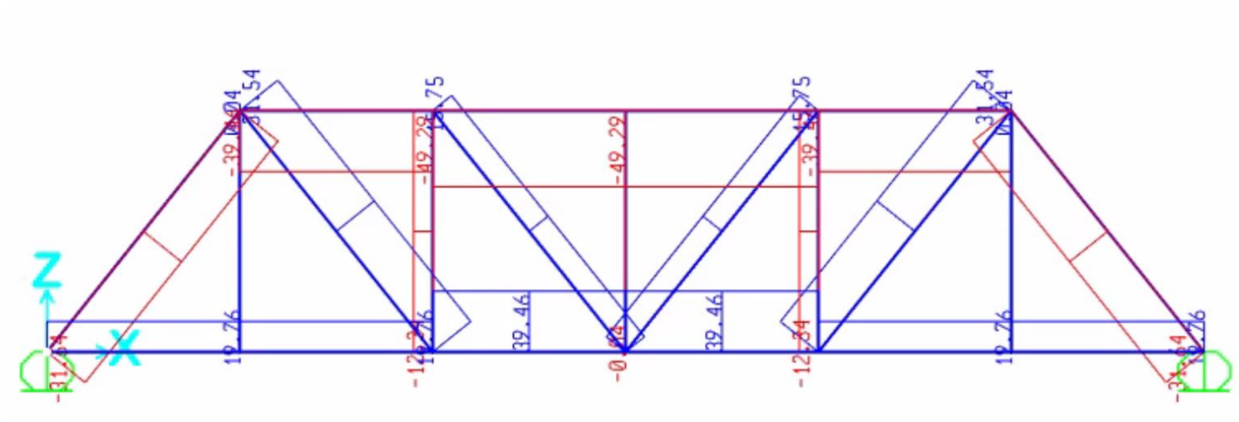


Figure R, Grant Road Bridge with two downward forces about the center of the truss, separated by 100mm with a combined force of 49N (Youssef)