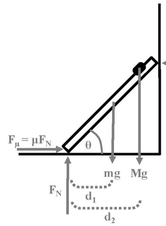
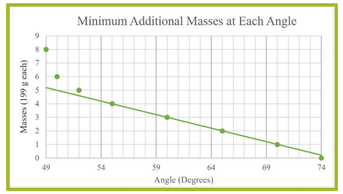
Penn Engineering

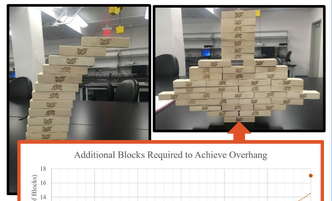
Courtesy of
Dr. Bruce Kothmann

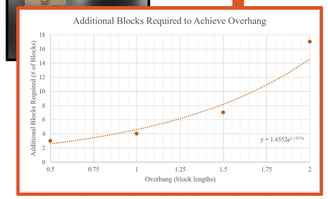
Students in Dr. Kothmann's Mechanical Engineering and Applied Mechanics course are asked to create ePortfolios to document their work from start to finish. As part of the assignment, students reflect and draw conclusions about the process, course content, and their own learning.

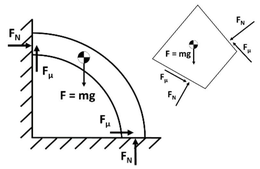
Blocks and Ladders

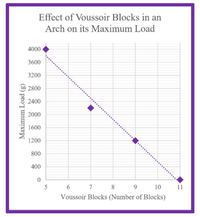






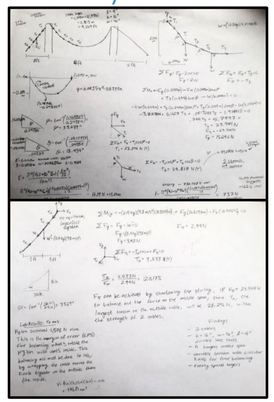


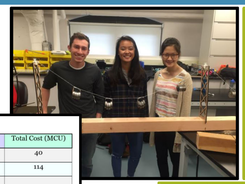


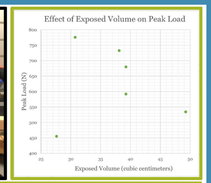


Suspension Bridge

Role: Pylon Officer





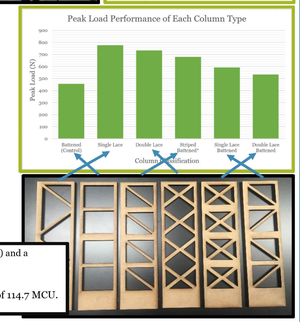


Demonstration Price Breakdown – The Original Bridge

Element	Unit Cost	Quantity	Total Cost (MCU)
Pylon Location	10 MCU/40 MCU	Short Span	40
Pylon Volume	1 MCU/cc	114 cm³	114
Cable Strands	10, 20, 30, 50 … MCU	2 Strands	30
Hangers	5 MCU	4 Hangers	20
Deck Truss	(max. dist. in.)²/40	9.6 in	2.3
Aesthetic Prize	-25 MCU/-10 MCU	No Prize	0
			206.3

Estimated Minimum Price Breakdown – The "Minimalist" Bridge

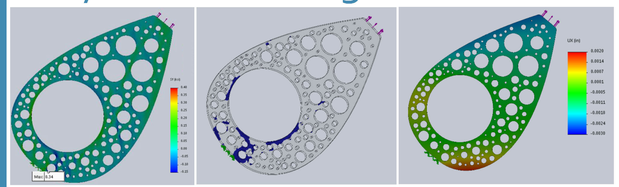
Element	Unit Cost	Quantity	Total Cost (MCU)
Pylon Location	10 MCU/40 MCU	Short Span	40
Pylon Volume	1 MCU/cc	25.3 cm³	25.3
Cable Strands	10, 20, 30, 50 … MCU	2 Strands	30
Hangers	5 MCU	3 Hangers	15
Deck Truss	(max. dist. in.)²/40	12 in	3.6
Aesthetic Prize	-25 MCU/-10 MCU	No Prize	0
			113.9



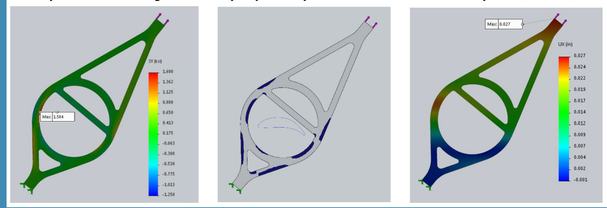
A 16" x 4" x ¼" pylon with a double lace truss structure (66% volume reduction) and a minimum cross sectional length of 1/2" can withstand:

$$F = \frac{\pi^2(4.0x10^9 \frac{N}{m^2})(\frac{3w^3}{12})}{(2h)^2} = \frac{\pi^2(4.0x10^9 \frac{N}{m^2})(\frac{(0.0127m)(0.00635m)^3}{12})}{(2(0.4064m))^2} = 16.19N$$ at a price of 114.7 MCU.

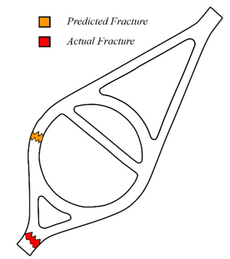
Acrylic Part Testing



Y Stress, Maximum Stress Areas, and X Lateral Displacement Visual Representations for initial proposed part (above) and tested part (below)



Failure Load (Tension): 1200 lbs.
Part Weight: 0.17 lbs.



Suspension Bridge

A. Things I Learned
   i. Nifty devices (see right) help give calculations some breathing room by allowing for on-the-spot adjustments
   ii. For problems with many interacting variables, arbitrary or ill-informed decisions and assumptions are necessary for the sake of moving forward (and can later be revisited)
   iii. Neither total pylon volume nor cross-sectional area is directly proportional to a pylon's buckling strength – therefore, different trusses can make a non-uniform solid stronger
   iv. Many elements with safety factors too near to one will cause a system to inevitably fail

B. Things I Am Confused About
   i. Why exactly were some pylon trusses (with the same minimum cross-sectional area) stronger than others, if, by the buckling formula, they have the same theoretical load strength?
   ii. How do stresses act on a braided string, and is there some benefit or trade-off for braiding string anyway?

C. Things I Want to Learn More About
   i. How are bridges constructed progressively? We had the benefit of working with the whole bridge simultaneously, but real construction has its own set of constraints.

Blocks and Ladders

A. Things I Learned
   i. Ladders under such loading approach a linear limit, in this case sustaining one additional 200 gram mass per 5 degrees in angle from horizontal
   ii. Planar stacking blocks abide by the harmonic sequence, which diverges, meaning that stacked blocks can theoretically achieve infinite overhang
   iii. Sometimes the best way to understand a system is to cut it in half (partial free-body diagrams explain arch forces)

B. Things I Am Confused About
   i. Is an asymmetric arrangement for nonplanar blocks more effective than symmetric is?
   ii. What shape or angles maximizes the "effective arch volume"?

C. Things I Want to Learn More About
   i. Planar block stacking had a neat mathematical limit. Do the other block stacking arrangements have a generalized mathematical theory?
   ii. Builders of stone arches do not need to worry about loads, because generally, if the bridge stands, any load will be relatively small compared to the weight of the bridge itself. I would be interested to study the effective arch volumes of bridges made of heavier blocks, where this principle applies.

Acrylic Part Testing

A. Things I Learned
   i. The listed fracture stress on an online reference guide or the pre-programmed specifications for materials on SolidWorks are rarely correct
   ii. The clamps of the MTS unit create a local stress that can cause a part to fracture sooner than expected
   iii. Always measure the testing scenario yourself before building the part

B. Things I Am Confused About
   i. The clamps apply a force inwards on the two sides of the part, and yet the Finite Element Analysis treats the bottom face as the fixture point. Is there a better way of representing the clamp's effect in the Finite Element Analysis?
   ii. I found that I could subtract material and the maximum stress would decrease in Finite Element Analysis. How is this possible?

C. Things I Want to Learn More About
   i. We designed and studied samples under compression (suspension bridge pylon, mystery metal) and under tension (acrylic part). I would be interested in learning how to design and select a material for a part that is under a dynamic compressive and tensile load. It would be a challenge to design a part which optimizes performance under a variety of loads.