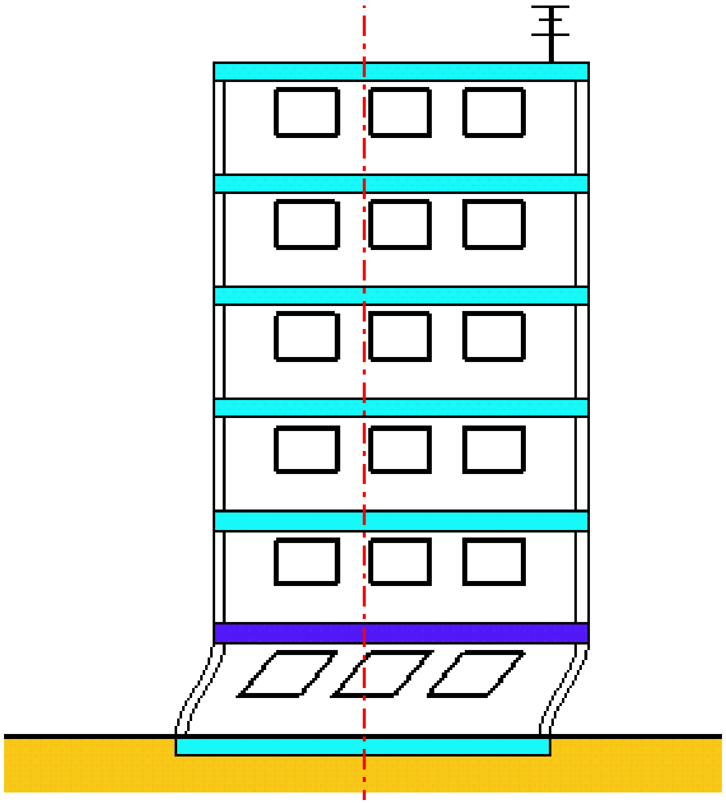
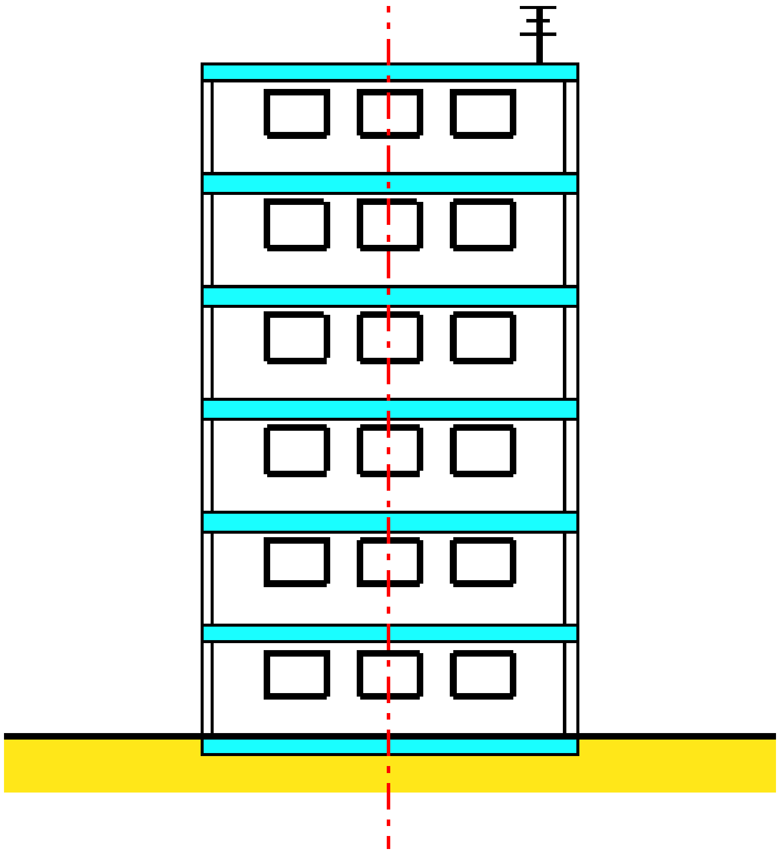
Loading + Failure

Wind load hitting Skyscraper

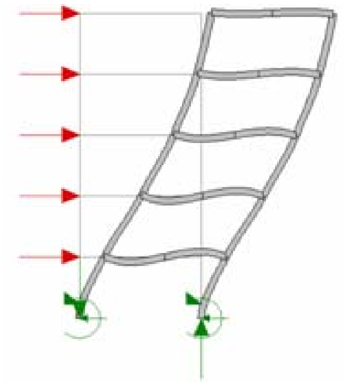


Earthquake hitting Skyscraper



Lateral Load Systems

1. Frame → rigid joints



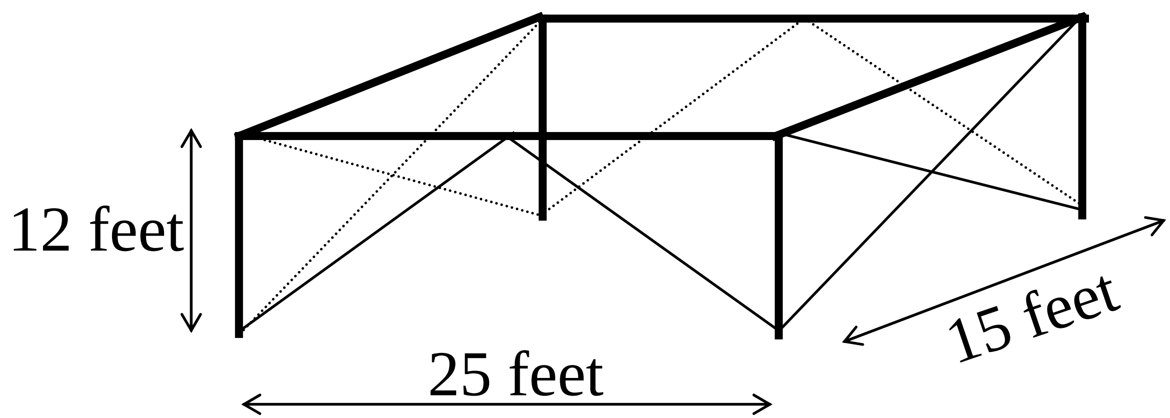
2. Bracing → diagonal elements

3. Shear wall → diaphragm

Good Practice in Wind Design

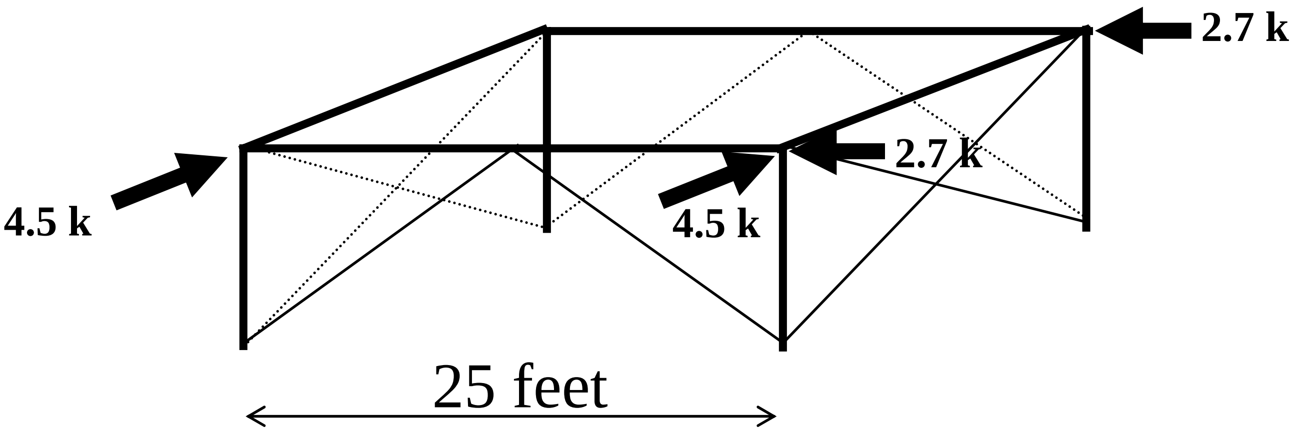
- Provide greater resistance along shorter dimension
- Careful attention to detail
  - Continuity of structure
  - Provide ties for each element
- Greater weight can provide greater wind resistance
- Protect inhabitants from flying projectiles

Wind Bracing Example



- **Wind loading of 30 pounds per square foot applied on each side**

Wind Bracing Example



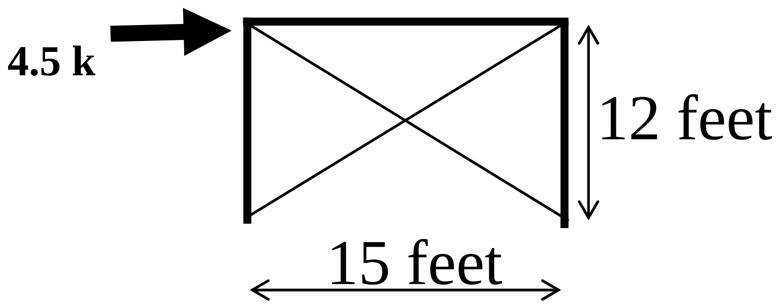
(25 ft)(12 ft)(30 psf) = 9,000 lbs

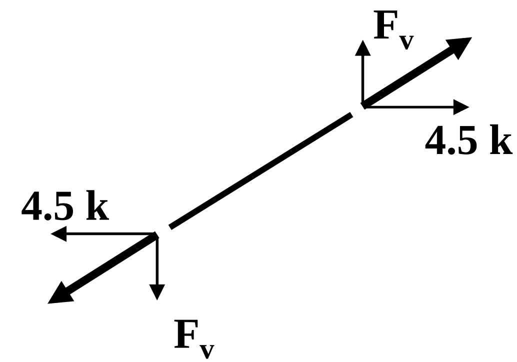
Applied at top of wall, 4,500 lbs/frame (4.5 k)

(15 ft)(12 ft)(30 psf) = 5,400 lbs

Applied at top of wall, 2,700 lbs/frame (2.7 k)

Wind Bracing Example



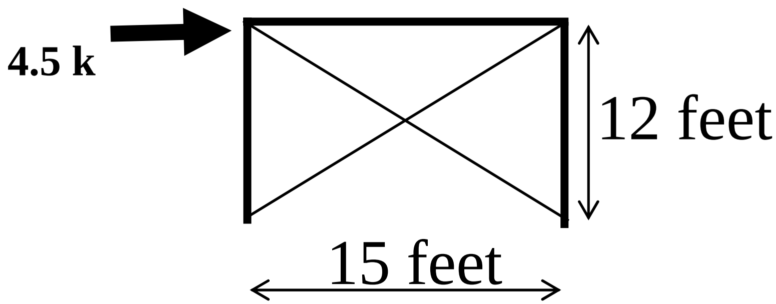


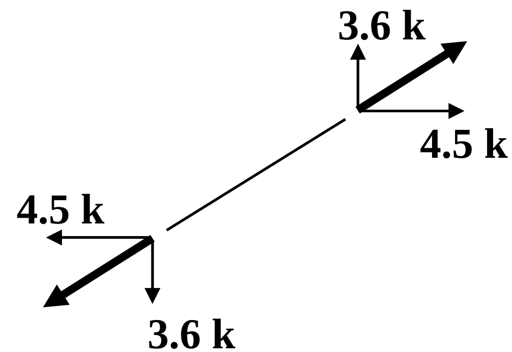
If the cable carries 100% of wind load, then the horizontal component of force in the cable must be 4.5 k

$$F_v/(4.5\ k) = (12\ ft)/(15\ ft)$$

$$F_v = 3.6\ k$$

Wind Bracing Example

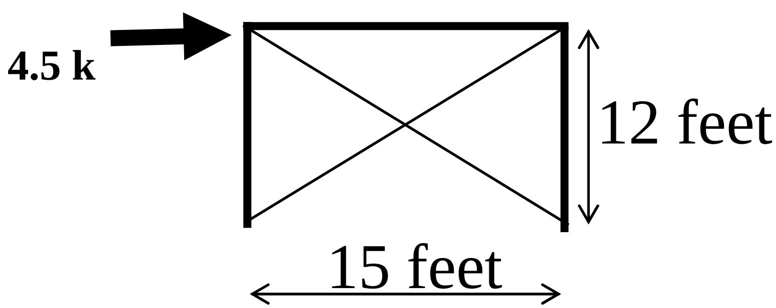


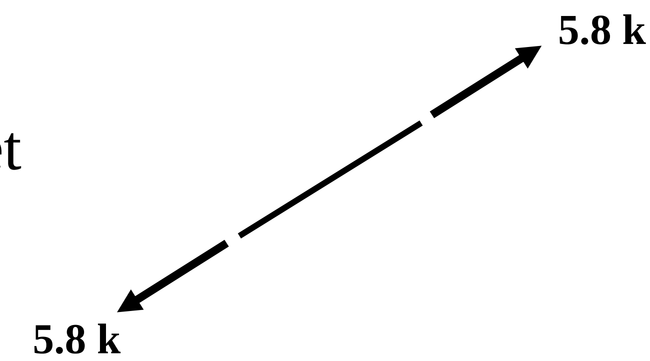


Internal force in the cable is found from Pythagorean Theorem

$$F_{cable} = \sqrt{(4.5\ k)^2 + (3.6\ k)^2} = 5.8\ k$$

Required Area of Steel Cable





Maximum allowable stress in cable is 15 ksi (given)

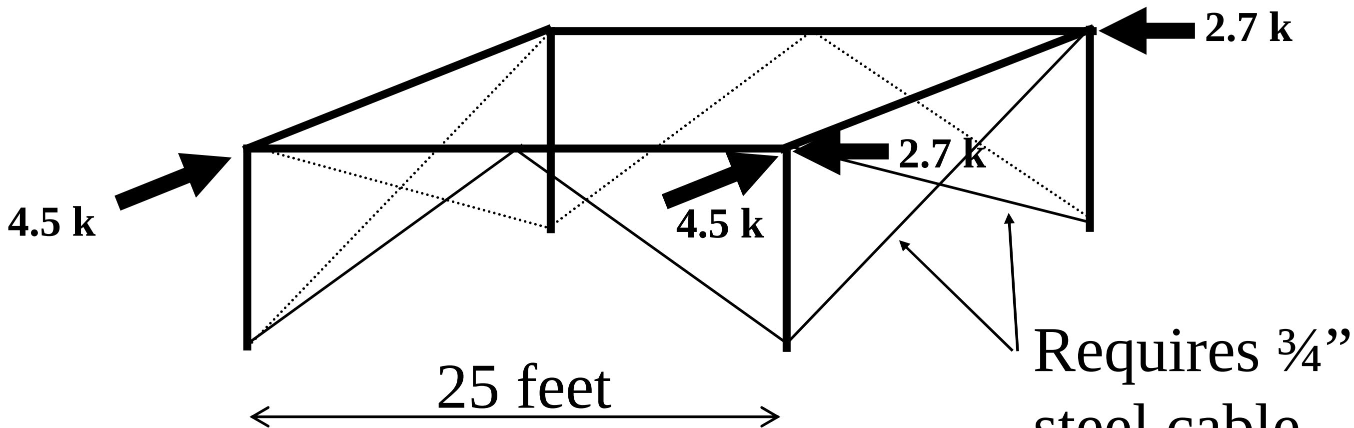
Stress = Force/Area

$A_{req'd}$ = Force/Stress = 5.8 k/15 ksi = 0.38 in^2

Cable diameter, d = 0.7 inches (A=$\pi(0.7)^2/4$ = 0.38 in^2)

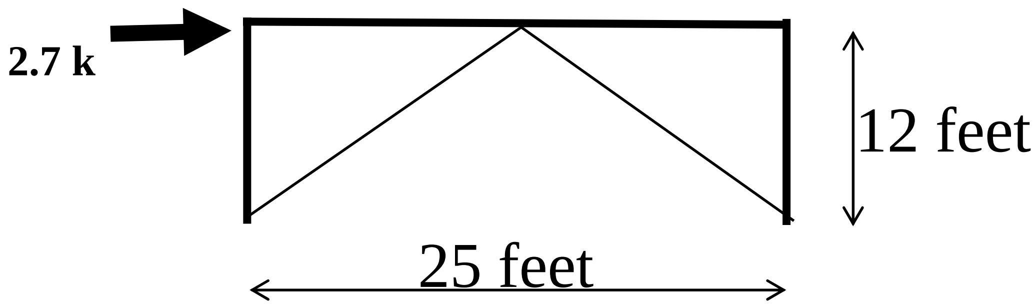
Specify ¾" steel cable (A = 0.44 in^2)

Wind Bracing Example



What about bracing in other direction?

Wind Bracing Example

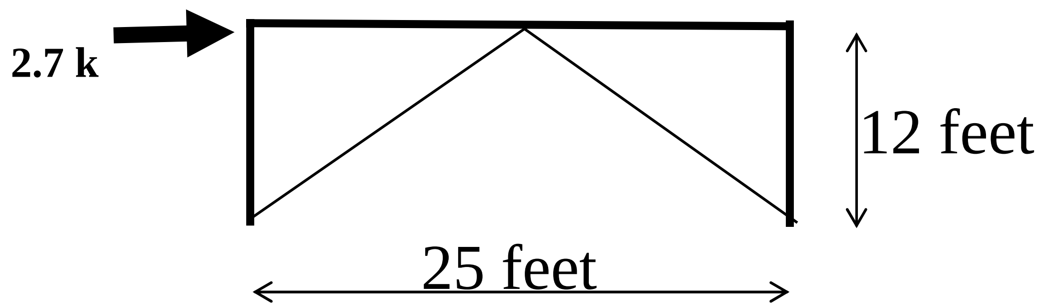


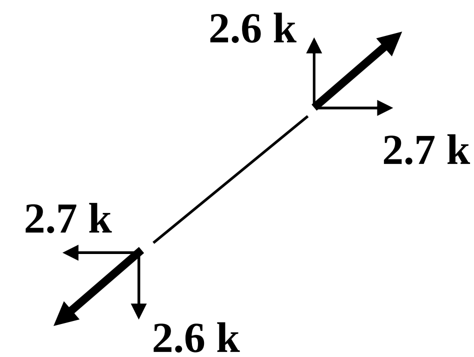
Assume bracing carries 100% of wind load, then the horizontal component of force in the cable must be 2.7 k

$$F_v/(2.7\ k) = (12\ ft)/(12.5\ ft)$$

$$F_v = 2.6\ k$$

Wind Bracing Example

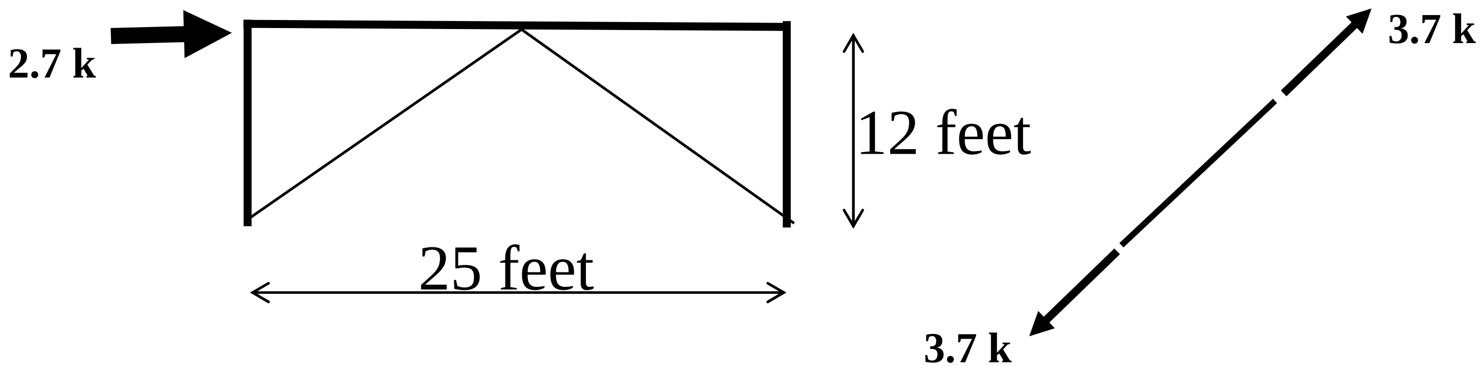




Internal force in the cable is found from Pythagorean Theorem

$$F_{cable} = \sqrt{(2.7\ k)^2 + (2.6\ k)^2} = 3.7\ k$$

Required Area of Steel Cable



Maximum allowable stress in cable is 15 ksi (given)

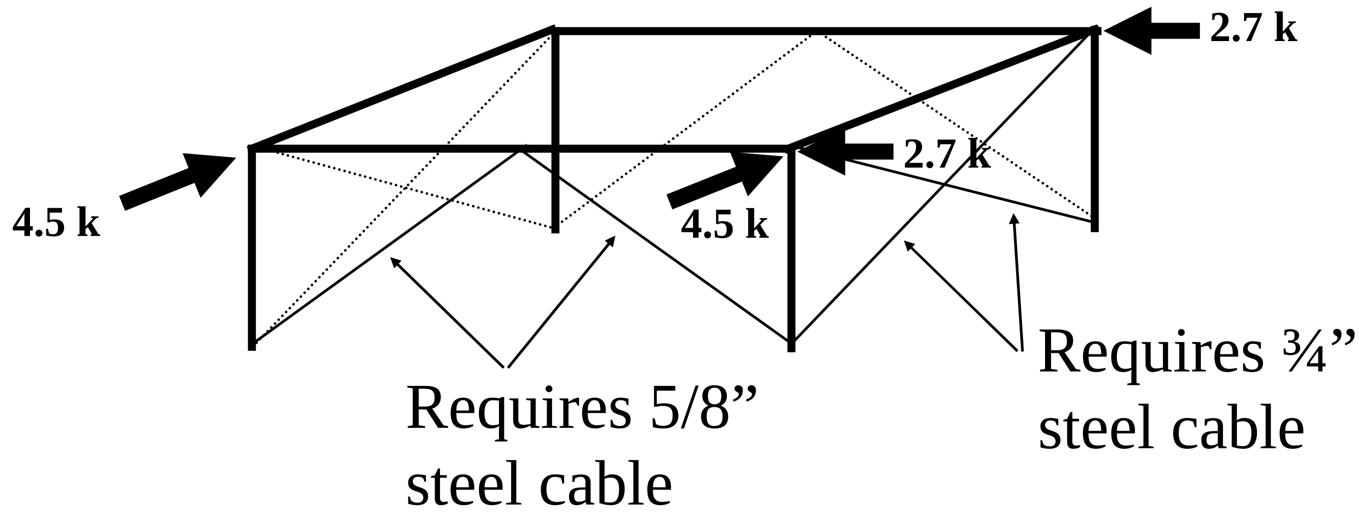
Stress = Force/Area

$A_{req'd}$ = Force/Stress = 3.7 k/15 ksi = 0.25 in^2

Cable diameter, d = 0.56 inches (A=$\pi(0.56)^2/4$ = 0.25 in^2)

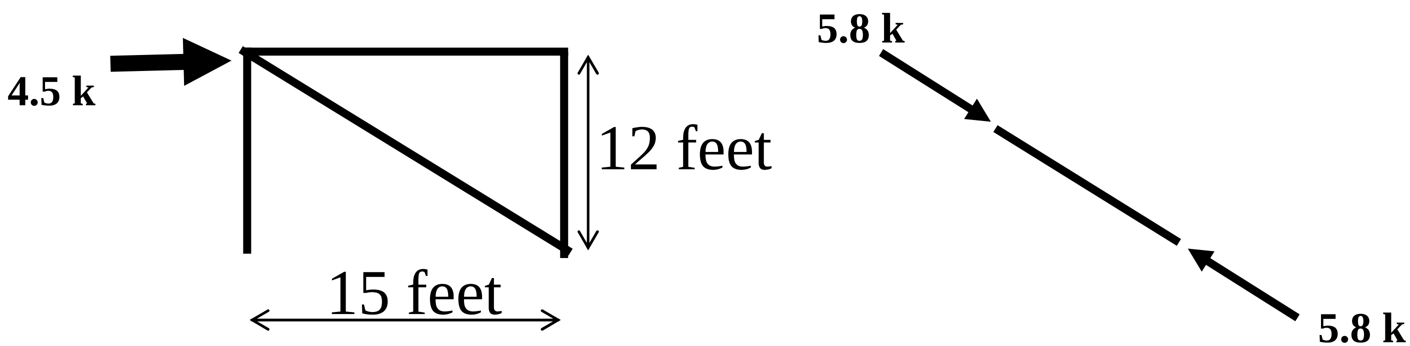
Specify 5/8" steel cable (A = 0.31 in^2)

Wind Bracing Example



Design of wind bracing for cables

Compression Element as Wind Bracing

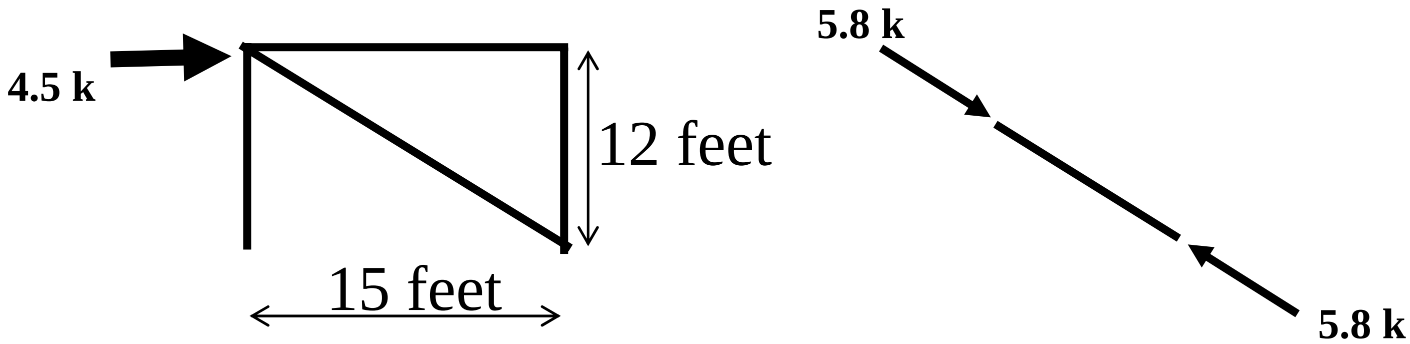


Now one element must carry 5.8 k in both tension and compression

For tension, must have an area of 0.38 in^2 (3/4 in diameter bar)

So cross-sectional area must be greater than 0.38 in^2

Compression Element as Wind Bracing



Compression element requires about 6 times the material (to resist buckling)

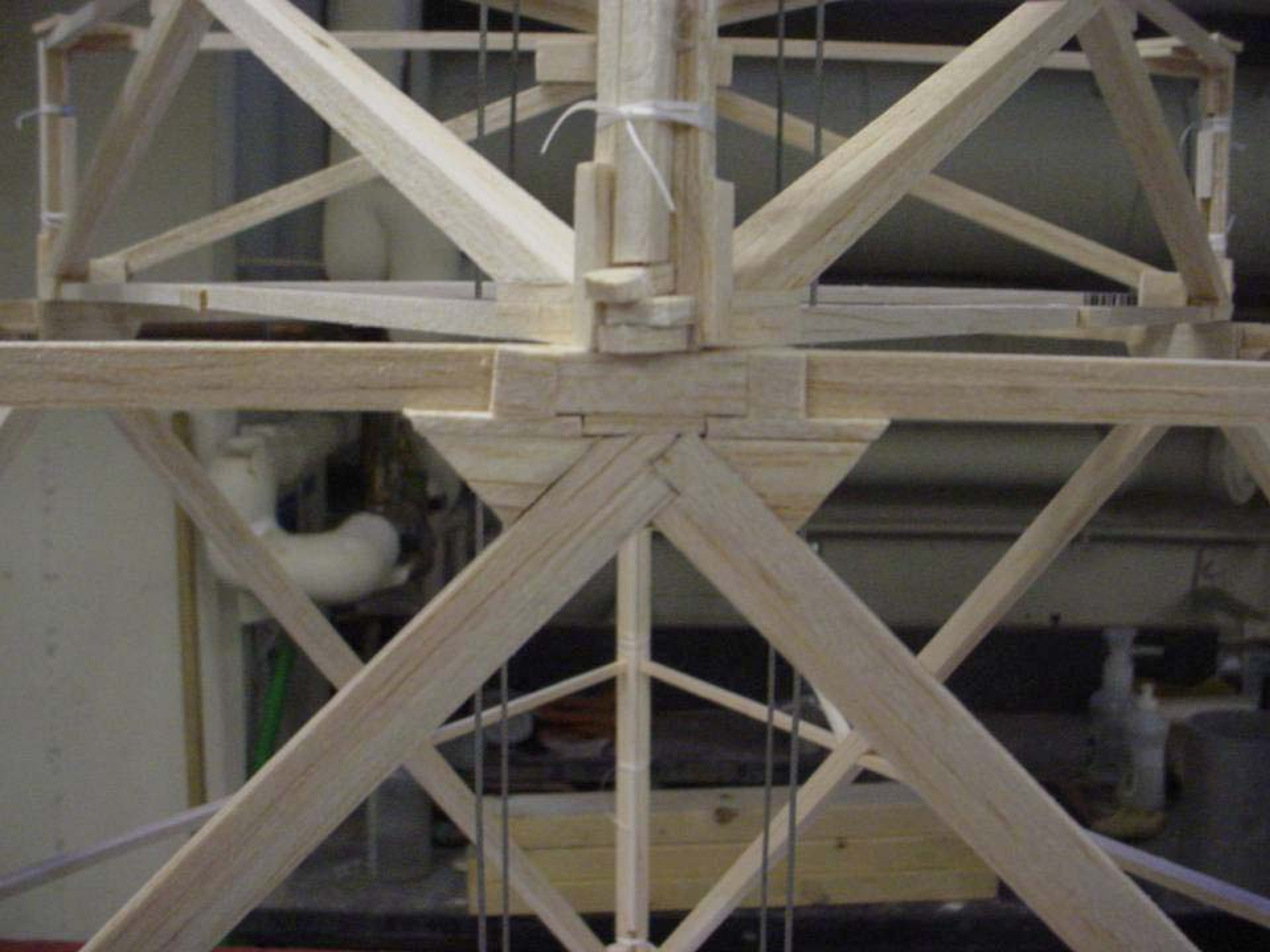
Design Considerations

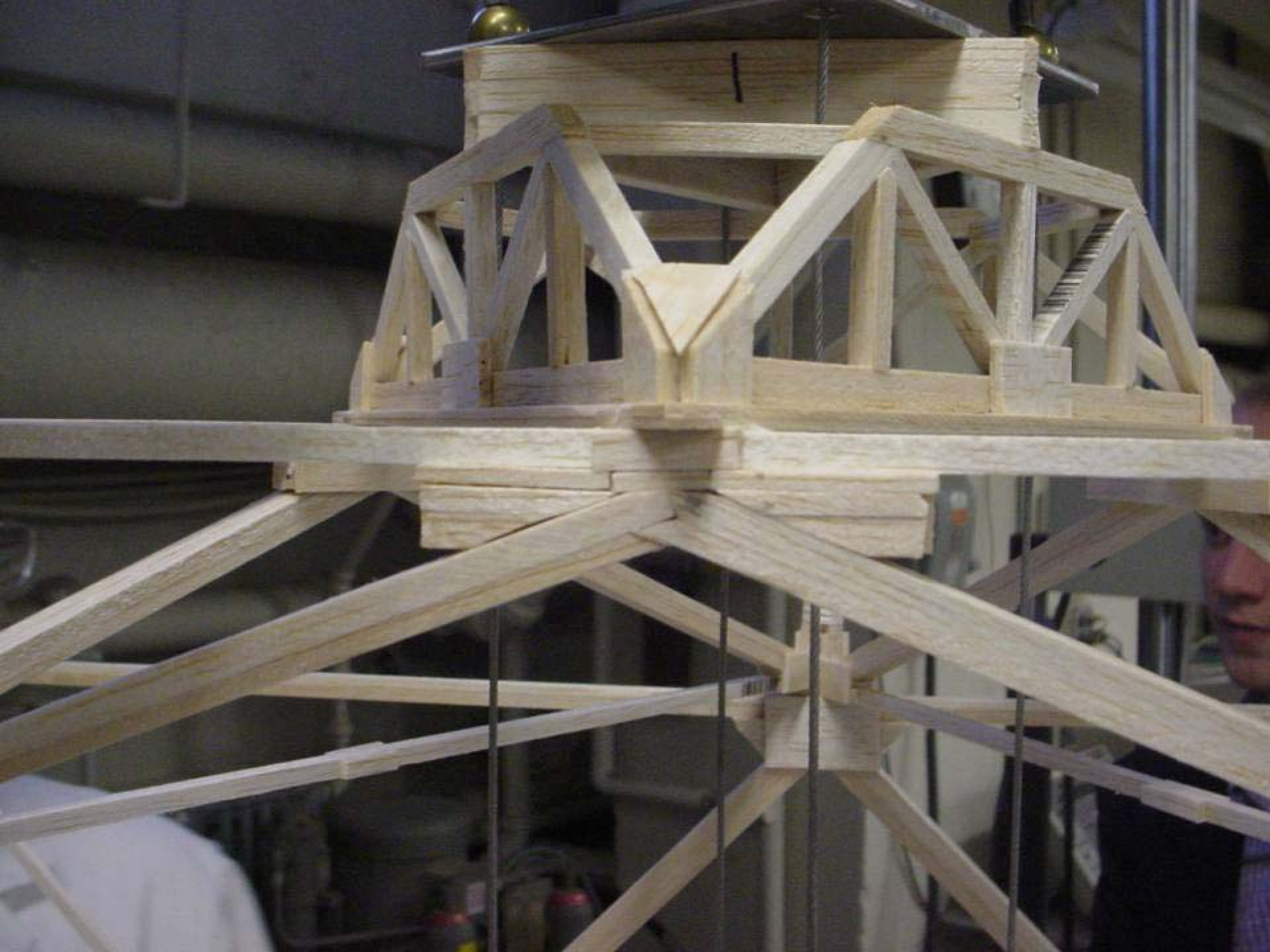
- Tension braces use less material than compression braces for lateral loads
- Compression members must resist buckling which requires extra material
- Must consider buckling about either axis, and should brace the weak axis

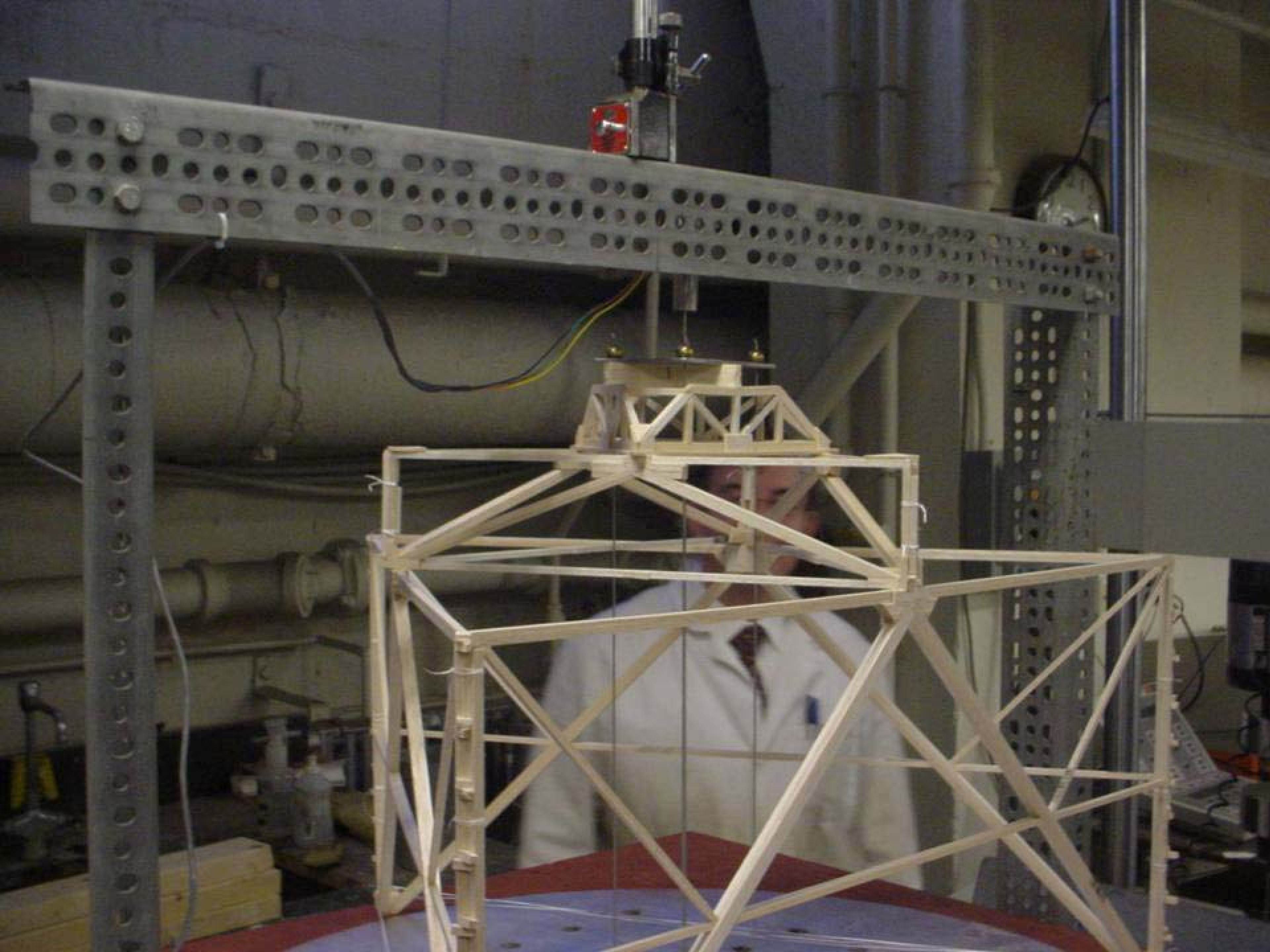
Design Considerations

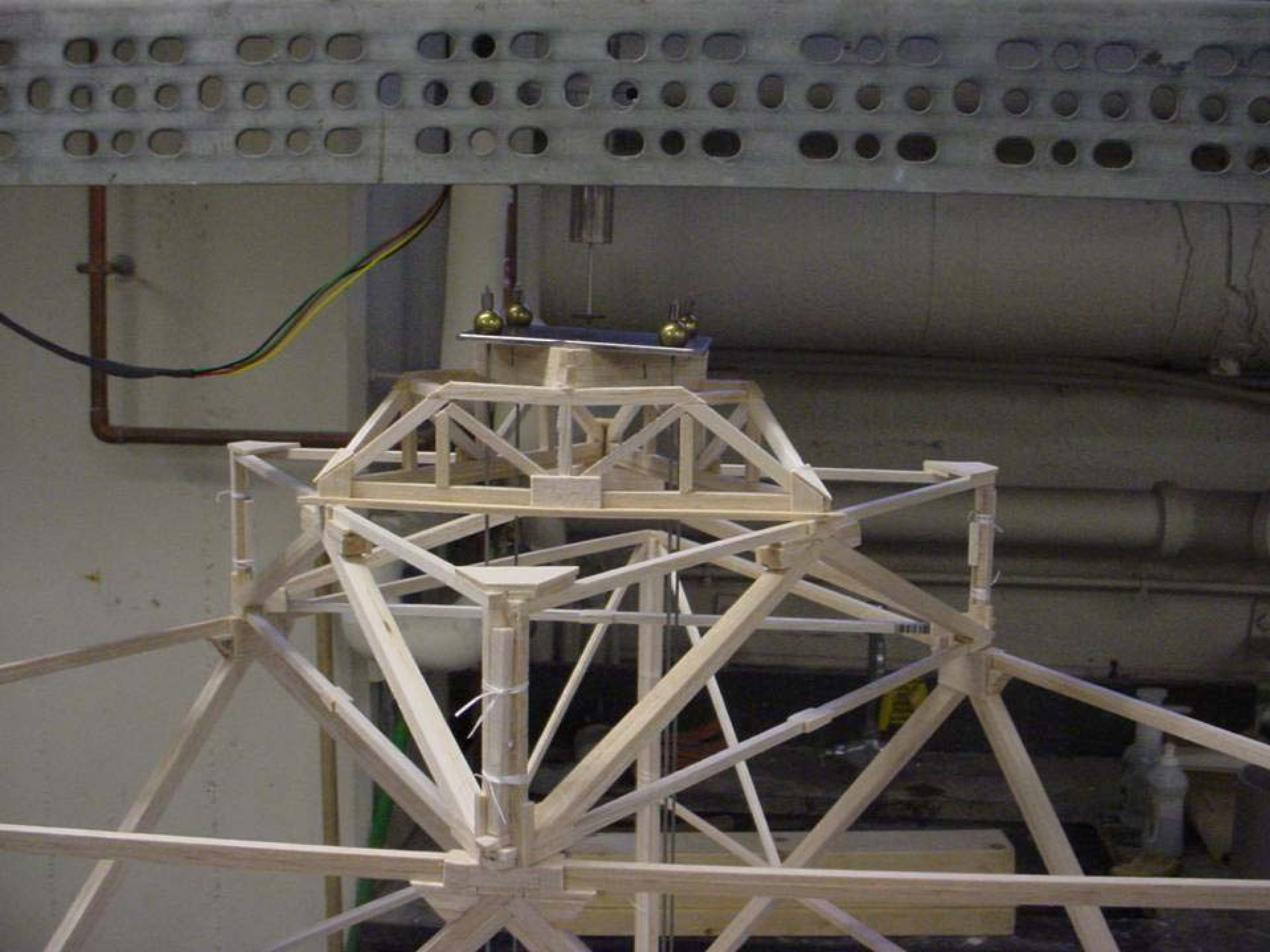
- Want to have ductility in our structures so that sudden collapse does not occur
- Failure by buckling may be sudden and unexpected → not a ductile failure
- Statically determinate structures are easier to design because you can know the internal forces exactly

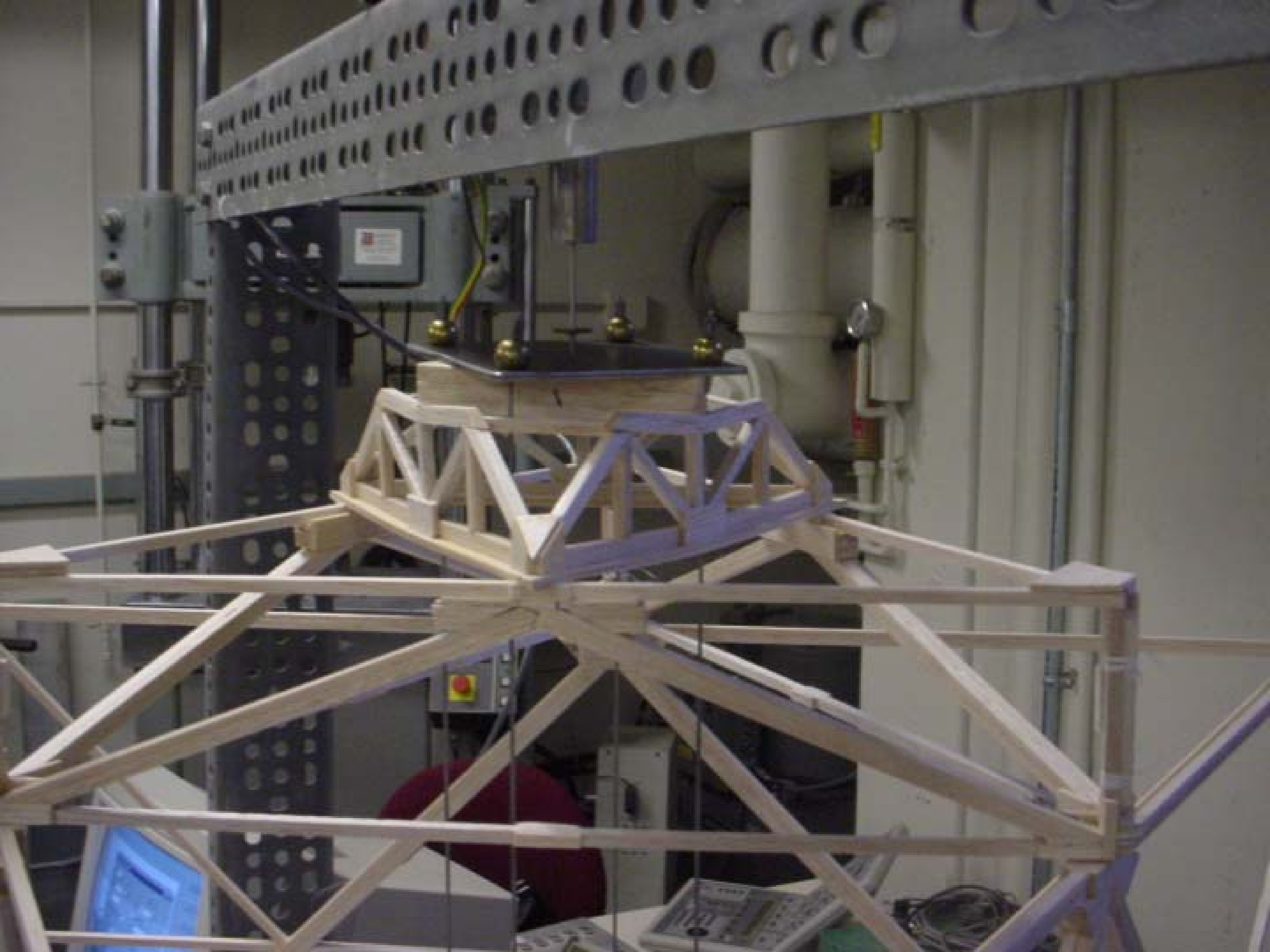
Balsa Dancing

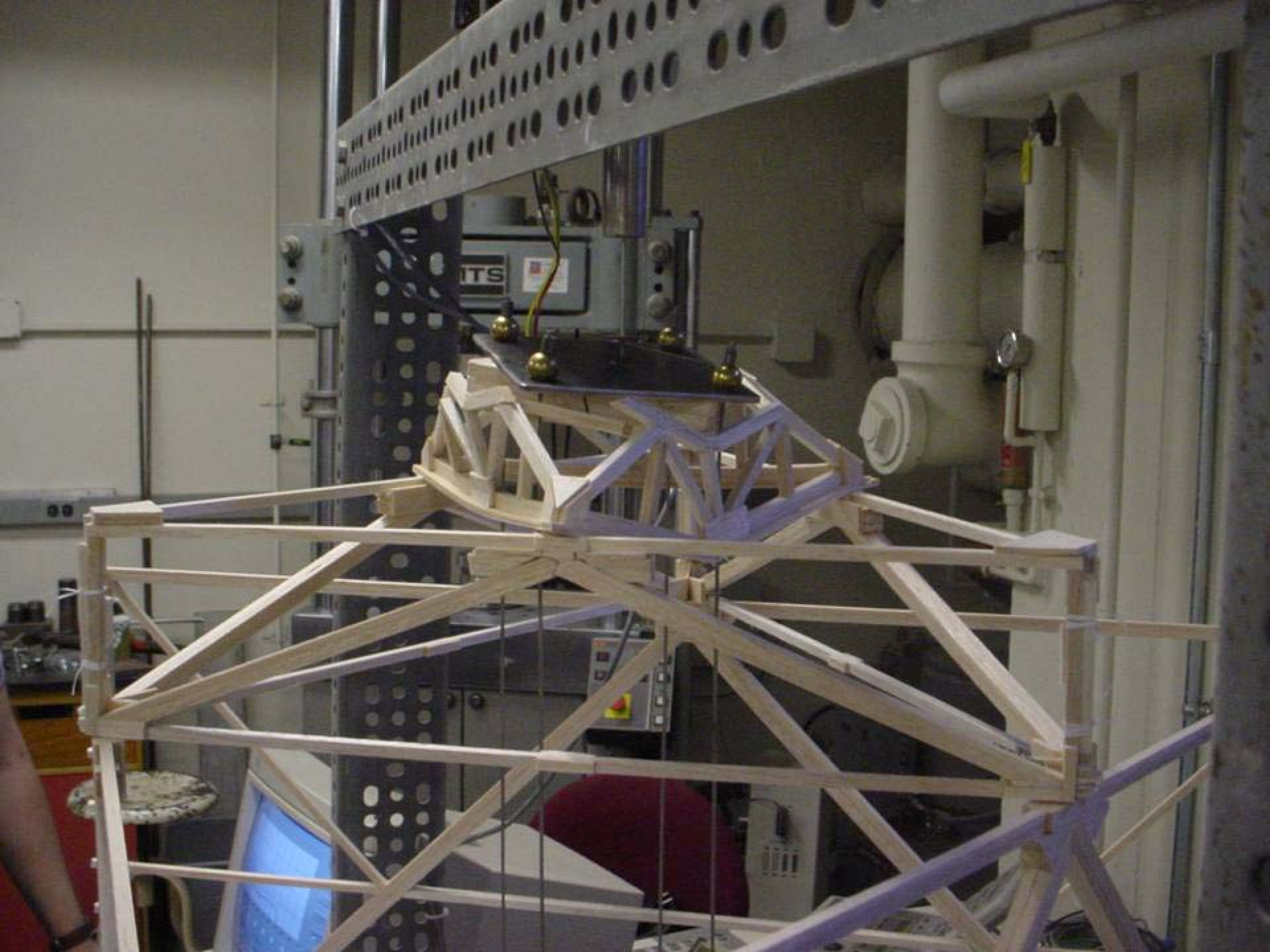


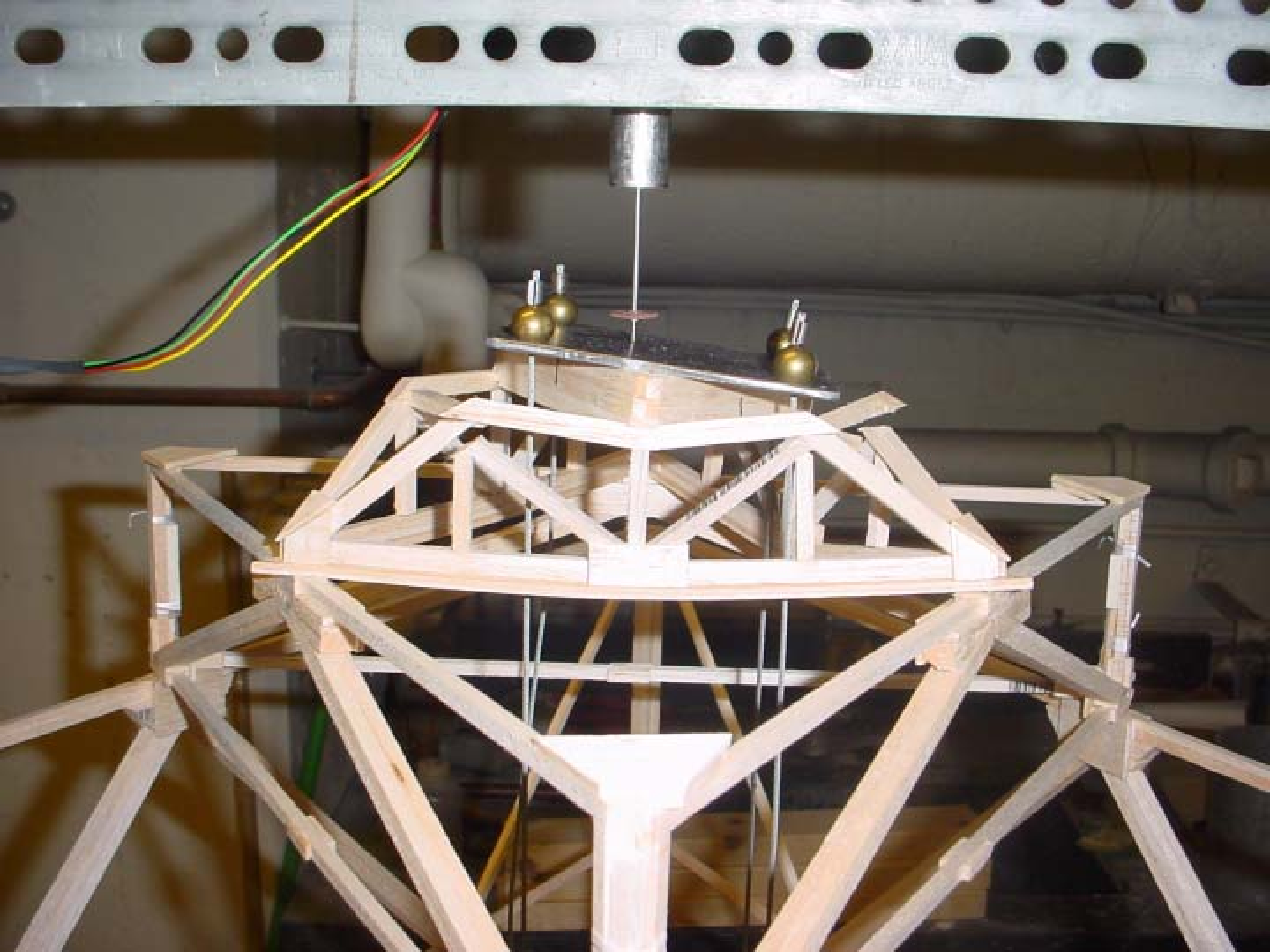


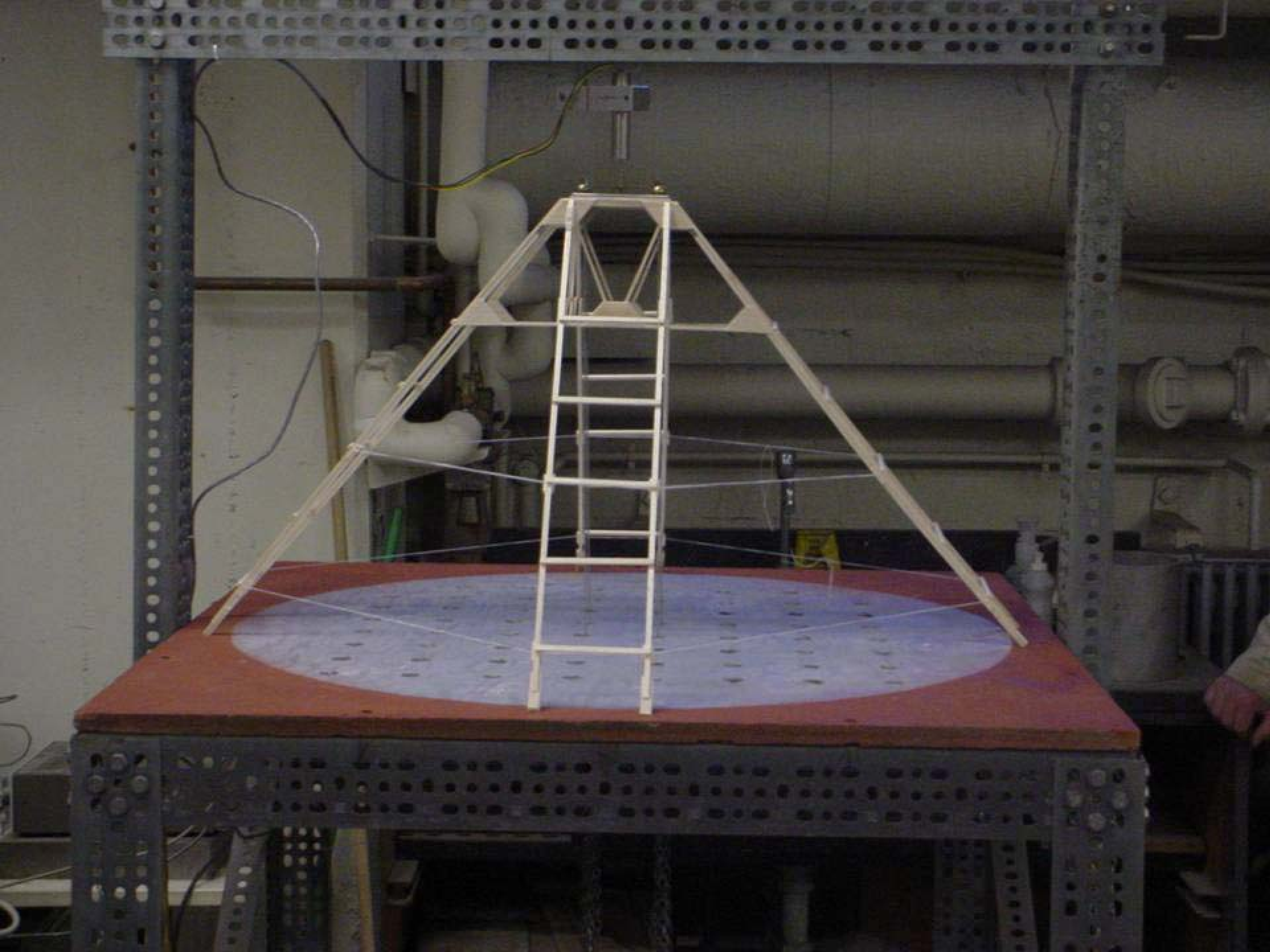


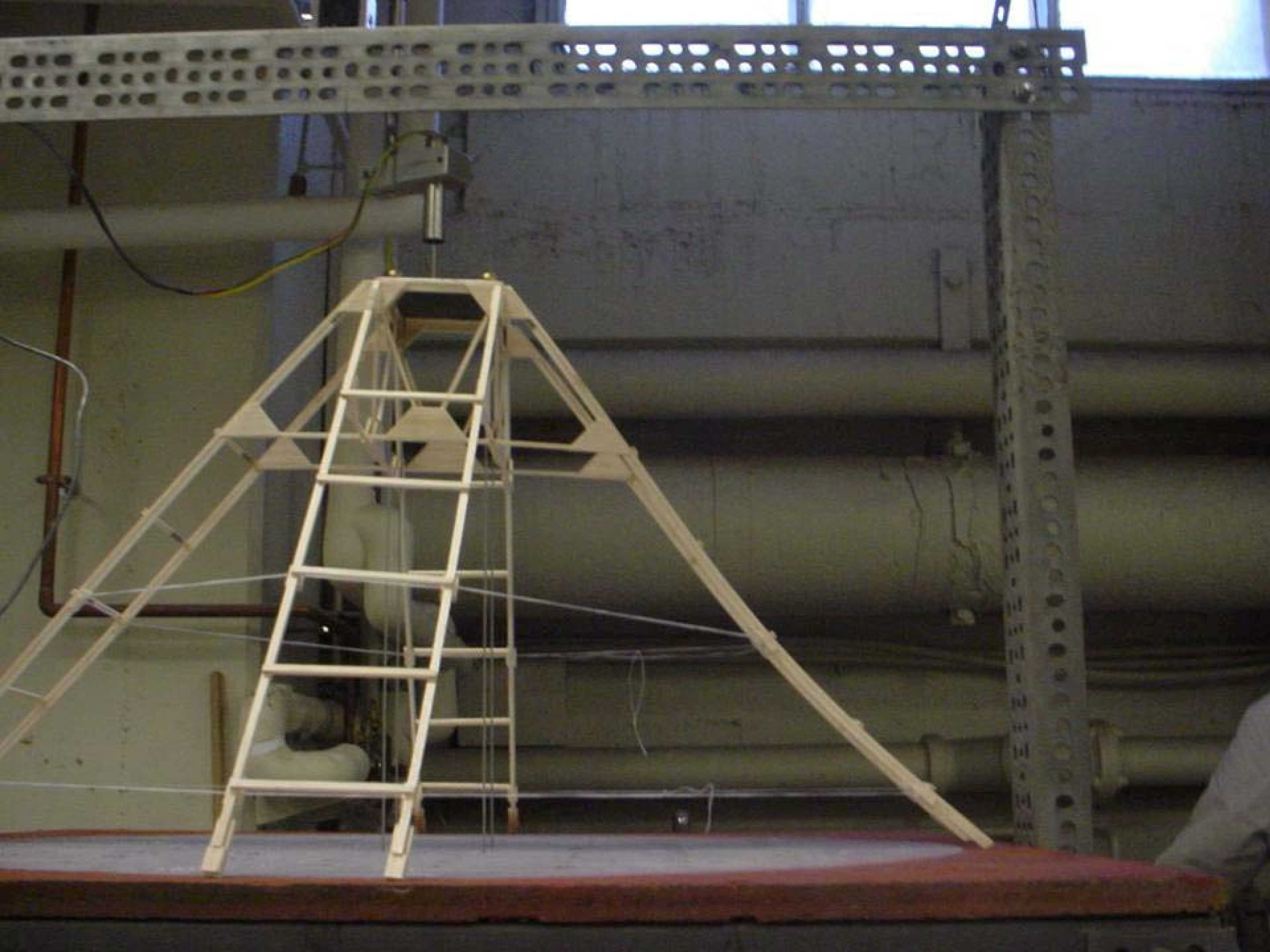


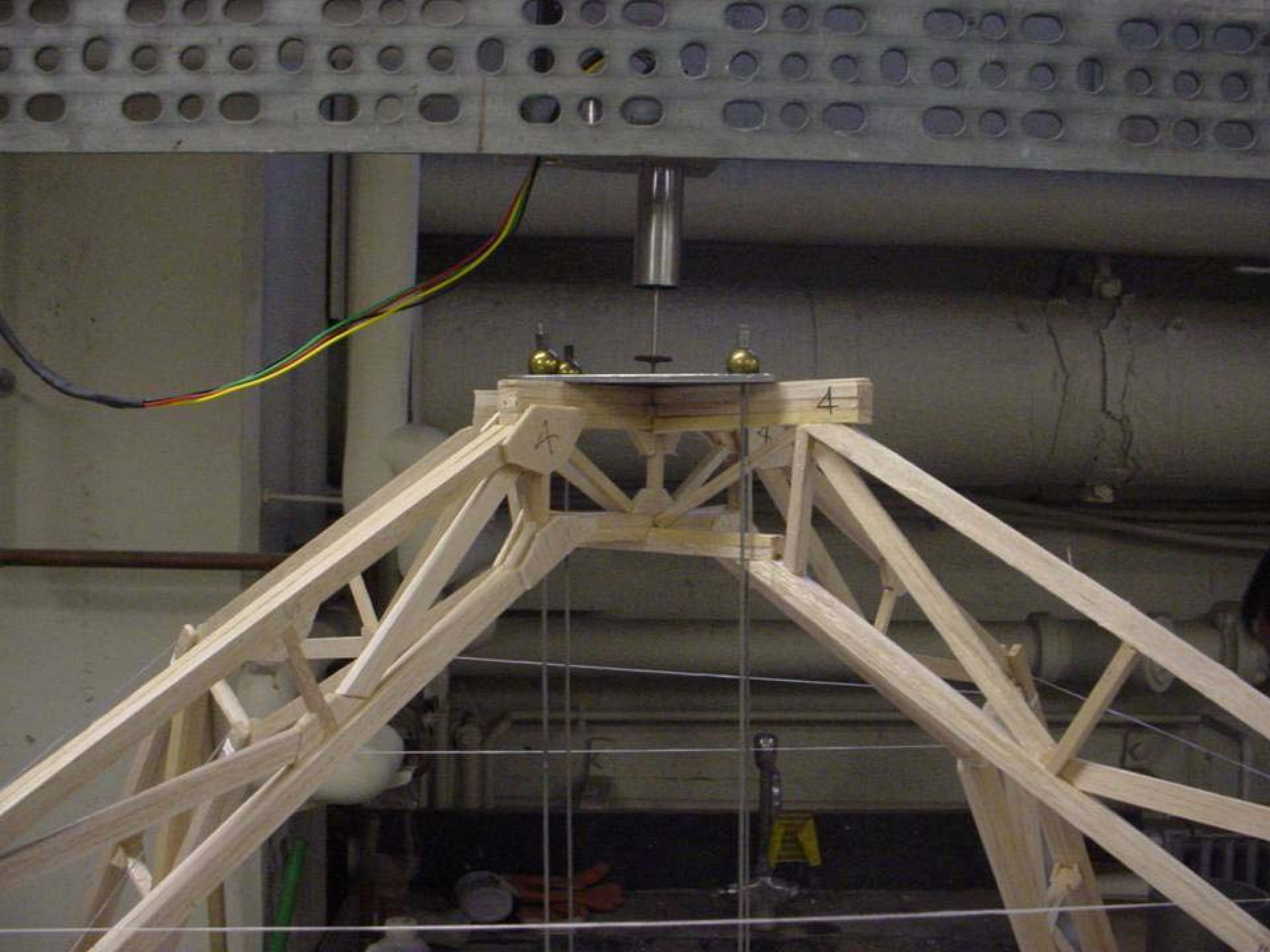








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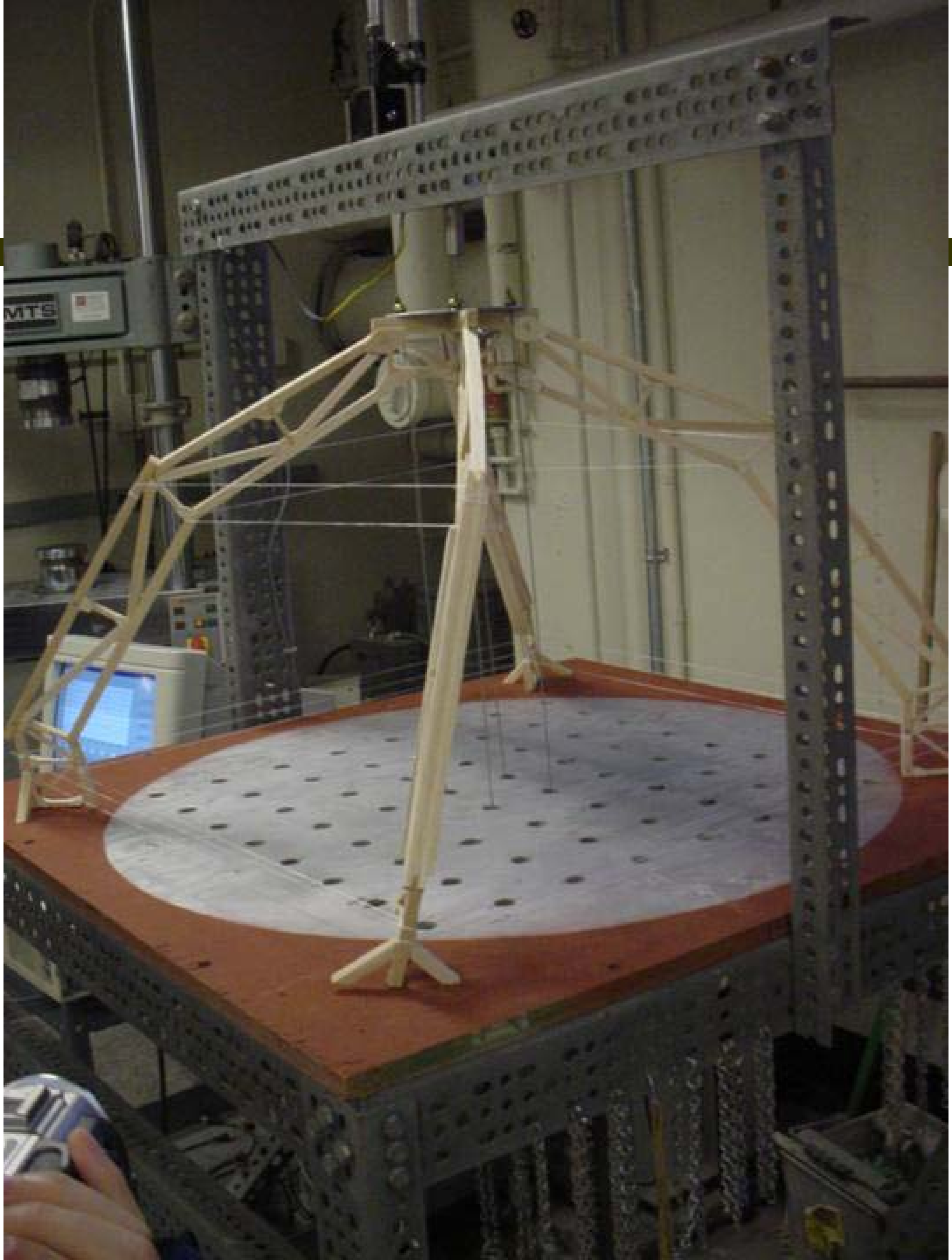
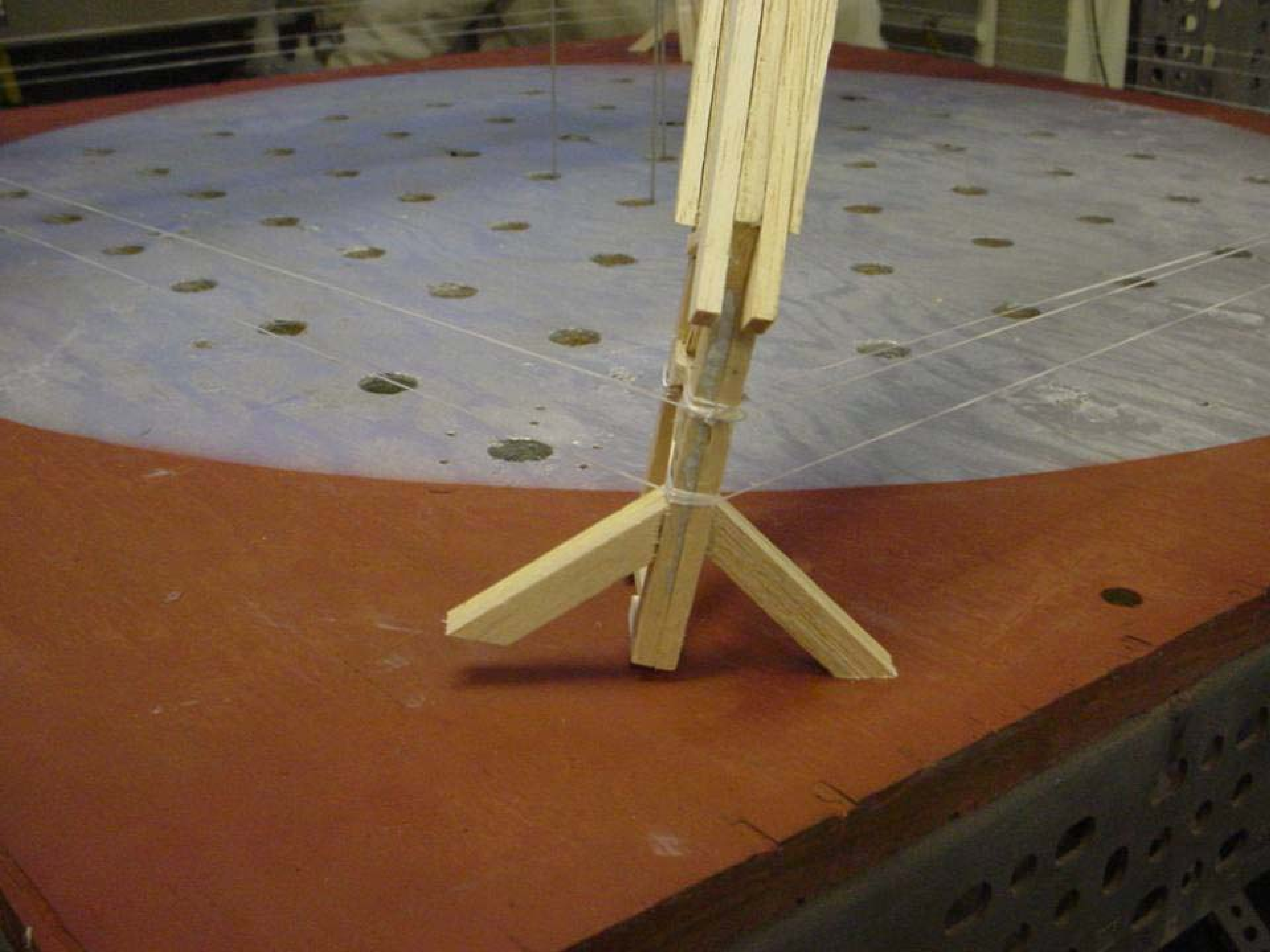
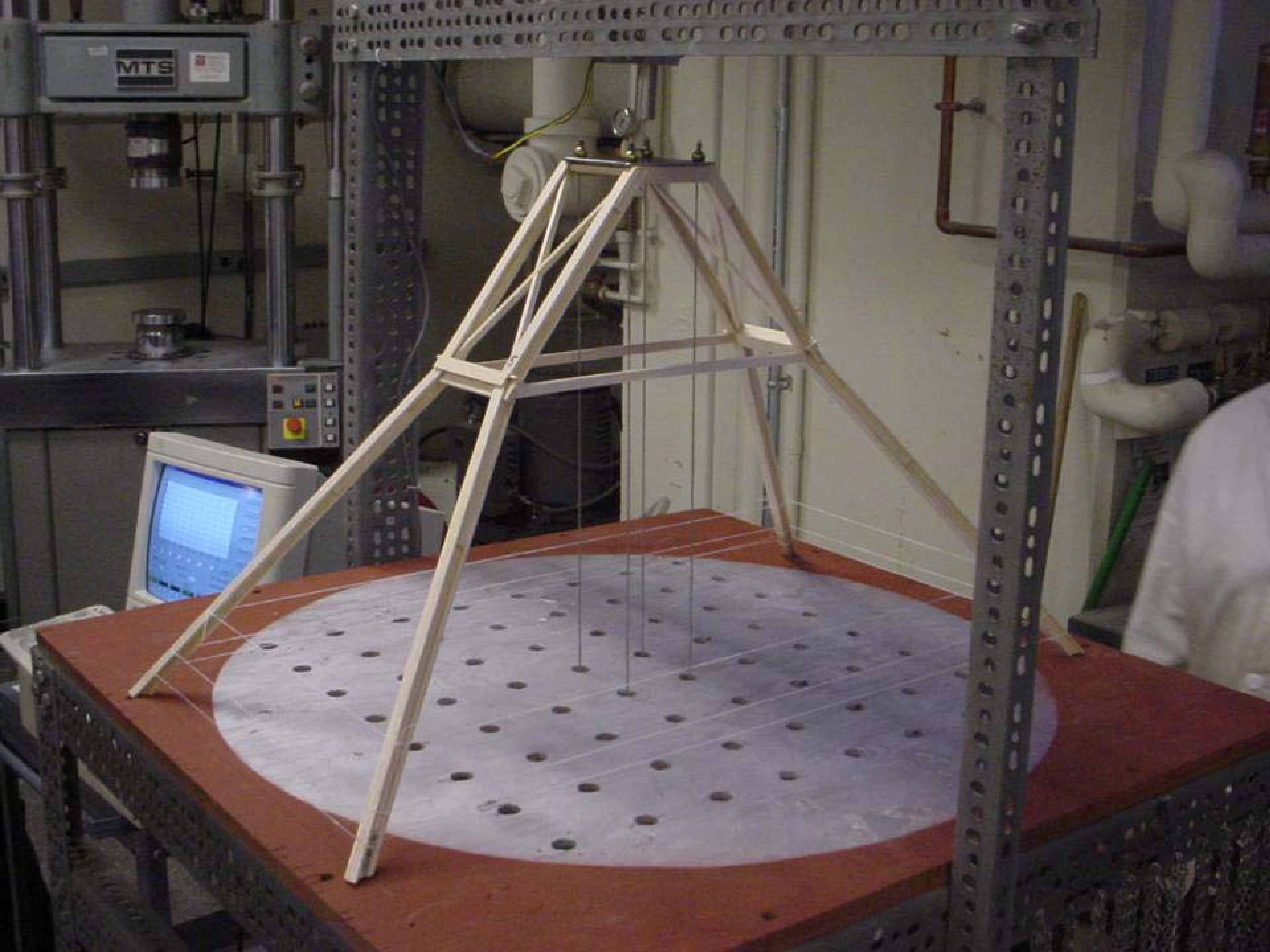
4


MTS

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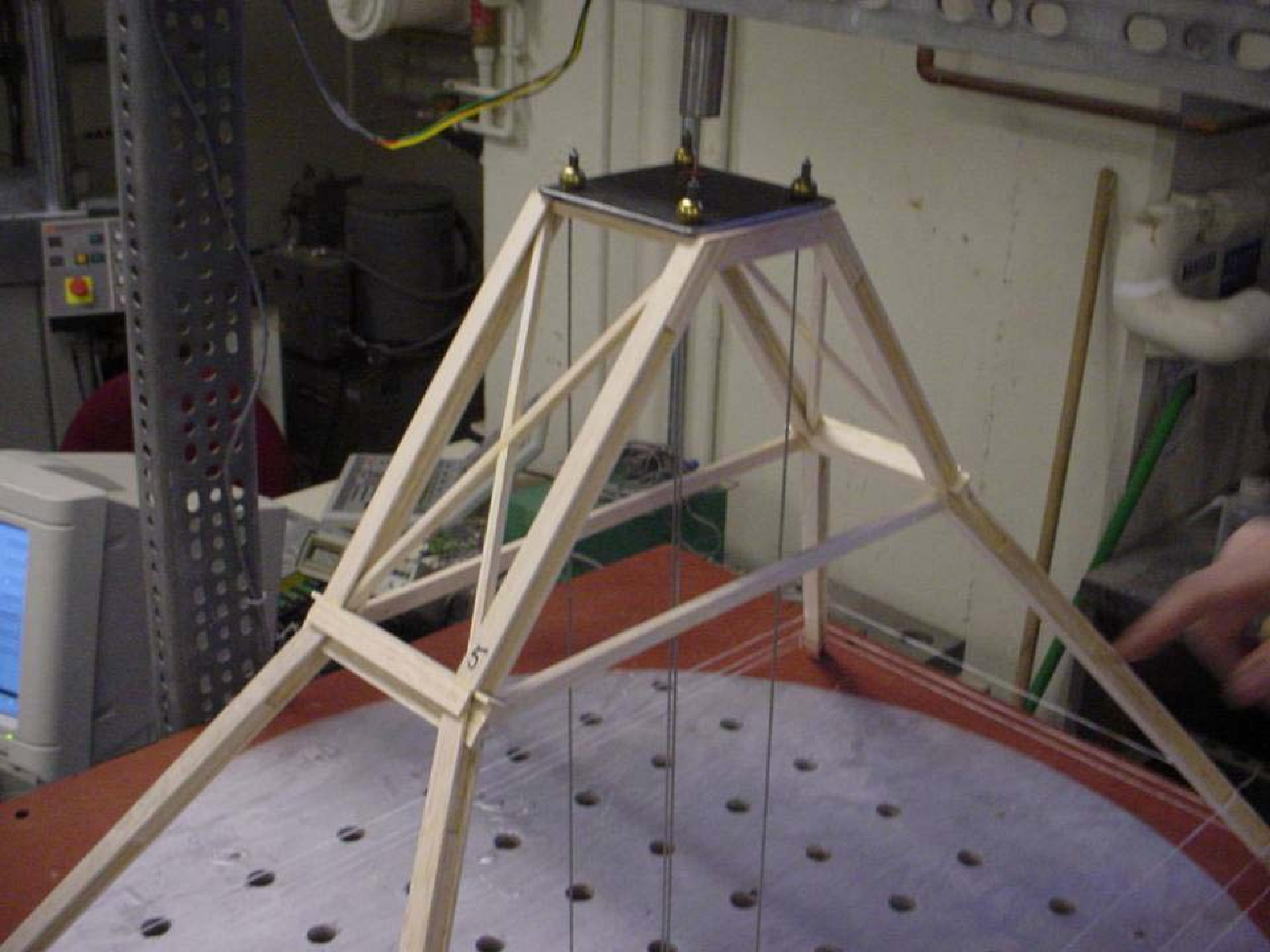
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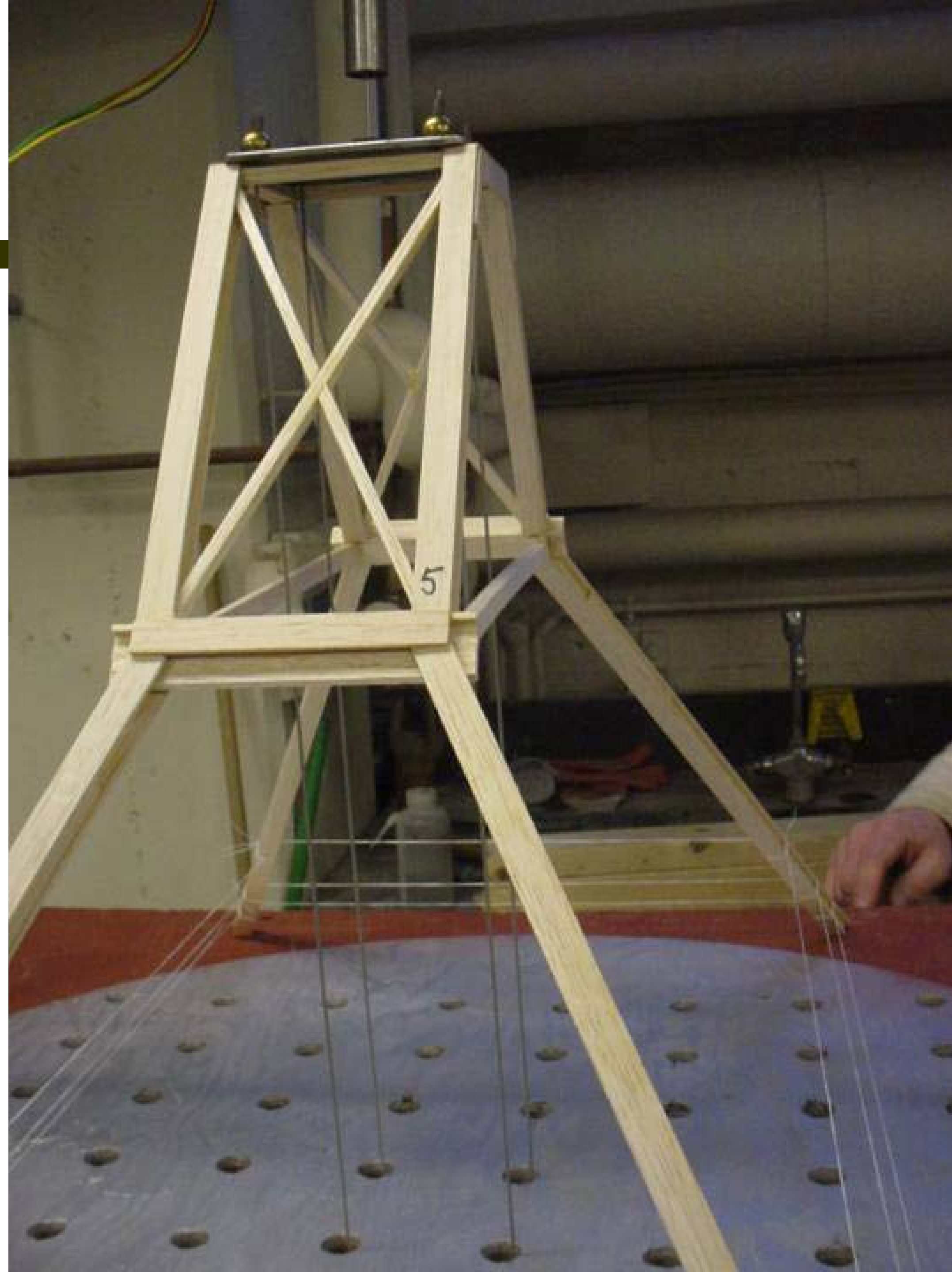
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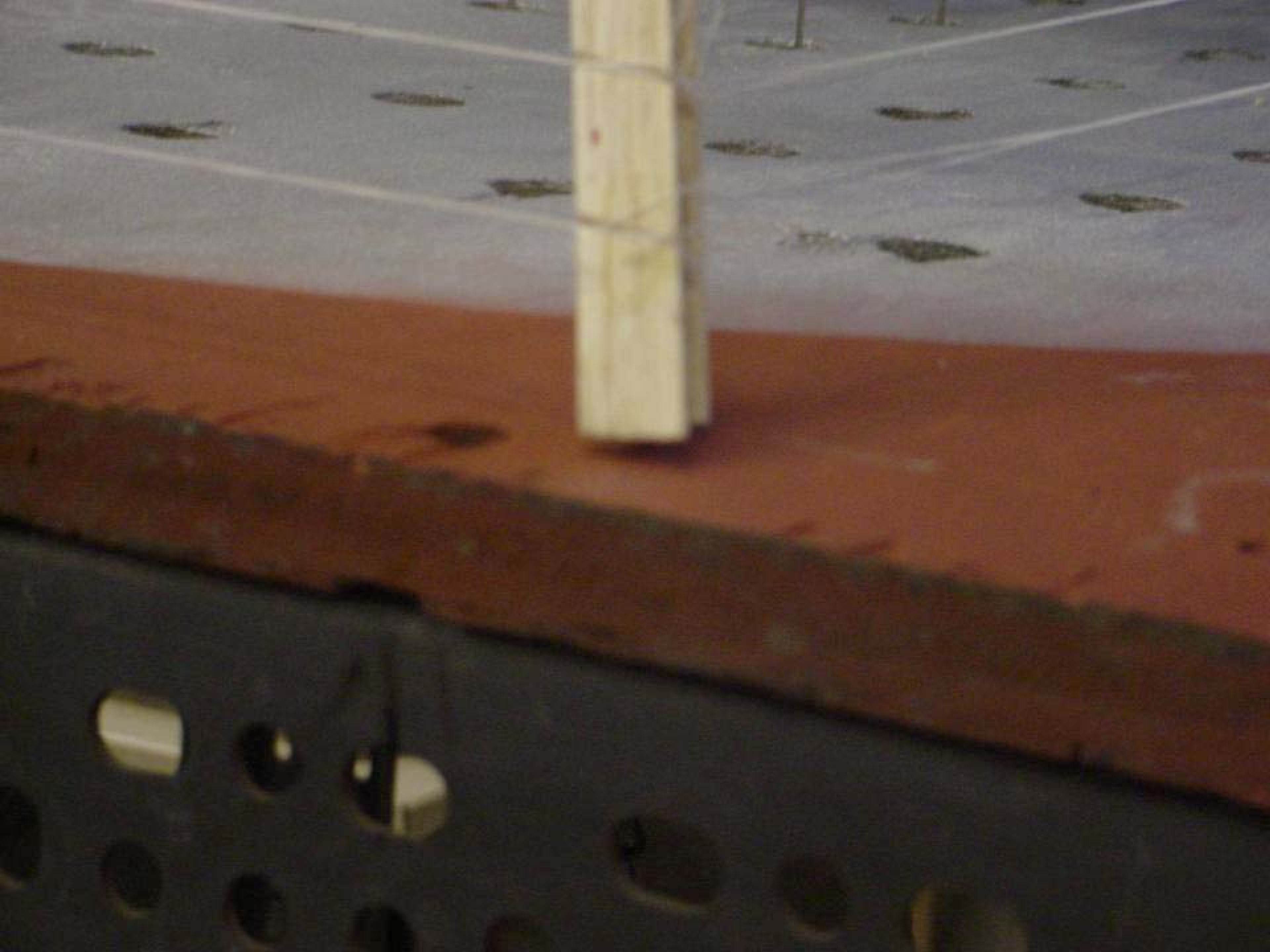

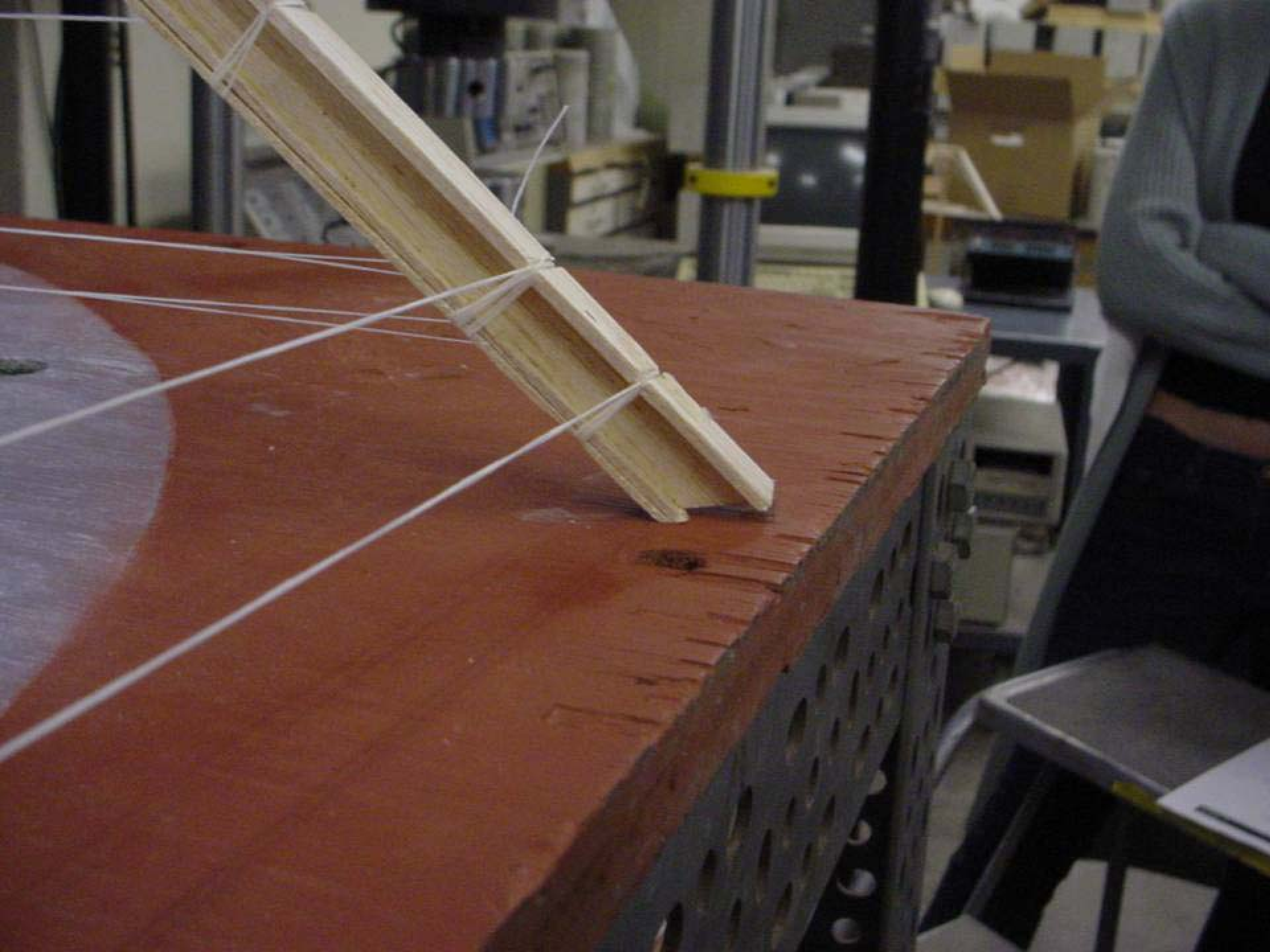

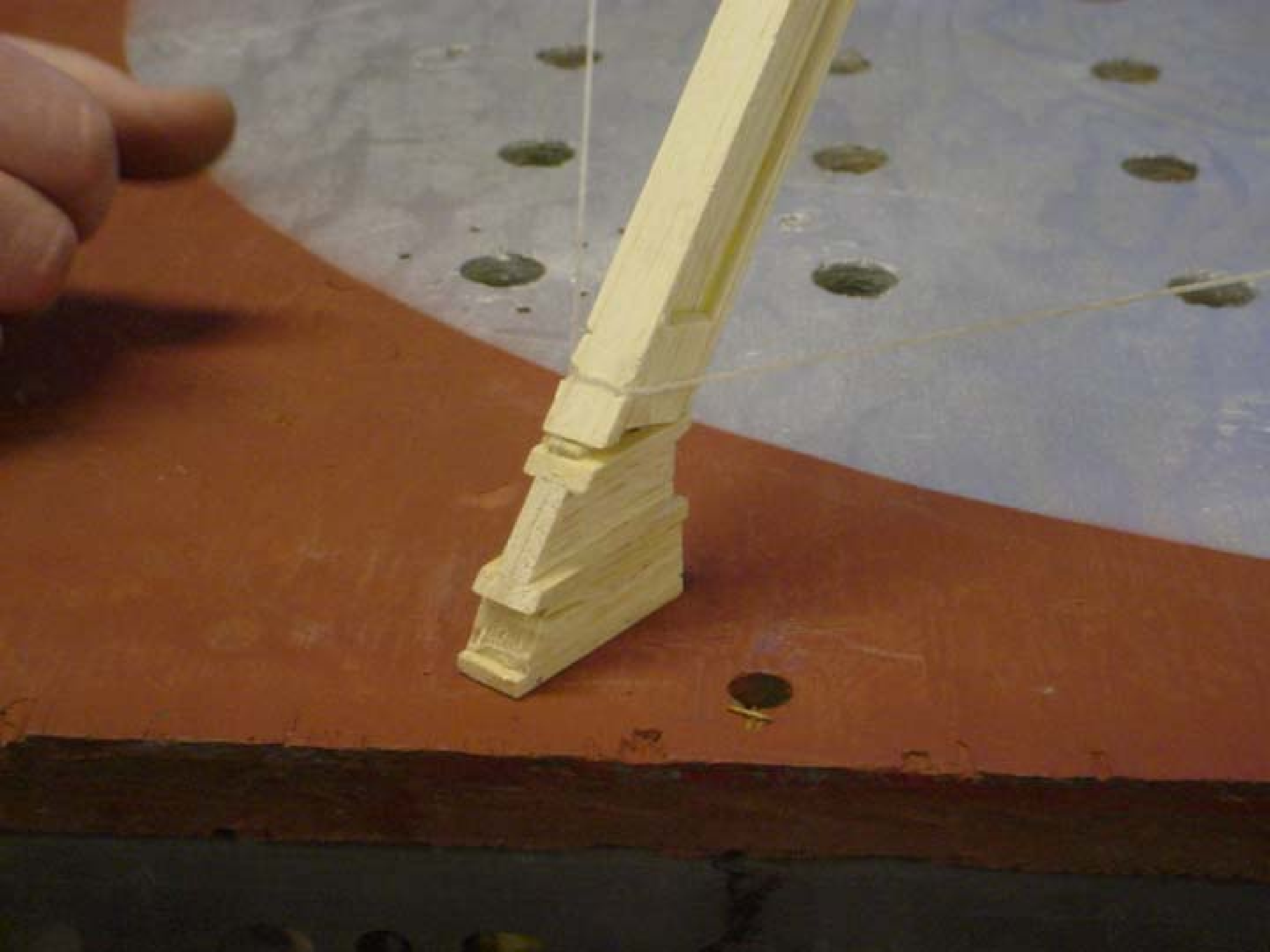

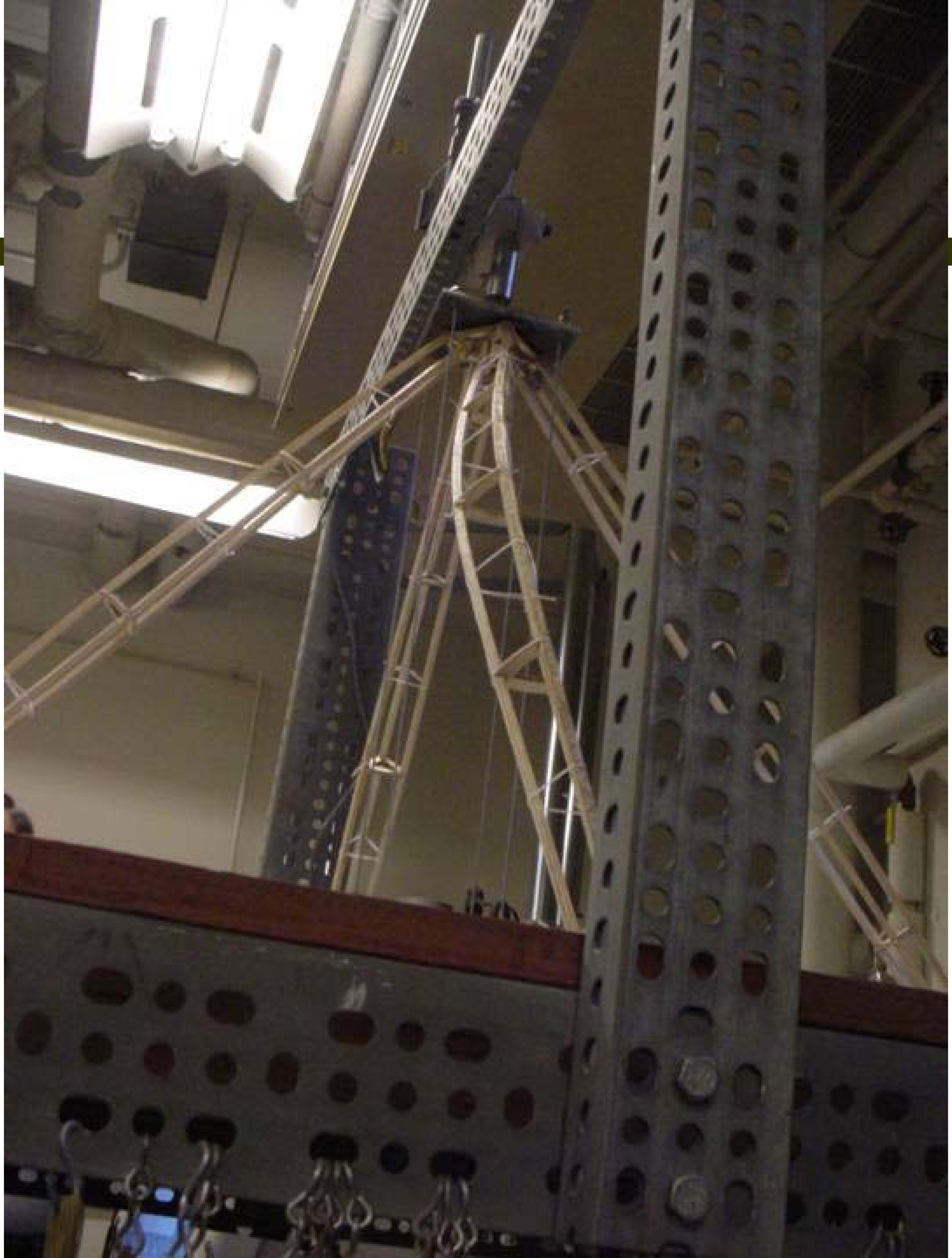

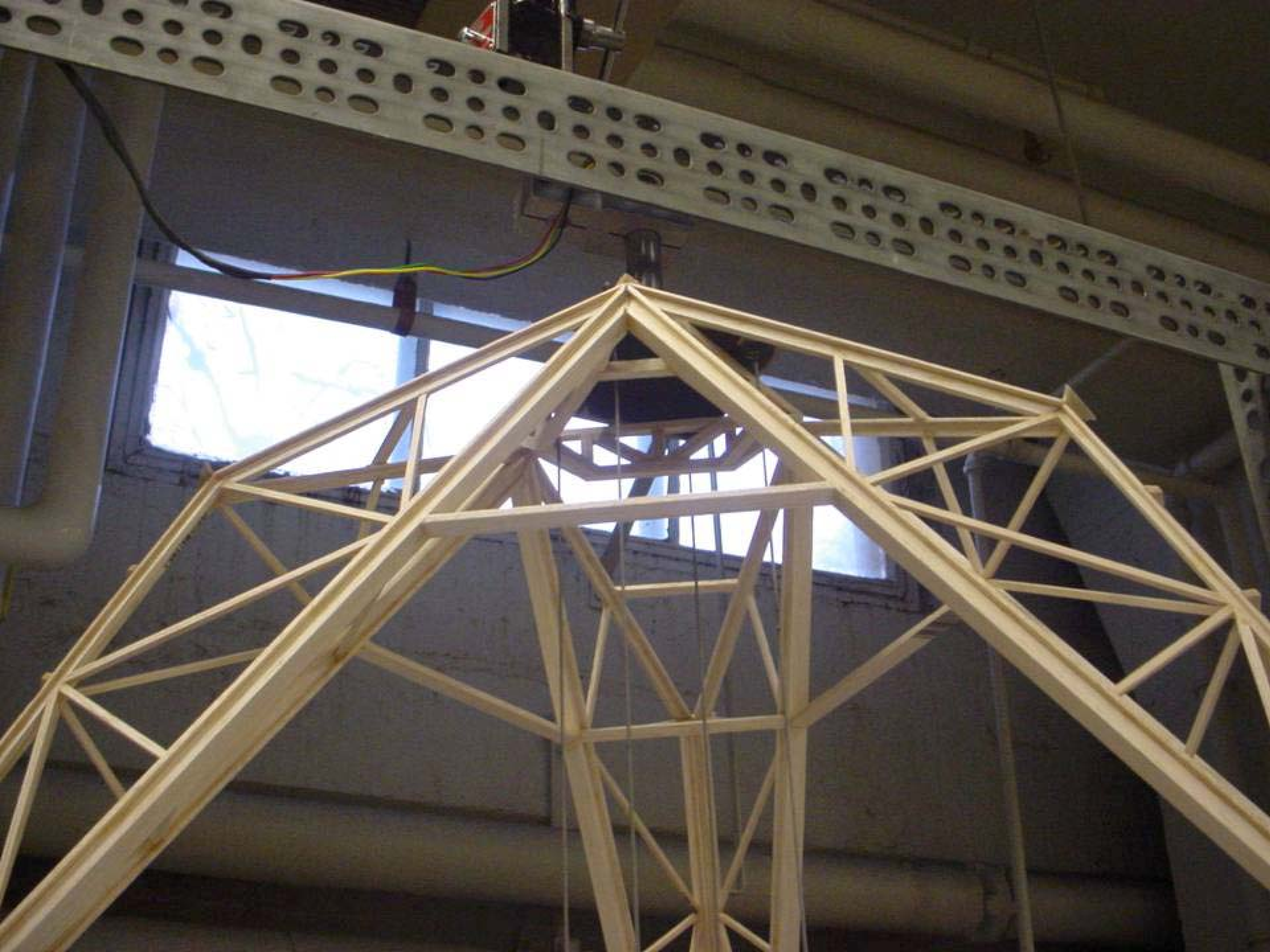

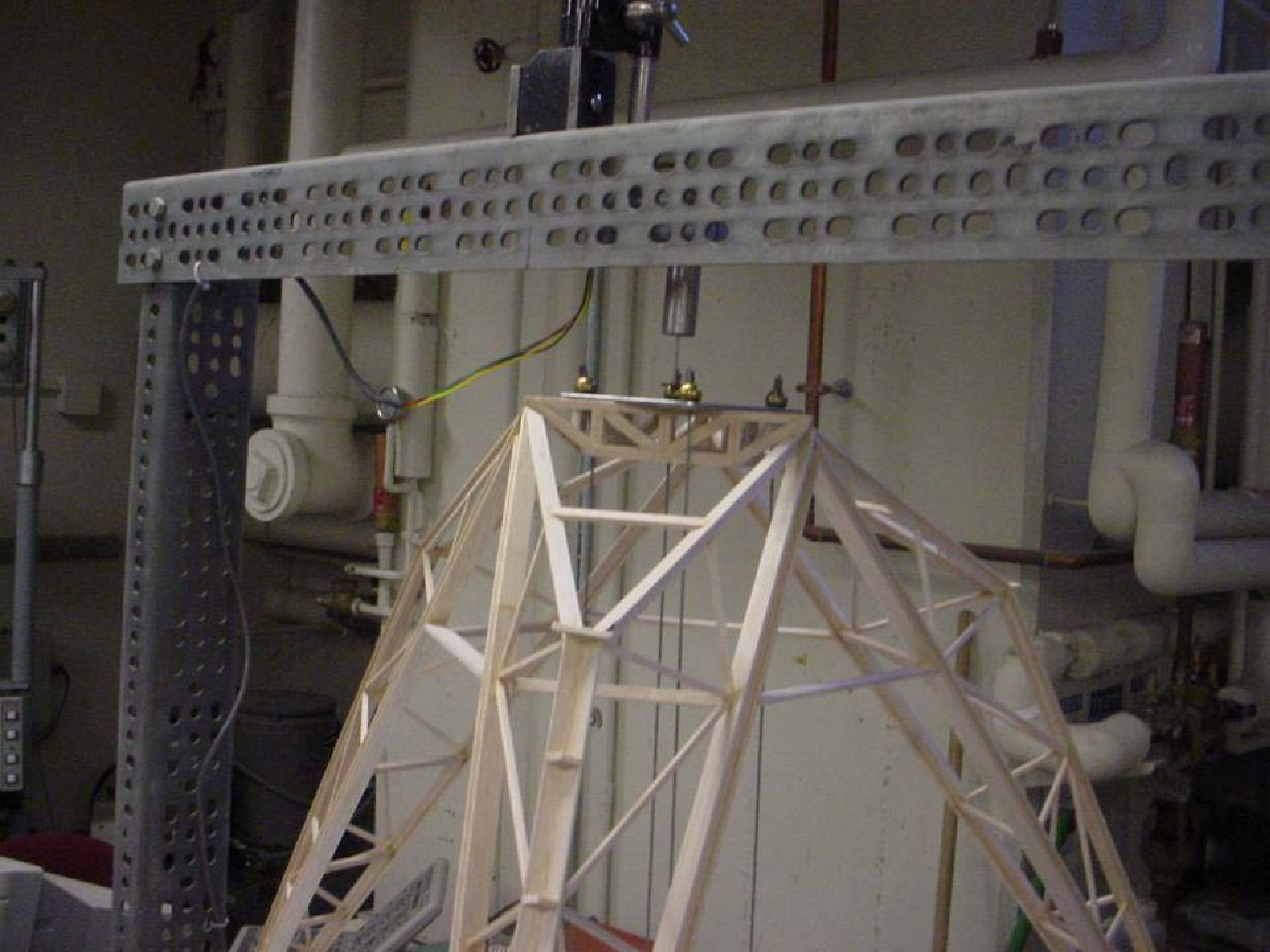

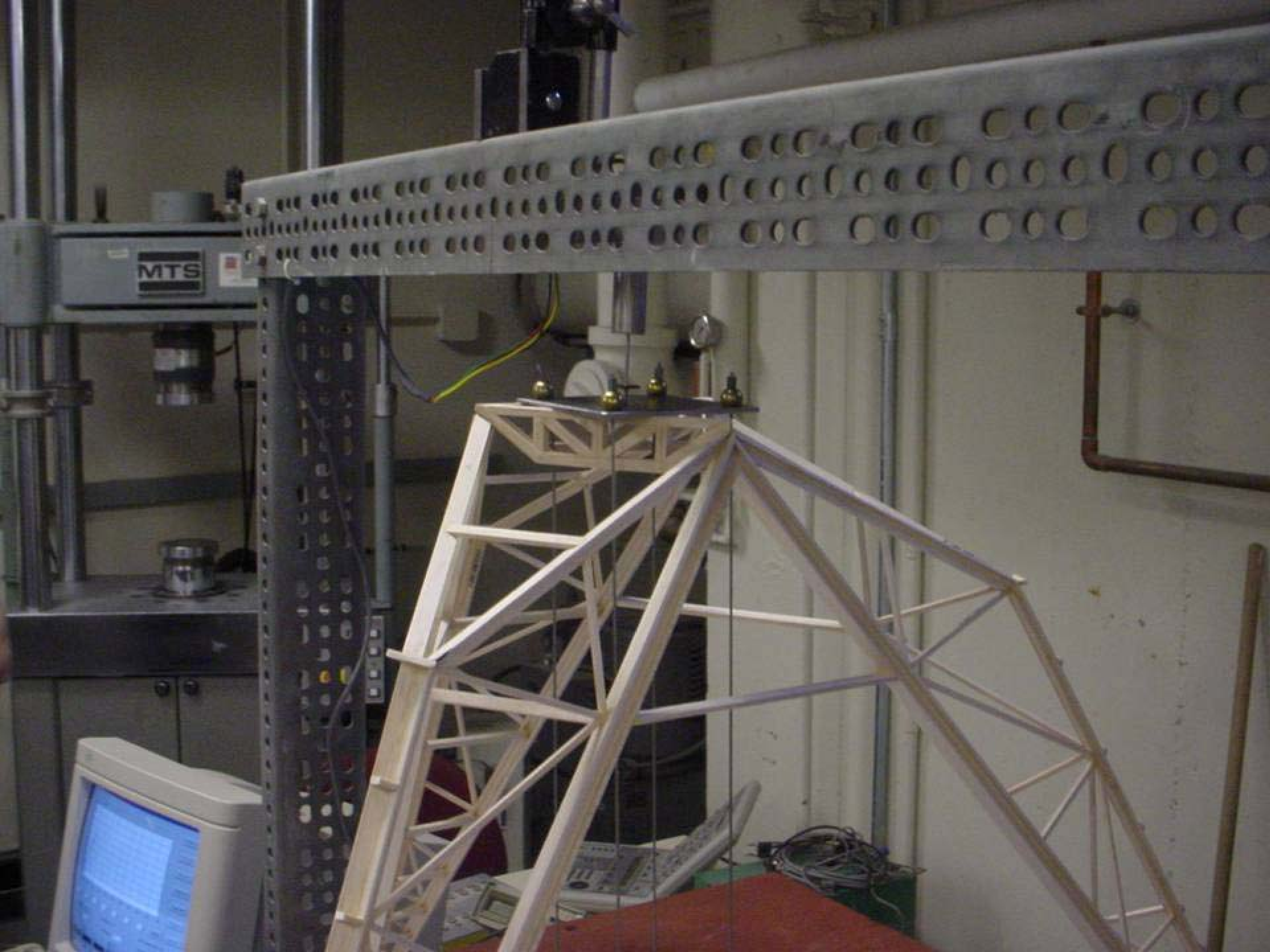
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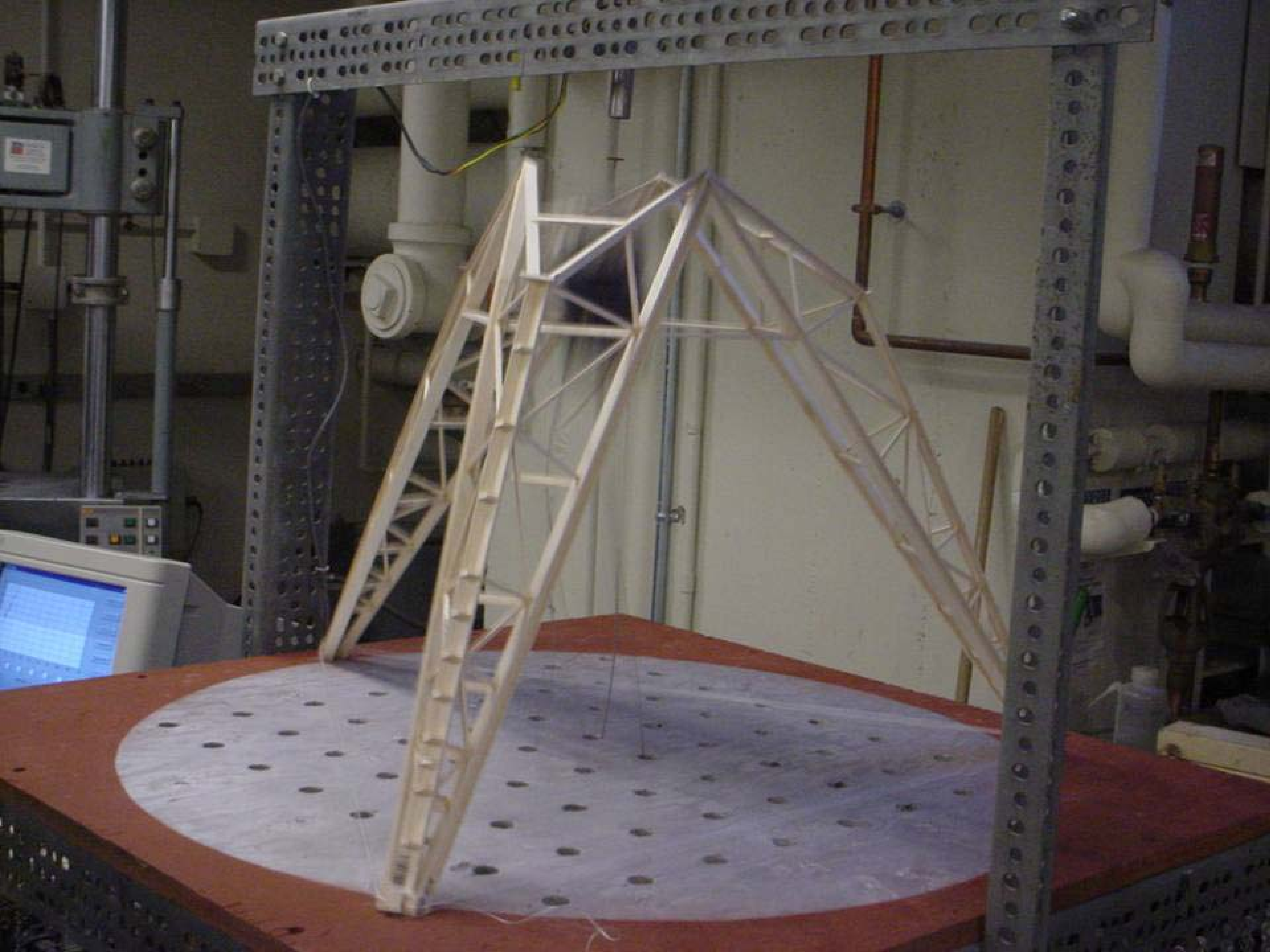
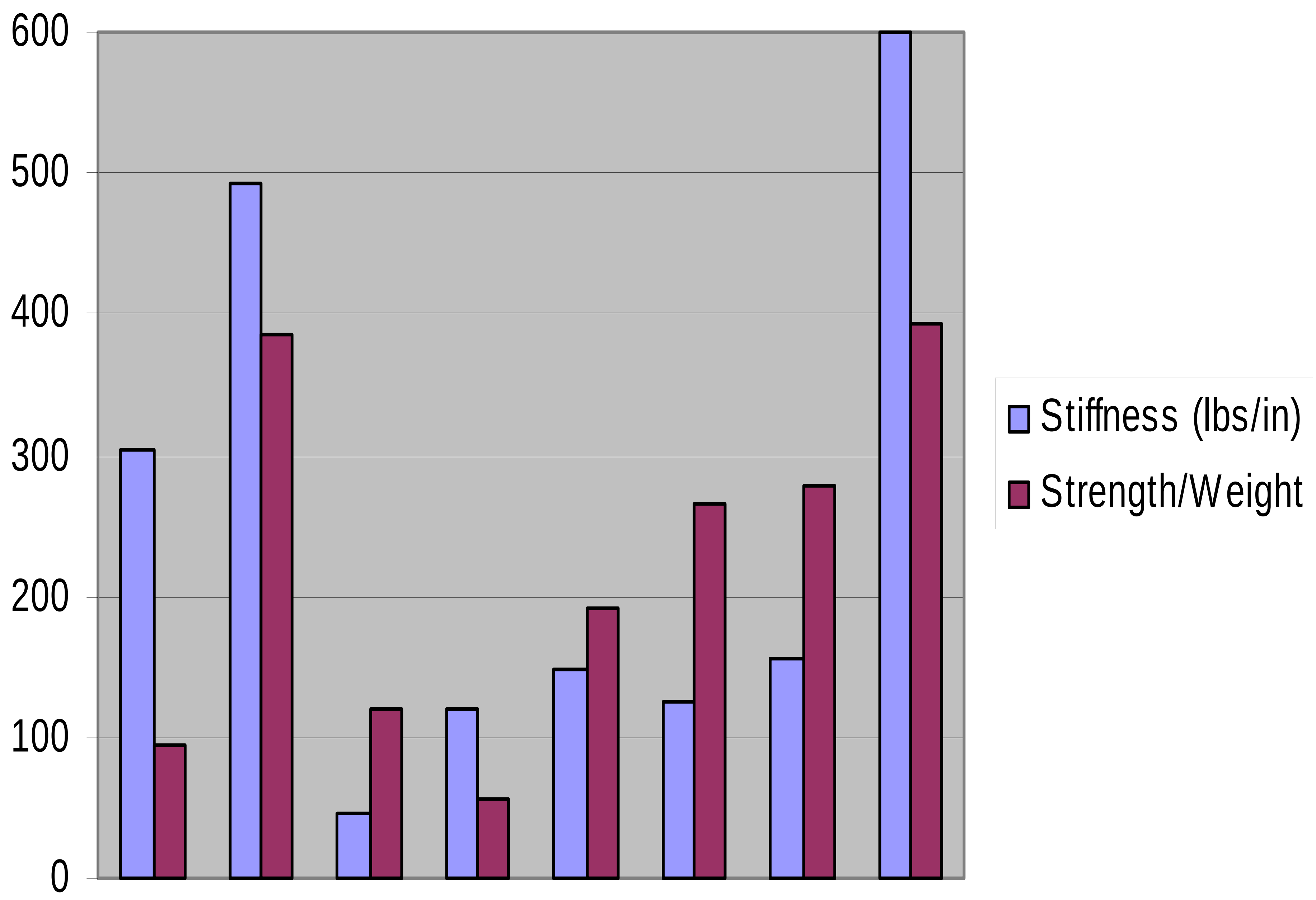
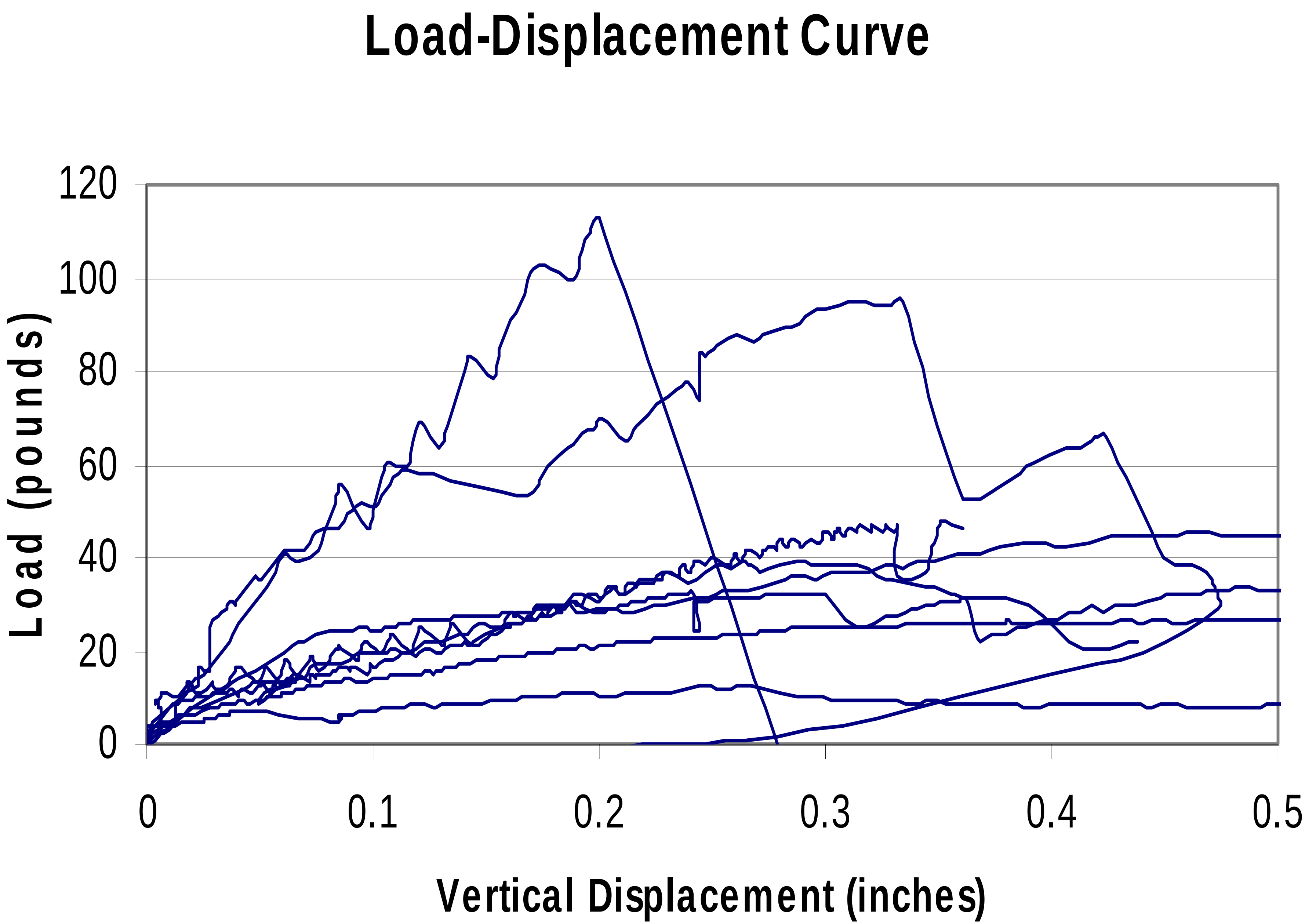
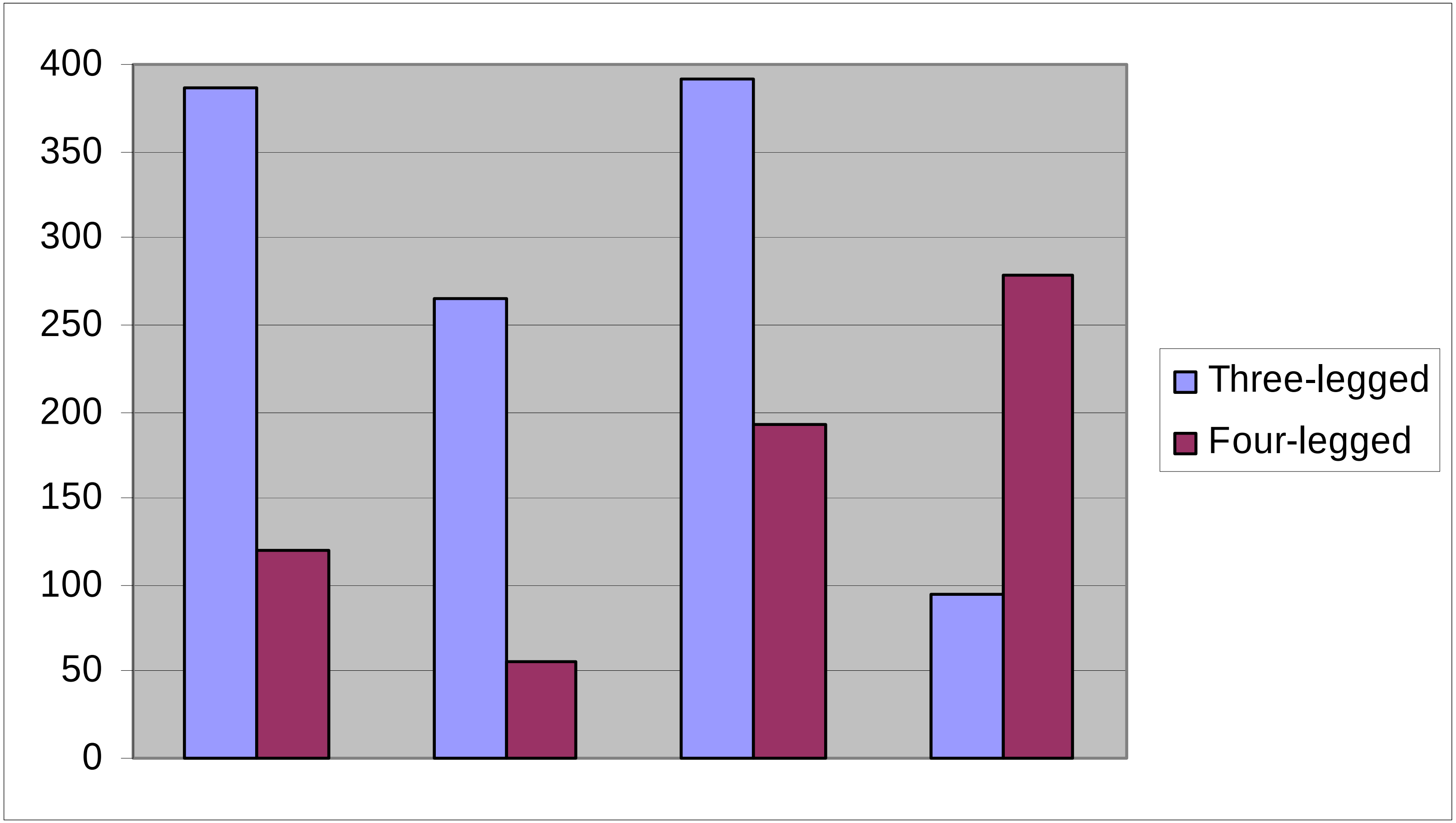


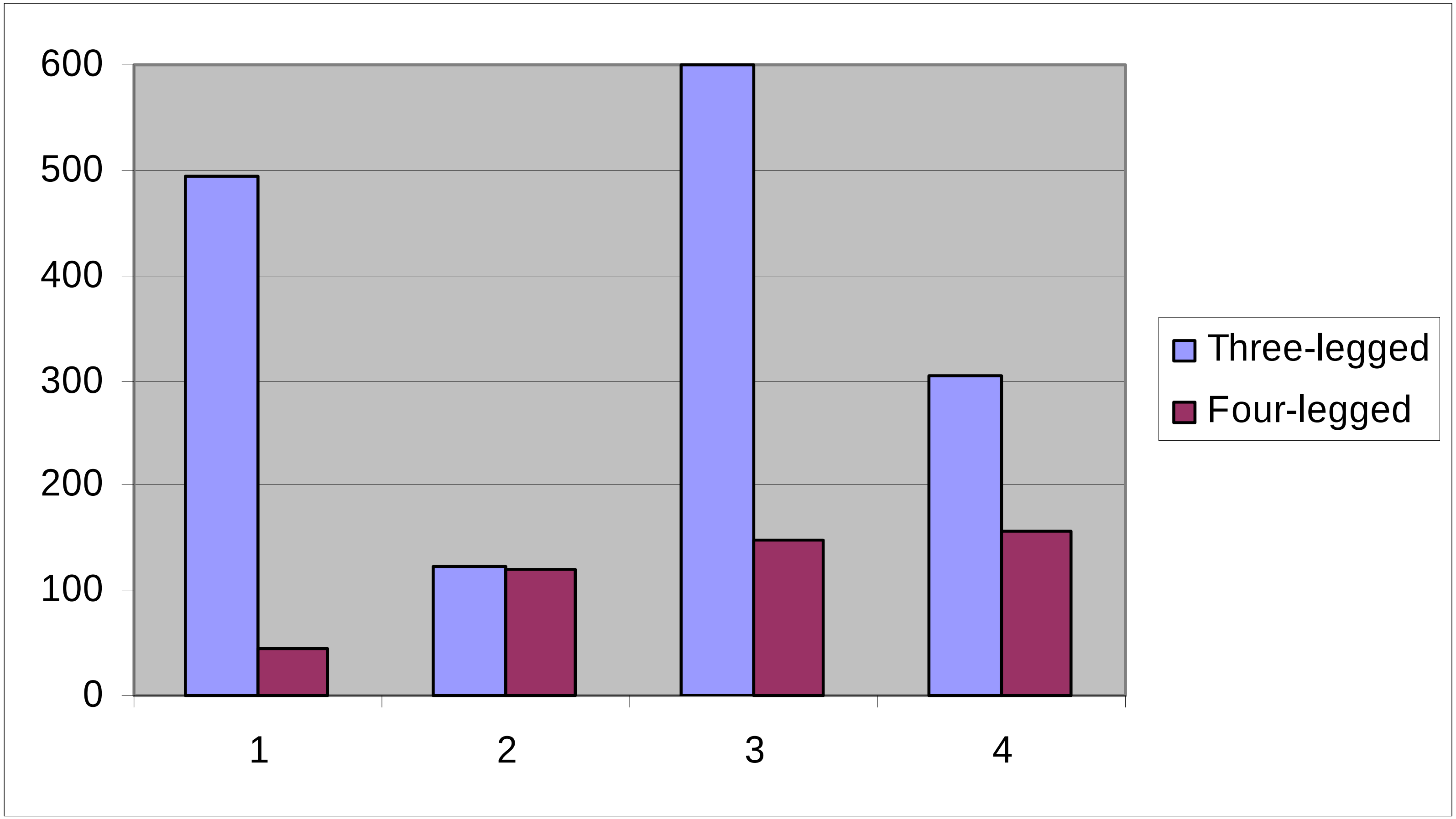

600
500
400
300
200
100
0
Stiffness (lbs/in)
Strength/Weight


Load-Displacement Curve
Load (pounds)
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
Vertical Displacement (inches)

Strength to Weight Ratio

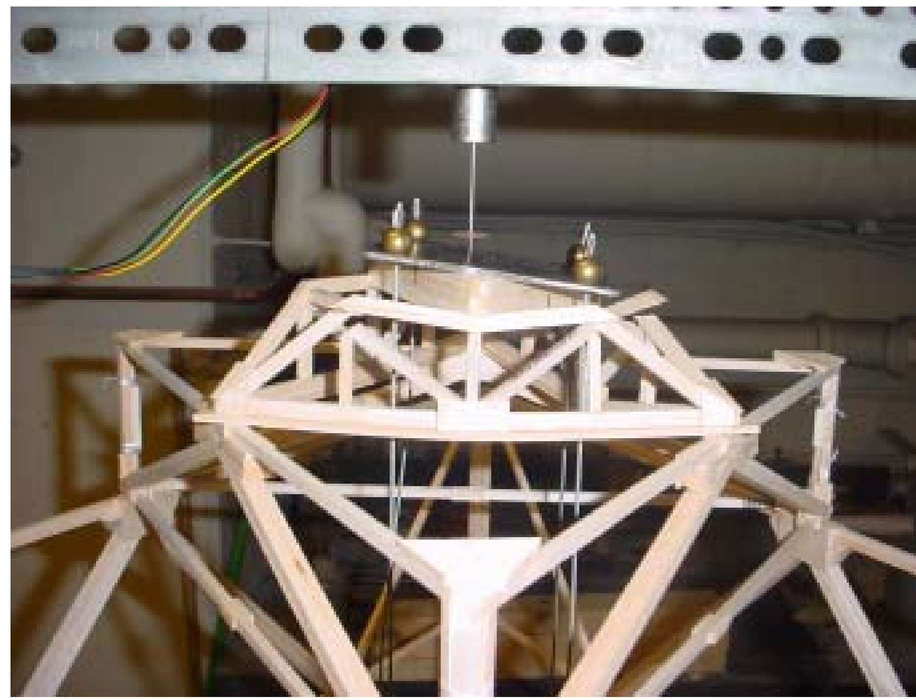


Stiffness (slope of load-displ curve)



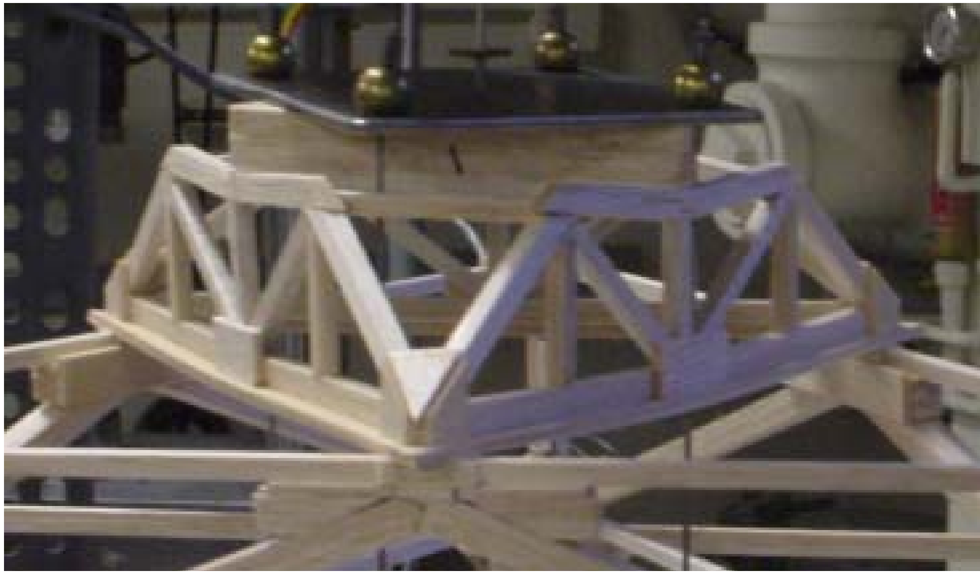
Lessons: Concept

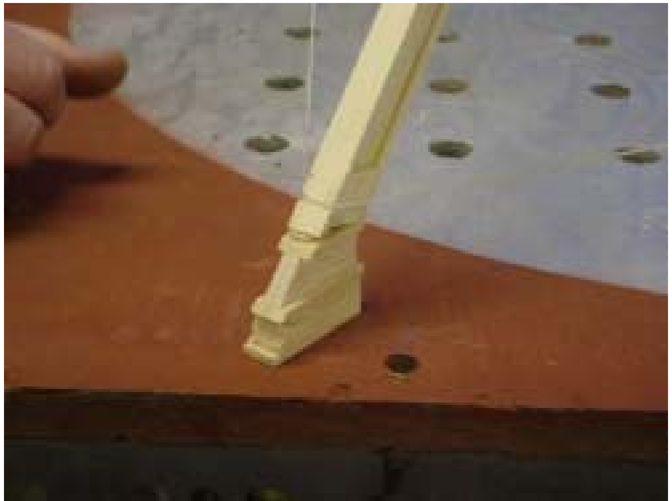
- Systems with many unknowns are difficult to predict
- Structures which are simple and clear in their load paths are easier to design



Lessons: Construction

- Details are critical
- Repetition helps
- Small differences add up to big differences
- 3D joints are not easy!





Lessons: Buckling

- **Failure occurred significantly below calculated values:**
  - **Sensitive to imperfections**
  - **Support conditions**
  - **Insufficient bracing**
  - **Lower load in post-buckled state (not a ductile failure)**
  - **Effective buckling length was typically much *longer* than assumed**