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MECH 312
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Finite Element Analysis Project: Roof Design

<u>**Purpose:**</u>

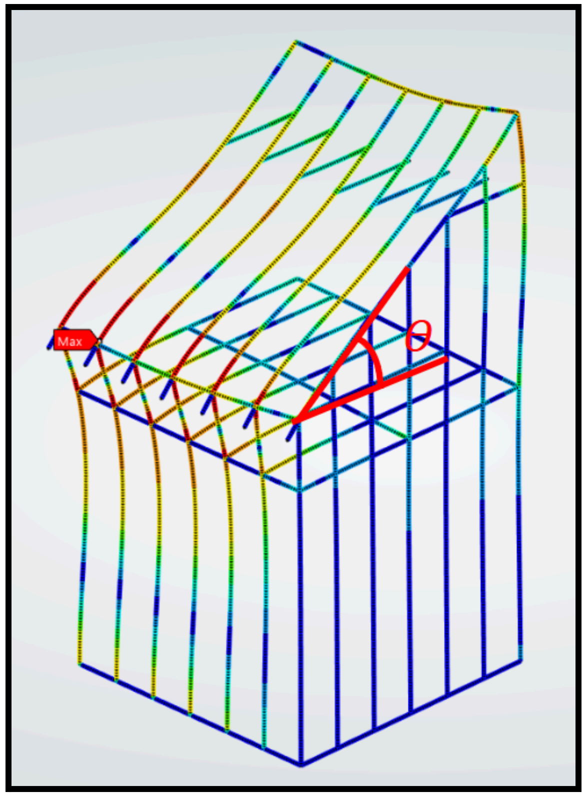
I set out to do an analysis of a two story, basic wooden framed house with the intent that one day I would be able to build this as a cabin and use the information from this project to make the structure both safe and comfortable to live in. I conceived of this idea during a recent trip to Gatlinburg, Tennessee where I noticed many of the homes had far steeper roofs than are in the Northeast. This observation combined with the fact my own bedroom has mostly pitched walls due to the roof shape, I was determined to find a solid compromise between structural integrity and comfort of habitation to act as a robust design for a future project.

<u>**Assumptions:**</u>

- Most likely situation for failure would be excessive snow load, which will be simulated with the largest recorded snow fall by depth in Northern NJ, ~34 inches of fresh snow
- Failure location will be localized to the home frame rather than the roof panels as evidenced by real world building collapse investigations
- Entire framing construction will be made of simple spruce wood 2”x4”s
- Doorways, windows, and stairwells are more highly supported than regular walls and will therefore be omitted from the model
- Usable floorspace is defined as floor area with at least 3 feet of clearance to the ceiling

<u>**Model Development:**</u>

The construction model, depicted to the top right, takes advantage of two planes of symmetry, dividing this 16’x16’ home into a one quarter section, allowing the simulation to have a much more refined and accurate mesh for minimal computational time. This design was based on current standards for wall studs and roofs.



<u>**Loading:**</u>

- Gravity
- *Line Pressure 1: 1.88 lb/ft, roof weight
- *Line Pressure 2: 10.70 lb/ft, snow weight

*Applied along rafters.

<u>**Supports:**</u>

- Fixed Supports at ground nodes
- Displacement Supports: Free in plane, zero out of plane at symmetry nodes
- Rotation Supports: Free about out of plane, fixed about in plane directions at symmetry nodes

<u>**Preliminary Analyses:**</u>

To begin this analysis, I performed several preliminary experiments to verify my model and the range of stress values. By looking at the different forms of stress within the structure, I determined that maximum bending stress is the failure criteria. Then, examining pitch angle Θ at the extremes for this situation, 0° and 45°, I received a stress range from 176.2 to 1144.6 psi, which, while high on the one end, is reasonable and expected for this situation.

Optimization and Continued Examination:

Through the Ansys' optimization feature, I was able to determine the pitch angle that would create an equal balance of room size and stress, being 36.5°. This roof design would have a maximum bending stress of 506 psi and a floorspace availability of 84.5%. While this solution gave me a good baseline design, I was not satisfied due to the loss of floorspace. To pursue a design that more suited my needs, a roof pitch of < 32°, I conducted a full pitch range analysis, as seen below, to see if a more preferable design is possible. From this I found that I would have at least ~677 psi of bending stress from the 32° pitch angle.

Moving Towards the Real World:

To see if this is reasonable, I consulted the American Wood Council's design values for bending stress in roofs and rafters under the Eastern Softwood 2'x4' section and compared them to my analysis data. Looking at the graph, lowering the pitch angle to 32° is very possible but would require a higher grade of quality. Additionally, since I am accepting a higher stress value, a more reliable wood grade for this project, like No.2. would be preferred. In this case, it would offer a factor of safety of ~1.68. While this value does not appear to be very large, these AWC stress design factors have a built in margin of safety that allow designers to build structures right up to that limit, assuming all variables are accounted for. Since I cannot predict the exact moisture content, grain structure, and temperature of these boards in my simulation, a sizable FOS acts as a barrier for this, as is done in industry. Additionally, by plugging my stress values into a spruce lifecycle graph detailed in "*A comprehensive analysis of fatigue in wood and wood products*" by Yang et al., I found that I can expect this frame to last at least 100-120 years, which for my purposes is plenty. To finish this off, I looked into the material cost for this construction and determined I would need 184 2"x4"x8' boards to the tune of $965 which is very reasonable. With that I have rigorously designed a frame structure for my future cabin, and at a reasonable price!