Reconfigurable Rock Climbing Wall

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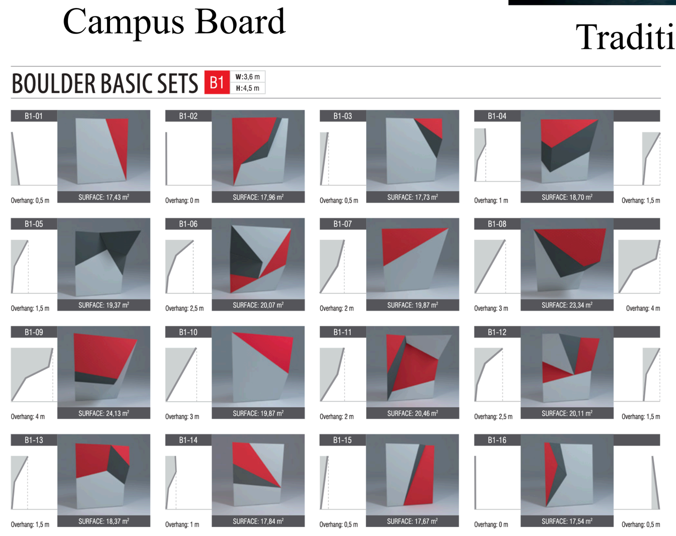
Introduction

The Trinity College rock climbing training room was taken down in the Summer of 2018; many of the materials used to build the project was left unused as the club could not find a new location to move the training room as the wall was too big and required drilling into fixed structures.

Thus, a reconfigurable rock climbing wall was designed to address the requirements of the club. A modular system was implemented to allow different configurations of angle as well as the ability to turn the climbing wall into a campus board using the same structure.

Campus Board

Traditional climbing wall.



Commercial climbing walls with different geometry.

Objectives

Design and fabricate a climbing wall that:

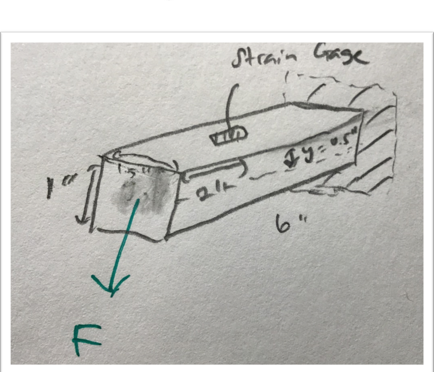
- Is safe for climbing.
- Has free-standing and self-supporting structure.
- Is capable of different geometry configurations.
- Can be easily broken down into component parts and stored.
- Has modular front panels with different holds or training tools.

Force Transducer

The forces exerted on a climbing wall by a climber through different movements were first quantified in order to ensure that the climbing wall can withstand any type of loading. Quantifying every type of movement would be too time consuming, thus the worst case scenarios were assumed to be:

- Climber doing a pullup, exerting more force than weight
- Climber jumping and catching a hold, generating large impulse forces

To quantify this, a force transducer was developed using strain gages and a climbing hold.



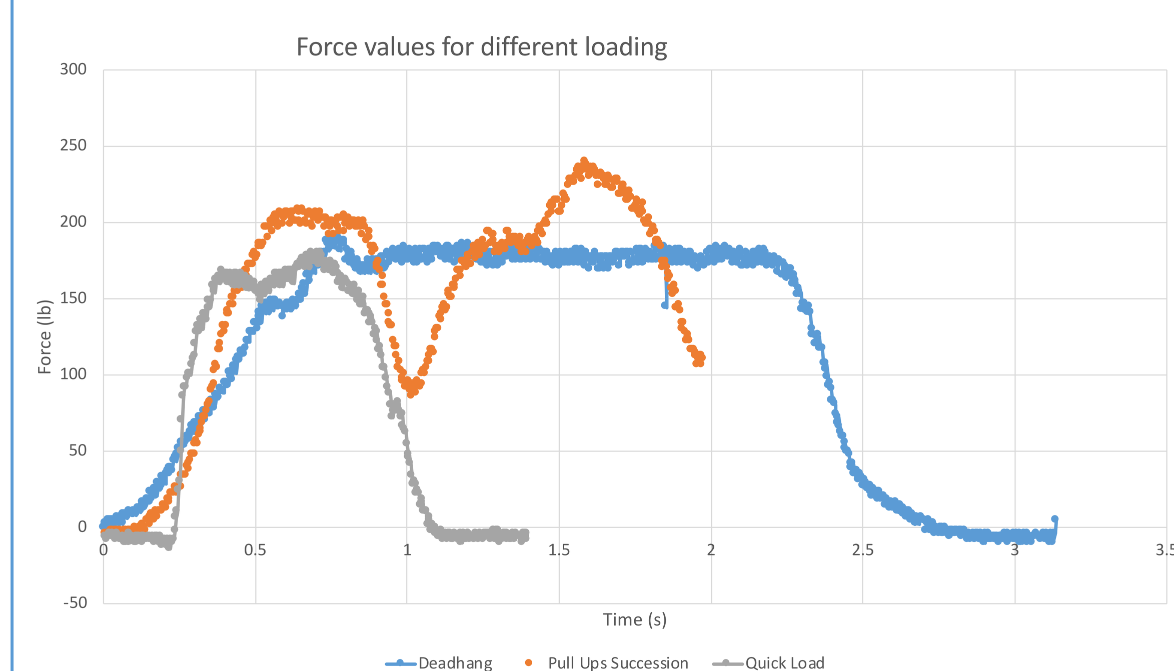
Quantifying Forces

The strain measured was measured by connecting the strain gage into a Vishay Strain Gage Box, which outputted a voltage . This voltage was then recorded using an Arduino and calibrated using known weights and the bending strain equation for a cantilever beam:

$$\epsilon = \frac{Fly}{IE}$$

Where F is the force applied, l is the length between the strain gage and force, y is the distance to the neutral axis, I is the moment of inertia and E is the modulus of elasticity.

Once the transducer had been calibrated, the different loading scenarios were applied to the transducer and the data was recorded. The Vishay Strain Gage Box outputs data at 480 samples a second, or at ~2ms.



The deadhang loading showed that the calibration of the transducer was working correctly, as the test subject weighted 176lb. However, the predicted increased load due to the impulse forces was not shown in the quick loading test, where the test subject jumped around 20cm and quickly caught the hold while falling.

Thus, the impulse equation was reconsidered:

$$\int_{t1}^{t2} F_I = M(v_2 - v_1)$$

For the case where impulse force, F_I was assumed to be constant:
Kinematics equations used to find the final velocity of the climber:

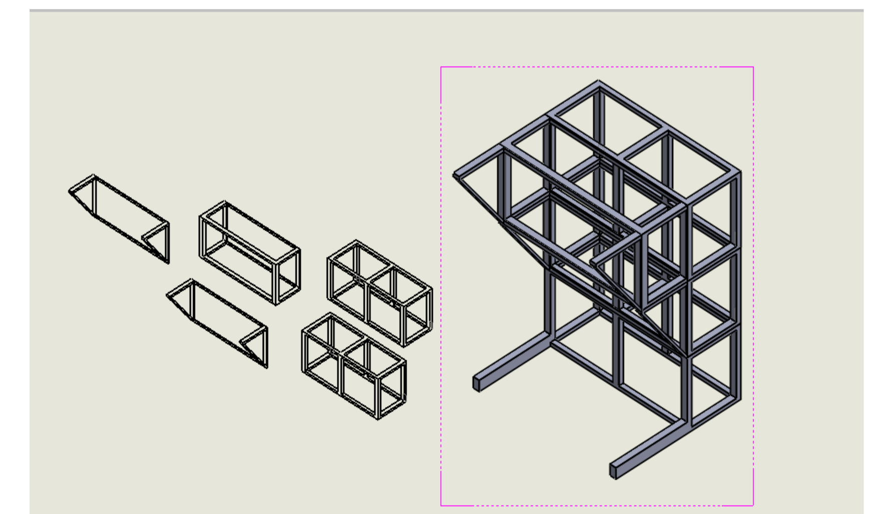
$$v^2 = 2 * 9.81Ms^{-2} * 0.2m$$
$$v = 1.98\text{ms}^{-1}$$

Contact time taken from quick loading data: 0.16s for a 76kg climber,

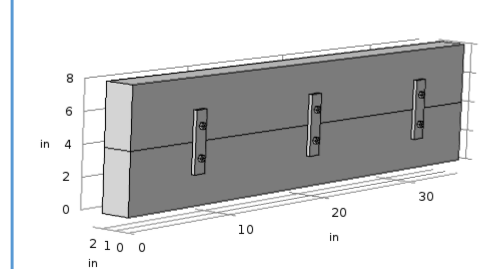
$$F_I = 76kg * \frac{1.98\text{ms}^{-1}}{0.16\text{s}} = 942\text{N}$$

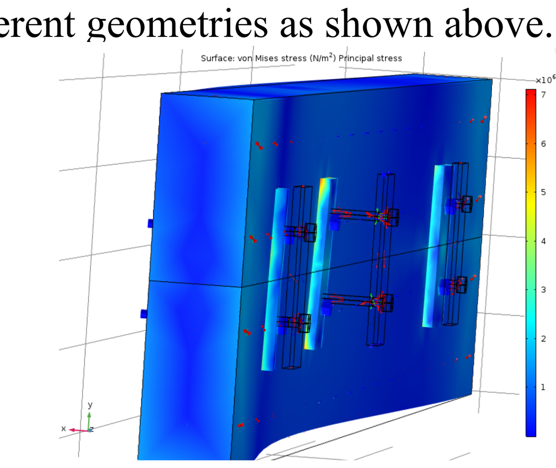
Where the total force is only 1.26 times the mass of the climber. Thus, the maximum force generated due to impulse loading of 221lb would still be less than the measured pullup force of 246l. Thus, the measured pullup force was taken as the maximum loading force used to develop the following COMSOL models.

Final Design and COMSOL analysis

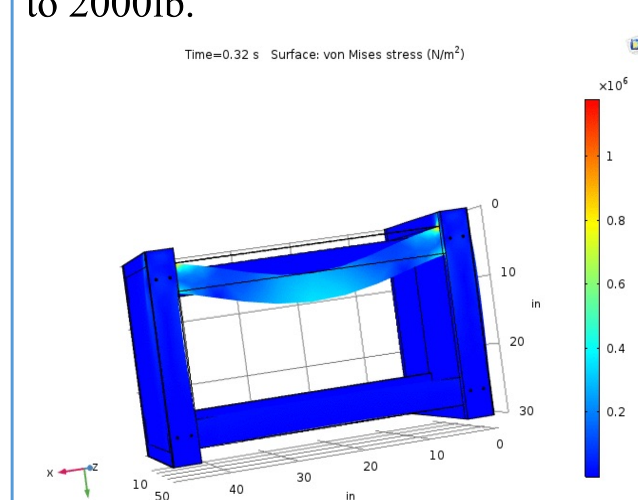


A modular concept was designed such that the modular components could be used to generate different geometries as shown above.

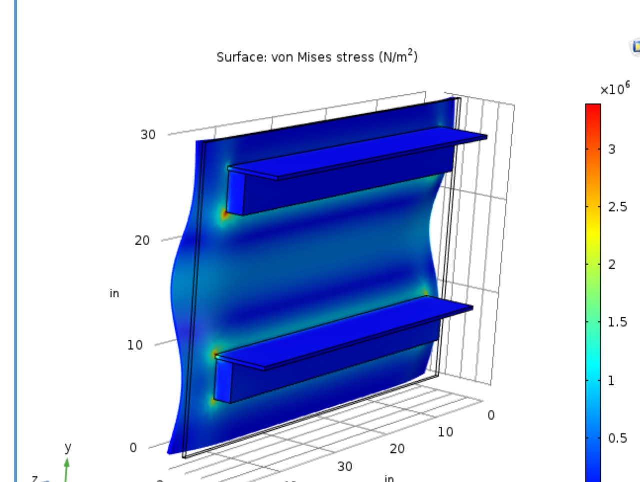




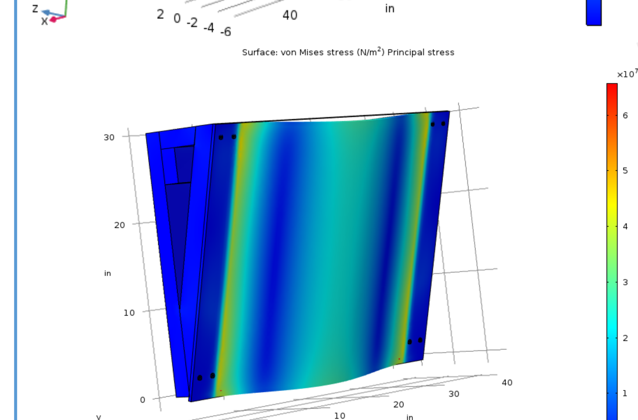
First, the connections between each supporting block were tested using stainless steel plates and bolts as the supporting back 3 boxes of the structure would not be frequently switched out. By applying a 2000lb load in each direction, the maximum von Mises stresses were found to be 7MPa. This produces a factor of safety of 12.3 as the modulus of rigidity of the Douglas fir wood used is 86.2 MPa. This factor of safety was calculated using the $n = \frac{Failure\ stress}{Actual\ stress}$. This factor of safety was found even after increasing the load from 246lb to 2000lb.



Moving onto the structural blocks, the maximum pull up force was applied the the top front supporting beam. It can be seen that the maximum stresses were only on the order of 1MPa. Giving a the highest factor of safety of 86.



For the vertical front panel module, a 2000lb force was applied in the z and y axes. The principle stress of 3.5MPa was used to calculate the factor of safety of 24.6.



Finally, the 2000lb load was applied to the 15 degree front panel module. The maximum stress of 65MPa was found. The secondary factor of safety equation $n = \frac{Failure\ load}{Actual\ load} = \frac{2000lb}{242lb} = 8.26$ was used.

Fatigue

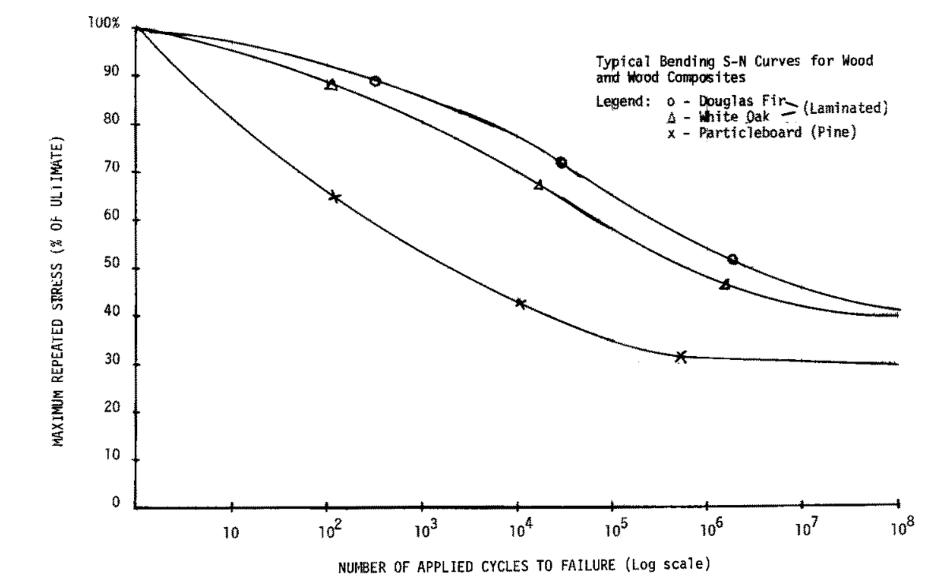
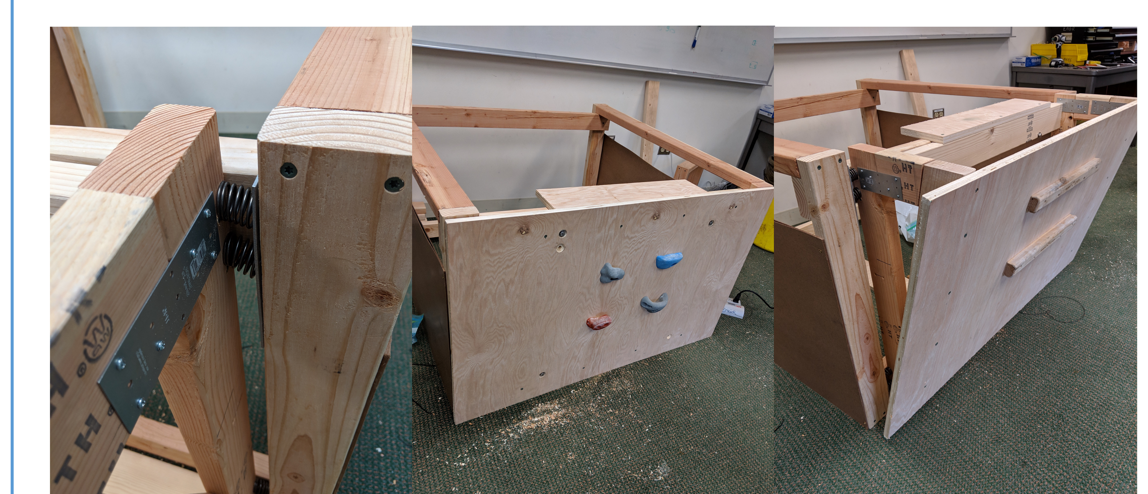


Figure 7. Number of applied cycles to failure (Log scale)

As all the maximum stresses in the model are around 10% of the modulus of rigidity, both the oak wood and Douglas fir wood would be able to withstand at least 10^8 loadings. [1]

Final Physical Model

The final model was then built using the springs and bolts to hold the front panels into place. Due to budgetary and time constraints, only one structural module of 2.5'x4'x4' was fabricated.



Bolts and springs were used to hold the front panels in place while bolts were attached as fasteners. To switch the vertical panel with climbing holds to the 15 degree panel with campus training rungs took ~3minutes and only requires a ratchet. The materials used to build one module with two geometry options totaled $161; a full size wall of 10'x8'x4' would cost around $1300.

Conclusions

Although only one module was built due to various constraints, the model was stable and was at least 8 times stronger than required to withstand the forces exerted by a climber. Additionally, the dimensions and materials were chosen such that each structural block can be transported easily as it can fit through regular doors. The main safety concern would be the wear and tear introduced by the changing of holds and bolts.

More work is needed to improve the connectors such that the connecting time is reduced while maintaining structural stability.

References

Khyanka, George. Fatigue properties of wood and wood composites, 1979.

Acknowledgements

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