THUMB-TACK BIKE RACK

ENGR2320 Final Project

Ben Chapman Gaby Waldman-Fried David Pudlo

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Abstract

Wall mounted bike stands usually require many screws and metal support bars. We tested the force which common thumbtacks can support in drywall at various angles and used this inform a new design. Our bike rack design can fully support a bike using only 4 thumbtacks in a wall. The tacks are subjected to shear force, which allows the tacks to withstand high loading. The moment from the lever arm is minimized with a long distance between the tacks and the force from the bike.

Contents

List of Figures

1 Introduction

Given the constraints of dormitory regulations regarding methods of attaching items to walls, we sought to design a bike rack that can be only held up by thumb tacks, the only legal form of anchoring. We first measured the maximum shear and normal force that a tack can withstand without coming out of the wall, and then designed a wall-mounted bike rack that can be supported with as few tacks as possible. The design of the rack took into consideration the ideal load angle and the rotational moment caused by the weight of the bike cantilevered out away from the wall.

2 Method

We tested the force it takes to remove a tack from drywall in the Instron Universal Mechancal Tester at a variety of angles between 0 and 90 degrees from the plane of the drywall. We wanted to find the angle at which the tack could stay engaged in the drywall and resist the greatest force. Characterizing the loads a tack can support was necessary for us to refine our design. We used the results from the testing to calculate the number of pins it would take to hold up a bike for a given frame geometry.

2.1 Testing Setup

We cut a 5”x5” piece of half-inch drywall and clamped it in the bottom of the Instron. To prepare the tack, we soldered a small ring of copper wire and slipped it on the end of the pin, as shown in Figure 1. We then pushed the tack into the drywall and tightened the other end of the copper wire into the top clamps on the Instron. During the test, the upper clamp was pulled away from the drywall until the pin came out. We plotted our results on a graph of extension vs. force. One important note is the relative weakness of the drywall scrap we tested with compared to an actual wall.

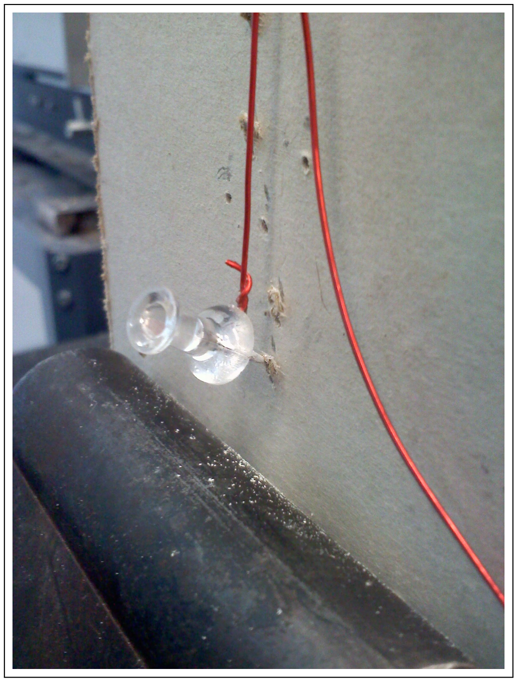

Figure 1: Force Testing in the Instron

3 Results

3.1 Force Testing

The results from force testing show that the tack pulled at an angle resists load better than a tack pulled straight out. Thus, the maxiumum shear force necessary to pull out the tack is greater than the maximum normal force. Furthermore, the precise angle of the force with respect to the drywall (as long as it was above 45 degrees) did not significantly change the force the tack could take, as shown in Figures 2 and 3 below. The maximum shear stress occurs when the load is parallel to the wall, and thus at a 90 degree angle with the tack pin (see Figure 1 for this configuration).

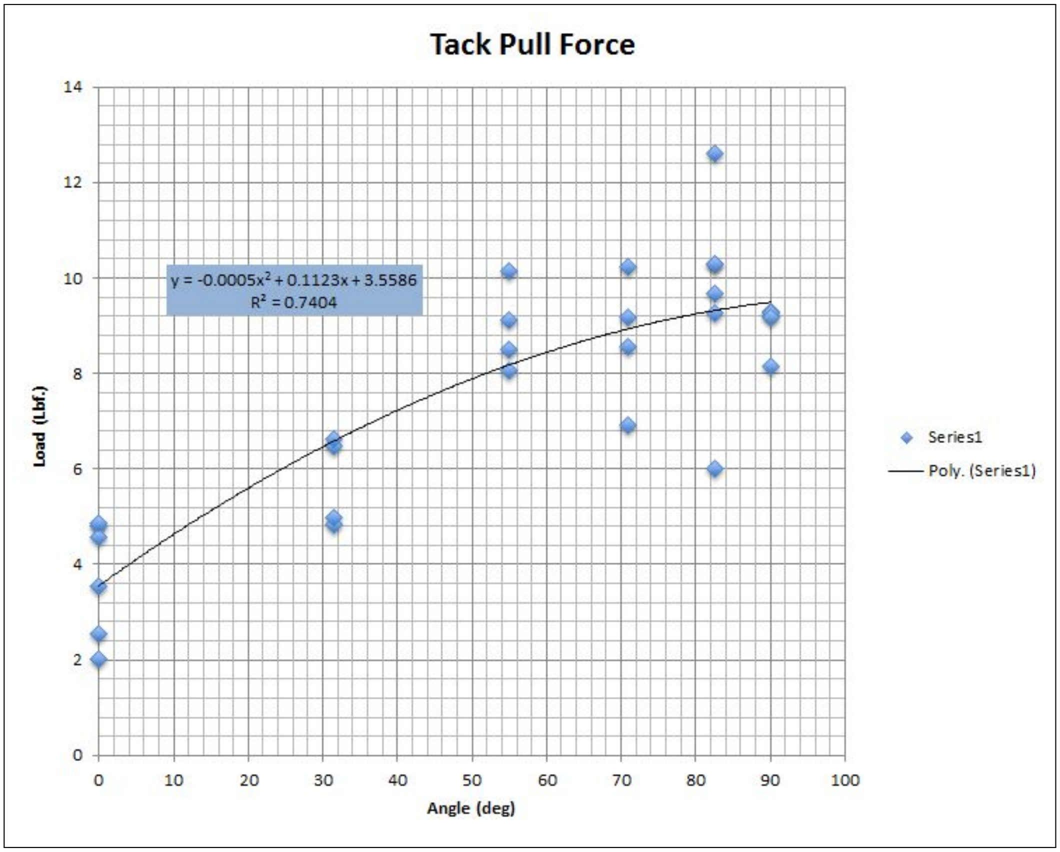

Figure 2: Tack Pull Force

The tack was very easy to pull out of the wall when the drywall was parallel with the ground (at 0 degrees). At this orientation all of the force translated into normal force and the tack could be pulled out with a load of around 6 lb. As the angle increased, the tack could support a greater load. The maximum load of 56.13 Lbf occured at an angle of 82.5 degrees.

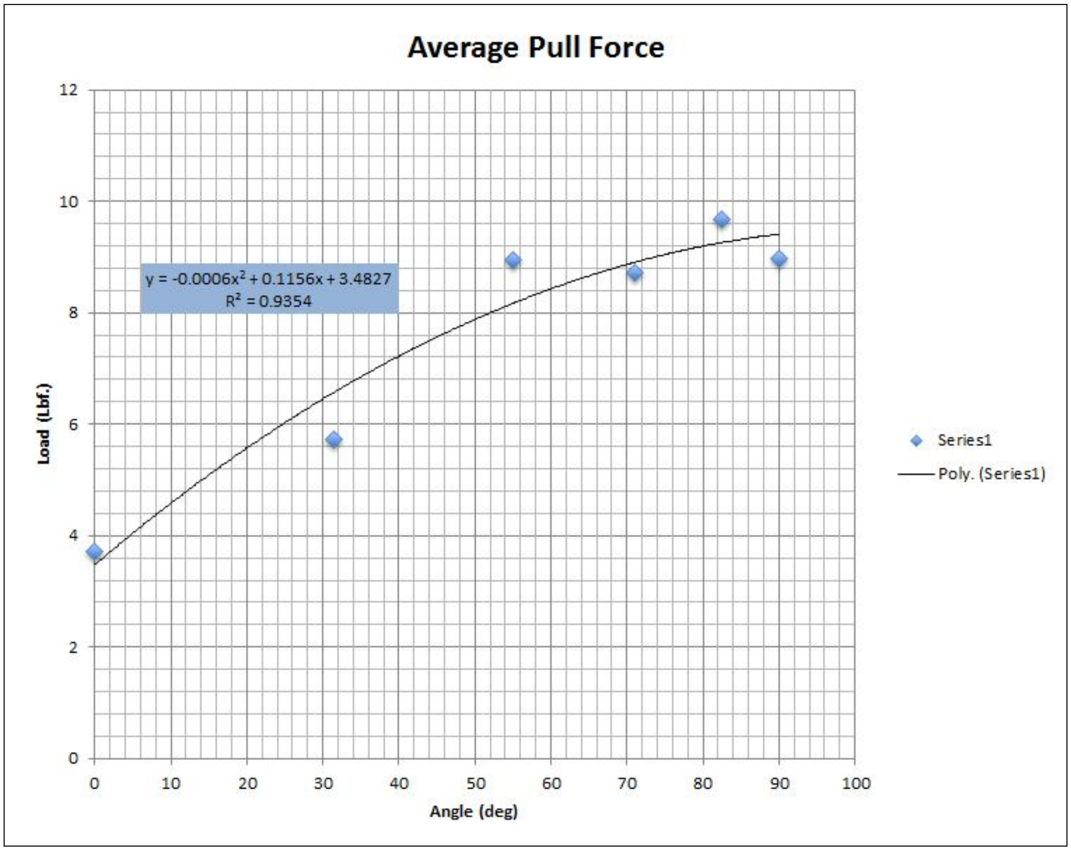

Figure 3: Average Tack Pull Force

The data we collected shows a good fit for a polynomial curve. However, logically the data trend seems to point towards a sinusoidal curve, where the maximum load is held at 90 (270, etc.) degrees. The maximum loads for the tack at angles above 45 degrees are very similar and round out at about 9 Lbf.

4 Design

4.1 First Prototype

We built our prototype from 6061 T6 Aluminum 1/16” sheet metal. The two holders were basic ”L” supports with an additional flange to wrap around the top tube. They were each supported with 8 tacks.

Figure 4: First Prototype

4.1.1 Calculations

The tacks must provide the vertical force to counteract the bike’s weight as well as the horizontal force that counteracts the moment from the bike’s weight cantilevered out away from the wall. For this first prototype, the vertical force was the 30 pounds from the bike, but the horizontal “pull

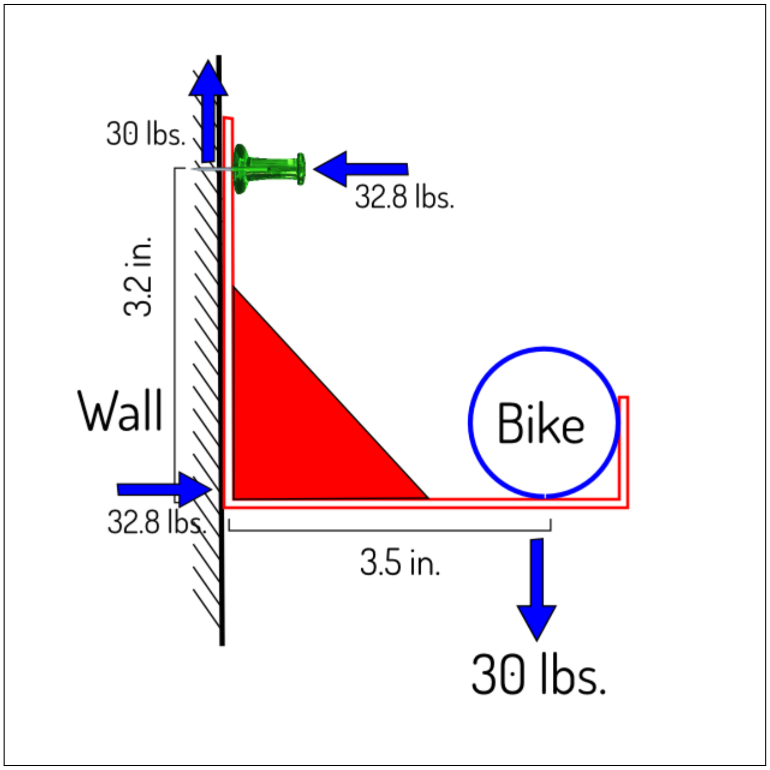

Figure 5: Free Body Diagram for First Prototype

out" force equalled $\frac{30lbs \times 3.5in}{3.2in.} = 32.8lbs$. The vector combination of these two forces equals 44.5 lbs at an angle of 42 degrees. According to our testing, one tack can resist about 7.3 pounds of force at 42 degrees, so this design would require a minimum of 6.1 tacks.

We tested this design with 16 tacks in our large piece of sample drywall and the rack immediately failed. The tacks were pulled almost straight out of the wall and left perfectly round holes, as if there was negligible vertical force in comparison to the vertical shear force.

4.1.2 Failure

Unfortunately this system did not work as planned. When the bike was placed on the supports, the pins were immediately pulled from the drywall, leaving behind the clean holes suggestive of forces normal to the wall surface.

There are several explanations for why the rack failed even with a large factor of safety. One possibility is that the force was not distributed eqally on the tacks and the ones bearing the highest load failed, leading to a domino effect as the force shifts to other tacks and each of them fails. Another possibility is that putting 30 pounds of shear force and 32.8 pounds of normal force does not have the same physical meaning as 44.5 pounds exerted at 42 degrees. The tacks also lost 14% of their pin length to the thickness of the sheet, potentially reducing the force which the tacks could hold.

4.2 Final Prototype

Our final prototype decreased the moment force from the lever arm by increasing the vertical distance between the location of the bike and the tacks. By increasing the vertical height in comparison to the width, the horizontal ”pull out” force on the tacks was greatly reduced. With our new design (as shown on the cover page), the resultant force on the tacks was coming at a 83 degree angle rather than 42 degrees for the first prototype. Additionally, we decreased the thickness of the plates that the tacks poke through. This ensured that about 93% of the tack's length was imbedded in the drywall versus about 86% for the first prototype.

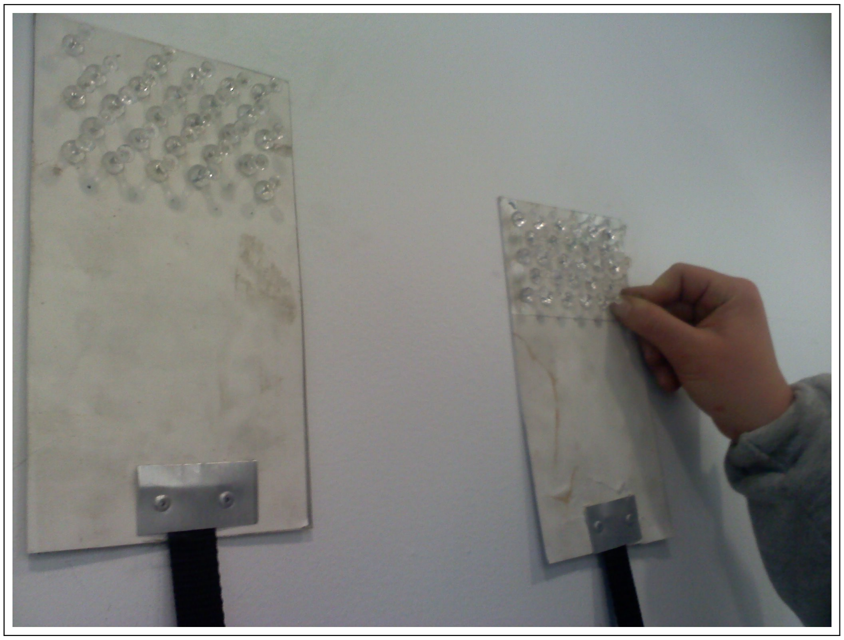

Figure 6: Tack Mounting Plate

We added nylon webbing rope to connect the tack plates to the bar holding up the bike. The nylon webbing was attached at either end by a plate that compressed it and kept it from slipping, as shown in Figure 7.

Figure 7: Nylon Attachment Plate

The bike holder is a sheet metal part that has two "hooks" that hold the top tube of the frame, as shown in figure 8.

Lastly, We placed a buffer block of pink foam between the bike mount and the wall so the handlebars and the petals will have space to rest and not hit the wall. Although this member bears no vertical load, it keeps the bike the correct distance from the wall and transmits the necessary horizontal force.

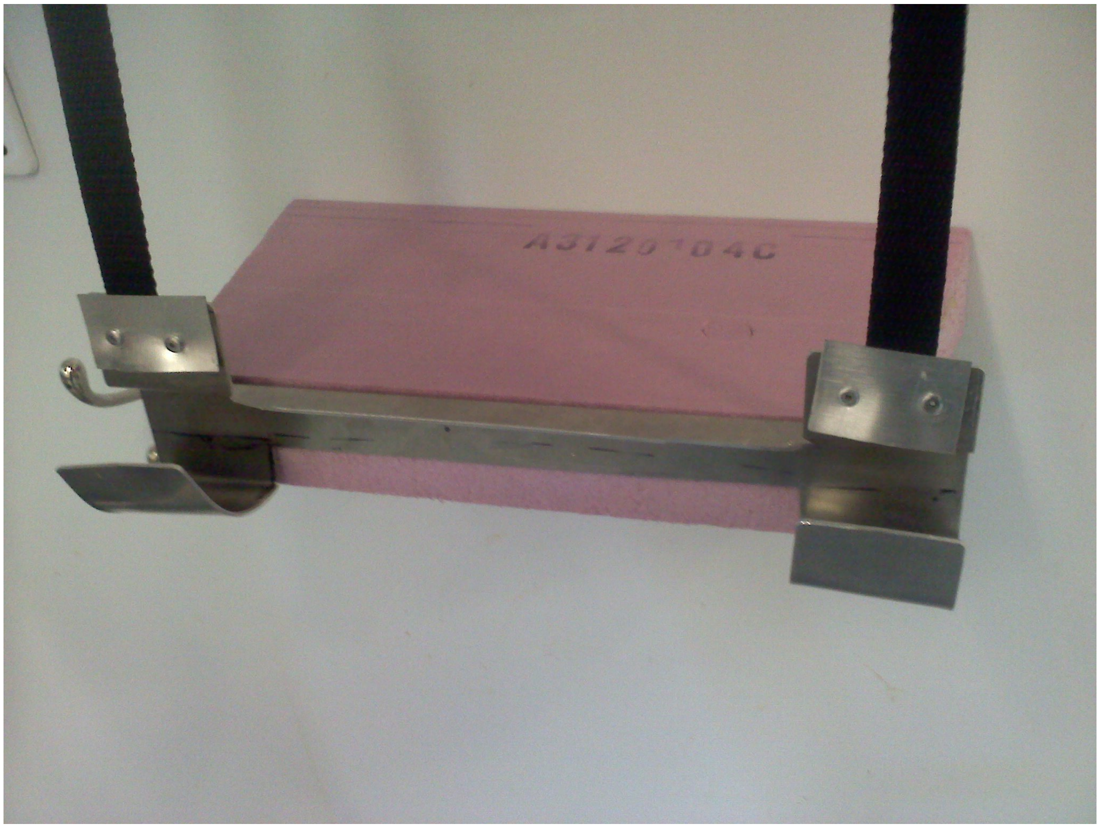

Figure 8: Bike Holder

4.2.1 Calculations

For the final prototype, the vertical force was still the 30 pounds from the bike, but the horizontal "pull out" force equalled $\frac{30lbs \times 6in}{48in.} = 3.75lbs$. The resultant force is 30.2 lbs at an angle of 83 degrees. According to our testing, one tack can resist about 8.6 pounds of force at 83 degrees, so this design would require a minimum of 3.5 tacks.

Based on our earlier experience, we decided to test this prototype with a large factor of safety in the number of tacks. We started with about 56 tacks and the rack worked perfectly! We decided to remove tacks until we reached failure. We removed all but four tacks and the rack was still holding the bike securely. When we went to remove the next one, the structure started to move. This result fits very well with the theoretical calculation which estimated 3.5 tacks were necessary.

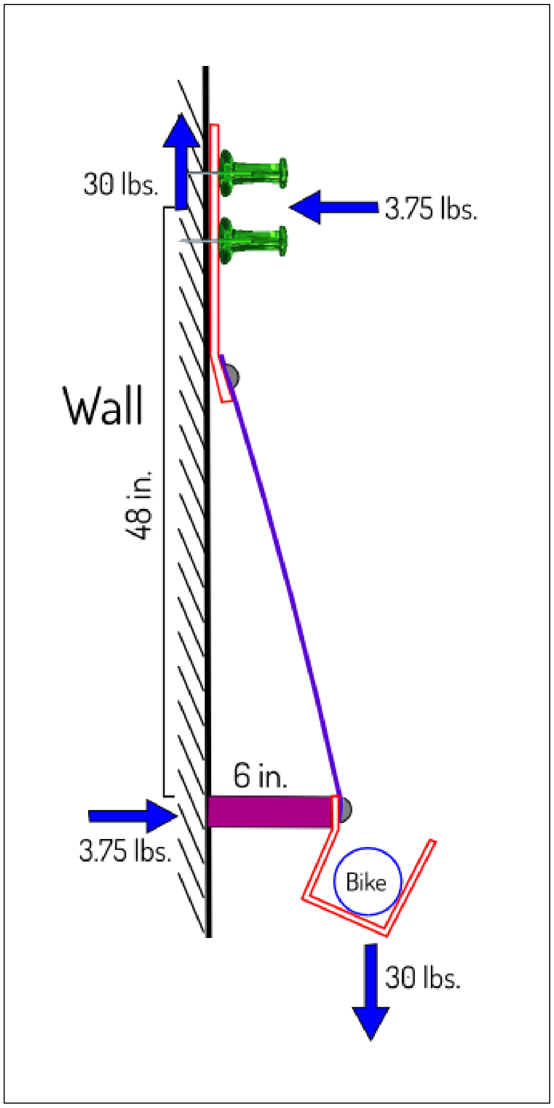

Figure 9: Free Body Diagram for Final Prototype

One discrepancy between the holder testing methods was the drywall it was mounted on. The first prototype was mounted on the half-inch drywall we used in force testing. The final prototype was mounted on an actual wall. The actual wall was presumably much stronger than the scrap drywall, which may have contributed to the instant failure.

5 Further Work

Although our final protoype design was successful, there are many ways we could improve our design. Currently, the rope from the tack plates to the bike holder is very long. Although shortening the rope would increase the moment arm, it would not be enough to cause the tacks to pop out of the wall and it would increase usability of the rack substantially. We would like to find a better balance between number of tacks and height of the mounting plates.

In terms of manufacturing methods, the bike holder could be fabricated more cleanly with more rounded frame holders and less jagged edges. Overall, all fabrication could benefit with more precise measurements and alignment.

The current design for the hooks on the bike holder does not fit bikes with large or non-circular top-tube shapes, such as foldable bikes. Any further prototypes would have a larger space for the top tube to slide in easily.