Background

Research has found that 42% of construction worker deaths involved falls. Of those who were killed, 54% did not have access to a Personal Fall-Arrest System while 23% had access but didn’t use it. With an anticipated increase in solar-panel installations on residences, it is likely to see an increase in the number of workers exposed to rooftop fall hazards in the near future.

There are already fall-protection requirements in place through OSHA [1] that include Personal Fall-Arrest Systems (PFAS), guard rails, and safety nets. Despite this, many construction workers do not have access to PFAS or choose not to use them. One common reason is that PFAS take too long to set up. This is especially true with residential construction work. Therefore, the goal of this project is to design, build, and test a practical, affordable fall-arrest system that is adaptable to many residential roof configurations.

Solution

Two C-shaped hooks are positioned onto the eave of a home with an extension pole, allowing workers to set up directly from the ground. The C-shaped hooks are secured to the eave by the use of a tensioning system. An attached safety line allows workers to safely ascend, traverse, and descend from the roof -- while being always secured to the system. The C-shaped hooks are secured to the eave by the use of an extension pole, allowing workers to set up directly from the ground. The prototype hooks were positioned on to the eave of the structure and secured into the rooftop pitch of 4/12 (18.49 degrees). The test structure included an energy absorber which was not included during the test, making the test conservative. With more resources and time, we would pursue a more in-depth prototype of the system includes an energy absorber which was not included during the test, making the test conservative. With more resources and time, we would pursue a more in-depth prototype of the system.

To satisfy OSHA’s requirements for a fall arrest system, as well as provide a viable product for those working in the industry, the following system was developed:

1. C-Shaped Hooks
   - Attaches over the eave structure of roofs
   - Can be temporarily installed on the roof without drilling
   - 28 inch wide rubber coated arms to distribute load across roof and increase friction

2. Extension Pole
   - Enables the user to position the hook on the roof from the ground
   - Allows for single user installation

3. Adjustable Base
   - Allows for stable set up on a variety of different surfaces including concrete, grass, gravel, and dirt
   - Adjustable stand design allows for secure angle adjustment for safe positioning of hook on variety of roofs

Analysis

The average force felt by an individual after free fall is dependent upon the following equation:

\[ F = \frac{mgh}{d} \text{ (lbf)} \]

A 250 lb worker falling 6 ft while attached to a 1 ft long energy absorber would generate a maximum arresting force of 1500 lbs. OSHA 1910.140(d) requires the system to limit the maximum arresting force felt by the user to be less than 1800 lbs and to be capable of withstanding twice the potential impact force. For that 250 lb worker, this potential impact force would be 3,000 lbs.

The C-shaped hook will experience the highest internal stresses when it is being used on low pitch roofs. To verify the strength of the hook, simulations were ran with a 3,400 lb load applied at an angle just smaller than the pitch of a 4/12 roof (12 degrees vs. 18.49 degrees). To keep the hook positioned properly on the roof, a minimum coefficient of friction was calculated to be ~0.4.

Conclusion

From our drop tower test, we successfully tested two of our prototype hooks against OSHA 1910.140(d). Both hooks were successful in withstanding the force from a 250 lb weight falling from 7 ft, resulting in a load of ~2000 lbs without any deformation or displacement. The final system includes an energy absorber which was not included during the test, making the test conservative. With more resources and time, we would pursue a more in-depth prototype of the extension pole and design a hook constructed from aluminum rather than steel. Our design was successful in remaining non-intrusive and OSHA compliant; while helping users stay safe from the moment they step onto the roof to the moment they step off.

Testing

A. Preliminary Materials

Verification Testing

Dogbone samples were modeled, cut, and then tested using an Instron tensile test machine. The force, elongation, stress, and strain were recorded during the test. These parameters were used to find the ultimate tensile stress and the modulus of elasticity.

B. Drop Tower and Test Structure

The purpose of this test was to verify the structural integrity of our hook based on the OSHA standards set in 1910.140(d): Personal Fall-Arrest Systems. To do this, we tested the hook with a 250 lb weight free falling 7 feet. A 9x4x6 ft wooden test structure was built with a rooftop pitch of 4/12 (18.49 degrees). The test structure had similar features to a standard rooftop eave. The prototype hooks were positioned on to the eave of the structure and secured into place with a tensioning system.

Using a system of pulleys, progress capture devices, and carabiners the weight was raised to the top of the 10 ft drop tower. From a safe distance, a quick release latch was pulled--allowing the weight to drop--dynamically loading the hook. This test was repeated for different hook geometries and drop distances.