

Sloped Roof Fall Protection: A Case Study of the Development of a Portable Fall Protection Anchor Device

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This case study documents the development and testing of the prototype of a portable anchor for fall protection systems used on sloped roofs. Injuries and fatalities resulting from falls is the most serious safety issue facing the construction industry. Falls are, by far, the leading cause of fatalities on construction sites. In addition, fall protection violations result in both the largest number and monetary amount of OSHA fines. One problem in providing proper fall protection on sloped roofs is locating suitable anchor points for fall arrest systems. In response to this problem, the Werner Company collaborated with Auburn University to develop a fall protection anchor device that is portable, lightweight, easy-to-use, non-damaging to roofing systems, and meets OSHA standards. Auburn University students and faculty from Building Science, Mechanical Engineering, and Industrial Design collaborated to design, develop and conduct preliminary testing on a working prototype of a portable fall protection anchor device. With the development of a prototype, the Werner Company and Auburn University are poised to move forward with repetitive operation testing and product refinement to determine if production and eventual use in the industry is feasible.

Key Words: fall protection, collaboration, safety, roofing

Introduction

Fall protection is the most serious safety issue currently facing the construction industry. 349 of the 899 total fatalities that occurred in the construction industry during Fiscal Year (FY) 2014 were the result of falls (Bureau of Labor Statistics, 2016). As an ongoing trend, the Occupational Safety & Health Administration (OSHA) concentrates a large portion of its resources and inspection efforts on fall protection and prevention. Table 1 shows the OSHA inspection and citation history for fall protection violations for the period beginning on October 1, 2015 and ending on September 30, 2016 (FY 2016).

Table 1

Summary of OSHA inspections and citations for fall protection (OSHA, 2016)

Category	Inspections	Citations	Penalties	% of All Penalties
Construction of Buildings	768	831	\$2,713,122	34.0%
Residential	520	567	\$1,960,573	42.7%
Nonresidential	248	264	\$752,549	22.2%

Note: "Residential" and "Nonresidential" are subcategories of "Construction of Buildings"

As can be seen in Table 1, 34.0% of all OSHA penalties levied from inspections conducted on building construction sites resulted from citations issued for fall protection violations. In the residential sector, the percentage was even

higher. However, penalties and fines are only a small portion of the costs associated with construction falls. In statistics compiled by OSHA from 2005 through 2007 for 36 states, there were 1,511 “fall or slip injuries from elevation” (OSHA, 2012). The cost of the insurance claims from these injuries was \$164 million or approximately \$106,000 per injury. Some of the reasons cited for failure of roofing contractors to provide adequate fall protection is that they are under constant pressure to perform jobs faster and cheaper (Claussen, 2011). Many in the industry view providing fall protection as expensive and reducing productivity. In addition, there is a cultural resistance to change in the roofing industry at all levels including management, on-site supervision and workers. The lack of adequate anchor points on sloped roofs that are easy to install and use often complicates the use of current fall protection systems (Claussen, 2011).

In order to address this issue, the Werner Company collaborated with Auburn University beginning in August 2014 and continuing through 2016 to develop a portable fall protection anchor device that would eliminate the problem of locating suitable anchor points for fall protection systems on sloped roofs. This case study documents the development of a working prototype of this portable fall protection anchorage device.

Literature Review

The research began with a review of the OSHA codes for fall protection applicable to roofing and other trades that work on roofs. Table 2 contains these applicable codes.

Table 2

OSHA code requirements applicable to work on sloped roofs (OSHA, n.d.)

OSHA Code No.	Text
1926.501(b)(2)(i)	Each employee who is constructing a leading edge 6 feet (1.8 m) or more above lower levels shall be protected from falling by guardrail systems, safety net systems, or personal fall arrest systems.
1926.501(b)(13)	"Residential construction." Each employee engaged in residential construction activities 6 feet (1.8 m) or more above lower levels shall be protected by guardrail systems, safety net system, or personal fall arrest system unless another provision in paragraph (b) of this section provides for an alternative fall protection measure. Exception: When the employer can demonstrate that it is infeasible or creates a greater hazard to use these systems, the employer shall develop and implement a fall protection plan which meets the requirements of paragraph (k) of 1926.502.
1926.502(d)(13)	Self-retracting lifelines and lanyards which do not limit free fall distance to 2 feet (0.61 m) or less, ripstitch lanyards, and tearing and deforming lanyards shall be capable of sustaining a minimum tensile load of 5,000 pounds (22.2 kN) applied to the device with the lifeline or lanyard in the fully extended position.
1926.502(d)(15)	Anchorage used for attachment of personal fall arrest equipment shall be independent of any anchorage being used to support or suspend platforms and capable of supporting at least 5,000 pounds (22.2 kN) per employee attached, or shall be designed, installed, and used as follows: (i) as part of a complete personal fall arrest system which maintains a safety factor of at least two; and (ii) under the supervision of a qualified person.

Fall Protection Anchor Devices Currently on the Market

There are currently several available products used as anchor points for fall protection systems. Figure 1 shows the most popular of these commercially available fall protection anchor systems for use on sloped roofs.



Figure 1(a): CB-12 anchor point (Guardian Fall Protection, 2016)



Figure 1(b): Reusable hinged roof anchor (Capital Safety, 2016).



Figure 1(c): Reusable swiveling roof anchor for SRL (Capital Safety, 2016).



Figure 1(d): Reusable swiveling quad-pod roof anchor with SRL (Capital Safety, 2016).

Figure 1: Commercially available fall protection anchor systems.

Workers are required to fasten to the roof all of the fall protection anchors currently available to the roof using mechanical means. Depending on the distance from the bottom edge of the roof to the ground and the fall arrest system used, workers must frequently relocate these anchor systems to allow access to the work while ensuring the fall arrest system has sufficient distance to engage and prevent a falling worker from hitting the ground. Depending on the roof configuration, this can take a great deal of prior of planning. Also, installing and subsequently removing these mechanically fastened fall protection anchors can be time consuming and cause significant damage to the roof substrate in multiple locations. This is an impediment to the use of these devices by roofers and other trades that work on roofs during construction and maintenance activities. Therefore, there is market potential for a portable anchor system that is lightweight, easy-to-use, and only deploys in the case of an actual worker fall.

Prototype Development

The Werner Company, located in Greenville, Pennsylvania, is a world leader in the manufacturing and distribution of aluminum and fiberglass ladders. While the Werner Company's base business is the manufacture and sale of ladders, they have expanded their business in recent years to include other climbing equipment, access products, and fall protection equipment/devices. The Werner Company collaborated with Auburn University to develop a fall protection anchor system for use on sloped roofs that is portable, lightweight, easy to use, and non-damaging to roofing systems while meeting OSHA standards. In 2010, Auburn University established the Center for

Construction Innovation and Collaboration (CCIC) within the College of Architecture, Design, and Construction. The CCIC focuses on innovative and collaborative approaches to real-world problems related to construction products and processes. It brings together faculty, students, industry representatives, product producers and others to formulate effective and innovative solutions—a place where technology, experience and cutting-edge ideology work together. As part of its charter, the CCIC actively seeks opportunities to collaborate with multiple colleges within the university.

The Center received a small grant to work on the development of a prototype for the portable fall protection anchor device, and work began in the fall semester of 2014 by students and faculty in the School of Building Science Management and Mechanical Engineering departments as a senior design project. Their initial work centered on developing various frame or clamp systems to provide a suitable fall protection anchorage point. The most promising concept was a center-of-gravity fixed-frame anchor device. Figure 2 shows the drawings for this concept.

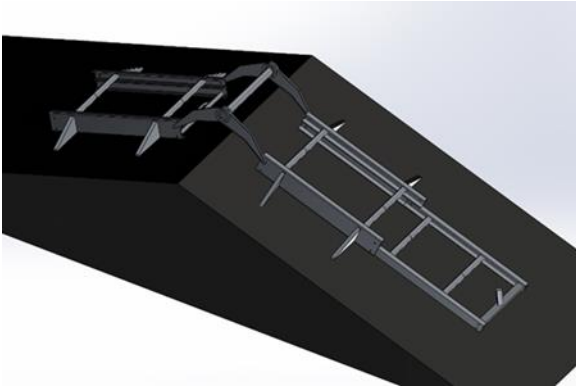


Figure 2(a): Center of gravity fixed frame (deployed).
Figure 2: Initial prototype concept.

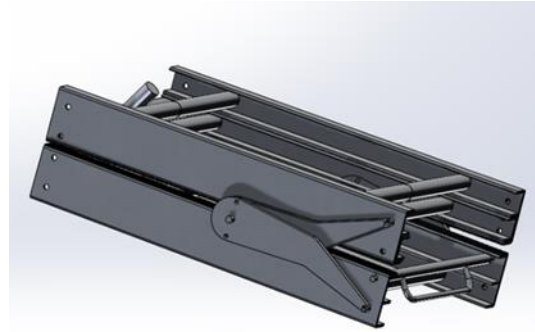


Figure 2(b): Fixed frame (transport/storage mode).

Work continued on the project during spring 2015. After conducting a series of performance tests, the team abandoned the fixed frame concept. It was determined that it was too bulky and heavy since it relied on the attachment of a counterweight to the frame in order to anchor a worker in the event of a fall. The bulk and weight of the device limited its portability. In response to these concerns, the team formulated a new concept using a powder-actuated device that would attach to the roof when a fall occurred. The concept was further refined during fall 2015. Figure 3 shows the details of this new design concept.



Figure 3(a): Steel base.

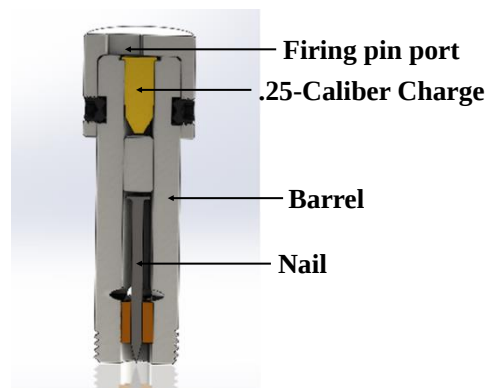


Figure 3(b): Barrel design.

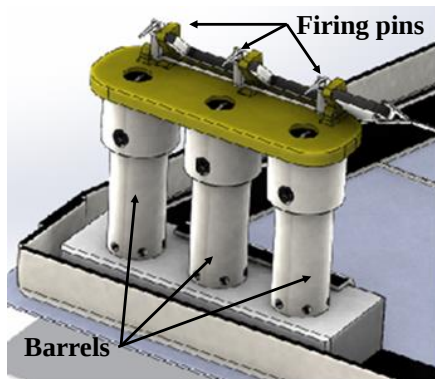


Figure 3(c): Firing mechanism.

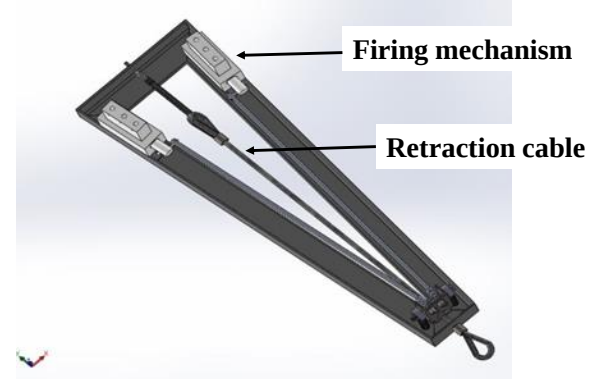


Figure 3(d): Operational Prototype.

Figure 3: Refinement of powder actuated design.

The concept behind this design is relatively simple: the fall protection anchor device, when triggered by a worker falling, uses powder actuation to fire nails into the roof substrate securely attaching the device to the structure. Once securely attached, the device serves as the anchor point for the worker's fall protection system. Since powder actuation is the same process used in some nail guns currently on the market, the design team took advantage of existing technology. What makes this device unique is that it is non-invasive unless activated by an actual worker falling. Therefore, anchoring the device by mechanical means is not necessary. Activation of the device when a worker falls is the only time any damage to the roof occurs.

Figure 3(a) shows the construction of the frame for the base of the portable anchor point. The team constructed the base using 1/4-inch thick, 1.5-inch x1.5-inch angle iron. The frame was triangular to provide maximum load carrying capacity while conserving weight and maintaining easy portability. It was 30-1/4 inches long and 10 inches wide at it widest point. This was much smaller, lighter, and more portable than the original gravity fixed-frame device concept.

The design team chose to use .25-caliber Ramset[®] cartridges in their concept design due to their commercial availability that simplifies production while being cost-effective. After considering several options, the team selected a system of multiple barrels firing individual nails simultaneously into the roof substrate to ensure that the anchor system would be able to resist the loads imposed by a falling worker. Figure 3(b) shows the barrel design. For the initial prototype, a bottom plate was 3D printed from plastic and used to position the barrels precisely on the frame.

Figure 3(c) shows the design for the interior of the firing mechanism. The exterior housing of the firing block consisted of a 3D printed block with the center machined out to accept a firing rod. The team constructed the 3D printed block using ABS plastic to reduce cost and for ease of manufacturing. Press fitted sleeve bearings supported the firing rod on either end to reduce friction. The three firing pins were spring-loaded in chambers above the rod. Pulling the rod through the block allowed the pins to travel through the slots in the firing rod and activate the device.

The spring was compressed and held in place by the firing pin and rod. Exerting enough pressure (i.e. when a worker falls) on the firing rod overcame the friction of the firing pins pushing down on it and initiated the process of firing the cartridge. . The holes drilled in the firing rod for the firing pins line up with the firing pins and the cartridge casing below. Pulling the activating the firing rod caused all of the firing pins to travel simultaneously through their designated holes in the firing rod and made contact with the firing pins. The firing pins struck the primer on the rear of the cartridge. In order to make positive contact with the primer of the rim fire cartridge, the

cartridges and barrels were offset to ensure the ends of the firing pins only contacted the edge of the cartridge, crushed the rim, and fired the round.

The team connected the triggering mechanism to the firing mechanism by two, 1/4-inch steel rods that initiated the firing mechanism. The triggering mechanism had two main components, the retraction system and the catch. The next section contains a description of the retraction system. They attached the catch to a hinge placed at the front of the device. Once the cable travelled 24 inches, the thimble caught the hinge allowing the hinge to rotate forward and activate the firing mechanism.

The design of the cable retraction system allowed the user approximately a 24-inch range of motion while using the device. A spring attached to one end of the cable and the frame allowed the cable to extend and then retract back into the device as the user moves away or toward the device. Pulling the cable 24 inches activated the device and the device attached itself to the roof. The team designed the prototype anchor device for use with a fall protection system that includes a body harness and shock-absorbing lanyard attached to the end of the cable retraction system.

Figure 3(d) shows the operational prototype of the portable fall protection anchor system. The design team performed operational testing at Building Science's field demonstration site. They constructed a roof with a 5.5:12 pitch on an existing frame structure at the demonstration lab. Tests on four different roofing substrates including 1/2-inch plywood, 5/8-inch plywood, 1/2-inch OSB, and 5/8-inch OSB. The team used a 50-lb weight dropped off the edge of the roof. Using the 50-lb weight ensured that the triggering mechanism for the device was sensitive enough to activate in the case of an actual worker fall. This testing indicated that the firing mechanism for the prototype was very reliable. The device activated, fired the nails, and secured the anchor device to the roof substrate on every repetition of multiple field tests on the various substrates. Figure 4 contains photographs of the prototype testing.



Figure 4: Prototype testing.

After the completion of initial testing of the working prototype, the CCIC engaged graduate students from the Industrial Design department to: (1) explore ways to improve the human-machine interface and enhance the prototype's functionality, safety, and operation and (2) provide an attractive, functional, and marketable product for the client. Figure 5 shows some of the noteworthy improvements to the design.

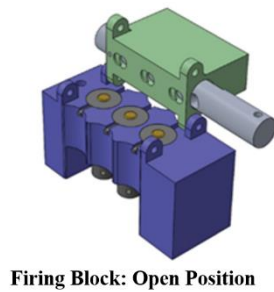


Figure 5(a): Break-action firing block.

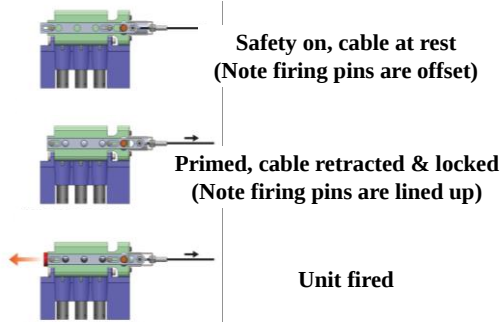


Figure 5(c): Disarming mechanism.

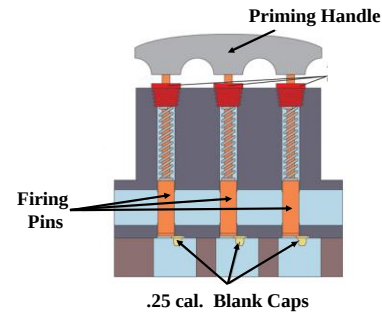


Figure 5(b): Grouped firing pin assembly.

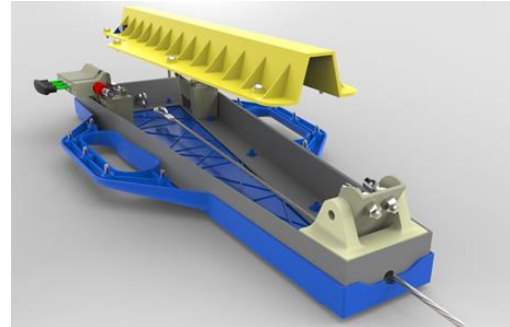


Figure 5(d): Cable shroud.



Figure 5(e): Swing open access doors.



Figure 5(f): Completed exterior enclosure.

Figure 5: Final prototype.

The first operational improvement involved revising the firing block to a break-action configuration shown in Figure 5(a). This revised firing block design permitted easier resetting and loading, reduced weight when compared to the previous design of the firing block, and permitted both left- or right-hand use by simply changing the location of the pins connecting the top and bottom portions of the firing block with no additional parts being required. The design team developed a grouped firing pin assembly shown in Figure 5(b). This innovation made the firing pin easier to reset and gave the user a clear visual indication whether or not the anchor system is “armed” and ready for use. The team also developed a sliding safety and disarming mechanism shown in Figure 5(c) to improve the safety of the anchor system by preventing accidental discharge during storage and transport. Twisting a device on the control cables engaged the safety device. Engaging the safety offsets the firing pin holes, preventing the anchor system from firing. Offsetting the firing pin holes allowed the anchor system to be dry-fired to permit safe transport and storage. This feature eliminated the need to remove the cartridges when the device is not in use.

The next step was to design the exterior shell and related features that limited access to only those areas of the operational mechanism of the device required for operation and maintenance by the user. The design team added a cable shroud shown in Figure 5(d) to prevent the entanglement of the operating cable with the internal hardware. The external shroud was fitted with swing-open doors shown in Figure 5(e) to allow for easy loading and unloading of the firing cartridges. Figure 5(f) shows the remainder of the exterior enclosure. It is a combination of yellow and

blue ABS plastic to match the Werner Company's corporate color scheme while still being highly visible. The addition of a horizontal inclinometer indicated the safe operating range in relation to alignment with the ridge of the roof (+/- 40 degrees from perpendicular). A vertical inclinometer was included to give a clear indication to the user of the safe operating range on slope roofs. The vertical inclinometer shows a safe operating range (green indicator) on roof pitches of 6:12 or less. It is possible to use the device on roof pitches between 6:12 to 8:12 (yellow band). However, the design team does not recommend using the portable anchor on roof pitches greater than 6:12. The design team added a clear storage compartment on the top of the enclosure for storage of spare firing cartridges and two handles on the exterior shell to provide easy portability. The dimensions of the final concept configuration of the prototype for the portable fall protection anchor system are 32.15 inches long, 15.75 inches wide, and 7.09 inches tall, and it weighs 30.63 lbs.

Discussion

This case study documents the detailed design, development and initial testing of a functional prototype of a fall protection anchor device. It demonstrates the value of collaboration in the design and development of new products for the construction industry using an interdisciplinary approach. By bringing together the collective talents of Construction Management, Mechanical Engineering, and Industrial Design, Auburn University's CCIC facilitated the production of a working prototype of a portable anchor device that becomes part of a complete fall protection system for sloped roofs. The collaborative team used an iterative process to develop the best design to meet the client's requirements and address an important problem in the construction industry.

The prototype anchor system meets the Werner Company's criteria of being portable, lightweight, easy to use, and non-damaging to roofing systems (except in the case of deployment in an actual fall). Initial design calculations indicate that the portable anchor system meets OSHA standards. However, given the liability issues associated with products of this nature, further engineering and detailed, repetitive operational testing is required to confirm that the anchor device meets OSHA requirements and will perform with a very high degree of reliability in the field on a wide variety of roof substrate materials. The Werner Company has indicated there is strong market potential for the portable anchor device and have indicated their desire for further collaboration with Auburn University moving forward with further product development and operational testing. Planning is underway to construct a revised operational prototype incorporating the latest design improvements. After this prototype is constructed, the design team will subject the device to detailed operational testing in a variety of roofing substrates to ensure that it operates reliably and meets OSHA standards for anchor devices for fall protection systems. The Werner Company and Auburn University will jointly develop a testing protocol and methodology. Depending on the results of the operational testing, the design team will make further design changes and enhancements prior to final testing and eventual production of the device for sale on the commercial market.

References

- Bureau of Labor Statistics, U.S. Department of Labor. (2016, April 21). Fatal occupational injuries by industry and event or exposure. *2014 Census of Fatal Occupational Injuries*. [WWW Document]. URL <http://www.bls.gov/iif/oshwc/cfoi/cftb0286.pdf>
- Capital Safety. (2016). Reusable hinged roof anchor. [WWW Document] URL <https://www.capitalsafety.com/en-us/Pages/ProductDetails.aspx?prodId=1373>

Capital Safety. (2016). Reusable swiveling roof anchor for SRL. [WWW Document] URL
<https://www.capitalsafety.com/en-us/Pages/ProductDetails.aspx?prodId=1368>

Capital Safety. (2016). Reusable swiveling quad-pod roof anchor with SRL. [WWW Document] URL
<https://www.capitalsafety.com/en-us/Pages/ProductDetails.aspx?prodId=1369>

Claussen, L. (2011). No alternative? OSHA rescinds directive on residential construction fall protection requirements. *SH-Safety and Health-National Safety Council*, 183(3), 38.

Guardian Fall Protection. (2016). CB-12 anchor point. [WWW Document] URL
<http://www.guardianfall.com/performance-safety-products/anchor-points/product/cb-12-anchor-point>

Occupational Safety & Health Administration [OSHA], U.S. Department of Labor. (2012). Workers' compensation costs of falls in construction. [PowerPoint] URL
https://www.osha.gov/doc/topics/residentialprotection/2012_fall_costs/index.html

Occupational Safety & Health Administration [OSHA], U.S. Department of Labor. (n.d.). 1926.501 - Duty to have fall protection. Regulations (Standards-29 CFR). URL
https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10757

Occupational Safety & Health Administration [OSHA], U.S. Department of Labor. (n.d.). 1926.502 - Fall protection systems criteria and practices. Regulations (Standards-29 CFR). URL
https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10758

Occupational Safety & Health Administration [OSHA], U.S. Department of Labor. (2016). NAICS Code: 236 construction of buildings. [WWW Document] URL
https://www.osha.gov/pls/imis/citedstandard.naics?p_naics=236&p_esize=&p_state=FEFederal

Occupational Safety & Health Administration [OSHA], U.S. Department of Labor. (2016). NAICS Code: 2361 residential building construction. [WWW Document] URL
https://www.osha.gov/pls/imis/citedstandard.naics?p_naics=2361&p_esize=&p_state=FEFederal

Occupational Safety & Health Administration [OSHA], U.S. Department of Labor. (2016). NAICS Code: 2362 nonresidential building construction. [WWW Document] URL
https://www.osha.gov/pls/imis/citedstandard.naics?p_naics=2362&p_esize=&p_state=FEFederal