Construction Guardrails

Development of a multifunctional system

By Thomas G. Bobick and E.A. "Tony" McKenzie Jr.

IN BRIEF
- The primary cause of fatal injuries in U.S. construction is workers falling from heights.
- In 2008, 975 workers were killed in construction, 336 (34%) involved falling. Of these 336 fatalities, 113 (34%) involved workers falling from a roof edge, through roof and floor openings, or through skylights.
- NIOSH researchers developed a multifunctional guardrail system. When correctly installed, this innovative guardrail system should help to prevent fall-related injuries and fatalities.

Fall-related incidents are the primary cause of fatalities in the U.S. construction industry. A NIOSH analysis of fatality data from the Bureau of Labor Statistcis Census of Fatal Occupational Injuries (CFOI) indicated that from 2004 to 2008, a total of 5,844 construction workers were killed from all causes (annual average 1,169) (BLS, 2005, 2006, 2007, 2008, 2009). During the same period, 2,055 construction fatalities occurred due to falling (annual average 411). Workers falling accounted for more than 35% of all fatalities that occurred in construction from 2004 to 2008. Further analyses of CFOI data indicate that construction-related falls from roof edges, through roof and floor openings, and through skylights resulted in a 5-year total of 767 fatalities (annual average 153).

Table 1 presents a 5-year breakdown of these data, along with a total number of fatalities and total number of fall-related fatalities in all U.S. workplaces for comparison. The last category of construction workplace situations (falls from roof edges, and through roof and floor openings and skylights) are situations that can be addressed with a guardrail system to prevent falls to a lower level.

Mandatory regulations for the construction industry are found in OSHA 29 CFR 1926. Specifically, Subpart M, which includes sections 1926.500 through 1926.503 and appendixes A through E, lists requirements related to workplace falls.

In addition, OSHA issued Directive No. STD 3.1 (Dec. 5, 1995), which provided an interim enforcement policy on fall protection for certain residential construction activities involving installation of floor joists, floor sheathing, exterior walls, roof trusses and rafters, and roof sheathing. Directive 3.1 has been superseded by Directive No. STD 3-0.1A (June 18, 1999); it provides a plain language rewrite of the previous directive and is found at **www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=DIRECTIVES&p_id=2288.**

In addition, ANSI/ASSE (2007a) A10.18 prescribes minimum safety requirements for construction and demolition activities, while ANSI/ASSE (2007b) A1264.1 prescribes safety requirements for modifications and renovations to existing industrial and commercial facilities and work areas. Some state regulations may specifically cite these national consensus standards.

Section 1926.501 of Subpart M discusses fall protection requirements. Subsection 1926.501(b)(4)(i) states, "Each employee on walking/working surfaces shall be protected from falling through holes (including skylights) more than 6 ft (1.8 m) above lower levels, by personal fall arrest systems, covers or guardrail systems erected around such holes" (Mancomm, 2008). Guardrail systems also must comply with OSHA 29 CFR 1926.502(b)(3), which states, "Guardrail systems shall be capable of withstanding, without failure, a force of at least 200 lb (890 N) applied within 2 in. (5.1 cm) of the top edge, in any outward or downward direction, at any point along the top edge" (Mancomm).

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E.A. "Tony" McKenzie Jr., Ph.D., P.E., has been with NIOSH for 10 years. His research efforts focus on residential construction with emphasis on falls to lower levels and the agricultural sector, specifically rollover protective structures (ROPS). McKenzie is a member of the ASABE PM 23/2/2 ROPS subcommittee and the X599 Committee. He is the lead design engineer for the NIOSH AutoROPS and CROPS. McKenzie is a graduate of WVU, where he is an adjunct professor in the Department of Mechanical and Aerospace Engineering.

Photo 1
The initial design, developed for use on residential roofing, was based on the footprint of the commonly used roof bracket, 3 in. wide by 18 in. long, that uses three 16-penny (16d) nails to attach the bracket to a sheathed roof truss.

Covers and guardrail systems are effective measures to protect workers from falling through roof and floor holes. Guardrail systems, whether commercially available or built on site, can provide protection for unguarded roof edges (steep slope and low slope) or interior edges, including balconies or stairways, during residential, commercial, and industrial construction and renovation activities.

NIOSH's Research to Practice Initiative

NIOSH's Research to Practice (r2p) initiative was established in 2004. Its goal: Ensure that NIOSH-generated findings are transferred and translated into the workplace to prevent injury, illness and fatalities (NIOSH, 2009). The initiative focuses on:

> . . . the transfer and translation of knowledge, interventions, and technologies into highly effective prevention practices and products which are adopted into the workplace. [It] is a way of conducting research to help ensure that it is relevant to our stakeholders and results in the reduction of workplace injuries, illness and fatalities (NIOSH, 2009).

Hsiao (2008) discusses various r2p activities related to engineering research projects.

One way to transfer research-related products and technologies is to establish licensing partnerships with companies that will then manufacture and/or commercially market the products. This is a critical aspect of transferring research developments to the workplace where those interventions, when properly installed, may prevent injuries and deaths.

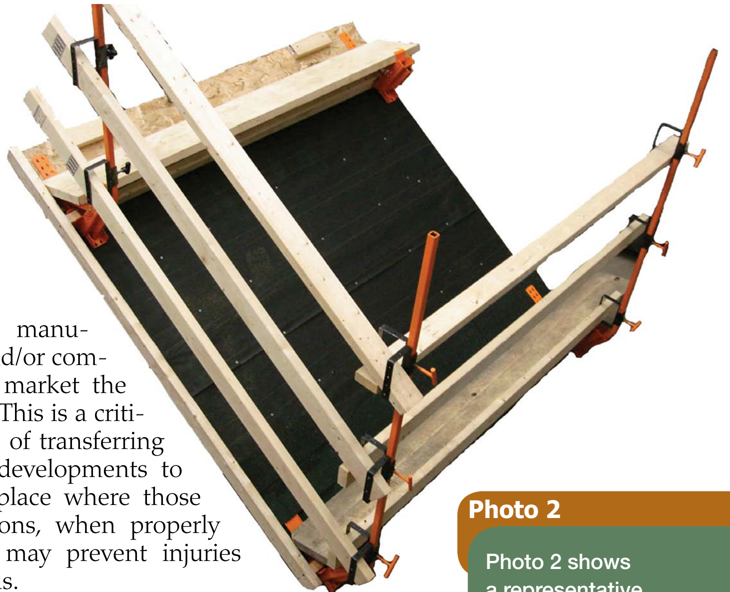


Photo 2
Photo 2 shows a representative installation of the NIOSH-designed roof bracket-guardrail system.

Initial Guardrail Design for Sloped Configurations

Researchers at NIOSH's Division of Safety Research developed a patented multifunctional guardrail system that can protect construction workers from exposures to potential fall-to-lower-level hazards (U.S. Patent No. 7,509,702; Canada patent-pending). The initial design, developed for residential roofing applications, was based on the footprint of the commonly used roof bracket, 3

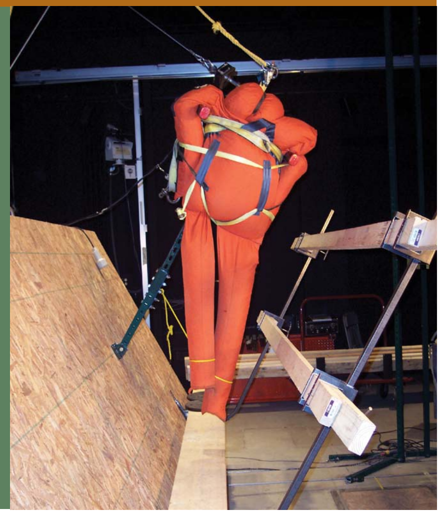
Table 1
Fall-Related Fatalities

Event	2004	2005	2006	2007	2008
Total U.S. occupational fatalities	5,764	5,734	5,840	5,657	5,214
Total U.S. occupational fatal falls	822 (14%)	770 (13%)	827 (14%)	835 (15%)	700 (13%)
Total construction fatalities	1,234	1,192	1,239	1,204	975
Total construction fatal falls	445 (36%)	394 (33%)	433 (35%)	447 (37%)	336 (34%)
Construction fatal falls involving roofs[a] and floor openings	175 (39%[b]) (14%[c])	147 (37%[b]) (12%[c])	170 (39%[b]) (14%[c])	162 (36%[b]) (13%[c])	113 (34%[b]) (12%[c])

Note. *Fall-related fatalities, all U.S. industries and construction, 2004-2008. Data from Table A-9, "2004 Census of Fatal Occupational Injuries," by Bureau of Labor Statistics (BLS), 2005, Washington, DC: Author, Department of Labor (DOL); Table A-9, "2005 Census of Fatal Occupational Injuries," by BLS, 2006, Washington, DC: Author, DOL; Table A-9, "2006 Census of Fatal Occupational Injuries," by BLS, 2007, Washington, DC: Author, DOL; Table A-9, "2007 Census of Fatal Occupational Injuries," by BLS, 2008, Washington, DC: Author, DOL; and Table A-9, "2008 Census of Fatal Occupational Injuries," by BLS, 2009, Washington, DC: Author, DOL.*
[a]From roof edge, and through roof openings and skylights. [b]Percentage value of "total construction fatal falls." [c]Percentage value of "total construction fatalities."

Photo 3

The system has successfully supported an impact force of 435 lb from a test manikin that fell against the top rail (shown here), more than twice the OSHA requirement, without slippage or failure of any components. This photo shows the test setup with the roof slope set at 24/12 (63°).



in. wide by 18 in. long, that uses three 16-penny (16d) nails to attach the bracket (Photo 1, p. 49) to a sheathed roof truss.

Photo 2 (p. 49) depicts the NIOSH-designed roof bracket-guardrail system. The roof bracket base is designed to be used on flat surfaces and can be adjusted to seven roof slopes [6/12, 8/12, 10/12, 12/12, 15/12, 18/12 and 24/12—or 27°, 34°, 40°, 45°, 51°, 56° and 63° (A-frame)].

As the roof slope increases in steepness, the vertical tube that supports the top rail and midrail will lean backward from vertical; this may cause the height of the top rail to be less than the 39-in. minimum required by OSHA 29 CFR 1926.502(b)(1). To ensure that the height regulation is met, NIOSH's system has been designed so the fixtures that support the top rail and midrail can be adjusted. Fixtures are loosened with a handle at the back of the fixture that permits it to be slid up the vertical tube to the required OSHA height.

Lab testing has verified that hand tightening is sufficient to ensure that cross-members will not slip down the vertical tube when contacted with a 200-lb force, as specified by OSHA. In fact, the system has successfully supported an impact force of 435 lb (more than twice the OSHA requirement) from a test manikin that fell against the top rail (Photo 3) without slippage or failure of any components (McKenzie, Bobick & Cantis, 2004; Bobick & McKenzie, 2005).

Photo 3 shows the test setup with the roof slope set at 24/12 (63°). The guardrail system has been designed to lean away from the roof as the slope increases. This feature provides increased space for workers as well as the close-proximity guardrail protection.

Photo 4 shows the system's component parts. For each of the seven sloped configurations, the plank for the walking/working surface is always level. The design also incorporates a slide guard that is perpendicular to the roof slope. The cross-members (top rail, midrail, toe board) are supported by the vertical tube. For the roof design, the bent rail tube slides into the pocket at the rear of the roof bracket base.

Thanks to this adaptable design, a guardrail can be installed anywhere on a residential roof, either to facilitate shingle installation or to protect a worker who must spend multiple shifts in one location, such as for chimney installation or repair, or dormer construction or repair. As Photo 5 shows, this multifunctional guarding system provides three-sided protection for masons, carpenters, laborers and other roof workers.

Photo 4

Photo 4 shows the component parts of the bracket-guardrail system. For each of the seven sloped configurations, the plank for the walking-working surface is always level. Also shown in this photo, the design incorporates a slide guard that is perpendicular to the roof slope.

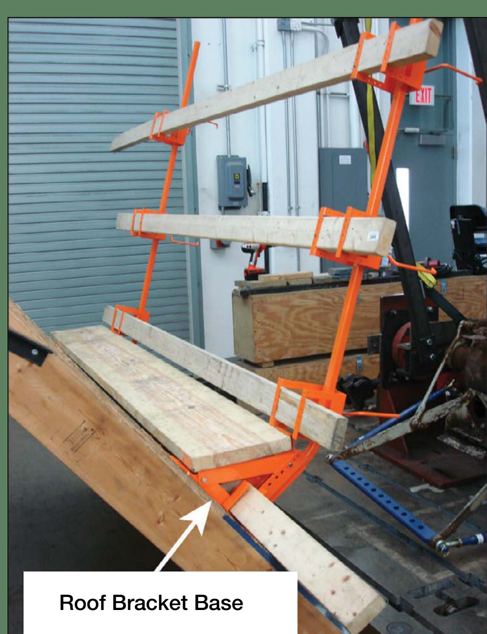
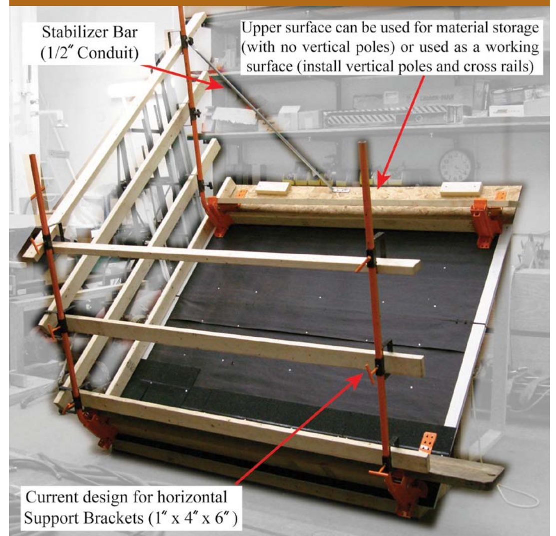
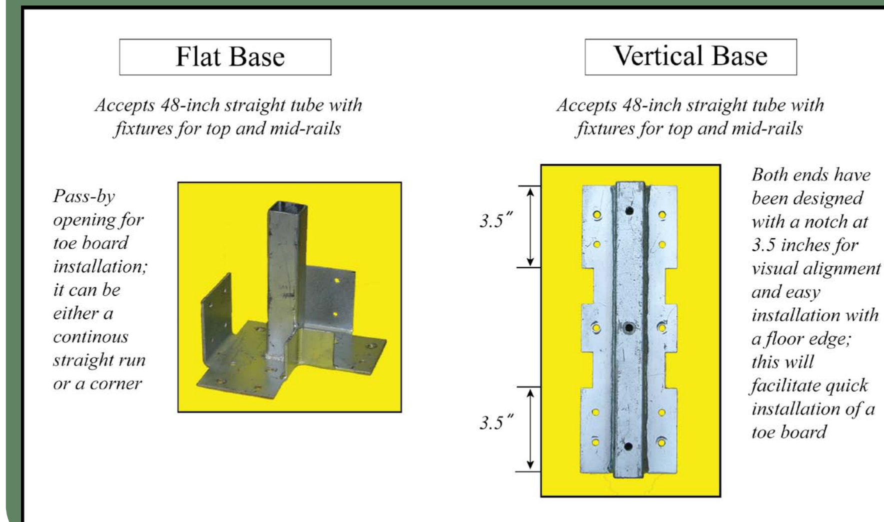


Photo 5



This multifunctional guarding system provides three-sided protection for masons, carpenters, laborers and other roof workers.

Figure 1
Flat & Vertical Bases



Additional bases have been developed with smaller footprints—6 x 6 in. for the flat base and 3.5 x 12 in. for the vertical base.

Flat & Vertical Designs

During an initial field test in Florida, the contractor attempted to use the system for edge protection inside the residence under construction. The initial design of the base plate was not practical for use on stair treads. Additional bases (flat and vertical, shown in Figure 1) have been developed with smaller footprints: 6 x 6 in. for the flat base and 3.5 x 12 in. for the vertical base. These bases are ideal for temporary handrail construction during the framing phase.

Information from a contractor in Virginia and discussions at a site in North Carolina indicated that staircases of finished wood, such as oak, are often installed as an entire unit. This situation precludes nailing into the finished wood surface. In response, the researchers developed the vertical offset base (Photo 6). This base can be mounted on the drywall surface below the finished staircase stringer or skirtboard by screw fastening to the studs of the supporting wall. As the inset in Photo 6 shows, the offset bracket allows the vertical rail to clear the overhang of the finished stair treads.

Photo 6

Vertical offset base mounted below a simulated staircase. This base can be mounted on the drywall surface below the finished staircase stringer or skirtboard by screw fastening to the studs of the supporting wall. As the inset shows the offset bracket allows the vertical rail to clear the overhang of the finished stair treads.

Commercial Development

The guardrail system design is available for commercial development through a licensing agreement with NIOSH. The preliminary step in this process is for a company to sign a material transfer agreement (MTA). This gives NIOSH permission to transfer engineering design drawings and a sample of guardrail products to that company, which it can use to make an informed decision as to whether the company wants to pursue the option of manufacturing and marketing the system. The MTA also provides a company an opportunity to manufacture a prototype from the drawings to determine whether its manufacturing processes are appropriate for producing the system.

Contact NIOSH's Technology Transfer Office at **www.cdc.gov/niosh/r2p/technology.html** for more information about the MTA and the licensing agreement.

Download a brochure about the guardrail system and information for commercialization opportunities **www.cdc.gov/niosh/r2p/pdfs/NIOSH_Innovations_SafetyRailSystem.pdf.**

Photo 7

Photo 8

Photos 7 and 8 show the flat and vertical bases being used to install temporary handrails for stair construction. When either of these bases is installed on site, proper fasteners must be used and must be correctly and securely inserted.

When any of the bases are installed on site, proper fasteners must be used and must be correctly and securely inserted into the roof truss, floor joist or wall stud. It is recommended that three 16d nails, which are 3.5 in. long, be used during installation. Three 3-in. all-purpose screw fasteners are recommended to install the flat and vertical bases to ensure that the system is properly mounted to the structure to provide adequate worker protection.

A pneumatic nail gun should never be used to install nails with the metal base plates. A slight misalignment can easily result in a nail ricochet that can severely injure the nail gun operator or a nearby coworker. It is also harder to determine that the nail driven by a nail gun has been correctly inserted into the roof truss, floor joist or wall stud. If the air-driven nails miss the wood underneath, then the protective guardrail is not properly mounted and secured.

Photo 9

Photo 9 shows the flat and vertical bases being used to install temporary guarding around a large floor opening.

The guardrail system has been displayed at several safety expositions. Feedback from safety professionals in the bridge construction industry indicates that the flat base system could be used in bridge construction. Bridge contractors note that the system, when installed along the length of the bridge deck during new or repair work, would reduce guardrail installation time as well as labor and raw material costs, when compared to constructing and installing stick-built guardrail systems.

All of the new base configurations (flat, vertical, vertical offset) use the same pocket, which receives the straight end of the 60-in. bent rail tube or a 48-in. straight rail tube to support the fixtures for the top rail and midrail cross-members. Photos 7 and 8 show the flat and vertical bases being used to install temporary handrails for stair construction. Photo 9 shows the flat and vertical bases being used to install temporary guarding around a large floor opening. Other designs are being developed by NIOSH for use in the construction (residential, industrial, commercial) and bridge construction industries.

Field Evaluation Study

To gain real-world experience over a lengthy period, the guardrail system will be evaluated during an extended field study by two West Virginia residential construction contractors, in conjunction with the West Virginia University (WVU) Safety and Health Extension and the North-Central West Virginia Home Builders' Association. During the first 2 months of this study, researchers will observe crew members as they work. This initial 2-month period will serve as a baseline.

WVU Extension construction specialists will train workers how to correctly and safely use the guardrail system. During the 5 to 6 months following the baseline study, the guardrail system will be used whenever it is appropriate to install and evaluate its various components. Extension specialists will monitor system installation and use during ongoing construction activities.

During roof work, workers often rely primarily on a slide guard for protection from falling off the roof. The slide guard is typically a 2 x 6 in. plank installed perpendicular to the roof surface that workers brace against while working. The slide guard has no vertical guardrail system. With no protective system behind them, workers tend to lean in toward the roof for stability. Standing and working in such awkward postures will likely increase worker

Falls to a lower level are the primary cause of fatal injuries in the construction industry. Typically, one of every three fall-related fatalities involves workers falling from roof and interior edges, or falling through roof openings or skylights. Such falls can be prevented by the use of guardrails.

Industry Response to the Guardrail System

Rosemont, IL: 2008 & 2009

Tom Broderick, executive director of Construction Safety Council, visited the NIOSH testing labs in Morgantown, WV, during 2007. He saw an early version of the system that had been assembled to make an OSHA-compliant walking/working surface with a guardrail (Photo 5, p. 50). He stood on, shook and bounced up and down on the system to physically test its strength.

Broderick became an important supporter of the design.

To help get the system in front of the construction community, he invited the research team to exhibit the system at the council's annual conference. The team displayed the system on a miniroof (10 ft wide x 8 ft upslope) for the first time.

In 2009, along with the miniroof setup, the research team displayed two additional bases, flat and vertical (Figure 1, p. 51), which were demonstrated on a ministair setup (similar to what is shown in Photos 6-9).

Response was excellent at both expositions. Because of the interest generated during the 2008 exposition, the research team developed a brochure, which has since been distributed to hundreds of interested parties. The team also collected video footage during the 2009 conference, showing the roof and stair setups, as well as an interview with Broderick. This footage will be included in a 7-minute DVD under development.

Washington, DC: July 2009

Tom Kavicky, assistant to the president of the Chicago Regional Council of Carpenters, visited the NIOSH booth during the 2009 Construction Safety Council exposition. He was interested in the system's adjustability and the reusability of the vertical poles and cross-members (top rails, midrails, toe boards). He felt that once this was a commercial product, the carpenters union would be interested in including the system in its apprenticeship program.

Kavicky is also cochair of the Fall Protection Work Group of OSHA's Advisory Committee for Construction Safety and Health (ACCSH). ACCSH meets quarterly in Washington, DC. The NIOSH research team was invited to show two displays (roof and stairs) at the work group's July 2009 meeting. Attendees included 15 to 20 fall protection specialists, and the overall response was great.

Harry Dietz of the National Roofing Contractors Association (NRCA) was one of the attendees. He watched the system as it was assembled, and commented about how easily the system went together. Such feedback, especially from an NRCA representative, was valuable.

When informed of the ongoing efforts to secure a partner (through a licensing agreement) to manufacture and market the system, Dietz suggested a roofing contractor from Texas. He agreed to speak to that company on the team's behalf and provide contact information for company officials. Partnership discussions are ongoing.

Rob Matuga, assistant vice president, labor, safety and health policy, National Association of Home Builders (NAHB), also expressed interest in seeing the NIOSH system be part of a field usage study (now approved and planned for 2011). Such interest resulted in an invitation to deliver a presentation on the system to NAHB's Construction Safety Training, Education and Research Subcommittee in January 2010.

Baltimore: June 2010

The researchers also demonstrated the system at ASSE's Safety 2010 conference. Visitors to the booth included five construction contractors (PA, MD, VA, HI, Australia); five insurance companies (IL, MN, NY, CA, TX); two power companies (MA, NC); four safety consultants (NH, PA, CA, DE); five safety products companies (MO, MN, NC, IN, WA); four corporate safety personnel (PA, GA, PA, FL); three researchers (CA, DC, Taiwan); one internet company (WA); six federal OSHA officials (CO, TX, GA, KS, NY, AL); and four state OSHA officials (NC, KY, MD, CA).

All expressed an interest in being notified when the system is commercially available. The research team also had discussions with personnel from the safety products company in Missouri that expressed interest in pursuing a licensing agreement.

fatigue. When workers must move around, they may be more likely to lose their balance because of this increased fatigue.

The NIOSH guardrail has a level walking/working surface with a secure guardrail system directly behind the work location. This should provide a more secure work station that 1) improves workers' posture and stability; 2) can be touched for reassurance; and 3) could prevent a fall to a lower level. Field researchers will collect information on worker posture and stability, and assess whether the guardrail system is used for reassurance, resting or protection.

Disclaimer
The findings and conclusions in this report are those of the authors and do not represent the views of NIOSH. The mention of company names and products does not imply endorsement by NIOSH.

Researchers will also collect data related to the time needed to install the system initially and the time needed to install the system after 4 months of use. Field researchers will also take digital photos to document workers' postures during the baseline period for comparison with postures after the system is installed, and solicit feedback from crew members and management about suggested modifications to improve the system's functionality.

Conclusion

Falls to a lower level are the primary cause of fatal injuries in the construction industry. Typically, one of every three fall-related fatalities involves workers falling from roof and interior edges, or falling through roof openings or skylights. Such falls can be prevented by the use of guardrails.

NIOSH's multifunctional guardrail system can be used on various unprotected workplaces in the residential, industrial and commercial construction industries. The initial design was developed for use on residential roofing and is adjustable to seven roof slopes. Subsequent modifications enable its use on flat and vertical surfaces that need guardrail protection, such as stairs needing temporary handrails, or balconies, decks and roof holes that need temporary protection. This easy-to-use system should help prevent fall-related injuries and fatalities. **PS**

Acknowledgment
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