Fall Protection
Peer-Reviewed

Construction
Guardrails
Development of a multifunctional system

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Fall-related incidents are the primary cause of fatalities in the U.S. construction industry. A NIOSH analysis of fall injury data from the Bureau of Labor Statistics 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, 2,053 construction fatalities occurred due to falling (annual average 413). 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 the 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 appendices 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 Directive 3.1 has been superseded by Directive No. STD 3.0-1A (June 18, 1999), it provides a plain language rewrite of the previous directive and is found at www.osha.gov/pls/oshaweb/owa disp.show_document?p_table=DIRECTIVES& p_id=228.

In addition, ANSI/ASSE (2007a) A10.18 prescribes minimum-safety requirements for construction and demolition activities, while ANSI/ASSE (2007b) A124.1 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 2000 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).

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 workplace 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 commercially market the products. This is a critical aspect of transferring research developments to the workplace where these interventions, when properly installed, may prevent injuries and deaths.

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 in. wide by 1.8 in. long, that uses three 10-penny (16d) nails to attach the bracket to a sheeted roof truss.
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). 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°). Thanks to this adaptable design, a guardrail can be used 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 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 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.

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.

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 the company to sign a material transfer agreement (MTA). This gives NIOSH permission to transfer engineering designs, 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/12p/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/12p/pdfs/NIOSH_Innovations_SafetyRailSystem.pdf.
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 misalignment can easily result in a nail ricochet.

When using fasteners, ensure that the system is properly mounted to the floor opening. Photo 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.

The guardrail system has been displayed at several safety expos. 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, or in 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. One design is 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 6- to 12-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.
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.

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**

References


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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.