Kinematic Response of the NIOSH Developed Safety Rail System in a Laboratory Setting

E.A. McKenzie, Jr., Ph.D., Sharon S. Chiou, Ph.D., and Thomas G. Bobick, Ph.D.
National Institute for Occupational Safety and Health, Morgantown, WV

Construction-related falls from elevations remain a leading cause of serious injuries, fatalities, and lost time. The National Institute for Occupational Safety and Health, Division of Safety Research developed and patented a roof-pitch adjustable working surface and safety rail system to provide fall protection for residential roofers. Compliance with the existing OSHA regulation that "a force of at least 890 N (200 lbs)" must be supported by the top rail of a guardrail system "in any outward or downward direction at any point along the top edge" was a mandatory target in its development. To comply with the OSHA standard and better understand the system's kinematic characteristics when excited by a worker falling into it, laboratory testing was performed. Laboratory tests were developed to simulate a 91 kg (200lb) worker falling into the system from an adjustable roof pitch surface. To capture the kinematic motion of the system, the PEAK® Motus Motion Measurement System was utilized. Reflective markers were placed on key structural points and the test manikin. The manikin simulated a worker falling in a rotational path pivoting at the worker's knees, and was calibrated to impact the system with a minimum 890N (200lb) force. The manikin was released into the system and the velocity and displacement of the system and manikin were recorded in three dimensions. The safety system performed as designed, thus proving it to be an acceptable form of fall protection for future applications.

Introduction

Many industries engage in work at elevation. In the construction industry it is a daily occurrence, thus a daily hazard. Occupational fall protection is essential to preventing worker related injuries and fatalities. By definition, "occupational fall protection is the backup system [to a worker's reflexes when] a worker … could lose his or her balance at a height; its purpose is to eliminate or control injury potential" [Ellis, 2001]. The National Institute for Occupational Safety and Health (NIOSH), Division of Safety Research, Morgantown, WV conducted research related to falls in residential construction. The project evaluated the effectiveness of existing commercial guardrail edge protection systems to prevent falls through roof and floor holes when used as a perimeter guarding system around a hole in a simulated roof work site.

Fall-related incidents are the primary cause of fatalities in the U.S. construction industry. An analysis of fatality data from the Census of Fatal Occupational Injuries (CFOI), maintained by the Bureau of Labor Statistics (BLS), U.S. Department of Labor (DoL), indicated that in 2007, a total of 1,178 worker fatalities occurred in construction, of which 442 involved falling. Of these 442 cases, a total of 160 involved workers falling from or through a roof, a floor opening, or an existing skylight [BLS, 2007]. These are all situations that could be prevented by implementing a guardrail system near the hazard.

Fall-related Regulations

The current mandatory regulations for the construction industry are contained in the Code of Federal Regulations (CFR), Title 29, Part 1926 (Construction), issued by the Occupational Safety and Health Administration (OSHA). Subpart M includes Sections 1926.500 through 1926.503 and Appendices A through E, and lists the requirements that are related to workplace falls. Section 1926.501 of Subpart M discusses the requirements for fall protection. Subsection 1926.501(b)(4)(i) states that "Each employee on walking/working surfaces shall be protected from falling through holes (including skylights) 6 feet or more (1.8 m) above lower levels, by personal fall arrest systems, covers, or guardrail systems erected around such holes." [Mancomm 2008]. The strength of guardrail systems must also meet OSHA regulation 29 CFR 1926.502(b)(3) which states that "Guardrail systems shall be capable of withstanding, without failure, a force of at least 200 pounds (890N) applied within 2 inches (5.1 cm) of the top edge, in any outward or downward direction, at any point along the top edge." [Mancomm 2008]. CFR 1926.502(b)(4) states in reference to CFR 1926.502(b)(3) that the "… edge of the guardrail shall not deflect to a height less than 39 inches (1.0 m) above the walking/working level…". In some residential construction activities for work at or over six feet, the OSHA Instruction STD 3-0.1A [OSHA 1999] would be applicable in terms of fall protection.

The use of covers and guardrail systems has been established as effective measures to protect workers from falling through roof and floor holes. Guardrail systems, commercially available and job-built construction, can be used to provide protection for unguarded roof edges, and interior edges during residential and commercial construction or renovation activities.

NIOSH safety rail system fall protection evaluation

Fall protection has a hierarchy, which is listed in the level of importance: 1) Eliminating fall hazards, 2) Preventing fall hazards by guarding, 3) Arresting falls, and 4) Applying administrative techniques [Ellis 2001]. The output of a NIOSH research project was a patented roof bracket and safety rail system with a walking/working surface (U.S. Patent No. 7,509,702). This system can provide fall protection for most of the residential construction situations that expose workers to potential fall-to-lower-level hazards. In order to validate this claim, laboratory testing was conducted in compliance with the OSHA standards. A test procedure and test apparatus were developed. Since the OSHA requirements do not describe the testing procedure, some level of interpretation was necessary. The test designed used a canvas filled manikin attached to a steel support frame. The frame was hinged at the knees of the manikin to simulate a worker falling into the guardrail with a minimum of 890N (200-lb) force [McKenzie et al. 2004; Bobick and McKenzie 2005]. For a sloped roof, it was determined that the worker would fall down slope into the guard rail.

To create the required load of greater than or equal to 890N (200 lbs), the fall distance of the manikin was the control variable. Force data were collected by data acquisition software, along with an A/D board, and a PCB Piezotronics, Inc. 4448N (1000-lb) piezoelectric force transducer. The force transducer was placed in-line between the manikin and an anchor point. The fall distance of the manikin was varied and the resultant force was measured. The drop distance of the manikin was adjusted so the manikin would stop within one inch of the top rail when the desired resultant force (> 890N (200 lbs)) was achieved (Figure 1). The iterative calibration drops approach ensured that the manikin was consistently applying a force of 890N (200 lbs) or more. When three successive

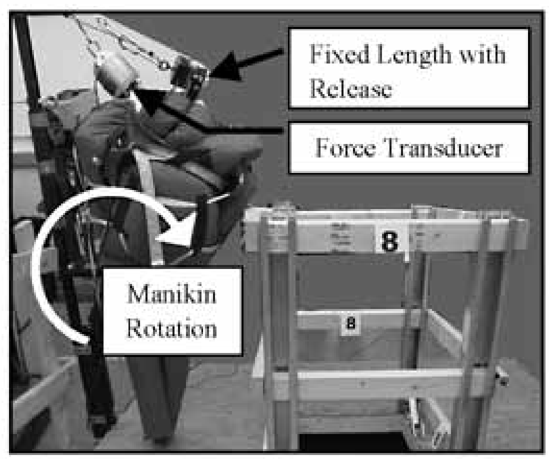

Figure 1 OSHA Drop Test

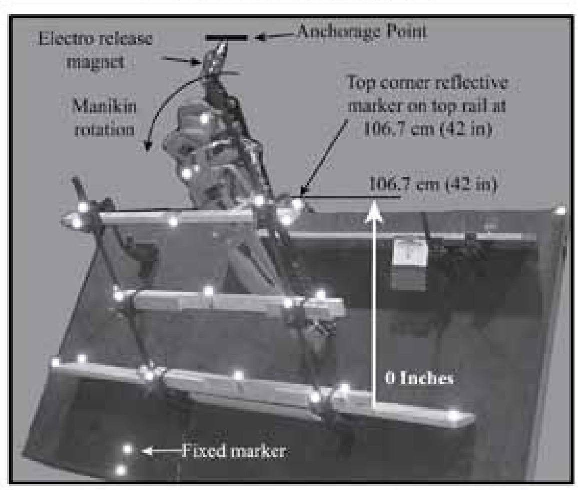

Figure 2 Peak Drop Testing

desired forces were measured, the force transducer was removed and replaced with a fixed length chain to ensure an equal fall distance to the guardrail.

The other aspect of the testing validation was related to the height of the top rail as stated above in CFR 1926.502(b) (4). To validate this requirement a six-camera Motion Analysis System (Peak Motus™, Vicon Corp., Centennial, CO) was utilized to collect the kinematic data of the roof bracket and safety rail system during the testing. A simulated roof surface was constructed in the laboratory, and the roof bracket and safety rail system was installed on it. A set of 23 reflective markers were used to monitor the three-dimensional spatial movement of the roof bracket before, during, and after the manikin drop.

Twenty markers were placed on the key structure points of the roof bracket, including eight on the vertical rails, nine on horizontal rails, and three on the walking working surface. Two additional markers were attached to the roof for reference and one on the head of the manikin. These markers were used with the features of the Peak Motus™ automatic digitization to determine kinematic parameters, including marker displacement, velocity, and acceleration. The 3D marker trajectory data were collected at 60Hz and low pass filtered using a fourth-order Butterworth filter with a 6 Hz cutoff frequency (Figure 2).

Testing Plan

Three different configurations were chosen for testing: 1) a rail with a spacing of 1.22 m (4 ft), 2) a rail with a spacing of 2.44 m (8 ft), and 3) a rail with a spacing of 2.44 m (8 ft), with left and right sides going up the slope. They are shown in Figure 3 below.

Each rail configuration was anchored to the roof structure using three 16d 8.89 cm (3.5 inch) common nails. The load was calibrated three times to deliver the required OSHA load or greater. The manikin was released and the Peak system recorded the deflections, velocities, and accelerations in the x-y-z directions and the resultant values. Four or more repeated drops were completed for each configuration.

Results

- The rail system with 1.22m (4 ft) spacing was subjected to an applied force greater than 983N (221 lbs) and the overall average deflection of the top rail in the z-direction (vertical direction with respect to a fixed marker on the roof structure) was 14.5 cm (5.71 inches).

- The rail system with 2.44m (8 ft) spacing was subjected to a force greater than 1125N (253 lbs) and the overall average z-direction deflection of the top rail was 18 cm (7.09 inches).

- The rail system with 2.44m (8 ft) spacing with side rails was subjected to a force greater than 1112N (250 lbs) and the overall average z-direction deflection of the top rail was 2.59 cm (1.02 inches).

Discussions

The OSHA regulation requires the overall deflection of the top rail to be no more than 7.62 cm (3 inches) with respect to the walking/working level. In all of the cases this regulation was met (max deflection of the top rail was less than 3 inches with respect to the walking/working level). This system absorbed the impact energy of the falling manikin by translating the roof bracket and safety rail system up the roof

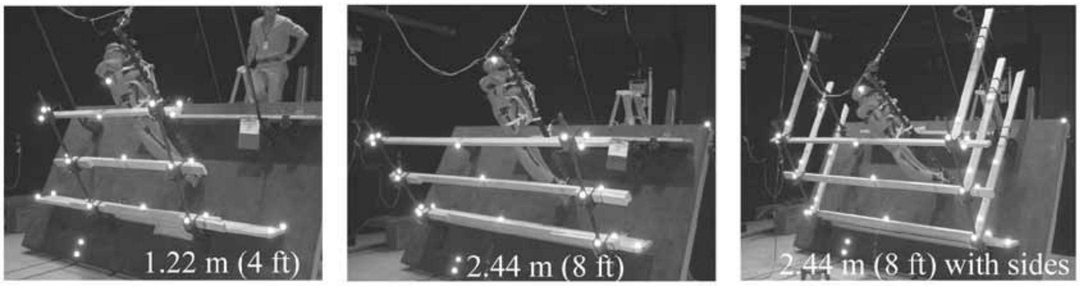

Figure 3 Roof Test Configurations

slope and rotating it away from the roof surface. The distance from the walking/working level during energy absorption stays constant during the test. At the conclusion of the test the walking/working level of the roof bracket and safety rail system was still capable of supporting the weight of a worker greater than 91 kg (200 lbs).

Conclusion

This system complies with the mandatory OSHA standards. It is recommended that if possible this system should incorporate the use of side rails for maximum worker fall protection.

Acknowledgement

The authors would like to extend their appreciation to Mr. Doug Cantis, Physical Science Technician, NIOSH for his efforts related to the goals of this project.

Disclaimer

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

References

Bobick TG, McKenzie EA Jr. [2005]. Using guardrail systems to prevent falls through roof and floor holes. In: Proceedings of the 2005 ASSE Professional Development Conference, New Orleans, LA, June 12–15, 2005, Session No. 601.

BLS [2007]. Fatal occupational injuries by event or exposure and major private industry division, all U.S, 2007. Table A-9. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics.

Ellis JN [2001]. Introduction to fall protection. 3rd ed. Des Plaines, IL: American Society of Safety Engineers, pp. 3, 20.

Mancomm [2008]. Subpart M, 29 CFR 1926, OSHA construction industry regulations. Davenport, IA: Mangan Communications, Inc., pp. 285-302.

McKenzie EA, Bobick TG, Cantis DM [2004]. Design of testing apparatus to evaluate the strength of guardrail systems. In: Proceedings of 2004 ASME International Mechanical Engineering Congress & Exposition, Anaheim, CA, Paper No. 59575.

OSHA [1999]. STD 03-00-001 Plain language revision of OSHA instruction STD 3.1. Interim fall protection compliance guidelines for residential construction [www.osha.gov].

2010 International Conference on Fall Prevention and Protection

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Disclaimer: These proceedings do not constitute endorsement of the views expressed or recommendations for the use of any commercial product, commodity, or service mentioned by the National Institute for Occupational Safety and Health (NIOSH). The opinions and conclusions expressed in the presentations and report are those of the authors and not necessarily those of NIOSH. All conference presenters were given the opportunity to review and correct statements attributed to them within this report. Recommendations are not final statements of NIOSH policy or of any agency or individual involved. They are intended to be used in advancing the knowledge needed for improving worker safety.

Research and Practice for Fall Injury Control in the Workplace:

Proceedings of International Conference on Fall Prevention and Protection

Disclaimer

Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health (NIOSH). In addition, citations to Web sites external to NIOSH do not constitute NIOSH endorsement of the sponsoring organizations or their programs or products. Furthermore, NIOSH is not responsible for the content of these Web sites. All Web addresses referenced in this document were accessible as of the publication date.

Ordering Information

To receive documents or other information about occupational safety and health topics, contact NIOSH at

Telephone: 1-800-CDC-INFO (1-800-232-4636)

TTY: 1-888-232-6348

E-mail: cdcinfo@cdc.gov

or visit the NIOSH Web site at www.cdc.gov/niosh.

For a monthly update on news at NIOSH, subscribe to NIOSH eNews by visiting www.cdc,gov/niosh/eNews

DHHS (NIOSH) Publication No. 2012-103

November 2011

SAFER • HEALTHIER • PEOPLE™