The XXVIII[th] Annual Occupational Ergonomics and Safety Conference
Chicago, Illinois, USA
June 9-10, 2016

Construction Fall From Height Accident Reconstruction and Safety Analysis

Erick H. Knox, Steven J. Smith, and Joseph T. Eganhouse

Engineering Systems Inc., 4215 Campus Drive, Aurora, Illinois 60504

Corresponding author's Email: ehknox@engsys.com

Abstract: A human factors accident reconstruction was conducted to analyze the circumstances surrounding a fall from height at a grain elevator construction site. A worker fell to his death when the makeshift work platform he was working on failed and the incorrectly used fall protection equipment disconnected from the anchor point. This accident would have been prevented had an adequate walking/working surface been provided for the work at elevation, or if the worker was properly trained in accordance with OSHA 1926 Subpart M Fall Protection regulations, which would have allowed workers to identify the proper use of fall protection equipment for this specific situation. Proper preparation for the work to be conducted is also identified as a key to job safety.

Keywords: Fall Protection, Safety Training, Standards.

1. Fall Related Accident Statistics

A survey of National Electronic Injury Surveillance System (NEISS) data for the years 2001 through 2014 indicates that unintentional falls resulted in an estimated 117+ million injuries in that time period, and were by far the leading cause of nonfatal injury; over 27% of all injuries (CDC, 2016a). For the calendar year 2005 alone, unintentional fall injuries resulted in an estimated financial impact of $68.5 billion dollars, which included the cost of medical treatment and the cost of work loss (CDC, 2016b).

In the construction industry, falls are the leading cause of fatalities, and in 2014 resulted in 349 worker deaths (OSHA, 2016a). This accounted for nearly 40% of all construction fatalities in that year. In a broader data set analyzed by the Center to Protect Worker's Rights between 1992 and 2010 the single biggest cause of construction fatalities was falls to a lower level, resulting in 6,678 deaths (CPWR, 2013). Over the same period, falls were also one of the leading causes for nonfatal injuries in construction (CPWR, 2013).

Fall protection is at the top of OSHA's most-frequently cited violations for fiscal year 2015 (OSHA, 2016b), resulting in a total of 7,402 violations (Morrison, 2015). 2015 marks the fifth year in a row that fall protection has topped this list (ISHN, 2016). Furthermore, fall protection is number one in the top ten lists of "willful" and "serious" violations (Morrison, 2015).

2. Accident Description

In October, 2012 a 130 foot tall grain elevator system was being constructed to facilitate loading grain into railcars from the adjacent silos. On the day of the accident, an electrical contractor had a 4 man crew working to pull wiring to the top of the structure, and a junction box located between the elevator legs at a height of aproximately 75 feet served as the work location (Figure 1A). This particular work location was inaccessible with a boom lift and required the use of personal fall protection equipment outside the guardrails of the structure. The workers placed a makeshift platform on top of adjacent structural steel and accessed this location by climbing down a portable ladder from the adjacent catwalk, which was approximately 10 feet above the plaftorm (Figure 1B). The platform was made out of two sections of OSB panel that had been present at the site and weathered. One of the workers descended the ladder and had tied off his fall protection lanyard to nearby structural steel. Shortly thereafter, the temporary platform failed or became dislodged (Figure 1C) and the worker was seen suspended briefly from the his personal fall protection equipment before this disconnected and he fell approximately 50 feet to a structure below (Figure 1D). The worker sustained fatal injuries. Investigators found that the gate of one of the snaphooks on the worker's double leg lanyard was outside of the nose/tip, and that the shock-absorbing component was not deployed or

ISBN: 97819384965-4-7

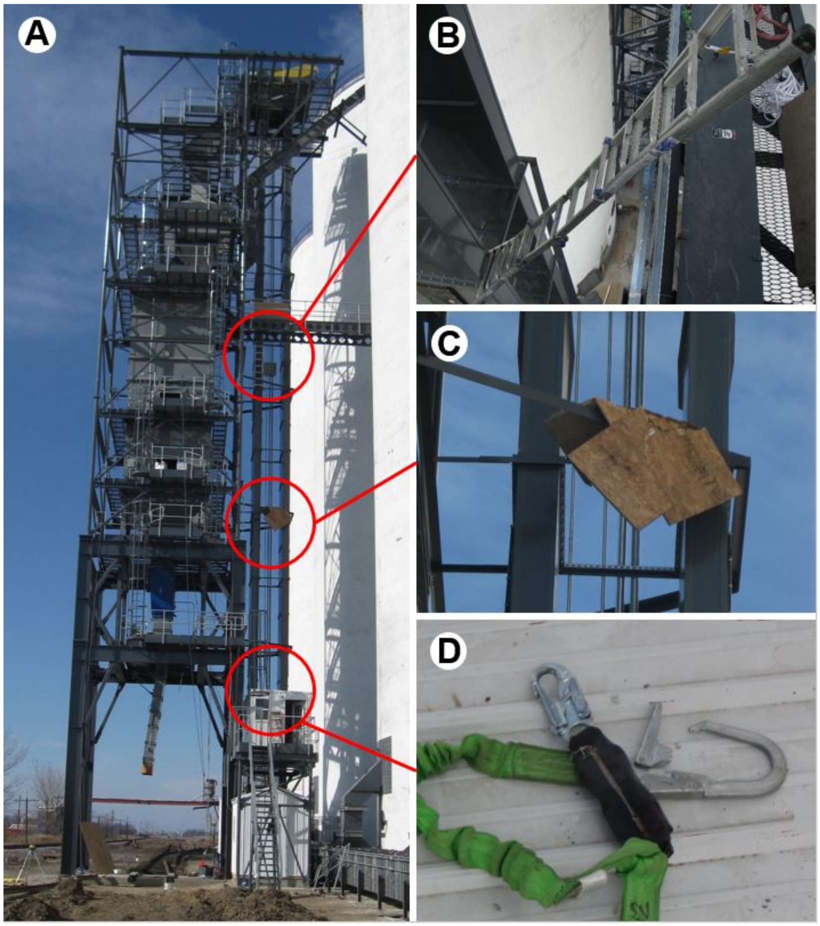

Figure 1. Accident site.

stretched (Figure 1D). Eyewitness accounts of the accident were incomplete and inconsistent as to where and how the worker secured his fall protection, and the specific sequence of events.

3. Accident Reconstruction Analysis

The personal fall protection system utilized by the worker was inspected (Figure 2). The lanyard was an elastic dual leg lanyard with form snaphooks and a shock absorber manufactured in May of 2012. The shock absorber was not deployed or stretched as a result of the fall, possibly indicating a reduced dynamic component to the fall. The snaphooks had locking gates and were manufactured in 2010. One snaphook functioned normally, while the other was damaged: the gate was outside the nose, the left tab of the gate was deformed outward, the left outside corner of the gate was abraded with dark grey transfer, and there were several other witness marks.

The accident site geometry of the tower structure was documented with a three-dimensional (3D) Faro laser scanner to an accuracy of approximately ±1 mm at a range of 30 m. This tool provides a 3D point cloud of site geometry and was particularly helpful in documenting inaccessible portions of the structure with line of site laser measurements, and allowed the investigators to measure the site in a safe manner. At the time of the inspection, the accident site had been changed, as post accident remedial measures in the form of a steel platform and guardrails were in place. A 3D computer model of the accident site was generated using the Faro point cloud data to reconstruct and visualize the accident site as it existed on the day of the accident and identify the possible fall protection anchor locations. Figure 3A shows the location of the work site and the

Figure 2. Subject lanyard.

electrical junction box between the grain elevator legs that the workers were going to access as viewed from the catwalk. Figure 3B is a view from above and to the side of the work site that highlights the possible locations identified by witnesses for attaching the fall protection lanyard. This included angle iron at the level of the workers feet measuring 2 inch by 2 inch and 4 inch by 4 inch, as well as a 12 inch by 6 inch I-beam at approximately shoulder level. Both images show the temporary OSB platform properly scaled (31 inches by 63 inches) and supported in an unsecured fashion by the angle iron, as it was at the time of the accident. Note also that the ladder is not supported by the feet on the OSB platform, but is wedged with a rail on either side of an elevator leg.

Physical accident reconstruction analysis could not be conducted at the accident site due to safety concerns and the post accident remedial measures. Therefore, the Faro laser scan data was also used to create a dimensionally accurate full scale mockup of the relevant geometry of the accident site at ground level (Figure 4A). In this manner, accident reconstruction hypotheses could be tested safely at ground level using established scientific methods (Knox, 2015). The available data concerning the accident, including the site geometry, physical evidence of the fall protection system, and the witness statements were analyzed to determine the most likely accident sequence. One primary issue concerned resolving the differing witness statements as to where and how the worker secured their fall protection, and whether both legs of the dual leg lanyard were secured. One of the investigators donned an exemplar harness and lanyard and examined the various body positions and lanyard securing options presented at that work location (Figure 4B). It was determined that the worker secured his lanyard back onto itself after wrapping it around the 12 inch tall I beam in a tie-back fashion. Although there are lanyards designed for this method of anchoring, this particular lanyard was not so designed. Witness statements that the worker tied the second leg of the lanyard to the 2 inch by 2 inch angle iron at the opposite edge of the work platform were found to be inconsistent with the reach of the lanyard. Various orientations of tieback and positions of the snaphook over angle iron were examined for their potential to create loading of the gate that would account for the subject snaphook damage (Figure 4C and 4D). It was determined that an external force directed to push the gate inward and to the side was most consistent with the physical evidence. In the final analysis, it was determined that the unsecured temporary work plaform broke or disloged causing the worker to fall suspended on the fall protection lanyard that was incorrectly tied back onto itself. This likely caused the external gate to be forced open and disconnect the lanyard from the structure, although it could not be ruled out that the snaphook was damaged prior to the accident and used with the gate lodged open.

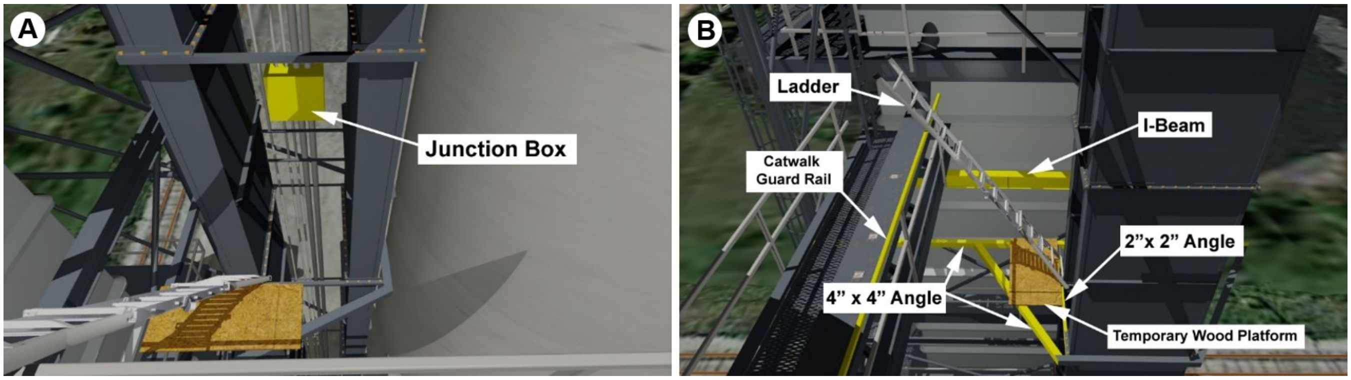

Figure 3. Three dimensional computer model of the accident site.

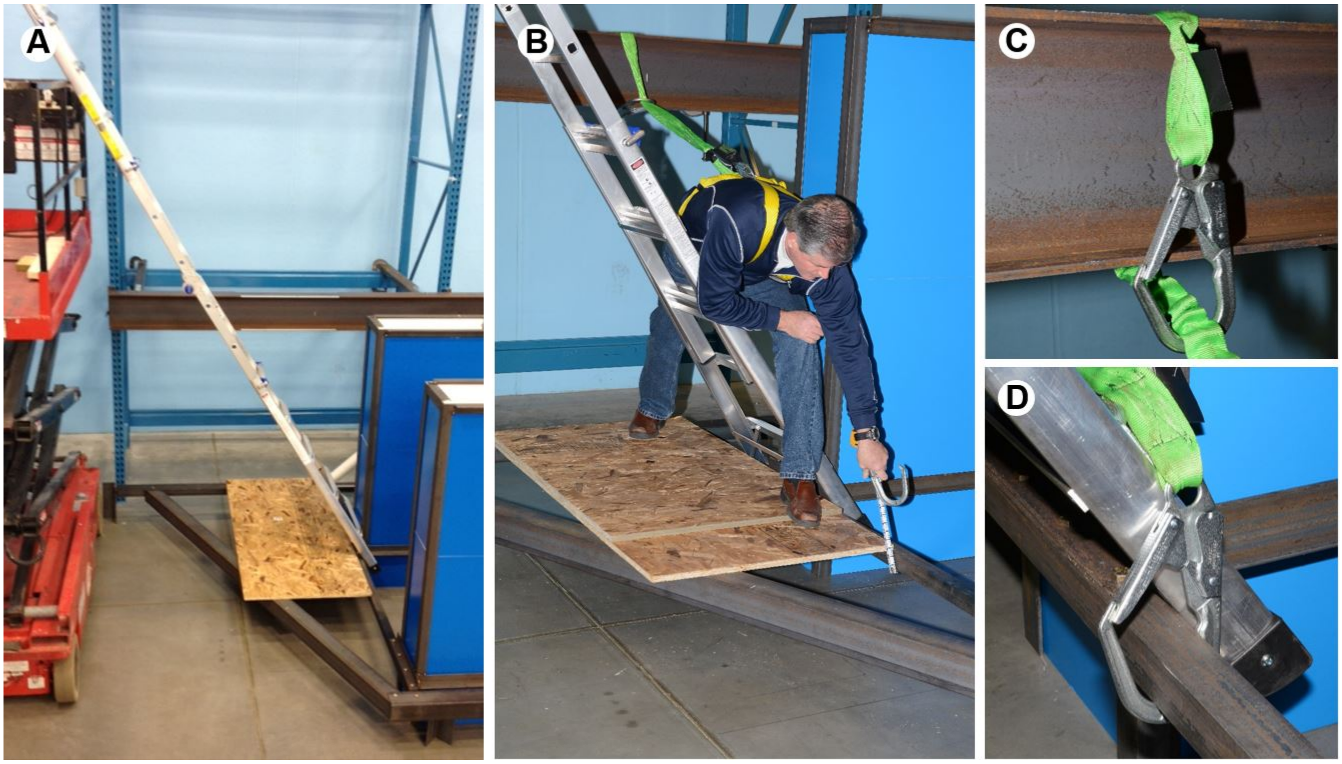

Figure 4. Full scale mock up for accident reconstruction analysis and testing.

4. Fall Protection Standards

OSHA 1926 Subpart M sets forth mandatory requirements and criteria for fall protection in construction work places. OSHA requires that employers have fall protection for its employees. There are numerous provisions within Subpart M that cover the duty to have fall protection, as well as the specific requirements of fall protection systems, and training requirements. OSHA 1926.503 requires employers to assure (and document) that employees are trained on the nature of fall hazards in the work area, as well as the proper use and operation of personal fall arrest systems. OSHA 1926 Subpart M Appendix C highlights many important factors including one of the most important aspects of personal fall protection systems is fully planning the system, including suitable anchorage points, *before* it is put into use. Further, in situations where an existing structure (e.g. steel I-beam) is used for an anchor point, a lanyard with a snaphook clipped onto itself should not be used unless it is specifically designed for such use. OSHA requirements for snaphooks are that they have a minimum tensile strength of 5000 pounds.

The applicable ANSI standard for the use of the subject locking snaphook (otherwise known as a form hook or rebar hook) for fall protection in the construction industry was ANSI A10.32-2004 titled "Fall Protection Systems – American National Standard for Construction and Demolition Operations". This voluntary standard has performance criteria that includes a 5000 pound minimum tensile strength, as well as a gate face strength of at least 220 pounds (without the gate separating from the nose by more than 1/8 inch), and a gate side load strength of at least 350 pounds (without permanent deformation of more than 1/8 inch or separation by more than 1/8 inch). The ANSI gate strength performance tests were conducted on this snaphook design and found to meet these requirements.

The ANSI/ASSE Z359 Fall Protection Code series of standards cover fall protection performance requirements for general industry. These standards made a change from the 220 pound / 350 pound gate strength requirements to a significantly higher 5000 pound requirement as early as 2007. However, these standards specifically do not apply to the construction industry, and this is noted within the Z359 standards themselves, as well as an OSHA letter of interpretation from 2010. The next revision of the A10.32 standard after the 2004 revision also had increased gate strength requirements (ANSI A10.32-2012), but this revision did not take effect until January 2013 after the subject hook and lanyard were manufactured. The subject snaphook and lanyard were in compliance with the applicable safety standards and regulations at the time it was manufactured.

5. Safety Analysis

5.1 Safe Walking/Working Surface

The electrical contractor had identified the need for a work platform in the area of the junction box several weeks prior to the accident. A permanent platform with guardrails was not installed before the accident, in part due to a lack of agreement between the contractors as to who would pay for it. However, a permanent platform was installed after the accident (Figure 5). This system provides a strong stable working surface for safe access to the junction box with no additional need for fall protection. This is the preferred solution over the temporary make-shift OSB platform that failed on the day of the accident. However, at the time of the accident, the electrical crew could also have arranged for a platform suitably designed and rated as a walking/working surface such as scaffold planks with known strengths. Several planks would likely have been necessary because of the space requirements and the fact that more than one individual would be working in the same vicinity. Furthermore, the planks should be secured in place to prevent unexpected movements on a support structure that was not designed for that purpose. If the substandard temporary OSB platform had been replaced by either the now existing fixed steel platform or other suitably strong and secure walking/working surface, the worker's accident would not have occurred. Although there were several misuses of the ladder, this did not likely play any particular role in the accident, but does represent another indication that the work crew did not know and/or follow safe work practices.

5.2 Fall Protection Training

The worker was an apprentice electrician and had worked for the company for approximately 6 months prior to this accident Neither the worker nor his coworkers were properly trained to identify fall hazards in the workplace and prevent them. Additionally, they were not adequately trained on the subject of fall protection, as required by OSHA. In particular:

- They did not plan for suitable anchor points before they began working.
- They did not recognize (or knew and disregarded) the misuse of tie off of the snaphook back onto the lanyard
- They did not recognize (or knew and disregarded) the misuse of tie off at one's feet
- They did not have suitable means for securing the lanyard to the I-beam

If the electrical contractor employees were properly trained they could have planned better and been prepared for the fall protection requirements of the job. For example, they could have acquired and used a proper anchorage connector for the I-beam, or acquired a specially designed tie-back lanyard. If the worker had been properly trained in fall protection and followed the principles outlined in that training, his accident would not have happened.

5.3 Proper Use of Fall Protection Equipment

Misuse of the equipment is clearly related to the lack of proper training on fall protection. However, in the absence of formal training, one can also review the safety instructions that came with the product. The applicable instruction manual for the lanyard provided information about the selection, use, inspection and maintenance of fall protection systems and their components, and further emphasized critical warnings about the limitations of fall protection equipment. The manual has specific language pertaining to the use of specialized anchorage connectors as a part of the total fall protection system.

In this accident circumstance, failure of the snaphook gate was likely the result of the gate being loaded from outside the enclosed hook. This can only happen in a misuse circumstance where the gate is exposed to contact with the environment. This does not happen when proper consideration is given to anchorages and connection to anchorages. If the worker had used the system properly, as provided in the instruction manual and/or proper training by qualified personnel, his fall to the roof would not have happened.

Figure 5. Permanent platform at accident site.

6. Conclusions

The results of this accident reconstruction and safety analysis indicate that the accident was the result of a combination of unsafe work practices. In the absence of a permanent work platform to access the junction box, the use of an unsecured and insufficient work platform, and the poor planning and improper use of fall protection were the primary causative factors of the fall. Proper training on the identification of workplace fall hazards and the set up and use of fall protection equipment would have allowed the work crew to properly plan and conduct their work safely. Consistent with the National Campaign to Prevent Construction Falls (NIOSH, 2016), contractors must provide the right equipment for working at heights, and train their workers to use the equipment. Along with their workers, they are also encouraged to plan before every job to work safely at heights.

7. References

ANSI A10.32 (2004). Fall Protection Systems – American National Standard for Construction and Demolition Operations.

ANSI A10.32 (2012). Fall Protection Systems – American National Standard for Construction and Demolition Operations.

ANSI/ASSE Z359 Fall Protection Code Package.

Centers for Disease Control and Prevention (2016a, April). 10 Leading Causes of Nonfatal Injury, United States. Retrieved from: http://webappa.cdc.gov/sasweb/ncipc/nfilead2001.html

Centers for Disease Control and Prevention (2016b, April). Cost of Injury Reports. Retrieved from: http://www.cdc.gov/injury/wisqars

Center for Protection of Workers' Rights (2013). *The Construction Chart Book: The U.S. Construction Industry and Its Workers*. 5th Edition. ISBN: 978-0-9802115-1-1.

Industrial Safety and Hygiene News (2016, February). OSHA's Top 10 Violations of 2015 Analyzed. Retreived from: http://www.ishn.com/articles/103334-oshas-top-10-violations-of-2015-analyzed

Knox, E.H., Mathias, A.C., Stern, A.R., Van Bree, M.P. & Brickman, D.B. (2015). Methods of Accident Reconstruction: Biomechanical and Human Factors Considerations. *Proceedings of the ASME 2015 International Mechanical Engineering Conference and Exposition, IMECE2015-53666*, 1-11.

Morrison, K.W. (2015). "OSHA's Top 10 most cited violations: Growing data and changing inspection strategies". *Safety and Health Magazine*, 192(6), 46-54

NIOSH (2016, April). Campaign to Prevent Falls in Construction. Retreived from: http://www.cdc.gov/Features/PreventingFalls

OSHA (2016a, April). Commonly Used Statistics: Federal OSHA Coverage. Retrieved from: https://www.osha.gov/oshstats/commonstats.html

OSHA (2016b, April). Top Ten Most Frequently Cited Standards for Fiscal 2015. Retrieved from: https://www.osha.gov/Top_Ten_Standards.html

OSHA 1926 Subpart M – Fall Protection.