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Accident Reconstruction of a Ladder Slide-Out: Integrating Human Factors, Design, and Safey

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Abstract: Portable, non-self-supporting ladders can provide tremendous utility for workers, but safe operation depends critically on proper set-up and use. In practice, adherence to routine pre-use inspection practices – such as verifying the ladder is stable and secure from movement, ensuring a proper angle of inclination, and visual confirmation of the engagement of all locking mechanisms – remains paramount to preventing ladder accidents. A biomechanical accident reconstruction and human factors analysis were used to investigate a fall from a ladder at a residential property. A home inspector fell while using an articulated extendable ladder in its straight ladder configuration as it was leaned against a gutter to access a roof. Both the worker and the ladder fell to the ground, leading to questions about the sequence of events and the cause(s) of the accident. Detailed site inspections, thorough examination of the subject ladder, and the application of well-established science and engineering principles were central to reconstructing the accident as part of a comprehensive forensic investigation. Witness testimony helped guide the initial investigation. However, discrepancies between the testimony and physical evidence required further evaluation, ultimately illustrating the importance of corroborating memory-based accounts with objective forensic analysis. It was determined that the ladder's design met applicable ANSI A14 and OSHA safety standards and was engineered to provide adequate strength and resistance to sliding. The ladder's ergonomic design made it straightforward to set up and use properly. On-product labels also provided warnings and instructions to facilitate safe use. Quantitative biomechanical testing illustrated that the friction required to resist slide-out increases as the user climbs higher on the ladder and increases even further when the ladder is set at decreasingly shallower angles. Investigators concluded that the worker failed to properly set up and use the ladder, placing it at an angle well below the recommended 75.5 degrees and that the ladder slid out as the worker was transitioning from the ladder to the roof. The ladder's feet moved out away from the structure against which it was leaning until the ladder lost contact with the upper support and the ladder and the worker fell to the ground.

Keywords: Human factors, accident reconstruction, ladder slide-out, biomechanics, forensic engineering, workplace safety, ANSI A14, OSHA

1. Ladder Safety

1.1 Ladder Safety Standards

Articulated extendable ladders are a highly useful portable ladder that can be set up in several modes, such as a straight ladder (a type of non-self-supporting ladder), stepladder, scaffold, or work table (ANSI A14.2-2017). The American National Standards Institute (ANSI) safety standards for portable metal ladders like the subject ladder sets forth design specifications and performance testing and dimensional criteria for evaluation of ladder design. The ladder that is the subject of this analysis complied with all the ANSI A14.2 provisions. In addition, portable metal ladders used in the workplace are subject to the Occupational Safety and Health Administration (OSHA) regulations related to workplace safety and health covered in 29 CFR 1910 Subpart D – Walking-Working Surfaces and 29 CFR 1926 Subpart X – Stairways and ladders. The ladder also met these regulations.

Since their inception, ANSI ladder safety standards and OSHA regulations have instructed users that the proper angle of inclination for straight and extension ladders is 75.5 degrees from the horizontal (ANSI A14.2, 1956; ANSI A14.5, 1974; OSHA 29 CFR 1910.26, 1971). This angle is the optimum balance between resistance to ladder slide out, strength of the ladder, and balance and comfort of the climber.

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1.2 Ladder Slide Out

Ladder slide-out is a type of accident in which the feet of the ladder slide out away from the top support point. This loss of stability leads to the ladder and user falling down to the ground. Generally, ladder slide-out is one of the leading causes of accidents for non-self-supporting ladders (Dewar, 1977; ANSI A14.2-2017) Setting extension ladders and other non-self-supporting ladders at angles shallower than the recommended angle of 75.5 degrees has been found to increase the risk of ladder slide out at the base (Axelsson & Carter, 1995; Faegemann & Larson, 2001). Research also shows that the risk of slide out increases when 1) the friction between the ladder feet and support surface goes down, 2) the climber is higher on the ladder, 3) the ground slopes down away from the upper support, and 4) there are significant dynamic forces during climbing (Chang et al., 2005, Barnett & Libor, 2004, Knox & Van Bree, 2015).

2. Subject Incident Description

A home inspector set up the subject articulated extendable ladder on the concrete driveway of a residence and against the horizontal gutter to gain height and access to the roof. The driveway was sloped down away from the house nearly 6 degrees. The worker and the ladder fell to the ground. The man sustained a depressed skull fracture to the occipital region (back of his head) and suffered retrograde amnesia.

While the worker testified, he did not remember the subject incident, a neighbor and his wife who lived on the same street were witnesses to portions of the incident. The neighbor testified at his deposition (over 2 ½ years after the incident) that he saw the ladder leaning against the gutter and the worker with his hand(s) on the ladder as he and his wife were driving home. A short time later after pulling into their driveway, the first indication that he had that there was an incident was his wife indicating to him that the man was falling. The neighbor looked and saw the home inspector near the ground falling backwards onto the driveway. He estimated that he saw this action from a distance of 50-60 feet away. He testified that he went over to where the worker fell to see what happened. Others began gathering at the scene, and one of them called 9-1-1. The neighbor denied calling 9-1-1. His wife testified that she was able to see the worker on the ladder, and she believed he was above the middle of the ladder. She stated she essentially saw the worker falling backward and holding onto the ladder bringing it down with him and saw him strike the concrete. She testified that the ladder ended up on top of the worker. However, she did not go over to where the worker fell.

Emergency medical personnel (EMS) who were the first responders to the scene reported that the worker was found lying partially on top of the ladder in a supine (face-up) orientation with his feet closer to the house and his head toward the street. There was only one person present, other than the unconscious worker, when EMS arrived and this person stated that he heard a loud noise, went and looked, and found the worker on the ground on top of the ladder, so he called 9-1-1.

3. Accident Reconstruction Analysis

3.1 Site Geometry Analysis

Accident reconstruction methods utilized the scientific method as the framework for determining the most likely sequence of events and included consideration of human factors, ladder design, and safe work practices (Knox et al., 2015). The worker's visibility from the witnesses' perspectives was central to the analysis, with their testimony providing critical guidance for the investigation. Figure 1A shows a photograph of the subject incident site with the subject ladder laying on the driveway shortly after the injured worker was removed from the scene by EMS. Figure 1B shows an image of the incident scene at the time of site inspection. An exemplar ladder was used to reconstruct the position of the subject ladder. Note that the palm tree that was present in the garden area at the front of the house at the time of the incident was removed prior to the site inspection. The incident site was documented with FARO laser scanning, and a three-dimensional (3D) digital model of the site was created. The size and location of the palm tree were an important consideration in what the witnesses were able to see, so advanced 3D digital analysis methods were used to virtually reconstruct a palm tree and place it into the 3D virtual site model using a camera matching utility and corresponding points in the photo (Figure 1C) and the digital model (Figure 1D). The digitally reconstructed palm tree is seen in Figure 1D.

Figure 1. Site Geometry with digitally reconstructed palm tree

3.2 Visibility of the Worker by the Witnesses

Blood stains on the driveway, as well as knowledge of the ladder geometry and worker anthropometry, were used to determine the final rest position of the worker and the location where the ladder was set against the gutter. Figure 2 models the ladder at this location with the worker on the ladder. This figure also shows the general location of the witnesses residing across the street. It is noted that the palm tree is in these witness' line of sight, obstructing their view of the ladder and worker. Figure 3A shows the 3D virtual site model, with the worker on the ladder but without the palm tree. The geometry of the house and nearby vegetation obscures a large portion of the worker's body and ladder. When the digitally reconstructed palm tree was added to the 3D virtual model, the worker was fully obstructed from view (Figure 3B). Additional analysis showed that only a portion of the worker and the ladder could be viewed during a portion of the fall sequence from the witness' testified location. It was concluded that the worker could not have been seen as described by the witness.

3.3 9-1-1 Call

Retrieval of the 9-1-1 call audio, which was not produced until after the testimony of the husband and wife, confirmed that the husband was actually the individual who called 9-1-1. In the call, he stated, "The ladder must have slipped out, and he's [lying] partly on top of the ladder, which is on the ground." This statement, made within moments of the incident, directly supported a ladder slide-out scenario and aligned with the physical evidence observed by first responders. In contrast, his later deposition testimony was vague and internally inconsistent – he could not recall whether the man had been on the ladder, whether he witnessed the fall, or where the ladder ended up – making his recollection less credible than his initial 9-1-1 call.

Figure 1. Witness' line of site to the worker from across the street

Figure 2. Virtual model with reconstructed view of the worker from the witness' location A) without palm tree, B) with digitally reconstructed palm tree

3.4 Testing

Exemplar ladder testing at the site indicated that when the ladder is leaned against the gutter and set up at an angle of approximately 67 degrees, application of a downward force of approximately 180 pounds near the upper support point (as if the worker were standing on the rung below the gutter and stepping up onto the roof) initiated a slow or creeping slide of the feet down the driveway. While this ladder angle of inclination is not in keeping with the warnings and instructions on the ladder, it is within the range of common set up angles (Knox & Van Bree, 2015). However, the downward slope of the driveway of approximately 6 degrees noticeably increases the risk of the ladder's feet sliding (Barnett & Liber, 2004). This was confirmed with testing in which a mock-up of the relevant site geometry (including roof and gutter) was constructed in a forensic laboratory, and the feet of an exemplar ladder were set on six-axis force plates, with the ladder placed at various angles of inclination. For each ladder angle, ground reaction forces were measured while a user climbed up the ladder and transitioned off the ladder onto the roof. The required coefficient of friction was calculated, and it was determined that shallower angles of inclination had a higher traction demand between the feet and the support surface. Additionally, as the climber got higher, the traction demand increased, indicating that the greatest risk of slide-out occurs when the user is at the top of the ladder. It was also noted that pushing on the portion of the ladder above the roof while stepping onto the roof can momentarily require an even higher traction demand. These data are consistent with the physics of ladder slide-out and previous research on the topic.

Figure 4. Fall kinematics during slide out while transitioning to a roof

In the subject incident, the worker fell and came to rest with his head further away from the house and his feet closer to the house. Generally, in slide-out incidents in which the user rides down with the ladder without touching or grabbing anything else, their body ends up in the opposite orientation with their head closer to the top support. Laboratory testing was conducted to study and demonstrate the kinematics of a ladder user during a slide-out that begins when the user is transitioning to a roof. A user, who was protected from falling through a climbing harness and belay, ascended an exemplar ladder that was leaned against the gutter of the site mock-up. During the transition to the roof, the ladder began to slide out, and the continued loss of support from the ladder caused a downward falling motion for the user. However, the leg that was on the roof caused the user to rotate backward and off the roof in a generally supine position (Figure 4). Additionally, portions of the user's body were directly above the ladder. The user, in a true fall, would have therefore landed on top of the ladder. It is important to note that the subject ladder exhibited damage consistent with being impacted while flat on the ground. The laboratory findings of the user kinematics and trajectory of the fall were consistent with the evidence provided in the subject incident that the worker was found face up on top of the ladder.

Alternatively, the physical evidence and testing did not support the witness testimony that the worker pulled the ladder over with him during a backward fall. First, the user position near the top of the ladder creates a moment that forces the top of the ladder toward the top support, not away from it. Second, neither the final rest position of the user on top of the ladder nor the noted crushing damage to the ladder are possible if the ladder is above the user at the time of ground impact.

3.5 Accident Reconstruction

The available evidence indicates that the worker set the ladder on the sloped driveway and against the horizontal first-story gutter of the house. As he was transitioning to the roof, the ladder began to slide out, causing his body to fall down and rotate backward off the edge of the roof. He struck and damaged the ladder below him. He also impacted the concrete driveway with the back of his head, ending up lying partially on the ladder in a face-up orientation.

The design of the subject ladder model's feet met the ANSI A14.2 slip resistance requirements, as well as the other performance criteria and specifications set forth in the safety standard. The on-product labels provided warnings and instructions on how to safely set up and use the ladder, including how to achieve the proper angle of inclination. There was no failure of the ladder structure, and the locking mechanisms for both the hinges and telescoping lock tabs functioned properly and were simple and straightforward to lock.

4. Conclusions

Advanced 3D digital reconstruction and targeted physical testing were used to analyze the circumstances of a ladder fall incident. These techniques helped the investigators apply the scientific method and quantify critical factors—ladder geometry, surface slope, and user kinematics—needed for an evidence-based, robust accident reconstruction. The analysis showed that, consistent with the available evidence, the ladder feet slid outward as a result of improper set-up and use of the subject articulated extendable ladder. The worker placed the ladder at an angle well below the recommended 75.5 degrees, creating an elevated slide-out risk during his transition from ladder to roof. That risk was magnified because the ladder rested on a driveway that sloped downward away from the upper support (Barnett & Liber, 2004).

Less-than-ideal site conditions such as sloping surfaces, can be mitigated by lashing, footing, or otherwise securing the ladder from movement (Hepburn, 1958). Ultimately, ladder users must read and follow on-product warnings and instructions.

In any reconstruction, some data sources may conflict. When the inconsistencies involve eyewitness testimony, those statements should be treated as hypotheses to be tested—recognizing that factors such as viewing distance, obstructions, stress, and time delay can influence recall (Resnick, 2014; Colwell & Knox, 2022). By following the scientific method and anchoring the investigation in measurable scene evidence and engineering principles, the slide-out scenario remained the most plausible and scientifically supported explanation of the incident.

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