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# A Previously Unidentified Failure Mode for Ladder-Climbing Fall-Protection Systems


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## Introduction

In the field of fall protection, ladder-climbing systems occupy a specialized niche. There are unique requirements for such systems when compared to other forms of fall protection. While on a ladder the user is constantly transitioning from one position of stability through a position of inherent instability and back to a position of stability as they ascend or descend a ladder. Most safety protocols require the user to have a minimum of three points of contact at all times. The user must utilize both their hands and feet to maintain proper contact with the ladder. The fall-protection system must be easy to use and must not interfere with the physically demanding task of climbing the ladder.

As research progresses in the area of fall protection, it is inevitable that new research methods will be developed in response to the evolution of new technologies and through the investigation of rare events. The focus of this research was to investigate potential failure modes of a ladder-climbing fall-protection system that was involved in a fall from a telecommunications tower. This paper describes testing conducted by Exponent Failure Analysis Associates during the investigation of a rare failure mode of a ladder climbing system. The purpose of the paper is to raise awareness in the industry about a potential failure mode of ladder-climbing systems. While it is likely that this type of event is rare, it has potentially fatal consequences. The research did not address the range and variety of ladder climbing systems that are available on the market today.

## Background

During ascending, descending and while transitioning from climbing to working workers utilizing an integrated ladder-climbing fall-protection system should be able to assume that they will be protected from a fall should they lose their grip or footing on the ladder. This assumption is only valid if the equipment meets applicable CFR and ANSI standards, is properly installed, maintained and used. If these conditions are not met, there is no benefit to the use of the integrated system and the worker is forced into using a system requiring a 100% tie-off situation using two lanyards. This process is likely to result in reductions in productivity, overall safety and increases in fatigue and noncompliance with fall-protection requirements on the ladder. The applicable standards provide detailed methods for the evaluation of a system's ability to arrest a fall from the ladder when the fall occurs in a specific direction, which is when the principal direction of the fall is straight down. In the majority of situations this is a valid assumption. However, what will occur if during the initial phases of a fall or loss of balance the principal direction of the fall is away from the ladder? Under these circumstances, the relatively short length of the linkage between the chest D-ring and the integrated fall-protection system (no more than nine inches) should limit the movement of the climber and may allow them to recover from the loss of balance. If a recovery does not occur and the outward movement of the torso away from the ladder is part of a larger loss of balance or loss of footing and/or a loss of handgrip, how will the system perform?

## Investigation

Because this investigation is part of a larger project that involves litigation, certain aspects of the work have been omitted. The specifics of the incident do not need to be addressed in this paper in order to bring this potential failure mode to the attention of the industry and safety professionals. The incident involved a male worker who was using an ANSI-approved full body harness and an ANSI-approved ladder-climbing system to ascend a telecommunications tower. At some point the worker fell from the ladder, and there are indications that the integrated fall-protection system failed to arrest the worker's fall within the distance required by the standard. The integrated ladder climbing system consisted of a notched steel tube affixed to the ladder at the centerline of the rungs at regular intervals. Riding on the rail was a sleeve with an integrated snap-hook attached to a spring-loaded lever and a pawl mechanism inside the sleeve that interacts with the notches on the rail to prevent downward travel if the pawl is not retracted. Upward travel is unrestricted by the mechanism. After the incident the sleeve was inspected and found to be in working order. There were no visible malfunctions that could have caused this failure.

## Apparatus

The ladder-climbing fall-protection system in question was installed onto a vertically oriented 10-foot ladder that was mounted rigidly to a drop tower. The ladder-rung spacing was one foot and the diameter of each rung was approximately one inch. Rather than using the specified standard rigid test torso as the human surrogate, we utilized a 50th percentile male Hybrid-III anthropomorphic test dummy (ATD) with a pedestrian pelvis. The ATD was ballasted to approximate the height and weight of a man that was 307 pounds and 5 feet 11 inches tall. The ATD was adorned with minimal clothing, shoes, and appropriately sized and adjusted safety harnesses for each test. The use of the ATD allowed for an examination of starting postures on the performance of the system, which is an obvious limitation of the standard rigid test torso. In all tests the ATD was positioned and supported by an overhead hoist that attached to the top of the ATD. The release of the ATD was controlled by a pneumatic quick release hook. The ATD was connected to the fall-protection system through the chest D-ring and the integrated snap-hook that was permanently affixed to the fall protection sleeve.

Initial testing was performed to confirm that the system did arrest a fall properly when tested in a manner similar to what is required in the ANSI standards. See Exhibit 1 for the initial configuration. Testing demonstrated that when the test ATD was dropped straight down, the sleeve locked onto the rail within 6 inches and performed as is required in the standards.

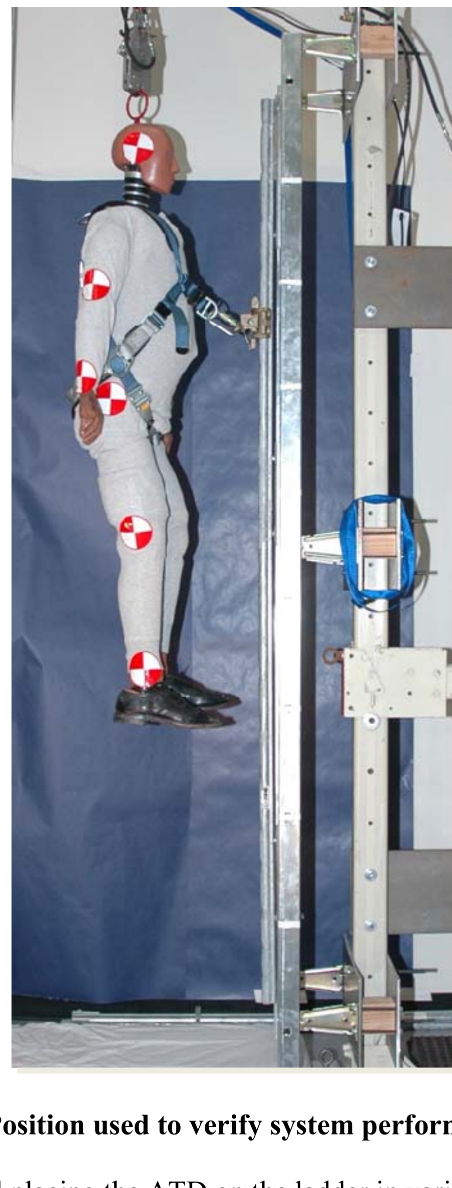

**Exhibit 1. Test 1 (T1) Position used to verify system performance during dead drop.**

The next set of tests involved placing the ATD on the ladder in various simulated climbing postures. These postures were selected to approximate postures that a climber may utilize during ascending, descending and resting. See Exhibits 2-4 below for a sample of the starting positions used.

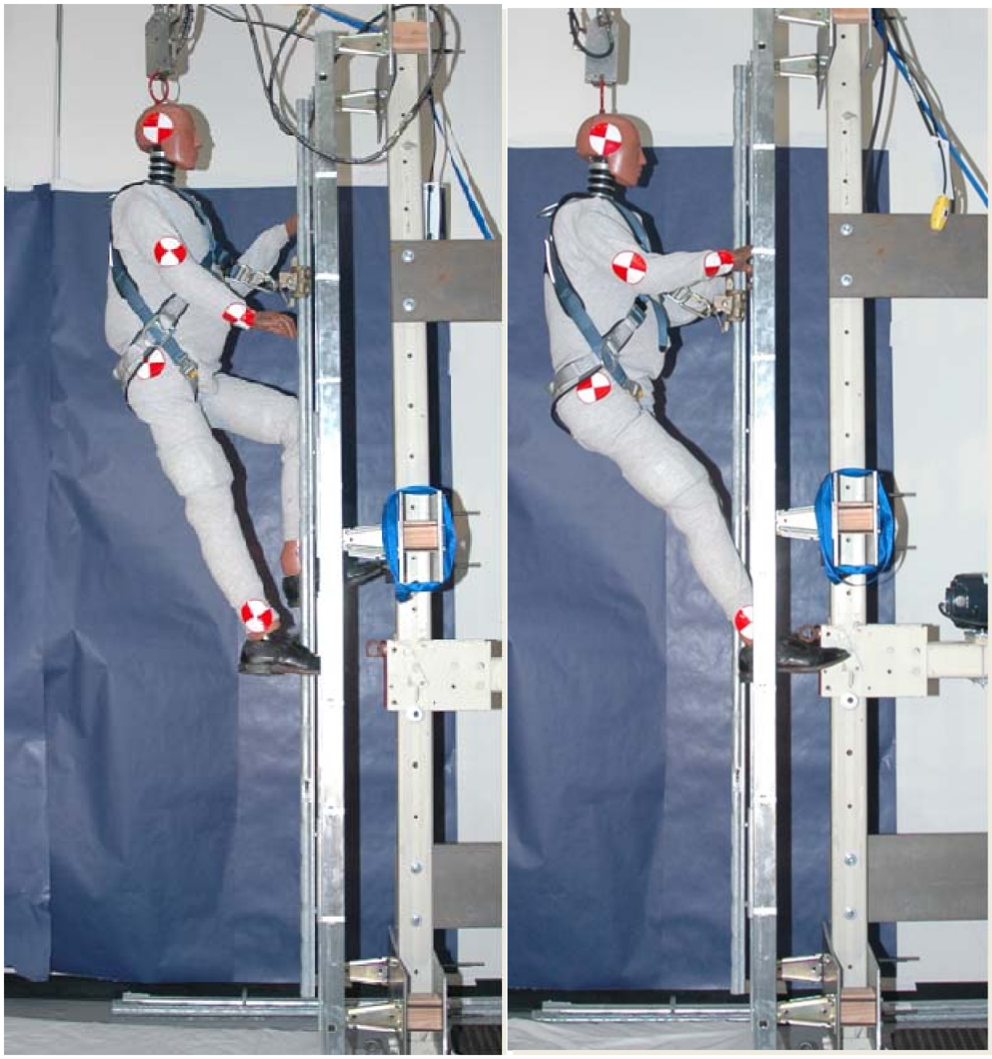

**Exhibit 2. T2 & T3 Climbing with split and parallel limbs, pawl position just below engagement notch.**

In both tests the ATD was suspended at a point where a climber's torso would be farthest from the ladder. This positioning characteristic was selected in order approximate the conditions of a real-world fall, similar to what could occur if the climber lost his/her grip on the rungs and fell away from the ladder by rotating about their feet that were still in contact with the rungs.

Additional tests were done with the ATD's torso positioned as close to the ladder as possible and as far from the ladder as the chest connection snap-hook would allow (Exhibit 3).

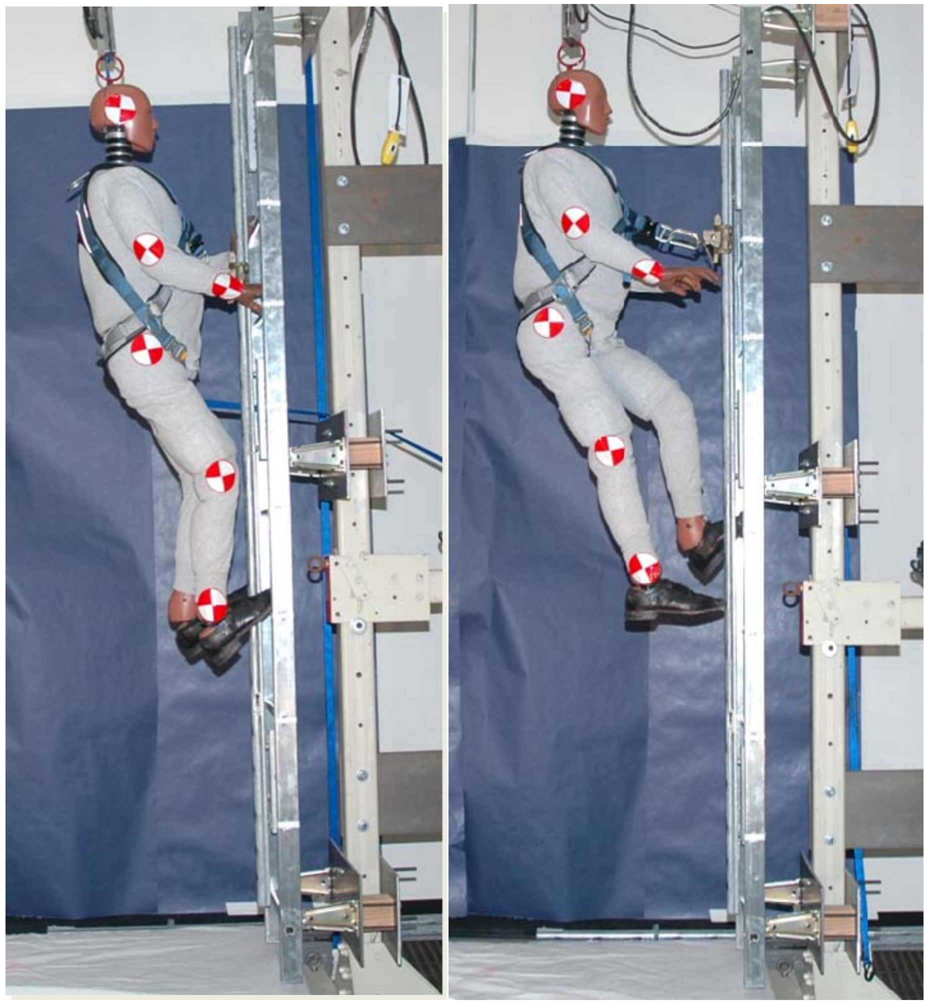

**Exhibit 3. T4 & T5 Climbing with torso positioned as close and as far as possible from ladder.**

Two tests were performed that were not directly related to the incident investigation. During the first trial, we outfitted the ATD with a waist belt instead of the full body harness. This was only done to examine the effects of positioning the connection point lower on the dummy as opposed to the chest D-ring location. In the second test, we evaluated a different type of ladder-climbing fall-protection system that uses a cable and a cable grab. See Exhibit 4 for the initial starting positions for these two tests.

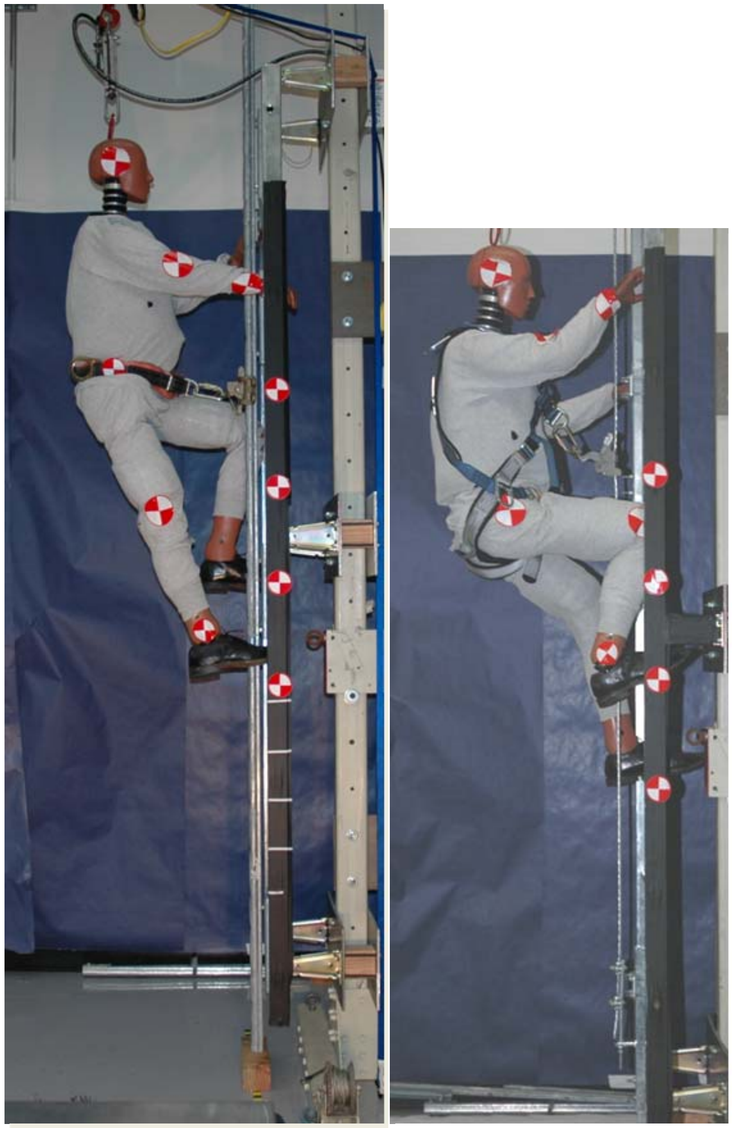

**Exhibit 4. T6 & T7 waist belt and cable system.**

In all of the tests with the rail-and-sleeve system, the position of the sleeve was supported by snap-hook and was positioned such that the pawl was just below one of the engagement notches. This position was selected as the worst-case scenario situation, which could occur during normal use.

All tests were filmed with conventional and high-speed cameras.

## Results

Table 1 lists the initial condition and the result of each test.

| Test | Initial Condition | Result |
|---|---|---|
| T1 | Dead drop | Fall arrested within 6 inches |
| T2 | Climbing with split limbs | Unrestrained fall to ground |
| T3 | Climbing with parallel limbs | Unrestrained fall to ground |
| T4 | Climbing with torso as close to ladder as possible | Fall arrested within 6 inches |
| T5 | Climbing with torso as far from ladder as possible | Unrestrained fall for more than two feet until foot of ATD caught in ladder, stopping the fall |
| T6 | Waist belt | Unrestrained fall to ground |
| T7 | Cable system | Fall arrested immediately |

**Table 1. Initial conditions and results**

Instrumentation was added to the sleeve to dynamically measure the position of the pawl-retraction lever during the fall events. Data revealed that the rearward fall of the dummy disengaged the pawl, allowing the sleeve to drop in a freefall manner at the same speed as the ATD. Due to the weight of the sleeve and the very low friction between the sleeve and the rail, the sleeve is, in effect, suspended by the connection linkage and remains disengaged during the fall. A positional sensor monitored the angle of the linkage during the fall. A plot of the angle of linkage is shown in Exhibit 5.

The testing showed that during the first fraction of a second after the release of the ATD the pawl begins to close but never reaches the point of engagement. Then in the next 0.1 seconds the pawl begins to pull away until it reaches the point of maximum travel where it stays for the duration of the fall until the dummy impacts the ground. This was also confirmed by examining the surface of the rail, which had been painted so that any contact between the pawl and the rail would be visible. Visual inspection of the rail showed no contact between the rail and the sleeve during the fall event.

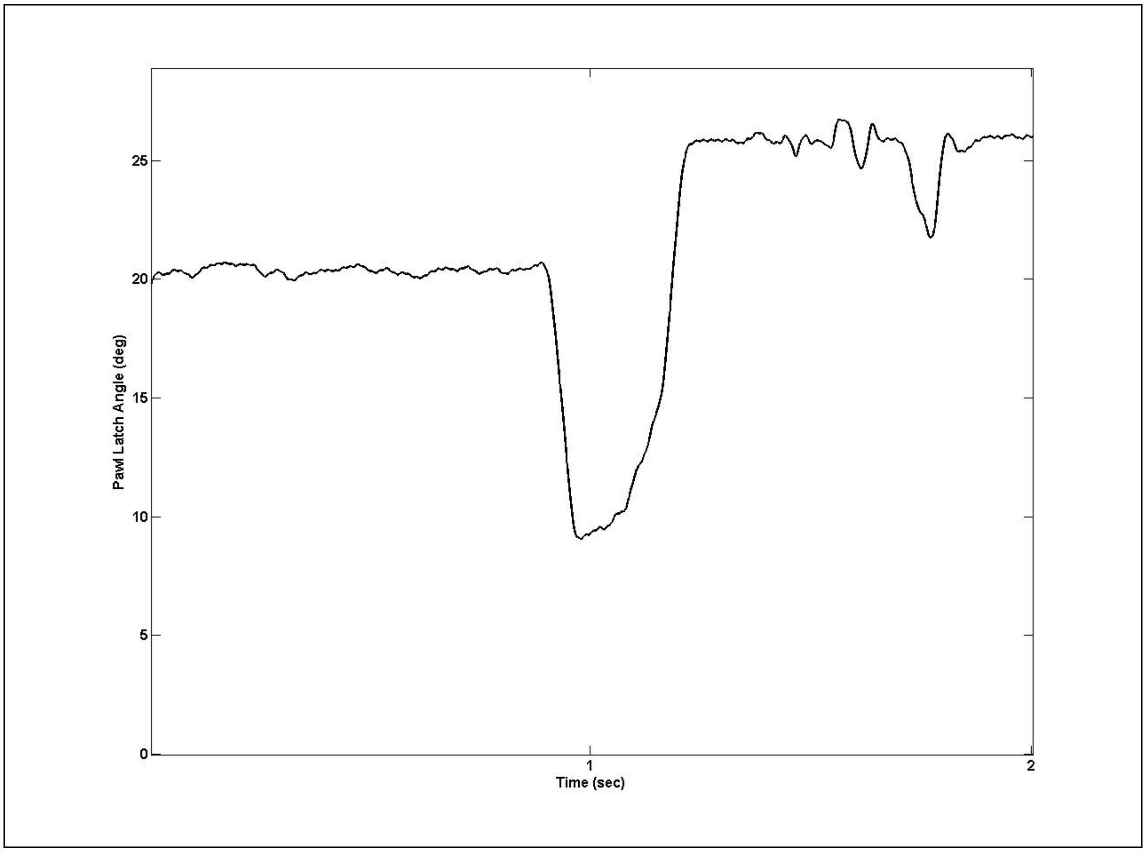


**Exhibit 5. Angular position of pawl linkage during a fall event, a angular position of zero degrees would indicate engagement of the pawl into a notch on the rail.**

The final test with this system demonstrated that connecting at the waist made no difference in the outcomes, as long as the ATD begins in a position with tension on the linkage.

Two tests were conducted with cable grab system. In both tests the fall was arrested almost immediately.

## Discussion

This testing was not intended to be an exhaustive examination of ladder-climbing fall-prevention systems. Only one system was examined in depth and that system was examined with the focus on investigating a failure mode that would explain an injury event.

The use of a Hybrid III ATD has limitations when attempting to compare the response of the dummy to the response of a falling person. The ATD has fixed resistance at each of the joints and is not able to react to the various perturbations that a normal person would. From an anthropometric standpoint, however, the ATD allows the investigation of various body positions and postures that a normal person could assume while ascending or descending a ladder.

This research suggests that manufacturers, fall-protection consultants, safety professionals and employers should examine their fall-protection systems in order to determine if this type of fall event could cause a failure of their product. If a system failure is possible, further investigation into the performance of the system should be conducted.

Further research should be conducted to determine if additional qualifications and/or tests should be prescribed in the ANSI standards to define acceptable performance criteria in order to prevent events like the one that initiated this investigation.