FALL PROTECTION

Peer-Reviewed

FALL SAFETY IN STEEL CONSTRUCTION

A Research Study

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LEOPATRIZI/E+/GETTY IMAGES

WORKING AT ELEVATION presents a fall-to-lower-level exposure to all workers. In situations such as high steel erection, the typical and most effective techniques used in construction cannot always be implemented due to extreme challenges. The typical personal fall protection and fall prevention techniques utilized are:

- A personal fall arrest system requires the worker's fall arrest lanyard, which incorporates a personal energy absorber, to be connected to the anchorage (tie off) above the D-ring on a protective harness, situated approximately in the middle of the shoulder blades of the worker.
- Fall prevention requires a form of safety railing system or barrier to be implemented.

Providing workers with fall protection for the high steel commercial construction industry is challenging due to the lack of accessible or existing overhead anchorage. According to ANSI/ASSP Z359.0, an anchorage is a secure connecting point or a terminating component of a fall protection system. Workers are sometimes forced to tie off at the foot level (walking-working surface), which could lead to falls with more than 6 ft of free fall and swing falls, depending on the lateral distance from the anchorage. A personal fall arrest system is designed to stop workers from experiencing free falls, which is the part of the fall before the personal fall arrest system starts to engage. However, even after the system engages, a worker will continue to fall. The distance a worker falls includes the free-fall distance, the harness stretch from the force of the fall, and the deceleration distance if the worker uses a personal energy absorber. OSHA determines and regulates the acceptable fall distances (the personal energy absorber pullout) to be used in the field. Personal energy absorbers, whether meant for a 6- or 12-ft free fall, must maintain arresting forces below OSHA's 1,800-lb limit (OSHA 2014a). The trade-off in using a specially designed 12-ft free fall energy-absorbing lanyard is that elongation of the energy absorber element will be greater, requiring additional clearance below the fall path.

The practice of foot-level tie off increases the free fall distances and the possibility of increased swing falls. Swing falls are especially hazardous because a falling worker can hit an object or a lower level during the swinging pendulum motion. Using the correct personal fall arrest lanyard is imperative for producing the desired fall-arresting results. The ANSI/ASSP Z359 fall protection and fall restraint standards are intended as a guide to aid manufacturers in the development of fall safety products and end users in the use of fall safety products.

ANSI/ASSP Z359.13-2013, Personal Energy Absorbers and Energy Absorbing Lanyards, addresses the design, performance, and testing of personal energy absorbers and energy absorbing lanyards. According to the standard:

> Personal energy absorbers and energy absorbing lanyards shall arrest the drop of a 282-lb weight from a height equal to their approved free fall rating (6-ft or 12-ft). The 6-ft free fall lanyards shall have a maximum deployment distance of 48 in., an average arrest force of no greater than 900 lb, and a maximum arrest force of no greater than 1,800 lb. The 12-ft free fall lanyards shall have a maximum deployment distance of 60 in., an average arrest force of no greater than 1,350 lb, and a maximum arrest force of no greater than 1,800 lb.

Steel erection differs from general construction in three major respects: the narrowness of the working surface; its location above, rather than below, the rest of the structure; and a minimum distance of approximately 15 ft to the next lower level. It also varies from other construction trades because it often involves the creation of walking-working surfaces and leading edges where none previously existed. Work performed from these surfaces can be at elevations that are significantly higher than ground level or other protective work surfaces below. This exposes workers to potential fall-from-height hazards. Steel erection work performed on the upper level of a structure does not have anchorage points above to serve as tie-off locations. This type of work environment has fewer fall protection options available for use by ironworkers. These conditions expose ironworkers to fall hazards that require nontraditional fall protection solutions.

According to U.S. Bureau of Labor Statistics (BLS) fatality data from 2014 to 2019, steel erection is consistently one of the top 10 most hazardous occupations. Steel erection work includes heavy-duty high-rise structures, metal buildings and signs. Steel erection is often the skeletal core of bridges, office buildings, and commercial, retail and industrial structures.

In consideration of the unique nature of steel erection work, federal construction safety regulations include standards that are specifically applicable to the steel erection industry. OSHA regulations specific to steel erection work are found in 29 CFR 1926 Subpart R, Steel Erection (OSHA, 2014a). OSHA regulations specific to steel erection fall protection are found in 29 CFR 1926.760, Fall Protection (OSHA, 2014a). OSHA regulation 29 CFR 1926.760(a)(1) requires that all employees (except connectors, who are workers who connect the steel to the frame) engaged in steel erection with an unprotected side or edge more than 15 ft above a lower level to utilize adequate fall protection. In addition, 29 CFR 1926.760(b) requires connectors to utilize fall

KEY TAKEAWAYS

- **Workers at elevation can be exposed to falls to a lower level when working. A personal fall arrest system is designed to stop workers from experiencing free fall, but even after the system engages, a worker will continue to fall. A NIOSH study compared the end effects of using a proper and improper personal fall arrest lanyard in a 12-ft free fall foot-level tie off.**
- **A 12-ft free fall personal fall arrest lanyard should always be used for free fall distances greater than 6 ft. A 6-ft free fall personal fall arrest lanyard should never be used at foot-level tie off. The personal energy absorber reached its maximum effectiveness during pullout and stopped extending. When this occurred, an excessive force spike was measured before the fall was fully arrested.**
- **Energy is absorbed in the mannequin's harness, as well as the personal fall arrest lanyard during a fall arrest, resulting in a shorter pullout length of the personal fall arrest lanyard as compared to a drop weight.**

TABLE 1

U.S. FALL-RELATED FATALITIES (2014-2019)

Selected fall-related fatalities, all U.S. industries, and the construction industry, with overall rates of fatal occupational injuries for structural ironworkers and steelworkers versus the construction industry and all U.S. industries, 2014 to 2019.

	Category	2014	2015	2016	2017	2018	2019
1	Total U.S. occupational fatalities	4,821	4,836	5,190	5,147	5,250	5,333
2	Total U.S. occupational fatal falls to lower level[a]	660	648	697	713	615	711
	Percent of falls from the total U.S. occupational fatalities	14%	13%	13%	14%	12%	13%
3	Overall fatality rate[b] for all U.S. industries	3.4	3.4	3.6	3.5	3.5	3.5
4	Total construction fatalities	899	937	991	971	1,008	1,061
5	Total construction fatal falls to lower level	345	350	370	366	320	401
	Percent of falls to a lower level from the total construction fatalities	38%	37%	37%	38%	33%	38%
6	Overall fatality rate[b] for construction industry	9.8	10.1	10.1	9.5	9.5	9.7
7	Total number of fatalities (structural ironworkers and steelworkers)	15	17	16	14	15	18
8	Fatality rate[b] (structural ironworkers and steelworkers)	28.3	29.8	25.1	33.4	23.8	26.3

Note. Data from U.S. BLS (2016a, b, c, 2017a, b, c, 2018a, b, c, 2019a, b, c, 2020a, b, c, 2021a, b).
[a] Fatal falls are defined by BLS Occupational Injury and Illness Classification Systems (OIICS). Data for 2014 to 2019 are based on OIICS version 2.01
[b] The fatality rate is the number of fatal occupational injuries per 100,000 full-time equivalent workers

protection when working above a lower level of two stories or 30 ft, whichever is less.

The location of an anchorage, in conjunction with several other factors, affect the fall arrest distance, or the distance a worker will fall before the fall arrest system stops the fall. The fall arrest distance is the sum of the distance the worker falls before the fall arrest system begins to stop the fall, plus the additional distance that it takes for the system to slow and then finally stop the fall completely. Other factors that affect the fall arrest distance include the type of working surface, the type of fall protection system components, and how the system is configured and anchored. The degree of mobility needed for the worker, location of available anchorage, and the need to limit the arresting forces on the worker's body also affect the choice of the system and its installation.

Three common types of anchorage systems are horizontally mobile and vertically rigid (e.g., trolley connected to a flange of a structural beam), horizontally fixed and vertically rigid (e.g., an eyebolt, choker or clamp connected to a structural beam, column or truss), and horizontally mobile and vertically flexible (e.g., a horizontal lifeline suspended between two structural columns or between stanchions, which are attached to a structural beam and designed to support the lifeline). In a situation where limiting the free fall to 6 ft is infeasible, the employer would be required to limit the free fall to ensure that the arresting force would not exceed 1,800 lb (see OSHA, 2014a).

A NIOSH research study compared the end effects (arresting forces and deceleration distances of the personal energy absorber) of using a proper and improper personal fall arrest lanyard in a 12-ft free fall foot-level tie off. The end effect data collected were based upon the 2013 version of the ANSI/ASSP Z359 standards.

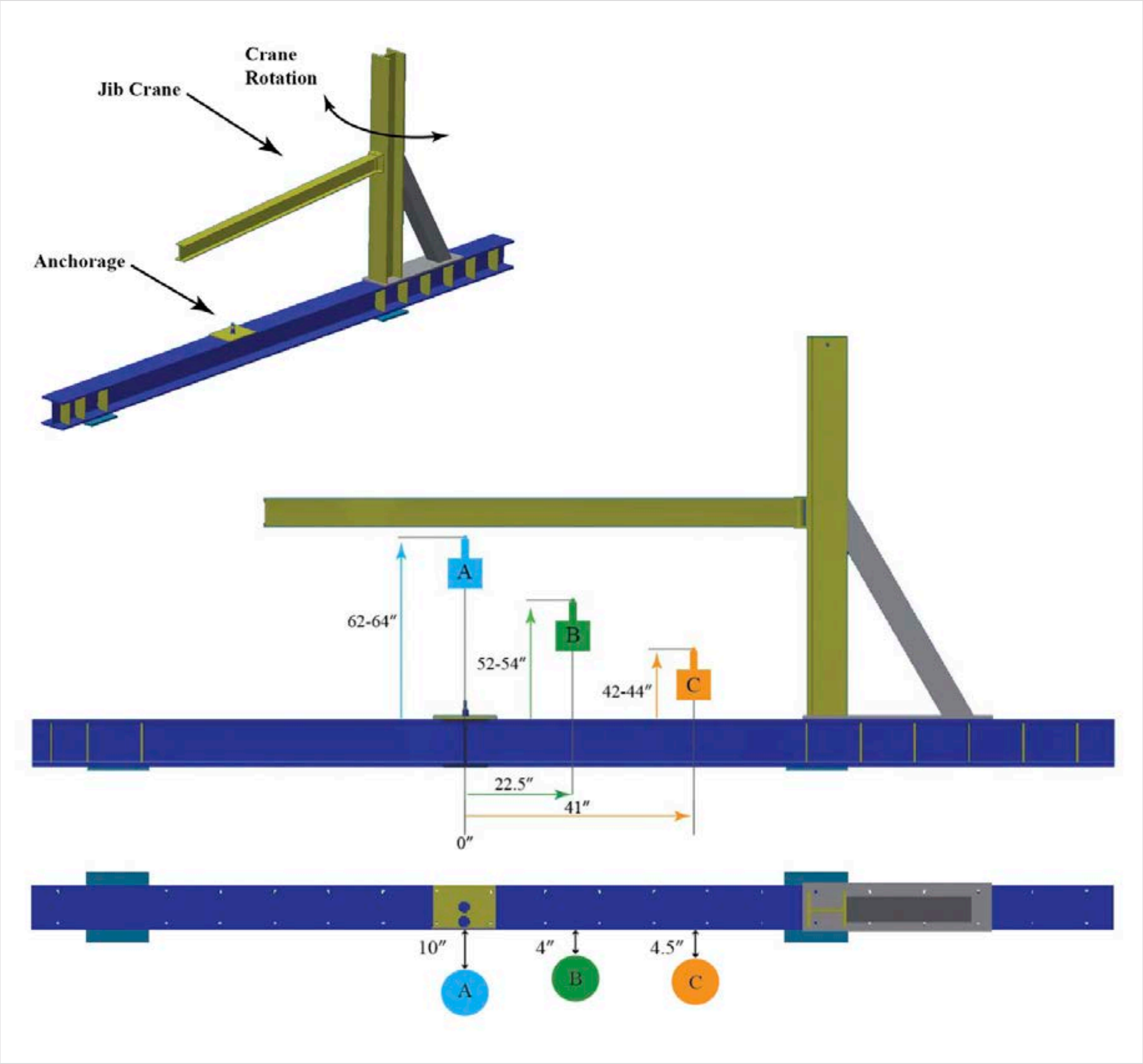
Construction Fatalities

According to BLS, the construction industry sector, which employed 7.2 million workers in 2018, had the greatest number of fatal traumatic injuries. Between 2014 and 2018, about 320 to 370 fatal falls to a lower level were reported annually. In 2018, more than seven times as many fatal falls occurred in the construction industry as compared to the manufacturing industry, which had the second highest number of fatal falls (BLS, 2020a). Other occupations that have an increased risk of fatal falls include laborers, roofers, ironworkers, power line installers and helpers (BLS, 2020c).

A compilation of data for the years 2014 to 2018 from the Census of Fatal Occupational Injuries database is presented in Table 1 (BLS, 2015a, b, c to 2020a, b, c). The table shows the total number of fatalities in all U.S. industries (row 1), the total number of construction-related fatalities (row 3), the total number of deaths caused by falls to lower level for all U.S. industries (row 2) and for the construction industry (row 4). Fall-to-lower-level fatalities averaged about 13% of all fatalities occurring in all U.S. industries from 2014 to 2018. In the construction industry, fall-to-lower-level fatalities averaged about 36% of all construction-related fatalities during the same period.

Other BLS data indicate that structural ironworkers and steelworkers are a high-risk work group. Table 1 compares the overall fatality rates for all U.S. industries and the construction industry with the overall fatality

FIGURE 1
LANYARD STUDY DROP LOCATIONS



rates for ironworkers and steelworkers from 2014 to 2018 (rows 3, 6 and 8 respectively). For 2018, the fatality rate for ironworkers and steelworkers was 23.8 deaths per 100,000 full-time equivalent workers, 2.5 times the fatality rate of all construction workers (9.5 deaths per 100,000 full-time equivalent workers; BLS, 2020c). Included in row 7 is the total number of fatalities for ironworkers and steelworkers for the same 5-year period.

The lack of variance over the 5-year period shows the consistent lack of reduction in fatalities related to fall from elevations in the construction industry.

Experimental Rationale

To investigate foot-level tie off fall protection, several parameters had to be established for the study. The researchers wanted to focus on a worker on high steel construction tied off at foot level. Thus, the researchers chose to use a fixed anchorage connection point on top of the test beam. Three locations were chosen to simulate a worker located on the beam and then falling off:

FIGURE 2
ANSI/ASSP Z359.13 DROP WEIGHT

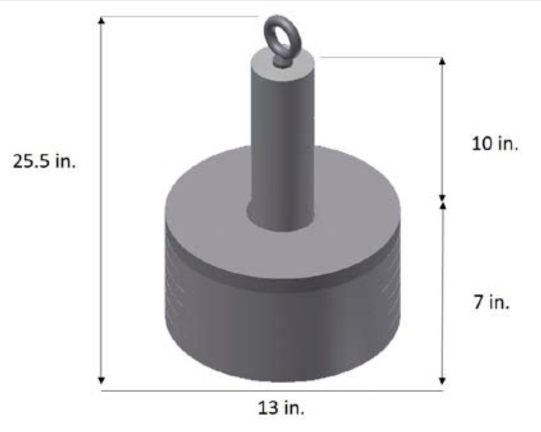


FIGURE 3
DROP WEIGHT TEST

The ANSI/ASSP Z359.13 standard defined drop weight test for 12-ft free fall lanyard.

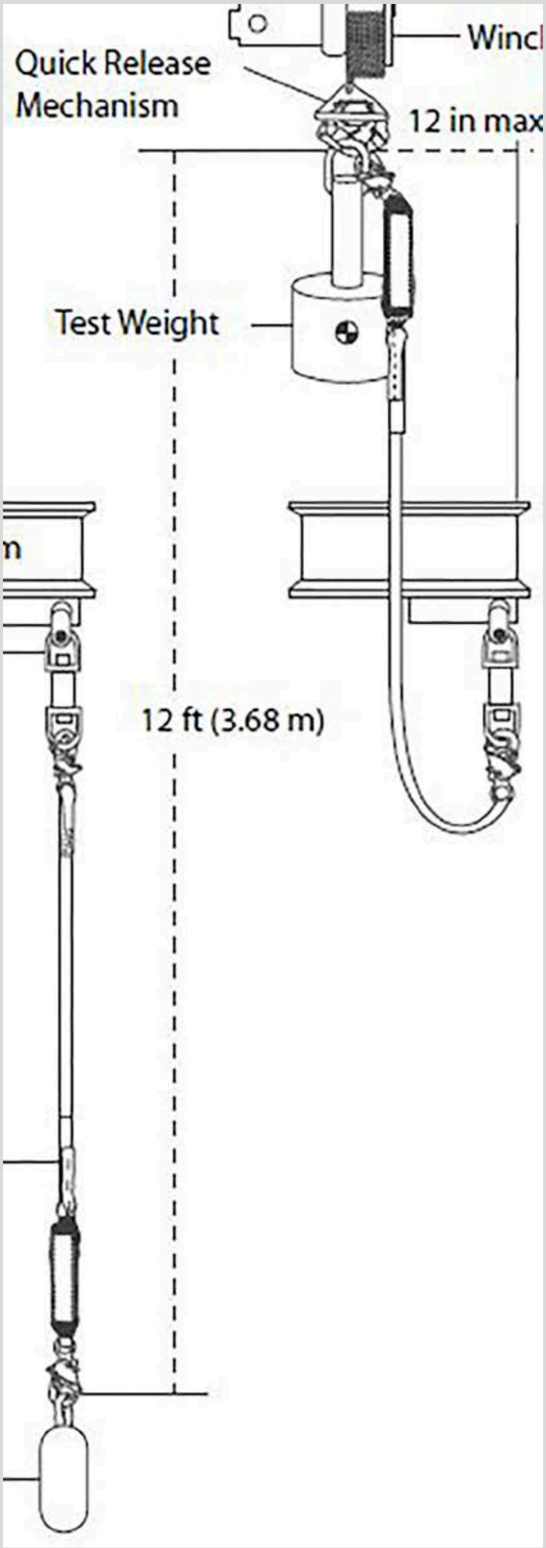
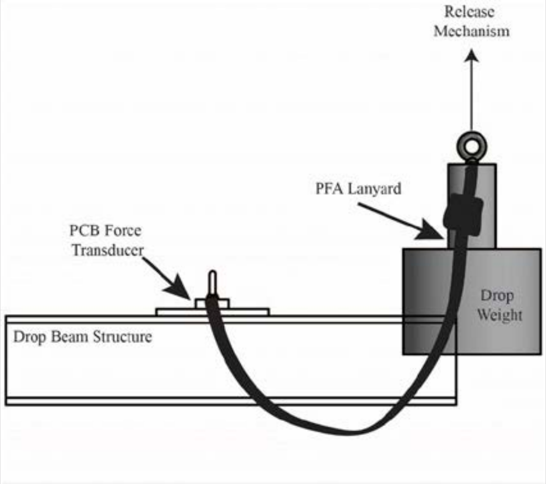


FIGURE 4
MODIFIED DROP WEIGHT TEST

The modified ANSI/ASSP Z359.13 standard defined lanyard drop weight test for 12-ft free fall lanyard, with the anchorage point on top of the drop beam.



•Position A was at the anchorage connection point and simulated a person standing straight up and falling off the beam;

•Position B was approximately midway from the anchorage connection point to the furthest point accessible using a 6-ft-long lanyard and represented a worker slightly bent over or kneeling before falling off the beam; and

•Position C was the furthest from the anchorage connection point and represented a worker stretching as far as they can before falling off the beam.

The horizontal distance from the anchorage connection point for position A is zero, for position B is 22.5 in. and for position C is 41 in. The vertical distance was defined as the approximate height where the D-ring of the full-body harness would be located when attached to the personal fall arrest lanyard. The vertical distances from the top of the test beam were:

•Position A: 62 to 64 in.
•Position B: 52 to 54 in.
•Position C: 42 to 44 in.

The horizontal distances from the edge of the beam were:

•Position A: 10 in.
•Position B: 4 in.
•Position C: 4.5 in.

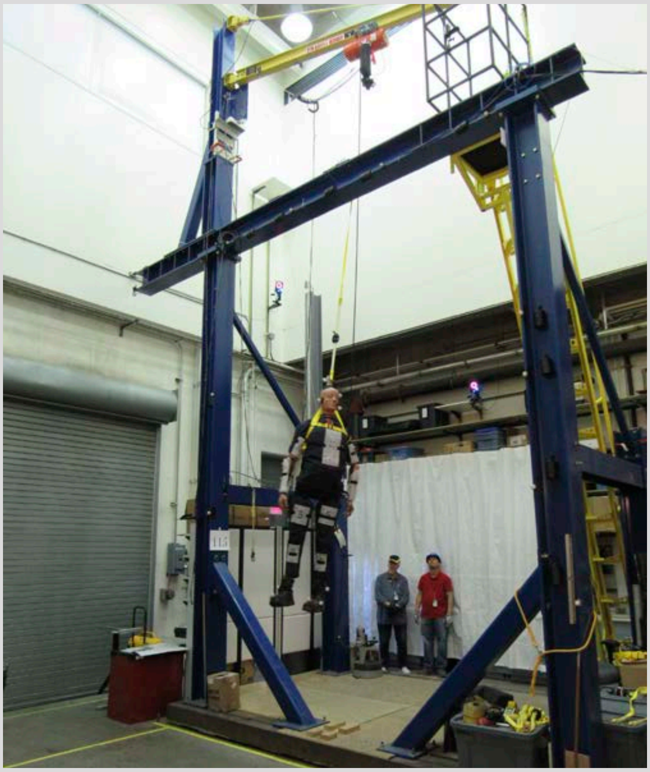
The horizontal distances were related to the position of the jib crane located on the test structure and the diameter of the test weight (shown in Figure 1, p. 23). The arresting forces are greatest during a straight fall (position A) and decrease as the swing increases (horizontal distance increases from the anchorage). The personal fall arrest lanyard pullout will decrease with the increase of the swing fall.

Methods

Two datasets were collected during the testing: the fall arresting force and the before and after lanyard lengths of the 6-ft free fall and 12-ft free fall lanyards.

The researchers utilized a steel drop structure constructed specifically for this project (Photo 1); each test is referred to as a "drop." The ANSI/ASSP Z359.13 standard defines the shape and weight (282 lb) of the test drop weight (Figure 2, p. 23). The drop weight utilized in this study was 7 lb heavier at 289 lb, a 2.5% increase. The 7-lb increase in weight was due to the available weights and connection devices utilized in the test. ANSI/ASSP Z359.13 also defines the configuration that should be used for each test (Figure 3). As shown, the arresting force measurement device is mounted on the bottom of the beam. NIOSH researchers modified the test configuration to match a real-life application by mounting the arresting force measurement device on top of the beam, which is where an actual anchorage would be located. Note that the ANSI/ASSP Z359.13 standard is used to aid manufacturers in the design of personal fall arrest lanyards. However, the NIOSH researchers were investigating real-world applications of fall protection equipment (Figure 4). In addition, the aim was to see if the arresting forces or deployment distances would change if a mannequin was dropped instead of the specified drop weight. To perform this portion of the study, an advanced dynamic anthropomorphic mannequin (ADAM) equipped with a full-body harness (Photo 2) was used. Because the ADAM weighs 234 lb, the drop weight was adjusted accordingly to match the weight of the mannequin (Photo 3).

The arresting forces were measured using a 10,000 lb PCB Piezotronics Triaxial ICP. The length of the lanyard was measured by using a tape measure fixed to the floor of the lab. Measurements were taken before and after each drop; the deployment distance was the difference between the measurements.



(Clockwise from top) Photo 1: NIOSH drop structure located in High Bay Laboratory. Photo 2: The advanced dynamic anthropomorphic mannequin (ADAM) was equipped with a full body harness. Photo 3: Modified 234-lb drop weight.

Testing Plan

Three Positions From the Anchorage

Three horizontal positions from the anchorage (A, B and C) were chosen to represent three working conditions (Figure 1, p. 23). The vertical and horizontal heights of the D-ring were determined by measuring project team members and using the average heights in the three configurations: standing, kneeling and reaching. Other defining factors were dependent on the jib angular position, trolly horizontal position and hoist chain vertical position. The jib angular position had two adjustments: one for location A and B and one for location C. The trolley, located on the jib crane, had three preset horizontal positions: one for each location (shown in Figure 1, p. 23). The height of the drop weight or mannequin was controlled by the chain hoist on the trolley. The chain was marked with three heights and was controlled by a team member on the floor, so the height was within one or two chain lengths and could vary by ±1 in.

Lanyards Used in the Study

Three fall protection lanyard manufacturers were chosen. These were commonly used in the construction industry as stated by the Z359 standards committee. This study refers to three lanyard manufacturers (X, Y and Z). The 6-ft free fall and the 12-ft-free fall lanyards were chosen. Both lanyards are 6 ft long. The 6-ft free fall lanyard (a white label with black text) is designed to absorb energy from a 6-ft-free fall and engage at 900 lb. The 12-ft free fall lanyard (a black label with white text) is designed to absorb energy from a 12-ft free fall and engages at 1,350 lb. Both lanyards have a capacity for a worker weighing between 130 and 310 lb.

Test Matrix: Drops

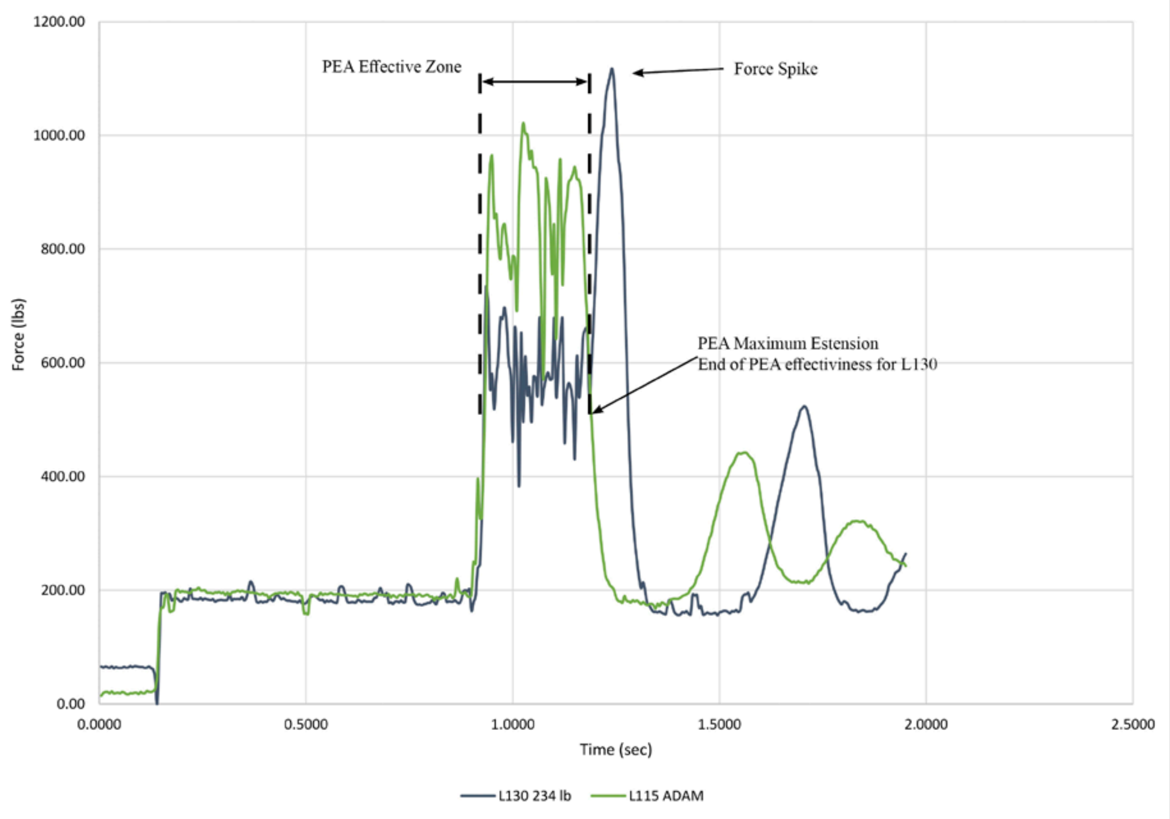
Initial Drop Evaluation

NIOSH researchers presented data from a large swing fall study of 126 test drops, which demonstrated the consistency of data collection and the repeatability of performance of the manufacturers of the personal fall arrest lanyards. Findings from the large study were presented at the 2018 and 2019 ASSP Professional Development Conferences (McKenzie & Bobick, 2018, 2019). The study matrix included three manufacturers of personal fall

FIGURE 5

ARRESTING FORCES: 6-FT FREE FALL LANYARD

The arresting force utilizing a 6-ft free fall lanyard comparing the 234-lb mannequin (ADAM, green line) with the 234-lb test weight (black line), using Company Z lanyards. Both test falls start at test position A.



arrest lanyards; 6-ft free fall and 12-ft free fall lanyards were used. The 289-lb test drop weight was utilized for all 126 drop tests. Three test drops of each manufacturer's personal fall arrest lanyards were used at each drop location. Data collected were fall-arresting force and the before and after lanyard lengths of the 6-ft free fall and 12-ft-free fall lanyards. The recorded data were consistent and repeatable throughout the study. A new lanyard was used for each experimental drop test.

Current Drop Evaluation

This follow-up study was based on discussions at an ANSI/ASSP Z359 semiannual meeting about whether the personal fall arrest lanyard fall arrest test would perform the same using a test weight or a test mannequin. The problem was that there was not a 289-lb test mannequin available, so the drop weight was reduced to 234-lb to equal the weight of the available 234-lb test mannequin for comparable testing.

A total of 36 test drops were performed using the 234-lb modified drop weight and the 234-lb mannequin. For every drop with the 234-lb weight, a corresponding drop was performed with the 234-lb mannequin (18 drops each). The series of tests incorporated all three lanyard manufacturers (X, Y, Z), 6-ft free fall and 12-ft-free fall lanyards, and the three locations shown in Figure 1 (p. 23; A, B, and C). The arresting forces and the before and after lanyard lengths were recorded. A new lanyard was used for each experimental drop test.

Results

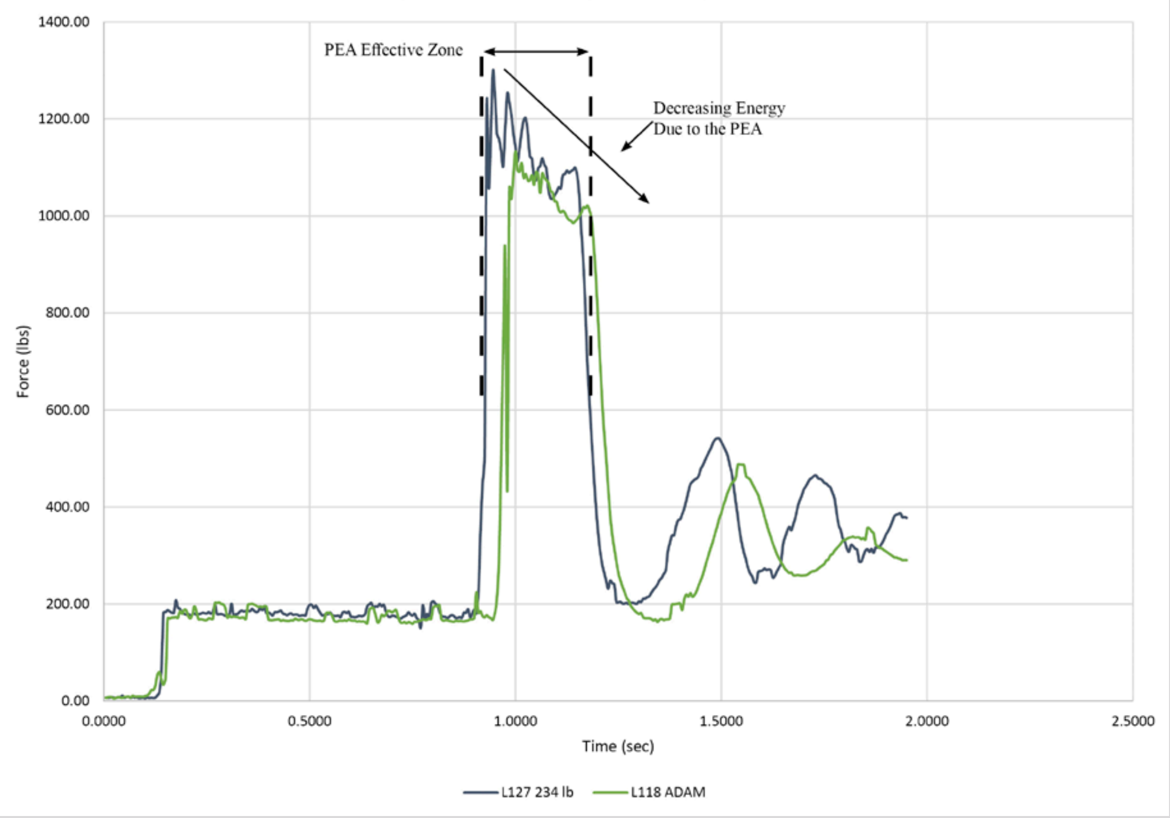
Figures 5 and 6 show the comparison of the modified test weight and the ADAM utilizing a 6-ft free fall and a 12-ft free fall lanyard during a fall arrest event. A sample of the arresting forces for a 6-ft free fall lanyard is shown in Figure 5. The arresting force of the 234-lb drop weight pulled the personal energy absorber to the maximum deployment distance, thus causing a force spike in the lanyard of more than 1,000 lb. The arresting force for the 234-lb mannequin did not deploy the personal energy absorber to the maximum distance; this is mostly due to energy being absorbed in the harness.

The arresting forces were measured and reported to show the effectiveness of the personal fall arrest lanyards to reduce the fall arrest effects on the subject and the overall functionality of the lanyards. The arresting forces followed similar patterns for arresting the fall of the 234-lb drop weight when compared to the arresting force

FIGURE 6

ARRESTING FORCES: 12-FT FREE FALL LANYARD

The arresting force utilizing a 12-ft free fall lanyard comparing the 234-lb manikin (ADAM, green line) with the 234-lb test weight (black line), using Company Y lanyards. Both test falls start at test position A.



of the 234-lb mannequin using 12-ft free fall lanyards as shown in Figure 6. The similarity in arresting force is mostly due to the fact that the 12-ft free fall personal fall arrest lanyard is designed for a foot-level anchorage.

The lanyard deployment distance was less with the 234-lb mannequin compared with the 234-lb drop weight for the 6-ft free fall lanyard and the 12-ft free fall lanyard. For the 6-ft free fall lanyard, the average pullout distance of the personal energy absorber was 22% to 32% greater using the drop weight than the mannequin. For the 12-ft free fall lanyard, the average pullout distance of the personal energy absorber was 10% to 11% greater using the drop weight than the mannequin. Samples of the deployment distances are shown in Figures 7 and 8 (p. 28).

Discussion

This study was based on discussions at an ANSI/ASSP Z359 semiannual meeting about whether the personal fall arrest lanyard fall arrest test would perform the same using a test weight as a test mannequin. The study matrix included three manufacturers of personal fall arrest lanyards; 6-ft free fall and 12-ft free fall lanyards were used. ADAM was used for the 18 drop tests. Three test drops of each manufacturer's personal fall arrest lanyards were used at each drop location. Data collected were fall arresting force and the before and after lanyard lengths of the 6-ft free fall and 12-ft free fall lanyards. The recorded data were consistent and repeatable throughout the study. The lanyard arresting force and personal fall arrest lanyard pullout distances were consistent within each manufacturer and similar among the lanyards of the three manufacturers. In general, this study demonstrates the performance characteristics of the fall arrest differences between a solid weight and a mannequin (ADAM).

Figure 5 demonstrates that the 6-ft-free fall personal fall arrest lanyard will fully extend to its effective length before the fall is completely arrested during a foot-level tie off scenario. This will generate a force spike in excess of 900 lb using the 234-lb modified drop weight. The same test using the 234-lb ADAM fitted with a harness does not fully extend the personal fall arrest lanyard and thus does not have a resulting force spike. Figures 7 and 8 (p. 28) show that the pullout of the personal fall arrest lanyard is less with ADAM fitted with a harness, as compared to the 234-lb test weight. The most probable explanation is due to energy being absorbed in the fall harness, which is the only variable between the two test conditions. Utilizing the triaxial force transducer to record the fall arrest force did not extend the length of the lanyard or the fall distances as illustrated in Figures 3 and 4 (p. 24).

During the testing, it was discovered that each manufacturer had a different method of satisfying the requirements to identify the 6-ft free fall and the 12-ft free fall personal fall arrest lanyards. These differences could impact selecting the correct lanyard for the type of application needed. For redundant safety compliance, color coding the end hooks to add an additional identification method between the 6-ft free fall and 12-ft free fall lanyards could minimize the potential misuse of lanyards. A suggestion could be to use black hooks for the 6-ft free fall lanyard and white hooks for the 12-ft free fall lanyard; this would correspond to the text color on their corresponding labels.

FIGURE 7
DEPLOYMENT LENGTHS: 6-FT FREE FALL LANYARD

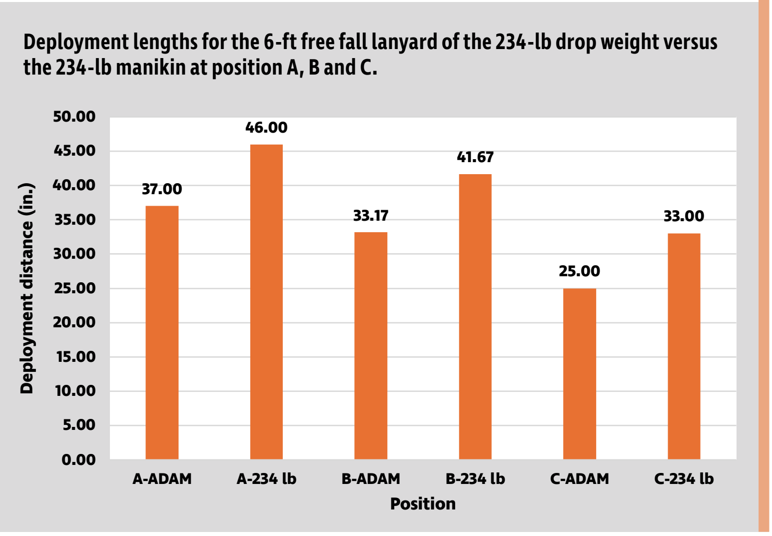
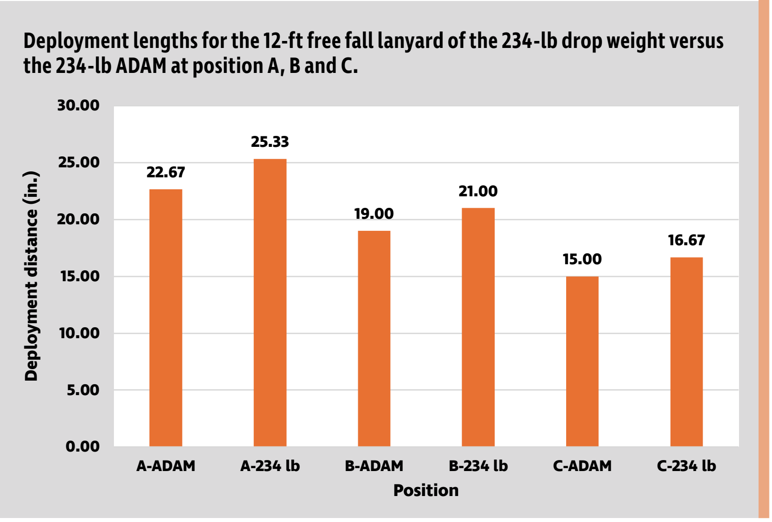


FIGURE 8
DEPLOYMENT LENGTHS: 12-FT FREE FALL LANYARD



Study Limitations

The reliability of this study is based upon the data collection method of the larger NIOSH study that was presented at the 2018 and 2019 ASSP conferences (McKenzie & Bobick, 2018, 2019). This study simulated the real-world application of foot-level tie off, unlike the test conditions specified in the laboratory testing described in ANSI/ASSP Z359.13. Three fall conditions were evaluated: at anchorage (straight fall), 22.5 in. from anchorage (minimum swing), and 41 in. from anchorage (maximum swing) using lanyards from the same batch as the ones tested in the larger study (McKenzie & Bobick, 2018). An additional limitation of this study is the small number of drops (36) with only one drop per manufacturer at each drop point. Multiple drops at each drop point for each manufacturer would be required to be able to perform a statistical analysis.

Conclusion

The measured deployment distance of personal energy absorber of the ANSI/ASSP Z359 modified 234-lb drop weight was 24% to 32% greater as compared to the deployment distance of the mannequin using a 6-ft free fall personal fall arrest lanyard. In comparison, the personal energy absorber distances of the drop weight were 10% to 11% greater as compared to the deployment distance of mannequin using a 12-ft free fall personal fall arrest lanyard. The differences are most likely due to energy dissipated in the harness worn by ADAM.

The personal energy absorber utilized in 6-ft-free fall personal fall arrest lanyards reached its maximum effectiveness during pullout and stopped extending. When this occurred, an excessive force spike was measured before the fall was fully arrested (Figure 5, p. 27), validating the use of the 12-ft free fall personal fall arrest lanyards at foot-level anchorages. In addition, the authors conclude that determining which lanyard to use based solely upon the black and white label colors could be confusing to the end user.

Based on the results of this study, the authors recommend the following:

•Foot-level tie off should be the last method of anchorage for fall protection. Foot-level tie off would increase the safe required distance below the anchorage connection point.

•A 12-ft free fall personal fall arrest lanyard should always be used when foot-level tie off must be utilized. This will reduce the free fall distance and the arresting force subjected to the person's body as compared to the 6-ft free fall personal fall arrest lanyard.

•A 6-ft free fall personal fall arrest lanyard should never be used at foot-level tie off, as shown in Figure 5 (p. 27), where the personal energy absorber is at full extension resulting in an extreme increase (force spike) in measured arresting force. **PSJ**

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Reference

ANSI/ASSP. (2013). Personal energy absorbers and energy absorbing lanyards (ANSI/ASSP Z359.13-2013).

ASSP. (2018). Z359 committee guidance document for definitions and nomenclature used in Z359 fall protection and fall restraint standards (ASSP Z359.0-2018).

McKenzie, E.A., Jr. & Bobick, T.G. (2018, June 3-6). *NIOSH: Swing fall analysis of below D-ring anchorage* [Conference session]. ASSP Safety 2018, San Antonio, TX.

McKenzie, E.A., Jr. & Bobick, T.G. (2019, June 9-12). *Arresting forces: Manikin vs. the weight specified by ANSI/ASSP Z359* [Conference session]. ASSP Safety 2019, New Orleans, LA.

OSHA. (2014a). Fall protection (29 CFR 1926.750 to 1926.761, Subpart R, Steel Erection). www.osha.gov/laws-regs/regulations/standardnumber/1926/1926SubpartR

OSHA. (2014b). Personal fall protection systems (29 CFR 1910.140, Subpart I). www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.140

U.S. Bureau of Labor Statistics (BLS). (2016a). Fatal occupational injuries by event or exposure for all fatal injuries and major private industry sector, all United States, 2014 (Table A-9). www.bls.gov/iif/fatal-injuries-tables/archive/fatal-occupational-injuries-table-a-9-2014.pdf

U.S. BLS. (2016b). Fatal occupational injuries by primary and secondary source of injury for all fatal injuries and by major private industry sector, all U.S., 2014 (Table A-4). www.bls.gov/iif/fatal-injuries-tables/archive/fatal-occupational-injuries-table-a-4-2014.pdf

U.S. BLS. (2016c). Fatal occupational injuries, total hours worked, and rates of fatal occupational injuries by selected worker characteristics, occupations, and industries, civilian workers, 2014. https://web.archive.org/web/20170505213238/https://www.bls.gov/iif/oshwc/cfoi/cfoi_rates_2014hb.xlsx

U.S. BLS. (2017a). Fatal occupational injuries by event or exposure for all fatal injuries and major private industry sector, all U.S., 2015 (Table A-9). www.bls.gov/iif/fatal-injuries-tables/archive.htm

U.S. BLS. (2017b). Fatal occupational injuries by primary and secondary source of injury for all fatal injuries and by major private industry sector, all U.S., 2015 (Table A-4). www.bls.gov/iif/fatal-injuries-tables/archive.htm

U.S. BLS. (2017c). Fatal occupational injuries, total hours worked, and rates of fatal occupational injuries by selected worker characteristics, occupations, and industries, civilian workers, 2015. https://web.archive.org/web/20170131035630/https://www.bls.gov/iif/oshwc/cfoi/cfoi_rates_2015hb.xlsx

U.S. BLS. (2018a). Fatal occupational injuries by event or exposure for all fatal injuries and major private industry sector, all U.S., 2016 (Table A-9). www.bls.gov/iif/fatal-injuries-tables/archive.htm

U.S. BLS. (2018b). Fatal occupational injuries by primary and secondary source of injury for all fatal injuries and by major private industry sector, all U.S., 2016 (Table A-4). www.bls.gov/iif/fatal-injuries-tables/archive.htm

U.S. BLS. (2018c). Fatal occupational injuries, total hours worked, and rates of fatal occupational injuries by selected worker characteristics, occupations, and industries, civilian workers, 2016. https://web.archive.org/web/20181014222656/https://www.bls.gov/iif/oshwc/cfoi/cfoi_rates_2016hb.xlsx

U.S. BLS. (2019a). Fatal occupational injuries by event or exposure for all fatal injuries and major private industry sector, all U.S., 2017, (Table A-9). www.bls.gov/iif/fatal-injuries-tables/archive.htm

U.S. BLS. (2019b). Fatal occupational injuries by primary and secondary source of injury for all fatal injuries and by major private industry sector, all U.S., 2017 (Table A-4). www.bls.gov/iif/fatal-injuries-tables/archive.htm

U.S. BLS. (2019c). Fatal occupational injuries, total hours worked, and rates of fatal occupational injuries by selected worker characteristics, occupations, and industries, civilian workers, 2017. https://web.archive.org/web/20181014222656/https://www.bls.gov/iif/oshwc/cfoi/cfoi_rates_2017hb.xlsx

U.S. BLS. (2020a). Fatal occupational injuries by industry and event or exposure, all United States, 2018 (Table A-1). www.bls.gov/iif/fatal-injuries-tables/archive/fatal-occupational-injuries-table-a-1-2018.htm

U.S. BLS. (2020b). Fatal occupational injuries by primary and secondary source of injury for all fatal injuries and by major private industry sector, all United States, 2018 (Table A-4). www.bls.gov/iif/fatal-injuries-tables/archive/fatal-occupational-injuries-table-a-4-2018.htm

U.S. BLS. (2020c). Fatal occupational injuries, total hours worked, and rates of fatal occupational injuries by selected worker characteristics, occupations, and industries, civilian workers, 2018. https://web.archive.org/web/20181014222656/https://www.bls.gov/iif/oshwc/cfoi/cfoi_rates_2018hb.xlsx

U.S. BLS. (2021a). Fatal occupational injuries by industry and event or exposure, all United States, 2019 (Table A-1). www.bls.gov/iif/fatal-injuries-tables/archive/fatal-occupational-injuries-table-a-1-2019.htm

U.S. BLS. (2021b), Fatal occupational injuries, total hours worked, and rates of fatal occupational injuries by selected worker characteristics, occupations, and industries, civilian workers, 2019. www.bls.gov/iif/fatal-injuries-tables/fatal-occupational-injuries-hours-based-rates-2019.xlsx

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