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Evaluating the Stability of a Freestanding Mast Climbing Work Platform

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Abstract

Mast Climbing Work Platforms (MCWPs) are becoming more common at construction sites and are being used as an alternative to traditional scaffolding. Although their use is increasing, little to no published information exists on the potential safety hazards they could pose for workers. As a last line of defense, a personal fall-arrest system can be used to save a worker in a fall incident from the platform. There has been no published information on whether it is safe to use such a personal fall-arrest system with MCWPs. In this study, the issues of concern for occupational safety included (1) the overall stability of the freestanding mast climber during a fall-arrest condition and (2) whether that fall-arrest system could potentially present safety hazards to other workers on the platform during a fall-arrest condition. This research project investigated those safety concerns with respect to the mast climber stability and the workers using it by creating fall-arrest impact forces that are transmitted to the equipment and by subsequently observing the movement of the mast climber and the working deck used by the workers. This study found that when the equipment was erected and used according to the manufacturer's recommendations during a fall-arrest condition, destabilizing forces were very small and there were no signs of potential of MCWP collapse. However, potential fall hazards could be presented to other workers on the platform during a fall arrest. Workers near an open platform are advised to wear a personal fall-arrest system to reduce the risk of being ejected. Due to the increasing use of MCWPs at construction sites, there is a corresponding need for evidence and science-based safety guidelines or regulations. To fill the knowledge gap, this research begins to investigate the effects of fall-arrest on the overall stability of a freestanding MCWP and workers while wearing a personal fall-arrest system.

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7.0. Disclaimers

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Keywords

mast climbing work platform; MCWP; fall exposure; fall-arrest; fall hazard; harness; lanyard; mast climber

1.0 Background

Mast Climbing Work Platforms (MCWPs), or mast climbers, are a type of construction elevating equipment used as an alternative to traditional tube and coupler scaffolding. They are equipped with a powered drive unit for propelling the work platform up and down a vertical mast structure. Compared to traditional scaffolding, MCWPs are capable of handling larger loads (workers and materials) and reaching greater heights, thus improving the efficiency of construction projects. Research on stability of equipment during a fall arrest has been completed on traditional scaffolds and other equipment, such as scissor lifts, that fall under the OSHA scaffold standards. However, little research has been done on mast climbers as a whole, and with increasing use comes a new set of occupational safety challenges and concerns to investigate (Harris et al., 2010). Of particular concerns are the stability of freestanding MCWPs, the contribution of this device to a fall-related injury, and the potential for catastrophic failure. The fact that MCWPs are increasingly being used in U.S. construction, the lack of pertinent regulations, and the fact that they are rapidly replacing traditional elevating equipment, calls for research focusing on the safety hazards of MCWPs (Pan et al., 2012 a). This article describes the ongoing research at the National Institute for Occupational Safety and Health (NIOSH) that focuses on the stability, functionality, and safety hazards of MCWPs.

1.1. MCWP Use and Injury Statistics

MCWPs have been available in the United States since the 1980s, with usage increasing to present day. The increase in adoption is largely because of the advantages offered over tube and coupling scaffolding which include increased productivity, increased flexibility, and increased capacity. More commonly used in the construction industry in Europe and Canada, current configurations of MCWPs offer great variability; they range from quickly deployed freestanding models used with abbreviated working heights to anchored models capable of reaching heights over 1,000 feet (304.8 m).

Each day in the U.S., up to 16,800 workers are using mast climbers at any given time. They are usually found on construction sites and total up to 5,600 units. Each mast climber can be dis-assembled and re-erected multiple times per year, creating up to 3.3 million man-hours in the moving process of MCWPs each year (Susi et al., 2010).

Over the past decade, numerous incidents have occurred using mast climbers, resulting in serious injuries, or in some cases, worker fatalities. In 2008, Ayoub, O’Shea, and Susi individually presented data on these fatal and nonfatal injury incidents to the Advisory Committee on Construction Safety and Health and identified the following potential hazards (OSHA, 2008 a–c.). These incidents have frequently been the consequences of fall hazards due to catastrophic failure of the equipment, slip, trip, and fall hazards, and fall-related hazards pertinent to construction (lack of fall-arrest protection). The widely varying configurations of MCWPs cause little commonality to these hazards, aside from occurring at elevation on an extendable platform. This study focuses on the fact that the platforms in incidents were subjected to destabilizing forces leading to possible catastrophic failure and subsequent collapse leading to injury events. The additional hazardous exposures as a function of slip, trip, and fall injuries found at numerous construction sites are significant but do not form the focus of the present work, which focuses on anticipated destabilizing forces on the platform.

Recent incidents have recorded a number of equipment failures and subsequent fatal injuries caused by platform collapses. From 1990 to 2010, twelve documented incidents resulted in eighteen deaths (Susi et al., 2010). In March of 2015, an incident in Raleigh, North Carolina, resulted in three worker fatalities and one serious injury (Kenney and Bracken, 2015). These incidents were of concern for occupational safety researchers, and all involved failures of MCWPs. This concern led to basic and advanced research on worker exposures to falls as a function of work on MCWPs.

1.2. Fall-arrest Requirements for MCWP Use

Mast climbers are considered by the Occupational Safety and Health Administration (OSHA) regulations to be a “scaffold” structure. OSHA regulation (1926 Subpart L) requires the use of guardrails or personal fall-arrest systems as primary safety controls for MCWPs (OSHA, 1999). Under these OSHA regulations, a person must use a personal fall-arrest system while working at elevation and assembling/dismantling the structure when an open edge of the working platform is present and when a guardrail system is not present.

1.3. Problem Statement and Scope of Study

Very little research has been completed on MCWPs outside of manufacturer testing. Currently, the OSHA regulation, 29 CFR 1926 Subpart L, encompasses types of equipment other than traditional scaffolding, such as certain types of aerial work platforms, like scissor lifts. No published data has been found on fall-arrest hazards of mast climbers. Scientific research has been completed on other equipment that would fall under the OSHA 29 CFR 1926 Subpart L standard. Harris and colleagues found a scissor lift would remain stable during a fall-arrest scenario, even under adverse conditions, as long as it was used within the manufacturer’s recommended parameters (Harris et al., 2010).

Mast climber equipment is thought to be inherently safe, although performance under certain scenarios is not fully understood. The purpose of this study is to begin to fill that knowledge gap, specifically investigating fall-arrest loading. Most mast climbers are anchored to the adjacent structure, while others are used in a freestanding configuration. Anchoring may prevent equipment failure due to added stability. It is unknown if a mast climber could become unstable and pose a risk to other workers on the platform if a fall-arrest event occurred on a freestanding configuration.

Current OSHA standards do not require a personal fall-arrest system (PFAS) unless assembling/disassembling equipment or while working near an open edge. However, under certain scenarios, workers may feel more protected by wearing a PFAS and it is common practice to wear a fall-arrest system under conditions like working near an open edge (Pan and Chiou, 1999). Therefore, workers are commonly secured to their MCWP under mandatory conditions - such as during erection, disassembly, and other conditions. In the event of a fall, the act of securing the lanyard and harness—one end attached to the worker and the other to the platform—subjects the platform to potentially destabilizing forces. Further research is needed on MCWPs under working conditions to examine these potentially destabilizing forces and their contribution to catastrophic failure and collapse leading to injury (Harris et al., 2010; Pan et al., 2012 b).

Stability of the MCWP was the focus of this study. Stability was measured by the working platform displacement, accelerations measured at the MCWP base and working platform under loading, and the ability of the unit to remain in an uncompromised position (i.e., where a tip over would not occur and where the worker is safe). Severe injury events generally occur as a function of tip over/collapse/fall events. The most unstable conditions possible for a fall-arrest scenario to create a worst case scenario were investigated.

This research intends to address two unresolved questions: (1) Will a freestanding MCWP under normal work conditions remain stable if a fall-arrest event occurred? and (2) In the event of a fall-arrest, what additional fall hazard risks exist, if any, to other workers on the platform?

2.0. Methods

The methods used to determine the stability of a freestanding MCWP under potentially destabilizing conditions were based off of other construction equipment studies (Pan et al., 2012 b; Harris et al., 2010; Wu et al., 2001). The methods followed are consistent with the existing ANSI standard for fall protection (Z359.1-2007).

In the current research effort, two scenarios were examined. In the first, a dead weight—consisting of weighted plates—was dropped from a fixed anchorage point that would generate the maximal rotational force. The weight was then steadily increased until it exceeded the ANSI standard. The second scenario examined the drop of an Advanced Dynamic Anthropomorphic Manikin (ADAM) from three initial conditions: (1) an unloaded platform, (2) a fully loaded platform recommended by the manufacturer’s load chart, and (3) two overloaded platforms recommended by the manufacturer’s load chart.

Due to the complexities of a mast climber, only certain configurations and test conditions were used for this initial study. The independent variables were the overall base/platform/mast configuration, the dead weight/ADAM manikin fall arrest input, and the platform weight loading. The dependent variables, which were to be measured as an overall evaluation of the mast climber, were the platform displacement in the vertical direction along the loaded side of the platform, the platform and base accelerations at various locations, and the input force observed from the fall arrest itself. A measure of these dependent variables give an indication, albeit not definitive, of whether the mast climber would remain stable during fall arrests.

A total of twenty-nine different test conditions were performed. The most unstable conditions created the most movement of the platform of the mast climber. The results of the dead weight drop tests, as well as six specific fall-arrest scenarios (tests 24–29) were deemed to be the worst case scenarios.

2.1. Dead-weight Drop Tests

2.1.1. Nystron Rope Break In—To test the stability of the MCWP, dead weights were used in conjunction with a Nystron rope (Samson Rope Technologies Inc., Ferndale, WA and Gravitec Systems Inc., Bainbridge Island, WA) to create an impact that would meet and surpass the ANSI standard for maximum allowable force transmitted to the worker. The ANSI Z359.1-2007 standard sets the maximum allowable force applied to the harness portion of a personal fall-arrest system at 1,800 pounds (8,000 N) (ANSI/ASSE, 2007). In conjunction with the 1,800-pound maximum arresting force (MAF), a 2,400-pound (10,675-N) MAF force was also used to check the safety margin/factor of the MCWP.

A procedure similar to the one tested by Harris was used to break-in (eliminate the construction stretch) the Nystron rope, which consists of a polyester jacket with a double-braided nylon core. A 6-foot (1.83-m) Nystron rope, 5/8 inches (0.127 m) in diameter with split thimble ends, was affixed to a set of rigid weights on a threaded rod with locking hardware. The Nystron rope break-in configuration can be seen in Figure 1.

The rope length was measured with a string potentiometer [Celesco model SP2-50, Chatsworth, CA] to ensure all the stretch was removed. The string potentiometer was then used to detect the vertical linear position the weights needed to be dropped from to achieve the 1,800-pound (8,000-N) and 2,400-pound (10,675-N) impact forces. The weight and drop height configurations needed to achieve the 1,800-pound (8000-N) and 2,400-pound (10,675-N) impact forces were calculated at 118 pounds (53.5 kg) at 30.5 inches (0.77 m), and 168 pounds (76.2 kg) at 30.5 inches (0.77 m) respectively.

2.1.2. Instrumentation and Materials—The configuration consisted of a Fraco ACT8 (described in section 2.1.3.) where dead weights were attached to the end anchor point of the platform. A 3,000-pound (13,400N) Interface (Interface Inc., Scottsdale, AZ) S-type load cell was used to record the force transmitted between the Nystron rope eyelet and the last anchor point. Shackles and eye bolts were used to make the connection. The load cell signal was passed through a signal conditioner and connected to a National Instruments 9191 wireless data acquisition device (National Instruments Corporation, Austin, TX) that was connected to a laptop.

2.1.3. Mast Climbing Work Platform—A freestanding Fraco ACT8 mast climber was used for all testing. To create the most unstable condition under fall-arrest loading, the load point was placed at the furthest end of the working platform to create a greater tipping moment of the equipment. To construct this configuration, the Fraco ACT8 consisted of the following:

- Freestanding ground base with outriggers placed according to manufacturer recommendations,

- 45-foot mast height with no anchor point,
- Diesel drive unit,
- Six 10-foot (3.05-m) sections of platform for a total of 30 feet (9.14 m) on each side of the drive unit, and
- One section of I-beam Monorail system used for tying off at the end of the platform.

All manufacturers recommend that during installation of freestanding mast climber equipment, all mast bases should be properly supported by stable extending outriggers in their appropriate position. For this project, the outrigger arms were extended to their maximum distance (48 inches (1.23 m) for front stabilizers and 28 inches (0.71m) for rear stabilizers). The outriggers were placed on wooden pads that measured approximately 18 x 18 inches (0.46 x 0.46 m) and were 6 inches (0.15 m) tall. The mast climber base was placed on a large outdoor concrete pad. Lag bolts were placed in the concrete and chains were draped loosely over the outrigger legs of the base for safety purposes. The chains were loose enough in case the base began to rise from the ground, the legs would lift several inches before contacting the chains. The chains were draped over the legs, allowing 3 to 4 inches of vertical travel room for the leg to move without allowing the unit to fully detach from the outrigger pad. For safety purposes, a mobile crane was also attached to the top of the mast via straps (with 3–5 feet (0.92–1.52 m) of travel). An overview of the MCWP test configuration used is shown in Figure 2.

2.1.4. Procedure—The first portion of testing consisted of using dead weights to create a maximum allowable force (transferred to the worker during fall arrest) transmitted through the Nystron rope to an anchor point on the platform. To achieve the 1,800-pound (8,000-N) and 2,400-pound (10,675-N) impact forces needed, the dead weights were attached to the Nystron rope and lifted to the corresponding heights. The Nystron rope was fixed to the weights with a turnbuckle and to the platform wall side at the furthest anchor point from the drive unit. The weights were hoisted to the desired height by a hand-operated winch connected to the platform by the I-beam Monorail system. An electromagnetic disconnect was used to hold the weights at a desired height. The ACT8 drive unit was then raised by remote control to its maximum allowable freestanding height of approximately 38 feet (11.58 m). The electromagnet was then deactivated by a remote control to release the weights that create the desired forces. Data recording began before the start of the weights free-fall and continued until the platform rocking motion had stopped (approximately 15 seconds). The dead-weight testing configuration is shown in Figure 3.

2.2. Drop Tests Recreating a Fall-arrest Scenario

2.2.1. Instrumentation and Materials—An Advanced Dynamic Anthropomorphic Manikin (ADAM) was used as a human surrogate for the fall-arrest testing. ADAM was designed to replicate joint articulation and dynamic body responses of a human since it represents the 95th percentile for height and weight of a U.S. male. ADAM was equipped with a PFAS, work boots, and coveralls - resulting in an overall height of 6 feet 2 inches (1.88 m) and approximately 220 pounds (99.8 kg).

The second component of a PFAS was the connecting device. Various combinations of market-available, shock-absorbing lanyards were used, including: 6-foot (1.83-m) shock-absorbing lanyards that had two plated, double-locking snap hooks with 3/4-inch (0.019-m) throat openings and an integral shock absorber, and 6-foot (1.83-m) shock-absorbing lanyards with a one plated, double-locking snap hook and one plated, double-locking rebar hook. The third component of a PFAS was the full-body harness. A vest-type harness, from the same manufacturer as the shock-absorbing lanyard, was used.

The Interface S-type load cell was used to record the force transmitted between the snap hook eyelets and the last anchor point. The load cell signal was passed through a signal conditioner and connected to a National Instruments 9191 wireless data acquisition device (National Instruments Corporation, Austin, TX) connected to a laptop. Five in-house packaged tri-axial accelerometers (Kionix, Model KXRB5, Ithaca, NY) were attached to the MCWP for vibration measurement. They were placed on the main platform section of the steel truss structure at evenly spaced 5-foot (1.53-m) increments from the end going inwards on the platform on one side of the drive unit. Two accelerometers were also placed on the outrigger pad columns at the base of the MCWP for measurement, one on the top section of each leg and secured with double sided tape, as shown in Figure 4.

The accelerometers operated at 3.3 volts and measured accelerations with values at ±6 G with the sensitivity of 220 millivolts/G. The signals from the accelerometers were input to the wireless data acquisition system (National Instrument Analogue Input Module 9205 with Compact DAQ chassis 9191) and a LabVIEW program was developed to record, store, and display the acceleration time history data in real time.

2.2.2. Procedure—To re-create a fall-arrest scenario using the MCWP, the ADAM manikin was dropped from the far end of the main working platform. The platform weights for the specific testing configuration—unloaded, fully loaded, and overloaded—were put into place before each test. The ADAM manikin was outfitted with a randomly selected PFAS that included a harness and 6-foot (1.83-m) energy-absorbing lanyard. The lanyard snap hook was tied to the D-ring of the harness on one end, and an eye bolt that was attached to the force gauge on the other end. The force gauge was hooked by another eye bolt to the last anchor point on the platform's end that was furthest from the drive unit. The total force gauge configuration was approximately 12 inches (0.305 m) in length. The ADAM manikin was hooked to the I-beam Monorail tie-off system via a winch and pulley and was raised into position. ADAM was held to the cable by the electromagnetic disconnect system. A small section of the second step-down planking was removed to allow ADAM to free fall without interference. All data, photo, and video recordings began prior to the first drop. The ACT8 drive unit was raised to its maximum allowable freestanding height, and once stabilized, the ADAM manikin was released and allowed to free fall. Once the mast climber (entire structure) stopped moving, the drive unit was lowered and reset. The fall-arrest scenario test configuration is shown in Figure 5.

3.0. Experimental Results

The results of the experiment included the arrest forces measured by the force gauge, vertical platform displacement measured by the string potentiometers, and the overall stability of the MCWP system.

3.1 Dead-weight Drop Test Results

As discussed in Section 2.1.1, dead-weight impact forces of 1,800 pounds (8,000 N) and 2,400 pounds (10,675 N) were created by dropping dead weights at pre-determined heights using the Nystron rope. While the base of the MCWP remained stable during these tests, the greatest platform instability occurred during the 2,400-pound (10,675-N) force.

To achieve the 2,400-pound (10,675-N) MAF, the 168-pound (76.2-kg) dead weight was dropped 30.5 inches (0.77 m), the height used during the Nystron rope break in. Using the configuration of the 2400-pound (10,675-N) MAF, an impact force of 2,120 pounds (9430 N) was achieved with the platform flexibility dampening the response. The impact force, recorded at the furthest end of the platform, is shown in Figure 6.a.

Platform displacement measurements were taken at three locations along the main platform. The last string potentiometer (furthest from the drive unit) consistently measured the greatest displacement. For the 2,400-pound (10,675-N) MAF test, the platform displacement measured a vertical change of approximately 2.5 inches (0.064 m) over a course of 0.15 seconds. Figure 6.b. shows the measurement during impact of the string potentiometer furthest from the drive unit. The platform travels upward vertically for approximately 0.5 inches (0.013 m) at the moment the weight is released, prior to the imposition of impact force. All data past 4.5 seconds for the dead-weight drop tests were not considered in the analysis because the sway displacement (left to right platform movement) was largely responsible for invalidating data recorded after this time. The third platform displacement (between 4 and 4.25 seconds) exceeded the first two impacts due to the overall sway of the platform and mast.

During both the 1,800-pound (8,000-N) and 2,400-pound (10,675-N) MAF impact force tests, the MCWP remained stable. The outriggers did not move from the outrigger pads and the MCWP base did not noticeably move. Although the platform moved vertically downward 2.5 inches (0.064 m), the motion (horizontal and vertical sway) quickly subsided and the MCWP returned to its full, stable resting position.

3.2 Fall-arrest Scenario Test Results

For this testing the Fraco ACT8 used a variation of platform loading using concrete weights. According to the ACT8 user’s manual (Fraco, 2015), for the configuration used with a cantilevered platform measuring 30 feet (9.14 m) in length, a reduced load of 50% must be used on both sides of the drive unit. To achieve the most unstable scenario, the Fraco ACT8 had 60 feet (18.29 m) of platform but loading was only completed on one side of the drive unit. The maximum allowable load was 1,500 pounds (680.39 kg) located 5 feet (1.53 m) from the center of the mast, and 500-pounds (226.8 kg) distributed throughout the rest of the platform length. For all scenarios, the 500-pound (226.8-kg) weight was distributed throughout the rest of the main platform independent of the 1,500-pound (680.39-kg) load and 5 feet (1.53 m) from mast center. The configuration included the ADAM manikin, I-beam Monorail system, instrumentation, and small concrete weights. The platform loading weight distribution with the overloaded weight scenario is shown in Figure 7.

The final six test configurations the MAF recorded and the maximum vertical platform displacements are shown in Table 1.

In Table 1, *Torque* (ft*lbs about mast center) is calculated from the weight about the center of the mast. *Percent (%) of the Max Load* is based on a 100% maximum load with 1,500 pounds (680.39 kg) centered 5 feet (1.53 m) from the mast, and 500 pounds (454 kg) distributed throughout the rest of the platform (centered halfway from the 1,500-pound (680.39-kg) load and the end of the platform furthest from the mast). The *Max Force Recorded* is the vertical force applied to the load cell from the end hook of the energy-absorbing lanyard. The *Maximum Initial Vertical Platform Displacement* is measured by string potentiometers from the moment the platform begins its downward movement (not the rising movement from the weight release of the ADAM manikin) until it begins its upward movement. For every trial, the results were expected since the maximum initial vertical recorded platform displacement was at the platform's end furthest from the center of the mast with platform weights.

Also shown in Table 1, the forces recorded for the final six trials were between 950 and 1,250 pounds (4226 and 5560 N) with a maximum initial vertical platform displacement of 3.3 to 3.8 inches (0.084 to 0.096 m). The other twenty-three trials showed maximum force values and platform displacement values similar to the results in Table 1. It should also be noted the maximum allowable force applied to the harness portion of the personal fall-arrest system was under the 1,800 pound (8000 N) ANSI Z359.1-2007 standard (ANSI/ASSE, 2007) for all trials.

The accelerometers on top of the outrigger arms collected data that showed the accelerometer on the front arm, located furthest from the ADAM manikin, saw the greatest amount of movement and acceleration. There were no noticeable accelerations for any trial during the maximum loaded and unloaded platform conditions. The overloaded platform had accelerations of approximately 1 G (9.8 m/s^2) for both trials. In one trial, the outrigger arm lifted approximately ½ inch off the wooden box and immediately returned to its position. The mast climber remained stable throughout the test.

The most interesting results were ones that created the most unstable platform. The following figures illustrate the greatest platform displacements and accelerations recorded at the furthest end of the platform. Each figure contains the two repeated trials for each condition - shown in red and black respectively. Figures 8, 9, and 10 contain the graphs of the fall-arrest force, platform displacement, acceleration at the end of the platform, and acceleration at the outrigger arm base for the various platform conditions.

Also of note, as shown in the aforementioned figures is that an initial vertical rise was shown in the platform displacement at the release of ADAM as expected. Upon the lanyard deployment, there was an initial downward displacement of the platform approximately 4 inches (0.102 m) for each scenario, followed by a brief rise of the platform of 2 inches (0.051 m). After the deployment, another platform drop of 4 to 6 inches (0.102 to 0.152 m) was observed for each trial.

The first acceleration peak on graphs 8, 9, and 10 correspond to the initial force placed on the lanyard and its full impact force after the energy-absorbing portion had fully deployed. The overloaded platform scenario found both peaks were approximately 2 G (19.6 m/s^2) to 3 G (29.4 m/s^2). The maximum loaded and unloaded platform scenarios found the first peak to be near 1 G (9.8 m/s^2) and the second peak to be approximately 3 G (29.42 m/s^2).

Figures 9 shows the corresponding graphs of the maximum loaded platform condition.

Figures 10 shows the corresponding graphs of the unloaded platform condition.

4.0. Discussion and Conclusion

4.1 Stability of the MCWP

This research project investigated whether a freestanding MCWP under normal work conditions would remain stable should a fall-arrest event occur. The MCWP was erected and tested under both the manufacturer's recommended operating conditions, as well as misuse scenarios that could potentially occur during equipment use. The methods used to evaluate stability of aerial work platforms during fall-arrests followed the ANSI standard for fall protection to determine a baseline testing condition.

To evaluate the stability of the mast climber, vertical platform displacement and acceleration, acceleration at the MCWP base, and the fall-arrest forces were measured. The stability of the mast climber inherently relies on the performance of the mast base as it is the foundation of a freestanding configuration. Therefore, the base of the MCWP was configured to exact manufacturer and industry recommendations for every test scenario.

However, manufacturers recommend that the outrigger pad supports be checked every day before work begins. During the drop arrest trials the mast climber remained stable and little to no movement was visible at the outrigger pads. Manufacturers also indicated that improperly supported, positioned, or worn outrigger pad or base could lead to catastrophic failure. Outrigger supports should always be checked before MCWP use, especially if there is any potential for the pad support to become unstable, such as in the case of inclement weather or extreme movement from the equipment.

The arrest force, platform displacements, and platform accelerations were consistent with the anticipated results from previous aerial work platform fall-arrest research (Harris 2010). During the three tested conditions, the MCWP remained upright and posed limited threat to potentially tip over. The results of this study suggest a personal fall-arrest system can be used in conjunction with freestanding mast climber equipment under the recommended guidelines from the manufacturer and the assumption that the equipment is properly assembled/erected when used.

4.2 Stability of the Working Platform

Another unresolved issue addressed were possible fall hazard risks for other workers on the platform in the event of a fall-arrest from a worker using a harness/lanyard system. During the evaluation of the overall stability, the platform movement was thoroughly considered and evaluated during the ADAM manikin drop tests because it closely simulated a real work case scenario. The six trials concentrated on an improper tie-off position (at foot level) with varying platform loadings. In each of the arrest force graphs there were two peaks during each trial. The first peak occurred when the ADAM manikin had fallen and the lanyard/harness began to stop its descent. The rising portions after the first peak was the deployment of the energy-absorbing portion of the lanyard, and the second peak was when the lanyard had fully deployed causing a higher arrest force. The fall-arrest force levels were lower than the standard maximum allowable force transmitted to a worker found in the OSHA fall-arrest standards, even for a misuse scenario (OSHA, 1999). The arrest force graph shapes were found to be independent of the platform loading.

While there is little to no research on vertical platform perturbations, there has been scientific research on platform oscillations and other motion-based movement's effect on human response and performance; such as working on a ship deck at sea or on public transportation while moving (Wertheim, 1998). Lateral sinusoidal oscillations from 0.5–2 hertz and accelerations from 0.1–2.0 m/s^2 (0.33–6.56 ft/s^2) were shown to cause postural instability and the perceived risk of falling (Sari and Griffin, 2014). Repeated exposures to platform motions can also affect the human response—more exposure to the movement the better the adaptation to the movement (Duncan et al., 2014). Platform motions that would occur due to a fall arrest would most likely contrast this, giving a worker little or no time to adapt. The platform movement found in the overloaded and maximum loaded scenarios approached 3 G (29.42 m/s^2) and had a displacement of 4 to 6 inches (0.102 to 0.152 m) occurring over the 0.75-second time interval.

While workers are not required to tie off for general mast climber use, if an open edge is present they must do so under OSHA requirements. In many circumstances the tie off point is at the leading edge of the main working platform deck. If a worker was to fall while standing on the main deck and is tied off at foot level, it would create an approximate 11-foot fall. This study created this scenario for testing, it was considered the misuse scenario. The platform motions caused by the fall-arrest conditions evaluated in this study similar to or worse than those found in the aforementioned research (Wertheim, 1998, Sari and Griffin, 2014, and Duncan et al., 2014).

If a worker were standing on either the upper or lower working deck of the mast climber, it is very likely their postural stability could be compromised during a fall-arrest incident, thus creating a potential fall hazard. If any worker were tied off while working at a stationary height on the mast climber deck, all other workers near an open edge of the platform should also be tied off.

5.0. Impact

The research team will share the study recommendations with the OSHA construction directorate and relevant ANSI standards committees for consideration in updating appropriate regulatory and consensus standards. The study results will also be shared with the Advisory Committee on Construction Safety and Health and the Building & Construction Trades Department, Safety and Health Committee to establish MCWP safety guidelines. As the use of MCWPs continues to increase at construction sites, there will be a commensurate need for evidence and science-based safety guidelines or regulations.

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References

ANSI/ASSE. Safety requirements for personal fall-arrest safety systems, subsystems and components. New York: 2007. ANSI/ASSE Z359.1-2007.

Duncan CA, Langlois RG, Albert WJ, MacKinnon SN. The habituation of human postural responses to platform perturbations. International Journal of industrial Ergonomics. 2014; 44:874–881.

Fraco. Fraco User Manual. 2015. Retrieved from: http://www.fraco.com/en/downloads/user_manuel/ACT-8/98030280-06%20(MU-ACT8-AN-CE%2005-2010).pdf

Harris JR, Powers JR Jr, Pan CS, Boehler B. Fall arrest characteristics of a scissor lift. Journal of Safety Research. 2010; 41:213–220. [PubMed: 20630272]

Kenney, A., Bracken, D. The News and Observer. Raleigh, N.C: Mar. 2015 Raleigh scaffolding collapse kills 3 construction workers. Retrieved from: http://www.newsobserver.com/news/local/counties/wake-county/article16081955.html

Occupational Safety and Health Administration, U.S. Department of Labor. Presentation for the Meeting of the Advisory Committee on Construction Safety and Health; Washington, DC. 2008a. Docket number: OSHA-2008-0013

Occupational Safety and Health Administration (OSHA). Presentation for the Meeting of the Advisory Committee on Construction Safety and Health (ACCSH); Washington, DC. 2008b. Docket number: OSHA-2008-0029

Occupational Safety and Health Administration, U.S. Department of Labor. Presentation for the Meeting of the Advisory Committee on Construction Safety and Health; Washington, DC. 2008c. Docket number: OSHA-2008-0029

Occupational Safety and Health Administration [OSHA]. Safety standards for fall protection in the construction industry. 1999. (Standard 1926 Subpart L). Retrieved March 1, 2014 from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10752

Pan, CS., Chiou, S. Slip and fall: fall protection in construction safety. In: Mital, A.Ayoub, M.Kumar, S., Wang, MJ., editors. Industrial and Occupational Ergonomics: Users Encyclopedia. Cincinnati, OH: International Journal of Industrial Engineers; 1999.

Pan, CS., Chiou, S., Hsiao, H., Keane, P. Ergonomic Hazards and Controls for Elevating Devices in Construction. In: Bhattacharya, A., McGlothlin, JD., editors. Occupational Ergonomics: Theory and Applications. Vol. Chapter 25. 2012a. p. 657-697.

Pan CS, Powers J, Hartsell JJ, Harris J, Wimer B, Dong R, Wu JZ. Assessment of Fall Arrest Systems for Scissor Lift Operators: Computer Modeling and Manikin Drop Testing. Human Factors. 2012b; 54(3):358–372. [PubMed: 22768639]

Sari MH, Griffin JM. Postural stability when walking: Effect of the frequency and magnitude of lateral oscillatory motion. Applied Ergonomics. 2014; 45:293–299. [PubMed: 23684118]

Susi P, Pan CS, et al. 20 mast scaffold workgroup members. Reaching Higher: Recommendations for the Safe Use of Mast Climbing Work Platforms. The Center for Construction Research and Training (CPWR). White Paper. Dec.2010

Wertheim AH. Working in a moving environment. Ergonomics. 1998; 41:1845–1858. [PubMed: 9857842]

Wu J, Powers J, Harris J, Pan CS. Estimation of the Kinetic Energy Dissipation in Fall-Arrest System and Human Body during Fall Impact. Ergonomics. 2011; 54(4):367–379. [PubMed: 21491279]

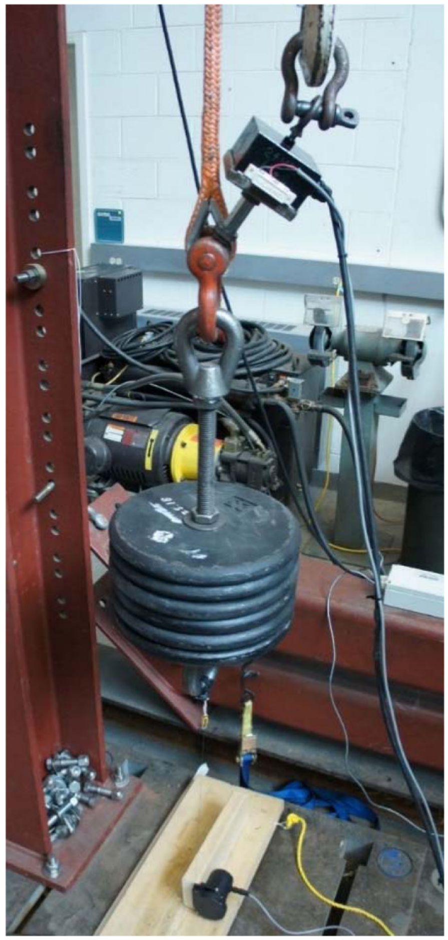

Figure 1.
Nystron rope “break-in” configuration

Figure 2.
Fraco ACT8 Mast Climbing Work Platform

Figure 3.
Dead-weight Drop Test Configuration

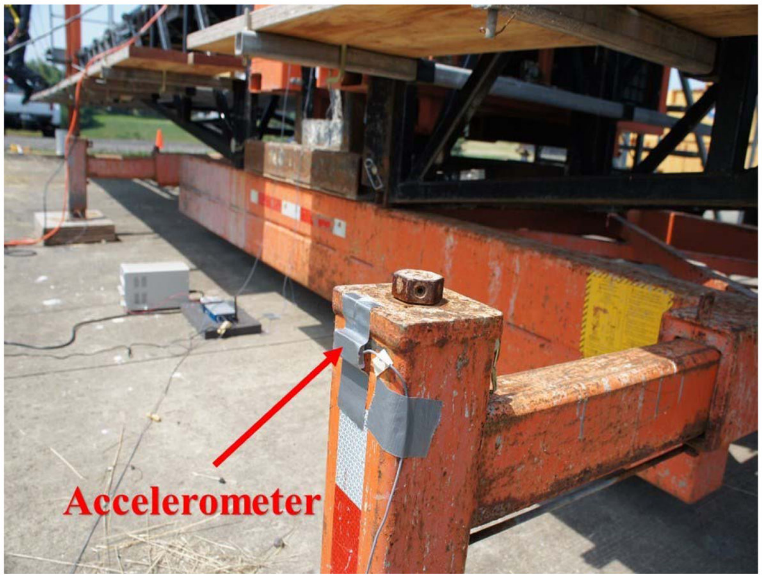

Figure 4.
Accelerometer on the outrigger pad column

Figure 5.
Fall-arrest Scenario Configuration

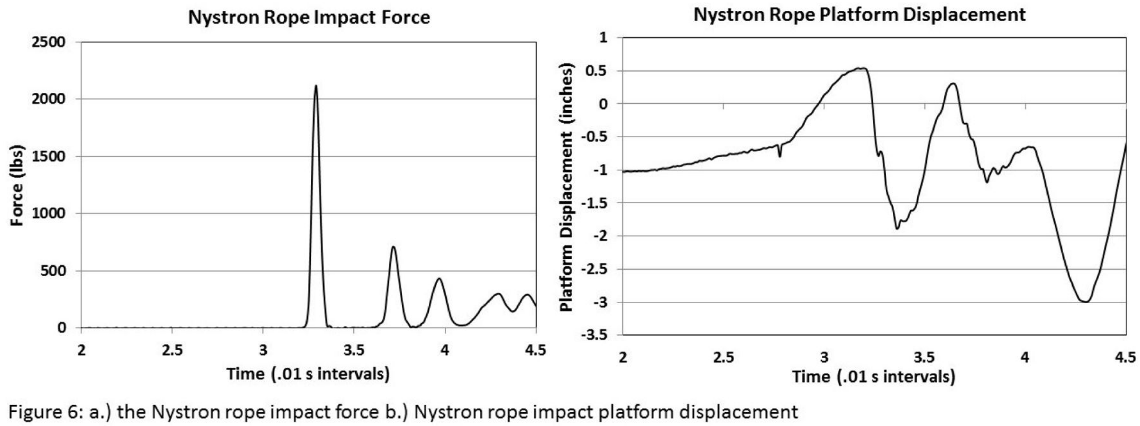

Figure 6.

Nystron Rope Dead-weight Drop Impact Force and Platform Displacement

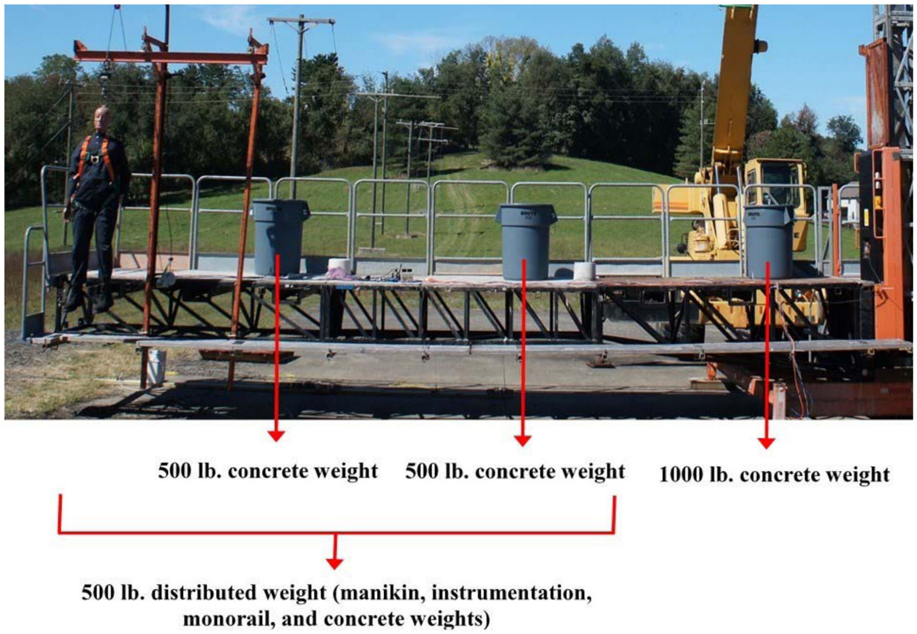

Figure 7.
Platform loading for the “overload” testing scenario

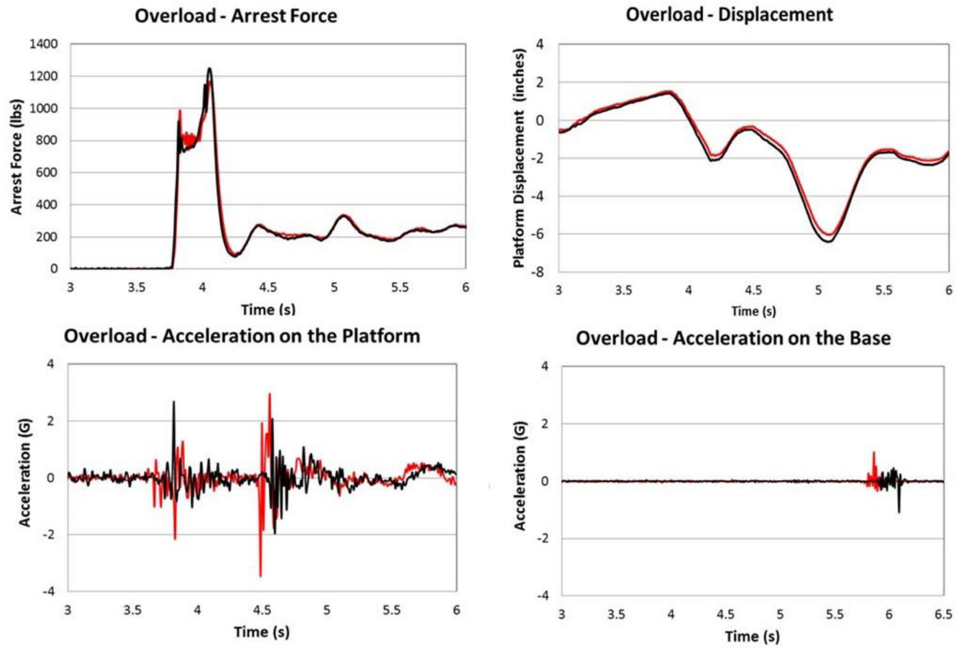

Figure 8.

MCWP Measurements for the Platform Overload Condition

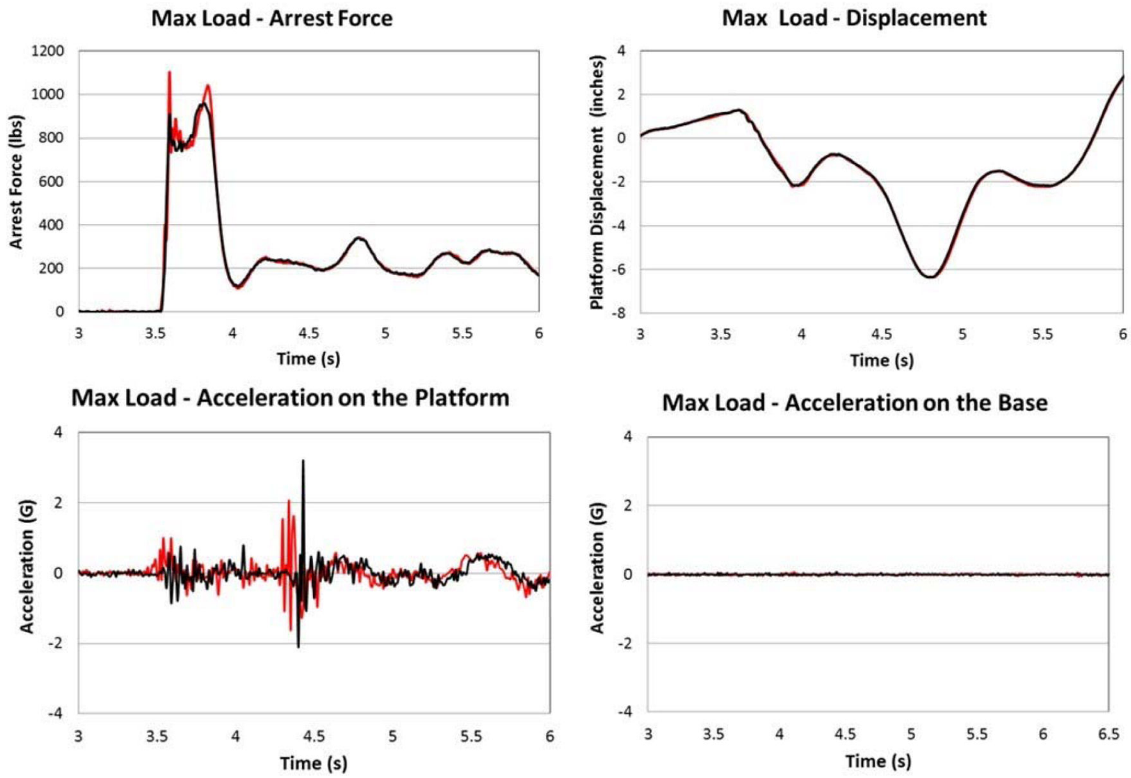

Figure 9.
MCWP Measurements for the Maximum Loaded Condition

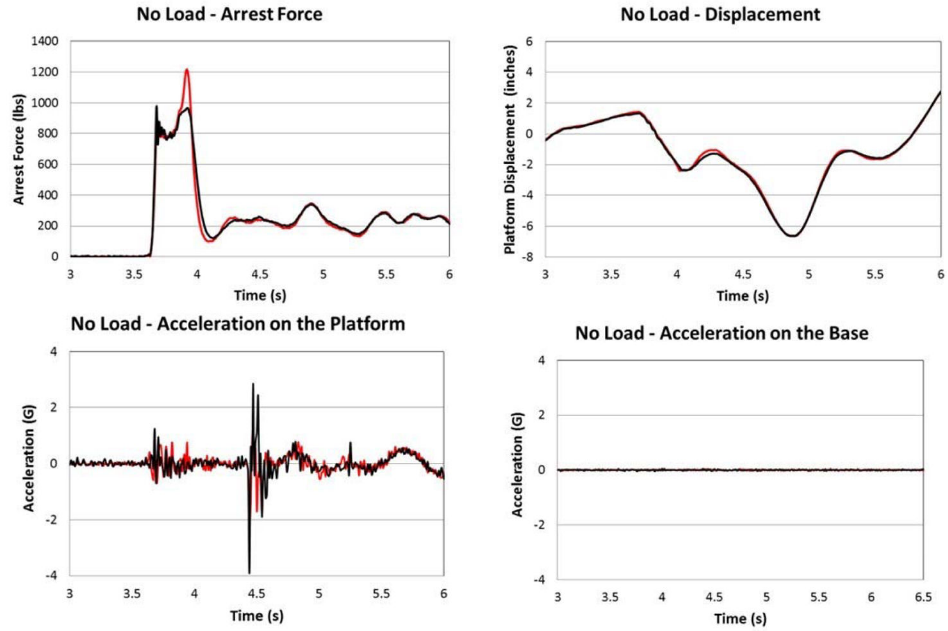

Figure 10.
MCWP Measurements for the Unloaded Platform Condition

Table 1

Test Matrix and Results for Specific Cases

Test Number (29 total)	1000lb (454 kg) W distance from mast	500lb (227 kg) W#1 distance from mast	500lb (227 kg) W#2 distance from mast	500lb (227 kg) W#3 (ADAM, instr., etc.) distance from mast	Torque (ft*lbs. about mast center)	% of Max Load (moment based)	Max Force Recorded (lbs)	Maximum Initial Vertical Platform Displacement (inches)
24	5′	14′6″	25′6″	20′	35000	200%	1247	3.6
25	5′	14′6″	25′6″	20′	35000	200%	1169	3.3
26	5′	5′	NA	20′	17500	100%	959	3.5
27	5′	5′	NA	20′	17500	100%	1103	3.4
28	NA	NA	NA	20′	10000	57%	979	3.7
29	NA	NA	NA	20′	10000	57%	1218	3.8