Fall Prevention and Protection for Scissor Lifts

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The goal of this multidisciplinary study was to analyze fall prevention and protection strategies and to validate intervention approaches for the workers at risk of fall injury from scissor lifts while performing work at elevation. There were two study components: (1) computer modeling and (2) drop tests. A multibody dynamic model of the scissor lift was developed using ADAMSTM. A lift operator model was incorporated into the scissor lift model using LifeMOD Biomechanics Human Modeler. Drop tests were conducted to evaluate lift stability and health impacts on operators during the drop/arrest. An advanced dynamic anthropomorphic manikin was used for testing. Using the validated scissor lift model, fall protection harness/lanyard deployment forces were simulated and assessed. The experimental results indicated that the scissor lift maintained structural and dynamic stability for all drop test conditions when fully extended. Regarding the health effects on operators, this study found that maximum arrest forces from four collaborative manufacturers' harnesses/lanyards were all within 1800 lbs for a 6-foot drop, which meets the ANSI Z359.1 standard. Further, lanyard deployment forces measured in the lanyard products from four manufacturers were all similar. Findings suggested that fall arrest systems may be beneficial when using scissor lifts as part of the overall risk mitigation plan for fall injury prevention and protection.

Introduction

The fall hazards associated with work on scissor lifts are well recognized within the scaffolding industry [Burkart et al. 2004]. Surveillance data reveals the increasing risk of severe injury and death associated with the adoption of this equipment in construction, telecommunication, and other industries [Pan et al. 2007]. Pan et al.'s [2007] review of these data indicated that extensibility factors—the extended height of the lift or the vertical position of the worker as a result of extension of the lift—were significant contributing factors for fatal injury. These height factors accounted for 72% of the scissor lift cases in the Bureau of Labor Statistics Census of Fatal Occupational Injuries (CFOI) data; 83% of scissor lift cases investigated by the Occupational Safety and Health Administration and the NIOSH Fatality Assessment and Control Evaluation Program involved falls/collapses/tip overs within the height categories of 10–19 feet and 20–29 feet. According to CFOI data, 72% of scissor lift fatalities occurred in the construction industry; in the OSHA and NIOSH investigation data, 74% of scissor lift fatalities occurred in construction. Based on these data, NIOSH developed an aerial lift project focusing on a laboratory study of a commercially available 19-foot electric scissor lift. Since there is no body of scientific knowledge that establishes the efficacy of personal fall protection systems for use on scissor lifts (OSHA depicts scissor lifts as mobile scaffolds), the utility of fall protection equipment on scissor lifts has not been universally accepted by lift safety experts as an effective safety control practice for reducing fall-risk exposure for operators. Results from Pan et al's study [2007] indicated that, for a significant percentage (82% for OSHA and NIOSH investigation data) of fall-from-elevation incidents, safety controls did not protect workers because existing fall protection systems were not in use at the time of the incident. Only 4 out of 13 scissor lift injury/fatality cases from OSHA/FACE reports showed the use of additional personal fall protection systems. Guardrails on the scissor lift platforms are enough to meet the OSHA mobile scaffold requirement (1926.451(g)(4)) for fall injury prevention for scissor lifts, and additional requirements for using personal fall protection systems currently are undecided by industry and standard committees (ANSI A92.6

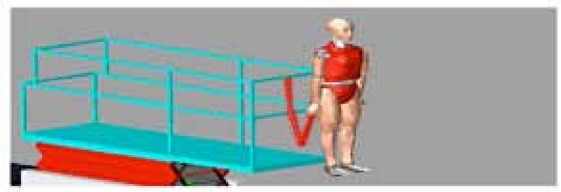
and ANSI A10.29). This represents a serious concern for the lift industry. The objective of this study was to examine the structural and dynamic stability of a scissor lift subjected to fall arrest forces. Second, a dynamic simulation model of the scissor lift was developed to evaluate/predict the effects of scissor lift stability associated with various fall harnesses and lanyards during drop tests.

Methods and Results

A commercially available 19-foot, electric scissor lift (Model SJIIIE 3219, Skyjack Inc., Ontario, Canada) was slightly modified to accommodate the existing laboratory equipment at the NIOSH Morgantown, WV and Pittsburgh, PA facilities. In previous physical experiments, the dynamic effects upon structural flexibility on the static and dynamic stabilities of the lift were analyzed [Ronaghi et al. 2009; Dong et al. 2010].

Computer Modeling: The computer model was generated using a commercial software package, Automated Dynamic Analysis of Mechanical Systems (ADAMSTM 2008r1, MSC Software Corporation, Santa Ana, CA). The model was refined based on experimental data obtained in three standardized ANSI-required dynamic tests—curb impact speed, braking distance and deceleration, and pothole depression. The computer model mass distribution was validated using lift center of gravity measured at four elevated heights [Ronaghi et al. 2009]. The connection stiffness and damping parameters of the model were estimated based on the experimental data obtained individually from a curb impact test, a braking evaluation test, and a depression test of the scissor lift in the NIOSH Pittsburgh Research Laboratory. The model was also validated and refined using the time histories of the lift dynamic responses measured in these physical experiments. The modeling results indicate that decreasing the stiffness of the scissor lift generally reduces both static and dynamic stabilities of the lift. This study showed that lift instability could be achieved by increasing the flexibility of the scissor-lift ground system, which commonly occurs from severe wear and decoupling of structural joints, damage to the joints resulting in decoupling of rigid frame members, and the use of the lift on deformable or uneven surfaces. Simulated operator information was also incorporated into the completed scissor lift model using 2008 LifeMOD Biomechanics Human Modeler (LifeModeler Inc., San Clemente, CA), which is a plug-in to ADAMS. Using this joint human/lift model, simulated fall-protection harness/lanyard deployment forces were assessed (Figure 1).

Figure 1: A refined computer model for simulating a fall protection harness/lanyard application during a drop



test using a manikin

Drop Tests: Tests were conducted under two test conditions—a dead weight drop and a manikin drop. The purpose of the tests was to assess the structural stability of the lift under dynamic loading conditions.

Dead Weight Drop: The basic test conditions consisted of a free-standing and fully elevated scissor lift which was subject to kinetic energy exposure through the release of secured dead weights. The weight was controlled by an electromagnet (capacity 700 lb, Model SE-35352, Magnetic Products Inc., Highland, MI); the release of the weight produced a sudden-load condition, with potential for scissor lift destabilization and tip over. Data on loading conditions was obtained through a load cell (3,000 lb S-type, Interface Inc., Scottsdale, AZ) and logging of data occurred through data acquisition software on a laptop computer. Data acquisition occurred in the LabVIEW software package (National Instruments Corporation, Austin, TX). Previously, test arrest forces were applied to Nystron rope (5/8 inch, Samson Rope Technologies Inc., Ferndale, WA, and Gravitec Systems Inc., Bainbridge Island, WA) and the scissor lift to evaluate structural and dynamic stability. Stability was evaluated for the two orthogonal and major tilt axes in the horizontal plane of the scissor lift. Test conditions were designed to reflect common exposure scenarios in "real world" operation, so test conditions were conducted on sloping ground. A well-accepted fall arrest equation [Sulowski 1981] was used to estimate the pre-drop weight and free-fall height requirements necessary to generate the desired arrest forces for this study component [Harris, et al. in press]. Fall arrest loads of approximately 2,400 lbs—an amount which was chosen as a conservative measure as it exceeded the ANSI Z359.1 requirement (i.e., 1,800 lb)—were applied to various anchorage point locations in the platform. In addition, potential fall scenarios were evaluated by conducting 6-ft and 11-ft drops. Eleven-ft drops were chosen for test conditions due to common misuse scenarios that occur when lift operators position their feet on the mid rails. A 95th percentile male (by height) was assumed as a test subject; the dead weight was positioned at a height equivalent to standing on the mid rail with the fall arrest system anchored to either the mid rail or top rail. It was assumed that lanyard-harness connection of the fall arrest system was at chest (nipple) height, 53.7 inches under the MILSPEC standard [DoD 1989]. Total fall height was 139 inches when anchored to the mid rail and 122 inches when anchored to the top rail. The results indicated that the scissor lift maintained structural and dynamic stability for all drop tests when fully extended and on an incline; energy absorption by the lift structure itself lessened the transmission of energy to the platform [Harris et al., in press].

Manikin Drop

The basic conditions for this test were similar to those in the dead-weight drop tests; a manikin was used instead of dead weights for this component, and anchorage conditions did not consist of multiple locations. A single anchorage (see Figure 1) was used, and fall location occurred only from the front of the platform, instead of various locations. An advanced dynamic anthropomorphic manikin (1998 ADAMTM, Veridian, Dayton, OH) was used as the surrogate. Embedded triaxial accelerometers within the manikin measured acceleration on three axes, and acceleration measures were used as surrogates for force measurements. Test conditions included the energy-absorption effects of four energy-absorbing lanyards (EAL), secured at a common position in the platform, together with their safety harnesses. Fall-arrest forces were logged by a load cell (Model SSM-S, Series 1000, Interface Inc., Scottsdale, AZ). Data was recorded as stated in the preceding section describing dead weight tests. The manikin was dropped three times from each of the two heights, 6 ft and 11 ft. Data analysis is underway; this will involve a systematic approach in which an additive model of the energy dissipated in the EAL and in the human body during the fall impact will be developed. The kinematics of the human body and EAL during the impact was derived using the data of the time histories of the arrest force, which was measured experimentally. Results from the computer simulation model indicate that reducing the stiffness (and stiffness ratio) of the scissor lift significantly reduces both static and dynamic stabilities of the lift. The four preliminary results of the manikin drops are listed below:

a. Lanyard deployment forces among four manufacturers were all similar (~800 lbs).

b. Maximum arrest forces in all but one case were under 1,800 lbs (6-ft and 11-ft drops).

c. Deployment forces were nearly constant for different drop distances (6-ft and 11-ft drops).

d. Repeated test trials for the same harnesses/lanyards produced similar results.

Discussion

Findings indicated that fall arrest systems may be beneficial when used in scissor lifts as part of the overall risk mitigation plan for fall injury prevention and protection. This study also identified that guardrails may serve as anchorage points without increasing the risk of scissor lift tip-over hazards. However, some drops produced deformation of guardrails. In addition, a refined scissor lift computer simulation model of this study may provide an efficient tool to predict and evaluate structural and dynamic stability of the scissor lift. Since all the measures of the maximum arrest forces were less than 1,800 lbs, this study suggested that all four collaborative manufacturers' harnesses/lanyards met the ANSI Z359.1 standard requirement. This study also identified that the arrest force calculated using the kinematic data agree well with those measured directly via a force sensor during the drop tests, and the accelerations calculated using the force data agree well with those measured directly from the ADAM manikin. These analyses indicated that the kinematics of the falling surrogate can be determined using measured arrest force, and vice versa. The arrest force in the EAL can also be determined using the accelerations measured at the surrogate. An ongoing study component will explore this important finding and further examine its implications to evaluate performance and select appropriate fall protection systems for this workforce on the basis of the impact energy absorption.

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