2019

Analysis of Construction Fall Protection Guardrails in a Population with Changing Anthropometrics

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ANALYSIS OF CONSTRUCTION FALL PROTECTION GUARDRAILS IN A POPULATION WITH CHANGING ANTHROPOMETRICS

BY

Connor S. Klinzing

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

Master of Science in Technology

IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY

CHARLESTON, ILLINOIS

2019

THESIS COMMITTEE CHAIR	30 APR 2019 DATE	DEPARTMENT/SCHOOL CHAIR	4/30/19 DATE
THESIS COMMITTEE MEMBER	4/30/19 DATE	THESIS COMMITTEE MEMBER	DATE
THESIS COMMITTEE MEMBER	APRIL 30, 2019 DATE	THESIS COMMITTEE MEMBER	DATE

Abstract

The construction trade has commonly been cited as one of the most dangerous industries within the United States, with falls from elevation being the most predominate cause for injuries and deaths. The OSHA standards related guardrails has not changed since its implementation in 1970. These standards originally derive from the 1950s, which expect a 160-pound person with 40 pounds of equipment, tools, etc. However, the anthropometrics of the common working age citizen has dramatically changed in respects to their weight. This study examines the relationship of the guardrail system to the changing anthropometrics to determine if a reform is necessary for the [1926.502] Guardrail System as a form of fall protection is needed.

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Introduction

Many Americans make their living working in hazardous conditions on a daily basis. According to the Bureau of Labor Statistics, the primary cause of work-related fatalities in the construction industry are when workers fall to a lower level [1]. While working on elevated surfaces can be an extremely dangerous task, many different methods can be taken to eliminate the risk of injury. According to the Occupational Safety and Health Administration (OSHA) the construction industry classifies a fall as a distance of six (6) feet or greater to a lower level requires fall protection [2]. The best method to prevent a fall is to stop the individual before they are exposed to the hazard. OSHA recognizes: guardrail systems, safety nets systems, personal fall arrest systems, positioning device systems, warning line systems, controlled access zones, safety monitoring systems, covers, and protection from falling objects as forms of fall protection [3]. Certain situations call for different methods to be utilized depending on the task of the employee and the nature of the work. Many tasks require the need for complete mobility, eliminating many of the possible fall protection methods due to the additional hazards they impose. For instance, tripping hazards that are caused by personal fall arrest monitoring systems, positioning device systems, and safety monitoring systems propose more of a threat than aid in safety [4].

The National Health Examination and National Health (NHANES) & Nutrition Examination Surveys (NHES) were conducted in 1960 (NHES) and 2002 (NHANES) to find out what the mean weights and BMIs are for the average American adult. In just forty-two years between the surveys, the average body weight of adults has increased more than 24 pounds [5]. The OSHA standard for guardrails 1926 Subpart M as a form of fall protection became effective as a law in 1971 and has not been revised since its implementation. This standard was adopted from broader industry standards in the 1950s [6]. Since then, this standard has not evolved in any way to accommodate the changing anthropometrics of the common adult and more specifically to the construction workforce in the United States. The purpose of this research is to see if the OSHA standard [1926.501] Duty to have fall protection, is still adequate for the working and general public. This standard was adopted from the Williams-Steiger Occupational Safety and Health Act of 1970 (84 Stat. 1590 et seq., 29 U.S.C. 651 et seq.) [7]. Even if the standard is dated, the General Duty Clause of OSHA is to "furnish to each of his employee's employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees" [8].

In this research, the effectiveness of wooden guardrail construction methods, such as those used in residential construction, as a sufficient form of fall protection was evaluated in regards to anthropometric changes within the United States adult population. Three commonly used wooden guardrail systems from residential construction were constructed and tested. These tests allowed us to observe the ultimate breaking strengths through destructive testing to determine if the construction methods are compliant with OSHA standards. These results were analyzed with anthropometric data from the time the standards were created and current data to see what recommendations are needed to ensure the reliability of wooden guardrails as a form of fall protection.

Significance

In the late 1960s there was a tremendous public outcry by large factions of the labor force for the government to establish laws that would ensure safer working conditions. During the decade, work related injuries increased by 20 percent and deaths rose to 14,000 per year [9]. Because of the great public disapproval, the government took action. President Richard M. Nixon's administration created agencies to help regulate the working conditions of the labor force. Some of the agencies that were created, and are still very predominate in the professional world today, were the: Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Review Commission (OSHRC) [9]. Even with these regulations, the work place is still very hazardous. Research has shown that from 2006 – 2010 more than 350 construction workers annually have fatal accidents while working on elevated surfaces each year [1]. This research evaluates the OSHA Subpart M [1926.501] duty to have fall protection standard as it compares to a changing and growing labor force.

Research Questions

This research was driven by and intends to answer the following questions:

- Are common designs of guardrails strong enough as a form of fall protection that are compliant with current standards?
- Is there a significant difference in the strength of commonly used wooden guardrails in residential construction?
- Do commonly used wooden guardrails in residential construction maintain relevancy with changing anthropometrics?

Problem Statement

The construction industry consistently ranks as one of the most dangerous industries in the United States with the leading cause being falls from elevated surfaces. This study determines if a revision of the [1926.501] standard may be necessary to reduce the number of fatal and non-fatal accidents by examining commonly used wooden guardrails in residential construction.

Purpose

There are inadequate testing methods that compliance officers can use during their validation of temporary wooden guardrails. The current standard calls for guardrails to meet or exceed a force of 200 pounds in an outward or downward direction [10]. Compliance officers have to rely on what they perceive (rather than objectively test) is a substantial guardrail in order for them to approve the use of that particular guardrail. The process of checking the reliability of guardrails is left to the discretion of the compliance officer. Changing conditions from jobsite to jobsite makes the validation process even more difficult for both compliance officers and contractors. A series of tests were performed to ensure that construction methods can be standardized. The standardization of construction methods will warrant that proper specifications set forth by OSHA are being fulfilled. This study will provide information for compliance officers and contractors to be able to make more informed decisions on guardrail construction and assessment.

Limitations

In this study the limitations are as follows:

- Every piece of wood is different from another. In application to industry, there may be defective boards that are commonly used.
- Anthropometric data is given in means and standard deviations and it cannot account for situational extreme data points.
- The speed of the test is six (6) inches per second due to single speed of the Undergraduate Research Laboratory Test Bed.
- Assumed that the anthropometric data collection from 1960s was completed the same manner as the 2014 data collection.

Delimitations

In this study the delimitations are as follows:

- Only tested a limited number of samples of each design due to budgetary constraints.
- Only tested wooden guardrails from Douglas Fir (*Pseudotuga menziseii*) due to budget and supply of materials.
- Only conducted three test per guardrail design based off the allotted budget.
- Only tested a single post in the guardrail system due to the space limitations.
- Only looking at population within a few standard deviations from averages.

Literature Review

OSHA

History

America's first safety acts were implemented almost one hundred years after gaining its independence and were designed to assist with the protection and health of the working class. In 1877, Massachusetts passed the first safety and health legislation, which required the use of guards on belts, shafts and gears for elevators, in addition to proper fire exits [11]. On March 4, 1913, President William Howard Taft, signed an act that created the Department of Labor (DOL). The intentions of this act were to "foster, promote, and develop the welfare of working people, to improve their working conditions, and to enhance their opportunities for profitable employment" [12]. Currently, the DOL oversees many governmental programs and laws that govern employment in the United States. These affect more than 125 million workers and over 10 million businesses [13]. Some of the department's oversight consists of Occupational Safety and Health Administration, Mine Safety and Health Administration, The Fair Labor Standards Act, and other resources [14]. In 1933, Frances Perkins (a witness to the Triangle Shirtwaist Co. factory fire of 1911) was nominated by Franklin D. Roosevelt to become the new Secretary of Labor. Perkins created the Bureau of Labor Standards in 1934, which was the first agency solely to promote the safety and health of the working class [15] [11]. The health of the working class was still very poor in the 1960's. To help further make the labor force a safer environment, additional regulations were needed. In 1970, the Occupational Safety and Health Act (OSH Act) was. The Act became effective as a law by President Nixon in April 28, 1971, which created what is now known as the Occupational Safety and Health Administration (OSHA). This law enables OSHA to create and enforce standards regarding the safety and health of individual's which in turn gives employees the right to a jobsite that is free of all "recognized hazards" [16]. OSHA regulations were based off of the special safety and health laws for maritime, coal mining, and construction industries [16].

Safety in Construction

Background/General

In the late 1960s, a vast national public uproar began regarding the unsafe work conditions. As a result, the United States government was overwhelmingly encouraged to create new agencies that would serve to monitor the safety of the average American worker. Not all were pleased by the government's new laws and regulations that imposed steep fines if employers did not comply. Many people in the labor force believed that the regulations and additional steps would make their jobs more difficult which led to a struggle with compliance [17]. Aligning with the implementation of standards found in the Occupational Safety and Health Act has shown a large decrease in work related deaths from approximately 14,000 in 1970 to 4,400 in 2009, even though the work force more than doubled in size during this period [18]. These strict implementations, while seemingly unpleasant to some, actually cut workplace related deaths by a factor of greater than six. Refer to Figure 1 for a visual reference to see the continuous trends OSHA's

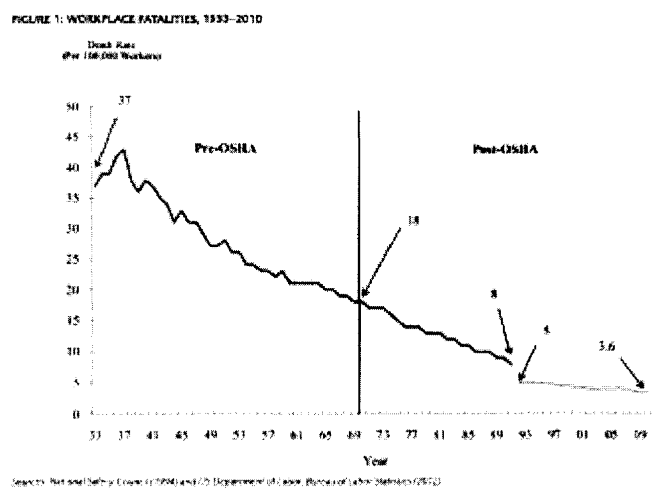

Figure 1: Workplace fatalities

regulations has had on the United States labor force [19]. Even with these trends, some empirical studies suggest that other influences have caused these statistics to gradually decline, leaving OSHA with a modest impact on the safety of the work. Some additional factors include employer incentives (not related to OSHA regulations), "industrial mix of workers", better awareness of safety hazards, and improvements in technology. These factors helped aid in the decrease of injuries amongst workers in the United States [19]. Some argue that to achieve a safer work environment, stricter and more numerous regulations alone are not what the industries need. What is needed is a new perspective when it comes to considering safety culture [20]. "Rather than simply increasing pressure to comply, organizations should invest in their understanding of the gap between procedures and practice, and help develop operators' skill at adapting" [21]. To put it simply, OSHA does not need to worry about the fine print of their tedious regulations, but rather focus their energy towards effectively communicating their imposed standards and training in layman's terms in hopes of simplifying the confusion and reducing the need for interpretation. Based on the work of Sidney Dekker, people tend to act in a safer manner when the hazards are identifiable to them [21].

The relevance of this guardrail regulation can be highlighted by the effectiveness of past OSHA implementations. Statistics have consistently shown that OSHA has played a major role in the health of the general working public [22]. One of the many examples is in the late 1980's when many workers were exposed to grain dust, which caused illnesses and eventually death. OSHA enacted a standard that helped to protect workers from grain dust exposure. Michaels goes on to say that, since the implementation of

[1910.272] injuries have declined by 60 percent and the deaths due to grain dust has dropped 70 percent. Another statistic that shows the importance of the implementation of OSHA is how illnesses and injuries in 1972 were 10.9 incidents per 100 workers. These numbers dropped to less than four per 100 workers in 2009 [18].

Enforcement

The primary means of enforcement is the responsibility of OSHA, who is empowered by the DOL. OSHA has delegated its authority to individuals who inspect working conditions to ensure that they meet the standards set forth via OSHA. These inspectors are experienced safety professionals who are trained to look for on-the-job hazards and ways to prevent injuries from occurring. These inspectors are referred to as compliance officers. Compliance officers have the authority to issue citations, fines, and criminal penalties [23]. If a citation is issued, a penalty must be proposed within six months from the occurrence of the violation. Violations are categorized as willful, serious, other-than-serious, de minimis, failure to abate, and repeated [18]. With OSHA having over eight million worksites [24], and dramatically less resources than when they started in the 1970's, it is not feasible for the

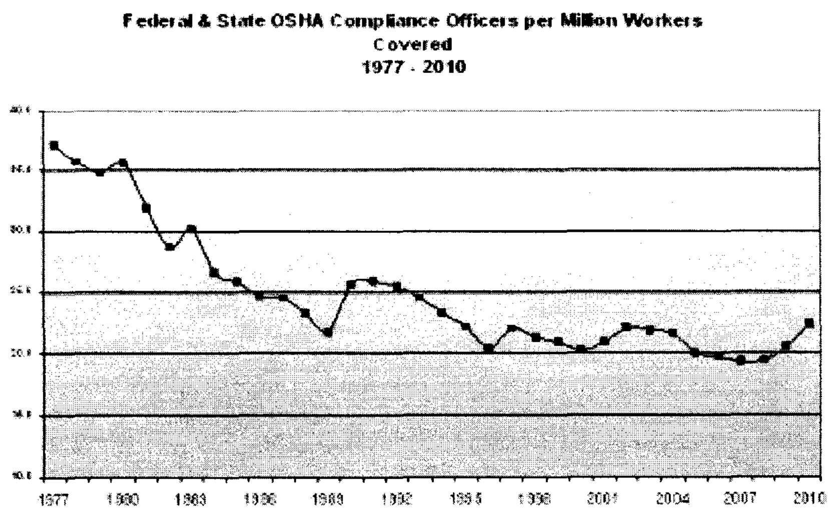

Figure 2: Number of Compliance officers

compliance officers to inspect every worksite. Currently there are about 2,100 compliance officers for more than 130 million workers; that is roughly 59,000 workers for one compliance officer [24]. Refer to Figure 2 for a visual of the declining compliance officers to workers [25]. To help ensure the safety of the workforce is achieved, OSHA has prioritized the importance of inspections. The inspection priorities are as follows:

> **1. Imminent danger situations**—hazards that could cause death or serious physical harm receive top priority. Compliance officers will ask employers to correct these hazards immediately or remove endangered employees.
>
> **2. Severe injuries and illnesses**—employers must report:
>
> • All work-related fatalities within 8 hours.
>
> • All work-related inpatient hospitalizations, amputations, or losses of an eye within 24 hours.
>
> **3. Worker Complaints**—allegations of hazards or violations also receive a high priority. Employees may request anonymity when they file complaints.
>
> **4. Referrals** of hazards from other federal, state or local agencies, individuals, organizations or the media receive consideration for inspection.
>
> **5. Targeted inspections**—inspections aimed at specific high-hazard industries or individual workplaces that have experienced high rates of injuries and illnesses also receive priority.
>
> **6. Follow-up inspections**—checks for abatement of violations cited during previous inspections are also conducted by the agency in certain circumstances.

[18]

When citations are issued, fines can reach up to $132,600 per violation [26]. Refer to Figure 3 for additional penalties per OSHA. Compared to other governmental agencies, this maximum fine for a single violation is negligible. For instance, the top penalty the Environmental Protection Agency (EPA) can enforce may not exceed $295,000 per violation [27]. These violations can prove even more costly if the EPA and the Department of Justice determine a greater citation is needed per the regulations. The difference between these two maximum fines equates out to be greater than $162,400. In addition to fines, OSHA has the authority of authorizing criminal sanctions. Among other circumstances, criminal penalties occur when an employer commits a willful violation, leading to the death of an employee. The result of an employee death has a maximum violation of a misdemeanor with up to six months of jail time [23]. In comparison to the authority given to other governmental agencies, the OSHA penalties imposed are minimal. In 2001, Delaware had an oil refinery tank explode leading to the death of thousands of fish and crabs the resulting in EPA, Clean Water Act, issuing a citation of $10 million. In addition to the wildlife being killed, a worker was killed by acid, which dissolved his body. The penalty imposed by OSHA, for the unsafe working conditions causing the loss of human life, was $175,000 [18].

Type of Violation	Penalty
Serious Other-Than-Serious Posting Requirements	$13,260 per violation
Failure to Abate	$13,260 per day beyond the abatement date
Willful or Repeated	$132,598 per violation

Figure 3: OSHA Penalties [26]

Fall Protection

With falls being the leading cause of worker deaths in the United States, it is imperative that a further investigation takes place to create better practices that can be implemented while working at heights [24]. The construction industry accounted for 20.7% of all work-related fatalities in 2017 in the private sector. Of the construction related deaths in 2017, four categories accounted for 59.8% of all deaths. These categories are known as "Construction's 'Fatal Four'" and they are as such: Falls (39.2%), Struck by Object (8.2%), Electrocutions (7.3%), and Caught-in/between (5.1%) [24].

In the fiscal year of 2018, fall protection was the number one most cited violation by compliance officers [24]. Unfortunately, we cannot change the fact that work needs to be performed at heights but smarter construction practices can be implemented to ensure the safety of these construction workers. A simple way to reduce falls would be to perform the work on ground level then raise in place. Unfortunately, this cannot be done for all jobs and working at heights is mandatory for the completion of jobs. In construction, OSHA defines the need to have fall protection as a walking/working surface with unprotected sides which are greater than six (6) feet or more above the lower level [28].

Types of Fall Protection

In the 26-year history of the Census of Fatal Occupational Injuries Summary, fatal falls reached its highest level in 2017 [29]. The need for better implementation of fall protection is evident. There are many different forms of fall protection in the industry to keep workers from falling to the next level. Not all of these methods are the best practice when it comes to the safety of the employees. Some fall protection methods may cause a greater risk than benefit when it comes to the safety of those who work at heights. For this reason, it is imperative that employers adopt the correct method of fall protection based off the type of work that is being performed. When working near a ledge the use of warning lines would not suffice as a form of fall protection because if properly installed and followed, it would hinder the accessibility to the ledge by six (6) feet [30]. A more appropriate form of fall protection would be the use of guardrail systems, safety nets, personal fall arrest, and positioning devices. Under the standard [1926.501], Duty to have fall protection, OSHA calls out several different systems and practices to help keep employees safe while working at heights. These systems are as follows: Guardrail system, Safety net system, Personal fall arrest system, Positioning device system, Warning line system, Controlled access zones, Safety monitoring system, Covers, Protection from falling objects, and Fall protection plan [31].

Guardrails

In regards to this research, a further examination of guardrails was conducted. According to the 1926.502(b) OSHA standard, all guardrails must comply with the appropriate specifications. These specifications are as follows:

1926.502(b)(1)

> Top edge height of top rails, or equivalent guardrail system members, shall be 42 inches (1.1 m) plus or minus 3 inches (8 cm) above the walking/working level. When conditions warrant, the height of the top edge may exceed the 45-inch height, provided the guardrail system meets all other criteria of this paragraph.

1926.502(b)(2)

Mid-rails, screens, mesh, intermediate vertical members, or equivalent intermediate structural members shall be installed between the top edge of the guardrail system and the walking/working surface when there is no wall or parapet wall at least 21 inches (53 cm) high.

1926.502(b)(2)(i)

Mid-rails, when used, shall be installed at a height midway between the top edge of the guardrail system and the walking/working level.

1926.502(b)(3)

Guardrail systems shall be capable of withstanding, without failure, a force of at least 200 pounds (890 N) applied within 2 inches (5.1 cm) of the top edge, in any outward or downward direction, at any point along the top edge.

1926.502(b)(4)

When the 200 pound (890 N) test load specified in paragraph (b)(3) of this section is applied in a downward direction, the top edge of the guardrail shall not deflect to a height less than 39 inches (1.0 m) above the walking/working level. Guardrail system components selected and constructed in accordance with the Appendix B to subpart M of this part will be deemed to meet this requirement.

Related Standards

OSHA is such a large governing body that they divided their efforts into four categories depending on the type of work that is being performed. There currently is the agriculture (29 Code of Federal Regulation (CFR) Part 1928), construction (Part 1926), general industry (Part 1910) and maritime (Parts 1915, 1917, and 1918). Additionally, the OSH Act constructed the General Duty Clause, which states that all employers are to provide every employee with a work environment free from recognized hazards [32]. The significance of the General Duty Clause is to encompass fully the safety of the employees. This helps to prevent employers from avoiding penalties by finding loopholes in the standards set forth by OSHA. The general industry encompasses any type of employment that is in the United States with the other three having more specialized regulations based on their type of work. However, the general industry and construction standards are not interchangeable [33]. In regards to the general industry and construction regulations, there is minimal variance amongst the two in respects to fall protection. In the standards of general industry, employers must protect employees when working on a walking/working surface that is greater than four (4) feet [34]. Construction requires the use of fall protection at heights greater than six (6) feet [28]. Other than this minor difference of two feet, the two standards are the same.

In addition to OSHA, there are additional resources to help employers keep their jobsites free of potential dangers. American National Standards Institute (ANSI) is a voluntary non-profit organization that helps to develop guidelines and procedures founded from national consensus process [35]. This resource however, does not adequately describe the specifics of how to test a temporary wooden guardrail acting as a form of fall protection.

National & Regional Programs with in OSHA

In order for the safety of the working public OSHA has created programs that analyze inspection data, injuries and illness data, NISOH reports, peer-reviewed literature, and analysis of inspection findings to locate potential hazards that may not be properly addressed in the current OSHA standards [36]. These programs are on a national, regional, and local level. Currently on the national level, there is no additional emphasis on any falling hazards. This is concerning considering that OSHA has fall protection in construction as the number one most cited standard as of 2018 [37]. This commonly cited violation accounted for the death of 381 construction workers in the calendar in 2017 alone [24]. However, there currently is not a national emphasis on the leading cause of death in the workplace which is falls from elevations. A further emphasis will lead to the evaluation of working at heights to create better fall protection requirements and building practices [36].

Types of Guardrails

OSHA standards can be very vague leaving it open to the interpretation of the reader. This makes it complicated to know exactly how to build guardrails that are able to withstand a force of 200 pounds. Since the 1926.502 standard has been left to the interpretation of the reader, many different construction methods have been erected. To help with the ambiguity of the standards, OSHA has developed letters of interpretation to help the reader put the standards in more understandable terms. In this research, three commonly used guardrail systems have been tested to see if they are currently meeting the OSHA standards.

Anthropometrics

Human bodies are varied in shape and size. To understand better this research, we examined many different measurements to see how the dimensions have changed over time among the labor force. The various types of measurements including body weight, height, abdominal circumference, hand length, hand thickness, and ear height to just name a few is called anthropometry [38]. The term anthropometric is broken down into two parts; 'anthropo' derived from the Greeks meaning 'human' and 'metric' derived from the French word mètre refers to 'measurement'. The statistical information derived from these studies have an effect on our daily lives. These studies help to form building code standards, help health care professionals evaluate the overall health of an individual, spur the creation of workstations as well as anthropometric data and even helps to aid professional athletes [39].

Anthropometrics can be further broken down into other demographic categories such as age, race, and geographical location. American lifestyle is commonly known to be extremely fast paced and busy, forcing many individuals to make sacrifices to cope with their way of life. Some of these sacrifices are coming at the cost of their health. For this reason, along with others, the fast-food industry is now a booming business. It is no wonder why America is the founder of the fast food industry with the founding of White Castle in 1921. Shortly after the foundation of White Castle, the fast food industry became even more convenient to the American people with the implementation of the assembly line system at McDonalds [40]. For many, the always on the go lifestyle is not conducive for healthy meal choices. Instead, many opt to choose the convenience of massed produced food. Moreover, GMOs influence our day-to-day lives in ways that we seldom realize. With our food sources being packed with more nutrients and being resistant to the natural wear and tear of the elements, we are seeing a more well fed and constantly growing society in not only population figures but overall body composition as well. These choices are having an impact on their anthropometric data, which is having a direct correlation from anthropometric data from recent years.

History

It is still unclear as to when the first human ancestor appeared on this earth as well as what exact ancestor we derive from. Many scientists believe it was between five million to seven million years ago in what is now known as Africa [41] [42]. Since then, humans (*Homo sapiens*) have evolved to fit better their surroundings and diets. In the start of humanity, their survival was based on their immediate surroundings, hunting and gathering of food. As the brain developed, humans began to create more technologies to make survival easier [42]. Megginson once said, "it is not the most intellectual of the species that survives; but the species that survives is the one that is able best to adapt and adjust to the changing environment in which it finds itself." [43]. This quote can outline the importance of updating common workplace safety regulations in order to adapt to the needs of larger individuals that inhabit our society today. Although the guardrail specifications of the 1970s were applicable for their time, it is prevalent that we as a responsible alliance of business professionals are concerned and actively working to update said guardrail regulations in order to secure adequately the safety of individuals that inhabit the common worksite today.

In the past, body configurations and dimensions were presented as means and standard deviations. These means and standard deviations were broadened to encompass the majority of people in the United States so that standards and regulations could be implemented. The broadened anthropometric data was the baseline that OSHA utilized when constructing their regulations [44]. These methods for accruing body configurations were used for decades but recently the implementation of three-dimensional scanning and shape quantification technologies are being utilized. These advancements in technology are allowing for a more encompassing body compositional measurement [45]. The new methods of collecting anthropometric data have already resulted in the improvement of fall-arrest harness sizing designs [46]. However, with the advancements in techniques, more accurate anthropometric data, and an advancing anthropometric database, there is a gap in its implementation into the labor force [45]. Workers warrant safe working conditions, which is why the gap between the anthropometric data and regulations needs to be reduced which in turn would reduce the injury rate in the labor force.

Implementation of OSHA Anthropometrics versus Current Anthropometrics

New technologies are constantly being constructed each day, making our daily lives easier and safer. With all the adaptation of new technology, some very important standards and regulations are overlooked, which can help many live a much safer life. Many of OSHA standards have been revised to protect better the working class. However, the [1926.502] OSHA standard has not been formally addressed for the past forty-eight years, which has the potential of saving many of lives. The standard has not been revised since OSHA made it a standard in 1971, even though the human body make up has dramatically evolved. When the guardrail as a form of fall protection was implemented back in 1971, OSHA used the industry standards from 1950s, which called for a 160-pound man with 40 pounds allotted for clothing and equipment equaling up to the 200 pound force that OSHA requires *[47] [6]*. With some anthropometric designs meant to be "designed for extremes" *[45]*, such as the guardrail system, the 160-pound man is not compliant with even the 25 percentile anthropometrical data found for the American worker in 2014 *[48]*. Refer to Figure 12: Males weights 1960-1962 and *Figure 14: Male Weights 2011-2014 for reference.*

Methodology

In order to measure wooden guardrails consistently as a form of fall protection on construction sites, tests were conducted to determine the maximum breaking point of three commonly constructed guardrail systems in wood-based residential construction. All tests were constructed and performed in the School of Technology's Undergraduate Research Laboratory at Eastern Illinois University, Charleston, Illinois during the month of February 2019. The ability to test guardrails on construction sites was deemed to have potential safety risk as well as not having a consistent testing environment may hinder the results. The undergraduate research lab had consistent conditions through the weeks of testing.

To ensure that all requirements were met for each test, a walking/working surface was constructed. In order for OSHA to recognize an area as a walking/working surface, it has to be deemed by the employer to have the strength and structural integrity to support employees safely [49]. The walking/working surface paralleled the common construction methods that are used in the home construction industry. A sixteen-foot (16') by two-foot (2') by eight-inch (8") platform was constructed. The significance of these dimensions was to allow for the greatest space for a guardrail to be attached in a continuous direction. The space in the Undergraduate Research Lab hindered the expansion of this walk/working platform. The sixteen-foot-long platform only allowed the construction of three guardrail posts to be constructed and tested at once. These specifications are called out in Subpart M Appendix B, Guardrail Systems Non-Mandatory Guidelines for Complying with 1926.502(b) stating that lumber posts are not to be spaced out more than eight feet apart on-center (OC), accordingly maximum distance of eight feet was tested to find the integrity of commonly constructed guardrails.

Walking/Working Surface

The (8″ × 24″ ×16′) frame was constructed using two 2 × 8 × 8 (actual dimensions 24″ × 7 ¼″ × 92 ¾″) Douglas Fir #2 grade, kiln-dried (KD) lumber, to construct the front and back of the frame. An additional faceplate was added to the front of the frame, which served multiple purposes. The faceplate consisted of a 2″ × 8″ × 4′ followed by a 2″ × 8″ × 8′ with another 2″ × 8″ × 4′ to complete the sixteen-foot length of the frame. The faceplate helped with securing the first two (2) 2″ × 8″ × 8′ together. This allowed for a more cost-effective way of testing the guardrails because only one board had to be replaced after each test. Additionally, it allowed for relocation of a weak point, which was the seam where the two sections of lumber were joined in the initial frame. An additional faceplate was not needed for the back of the structure because the structural integrity was not as critical in the rear of the walking/working surface since no tests were being performed at this location. In order to secure the two (2) 2 × 8 × 8 sections

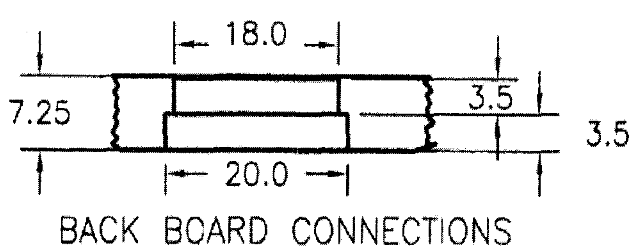

Figure 4: Connection of frame

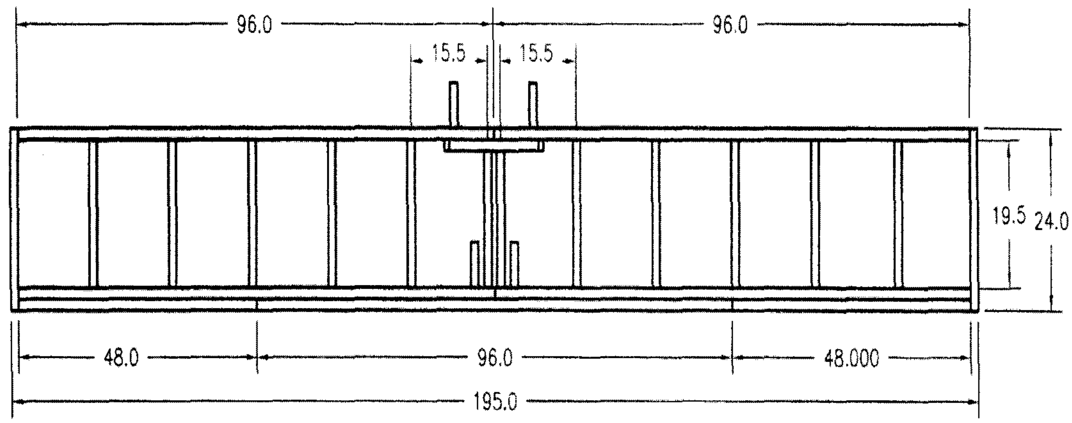

Figure 5: Frame

in the back together two (2) 2 × 4 (actual dimension 1 ½" × 3 ½") were secured to the 2 × 8 × 8 sections. The bottom 2 × 4 was 20-inches long and the top being 18-inches. Refer to Figure 4 for reference. The front and back sections of the walk/working surface were attached by a two (2) 2 × 8 × 2 sections. Refer to Figure 5 reference.

In this study, 2 × 8 floor joists were used because, depending on the functionality of the room and local codes, floor joists can vary in size [50]. The 2 × 8 joist are spaced out sixteen inches OC with ¾-inch Southern Yellow Pine (SYP) AB grade plywood [51]. Ten (10) 19 ½-inch pieces of 2 × 8 were cut to represent floor joists to help with the structural integrity of the walking/working surface. The longer more common 14-foot and 16-foot joists were not utilized due to the restricted space in the Undergraduate Research Laboratory [51]. All joists were spaced 16-inch OC with the exception of the middle joist. These joists were cut at lengths of 18-inches to accommodate for the additional. The double middle joist was spaced one inch apart, which helped to ensure the seam of the 2 × 8 did not have an effect on the test results. It also helped with the strength of the platform since this is where the force was to be applied.

In these tests, joist hangers were not utilized since not all building codes require the use of hangers when framing as well as due to budgetary constraints. Additionally, it was expected that the railing would fail before the butt joints of the joist in the platform. Refer to Table 1 for reference regarding all fasteners that were implemented in this research. The placement and type of fastener varied based upon the application and location of the fastener needs.

For the construction of the framework, screw A was used 2 3/8" from the top and bottom edge. This distance is roughly one third of the 2 × 8 lumber, which allows for the greatest potential holding ability. When fastening the additional faceplate to the front of the frame again, screw A was used but with 2 7/8" spacing. The previous spacing of 2 3/8" spacing was not utilized because an offset was needed to ensure the screws would not make contact upon securing. In the fastening of subfloor, screw B was used on every joist 5 1/2'" apart, with a total of four fastened into each joist.

Screw A:	#8 × 3 ceramic-coated decking screws
Screw B:	#6 × 1-5/8 drywall screws

Table 1: Screw size

A concern that arose during the preliminary construction planning was if the walking/working surface would be substantial enough not to move while the test is in progress. If this were to happen, the peak breaking forces would be inaccurate. To make sure the walking/working surface was stationary in the Undergraduate research, lab four (4) metal brackets were constructed to anchor the walking/working surface in place. A 1/8-inch mild-steel strap that was 2-inches in width was cut into foot-long sections. These sections were then bent six inches down at a 90° angle. Then holes for 3/8-inch bolts were drilled 2-inches and 4-inches from the ends to allow for anchors and bolts that fastened to the walking/working surface. Finally, 3/8-inch wedge anchor bolts were fastened the brackets to the concrete floor. Refer to Figure 6 for reference to the bracket.

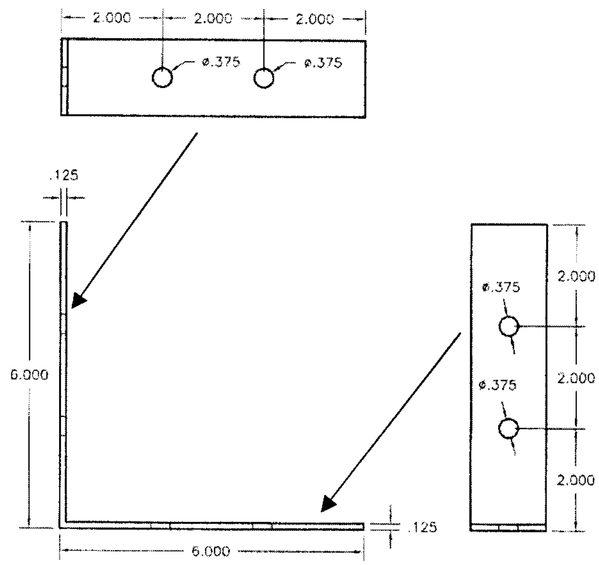

Figure 6: Metal Brackets

Types of Guardrails

According to Cass, the OSHA standards "lack of clear contextual referents, such as previous enactments or judicial understandings" [52]. With the standard being so vague, interpretation is needed, resulting in varying construction methods. Due to the ambiguity of the standard, many different methods to construct a compliant guardrail have occurred based off the standards set forth by OSHA [53]. In this research, three commonly seen methods within the industry were constructed for testing to see if they were compliant to the standards set forth by OSHA. The three methods that were tested in this research are the Overhang, Gusset, and the Safety Boot Guardrail System. Refer to Table 2 for reference of the fastening methods utilized in the construction process of guardrails.

Nail A:	3-1/4" × 0.131" 21° round head plastic strip smooth shank nail
Nail B:	2-3/8" × 0.113" 21° round head ribbed shank nail

Table 2: Nail size

Overhang

When constructing the overhang guardrail as a form of fall protection, a 2 × 4 was cut into a 48-inch section. This is six inches longer than what the standard calls for the maximum height of 42-inches plus or minus three of the top edge [28]. The additional six (6) inches will function as the overlay on the eight-inch tall walking/working surface. Two more sections were cut from the 2 × 4. These were 14-inches by and 17 ½-inches. The bottom of the 17 ½-inch section was fastened 9 ½-inches up from the bottom of the 48-inch section to account for the six inches of overlay with the 3 ½-inch gap for the toe board. The section was fastened using screw B 2 ½-inches from the top and bottom and 1 ¾-inches in from the 17 ½-inch section. A 3 ½ gap was left for the mid-rail which, per OSHA regulations, has to be at least 21-inches high [54]. The base of the mid-rail design sits at exactly 21-inches. The bottom of the 14-inch section was fastened 30 ½-inches from the bottom of the 48-inch guardrail or 3 ½-inches higher than the previously fastened 17 ½-inch section. Screw B was implemented two (2) inches from the top and bottom of the 14-inch section 1 ¾-inches in. This spacing allotted enough room for the 3 ½-inch 2 × 4 top edge of the guardrail to rest at 42-inches [28]. When fastening the guardrail post to the platform, a guide was created to make sure consistent nail placement was achieved. This ensures that the fulcrum of the test does not vary from guardrail to guardrail. Nail A was used when fastening the overlap to the walking/working surface. Refer to Figure 8 and Figure 7 for reference.

To construct the top rail, mid-rail, and toes boards 2 × 4 × 8 were placed on center of the middle post in the allotted 3 ½-inch gaps. A single nail: nail B fastened the

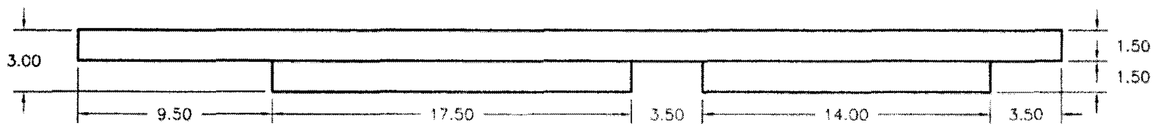

Figure 8: Overhang dimensions

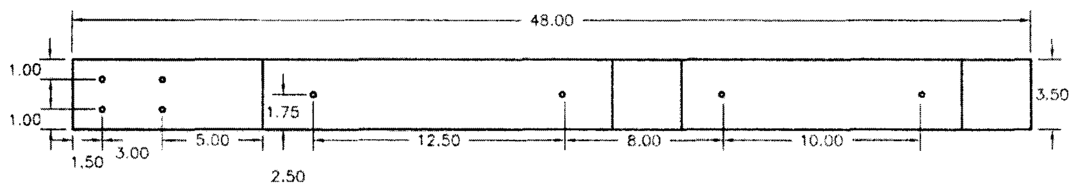

Figure 7: Overhang dimensions

rail to the center of the post. After each test, all posts were reconstructed in the same manner and positioned an inch to the right or left from the center to ensure that the same holes were not being inadvertently used. After all tests were completed, the front faceplates were removed and replaced to ensure these did not hinder the next set of tests.

Gusset

When constructing the gusset method of guardrails, a very similar approach was taken as the overhang. All steps followed the exact same procedure with the addition of the gusset. In order to construct the gusset, the ¾-inch yellow pine AB grade plywood was ripped into 12 × 12 inch squares. The square was cut directly in half to form a right isosceles triangle; the dimensions of this triangle were 12″ × 12″ × 17″. On the side of the right corner (90° angle), a rectangle was cut out with the dimensions being 3 ½-inches × 3-inches. The rectangle cut out allows space for the toe board, as well as the additional 17 ½-inch brace, which supports the mid-rail. For the gusset to properly be fastened to the walking/working surface, a cleat was needed. An 8 ¾-inch 2 × 4 acted as a cleat that was offset from the front ledge of the walking working surface by 1 ½-inch which accounted for the toe board. The cleat was fastened down by screw A that was two inches from the top and bottom by 1

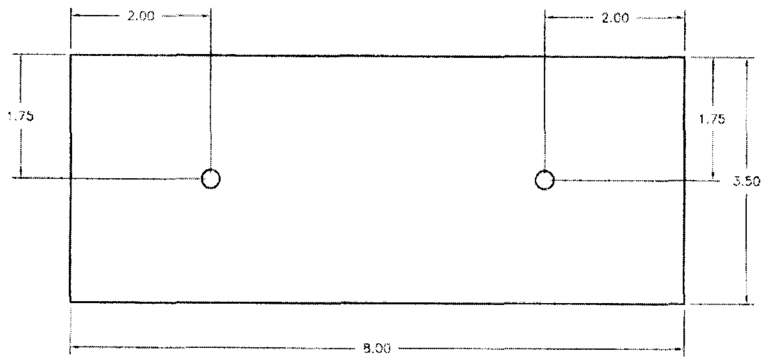

Figure 9: Cleat

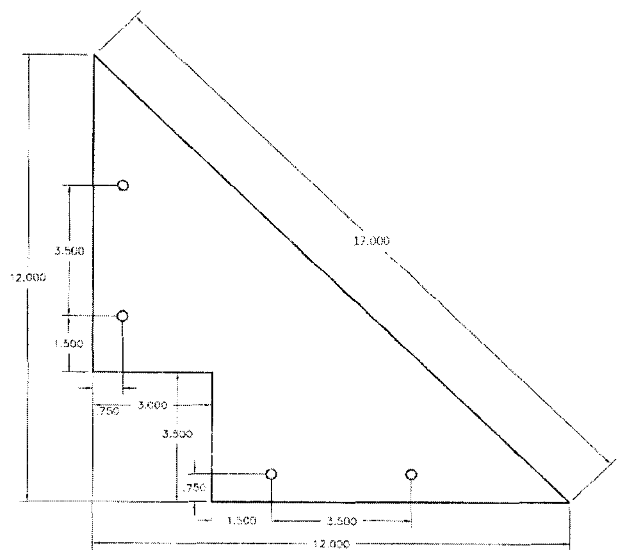

Figure 10: Gusset

¾-inches in. Refer to Figure 10 for reference. Four (4) nail B's were used to fasten the gusset to the guardrail post and the cleat. Refer to Figure 9 for reference.

Safety Boot Guardrail System

Before using the Safety Boot Guardrail System, the previous subfloor used for the testing of gusset guardrails was replaced to ensure that the pullout holes created from the cleats did not have an effect on the test results. Since no further testing requires the direct use of the faceplates, it was not crucial to replace these. The small holes created from nail A were only superficial and do not affect the integrity of the overall walking/working surface.

The safety boot was set back from the front of the walking/working surface 4 inches to accommodate for the double faceplates. These faceplates, which are fastened together, have a depth of three inches. The boot had predrilled holes intended for 3/8-inch lag bolts; these predrilled holes are set back one inch from the edge of the boot. With these factors taken into account, the four inches of set back from the front of the frame will be necessary to ensure that the lag bolts are not fastened to any other members of the walking/working surface and only to the intended ¾-inch AB grade Yellow Pine Plywood. Per manufacturer specifications, a systematic process needs be utilized to ensure the installation is done properly. Refer to Appendix A: Safety Boot Instructions, for the contents of the manufacturer instructions. In summary, each safety boot required, four (4) Hex-Head Lag Screws, 3/8 × 3-inch, five (5) 3/8 × 1 ½-inch Fender Washers, and one (1) Hex-Head Lag Screw 3/8 × 2-inch. Two (2) sections of 2 × 4 were cut into 42-inch segments and were fastened together by nail B four (4) inches from the top and bottom and ¾-inch in. The 2 × 4 was secured to the safety boot by using a Hex-Head Lag Screw 3/8 × 2-inch and the fender washer. Additionally, 3/16-inch pilot holes were drilled in the subfloor to align with the holes in the existing boots. Pilot holes were utilized to help keep the subfloor from splitting. Then the four (4) 3/8 × 3-inch lag screws and four (4) fender washers securely fastened the safety boots to the subfloor. From the walking working surface 21-inches was measured on each post to indicate where the bottom of the mid-rail would be fastened. The top of the top rail aligned with the top of the 42-inch post and was fastened with the toe boards. The same series of events, as used in the other two construction methods, was used when the other two construction methods were implemented for the top rail and mid-rail with the toe boards being securely fasted into the allotted space on the safety boot.

Testing

To test the structural integrity, a semi-dynamic test was performed on each guardrail. In the Undergraduate Research Laboratory, the Undergraduate Research Laboratory Test Bed (URLTB) was oriented to face perpendicular 61-inches away from the front of the walking/working structure. This would simulate a direct perpendicular impact that may occur if a worker made contact with the guardrail system. The OSHA standard calls out for a force of at least 200 pounds in an outward or downward direction within the top two (2) inches of the top rail [10]. For this test, a directly outward force was desired. The top rail height for all test was 56-inches above the floor. This comes from the walking/working surface height of eight (8) inches upon which the 42-inch guardrail would rest upon. The hydraulic ram, which generates the pulling force needed for the test, is at 36-inches. To ensure we had the force perpendicular to the guardrail system, a series of pulleys were implemented to reach the height of 56-inches. A series of pulleys were implemented between the ram and guardrail, in order to obtain a direct pull at the guardrail height of 56 inches. From the horizontal pulling a load cell

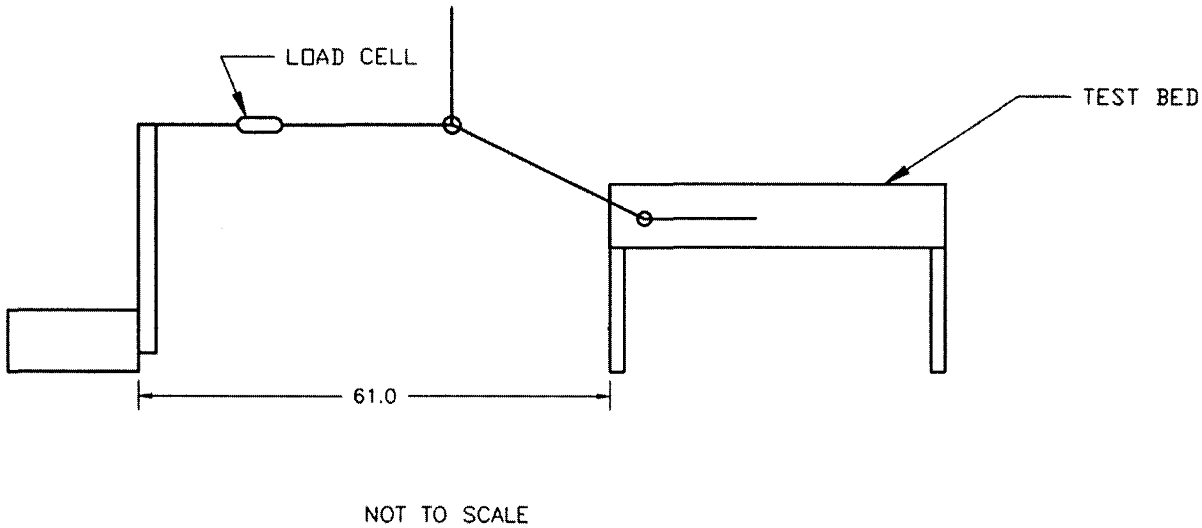

Figure 11: Testing set up

was used to find the peak force when the guardrail failed at total destruction. Refer to Figure 11 for a visual of the testing set up. The results were implemented into Microsoft Excel for a pairwise analysis with a T-test.

Results & Discussion

Three (3) tests were conducted for each type of commonly used wooden guardrail, with the means below each type of guardrail. The raw data of the destructive test are in Table 3:. To be noted, the means for the Gusset and Safety Boot are considerably higher than that of the overhang.

	Overhang (lb)	Gusset (lb)	Safety Boot (lb)
	142	297	291
	127	288	309
	149	274	275
Mean	139.33	286.33	291.67

Table 3: Individual Failure Strength Results for Three Guardrail Types

Using the Microsoft Excel data analysis tool pack, an F-Test Two-Sample for Variance was conducted for each pair of guardrails compared. The following hypotheses were tested using this F-Test:

$$H_o: s_1^2 = s_2^2$$

$$H_a: s_1^2 \neq s_2^2$$

An F-critical value of 0.05 was used to determine assumptions on equal variances. Any determined F-value greater than 0.05 would lead to the assumption that the variances were unequal. Refer to: Table 9: F-Test Overhang vs. Gusset, Table 10: F-Test Overhang vs. Safety Boot and Table 11: F-Test Gusset vs. Safety Boot. Table 4: F-Test for variance summarizes the results of the paired F-test for variance.

Test	F	F-Critical	Results
Overhang vs. Gusset	0.94	0.05	Reject null
Overhang vs. Safety Boot	0.43	0.05	Reject null
Gusset vs. Safety Boot	0.46	0.05	Reject null

Table 4: F-Test for variance

Pairwise t-Tests following the F-test for variance were based on the following hypotheses.

$$H_o: \mu_1 = \mu_2$$

$$H_a: \mu_1 \neq \mu_2$$

It was determined that if p-value was greater than 0.05, failed to reject the H_o, if p-value was less than 0.05, would reject H_o.

There appears to be a statistically significant difference between the overhang and the other two construction methods of guardrails. However, there is not a statistically significant difference between the gusset and the safety boot.

Test	P-Value (one-trial)	Results
Overhang vs. Gusset	0.00005	Reject
Overhang vs. Safety Boot	0.0005	Reject
Gusset vs. Safety Boot	0.302	Failed to Reject

Table 5: t-Test

Discussion

Over the course of the last 50 years, people in the United States have gotten significantly heavier. Data from the 1960-1962 study shows that the mean weight was 168 pounds. Data from the 2010-2014 study show that the mean weight was 196 pounds. Refer to Table 6: Male weights for reference. In performing a pairwise comparison of these individuals, a statistical significance exist in the difference of these two samples (*p*-value of less than 0.0001). Data on female anthropometrics were not incorporated into the statistical analysis is because as of April 2017 there were nine percent of women in the construction industry [54]. Of the women in the construction industry about 76% of them work in departments such as management and sales [55]. On average, males are larger than females both on a height and weight scale [48] [56]. Since these factors playing a significant role in the statistical analysis of the common construction worker who would perform work at heights, the anthropometric data of women was not incorporated into this study. However, with the mean body weights of the male population having a significant change from when the standard was first implemented to now, the heights of the male population has only increased by one (1) inch [48] [56].

		Percentile		
	Mean	5th	50th	95th
Male weight 1960-1962	168	126	166	217
Male weight 2011-2014	196	137	189	275

Because there are so many circumstances that cannot not all be calculated, it is difficult to determine an exact number where the standard should be. To gain a better understanding of the meaning of this data, a comparison of the about of work (torque) on

Table 6: Male weights

each rail system was compared. With the height of the guardrails (42 inches), table ___ shows the experienced torque on the joints.

Result	Force (N)	Moment (N-m)
Overhang	619.8	661.2
Gusset	1273.7	1358.8
Safety Boot	1297.4	1384.1
Standard	889.6	949.0

Further calculations were conducted based on the work put into a guardrail system as in if a person had their full mass to push on the guardrail. Along with the body weight, it also depends on what speed the individual is traveling when impact is made. Calculations were conducted for speeds ranging from two (2) miles per hour (0.89 m/s) to eight (8) miles per hour (3.58) to determine the amount of work experienced by the rail at the moment of impact ($KE = 0.5\ mv^2$). However, these calculations do not include shock-absorbing capabilities of any rail system; instead, the calculations are to provide perspective for what proportional effect may result from a body. As outlined in the in Table 7: Kinetic Energy and Table 8: Kinetic Energy Chart the greater the speed has a direct correlation to an increase in torque on the guardrail system. As demonstrated in the calculations, speeds of seven (7) and eight (8) miles per hour near and exceed the current standard requirements for the overhang guardrail method.

mph	m/s	1960-Mean	1960 95th	2014-Mean	2014-95th
2	0.89	30.44	39.31	35.48	49.90
3	1.34	68.50	88.45	79.82	112.27
4	1.79	121.77	157.25	141.91	199.60
5	2.23	190.27	245.70	221.73	311.87
6	2.68	273.99	353.81	319.30	449.10
7	3.13	372.93	481.58	434.60	611.27
8	3.58	487.09	629.00	567.64	[redacted]

Table 7: Kinetic Energy

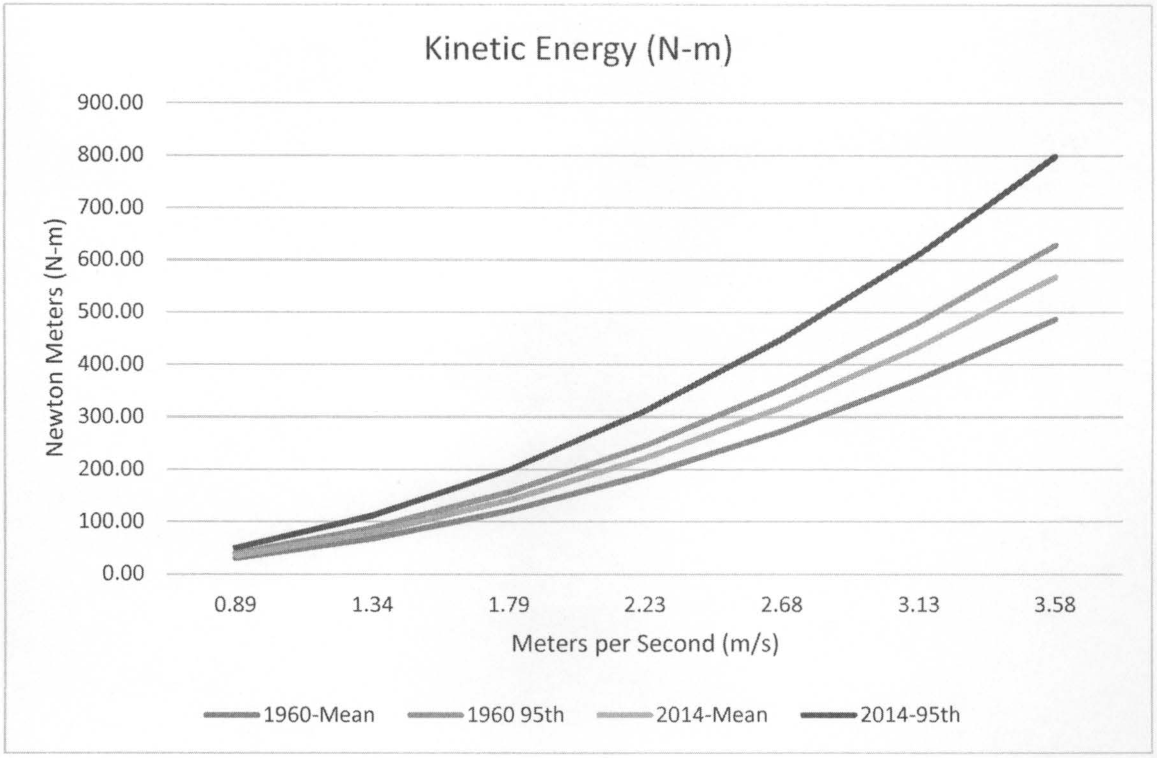

Table 8: Kinetic Energy Chart

As demonstrated in Table 7: Kinetic Energy and Table 8: Kinetic Energy Chart, the moment for the 1960 95th percentile going at eight (8) mph (629.00), and the 2014 95th percentile going seven (7) mph are nearing the peak breaking point for the overhang method 661.2. Moreover, the 2014 95th percentile exceeds the peak breaking point for the overhang method by 137.2 N-m.

It is difficult to determine how many deaths are caused by falling over the guardrail as compared to those who fell through the guardrail, improper construction methods, or the standard is not compliant with the anthropometrics of the worker. The difference between each of these scenarios determines whether the business or the worker is at fault for the accident and how much power OSHA has to enforce its sanctions. Furthermore, it is difficult to ascertain a proper conclusion based on vague statistical data that OSHA provides whether it is a complete lack of guardrails, guardrail failures, and/or lack of other fall protection, for example, improper harness application. Additional analysis of both fatal and non-fatal accidents needs to be examined to determine the direct causation of the leading cause of injuries and deaths, due to falls at heights.

With no statistically significant difference between the gusset and the safety boot other factors such as cost of supplies, time for installation and accessibility may have an effect on the intended uses. The construction industry is very dependent on time. Many of customers want their finished products as soon as possible so contractors like to push along the project in hopes to please the customers and save time. Having said that, the contracts ideally choose methods that are the most cost effective and time effective. In regards to these to the costs, currently Home Depot sells the safety guardrail boot for $25.81. Although the other two guardrail methods tested in this research can be constructed using the scrap that is around the construction site, the time to construct the gusset guardrails is significantly more than purchasing the boots online. In addition to the ability to reuse the boots for multiple different projects whereas the gussets only has a single use.

Within regards to standards and regulations it is difficult to be able to ensure all possible variations are met without knowing the changing conditions from project to project. The employer needs to comply with the 1990 ADA reasonable accommodation

[57]. In the situations where this sort of fall protection may be required, ADA rarely applies. Hsiao's research regarding fall arrest systems accounted for the 95 percentile of the population [58]. Meaning that the upper five (5) percent of Americans were not accounted for when the means were analyzed for finding the proper fall arrest sizing. However, it is also their obligation to protect the employee and grant them to their rights of the general duty clause [8].

More research needs to be conducted in order to find a more proactive method for preventing workplace incidents instead of a reactive approach that is currently accepted. For future research it would be beneficial to determine the deflection of each guardrail instead of the complete breaking point. If the deflection were recorded for each test, a stress-strain curve for each type of rail would be determined. The stress-strain curve would allow us to find the modules of toughness. Knowing this we can visually see the deformation of the guardrails.

In enforcement, OSHA still lacks a proper testing method for guardrails leaving each incident up to interpretation instead of a clearly quantifiable standard. Understanding the relationship between design types and strength could be beneficial for the compliance officers.

Conclusion

Since the 1970s, when guardrail regulations were first imposed by OSHA, the primary cause of workplace related deaths has consistently been form of falling from elevated surfaces. Eliminating the amount of time spent at heights where work could be performed is the best protection. However, work at heights is frequently unavoidable. This study examined a changing society in terms of size and compared it to three style of wood guardrails commonly used in residential construction. Without a doubt, some designs are better than others are, and some are more dangerous now than they were in the 1960s. It is still unclear if there is a need for a change in the OSHA regulations with respect to construction guardrails. Because of the obligation stated in General Duty Clause for employers to provide a place of employment free from recognizable hazards, it is important for contractors to examine all aspects of building guardrails, including their specific employees' body sizes.

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Appendix A: Safety Boot Instructions

Safety Boot® Guardrail System

◆ FASTENER SPECIFICATIONS ◆

WARNING! ⚠ NEVER USE NAILS OR UNSPECIFIED FASTENERS

to Anchor the Safety Boot - Different Types of Subfloor Material Require Different Types of Fasteners In Order to Exceed the 200 lb. OSHA Guardrail Requirement

FASTENER SPECIFICATIONS FOR VARIOUS TYPES OF SUBFLOOR MATERIAL APPLICATIONS

SOLID 2X WOOD APPLICATIONS

for solid wood applications use:

- 4 - Hex-Head Lag Screws, ⅜ X 2 inch and;
- 4 - ⅜ X 1-½ Inch Fender Washers **(Fender Washers supplied with all orders)**
- Anchor directly into solid 2X lumber using the four primary corner holes.

PLYWOOD (LESS THAN 1-⅛ INCH THICK) OR OSB APPLICATIONS

for plywood (less than 1-⅛ inch thick) or OSB applications use:

- 4 - Hex-Head Lag Screws, ⅜ X 3 inch and;
- 4 - ⅜ X 1-½ Inch Fender Washers **(Fender Washers supplied with all orders)**
- Anchor through the plywood or OSB into floor joists or solid 2X lumber blocking on the underside of subfloor using the four primary corner holes.

FOR OTHER SAFETY BOOT APPLICATIONS

The Safety Boot® Guardrail System must always be installed according to the manufacturers installation instructions. Any modifications, additions or alterations to the Safety Boot Guardrail System installation, as stated in these instructions is not recommended without the close supervision of a Certified Safety Professional or Safety Engineer. Always verify through a Certified Safety Professional or Safety Engineer that your completed system will support the required load as needed for your specific applications.

STURD-I-FLOOR® (1-⅛ INCH THICK) PLYWOOD

for Sturd-I-Floor® (1-⅛ inch thick) plywood applications use:

- 5 - Hex-Head Lag Screws, ⅜ X 2 inch and;
- 5 - ⅜ X 1-½ Inch Fender Washers **(Fender Washers supplied with all orders)**
- Anchor directly into Sturd-I-Floor® (1-⅛ inch thick) plywood using the four primary corner holes and by adding a 5th screw on the inside of the guardrail or stair rail system in the secondary hole provided.

CONCRETE APPLICATIONS

for concrete applications use:

- 4 - Common Masonry Fasteners or Similar Concrete Anchors and;
- 4 - ⅜ X 1-½ Inch Fender Washers **(Fender Washers supplied with all orders)**
- Anchor using the four primary corner holes.

ADDITIONAL CONCRETE INFORMATION

Due to the variances in concrete mixtures and applications (such as, concrete mixture type, psi strength, slab thickness, cure time, etc.), concrete fasteners used to secure the Safety Boot MUST be evaluated on a case by case basis by a qualified competent person. They should verify that the selected fastener specifications for average ultimate pullout and shear values are in compliance with the OSHA required strength standards.* Most concrete fasteners are packaged to include a product specification chart that denotes the average ultimate pullout and shear values in concrete and/or hollow block applications.

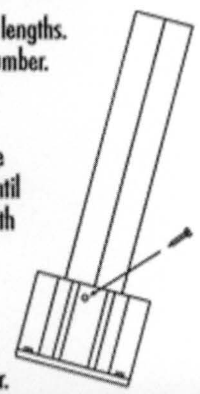
* OSHA STANDARD 1926.502(b)(3):

Guardrail systems shall be capable of withstanding, without failure, a force of at least 200 pounds (890 N) applied within 2 inches (5.1 cm) of the top edge, in any outward or downward direction, at any point along the top edge.

Use the Supplied Drill Adapter with a Power Drill and Socket for *Fast* and Easy Installation

◆ STEP ONE ◆
Assemble Posts

Assemble Guardrails Using (Stress Grade) Construction Grade Lumber



- Cut 2X4 lumber into two 42 inch lengths. DO NOT use wet or oversized lumber.
- Fasten the lengths together with screws or nails to form a post.
- Place one end of the post into the top of the Safety Boot and tap until the bottom of the post is flush with the bottom of the Safety Boot.
- Be sure and anchor the Safety Boot to the post using one Hex-Head Lag Screw, ⅜ X 2 inch with provided washer.

◆ STEP TWO ◆
Placement of Posts

Placement of Posts Should be Along Unprotected Sides or Edges

- Place Safety Boot Posts in line along all edges of unprotected walking/working surfaces of stairways, balconies, landings, roofs, on parapets, elevator shafts, bridges, etc.
- Space between the Posts MUST NOT exceed Eight (8) feet according to OSHA guidelines.
- Place Safety Boot Posts a maximum of Eighteen (18) inches on center away from all permanent wall structures. (Always leave ample room for drywall installation, if required).

NOTE

Maximum Distance of 8 Feet Between the Posts

◆ STEP THREE ◆
Anchor Posts to Surface

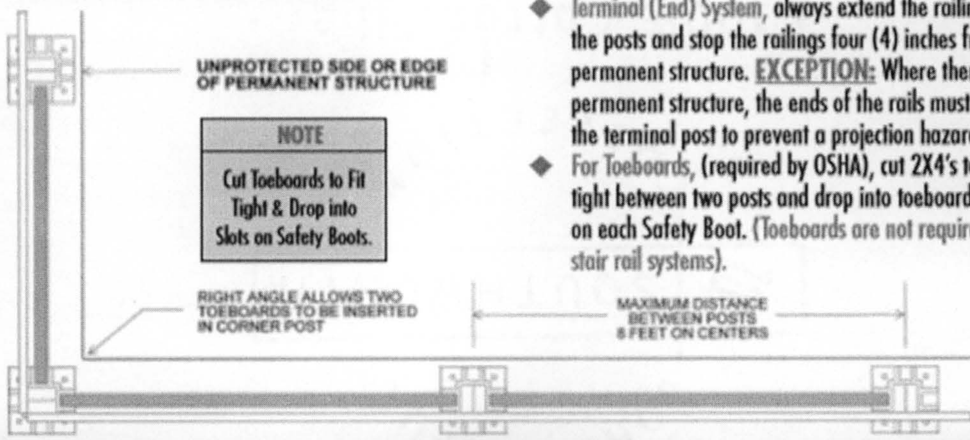
Anchor Posts to Subfloor Surface

- Securely fasten Safety Boots to surface using specified fasteners (see previous page) and provided washers.
- You MUST always use the correct fasteners for different types of flooring — To meet OSHA strength requirements refer to the Fastener Specifications Section in this instruction booklet for your specific subfloor application.
- DO NOT USE NAILS TO ANCHOR THE BOOTS! ALWAYS USE THE CORRECT FASTENERS!

◆ STEP FOUR ◆
Fasten Rails to Posts & Insert Toeboard

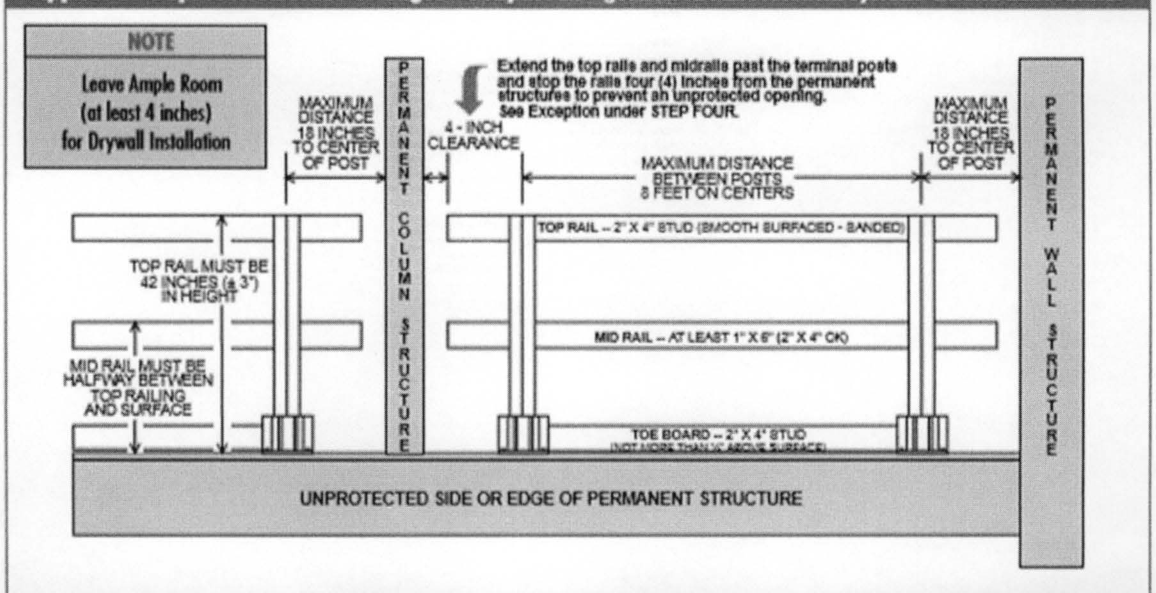
Fasten Top Rails and Mid Rails to Posts and Insert Toeboards Between Posts

- For Stair rails, including Handrails, top railings must be attached to the posts at approximately 39-40 inches.
  1926.1052(c)(7) states: When the top edge of a stairrail system also serves as a handrail, the height of the top edge shall be not more than 37 inches (94 cm) nor less than 36 inches (91.5 cm) from the upper surface of the stairrail system to the surface of the tread, in line with the face of the riser at the forward edge of the tread.
- For Guardrails, including Landings, top railings must be flush with top of posts (42 inches).
- For all Mid-rails, fasten halfway between top railing and flooring.
- Terminal (End) System, always extend the railings past the posts and stop the railings four (4) inches from any permanent structure. EXCEPTION: Where there is no permanent structure, the ends of the rails must stop at the terminal post to prevent a projection hazard.
- For Toeboards, (required by OSHA), cut 2X4's to fit tight between two posts and drop into toeboard slots on each Safety Boot. (Toeboards are not required on stair rail systems).

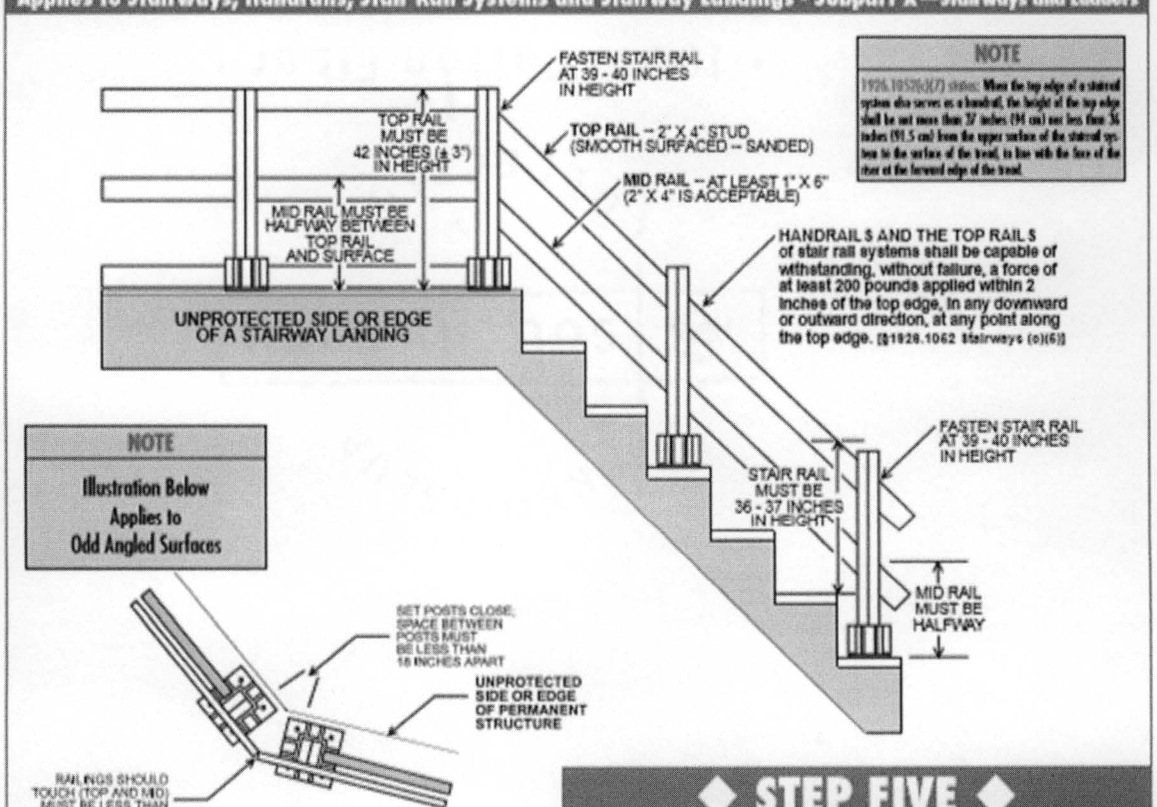


Applies to Walking / Working Surfaces and Stairway Landings

Applies to Unprotected Sides or Edges - Subpart M—§1926.502 Fall Protection Systems Criteria and Practices



Applies to Stairways, Handrails, Stair Rail Systems and Stairway Landings - Subpart X—Stairways and Ladders



◆ STEP FIVE ◆

Remove & Reuse Posts at Next Job Site

SUMMARY OF TESTS PERFORMED ON THE SAFETY BOOT®

PERFORMED FOR
SAFETY MAKER, INC.

PERFORMED BY
STRESS ENGINEERING SERVICES
HOUSTON, TEXAS

W. T. Asbill, P.E.

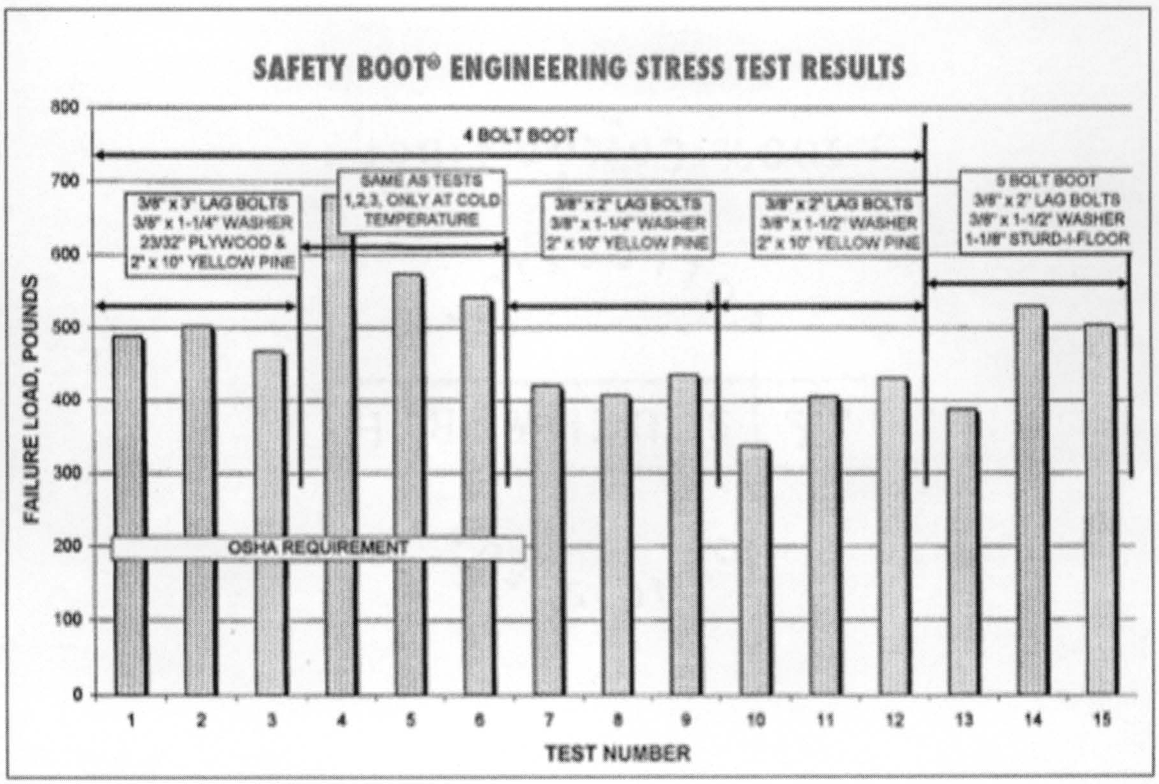
JULY 15, 2002
Revised April 11, 2003

STRESS ENGINEERING SERVICES (SES) IS A MULTI-DISCIPLINE ENGINEERING COMPANY THAT SERVES A VARIETY OF INDUSTRIES. ONE OF THE SERVICES PROVIDED BY SES IS A TEST FACILITY IN WHICH A VARIETY OF PRODUCTS ARE TESTED.

A SERIES OF TESTS WERE PERFORMED FOR SAFETY MAKER ON THEIR SAFETY BOOT®. THE PURPOSE OF THE TESTS WERE TO DETERMINE THE MAXIMUM LOAD THE BOOT AND FLOOR ASSEMBLY COULD WITHSTAND. THE TESTS WERE PERFORMED ACCORDING TO OSHA 1926.502 WHICH IS A CONSTRUCTION REGULATORY GUIDE FOR FALL PROTECTION GUARDRAIL SYSTEMS. THIS GUIDE REQUIRES THAT THE GUARDRAIL SYSTEM MUST BE ABLE TO WITHSTAND A FORCE OF 200 POUNDS AT A HEIGHT OF 42" ABOVE THE FLOOR.

A NUMBER OF TESTS WERE PERFORMED USING A VARIETY OF BOLTS AND SUBFLOORS. BELOW IS A TABLE AND PLOT THAT SUMMARIZES SOME OF THE TEST RESULTS. IN ALL TESTS SHOWN, THE SAFETY BOOT ASSEMBLY EXCEEDED THE OSHA REQUIREMENT OF 200 POUNDS FORCE. THE TESTS HAVE SHOWN THAT IT IS IMPORTANT TO HAVE THE CORRECT COMBINATION OF LAG BOLT SIZE, WASHER SIZE, NUMBER OF LAG BOLTS AND FLOOR MATERIAL THAT THE SAFETY BOOT IS ATTACHED TO. SOME FLOOR MATERIALS, SUCH AS PLYWOOD LESS THAN 1-1/8" THICK AND OSB, ARE INSUFFICIENT BY THEMSELVES AND MUST HAVE ADDITIONAL SUPPORT (2" PINE BOARD) FOR THE BOLTS TO PENETRATE. WITH THE ATTACHMENT COMBINATIONS SUMMARIZED, THE SAFETY BOOT EASILY EXCEEDED THE OSHA MINIMUM REQUIREMENT OF 200 POUNDS FORCE.

SUMMARY OF SELECTED SAFETY BOOT® STRESS TESTS PERFORMED BY SES				
TEST NO. & TEMPERATURE	LAG BOLT	FENDER WASHER	SUBFLOOR MATERIAL	MAX. FORCE POUNDS
1 : Room	3/8" x 3"	3/8" x 1-1/4"	23/32" STURD-I-FLOOR Plywood & 2" x 10" Yellow Pine	488
2 : Room	3/8" x 3"	3/8" x 1-1/4"	23/32" STURD-I-FLOOR Plywood & 2" x 10" Yellow Pine	502
3 : Room	3/8" x 3"	3/8" x 1-1/4"	23/32" STURD-I-FLOOR Plywood & 2" x 10" Yellow Pine	467
4 : 0°F	3/8" x 3"	3/8" x 1-1/4"	23/32" STURD-I-FLOOR Plywood & 2" x 10" Yellow Pine	680
5 : -13°F	3/8" x 3"	3/8" x 1-1/4"	23/32" STURD-I-FLOOR Plywood & 2" x 10" Yellow Pine	574
6 : -15°F	3/8" x 3"	3/8" x 1-1/4"	23/32" STURD-I-FLOOR Plywood & 2" x 10" Yellow Pine	542
7 : Room	3/8" x 2"	3/8" x 1-1/4"	2" x 10" Yellow Pine	420
8 : Room	3/8" x 2"	3/8" x 1-1/4"	2" x 10" Yellow Pine	407
9 : Room	3/8" x 2"	3/8" x 1-1/4"	2" x 10" Yellow Pine	435
10 : Room	3/8" x 2"	3/8" x 1-1/2"	2" x 10" Yellow Pine	337
11 : Room	3/8" x 2"	3/8" x 1-1/2"	2" x 10" Yellow Pine	405
12 : Room	3/8" x 2"	3/8" x 1-1/2"	2" x 10" Yellow Pine	430
13 : Room	3/8" x 2"	3/8" x 1-1/2"	1-1/8" STURD-I-FLOOR Plywood	387
14 : Room	3/8" x 2"	3/8" x 1-1/2"	1-1/8" STURD-I-FLOOR Plywood	530
15 : Room	3/8" x 2"	3/8" x 1-1/2"	1-1/8" STURD-I-FLOOR Plywood	504



Appendix B: Data Charts

F-Test Two-Sample for Variances

	Overhang	*Gusset*
Mean	139.3333333	286.3333333
Variance	126.3333333	134.3333333
Observations	3	3
df	2	2
F	0.94044665	
P(F<=f) one-tail	0.484654731	
F Critical one-tail	0.052631579	

Table 9: F-Test Overhang vs. Gusset

F-Test Two-Sample for Variances

	Overhang	*Safety Boot*
Mean	139.3333333	291.6666667
Variance	126.3333333	289.3333333
Observations	3	3
df	2	2
F	0.436635945	
P(F<=f) one-tail	0.303929431	
F Critical one-tail	0.052631579	

Table 10: F-Test Overhang vs. Safety Boot

F-Test Two-Sample for Variances

	Gusset	*Safety Boot*
Mean	286.3333333	291.6666667
Variance	134.3333333	289.3333333
Observations	3	3
df	2	2
F	0.464285714	
P(F<=f) one-tail	0.317073171	
F Critical one-tail	0.052631579	

Table 11: F-Test Gusset vs. Safety Boot

t-Test: Two-Sample Assuming Equal Variances

	Overhang	*Gusset*
Mean	139.3333333	286.3333333
Variance	126.3333333	134.3333333
Observations	3	3
Pooled Variance	130.3333333	
Hypothesized Mean Difference	0	
df	4	
t Stat	-15.7701278	
P(T<=t) one-tail	4.7231E-05	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	9.4462E-05	
t Critical two-tail	2.776445105	

Table 12: t-Test Overhang vs. Gusset

t-Test: Two-Sample Assuming Unequal Variances

	Overhang	*Safety Boot*
Mean	139.3333333	291.6666667
Variance	126.3333333	289.3333333
Observations	3	3
Hypothesized Mean Difference	0	
df	3	
	-	
t Stat	12.94145103	
P(T<=t) one-tail	0.000498006	
t Critical one-tail	2.353363435	
P(T<=t) two-tail	0.000996012	
t Critical two-tail	3.182446305	

Table 13: t-Test Overhang vs. Safety Boot

t-Test: Two-Sample Assuming Unequal Variances

	Gusset	***Safety Boot***
Mean	286.3333333	291.6666667
Variance	134.3333333	192.8888889
Observations	3	4
Hypothesized Mean Difference	0	
df	5	
t Stat	-0.553040904	
P(T<=t) one-tail	0.302025456	
t Critical one-tail	2.015048373	
P(T<=t) two-tail	0.604050913	
t Critical two-tail	2.570581836	

Table 14: Gusset vs. Safety Boot

Unpaired *t* test results

P value and statistical significance:
The two-tailed P value is less than 0.0001
By conventional criteria, this difference is considered to be extremely statistically significant.

Confidence interval:
The mean of Men 1960-1962 minus Men 2011-2014 equals -1.0000
95% confidence interval of this difference: From -1.2903 to -0.7097

Intermediate values used in calculations:
t = 6.7687
df = 8321
standard error of difference = 0.148

Learn more:
GraphPad's web site includes portions of the manual for GraphPad Prism that can help you learn statistics. First, review the meaning of P values and confidence intervals . Then learn how to interpret results from an unpaired or paired *t* test. These links include GraphPad's popular *analysis checklists* .

Review your data:

Group	Men 1960-1962	Men 2011-2014
Mean	68.2000	69.2000
SD	7.5800	5.7900
SEM	0.1363	0.0800
N	3091	5232

SCIENTIFIC SOFTWARE HOW TO BUY DATA ANALYSIS RESOURCES HELP COMPANY

https://www.graphpad.com/quickcalcs/ttest2/

Table 15: Unpaired t-Test results

Table 1. Weight in pounds, average weight and selected percentiles, by age and sex: United States, 1960-62

Average weight and percentile	Total, 18-79 years	18-24 years	25-34 years	35-44 years	45-54 years	55-64 years	65-74 years	75-79 years
MEN	Weight in pounds[1]							
Average weight--	168	160	171	172	172	166	160	150
Percentile[2]								
99--------------	241	231	248	244	241	230	225	212
95--------------	217	214	223	219	219	213	207	198
90--------------	205	193	208	207	209	203	198	191
80--------------	190	180	195	193	194	190	183	170
70--------------	181	171	185	184	185	180	172	161
60--------------	173	164	177	177	178	172	166	150
50--------------	166	157	169	171	171	165	161	146
40--------------	159	151	162	164	163	158	153	141
30--------------	152	145	154	158	156	151	146	137
20--------------	144	140	146	151	149	143	138	132
10--------------	134	131	136	141	139	131	126	120
5---------------	126	124	129	134	131	123	117	107
1---------------	112	115	114	121	116	112	99	99

Figure 12: Males weights 1960-1962

Table 2. Height in inches, average height and selected percentiles, by age and sex: United States, 1960-62

Average height and percentile	Total, 18-79 years	18-24 years	25-34 years	35-44 years	45-54 years	55-64 years	65-74 years	75-79 years
MEN	Height in inches[1]							
Average height--	68.2	68.7	69.1	68.5	68.2	67.4	66.9	65.9
Percentile[2]								
99--------------	74.6	74.8	76.0	74.1	74.0	73.5	72.0	72.6
95--------------	72.8	73.1	73.8	72.5	72.7	72.2	70.9	70.5
90--------------	71.8	72.4	72.7	71.7	71.7	71.0	70.2	69.5
80--------------	70.6	70.9	71.4	70.7	70.5	69.8	68.9	68.1
70--------------	69.7	70.1	70.5	70.0	69.5	68.8	68.3	67.0
60--------------	68.8	69.3	69.8	69.2	68.8	68.3	67.5	66.6
50--------------	68.3	68.6	69.0	68.6	68.3	67.6	66.8	66.2
40--------------	67.6	67.9	68.4	68.1	67.7	66.8	66.2	65.0
30--------------	66.8	67.1	67.7	67.3	66.9	66.0	65.5	64.2
20--------------	66.0	66.5	66.8	66.4	66.1	64.7	64.8	63.3
10--------------	64.5	65.4	65.5	65.2	64.8	63.7	64.1	62.0
5---------------	63.6	64.3	64.4	64.2	64.0	62.9	62.7	61.3
1---------------	61.7	62.6	62.6	62.3	62.3	61.2	60.8	57.7

Figure 13: Male Heights 1960-1962

Table 6. Weight in pounds for males aged 20 and over and number of examined persons, mean, standard error of the mean, and selected percentiles, by race and Hispanic origin and age: United States, 2011–2014

Race and Hispanic origin and age	Number of examined persons	Mean	Standard error of the mean	Percentile 5th	10th	15th	25th	50th	75th	85th	90th	95th
All racial and Hispanic-origin groups[1]				Pounds								
20 years and over	5,236	195.7	0.94	136.7	146.2	154.2	165.1	189.3	218.8	236.7	249.9	275.4
20–29 years	936	186.8	2.60	126.2	137.6	143.9	152.9	177.8	208.5	232.1	247.2	280.8
30–39 years	914	198.8	1.73	140.2	150.2	158.2	168.1	190.8	221.2	242.8	259.6	281.9
40–49 years	872	201.7	1.60	146.2	156.3	162.9	171.7	196.4	222.5	237.2	249.0	279.2
50–59 years	854	199.5	2.03	140.0	152.0	160.0	170.2	195.9	222.3	236.9	250.4	279.4
60–69 years	874	199.7	3.02	137.9	147.0	154.3	168.0	195.3	223.1	244.2	255.3	279.2
70–79 years	486	189.3	2.03	136.5	146.2	152.6	166.6	183.6	212.0	227.0	236.3	251.5
80 years and over	300	174.6	1.90	125.2	132.6	141.4	154.2	171.1	194.5	207.1	216.1	233.5

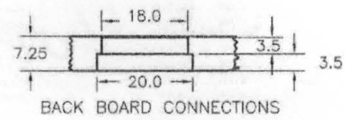
Figure 14: Male Weights 2011-2014

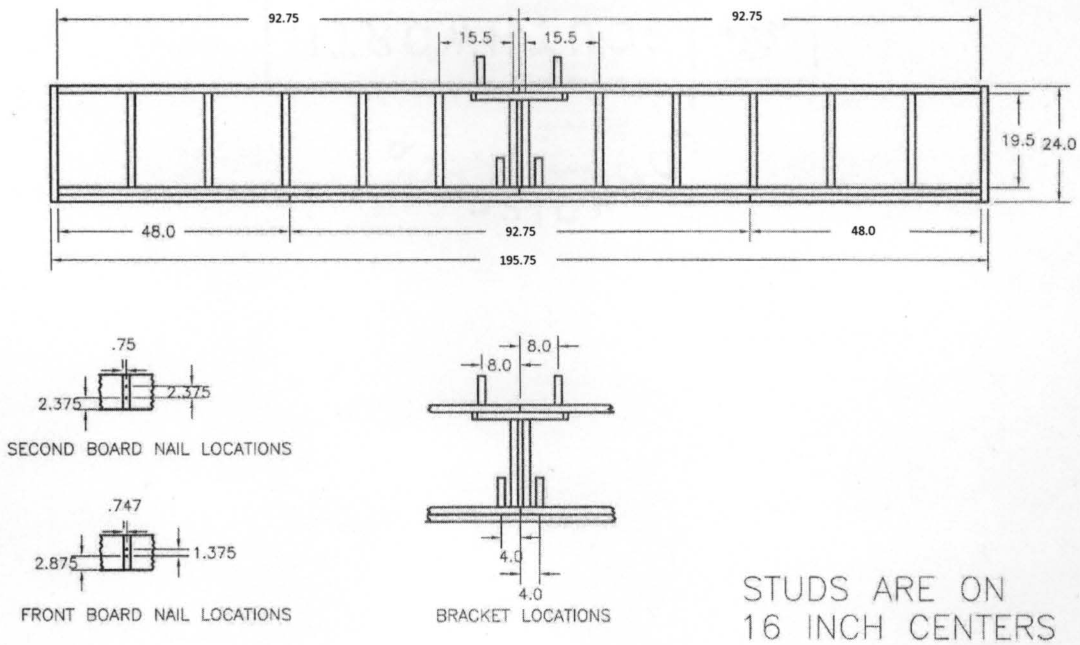
Table 12. Height in inches for males aged 20 and over and number of examined persons, mean, standard error of the mean, and selected percentiles, by race and Hispanic origin and age: United States, 2011–2014

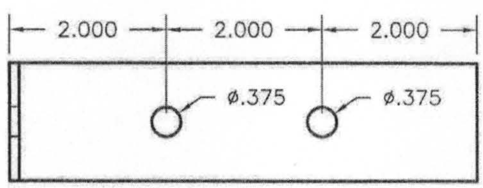
Race and Hispanic origin and age	Number of examined persons	Mean	Standard error of the mean	Percentile 5th	10th	15th	25th	50th	75th	85th	90th	95th
All racial and Hispanic-origin groups[1]		Inches										
20 years and over	5,232	69.2	0.08	64.3	65.4	66.1	67.2	69.1	71.2	72.3	73.0	74.1
20–29 years	937	69.4	0.10	64.9	65.7	66.3	67.4	69.4	71.4	72.6	73.4	74.3
30–39 years	914	69.5	0.12	64.5	65.8	66.5	67.5	69.5	71.5	72.6	73.5	74.4
40–49 years	872	69.4	0.17	64.5	65.7	66.3	67.3	69.3	71.2	72.6	73.1	73.9
50–59 years	852	69.3	0.20	64.8	65.7	66.3	67.2	69.1	71.4	72.3	73.0	74.2
60–69 years	877	69.0	0.18	63.8	65.2	65.9	67.1	69.1	71.2	72.1	72.5	73.8
70–79 years	486	68.1	0.12	63.9	64.7	65.1	66.3	67.9	69.8	70.9	71.7	72.9
80 years and over	294	67.6	0.23	62.9	64.2	64.7	65.9	67.7	69.4	70.5	71.0	72.0

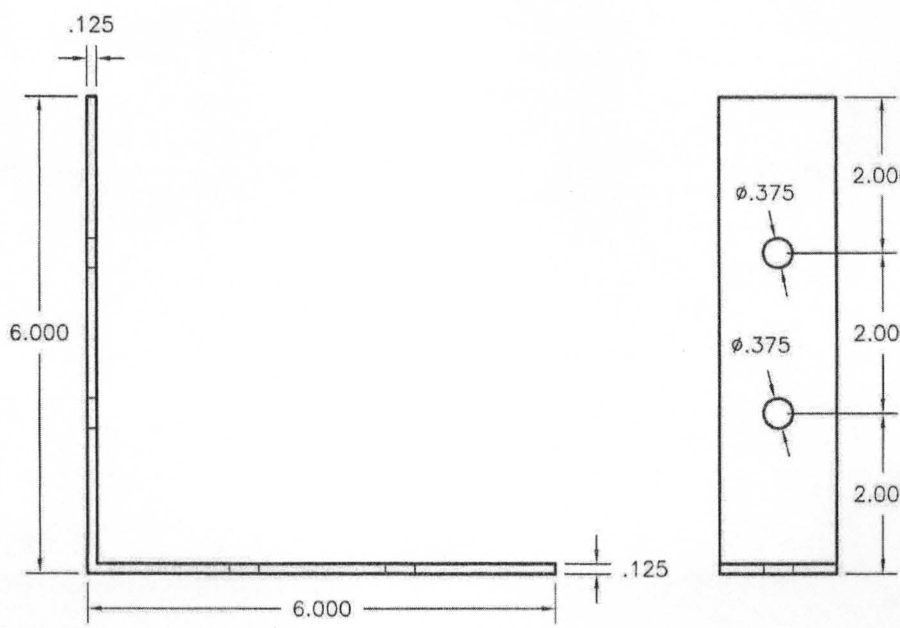
Figure 15: Male Height 2011-2014

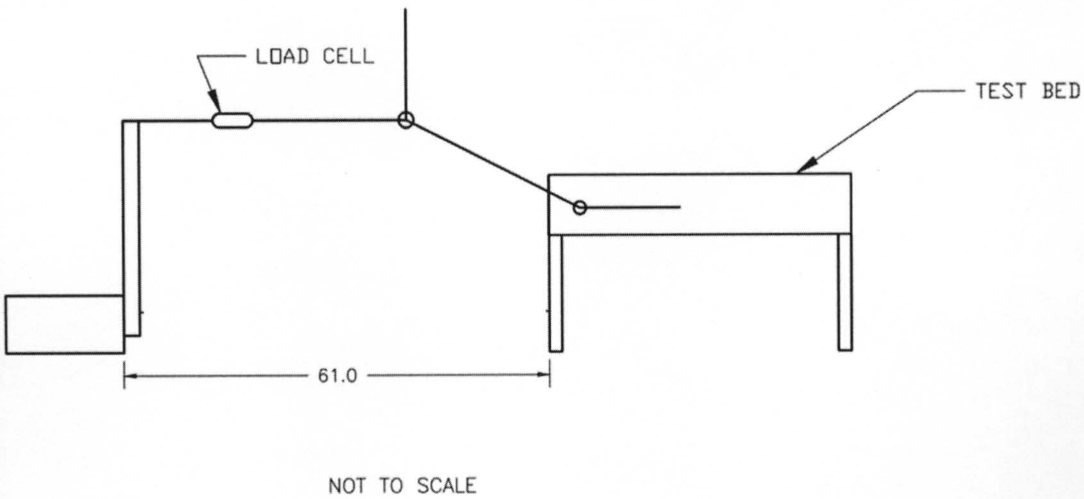
Appendix C: Drawings

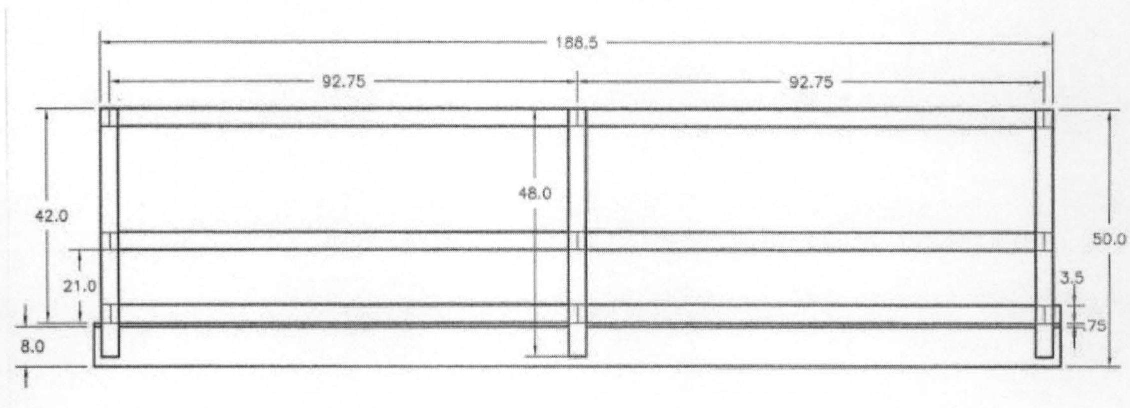


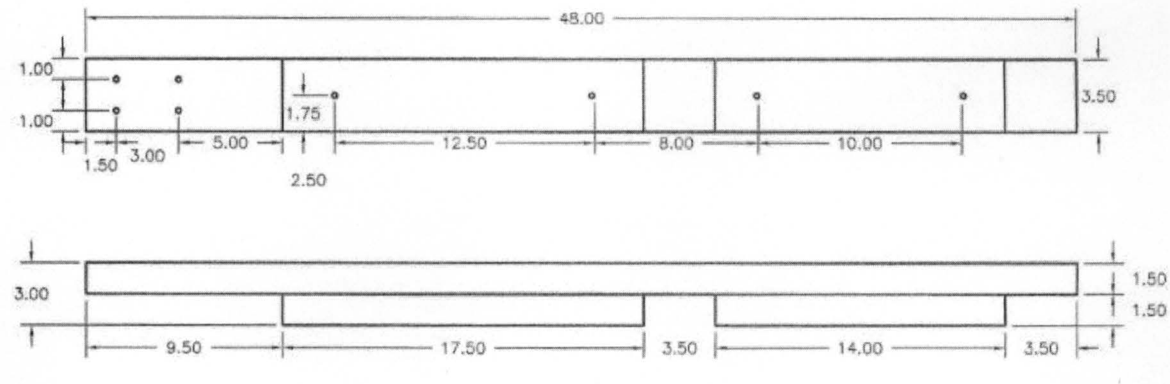


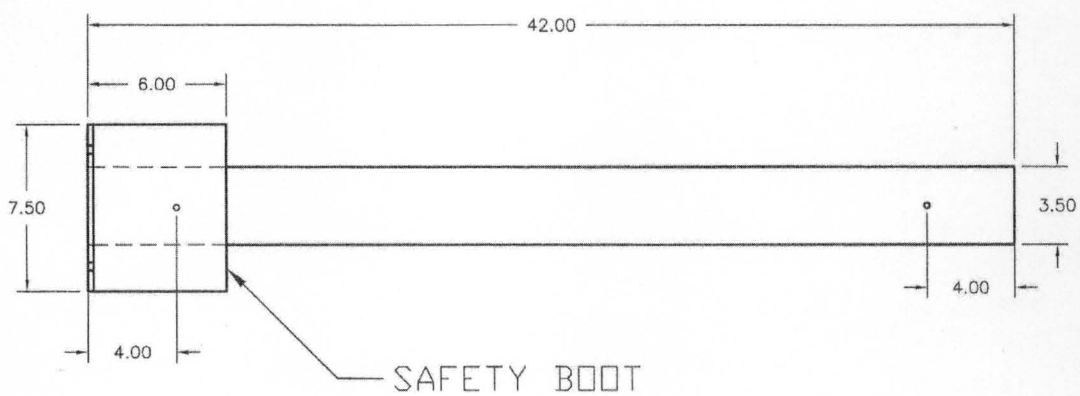


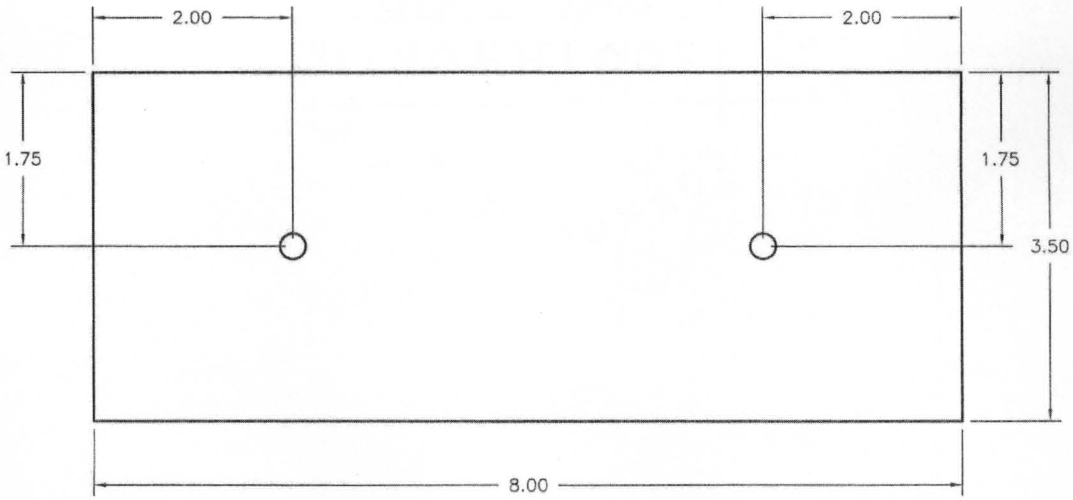


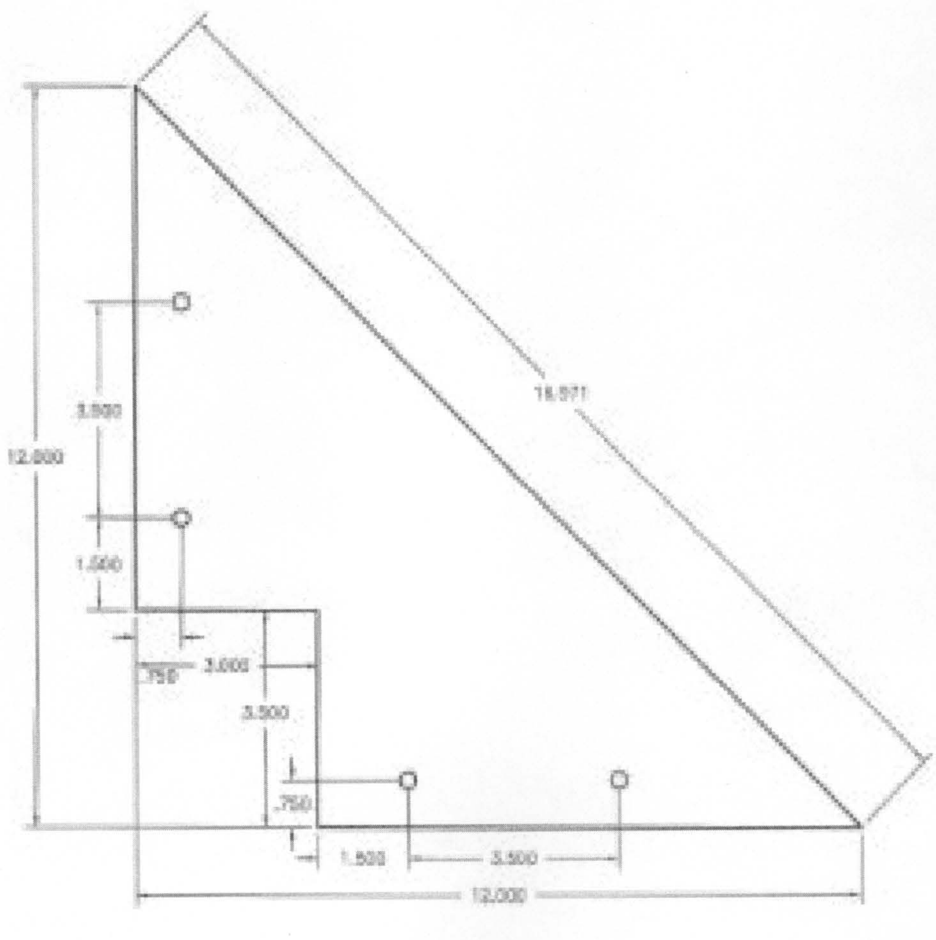

LOAD CELL
TEST BED
61.0
NOT TO SCALE


188.5
92.75
92.75
48.0
42.0
21.0
8.0
50.0
3.5
.75

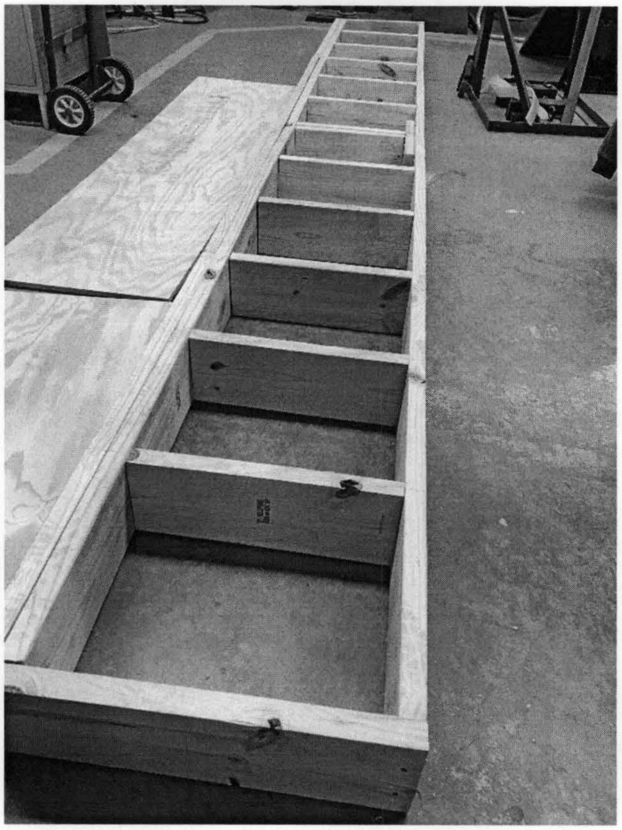

48.00
1.00
1.00
1.75
3.50
1.50
3.00
5.00
12.50
8.00
10.00
2.50
3.00
1.50
1.50
9.50
17.50
3.50
14.00
3.50

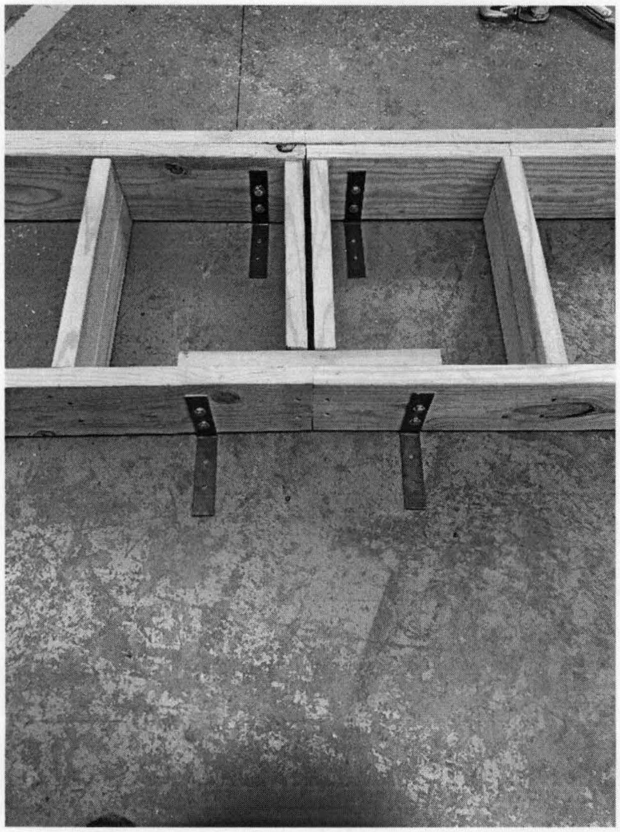

42.00
6.00
7.50
3.50
4.00
4.00
SAFETY BOOT

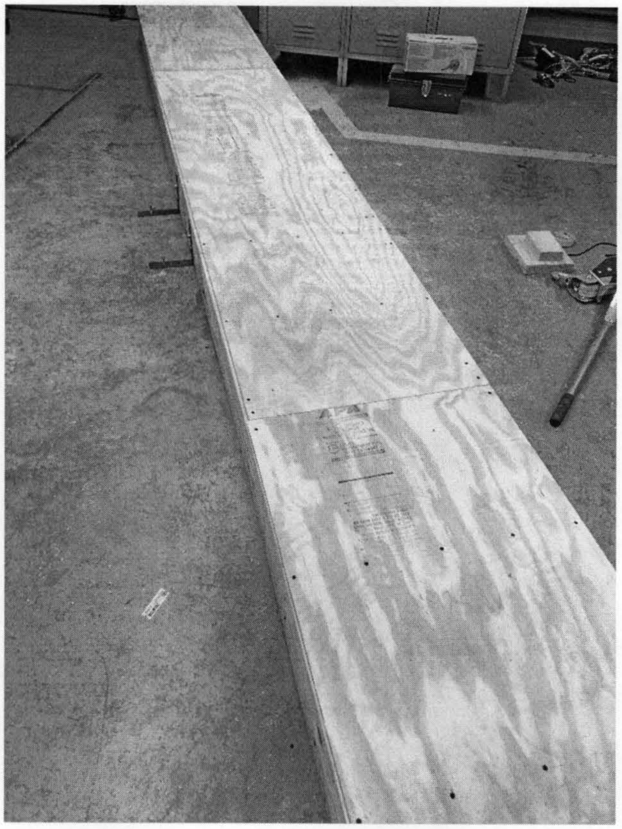

2.00
2.00
1.75
1.75
3.50
8.00

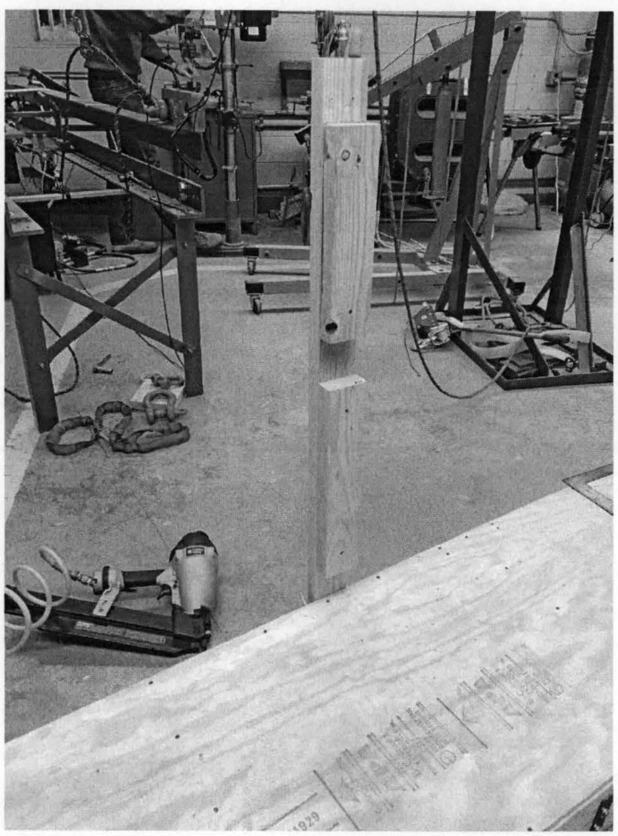

16.971
3.500
12.000
1.500
.750
3.000
3.500
.750
1.500
3.500
12.000

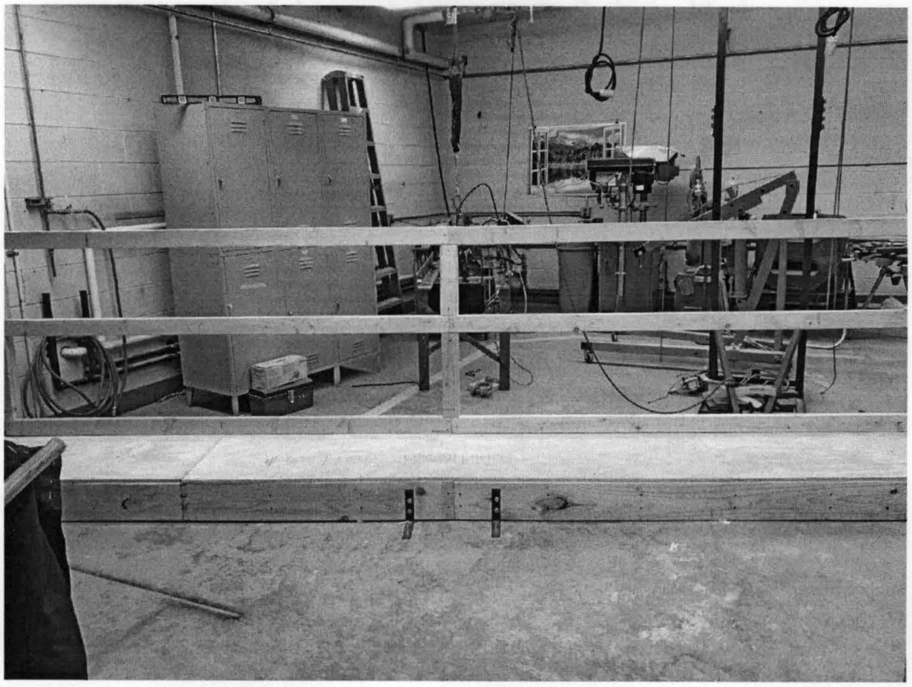
Appendix D: Pictures

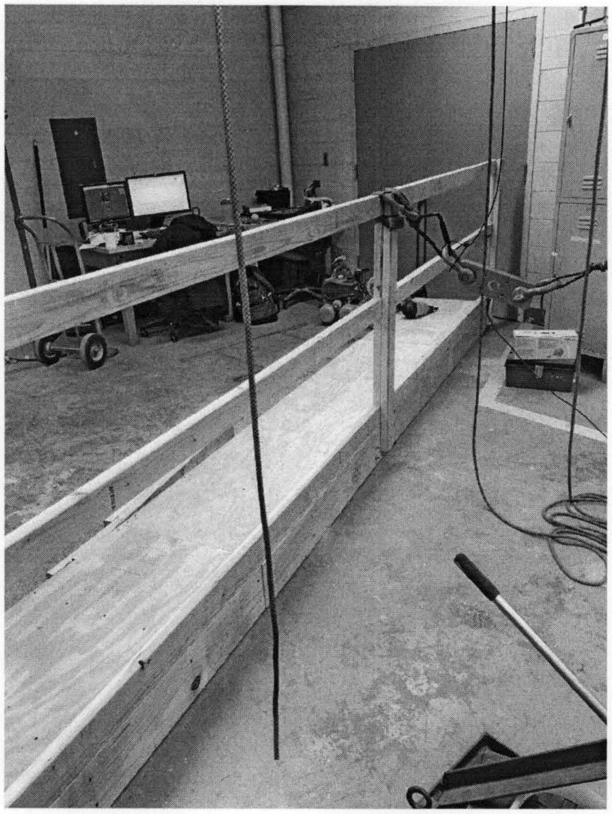


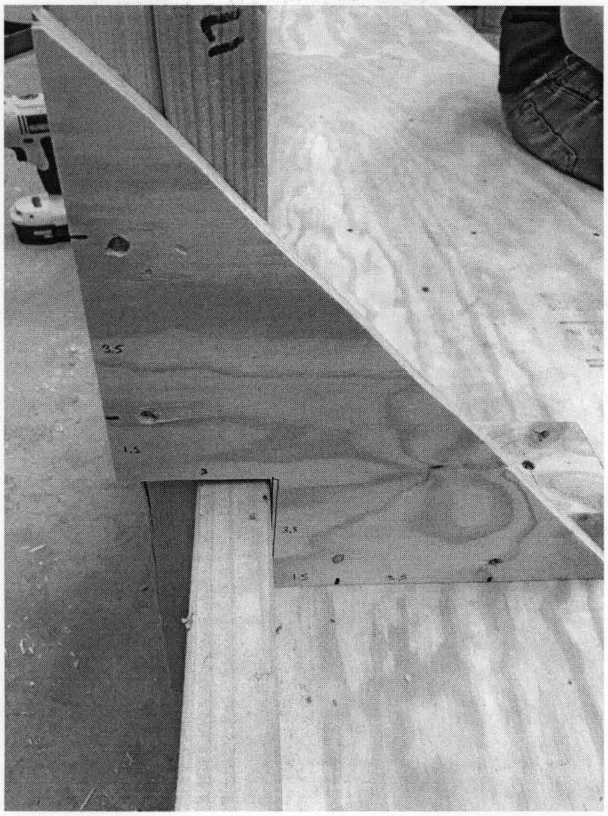


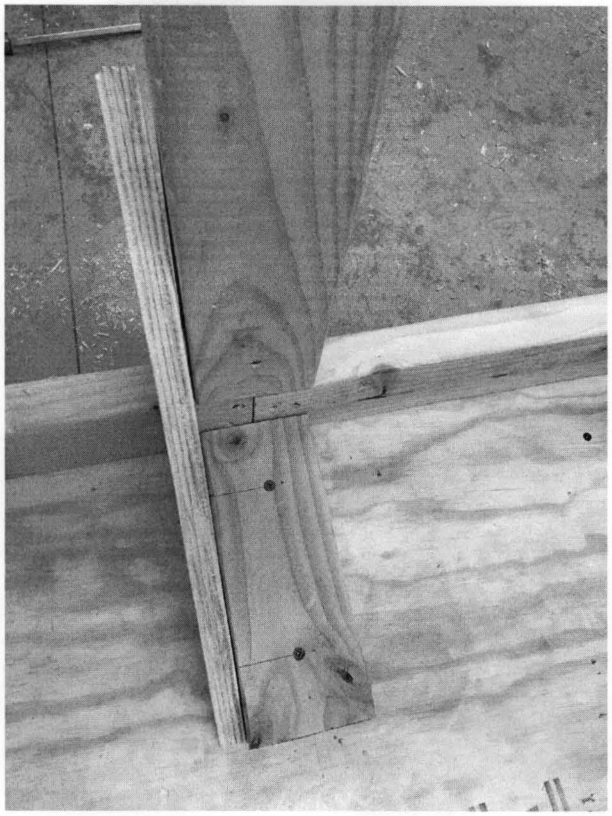













17.5