Fall Protection Analysis for Workers on Residential Roofs

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Abstract: Safety during residential roof construction and repair activities is of significant concern since many injuries occur, especially as a result of falls. The Hawaii Occupational Safety and Health Division of the Hawaii Department of Labor commissioned a research project to investigate this matter. This study involves an evaluation of existing regulations, construction practices, and alternate fall protection measures. It is found that the current state of compliance is poor; fall protection plans are not prepared as required, and positive safety measures such as guardrails and personal fall arrest systems are not used. The reasons for this are many, including the extreme competitiveness of the home building and roofing industries, unsafe worker behavior, design difficulties, conventional construction practices, and a lack of knowledge. Fall protection regulations are misunderstood, and the fall protection plan is particularly prone to poor implementation. For fall protection systems to be implemented voluntarily, they must be feasible, simple, economical, protective, and flexible. Several systems were analyzed for their ability to meet these criteria. The most promising systems included prefabrication of the roof system and personal fall arrest systems use. This paper presents the findings of the study and recommendations for optimal enforcement with an aim at reducing fall injuries.

BACKGROUND

In February 1995, the U.S. Occupational Safety and Health Administration (OSHA) enacted revisions to the construction industry safety standards that regulate fall protection systems and procedures. Yet in 1995, falls accounted for 12% of all residential construction accidents in Hawaii ("Custom" 1997a), and a failure to comply with these standards is one of the most frequently cited violations in inspections of residential construction sites (HIOSH, personal communication, 1996). A majority of these falls and citations for lack of fall protection occurred during residential roof construction. Therefore, the Hawaii Occupational Safety and Health Division (HIOSH) funded this investigation of fall protection systems, behaviors, and attitudes in the area of residential construction.

The scope of this study was limited to residential roof construction in Hawaii, to include new construction, renovation, and maintenance of single-family residences, town houses, and commercial buildings with residential-style (wooden or light-gauge steel truss and gable) roof systems. The objectives of this investigation were to

1. Assess the current status of compliance with fall protection regulation.
2. Analyze the sources of noncompliance with fall protection regulations in residential roof construction.
3. Identify the fall protection requirements of the various parties involved in residential construction safety.
4. Examine existing methods of fall protection for residential roof construction for their ability to meet those requirements.
5. Incorporate the results of the investigation into specifications and other actions for regulatory agency implementation.

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Note. Discussion open until March 1, 1999. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on July 30, 1997. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 124, No. 5, September/October, 1998. ©ASCE, ISSN 0733-9634/98/0005-0418–0428/$8.00 + $.50 per page. Paper No. 16323.

Existing Regulations

In February 1995, fall protection regulations for the construction industry were consolidated into 29 CFR §1926.500 to §1926.503, which are collectively referred to as Subpart M of the construction safety standards. Special construction circumstances, such as working from scaffolds or ladders, are not covered by Subpart M, but for general construction procedures, Subpart M gives the requirements for fall protection. According to Subpart M, construction employers are required to take action to protect workers from fall hazards whenever they are exposed to a fall of 1.83 m (6 ft) or more ("Safety" 1994).

During most situations, Subpart M requires the use of positive fall protection measures, whether through the use of guardrails, safety nets, or personal fall arrest systems (PFAS). However, contractors involved in residential construction, and particularly residential roof construction, have the options of protecting workers via alternative methods ("Safety" 1994). These methods do not provide positive protection; that is, there is no device or guard that will either prevent a fall or protect the worker from the impact of the fall. During residential roof construction, Hawaii permits several forms of alternative fall protection as follows:

- Safety monitoring systems—A worker is designated as the monitor to watch his or her coworkers and warn them of fall hazards. This system can only be used during low-sloped (slope $\leq$ 4:12) roofing application ("Safety" 1994).
- Warning line systems—A flagged line marks the unsafe area 1.83 m (6 ft) from the edge of the roof. Above the line, workers may work unprotected; below the line, they must be protected by some other form of fall protection. This system can also only be used during low-sloped roofing application ("Safety" 1994).
- Roof jack systems—Also known as slide guards, roof jacks are planks that are placed perpendicular to the roof at or near the roof's rake edge(s) to stop the slide of a falling person or object. They are attached to the deck of the roof using rafter brackets. Roofing material can be applied over the brackets, which can be removed following completion of the job. This system can be used for residential roofing application so long as the eave height does not exceed 7.62 m (25 ft) and the slope does not exceed 6:12 ("Draft" 1997).
- Fall protection plans—The employer performs an analysis of fall hazards on the site and delineates the method of preventing falls for each hazard. This system can be

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used during all phases of residential roof construction, as long as the contractor has shown that it is infeasible or creates a greater hazard to employ conventional fall protection measures. In actuality, the fall protection plan is not, by itself, an alternative form of fall protection; instead, it outlines the use of other alternative fall protection measures that will be employed ("Safety" 1994).

Upon becoming effective, Subpart M was immediately disputed by the home builders and roofers of the residential construction industry. In response to their appeals and resulting congressional pressure, OSHA issued two memoranda relaxing their stance on residential fall protection requirements (Stanley 1995; "Interim" 1995). The final result was that a fall protection plan is no longer required for residential construction, as long as safe work practices as outlined in Appendix E of the standard or in the memoranda, are in effect ("Interim" 1995). However, HIOSH has not adopted both memoranda. Instead, HIOSH still requires contractors to prepare a comprehensive fall protection plan before they can utilize alternative methods (HIOSH, personal communication, 1996).

METHODOLOGY

The investigation was undertaken in the following method:

1. A comprehensive search of fall protection regulations and citations was completed.
2. Residential homebuilders, union representatives, fall protection equipment suppliers, roofing contractors, safety officers, and HIOSH personnel were interviewed for their concerns and ideas.
3. Simultaneously, jobsites were inspected for their state of compliance and for fall protection methods employed.
4. Surveys were designed and solicited to obtain workers' views on fall protection.
5. The information gathered during the interviews and jobsite inspections and from the surveys and case histories was analyzed qualitatively and quantitatively using graphical and statistical analysis.
6. Alternative proposals were developed based on the ideas obtained.
7. The alternatives were analyzed for their ability to meet the requirements of contractors, labor, and enforcement.
8. Recommended courses of action were developed for regulatory agencies based on the research.

Case Histories

This stage of field investigations involved a review of HIOSH citations of residential construction sites since February 1995. The citations included both union and nonunion contractors involved in new construction and renovation. Although HIOSH records indicated that 20 residential construction inspections resulted in fall protection citations during the period of March 1995 to March 1997 ("Custom" 1997b), only eight cases were found to be relevant to the scope of this study. The eight case histories reviewed indicate that HIOSH is enforcing regulations throughout the industry, as they included one public-sector jobsite, two private developments, and five single-homeowner sites.

These eight inspections resulted in 18 citations related to failing to provide adequate fall protection. The majority of these citations were given to employers for allowing workers to walk the top plate unprotected during truss installation. The top plate is the top of the 5.08 × 10.16 cm (2 × 4 in.) frame wall, on which the roof trusses are erected. The conventional method of installing trusses is for two workers to balance along this top plate while moving the trusses into place and bracing them. This standard industry practice offers no protection to the workers and is a major concern to HIOSH. Consequently, HIOSH considers walking the top plate a violation of regulations. Workers are accustomed to walking the top plate and contractors seldom hinder workers from doing this. However, this practice is a blatant violation of regulations that are enforceable in court. Walking the top plate is not recommended by the National Association of Home Builders (*The fall* 1995).

One citation was related to a death. All other citations involved no injuries but were related to noncompliance. The majority of these citations involved roofs sloped 4:12, since this is the most common roof slope in Hawaii.

Jobsite Inspections

Typically, jobsite inspections were conducted in conjunction with interviews of the construction managers. These were arranged beforehand with them. Each visit involved a detailed discussion with the construction manager and a walk through the site.

Jobsites of every major builder in the city and county of Honolulu were visited. Thus the sample size is significantly representative of the residential housing construction ongoing. In all 16 jobsites were visited, in various stages of construction. These jobsites involved large developments, either privately owned or military family developments, and single homes, all privately owned (Johnson and Singh 1997). The sites visited spanned projects of a single house being constructed to 400 houses being constructed.

The sample jobsites studied were stratified in that every major category was covered—large developments, single homes, and military homes. Once stratified, the sampling was systematic—in that every major developer was visited and the major military housing projects were surveyed—or randomly clustered—in that a cluster of single-home contractors were interviewed at random. Consequently, the samples are probability samples (in contrast to being judgmental samples); therefore, probability sampling tests can be undertaken, if desired (Freund and Williams 1972).

The primary purposes of the jobsite inspections were to obtain the actual states of worker compliance and supervisory enforcement of fall protection regulations and to obtain information regarding the use and effectiveness of existing fall protection systems. The instrument used to conduct the site inspection, in the form of a checklist, is given in Appendix I. Several unique fall protection methods were observed in use on one or more of the job sites. These discovered methods of fall protection were analyzed for their effectiveness in meeting the requirements of contractors, labor, and enforcement, as described later in the section entitled Discovered Fall Protection Systems.

Interviews

Twenty-one interviews were held with representatives of each of the various parties involved in residential fall protection—management, labor, and enforcement. Interviews were held in conjunction with site inspections. The construction managers included representatives of developers, roofers, general contractors, owners, framers, and other organizations involved with employing workers in residential roof construction. Interviews were organized to find the construction managers' views and requirements for fall protection systems in the residential construction industry and involved a free-flowing discussion between the researcher and the manager. Each interviewee was asked several core questions at some point in the interview. These questions are as follows (Johnson and Singh 1997):

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- How compelled do you currently feel to comply with the existing fall protection regulations?
- What methods of fall protection have you used and how? Which method do you feel is most appropriate for each stage of roof construction?
- At what roof slope do you feel positive protection is needed?
- How frequently do you encounter problems that make it difficult for you to comply with the existing regulations? How would you characterize these problems?
- How would you regard your workers' level of compliance? Your supervisors', including subcontractors', level of enforcement?
- Why do your workers use positive fall protection? Why don't they?
- What could be done to increase worker protection while reducing current compliance problems?

Interviews were also obtained with the Training Coordinators of Roofers Local 221 and Carpenters Local 745. These interviews aimed at gathering the unions' views and labor's requirements for fall protection systems. Finally, interviews and meetings were conducted with the HIOSH staff and the OSHA program officer for Subpart M. These interviews were designed to obtain enforcement's perspective of the issues.

Worker Surveys

Based on the ideas proposed by the contractors and the union representatives, a survey was developed to obtain the workers' views on fall protection. The survey included demographics questions, accident history, questions related to the worker's exposure to various fall protection systems, and questions relating to the worker's opinions on fall protection, including the following:

- An appropriate use matrix that asked the workers what they considered to be the most appropriate method of fall protection for each phase of roof construction
- Use of positive protection, including both frequency of use and necessity for use
- The relative dangers of various roofing surfaces
- Problems encountered by workers in complying with fall protection regulations, including both frequency of problems and sources of problems
- Reasons for use and nonuse of fall protection systems
- Levels of supervisory enforcement and self compliance
- Actions to increase protection

The survey was distributed to the workers through the two unions' training coordinators. Twenty-three surveys were returned. Together with the union officials' interviews, the surveys formed the basis of labor's requirements for fall protection systems in residential construction.

RESEARCH FINDINGS

State of Compliance

The current state of compliance with fall protection regulations in Hawaii's residential roof construction is poor. The actual state of worker compliance and supervisory enforcement was measured during jobsite inspections on a scale of 1 to 5, with 1 being "always comply" or "always enforce" and 5 being "never comply" or "never enforce." The mean worker compliance score was 3.69, between "sometimes comply" and "seldom comply." The mean supervisory enforcement score was 3.44, between "sometimes enforce" and "seldom enforce."

TABLE 1. Average Compliance and Enforcement Levels by Sector, as Found during Jobsite Inspections

Industry sector (sample population) (1)	Worker compliance[a] (mean) (2)	Supervisory[b] enforcement (mean) (3)
Public sector (n = 5)	2.80	2.80
Private developer (n = 7)	3.57	3.00
Single homeowner (n = 4)	5.00	5.00
Overall industry (n = 16)	3.69	3.44

[a]For worker compliance, 5 = never comply; 4 = seldom comply; 3 = sometimes comply; 2 = comply most of the time; 1 = always comply.
[b]For supervisory enforcement, 5 = never enforce; 4 = seldom enforce; 3 = sometimes enforce; 2 = enforce most of the time; 1 = always enforce.

TABLE 2. Perceived and Actual Compliance and Enforcement Levels

Sample (population) (1)	Worker compliance[a] (2)	Supervisory enforcement[a] (3)
Construction manager interviews (n = 21)	3.21; r = 0.62	2.89; r = −0.32
Worker surveys (n = 23)	2.12; r = 0.87	2.47; r = 0.34
Jobsite inspections (n = 16)	3.69	3.44

[a]Mean of responses and correlation with inspection results.

The state of compliance improves with increased external supervision, as shown in Table 1. None of the sites in the single-homeowner sector (n = 4) complied with regulations whatsoever, nor was there any concern by the construction managers interviewed with the state of noncompliance. The private home developers' sites were typified by more external supervision, usually in the form of involvement from professional risk managers. Consequently, these sites had an average worker compliance score of 3.57 and a supervisory enforcement score of 3.00. Finally, the public sector sites (n = 5) had the most external supervision, usually involving direct owner involvement in the daily operations of the sites. These sites also had the best average compliance—an average 2.80 score for both worker compliance and supervisory enforcement, between "sometimes comply" and "mostly comply." These scores reveal the large variations in worker compliance and supervisory enforcement between public sector and single-homeowner projects.

The perceived state of compliance, as found in the construction manager interviews and worker surveys, is quite different from the actual state of compliance. Workers' responses were obtained from the returned survey, while construction manager responses were obtained during the time of interview by use of the checklist provided in Appendix I. Both the managers and the workers felt that they complied with and enforced regulations more fervently than was truly the case, as shown in Table 2. This indicates a lack of knowledge about the true fall protection requirements, for both the workers and their managers.

Sources of Noncompliance

Both the managers and workers were asked how frequently they encountered problems that made it difficult for them to comply with fall protection regulations. While 57% of the managers stated that they encountered problems frequently or always, only 33% of the workers encountered problems frequently, and none always encountered problems. Since workers do not discover, or do not by themselves become aware of a large bulk of problems, there is little they can do about them by themselves. Additionally, management participation and in-

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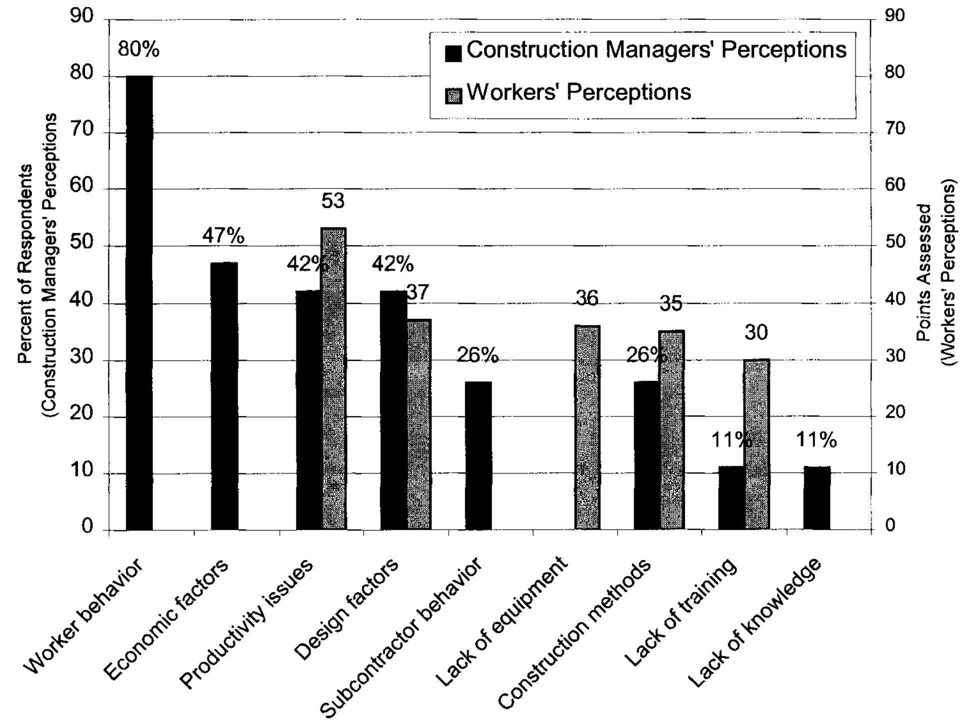

FIG. 1. Sources of Non-Compliance

put is required to rectify site deficiencies. This finding, therefore, indicates that frequently the problems encountered are not capable of being solved at the worker's level.

Characterization of Problem

When asked to characterize these problems, construction managers felt that the principal problem was with worker behavior. The next most frequently cited problems dealt with the competitive nature of their business, with economic factors and productivity impacts considered as the second and third most frequently occurring problems, respectively. Other factors leading to noncompliance included design factors, subcontractor behavior, construction methods, a lack of training, and a lack of knowledge. Findings from the workers' surveys echoed the construction managers, with productivity impacts considered as a principal source of noncompliance. Fig. 1 shows the contractors' and workers' responses to this question. Correlation between the two samples is quite high, at $r = 0.75$.

The interviews with union officials and enforcement officials reinforced the findings from the construction manager interviews and the worker surveys. Enforcement officials felt that confusion over regulations (a lack of knowledge), competitive pressures, and worker behavior were the principal sources of noncompliance. Union officials believed that the principal source of noncompliance was due to a push for production at the expense of safety, manifest by failing to provide adequate resources (labor, time, equipment, tools, material, or training) to accomplish a task safely.

Reason behind Safe/Unsafe Behavior

Because the construction managers and enforcement officials cited worker behavior as a principal source of noncompliance, this particular issue was examined in depth. Both the construction managers and the workers themselves were asked for the reasons behind safe and unsafe worker behavior. Their responses are shown in Table 3. The two populations gave quite different responses when asked why workers comply with regulations; correlation is only $r = 0.59$. Whereas the construction managers felt compliance was primarily due to

TABLE 3. Reasons for Worker Compliance and Noncompliance

Reasons for Worker Compliance		Reasons for Worker Noncompliance	
Workers' responses (points assessed)[a] (1)	Managers' responses (% of respondents)[b] (2)	Workers' responses (points assessed)[a] (3)	Managers' responses (% of respondents)[b] (4)
Personal concern for safety (52)	Requirement of employment (32)	Slows them down (54)	Slows them down (68%)
Requirement of employment (50)	Supervisory enforcement (32)	Uncomfortable (46)	Uncomfortable (53)
Supervisory enforcement (47)	Personal concern for safety (16)	Not a requirement of employement (26)	Believe they will not fall (53)
Peer pressure (31)	Peer pressure (11)	Supervisor does not enforce (25)	Peer pressure (32)
		Believe they will not fall (23)	Supervisor does not enforce (16)
		Peer pressure (22)	Not a requirement of employment (5)

[a]Points were assessed from rankings provided by workers.
[b]Percentages were assessed from responses received during interviews.

the actions of management, the workers believed that they complied out of a personal concern for their own safety. Since use by the worker ultimately indicates how much usage is being made of safety practices, the true motivation for safe behavior must come from within the individual worker, not as a result of supervisory coercion.

Noncompliance of Workers

The responses of workers and construction managers were more similar ($r = 0.78$) when asked why workers don't comply with regulations. Both the workers and construction managers felt that noncompliance was primarily due to its effects on productivity (slows them down) and a desire for comfort. However, the workers felt that the next most common reasons for noncompliance were due to a lack of supervisory enforcement; construction managers felt that a belief that they will not fall and peer pressure were greater concerns. This indicates that the workers are not in fact influenced by the macho con-

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struction attitude as much as by their own concerns for comfort and productivity.

Fall Protection Systems Use and Preferences

Many fall protection systems were found to be used on the jobsite inspections, and the construction managers and workers had experience with even a wider variety of systems. The most commonly used systems in Hawaii's residential roof construction industry were the PFAS and the fall protection plan, with 56% of the sites inspected using each method. Each system was found to have its unique advantages and disadvantages and to have an appropriate use in residential roof construction. PFAS was found to be most commonly used and to be most preferred for use during a roofing application, especially at slopes exceeding 4:12. The fall protection plan was most commonly used and preferred for use during truss installation. During sheathing, both PFAS and the fall protection plan were equally used and preferred by workers and construction managers.

Workers preferred passive protection systems such as guardrails to active protection systems such as PFAS, since passive systems protect them without interfering with their work. The vast majority of workers (79%) also felt that positive protection was required when working on all slopes above 4:12. Only a slight majority (52%) of the construction managers felt this was necessary. The correlation between the populations in this response was quite absent, at $r = -0.04$. This indicates that the construction managers, who don't feel protection is required to the same degree as the workers, may not offer positive protection to the workers when the workers feel that positive protection is required.

The workers were also asked to rate the relative dangers of the various surfaces encountered during residential roofing construction. The results indicated that the workers felt that bare rafters, found during truss installation and sheathing, were the most dangerous working surfaces encountered. Metal, clay tile, and sheathing were also considered to be dangerous surfaces. Cedar shakes, paper, and asphalt shingles were not considered to be dangerous by the workers. This shows that the need for positive protection is more important during truss installation and sheathing than during most roofing applications. Contrary to this need, however, jobsite inspections and construction manager interviews indicated that positive protection was frequently not used during these two phases of construction. For instance, workers reported that PFAS was used by only 37.5% of the employers during truss installation (Johnson and Singh 1997).

Actions to Increase Worker Protection

During the course of interviewing construction managers, union officials, and enforcement officials, all were asked for their ideas on how to increase the state of compliance without compromising worker protection. These various solutions are presented in Table 4. As shown in Table 4, developing innovative methods of fall protection was considered to be a possible action by each of the three parties. Therefore, the unique discovered fall protection methods were analyzed for their effectiveness in meeting the requirements of the contractors, labor, and enforcement.

SYSTEMS ANALYSIS FOR FALL PROTECTION DEVICES AND METHODS

From the construction manager interviews, the contractors' requirements for a fall protection system were synthesized. For a fall protection system to be implemented on a wide scale in residential roof construction, it must be

1. Economical—The system's costs must not exceed its benefits.
2. Flexible—The system should be applicable to various site conditions and phases of construction.
3. Passive—Because worker behavior is a source of noncompliance due primarily to the system's interference, the system should be passive and not require worker participation after installation.
4. Feasible—The system should be able to be implemented using common resources.
5. Simple—The system should not be difficult to understand nor to implement.
6. In addition to the preceding requirements, labor and enforcement felt that the system must meet the following requirement: Protective—The system must protect the workers from fall hazard at least to the degree required by Subpart M.

Discovered Fall Protection Systems

Several innovative and conventional methods of protecting workers from falls were discovered during jobsite inspections and from interviews. The more promising of these were analyzed for their ability to meet the six aforementioned criteria. They include the following systems and methods.

Guardrail Systems

One of the conventional methods of protection allowed under Subpart M for residential roof construction, guardrail systems can range from jobsite-manufactured guardrails to prefabricated guardrails. The most promising system encountered during site inspections was the PR20 Eave Catchguard system (Roofmaster Products, Monterey Park, Calif.). This system involves the use of prefabricated stanchions that connect to the deck of the roof using rafter brackets. As with roof jacks, the roofing material can be applied over the brackets, which can

TABLE 4. Actions for Increasing Worker Protection

Proposed solutions (1)	Recommending Party: Employers (2)	Labor (3)	Enforcement (4)
Develop innovative methods of fall protection	X	X	X
Increase training	X	X	—
Subsidize costs	X	X	—
Increase cooperation with HIOSH	X	X	—
Change the safety culture	X	X	—
Increase regulatory or owner oversight	X	X	—
Increase involvement of risk managers	X	—	—

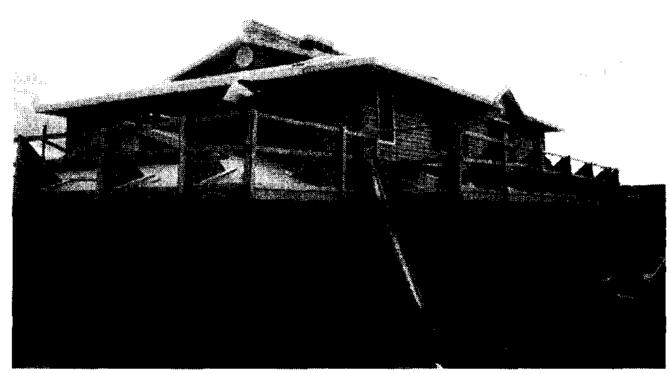

FIG. 2. Illustration of Guard Rail System for Roof Work on Residential Buildings

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be removed following completion of the job. (Roofmaster Products, personal communication, 1997). Fig. 2 illustrates a guardrail system used on a site.

PFAS with Roof Truss Anchor System

The roof truss anchor system is a standard PFAS that involves the installation of one or more anchors on the truss framework. The anchorage can be installed before, during, or after truss installation, depending on the system used. The most promising system encountered during site inspections was the Trus-T (Guardian Metal Products) anchor system. The system involves the use of permanent, bracket-type anchors that are attached to the peaks of the trusses prior to truss installation. The anchors can remain in place throughout roof construction—even throughout the lifetime of the roof—allowing for protection of workers engaged in roof maintenance and repair, years after construction is complete ("Trus-T" 1994). Fig. 3 illustrates a sketch where an anchor is used with PFAS.

PFAS with Safe-T-Strap System

The Safe-T-Strap system (Liberty Safety Products, Markham, Ontario, Canada) is another variant of the standard PFAS. Fig. 3 serves to illustrate this system too. In this system, the anchor is a 5.08 cm (2 in.) wide strip of nylon webbing that has a D-ring on one end. The D-ring end is nailed and wrapped around a member of the house frame, and then the D-ring end serves as an attachment point for a worker's lanyard. The D-ring end can also be wrapped around an anchor as Fig. 3 illustrates. Following completion of construction, the final user of the strap can cut the strap off with a sharp knife, leaving nothing exposed on the exterior of the home ("Safe-T-Strap" 1997).

Combination Warning Line/Lifeline System

This system is a composite of the PFAS and warning line system, which is applicable to low-sloped roofs. Used in a jobsite in Kona, this system involves the installation of roof anchors 1.83 m (6 ft) from the roof edges. While this particular job site allowed approximately 9.14 m (30 ft) between anchors, Subpart M requires that the anchors be placed no more than 4.57 m (15 ft) apart for lifeline use. The lifeline, made of synthetic line or wire rope, is looped through each roof anchor. When the workers are above the line, they are able to walk freely, without any protection. As soon as they cross the line, the workers attach their lanyards to the lifeline, allowing for freedom of motion in the horizontal direction while they are working at the roof's edge.

Combination Roof Jack and Fall Restraint System

This method is HIOSH's proposed system to improve worker protection and contractor compliance. This system involves the use of roof jacks, either solely or in conjunction with a fall restraint system, and is used under the conditions outlined in Table 5. Fig. 4 is a sketch illustrating the roof jack. Essentially the roof jack is a 2 × 2 in. lumber fixed to the edge of the roof (the eave). The philosophy of the roof jack is that a worker slipping from the roof may be able to use the roof jack as a restraining device.

A fall restraint system is similar to PFAS, but allows the worker to hook up his or her front or side, instead of his or her back, and also reduces the strength requirement of the anchorage from 2,270 N (5,000 lb) to 1,362 N (3,000 lb) ("Draft" 1997).

Use of Scaffolds and/or Work Platforms

Ellis (1993), a noted fall protection expert, explains that the best way of protecting workers from falls is to follow a hierarchy of fall protection. This hierarchy starts with elimination of the fall hazard, if possible, then moving on to prevention through such passive means as guardrails, then to restraint through PFAS, and finally to warning of fall hazards when nothing else can be done.

One method of eliminating the fall hazard is to work from scaffolds and/or work platforms, to reduce the fall height below the 1.83 m (6 ft) limit. The use of work platforms was observed during truss installation on two jobsites, by placing the platforms inside the second-story exterior frame walls. The most common platform observed was the sawhorse scaffold, which involved two or three 5.08 × 30.48 cm (2 × 12 in.) planks placed side by side on top of two standard sawhorses, elevating the worker approximately 0.91 m (3 ft) from the deck. For the typical worker, this platform placed his or her

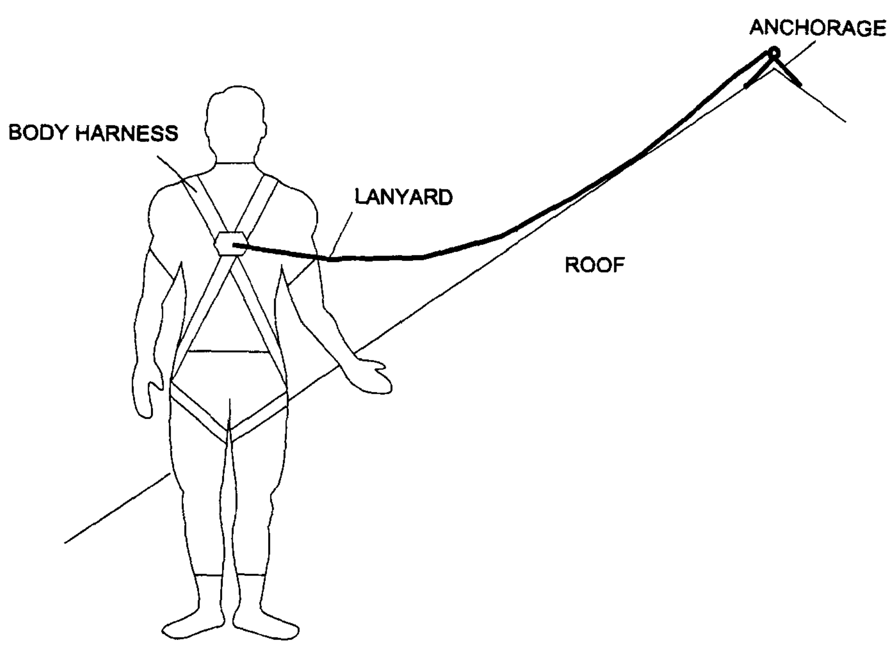

FIG. 3. Illustration of Personal Fall Arrest System (PFAS)

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TABLE 5. Roof Jack and Fall Restraint System Requirements

Condition (1)	Slope (2)	Eave height (3)	Requirement (4)
1	≤6:12	≤7.62 m (25 ft)	Roof jacks only
2	>6:12	≤7.62 m (25 ft)	Roof jacks and fall restraint system
3	Any slope	>7.62 m (25 ft)	Conventional fall protection system

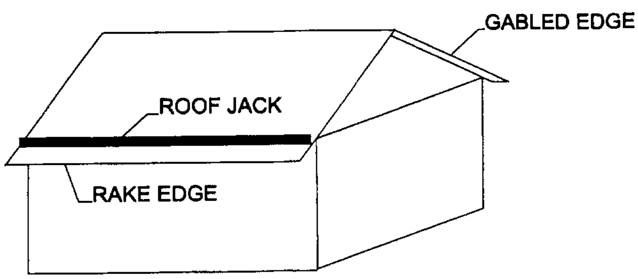

FIG. 4. Illustration of Roof Jack Placed above the Eave of a Sloping Roof

chest at the height of the top plate, allowing him or her to easily set and brace the trusses at chest height while working from the platform. Since the exterior walls were already framed in, the worker could use these walls as required to maintain his or her balance and to prevent falls to the ground below. Because the platform is less than 1.22 m (4 ft) in height, it is not considered a scaffold under OSHA construction standards; consequently, the interior side of the platform requires no guardrails. Fig. 5 illustrates a work platform used on construction sites for roof and roof truss work.

To use platforms during truss installation, the typical sequence of residential roof construction must be slightly altered. The typical sequence involves construction of both the exterior and interior second-story frame walls prior to truss installation. To allow room for the platforms, most of the interior second-story walls must be installed after truss installation is complete.

Prefabrication

Another method of eliminating the fall hazard is through prefabrication of the roof system on the ground. Prefabrication was used on one jobsite in central Oahu. At this site, only the truss system was prefabricated; sheathing and roofing application were accomplished after the truss system was lifted into place. Since the truss system is installed on the ground, there is no need for workers to walk the top plate. They can erect and brace the trusses from the ground or from short platforms. If sawhorse scaffolds are also erected around the interior of the house, as described previously, then the workers can use them as platforms when placing the truss system onto the frame walls. The workers would thereby be positively protected 100% of the time during truss installation. Prefabrication can also result in quicker completion of the roof system. Typical roof construction involves 12 days: prefabrication could reduce this requirement to 9 days, as truss installation can occur simultaneous to second-story framing. Likewise, truss installation proceeds more rapidly, as productivity increases, because the workers are able to focus on the work instead of their poise and balance. Fig. 6 illustrates a typical prefabrication yard for roof trusses for residential buildings.

Results of System Analysis

Each of the selection criteria was assessed a weight based on its relative importance to each of the three parties (employers, labor, and enforcement), with 1 meaning "of importance" and 2 meaning "of great importance." Each party's importance factors and the total factors are presented in Table 6.

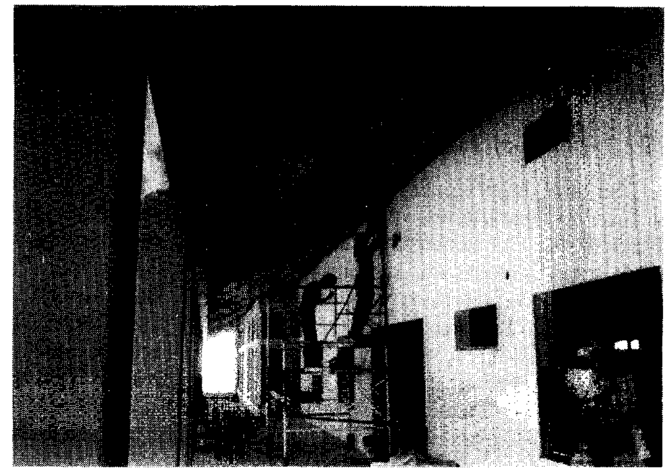

FIG. 5. Illustration of the Type of Work Platform Used for Installation of Roof Trusses

FIG. 6. Typical Prefabrication Yard to Manufacture Roof Trusses for Residential Buildings

TABLE 6. Relative Importance of Selection Criteria

Party (1)	Degree of feasibility (2)	Degree of simplicity (3)	Degree of economy (4)	Degree of flexibility (5)	Degree of passivity (6)	Degree of protection (7)
Employers	2	1	2	1	1	—
Labor	1	2	1	1	2	1
Enforcement	1	1	1	—	—	2
Total importance factor	4	4	4	2	3	3

Each of the discovered systems was then assessed scores from -2 to $+2$ for each criterion. The resulting criteria scores were then multiplied by the total importance factors given in Table 6 to produce weighted criterion scores. These scores were then summed to produce an overall system score in the range of -40 to $+40$. The results are given in Fig. 7.

The results show that prefabrication best meets the various parties' criteria. If modified and adapted for the entire roof system assembly, prefabrication could prove to be an effective method of fall prevention through the elimination of fall hazards. While only slightly feasible (as most home builders do not have cranes in their equipment inventory), prefabrication was found to be highly economical, highly protective, highly passive, moderately simple, and moderately flexible.

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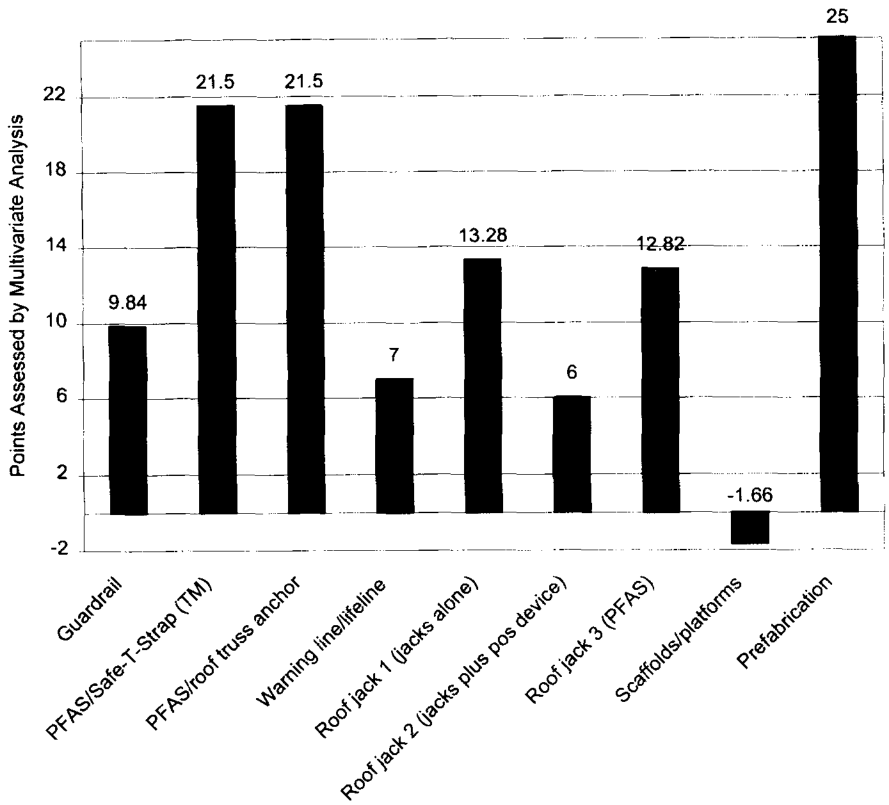

FIG. 7. Relative Strength of Fall Protection Systems

The next most promising systems are the PFAS variants. PFAS are highly feasible and protective and moderately simple, economical, and flexible. Still, these systems only achieve slightly more than half of the total points available. Their principal disadvantage is their low degree of passivity. These systems require frequent worker involvement, which also detracts from worker productivity.

The roof jack system also seems to be a promising system of fall protection under Conditions 1 and 3, receiving almost a third of the positive points. Under Condition 3, this system is very similar to the PFAS variants, except that it is not as flexible nor as economical. Under Condition 1, the roof jack system only has one disadvantage, that is, the degree of worker protection. Because the gabled edges of roofs are left unprotected, and this system is allowed at slopes exceeding 4:12, this system does not offer workers the same degree of protection as they are afforded under Subpart M. However, it is highly feasible, somewhat economical, quite passive, and moderately flexible.

Unfortunately, none of the systems discovered during this investigation were able to meet all of the criteria. Perhaps further investigation is warranted. Nevertheless, prefabrication, PFAS variants, and the roof jack system under low-sloped conditions appear to have enough support from the residential roof construction community to be self-sustaining, if a jump start is given.

CONCLUSIONS

The following conclusions can be drawn from the research:

1. Falls continue to be a serious issue that concerns contractors, labor, and enforcement. Therefore, protection of residential construction workers from fall hazards is vital. Workers themselves feel that positive protection is needed while working on all roofs having slopes exceeding 4:12.
2. The current state of compliance is poor, as observed during jobsite inspections. Compliance increases with external supervision—the single-homeowner sector has the worst state of compliance and the public sector has the best.
3. The character of noncompliance is varied, involving all parties in the residential construction industry. Factors of noncompliance include
   - The degree of competition found in the residential construction industry, as characterized by attempts to minimize costs and maximize productivity, sometimes at the expense of safety.
   - Worker behavior, caused primarily by concerns to increase productivity and comfort. Workers will comply with regulations if they feel a personal concern for their safety that outweighs their concerns for speed and comfort.
   - Design difficulties, such as vaulted ceilings, which may result in greater hazards to protect employees than to allow them to work unprotected under a fall protection plan.
   - Conventional construction methods, which call for techniques, such as walking the top plate during truss installation.
   - Lack of knowledge and training, for both the contractor and the worker.
4. The new fall protection regulations under Subpart M are cumbersome and difficult for workers and contractors alike to understand and to implement, especially for residential roof construction. The resulting confusion has led contractors and workers to believe that they are in compliance when in fact the inspections show otherwise. The fall protection plan is particularly misunderstood.
5. To improve worker protection, the following courses of action have support from the residential construction community:
   - Developing innovative methods of protection
   - Increasing worker and contractor training
   - Subsidizing costs of fall protection systems

- Increasing cooperation with HIOSH
- Changing the safety culture in residential construction
- Increasing regulatory oversight, especially in the single-homeowner sector

6. While current fall protection regulations stress that employers must protect their workers from falls, they do not emphasize the hierarchy of fall protection: eliminate the hazard, prevent the fall, arrest the fall, and finally, provide warning.

   If followed, we conclude that this hierarchy can result in the development of alternative methods of construction (such as prefabrication), which may prove both feasible to the contractor and protective of the workers.
7. For fall protection systems to be implemented on residential construction projects, they must be feasible, simple, economical, passive, protective, and flexible. No single available system meets every criterion. Those coming closest are prefabrication, PFAS, and the roof jack system.

RECOMMENDATIONS

Based on the preceding conclusions, the following recommendations are proposed to improve the protection of residential roof construction workers from falls:

1. Reduce the complexity of the regulations. Currently, residential roofers must comply with the requirements of §1926.501(b)(10) *Roofing work on low-slope roofs*, §1926.501(b)(11) *Steep roofs*, or §1926.501(b)(13) *Residential construction*. Each of these subparagraphs outlines different requirements, making it difficult for the residential roofing to know which one applies. Additionally, the fall protection plan regulation, §1926.501(k), currently does not require a thorough hazard analysis from contractors who use it. Therefore, the regulations should be changed as follows:
   - Redefine the exception for "residential construction" as "lightweight framing construction," defined to include frame wall erection, joist and truss installation, and floor and roof sheathing. This reduces the options available to roofing contractors.
   - Require contractors using the fall protection plan to include an examination of each of the protection measures in the hierarchy of fall protection.
2. Provide incentives for compliance. Through increased cooperation through voluntary compliance programs, discounts on workers' compensation rates, fall protection equipment subsidies or tax credits, and so on, the state of compliance can be increased without increasing enforcement.
3. Increase the oversight, if not the enforcement, of the single-homeowner sector, by requiring special permits for renovations and home repair, increased involvement from risk managers or owners, making licensing requirements more stringent, and increasing the amount of fines issued.
4. Develop a cooperative education program for contractors and workers alike. In a voluntary program, provide training in hazard analysis and the hierarchy of fall protection, followed by a certification of safe work practices that would allow for reduced regulatory inspections.
5. Improve the residential construction safety culture at all levels, from the worker to the developer to the individual homeowner. This can be accomplished by emphasizing the dangers inherent to residential roof construction through increased fines for unsafe work practices, dramatic training programs involving injured workers, and targeting the children of construction workers through coloring books aimed at identifying workplace hazards.
6. Finally, innovative methods of protecting the workers must be developed. As discussed previously, none of the methods found during the investigation meets all the criteria established by contractors, workers, and enforcement. An independent hazard analysis should be conducted for each phase of construction to determine appropriate methods of fall prevention and/or protection.

Need for Change

In summary, the current state of compliance and worker protection from fall hazards in the residential construction industry is poor. Six recommendations have been offered for improving the protection of residential roof construction workers. Each of the six recommendations can be effective and offer some improvements. The most dramatic improvement would result by implementing all of them together, but that may not be possible. Regardless, something must be done to initiate voluntary compliance. Business as usual will not result in fewer fall accidents. Confusion reigns in the residential construction industry regarding the application of fall protection standards, and often, this results in the worker failing to be protected from fall hazards. Sadly, falls remain the number one killer in construction. Why are we willing to risk the life of one worker in this debate? Now is the time for action. Only through a concerted effort of the entire community can residential construction workers be protected from the fall hazards they face daily.

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APPENDIX I. JOB SITE INSPECTION SHEET

Job Site Inspection Sheet

Date of inspection: ______________ Location: ________________________

Ownership: PRIVATE PUBLIC

Type of construction: NEW RENOVATION REROOFING

Number of units: ONE MULTIPLE

Type of units: SINGLE-FAMILY HOME TOWNHOME CONDOMINIUM UNITS
COMMERCIAL BUILDING/RESIDENTIAL ROOF

Stage of roof construction: FRAMING SHEATHING ROOFING COMPLETE

Type of roof:

Slope: ____:12

Material: ASPHALT CEDAR TILE METAL OTHER

Shape: GABLE HIP

Overall Compliance:

	Not Observed	Never	Seldom	Some-what	Mostly	Always
Supervisory enforcement level						
Worker compliance level						

Methods Used:

PFAS: ________________________

Guardrails: ________________________

Scaffolds: ________________________

Fall protection plans: ________________________

Other: ________________________

Photographs: ________________________

ACKNOWLEDGMENTS

The writers wish to acknowledge research grant No. 4-34599 from the Hawaii Occupational Safety and Health Division (HIOSH) of the Hawaii Department of Labor and Industrial Relations. Additionally, as a participant in the U.S. Navy Postgraduate School's Civilian Instruction Program, Lieutenant Johnson was assigned to study construction management at the University of Hawaii at Manoa for a full year. Without this generous, supported time away from other naval duties, this investigation would not have been possible.

APPENDIX II. REFERENCES

"Custom event profile for falls in residential construction in 1995."(1997a). Dept. of Labor and Industrial Relations, Honolulu, Hawaii.

"Custom report of fall protection citations for residential construction." (1997b). Hawaii Occupational Safety and Health Admin., Honolulu, Hawaii.

"Draft guidelines for fall protection in residential roof construction." (1997). Hawaii Occupational Safety and Health Admin., Honolulu, Hawaii.

Ellis, J. N. (1993). *Introduction to fall protection*, 2nd Ed., American Society of Safety Engineers, Des Plaines, Ill.

Freund, J. E., and Williams, F. J. (1972). *Elementary business statistics*. Prentice-Hall, Inc., Englewood Cliffs, N.J.

"Interim fall protection compliance guidelines for residential construction." (1995). *OSHA Instruction STD 3.1*, Occupational Safety and Health Admin., Washington, D.C.

Johnson, H., and Singh, A. (1997). "Residential roof construction fall protection analysis and recommendations." *Res. Rep. No. UHM/CE/97-06*, Univ. of Hawaii, Honolulu, Hawaii.

"Safe-T-Strap: The engineered fall protection system for the construction

J. Constr. Eng. Manage., 1998, 124(5): 418-428

worker.'' (1997). Liberty Safety Products, Markham, Ontario, Canada.
''Safety standards for fall protection in the construction industry; final rule.'' (1994). 29 CFR Parts 1910 and 1926, *Federal Register*, 59(no. 152; August 9), Part III, 40672–40753.
Stanley, J. W. (1995). OSHA Memorandum on Proper Application of Fall Protection Plan Criteria in Subpart M, Occupational Safety and Health Admin., Washington, D.C.
The fall protection compliance manual. (1995). Nat. Assn. of Home Builders, Washington, D.C., 1995.
''Trus-T fall protection anchor points.'' (1994). Guardian Metal Products.

J. Constr. Eng. Manage., 1998, 124(5): 418-428