Risk Assessment of Panelized Wall Systems in Residential Construction Using Critical Incident Technique

Hyung N. Kim, Maury A. Nussbaum, Hyang Seol, Sunwook Kim and Tonya L. Smith-Jackson

Proceedings of the Human Factors and Ergonomics Society Annual Meeting 2006 50: 2222
DOI: 10.1177/154193120605001907

RISK ASSESSMENT OF PANELIZED WALL SYSTEMS IN RESIDENTIAL CONSTRUCTION USING CRITICAL INCIDENT TECHNIQUE

Hyung N. Kim, Maury A. Nussbaum, Hyang Seol, Sunwook Kim, and Tonya L. Smith-Jackson
Grado Department of Industrial and Systems Engineering
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

Panelized wall systems are now extensively utilized in residential construction, which is recognized as a high-risk industry. A considerable number of construction injuries are reported every year. According to Occupational Safety & Health Administration (2005), 38,000 construction injuries occur each year. Safety on construction sites may not have the highest priority, as emphases of the construction industry are more on speed, efficiency, and economy. Furthermore, panelized wall systems have not been investigated in terms of hazard analysis. The primary purpose of the study was to identify the hazards related to panelized wall systems and to provide recommendations to improve the construction work environment. A critical incident technique was used to identify hazards through video-based observation, and the identified hazards were classified into five categories with twelve subcategories. Recommendations were provided for the hazards in each category. Based on the outcomes of the critical incident technique, risks associated with panelized wall systems were assessed using the MIL-STD-882B Risk Assessment Matrix.

INTRODUCTION

A panelized system in residential construction refers to pre-manufactured components (pre-assembled walls) used in constructing residential homes (Partnership for Advancing Technology in Housing, 2000). Speed, efficiency, and economy are the needs for building construction industry under the present circumstances (Lindow & Jasinski, 2001). Panelized systems meet these requirements and are a fast-growing segment in the construction industry market (Lindow et al., 2001). Many residential houses are currently built using panelized systems.

However, residential construction is known as a high-risk industry, which needs a strong commitment by management to encourage safety and health issues (Gilkey et al., 2003). It is reported that 38,000 construction injuries occur each year (Occupational Safety & Health Administration, 2005). According to the Occupational Safety & Health Administration (2005), it is estimated that 1.6 million Americans are hired in the construction industry and half of them work in residential construction. A number of residential construction workers are expected to have suffered occupational injuries.

The construction system associated with pre-assembled walls has not been seriously investigated in terms of hazard analysis, despite the fact that a large number of injuries occurs every year in residential building construction. Therefore, the panelized system, as one of the increasing trends in residential construction, was investigated to identify and prevent potential hazards.

METHODS

Participants

Three small-sized residential construction companies and 15 of their workers were invited to participate in the current study. All participants were physically healthy male adults. Three to five workers from three construction sites were videotaped while working at the construction site. In general, they worked as a team of three to eight individuals. A group of workers was comprised of both experienced workers and novice. The workers worked from 7 o'clock in the morning to sunset without a regular break.

Materials and Equipment

A digital video camera was used to record the workers performing construction tasks. A small palm-sized camera was used with minimal interruptions to the construction workers while working. Panels handled by workers in the current study varied in terms of width (0.15-4.5m), height (0.9-3.3m), and weight (16.5-98.6kg). In addition, main tools used by the workers were a nail gun, circular saw, ladder, tape measure, and hammer.

Procedure

An observer was located near the residential construction sites. The workers' activities associated with the residential construction were videotaped by the observer. The videotaping took about 3 hours for each construction site. Both supervisors and workers were informed in advance of the investigation and permission was obtained to videotape the work site. Therefore, the presence of investigators' activities such as the videotaping was not unfamiliar to the workers.

However, the observers kept their distance so as not to interrupt the construction workers. Additionally, it was ensured that no interruption occurred such as follow-up questions while construction workers were working. Audio recording was not included in the video tapes. The observations were performed for four days throughout the duration of work each day at on-going residential construction sites around Washington, D.C.

Data Analysis

The video tape showed how the construction workers performed their daily work activities. Observations from the video tape were analyzed using the critical incident technique to discover occupational hazards in residential construction, especially those associated with the panelized system. Identified critical incidents were categorized into five activities which are lifting, carrying, hoisting, holding, and fixing. Recommendations were provided for the incidents in each category. In addition, we measured the frequency of each incident, which was used to compute the level of risk using the Risk Assessment Matrix (U.S. Army, 1990). Each incident was classified according to the definitions in Table 1 and the critical incidents method was performed.

Table 1. Five categories of construction tasks of the panelized system

Category	Definition
Lifting	A worker grabs the panel and pulls it out of a stack of panels.
Carrying	A carry is performed after the "lifting" action. A worker moves the panel to the designated location.
Hoisting	After the carrying activity, a worker turns the panel from a horizontal to a vertical orientation and puts the panel into the desired spot.
Holding	A worker maintains the panel vertically after the hoisting task is completed.
Fixing	While a worker is holding the panel, the other worker is nailing to fix the panel.

RESULTS

Once the incidents were classified into the 5 categories, each incident was broken down into detailed subcategories. Based on the category system, a table (see Table 2) was developed with six columns labeled Category, Condition, Actions, People, Place, and Recommendation (CCAPPR). The detected critical incidents were organized into the CCAPPR table. For example, an activity was observed where a person was carrying a panel over uncovered holes on the work site ground (Figure 1, left). This case was allocated into the category "carrying". In another instance, a worker was fixing panels on the top without a life line (Figure 1, right), which was allocated into the category "fixing". The circumstances around the work site were described in the column "conditions," and relevant hazard(s) were entered in the column "actions". Using the same procedure, the remaining columns were completed.

Figure 1. Samples of video captured incidents at the residential construction sites. Carrying over uncovered holes on the work site (left) and fixing on the top without a life line (right)

The critical incidents revealed by the present study were 71 cases that were classified into five main categories with twelve subcategories (see Table 3). In addition, the frequency of the critical incidents was calculated within each main category.

Hazard levels for the incidents in each category were assessed in terms of risk. The risk was measured using the MIL-STD-882B Risk Assessment Matrix (U.S. Army, 1990). The matrix (Figure 2) was combined with the 'frequency of occurrence' and 'severity'. According to U.S. Army (1990), the frequency of occurrence and severity are defined as following:

Frequency of occurrence (letters A-E)

A. Frequent: Expected to occur frequently.
B. Probable: Will occur several times in the life cycle.
C. Occasional: Will occur sometimes in the life of an item.
D. Remote: Unlikely, but possible.
E. Improbable: Very unlikely…can assume it won't happen.

Severity (represented by numbers 1- 4)

1. Catastrophic: Death, system/massive property loss, irreversible environmental damage.
2. Critical: Sever injury, illness, major system damage, or reversible environmental damage.
3. Marginal: Injury requiring medical attention, illness, system damage, environmental damage that can be resolved and reversed quickly.
4. Negligible: Possible minor injury, minor system damage, minimal environmental damage.

Frequency of Occurrence	Severity			
	(1) Catastrophic	(2) Critical	(3) Marginal	(4) Negligible
(A) Frequent	1A	2A	3A	4A
(B) Probable	1B	2B	3B	4B
(C) Occasional	1C	2C	3C	4C
(D) Remote	1D	2D	3D	4D
(E) Improbable	1E	2E	3E	4E

Risk Categories: High Serious Medium Low

Figure 2. MIL-STD-882B Risk Assessment Matrix (U.S. Army, 1990)

We computed the 'frequency of occurrence' by considering the frequency of observed critical incidents (Table 4). The 'severity' for each incident was subjectively determined by the investigators. Thus, the risk level (see Table 5) was assessed in combination with the 'frequency of occurrence' and 'severity' (see Equation 1).

Risk = Frequency of occurrence * Severity (1)

Table 4. Frequency of occurrence is determined by frequency of observed critical incidents.

Frequency of observed critical incidents	Frequency of occurrence for matrix
Between 50% and100%	(A) Frequent
Between 5% and 50%	(B) Probable
Between 2% and 5%	(C) Occasional
Between 1% and 2%	(D) Remote
Between 0% and 1%	(E) Improbable

DISCUSSION

The primary purpose of the study was to investigate potential hazards in a residential construction site associated with panelized systems. The current study identified substantially hazardous incidents involved with lifting, carrying, hoisting, holding, and fixing activities.

In terms of the frequency of occurrence, inappropriate handling of the nail gun was a prominent issue. Due to the extensive usage of the panelized-wood walls, the nail gun was frequently used to fix the wood frames. However, although it is required to use the nail gun with caution, risky operations often occurred at the workplace such as pointing the nail gun toward co-workers and carrying it by its cord/wire. Accidental firing could hurt workers or coworkers. Proper use of the nail gun should be instructed to the nail gun operators.

In addition, according to the results of the risk assessment in this study, the hoisting and holding activities were recognized as high risk in comparison with other activities (i.e., lifting, carrying, and fixing). For instance, some workers worked on the top floor to hoist/hold the heavy panels; however, they were not provided with a life line to hold their body when they were working at the edge of the floor. Furthermore, irrelevant people were allowed near the workplace while a heavy panel was hoisted or held. A fallen panel could hurt the individuals passing by. Thus, a barrier needs to be installed to keep out other people (e.g., non-workers). The barrier and life belt are the minimal proactive protection from injuries/death, which even a small-sized residential construction company should provide for their workers.

There are several recommendations for considering the identified hazards by this current study. First of all, the CCAPPR table (see Table 2) provides a set of classified hazards, which could come to a 'safety checklist' for the panelized system of a residential construction. Additionally, the CCAPPR table offers recommendations for each type of possible incidents in the panelized construction work system. The recommendations could be transferable to a set of 'guidelines' for the panelized work system environment. Finally, based on the guidelines provided by this current study, future research might set up a web-based system with easily available guidelines, which accommodates the needs of construction designers/managers.

ACKNOWLEDGEMENTS

This study is associated with the Virginia Tech Center for Innovation in Construction Safety and Health, which is funded by the National Institute for Occupational Safety and Health (NIOSH).

REFERENCES

Gilkey, D. P., Keefe, T. J., Hautaluoma, J. E., Bigelow, P. L., Herron, R. E., & Stanley, S. A. (2003). Management commitment to safety and health in residential construction: HomeSafe spending trends 1991-1999. *Work, 20*, 35-44.

Lindow, E. S. & Jasinski, L. F. (2001). Panelized wall construction: design, testing, and construction procedures. *Symposium on Performance of Exterior Building Wall, AZ, USA*, 231-241.

Occupational Safety & Health Administration (2005). Residential Construction Industry. http://www.osha.gov/SLTC/residential/index.html [On-line].

Partnership for Advancing Technology in Housing (2000). *Panelized Systems in Redidential Construction.*

U.S. Army. (1990, June). *System Safety Management Guide*, Pamphlet 385-16. Washington, DC: Department of the Army.

Table 2. Samples of CCAPPR.

Category	Conditions	Actions	People	Place	Recommendation
Lifting: Inappropriate clothes & no PPE	A worker's t-shirt is tucked out and loose in hot weather. He is lifting up a panel without a hard-hat or gloves.	[PPE Hazard] While a panel is lifted, loose t-shirt might be caught and the worker could fall.	A worker is lifting panels. He takes off his shirt and ties it around his head.	Construction site is the top floor. There is no shade to take a rest. Weather is sweltering.	Workers should have their clothes tucked in. Wear proper apparel for the task. Loose clothing can become caught. Take a break regularly.
Carrying: Remove unused tools and other materials on the floor	There are several small pieces of wood on the work surface.	[Trip Hazard] Workers' foot is more likely to be caught on the wood, which may lead to a trip and fall.	Numbers of workers are rushing to carry panels.	2^{nd} floor, Residential construction work site. There is no exterior scaffoldings/ guard rail.	The construction work site should be cleaned and other objects not related to the relevant work should be removed.
Hoisting: Block unrelated people from work site(s)	A person is walking behind the panel which workers are hoisting and holding.	[Crash Hazard] The panel may accidentally fall down toward him. The person walking behind the panel gets jammed.	The person walking behind the panel is not involved with the hoisting project.	The heavy panel was held by several workers who did not see the person who is wandering behind the tall/wide panel.	Keep all people not involved with the work at a safe distance from the work area.
Holding: No life line	Two workers are holding the panel at the edge of floor. The work is on the 2^{nd} story. There is no life line.	[Fall Hazard] The weight of an exterior panel is about 98.9 kg. If a worker cannot keep the panel under control, he might lose his balance and fall down with the panel.	Due to the small sized of the residential company, only 1-2 workers generally take the task of 'holding'.	The exterior panels which are heavy and big (e.g., 98.9kg and 3m x 2.4m) need to be installed.	A life belt should be located for the holding activity. Additionally, more than two workers should get involved.
Fixing: Operation with a Nail gun	A worker climbs a ladder to get the top of panel and then he pulls up the gun nail with the cord/hose. Coworkers are working nearby.	[Fall Hazard] The nail gun may be disconnected from the cord and fall down on the coworker's head.	During the fixing activity, one worker handles the nail gun and the other is often holding the panel or helping the operator right next to him.	The work is to drive the nails on the top surface of the panels.	The operator of the nail gun (or heavy tools) should never carry a tool by the cord/hose. They might need to firmly attach the nail gun to their belt.

Table 3. Summary for the frequency of critical incidents in each category.

Category	Subcategory	*n* (%)
Lifting	Awkward work position	2 (18.0)
	Unused tools/materials on the work surface	1 (9.1)
	Inappropriate clothes	1 (9.1)
	No personal protection equipment (PPE)	2 (18.2)
	Over worker’s physical capability	4 (36.4)
	Unstable work surface (working on the top of panel stock)	1 (9.1)
	Sub-total	11 (100%)
Carrying	Unused tools/materials on the work surface	5 (56)
	Bad management of electric wires	2 (22)
	Over worker’s physical capability	1 (11)
	Unstable work surface (hole)	1 (11)
	Sub-total	9(100%)
Hoisting	Unrelated people at work site	2 (16.7)
	No barrier to keep non-workers out	7 (58.3)
	No life line	3 (25.0)
	Sub-total	12(100%)
Holding	No barrier to keep non-workers out	7 (50)
	No life line	7(50)
	Sub-total	14(100%)
Fixing	Awkward work position	3 (12)
	Bad management of electric wires	1 (4)
	Inappropriate clothes	2 (8)
	No life line	1 (4)
	Failure of using a nail gun	12 (48)
	No personal protection equipment (PPE)	6 (24)
	Sub-total	25(100%)
	Total	71

* n: number of observed instances

* %: percentage of occurrence within each category