International Journal of Industrial Ergonomics 68 (2018) 73–81

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Development of an observational checklist for falling risk assessment of high-voltage transmission tower construction workers

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ARTICLE INFO

Keywords:
High-voltage transmission tower construction
Observational checklist
Falling risk assessment
Movement
Stability
Fall protection measure

ABSTRACT

Falls from elevation have been reported to cause the highest number of fatalities in the Taiwan construction industry, accounting for 43.53% of all construction worker fatalities for the period from 2006 to 2015, inclusive. High-voltage transmission tower construction is a high-risk operation due to the construction site locations, extreme climatic factors, elevated working surfaces, and narrow working space. However, the factors contributing to the risk of falls in high-voltage transmission tower construction work have not been characterized. This paper describes the development and application of an observational checklist for assessing exposure to fall risks. Three contributing factors, movement, stability, and fall protection measures, were characterized based on the suggestions of ergonomic experts, interviews of supervisors and workers, and on-site observations. Inter-observer reliability test results showed that inter-observer reliability of the observational checklist was acceptable to excellent. A pilot study assessing five primary construction operations suggested that position shifting, wherein workers were found to have frequent exposure to the whole-body movement level and spent the least time in a tied-off full body harness, was the operation with the highest fall risk. These results demonstrated that the observational checklist can be used to identify specific construction operations with fall hazards.

1. Introduction

Taiwan has more than ten thousand high-voltage transmission towers, and a major portion of the towers need to be maintained annually or rebuilt. As shown in Fig. 1, high-voltage transmission towers are constructed in a wide variety of shapes and sizes, with a typical height ranging from 60 to 70 m. Most of these high-voltage transmission towers are located on remote, exposed mountainsides at elevations of 600 to 1000 m. To construct such towers, workers have to climb up and down the tower, carry the steel components, and deliver them manually, using a mall winch instead of a crane. Due to the locations of the construction sites, extreme climatic factors, elevated working surfaces, and narrow working space, high-voltage transmission tower construction is a high-risk operation. Slope has been shown to have a negative impact on worker productivity (Apud and Valdes, 1994) and workload (Kirk and Parker, 1993, 1994; Kirk and Sullman, 2001; Sullman and Byers, 2000). Differences in the physiological responses of high-elevation and ground-level workers have also been reported (Mao et al., 2000). Hsu, Lin, Lee and Chen (Hsu et al., 2016) recently demonstrated that despite similar task workloads at various working surface heights, tower construction workers perceived an increased level of mental stress as working surface height increased due to the sense of insecurity and uncertainty, the working environment, and visual issues. Some easy ground-level tasks become more difficult when performed in high-elevation workplaces (Steven and Mohamed, 1979).

In the year 2016, 937 workers in the construction industry of the United States died on the job, comprising 19.38% of all fatal work injuries, which is far more than in any other industry, and over one-third (364) of those workers died due to falls, slips and trips (U.S. Department of Labor, 2016). An examination of the number of deaths by industry in Taiwan revealed that the construction industry represented the second-largest share (18.54%) of the 6432 deaths for the years 2006–2015, inclusive (OSHA, 2016). A further investigation of the death toll by accident type showed that falls from elevation, slips, and trips cause the highest number of injuries and fatalities in the Taiwan construction industry, accounting for 43.53% of all construction worker fatalities in the past 10 years (OSHA, 2016). Chi, Chang and Ting (Chi et al., 2005) reported that falls from scaffolds, accounting for approximately 30.4% (189 cases) of accidents, are a leading cause of injury in the Taiwan construction industry, and falls from scaffold

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https://doi.org/10.1016/j.ergon.2018.06.011
Received 6 March 2018; Received in revised form 21 June 2018; Accepted 27 June 2018
0169-8141/

Fig. 1. The primary structure of a high-voltage transmission tower with a height of 62 m.

staging are associated with a lack of compliance in scaffold design and construction as well as bodily actions (e.g., climbing, walking, and leaning). Overexertion and fall injuries constitute the largest categories of injuries among scaffold workers (Cutlip et al., 2002).

The primary structure of a high-voltage transmission tower is a steel lattice, which is used to support overhead electricity conductors for electric power transmission. As shown in Fig. 2, while working on a high-voltage transmission tower with a typical height exceeding 60 m, workers have to stand on steel bars that are 15 cm wide while conducting lifting, delivery, and assembly tasks manually. In such an extremely elevated and rather limited standing space, high-voltage transmission tower construction workers are at greater risk of falling and suffer from more fear of heights than those who typically perform high-rise building construction activities on scaffolds or on flat and broad floors, even when equipped with a safety harness.

Fig. 2. The workspace of high-voltage transmission tower construction operations.

In Taiwan's construction industry, it is common for several subcontractors to contribute to one construction project, resulting in ineffective and inconsistent management of safety and health due to diversification of activities (Chang et al., 2009; Teo et al., 2005). Thus, with higher numbers of subcontractors, the probabilities of insufficient communication, coordination and control will increase (Debrah and Ofori, 2001; Rowlinson, 1997). Furthermore, the main contractors may shift all the safety responsibilities to subcontractors and may not ensure that the subcontractors are capable of providing a safe working environment (Wilson and Koehn, 2000). Moreover, construction projects generally require many skilled workers of different occupations during different work periods. For this reason, high-elevation construction workers are generally forced to either work on short contracts or at a particular construction site for a short period only. Unfamiliarity with the workplace further raises safety issues for high-elevation construction workers (Chang et al., 2009; Hsu et al., 2008). Studies of construction sites have shown that although many occupational safety programs target large firms, the construction industry is dominated by smaller firms (Kines and Mikkelsen, 2003), which are responsible for more deaths than large ones are (Kaskutas et al., 2009, 2010).

As described above, construction by its very nature is ergonomically hazardous, commonly requiring numerous awkward postures, heavy lifting, and other forceful exertions (Schneider and Susi, 1994), and falling from a scaffold is the major cause of death at a construction site. To determine the specific factors associated with falling risks in construction, studies to improve the quantification of exposures in construction work (particularly manual labor) are needed. Though high-voltage transmission tower construction workers are often required to assume non-neutral postures, perform strenuous manual material handling tasks, and operate hand and power tools, all of which might increase the risk of falls from scaffold structures, the factors contributing to the risk of falls in high-voltage transmission tower construction work have not been characterized. The objective of this study was to develop a method of characterizing the falling risk factors present in high-voltage transmission tower construction.

Several methods for quantifying ergonomic risk factors have been developed previously. These methods include various observational methods, as well as direct measurements using bioinstrumentation. Bioinstrumentation such as electromyography or electrogoniometry has rarely been used as a major tool for the collection of ergonomic hazards in construction for several reasons, including difficulties associated with worker mobility, obtrusiveness, and cost. In comparison to bioinstrumentation, observational methods, often developed for practitioners and adapted to the requirements of small and medium enterprises (SMEs) in the context of health and safety management at work, are easier to use, less costly, and more flexible when it comes to collecting data in the field. The most common observational techniques used to characterize ergonomic exposures are based on either time study or work sampling. Methods based on time study are usually used to create a continuous or semi-continuous description of posture and occasionally force level for estimation of the changes in the exposure level and the proportion of time a worker is at a given level (Buchholz et al., 1996). For this reason, such methods tend to be time intensive and are better suited for working with fairly short and easily-definable work cycles. The other approach, work sampling, involves observation of workers at either random or fixed, usually infrequent, time intervals and is more appropriate for non-repetitive work. Observations conducted during work sampling provide estimates of the proportions of time that workers in a particular job devote to different tasks, spend in various postures, and/or spend handling specified loads, although the sequence of events is lost (Buchholz et al., 1996).