Proceedings of International Structural Engineering and Construction, 9(1), 2022
State-of-the-art Materials and Techniques in Structural Engineering and Construction
Edited by Holschemacher, K., Quapp, U., Singh, A., and Yazdani, S.

ISSN: 2644-108X
www.doi.org/10.14455/ISEC.2022.9(1).CSA-04

RISK ANALYSIS OF FALLING FROM HEIGHTS IN THE GROWING CONSTRUCTION INDUSTRY

JEMA RICA LOPEZ, VANISSORN VIMONSATIT, and JOSHUA TUMBAGA

School of Engineering, Macquarie University, NSW, Australia

Based on the data released by the Australian Bureau of Statistics, the number of injuries and fatalities caused by falls from height (FFH) accidents at construction sites is one of the highest, making the construction industry relatively unsafe compared to other industries. This study has been made to find out the most common causes, probabilities, and appropriate mitigation measures in construction fall incidents in New South Wales (NSW), Australia. The findings obtained from NSW Construction Blitz in 2019 was used to analyze the probability of the common potential causes of falling from ladders, voids and edges, scaffolds, formworks and, mobile scaffolds and fall restraints. Five fault tree (FT) diagrams were used to illustrate various accident causes in order to determine the probability of risk of FFH in NSW. Following that, a schematic modeling was entered into Genie software for results validation and to determine the main contributor of FFH incidents. From this study, falling from voids and edges has the highest likelihood of falls in NSW with a probability of 27.15%. This is followed by falling from mobile scaffolds and fall restraints with 7.92%, which is closely followed by falling from scaffolds with 7.68%. While falling from ladders and falling from formworks were not too far behind, with 2.17% and 1.05% respectively. Preventative measures were then discussed for FFH accident scenarios. These findings will aid in the prevention of particular incidents and increase the overall level of safety on construction sites in NSW.

Keywords: Fall from ladders, Fall from voids, Fall from edges, Fall from scaffolds, Fall from formworks, Fall from mobile scaffolds, Falling from fall restraints.

1 INTRODUCTION

Slipping, tripping, and falling events in the construction business have gotten a lot of attention and investigation due to their significance and frequency. However, falling from height continues to have the highest rates among construction accidents when compared to other types of accidents and occurrences in other industries (Nadhim *et al.* 2016). Construction fall incidents are well known to have major financial and humanitarian consequences for the construction sector. It can result in a variety of issues, including worker demotivation, disruption of site activities, project delays, and a negative impact on the construction industry's total cost, productivity, and reputation (Hanapi *et al.* 2013). As a result, improving safety in the construction business is critical. In Australia, FFH was responsible for 12% of occupational deaths in 2013 (Hu *et al.* 2011) with the construction industry having 5.6 fatality rate per 100,000 employees just couple of years ago, which is more than twice the average for all industries (Khodabandeh *et al.* 2016). It is a commonly overlooked but serious hazard that has long been noted as a significant injury problem in epidemiological data.

With the growing numbers of fall-related workplace accidents, it is necessary to study and develop a quantitative risk analysis approach for the construction sector. This paper aims to

conduct a risk assessment and develop fault trees for different fall accident scenarios to illustrate FFH accident probability in NSW.

2 NSW CONSTRUCTION INDUSTRY IN RELATION TO FFH

This section provides a background overview of recent FFH data in the NSW construction sector. According to Safe Work NSW (SafeWork NSW 2020), falling from heights is the number one cause of death in the construction industry of NSW. Due to the rising numbers of concern in FFH in the NSW construction sector, the FFH construction blitz was initiated by Safe Work NSW since 2017 across the state, having visited over a thousand sites with the goal of raising public awareness about the dangers of working at heights and educating employers and workers, while ensuring compliance on safety procedures. The blitz was prompted by a threefold increase of recorded FFH accidents from 129 in 2013 to 476 in 2017. According to event reports from the time period, 61% of FFH accidents occurred between the heights of 2.1 and 4 meters.

A large number of visited sites were found to have a relatively high risk of falls attributed to poor scaffolding and unprotected voids and edges. Safe Work NSW inspectors focused on scaffoldings and formworks components, adequate protection of voids and edges, use of ladder for appropriate activities, recordkeeping and proper safety planning and management. Despite the progress in some areas in terms of safety, the amount of noncompliance for different fall protection measures is still unacceptable, and workers continue to be seriously or fatally wounded.

3 METHODOLOGY

This study was developed to examine the interconnections between the increasing construction in NSW and FFH incidents using fault tree analysis by utilizing a wide range of data gathered from Safe Work NSW, specifically the 2017-2019 construction blitz. Compiled accident case documentation, safety compliance of more than a thousand sites, non-compliance issues and notices, probable causes and probabilities recorded were used to construct the five fault trees (FTs). Probabilities for each scenario were computed and schematic modeling was entered into Genie software for results validation.

Based on the obtained data (SafeWork NSW 2019), the most common potential causes and probabilities of FFH in ladders, voids and edges, scaffolds, formworks and mobile scaffolds and fall restraints were found as shown in Table 1. The causes were categorized into different factors: human, management and physical/environmental factor and were used as a code to present in the FT diagram. The FT for each accident scenarios: scaffolds, voids and edges, formworks, ladders, and mobile scaffolds and fall restraints, are presented in Figures 1, 2, 3, 4, and 5, respectively.

In determining, probable reasons of failure are carefully mapped using a hierarchical deductive technique, and the likelihood of a top event can be assessed quantitatively or qualitatively (Kritzinger 2017). Boolean algebra and the breakdown rate of every component, FT analysis is used to calculate the breakdown probability of a top event. All breakdown situations are studied statistically and inductively, and a fault tree is built (Rajakarunakaran *et al.* 2015).

Table 1. Most common potential causes and probabilities of FFH in NSW.

Code	Scaffolds	Probability
SH1	Scaffold has been altered by unlicensed workers	0.36
SM1	PC failed to communicate that scaffold components are not to be removed by unlicensed worker	0.4
SM2	PC not knowledgeable on what needs to be in the handover certificate	0.17

Table 1 (contd).

SP1	Standard vertical gaps between decks/hop-ups and building edge not followed, missing scaffold components	0.31
SP2	Improper ground support	0.15
SP3	Loads placed exceeded the capacity	0.02
	Voids and Edges	**Probability**
VH1	Uncovered/unmarked voids with no physical barriers	0.42
VH2	Inadequate or no precautions to prevent falls from weak roofs	0.3
VH3	Inadequate or no protection on edges	0.55
VH4	Unsecured excavations and pits	0.32
VM1	Improper/no access system between levels or platforms	0.31
	Formworks	**Probability**
FH1	Formwork components are not in proper order	0.06
FM1	Improper/no access system to formwork decks	0.28
FP1	Inadequate or no protection on formwork edges	0.49
FP2	No proper protection in place for constructing/dismantling	0.27
	Ladders	**Probability**
LH1	Improper set-up	0.14
LM1	Inappropriate use of ladder	0.12
LP1	Ladder is below standard condition	0.04
	Mobile Scaffolds and Fall Restraints	**Probability**
MH1	No evidence of training for using harness	0.24
MM1	EWP operators do not have a necessary WP HRW license	0.11
MP1	Harnesses, lanyards, and other connected equipment do not meet industry requirements, are out of date, and are not in working order	0.17
MP2	Below industrial-grade mobile scaffolds or EWPs are not in good condition	0.09

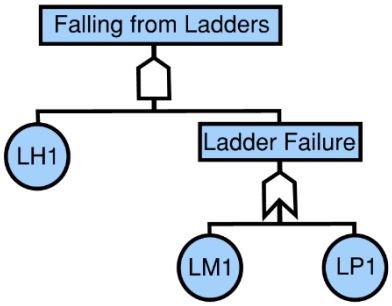

Figure 1. Fault tree diagram for falling from ladders.

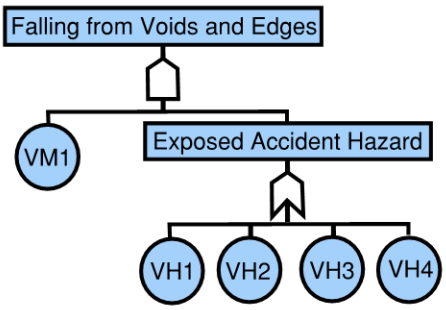

Figure 2. Fault tree diagram for falling from voids and edges.

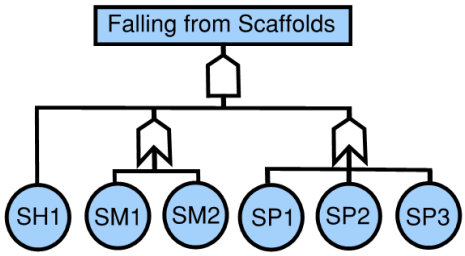

Figure 3. Fault tree diagram for falling from scaffolds.

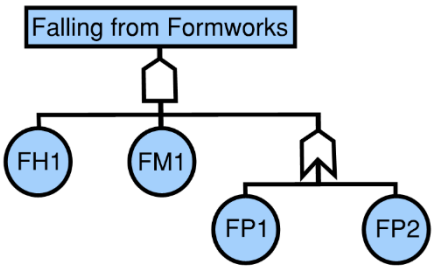

Figure 4. Fault tree diagram for falling from formworks.

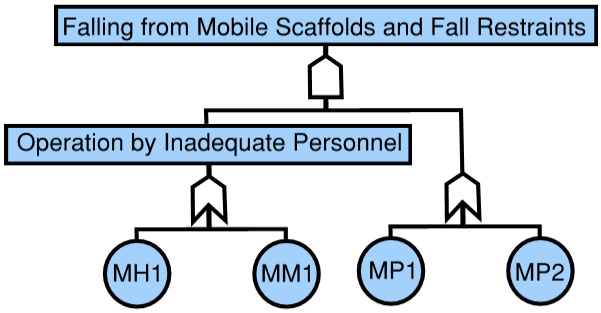

Figure 5. Fault tree diagram for falling from mobile scaffolds and fall restraints.

3.1 Results

In this study, a probability estimates of the likely causes of an FFH accident is necessary in order to quantify the risk of an FFH accident. The FT is used as a typical logical strategy for determining the likely causes of an undesirable incident or basic event that could pose a safety risk or result in financial loss. Based on the different probabilities and causes of accident scenarios as listed Table 2, the results were calculated using Boolean (BN) logic; Eq. (1) was used to calculate the probability of top events with AND gates, whereas Eq. (2) for the probability of top events with OR gates. The BN probability results are presented in Table 2.

$$P = P_1 * P_2 * P_3 * P... \tag{1}$$

$$P = 1 - (1 - P_1) * (1 - P_2) * (1 - P_3)... \tag{2}$$

Table 2. Calculated probabilities for the top events of FFH in NSW.

Top Events	Calculated Probability	BN Probability (%)
Falling from Ladders	0.0217	2
Falling from Voids and Edges	0.2715	27
Falling from Scaffolds	0.0768	8
Falling from Formworks	0.0105	1
Falling from Mobile Scaffolds and Fall Restraints	0.0792	8

4 DISCUSSION

Upon inputting the probabilistic data of the basic events for each accident scenario to Genie software using BN, the probability results were found to be the similar with the FT analysis calculations. Based on this study, falling from voids and edges has the highest likelihood of falls in NSW with a probability of 27.15%. This has a huge gap from the rest of the accident scenario, where falling from mobile scaffolds and fall restraints with 7.92%, which is closely followed by falling from scaffolds with 7.68%. While falling from ladders and falling from formworks were not too far behind, with 2.17% and 1.05%, respectively.

The probabilities of the five FFH scenarios and overall state-wide compliance in NSW were found to have significant connections upon further analysis of this research. The high probability result of falling from voids and edges can be related to the low compliance on some of the safety checklist of Safe Work NSW. With only 45% compliance on edges having adequate protection in place to prevent falls, 58% compliance in voids being marked, covered, or having barriers installed, 68% compliance for guarded or securely protected pits, 69% compliance on sufficient mechanism for accessibility between levels, and 70% compliance for protection measures on roofs to prevent falling from weak roofing. Falls from mobile scaffolds and fall restraints were associated with lack of evidence of training of personnel. Falls from scaffolds were associated with lack of communication from the management and being altered by unlicensed workers. Falls from ladders were associated with improper set up and the use for inappropriate activities. Falls from formworks were associated with lack of protection measures from formwork edges.

With the use of these valuable findings, mitigation strategies were outlined in the next section with an aim to further minimize the probability results of FFH incidents on NSW construction sites.

5 MITIGATING THE RISKS OF FFH ACCIDENTS IN NSW

In identifying fall hazards, it is important to be able to inspect and assess the workplace first. Developing a checklist that covers surfaces, levels, structures, entry and exit areas, edges and any holes or openings are one of the key things to look for. For assessing the risk, a generic risk assessment that includes evaluating the design and layout of work areas, regular inspection and maintenance of equipment, and factors such as weather conditions, adequacy of worker's knowledge and protection systems are just some matters that needs to be considered. While with controlling risk and reviewing measures, the emphasis is on correct safety and fall protection systems, as well as guidance for selecting appropriate fall protection measures based on the type of job done.

It is critical to highlight the importance of complying to the safety standards and procedures, such as wearing the proper safety equipment and ensuring that equipment is properly set up. Training and monitoring were also found to play a vital component in preparing for operation at heights. These should be required especially if the personnel are still getting familiarized with the job and work environment. With this, three general procedures to prevent dangers associated with

working at heights were established. The first is to consider another means to perform the activity on ground level. Employers must always ensure that an activity or task is not performed at heights when it is reasonably possible to do it safely on ground. Next is the use of PPE and ensuring personnel have adequate training. This also includes fall-prevention devices such as elevating platforms, perimeter handrails and guardrails and rope access systems. The third alternative is to utilize a fall-arrest and fall restraint systems, such as safety nets, harness, lanyards, and rope lines.

6 CONCLUSIONS

Based on the study presented in this paper, the higher compliance on the safety checklist means lower probability of falling from heights, and vice versa. Lack of compliance on standard protection measures and inadequate safety precautions were just some of the general causes. It is also found that a substantial proportion of all reported major causes of falling from heights in the NSW construction industry were due to a number of poor safety practice such as workers' conduct, failure to follow work procedures, working at a high elevation or high-risk activities, operating equipment without safety measures, poor site management, failure to utilize PPE, and a poor attitude towards safety. The most important mitigation measures that were found to be common to all, are to have on-site precautionary measures, ensure the compliance to Australian standards for tools, equipment and other components, and offer a proper combination of knowledge to establish the best safety solutions for specific construction work activities in which people are most vulnerable. Furthermore, developing brief training and safety courses for employees, as well as seminars and speeches concentrating on work at height dangers, may have a favorable influence on worker's behavior, resulting in fewer FFH accidents

The findings of this study present areas that require extra attention to reduce fall from height incidents in the NSW construction sector. It is intended that this paper would serve as a useful starting point in exploring further to better understand the causes and effects of FFH accidents. Knowing the probability of falls from height will aid in the prevention of particular incident and increase the overall level of safety on construction sites.

References

Hanapi, N. M., Kamal, M. M., Ismail, M. I., and Abdullah, I. A., *Identifying Root Causes and Mitigation Measures of Construction Fall Accidents*, Grading Business and Management Journal, 17(1), 65-79, 2013.

Hu, K., Rahmandad, H., Smith-Jackson, T., and Winchester, W., *Factors Influencing the Risk of Falls in the Construction Industry: A Review of the Evidence*, Construction Management and Economics, 29(4), 397-416, 2011.

Khodabandeh, F., Kabir, E., and Kahani, M., *Factors Associated with the Severity of Fatal Accidents in Construction Workers*, Medical Journal of the Islamic Republic of Iran, 30(1), 469-469, December, 2016.

Kritzinger, D., *Fault-Tree Analysis*, Aircraft System Safety, 59-99, 2017.

Nadhim, E. A., Hon, C., Xia, B., Stewart, I. and Fang, D., *Falls from Height in the Construction Industry: A Critical Review of the Scientific Literature*, International Journal of Environmental Research and Public Health, 13(7), 638, 2016.

Rajakarunakaran, S., Kumar, M. A., and Prabhu, A. V., *Applications of Fuzzy Faulty Tree Analysis and Expert Elicitation for Evaluation of Risks in LPG Refuelling Station*, Journal of Loss Prevention in the Process Industries, 33, 109-123, 2015.

SafeWork NSW, *Falls from Heights in Construction- Blitz 2.0*, 2019. Retrieved from https://www.safework.nsw.gov.au/__data/assets/pdf_file/0004/905980/Falls-from-heights-in-Construction-Blitz-2_2019.pdf, on July 27, 2020.

SafeWork NSW, *Working at Heights*, 2020. Retrieved from https://www.safework.nsw.gov.au/hazards-a-z/working-at-heights on April 6, 2021.