Improving Safety Through Statistical Analysis of Construction Fatalities

Yi Pin Chang, Jitendra Agarwal, Adam Crewe
Department of Civil Engineering, University of Bristol, Bristol, UK

ABSTRACT: The construction industry has the highest rates of fatalities, disabilities, and injuries & illnesses among all industries. While this situation has improved in some countries, for example the UK, to achieve sustained improvements accident data must continue to be analysed. The purpose of this paper is to apply statistical analysis techniques to examine construction accident data thus leading to the identification of the contributory factors and associations among them to help improve safety. This study used data from the occupational construction fatality reports in Taiwan during 2013 and 2014. Descriptive statistical analysis showed that more than two thirds of the fatalities resulted from falls, slips and trips. The analysis also revealed that the employers perform poorly when installing and adopting Occupational Safety and Health (OSH) equipment and measures. Inferential statistical analysis enabled the identification of the contributing factors and their related subfactors with statistical significance. Amongst these, reinforced concrete building construction, private project jurisdiction, scaffolds, staging and ladders, and unsafe conditions such as no guardrails, covers, or/and safety nets, were found to be the prominent factors. These factors were also found to have relatively strong association with each other on the occurrence of fatal accidents. Construction stakeholders and OSH authorities should take note of these to make decisions and/or develop accident prevention strategies.

1. INTRODUCTION

Occupational accidents are a prominent global issue, and the construction industry usually shows higher rates of workplace injury and death. The economic burden of poor occupational health and safety (H&S) practices is estimated at 3.94% of global Gross Domestic Product annually (ILO, 2018). In the construction industry alone, at least 108,000 people are killed on construction sites every year, a figure which represents about 30% of all occupational fatal injuries (ILO, 2018). Construction workers are 3 to 4 times more likely to die from accidents at work than other workers in a number of industrialized countries. In developing countries, the risks related to construction work may be 3 to 6 times larger (ILO, 2018). Construction remains the most hazardous industry in Taiwan (OSHA, 2015). From 2005 to 2014, 1551 workers died in the workplace in the construction industry, accounting for about 49% of occupational fatal injuries among all industries; however, the number of employees in the construction industry was only 10% of the total workers. Additionally, over the decade the average fatal injury rate per 100,000 construction workers was 8.4 times bigger than that of other industrial workers. Several studies have attributed these high rates of accidents to the inherently hazardous nature of construction projects, management factors, and personnel factors among others. Since 2001, OSHA, MOL (former Council of Labour Affairs, Executive Yuan in Taiwan), has intensively promoted accident mitigation programmes. Although the fatality figures decreased, it is important to find cost-effective strategies and new management techniques for construction industry. Thus, the objectives of this paper are to analyse the occupational fatal injury accidents of construction sites utilising the descriptive and inferential statistical methods, and to recognise the contributing factors, association thereof, and the occurrence of fatality accidents, thus enabling the owners, designers, and contractors to make safety policies and implement H&S.

2. LITRERATURE REVIEW

Construction accidents in Taiwan have been the subject of several papers (e.g. Tam et al. 2004, Chi et al. 2005, Cheng et al. 2010), and they all identified the following possible reasons: (1) the inherently hazardous nature of construction projects; (2) environmental and equipment factors; (3) management factors; (4) business entity factors; and (5) personnel factors. According to a survey of 284 owners, designers, and contractors (Chang 2020), potential reasons why employers are reluctant to comply with the H&S requirements include: (1) temporary or short-term work; (2) pressure to finish work quickly; (3) employers' lack of knowledge of safety regulations; (4) difficulty of installation of H&S equipment; (5) not enough budget for worker H&S. Chang and Chen (2005) employed the association rule of the data mining method for evaluating the association between different factors and identifying the patterns of industrial occupational injuries. Liao and Perng (2008) analysed 309 accident reports of fatal occupational injuries using association rule mining in the construction industry during the period 1999-2004. Contributing factors were identified in terms of individual factors (such as work experience, age), task factors (time of day, day of the week), management factors (the bid price of the project, the size of the contractor), and environmental factors (month, rainfall). The findings included that (1) the effect of rain on the occurrence of fatalities is of great significance; (2) in civil engineering, the worker's age (45-54) and time of service (more than 365 days) on the project influences whether a fatality is more likely to occur; (3) in building construction, worker's salary (skilled workers) and day of the week (Mondays or Tuesdays) also influence whether a fatal injury is more likely to occur (Liao and Perng, 2008). Cheng et al. (2010) mainly employed the same data mining method to analyse 1347 construction accident reports during the period 2000-2007. This paper found that accidents can happen when certain combinations of hazards are existing – especially working in high places without protective measures, inadequate experience, failure to utilise protective equipment, loss of balance when in motion, and injurious contact with unstable structures. Cheng et al. (2012) employed the classification and regression tree of data mining method to analyse 1542 construction accident reports during the period 2000-2009. Both these studies were aimed at building potential cause-and-effect relationships concerning serious occupational accidents in the construction industry.

The Occupational Safety and Health Act (the Act) (MOL, 2013) in Taiwan is compulsory for stakeholders such as employers and self-employed workers, and its functions serve as the minimum requirements of H&S level; therefore, the stakeholders should comply with the Act as well as its regulations and fulfill the requirements in workplaces. However, the owner business entities applicable to the Act are only responsible for the H&S of the workers they hire on the construction site; this does not include the workers of their contractors and subcontractors. Thereby, the construction H&S management mainly depends on major contractors.

The concept of Design for Construction Worker Safety (DCWS) is placed as the top priority in the hierarchy of controls to eliminate or avoid hazards prior to exposure on the worksites. Decisions made at the beginning of projects can influence construction worker safety, and through DCWS, the risk of a construction project can be reduced (Behm, 2005; Gambatese et al., 2005). In addition to implementing effective accident mitigation programmes, the H&S legislation such as the CDM regulations in the UK (HSE, 2015), can serve as a paradigm to improve the performance of the Taiwan construction industry.

3. MATERIALS AND METHODOLOGY

3.1. Study population

In this study, construction fatality reports from 2013 to 2014 in Taiwan were used to analyse the accidents, and construction fatality lists from 2005 to 2014 were used to view the trend of accidents. The fatality lists and reports were all obtained from Occupational Safety and Health Administration (OSHA) within Ministry of Labour (MOL) (OSHA, 2017). OSHA in Taiwan makes occupational H&S policies and laws; besides these, OSHA and authorised inspection agencies execute labour inspections. The occupational fatal injury accidents are investigated by trained governmental inspectors of the inspection agencies; then these reports are reviewed by OSHA before imposing any penalties or seeking criminal prosecution. Hence, the reports stick closely to the facts of the accidents, are appropriate to be used as the application of violation of regulations and are not biased against any stakeholders.

3.2. Descriptive statistics

Descriptive statistics can help obtain an overall trend and understanding of occupational fatal injuries in the construction industry, and this method is used in this paper. Data from the occupational construction fatality reports was extracted and categorised into factors to comprehend the main causes and distribution of the fatalities, and then the results can be utilised for the follow-up inferential statistics. Unfortunately, in the construction industry, there are relatively high proportions of violations of the Act in respect of H&S facilities and management aspects, and these are written down in the occupational construction fatality reports. Consequently, these aspects based on the article content of the Act could be divided into and regarded as factors to occupational fatal injury accidents. These factors include “H&S equipment and measures”, five types of H&S management measures viz. “H&S personnel”, “H&S education & training”, “H&S work rules”, “Self-inspections”, “H&S plans”, and two types of the original business entity (usually principal contractor) duties viz. “H&S issues notifications” and “Whole site H&S management”. Besides, the classification criteria of factors were employed by adopting Occupational Injury and Illness Classification Manual (BLS, 2012) in the American National Standard for Information Management for Occupational Safety and Health Z16.2-1995 (ANSI, 1995).

3.3. Inferential statistics

Most of the data in the occupational construction fatality reports are nominal such as “Gender”, “Worker type”, and “Event/exposure”, which have no specific numerical value. When the independent and dependent variables are categorical data, the Karl Pearson’s Chi-square Test can be used to analyse the data. The Chi-square Test including Goodness of Fit, Independence, and Homogeneity is employed in this paper along with the descriptive statistics. In this research, the SPSS software was used for statistical analyses, and the statistical significance level was set at α=0.05. The factors categorised from construction fatality reports were examined by the Goodness of Fit Test to obtain contributing factors with p-values less than α=0.05. This means that counts of a contributing factor are not evenly distributed across its subfactors but have a concentration on its certain specific subfactors. These contributing factors and their subfactors can supply information related to the prevention of the accidents and be further analysed by the Independence, and Homogeneity Test.

4. OCCUPATIONAL FATAL INJURIES AND CONTRIBUTING FACTORS

From 2005 to 2014, 1551 workers died on the construction sites in Taiwan. From 2013 to 2014, there were 339 reports and 340 deaths. Data from the occupational construction fatality reports in Taiwan was extracted and categorised in detail before analysing it. The classification criteria of factors and statistical methods discussed previously were employed.

4.1. An overview of occupational fatal injuries

In the construction industry, the rates of occupational fatal injuries had a downward trend from 2005 to 2009 having the lowest value at 15.92 per 100,000 workers. After that, there was an upward trend to 24.53 in 2014. The overall reduction rate was only about 16% during the ten years. However, the fatality rates in other industries had a steady descending tendency, and the overall reduction was 45% during the same decade.

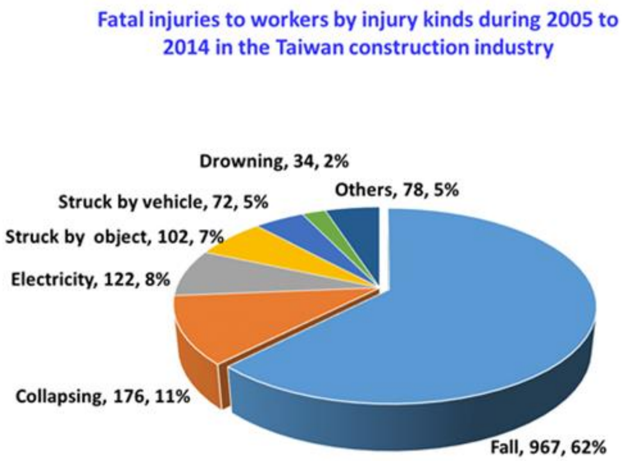

Figure 1: Fatal injuries to workers by injury kinds from 2005 to 2014 in the Taiwan construction industry [data from (OSHA, 2017a)].

Figure 1 shows the kinds of occupational fatal injuries observed in the Taiwan construction industry between 2005 and 2014 (OSHA, 2017). It is clear that "Fall" (excluding Slips, Trips, and Fall from collapsing structure or equipment) occupied the biggest part (967 deaths, 62%, over 10 years) among the seven injury types. "Collapsing" (including Fall from collapsing structure or equipment) was in second place, accounting for 11% (176 deaths). This was followed by "Electricity" (122 deaths, 8%). The first three injury types constituted over 81% of the total fatal construction injuries. Because the fatal "Fall" injuries of the Taiwan construction industry were an overwhelming majority among all injury kinds and had an ascending tendency, they should be the foremost target to decrease the fatal construction injuries.

4.2. Causes of construction fatalities

Among the 339 accident reports, there were only 14 reports (4 in 2013 and 10 in 2014, 4%) where the employers of accident business entities or self-employed workers did not contravene the Act about installing and adopting relevant "H&S equipment and measures"; conversely, 96% of them breached the Act, such as "No guardrails, covers or/and safety nets", "Unsafe scaffolds, staging or ladders", or "Lack of management and instructions" and resulted in accidents. Besides these, there existed another 21 reports (13 in 2013 and 8 in 2014, 6%) where although the employers of accident business entities or self-employed workers did not comply with the Act to install and adopt relevant "H&S equipment and measures", the accidents could partially attribute the reasons to the victims or the workers causing accidents due to some unsafe acts such as "Not using PPE" or "Lack of safety consciousness" in relation to the accidents. Because the Act serves as the minimum requirements of the H&S level and is mandatory to employers and self-employed workers, it is not appropriate to attribute the accident responsibility to the labourers' unsafe acts.

Traditionally, the reasons for accidents are categorised into unsafe conditions and unsafe acts (Choudhry and Fang, 2008), and they have different implications of duties. The former result from employers not fulfilling their duties, and the latter can be attributed to the construction labourers. The analysed data shows that 90% to 96% of the fatality cases arose due to *unsafe conditions*. This finding is different from several other studies which reported high proportions of the accidents due to *unsafe acts*. Human behaviour was a contributory factor in approximately 80% of accidents (Fleming and Lardner, 2002); 70-80% of the incidents were caused by human error (Anderson, 2005); up to 80% of accidents may be owed, at least in part, to the actions or negligence of people; and nearly 80% of construction accidents were led to by human unsafe behaviour (Chen and Tian, 2012). The argument supporting this huge proportion of unsafe acts as a major cause of accidents is that if unsafe conditions are present, it becomes the normal practice of workers to carry out construction activities by receiving the risks related to the work. However, under these circumstances, construction site accidents should not be solely attributed to the unsafe acts of workers (Choudhry and Fang, 2008).

4.3. Contributing factors of construction fatalities

The fatality cases under study were categorised using the factors stated in Section 3.2 and were examined by the Goodness of Fit Test. Table 1 presents the contributing factors, whose *p*-values are less than 0.05, and their subfactors along with the distribution of fatalities. The subfactors within a contributing factor are mutually exclusive.

Table 1: Distribution of occupational fatal injuries and Goodness of Fit Test for contributing factors in the Taiwan construction industry, 2013–2014 [data from (OSHA, 2017a)].

Factor / Subfactor	*N*	%
Event (exposure):		
Falls, slips, trips	241	71
Struck, caught, or crushed in collapsing structure, equipment, or material	22	6
Exposure to electricity	21	6
Struck by falling object or equipment	16	5
Struck by object or equipment	15	4
Transportation incidents	11	3
Others	13	4
Source of injury:		
Other structural elements	120	35
Scaffolds, staging	66	19
Construction machinery and highway vehicles	34	10
Floors, walkways, ground surfaces	30	9
Ladders – movable	23	7
Building materials—solid elements	21	6
Electric parts	18	5
Others	27	8
Project type:		
RC building - construction	123	36
Renovation/ demolition	64	19
Skeleton frame - renovation/ demolition	47	14
Skeleton frame - construction	40	12
Civil engineering - construction	37	11
Electrical and mechanical, telecommunications, and circuit engineering	16	5
Others	12	4
Unsafe condition:		
No guardrails, covers, or/and safety nets	110	32
Unsafe scaffolds, staging, or ladders	56	17
Lack of management and instructions	49	14
Lack of safe working method or procedure	35	10
No safety belts and anchorage points	29	9
No designing temporary structures or erecting as design	13	4
Unsafe working environment	13	4
The employer did not provide PPE (not including safety belts)	12	4
No restricted area and warning signs	12	4
No electric shock prevention devices	10	3
Project jurisdiction		
Private project	274	81
Public project	65	19
Contract amount (NTD):		
CA <1million	88	26
1m≤ CA <5m	49	14
5m≤ CA <25m	40	12
25m≤ CA <50m	18	5
50m≤ CA <200m	42	12
200m≤ CA <500m	36	11
500m≤ CA <1billion	12	4
1b≤ CA <5b	26	8
CA ≥5b	7	2
None or unknown	21	6
Accident entity contracting level:		
Level 0	9	3
Level 1	136	40
Level 2	125	37
Level 3	58	17
Level 4	10	3
Level 5	1	0
Worker type:		
Miscellaneous construction and related	59	17
Roofers	56	16
Form worker	36	11
Construction labourers	29	9
Plasterer	24	7
Structural iron and steel workers	24	7
Electricians	20	6
Machine operator/ truck driver	15	4
Painters	14	4
Scaffolding worker	13	4
Cleaner	10	3
Brickmasons, blockmasons, and stonemasons	9	3
Elevator installers and repairers	4	1
Others	27	8

5. ASSOCIATION BETWEEN CONTRIBUTING FACTORS

Once contributing factors to construction fatality accidents were identified, the association between these factors was determined through the Independence and Association Strength tests. The factors with significant results can be emphasized to make decisions and develop prevention strategies to alleviate the fatality accidents. The following nine pairs of factors were found to have relatively strong or strong association between the two selected contributing factors:

- Project type and Project jurisdiction, mainly including “Civil engineering” and “Public project”, “RC building - construction” and “Private project”, and “Skeleton frame” and “Private project”;
- Source of injury and Unsafe condition, mainly including “Scaffolds, staging, ladders” and “Unsafe scaffolds, staging or ladders”, “Structures and surfaces” and “No guardrails, covers, or/and safety nets”, and “Construction machinery and highway vehicles” and “Lack of management and instructions”;
- Event/exposure and Source of injury, mainly including “Falls” and “Structures and surfaces”, “Falls” and “Scaffolds, staging, ladders”, and “Contact with objects and equipment” and “Construction machinery and highway vehicles”;
- Accident entity size and Accident H&S personnel, mainly including “P<5” and “Not assigned H&S personnel”;
- Accident entity type and Accident H&S personnel, mainly including “Natural person” and “Not assigned H&S personnel”;
- Accident entity size and H&S education & training, mainly including “P<5” and “Not Implement H&S education & training”;
- Project type and Worker type, mainly including “Skeleton frame” and “High places workers”, “RC building - construction” and “Workers using scaffolds and ladders”, and “Renovation/ demolition” and “Construction labourers”;
- Event/exposure and Unsafe condition, mainly including “Falls” and “No guardrails, covers, or/and safety nets”, “Falls” and “Unsafe scaffolds, staging or ladders”, “Contact with objects and equipment” and “Lack of management and instructions”, and “Exposure to harmful substances or environments” and “Lack of management and instructions”;
- Source of injury and Worker type, mainly including “Structures and surfaces” and “High places workers”, and “Scaffolds, staging, ladders” and “Workers using scaffolds and ladders”.

The Chi-square Test of Homogeneity was used to determine whether the three business entities (i.e. owner entity, original business entity and accident entity) have the same proportions in their H&S management performance. This concluded that the proportions between the three entities differ but it does not inform where the entities differ. To understand how the owner entity influenced the original entity and how the original entity influenced the accident entity with regard to the H&S management in the contracting chains, the Independence and Association Test was utilised again. It was noted that (i) the performance of the owner entity in the H&S management had no association with that of the original entity and (ii) the original and accident entities were dependent and had moderate association.

6. DISCUSSION

The results of data analysis show that 90% to 96% of the fatality cases resulted from unsafe conditions as opposed to unsafe acts in the construction industry. Further, accident entities and the original entities had high violation rates on H&S management aspects. This means that the employers of accident entities and the original entities rather than the labourers should be responsible for improving construction safety according to the responsibilities stipulated in the Act. This result is different from findings of existing literature, possibly because the accident data was related to construction fatalities, not including other industries nor injury cases, and official construction fatality reports can provide detailed information of accidents for better analysis.

The top three injury types from 2005 to 2014 were “Fall”, “Collapsing”, and “Electricity”, and “Fall” accounted for 62% in the construction industry. These sequences are the same as identified by Cheng et al. (2010) from 2000-2007 data and Cheng et al. (2012) from 2000-2009 data. In the two studies, “Fall” made up 54% and 47% individually. “Fall” had a significant relationship with four subfactors, namely “Structures and surfaces”, “Scaffolds, staging, ladders”, “No guardrails, covers, or/and safety nets”, and “Unsafe scaffolds, staging or ladders”. They can display the significance of the occurrence of fatality accidents similar to Cheng et al. (2010) and Cheng et al. (2012) using the data mining method. Fall is still the major cause of fatal accidents, and detailed analysis is needed to discover accident causes and prevention measures.

The main recommendations from data analysis in this paper are:

- The employers or self-employed workers should preferentially install and adopt “H&S equipment and measures” in relation to the worksite hazards, especially installing guardrails, covers, or/and safety nets, and using standardised scaffolds and step ladders to prevent fall accidents.
- They should implement the H&S management to make sure that H&S resources are ready before construction and that “H&S equipment and measures” are in place during construction.
- Contributing factors with statistical significance on the occurrence of fatality accidents should be emphasised for construction stakeholders and H&S authorities to alleviate the fatality accidents.
- The owner entity should select the original entity with good performance in the H&S management and require it to facilitate the safety.
- The original entity should exactly carry out the whole site H&S management.

7. CONCLUSIONS

Occupational accidents in the construction industry are still a global issue, and the situation is much worse in Taiwan. Analysis of fatality figures from 2005 to 2014 shows that “Fall”, “Collapsing”, and “Electricity” account for more than three quarters of the total fatal construction injuries. Of these “Fall” comprises the largest part. Statistical analysis of 339 occupational construction fatality reports during 2013 and 2014 lead to the identification of the contributing factors of construction accidents and associations amongst them.

The Act and its regulations are mandatory for employers and self-employed workers, and they are used for the basic demands to protect workers’ H&S and to prevent occupational accidents. However, in the majority of fatality cases, the employers of accident business entities or self-employed workers were found to contravene the Act about installing and adopting “H&S equipment and measures”. In addition, original business entities violated seriously the Act in the H&S management aspects. In these circumstances, it is not helpful to shift the blame to labourers of their unsafe behaviour in reducing deaths from construction accidents. The H&S authorities should strengthen the enforcement of the laws, utilise H&S promotion, and/or enact laws to help the stakeholders take their responsibilities.

Owners along with designers decide construction period, H&S budget, and contractors. Also, design specifications influence construction methods and equipment. These are closely related to construction H&S. Therefore, owners, designers, and the original entities should be actively involved in construction safety to construct a completely safe environment.

8. ACKNOWLEDGEMENT

The authors would like to express their appreciation to the Executive Yuan, Republic of China (Taiwan) for a scholarship to the first author, and the Occupational Safety and Health Administration, the Ministry of Labour, for providing the occupational construction fatality reports and lists used in this research.

9. REFERENCES

American National Standards Institute (ANSI) (1995). American National Standards for Information Management for Occupational Safety and Health. New York, National Safety Council, ANSI 16.2-1995.

Anderson, M. (2005). Behavioural safety and major accident hazards: Magic bullet or shot in the dark? Process Safety and Environmental Protection 83(2): 109-116.

Behm, M. (2005). Linking construction fatalities to the design for construction safety concept. Safety science 43(8): 589-611.

BLS (2012). Occupational injury and illness classification manual. [pdf] BLS, U.S. Department of Labour Available at: <https://www.bls.gov/iif/oshwc/oiicm.pdf>.

Chang, L.-Y. and W.-C. Chen (2005). Data mining of tree-based models to analyze freeway accident frequency. Journal of safety research 36(4): 365-375.

Chang, Y. P. (2020). Construction Worker Safety and Accident Prevention in Taiwan. Department of Civil Engineering, University of Bristol. Doctor of Philosophy (PhD): 324.

Chen, D. and H. Tian (2012). Behavior based safety for accidents prevention and positive study in China construction project. Procedia Engineering 43: 528-534.

Cheng, C.-W., Leu, S.-S., Cheng, Y.-M., Wu, T.-C. & Lin, C.-C. (2012). Applying data mining techniques to explore factors contributing to occupational injuries in Taiwan's construction industry. Accident Analysis & Prevention, 48, 214-222.

Cheng, C.-W., Lin, C.-C. & Leu, S.-S. (2010). Use of association rules to explore cause–effect relationships in occupational accidents in the Taiwan construction industry. Safety science, 48, 436-444.

Chi, C.-F., Chang, T.-C. & Ting, H.-I. (2005). Accident patterns and prevention measures for fatal occupational falls in the construction industry. Applied ergonomics, 36, 391-400.

Choudhry, R. M. and D. Fang (2008). Why operatives engage in unsafe work behavior: Investigating factors on construction sites. Safety science 46(4): 566-584.

Fleming, M. and R. Lardner (2002). Strategies to promote safe behaviour as part of a health and safety management system, HSE Books.

Gambatese, J. A., Behm, M. & Hinze, J. W. (2005). Viability of designing for construction worker safety. Journal of construction engineering management, 131, 1029-1036.

HSE (2015). The Construction (Design and Management) Regulations 2015. [online] London: Health and Safety Executive. Available at: <http://www.legislation.gov.uk/uksi/2015/51/pdfs/uksi_20150051_en.pdf>

ILO (2018). Construction: a hazardous work. [Online]. Available at: <http://www.ilo.org/safework/areasofwork/hazardous-work/WCMS_356576/lang--en/index.htm>.

Liao, C.-W. and Y.-H. Perng (2008). Data mining for occupational injuries in the Taiwan construction industry. Safety science 46(7): 1091-1102.

MOL (2013). Occupational Safety and Health Act. [Online]. Taiwan: Ministry of Labour, [online] Available at: < http://laws.mol.gov.tw/Eng/FLAWDAT0201.aspx?lsid=FL015013>.

OSHA (2015). 2014 Labour Inspection Annual Report. [pdf] Taiwan, Occupational Safety and Health Administration, Ministry of Labour. Available at: <https://www.osha.gov.tw/1106/1164/1165/1168/1455/>.

OSHA (2017). The Inspection Information Management System of Labour Inspection Agency of OSHA [Online]. Taiwan: Occupational Safety and Health Administration, Ministry of Labour. Available at: <https://insp.osha.gov.tw/labchk/index.aspx>.

Tam, C., Zeng, S. & Deng, Z. (2004). Identifying elements of poor construction safety management in China. Safety Science, 42, 569-586.