Construction Accidents in a Large-scale Public Infrastructure Project: Severity and Prevention

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Abstract

The Hong Kong–Zhuhai–Macao Bridge related Hong Kong (HZMB-HK) project consists of a set of boundary crossing facilities and transport links that connect the main bridge (HZMB) to the Hong Kong territory. It is a featured large-scale public infrastructure project that involves construction works done above or near the sea. A number of accidents have occurred since the commencement of the project in November 2011. This study aims to analyze the construction accidents that occurred in the HZMB-HK project during the period from 2012 to the first half of 2017. The methodology comprises both quantitative and qualitative approaches. First, the safety performance of the project was quantitatively measured using three indicators: accident, fatality, and lethality rates. In this regard, it was identified that the safety performance of the project was worse than that of public work contracts and the construction industry in general. It was also found that fall and caught in/between were the deadliest types of accidents in the project. Second, eight fatal incidents that resulted in nine fatalities were qualitatively analyzed, based upon relevant accident investigation reports. In this regard, it was found that of the nine decedents, five died from drowning. This indicates that working above or near the sea poses a high risk of drowning to construction workers. Furthermore, measures to prevent accidents in large-scale infrastructure projects such as the HZMB-HK project were analyzed in this study. This study adds to the construction safety body of knowledge by analyzing the accidents in a large-scale infrastructure project that involves both land- and sea-based construction works. The lessons from this study could help stakeholders, such as policy makers and practitioners, improve the safety performance of large-scale infrastructure projects worldwide.

Author keywords: HZMB-HK project; Marine construction; Safety performance; Drowning; Causes; Preventive measures.

Introduction

The construction industry has long been recognized as one of the most unsafe industries in the world, owing to its high rates of work-related injuries and fatalities (Murie 2007; Zou 2010). In the US, the construction industry accounted for 19% of all industrial fatalities (Bureau of Labor Statistics 2015). Essentially, it was reported that the fatality rate of the construction industry (10.1 fatalities per 100,000 workers) was higher than that of any other industry (*ibid.*). In the UK, the mortality rate of the construction industry (1.37 mortalities per 100,000 workers) was more than three times higher than the average of all other industries (Health and Safety Executive 2017). Within Hong Kong, the construction industry accounted for 56% of all industrial fatalities (Labor Department 2017a), while in Singapore, the industry accounted for 36% of all industrial fatalities (Ministry of Manpower 2016). These statistics suggest that the construction industry is far from achieving a reputation as an accident-free industry (Zhou et al. 2015). Hence, greater efforts are required in order to prevent accidents and improve the safety performance of the industry.

Construction safety research could be done at various levels, including industry, company, and project levels. The existing literature has been dominated by project-level analyses (Zhou et al. 2015). The fact that project-level analyses can be instructive in identifying risky project tasks and formulating measures to prevent accidents and concomitant injuries (Hatipkarasulu 2010) provides an explanation for this dominance. Most of the previous project-level studies focused on examining safety issues in a number of similar or dissimilar types of projects. For example, Hatipkarasulu (2010) analyzed a total number of 350 fatal accidents that occurred in residential, commercial, and other types of building projects – industrial, civil, highway, and tower/tank/storage projects were also considered. Eventually, it was identified that most of the fatalities occurred in residential and commercial building projects (*ibid.*). As such, while the safety performance of building projects has received considerable attention from researchers, that of infrastructure projects has been given limited attention (Zhou et al. 2015). Of the few studies addressing the safety performance of infrastructure projects, Mahalingam and Levitt (2007) studied four cross-national infrastructure projects and found that coercive enforcement mechanisms were the most effective means to improve the safety performance of the projects. Lipscomb et al. (2006) studied the slip/trip accidents that occurred during the construction of the Denver International Airport, in the US, and found that environmental conditions were the main cause of the accidents. The present research expands the literature through analyzing the construction accidents that have occurred in a large-scale public infrastructure project in Hong Kong. It is worthy to note that because every construction project is unique (Doloi et al. 2011), safety issues may greatly vary even among similar types of projects. Therefore, analyzing the construction accidents in a specific large-scale public infrastructure project is crucial.

Marine construction is challenging and dangerous (Gudmestad 2013). Hence, marine construction safety cannot be ignored. More research is required to help enhance the marine construction safety. Certain safety issues associated with marine construction must be highlighted. First, in marine construction, workers might be exposed to many safety hazards, e.g., offshore wind, storm, waves, polar low pressures, and sea spray icing (Gudmestad 2013). Moreover, it is important to protect marine environment when performing construction works in coastal and estuarine areas (Bach et al. 1997). Additionally, marine construction typically involves tasks, such as dredging, dewatering, reclamation/filling, tunnel boring, and marine viaduct erection (Gudmestad 2013), which are inherently risky, difficult, complex, and prone to accidents. Hence, conducting a study that can help in efforts to prevent marine construction accidents is worthwhile.

The primary aim of this study is to analyze the construction accidents that occurred in the Hong Kong–Zhuhai–Macao Bridge related Hong Kong (HZMB-HK) project from 2012 to the first half of 2017. Background of the HZMB-HK project is provided within the next section. Specifically, this study has two objectives, which are (1) to measure the safety performance of the HZMB-HK project; and (2) to identify the descriptive characteristics, causal factors, and preventive measures of the fatal accidents that occurred in the HZMB-HK project. This paper contributes to the construction safety body of knowledge by presenting one of the first studies analyzing accidents in large-scale infrastructure projects involving construction works carried out above or near the sea. The lessons from this research can help stakeholders, such as policy makers and practitioners, improve the safety performance of infrastructure projects worldwide.

Brief Background of the HZMB-HK Project

The Hong Kong–Zhuhai–Macao Bridge (HZMB), situated on the waters of Lingdingyang of Pearl River Estuary, is a mega-sized, sea-crossing bridge that links together the Hong Kong Special Administrative Region (HKSAR), Zhuhai City of Guangdong Province, and Macao Special Administrative Region. In this paper, the term “main bridge” refers to the HZMB. In order to connect this bridge to the Hong Kong territory, some boundary crossing facilities and transport links have been introduced within Hong Kong. These boundary crossing facilities and transport links are collectively referred to as the HZMB-HK project and include the Hong Kong Boundary Crossing Facilities (HKBCF), the Hong Kong Link Road (HKLR), the Tuen Mun–Chek Lap Kok Link (TM-CLKL), and the Tuen Mun Western Bypass (TMWB). The HKBCF will be located on an artificial island; the HKLR will comprise a dual 3-lane highway that will connect the main bridge to the HKBCF; the TM-CLKL will comprise a dual 2-lane carriageway that will link together the northwest new territories (NWNT), the HKBCF, and the Hong Kong International Airport; and the TMWB will link together the NWNT, the main bridge, the Hong Kong International Airport, and the North Lantau (Highways Department 2011). While the construction works of the HKBCF, HKLR, and TM-CLKL were initiated in November 2011, May 2012, and June 2013, respectively, and are currently ongoing, those of the TMWB have yet to be initiated. Therefore, in order to examine the construction accidents that have occurred in the HZMB-HK project, this study focuses on the HKBCF, the HKLR, and the TM-CLKL.

The HZMB-HK project is a complex large-scale project and it involves tunnels, roads, sea viaducts, seawalls, artificial islands, and associated facilities. Frequent typhoons, crisscross navigation, airport height restrictions, and stringent environmental requirements and standards are examples of the critical challenges the project faces (Yeung 2016). Clearly, to overcome these challenges, it is necessary to implement innovative construction methods. Accordingly, for the first time in Hong Kong, the non-dredge reclamation method, for example, was used in constructing an artificial island on which the HKBCF will be located (Highways Department 2011). The key advantage of this method is that it can help reduce the environmental impacts of dredging and thereby contribute to sustainability.

Relevant OHS Legislations, Regulations, and Guidelines in HKSAR

Within Hong Kong, the local legislation differentiates between "land-based construction work over/near water" and "sea-based construction work carried out on vessels" (Labor Department and Marine Department 2015). While the former (including its safety) is "mainly regulated by the Factories and Industrial Undertaking Ordinance (CAP 59), the Occupational Safety and Health Ordinance (CAP 509), and their subsidiary regulations administered by the Labor Department", the latter (including its safety) is "regulated primarily by the Shipping and Port Control Ordinance (CAP 313), Merchant Shipping (Local Vessels) Ordinance (CAP 548) and their subsidiary regulations administered by the Marine Department" (*ibid.*). In this research, marine construction accidents refer to construction accidents that occur on vessels (Marine Department 2009), whereas industrial accidents in construction refer to injuries and deaths arising from construction activities that do not involve vessels (Labor Department 2017a).

Regulation 52A, Prevention of Drowning under the Part VII of CAP 59I, is a regulation governing construction works carried out above or near water in Hong Kong. For such works, the regulation mandates that employers provide rescue equipment and implement measures to curb the risk of (workers) falling into water. Aiding employers to comply with this mandatory requirement, the Code of Practice, Safety and Health at work (Land-based Construction over Water – Prevention of Fall), provides practical guidelines for the prevention of fall-into-water (Labor Department 1999). Marine construction activities such as dredging, drilling, pipe laying, buoy laying, cable laying, and caisson construction involve vessels, and to undertake them safely, workers should be equipped with the necessary knowledge and skills. Thus, the CAP 313X and CAP 548I regulations mandate that all marine construction workers take the Mandatory Safety Training Course (Marine Construction/Cargo Handling), launched in 2007. The Safety Guide for Construction Work over or near Water (Labor Department and Marine Department 2015) should also be mentioned. This guide proposes various measures to prevent accidents associated with conducting construction works over or near water in Hong Kong. Measures such as safety training, use of personal protective equipment (PPE), and safe means of access to site are emphasized.

Materials and Methods

This study used quantitative and qualitative approaches to analyze the construction accidents that occurred in the HZMB-HK project from 2012 to the first half of 2017. As stated earlier, this study focuses on the HKBCF, HKLR, and TM-CLKL. Quantitative approaches were used to calculate the HZMB-HK project's accident, fatality, and lethality rates, which were then used to measure the safety performance of the project. In this study, accident rate is defined as the number of accidents per 1,000,000 man-hours; fatality rate is defined as the number of fatalities per 1,000 workers; and lethality rate is defined as the number of fatalities per 100 accidents. This study also employed qualitative approaches to analyze fatal accidents as well as their characteristics, causes, and preventive measures. The overall research methodology is shown in Fig. 1.

[Insert Fig. 1 around here]

Quantitative Approach

Analyzing accidents data is crucial to understand the severity of safety problems (Kartam et al. 2000). Accident rate, fatality rate, and lethality rate have been widely used to measure safety performance in construction management studies (Niskanen and Saarsalmi 1983; Jeong 1998; Colak et al. 2004). They have also been widely used in occupational health and safety (OHS) statistics (Labor Department 2017a; Ministry of Manpower 2016; Bureau of Labor Statistics 2015; Health and Safety Executive 2017). In this study, to measure the safety performance of the HZMB-HK project, the accident rate, fatality rate, and lethality rate were used. The reason why these indicators were used in this study is that the information to facilitate their use were readily available and easy to understand. Similarly, these indicators are useful for comparative analyses (National Occupational Safety and Health Commission 1999). In addition, because the number of man-hours (300,000 man-hours) is large, it is statistically acceptable to use these indicators for measuring negative safety outcomes in this study (Lingard et al. 2017).

Relevant data on the HZMB-HK project were obtained from various sources. Data on the workers, including the number of workers and man-hours of the workers, were obtained from the Highways Department of HKSAR. Data on the industrial accidents, including the number and types of accidents, were obtained from the Labor Department. Data regarding the marine construction accidents were obtained from the Marine Department. Based upon these data, various industrial and marine construction accidents were identified and then grouped into four accident types, namely, fall, caught in/between, struck-by, and other (Hinze et al. 2005), for further analysis. Fall accident includes fall of person from height, slip, trip or fall on same level, step on object, and fall of person from a vessel. A caught in/between accident refers to when a worker is caught or trapped in or between objects or equipment. A struck-by accident refers to when a worker is struck by a fixed or moving object, equipment, or vehicle. “Other” accident includes injuries due to manual handling (lifting, carrying, towing, etc.), exposure to or contact with harmful substances, injuries due to boarding or disembarking vessels, and unclassifiable and miscellaneous incidents.

The accident and fatality rates of public work contracts and the construction industry in general, published by the Development Bureau of HKSAR, were used as the benchmarks for assessing the safety performance of the HZMB-HK project. Moreover, the lethality rate for each type of accident was calculated in order to identify the deadliest types of accidents in the project. Following the recommendations of Niskanen and Saarsalmi (1983), Jeong (1998), and Colak et al. (2004), equations 1-3 were used, respectively, to calculate the accident rate, fatality rate, and lethality rate of the project:

$$R_j^A = \frac{NI_j + NM_j}{MH_j} \times 1{,}000{,}000 \quad (1)$$

where R_j^A is the accident rate, i.e., the number of accidents per 1,000,000 man-hours within year j; NI_j is the number of industrial accidents within year j; NM_j is the number of marine construction accidents within year j; and MH_j is the man-hours of workers within year j.

$$R_j^F = \frac{S_j^F}{E_j} \times 1{,}000 \quad (2)$$

where R_j^F is the fatality rate, i.e., the number of deaths per 1,000 workers within year j; S_j^F is the number of fatalities that resulted from industrial and marine construction accidents within year j; and E_j is the number of workers employed within year j.

$$R_i^L = \frac{S_i^F}{NI_i + NM_i} \times 100 \quad (3)$$

where R_i^L is the lethality rate, i.e., the number of deaths per 100 accidents during the studied period; S_i^F, NI_i, and NM_i are the total number of fatal, industrial, and marine construction accidents, respectively, for an accident type i, during the studied period.

Qualitative Approach

Understanding past accidents is essential for suggesting measures to prevent future accidents (Zhou et al. 2014). The case study method is useful for performing detailed accident investigations and learn lessons from the past rather than generalizing findings based upon limited samples (Chan et al. 2008). Consequently, the case study method has been widely used in previous studies on construction accidents (Chan et al. 2008; Edwards and Holt 2010; Lingard et al. 2013). Likewise, the present study applied the case study method. A qualitative content analysis of relevant documentations, as suggested by Bowen (2009), was performed to identify the situational characteristics, incident sequence, and causes of the fatal accidents in the HZMB-HK project. This qualitative content analysis involved the following steps: first, a descriptive analysis of demographic information (e.g., age, gender, and working experience) of decedents was done (Hon and Chan 2013); second, the situational features of the fatal accidents (e.g., working surface and type of task and agent) were analyzed (Chua and Goh 2004); third, accident investigation reports were analyzed to identify the causes of the fatal accidents; and fourth, the incident sequence, consisting of the breakdown event, contact event, and consequences (Chua and Goh 2004), of each accident was identified.

The causes of the fatal accidents, identified through the content analysis, were categorized into three groups – immediate causes, safety management failures, and underlying factors – as suggested by Chua and Goh (2004). Immediate causes include substandard/unsafe conditions, substandard/unsafe behaviors, and immediate personal factors. Safety management failures include lack of safety measures, inadequate safety measures, and inadequate execution. Underlying factors can be further classified into three categories, namely, personal, job, and organizational factors. Personal factors are related to workers' knowledge, experience, skills, and capacity. Job factors are associated to work design, work execution, and work supervision. Organizational factors include organizational safety climate, structure, policies, and culture. Chua and Goh (2004) further distinguished between immediate personal factors and deep-rooted personal factors. For instance, whereas they considered "improper motivation to save time and effort" to be an immediate personal factor, they considered "lack of experience and knowledge" to be a deep-rooted personal factor.

Following the analysis of the causes of the fatal accidents, from the accident investigation reports, accident prevention measures were identified and then grouped into three preventive measure categories, namely, behavioral, engineering, and administrative controls (Goldenhar and Schulte 1994). According to Goldenhar and Schulte (1994), behavioral controls "attempt to influence workers' attitudes, knowledge, beliefs, or behaviors with respect to hazardous exposure". Engineering controls "pertain to engineered or physical manipulations of sources or routes of exposure to occupational hazards". Administrative controls refer to "management initiatives that modify a worker's work process and/or work exposure". Based on these three preventive measure categories, preventive measures proposed in the accident investigation reports are analyzed in this study to identify those that should be key to accident prevention in the context of large-scale infrastructure projects.

This study used the following accident investigation reports: the Concise Investigation Report by the Labor Department (2017b) and the Marine Accident Investigation Report by the Marine Department (2015a). These accident investigation reports offer useful information organized into sections such as "the place of the accident", "circumstances", "investigations", and "findings". Relevant court judgments (Judiciary 2016) were also used in conducting this study, as they provide insight into courts' decisions on the rights and liabilities of parties in legal proceedings. Specifically, the court judgments were used to identify the illegal behaviors that resulted in the deaths of people. These illegal behaviors might be considered causes of the fatal accidents. Furthermore, the "Green Cross" (OSHC 2015, 2016) was used to identify the circumstances and causes of various marine construction accidents. Although the Work Safety Alert (Labor Department 2012, 2014, 2015a, 2015b, 2016, 2017c) and the Marine Department Notices (Marine Department 2014, 2015b) identify various fatal accidents as well as their preventive measures, they do not provide demographic information about the decedents. Thus, a systematic search using WiseNews was performed to gather demographic information about the decedents. WiseNews is an electronic database that provides access to the contents of major local newspapers in Hong Kong (Hon and Chan, 2013). The search keywords included "construction site", "HZMB", and "accident" (in Chinese). The data collected from the newspapers (am730 2012; Apple Daily 2014; Ta Kung Pao 2014; Sing Pao 2014; Sun 2015a; Sun 2015b; Ming Pao Daily News 2016; Apple Daily 2017; Wen Wei Po 2017) and those collected from the governmental publications were cross-referenced, so as to ensure validity and reliability (Hon and Chan 2013). Table 1 summarizes the accident information as well as the sources of data used in this study.

[Insert Table 1 around here]

Results and Discussion

Safety Performance of the HZMB-HK Project

Fig. 2 shows that a total of nine fatal and 325 nonfatal industrial and marine accidents occurred in the HZMB-HK project from 2012 to the first half of 2017. The annual accident rates (R^As) and fatality rates (R^Fs) of the HZMB-HK project, public work contracts, and the construction industry in general are shown in Fig. 3. It could be noted that the highest R^A (R^A = 14.1) as well as the highest R^F (R^F = 2.5) of the HZMB-HK project were experienced in 2012, where the project was in its very early stages. This may be because the workers needed time to familiarize themselves with the project. From 2014 to the first half of 2017, the R^A remained above 7.0, while the R^F declined from 1.2 in 2014 to 0.1 in the first half of 2017. This finding is reasonable because not all of the accidents were fatal, and may also imply that workers are able to reduce fatal accidents as they obtain more experience in the project over time. Moreover, the results indicate that the average of the R^As of the HZMB-HK project (R^A = 8.4) was about 3.7 times higher than that of the R^As of the public work contracts (R^A = 2.3). Also, the average of the R^Fs of the HZMB-HK project (R^F = 0.75) was about 4.7 times higher than that of the R^Fs of the public work contracts (R^F = 0.16) and about 3.1 times higher than that of the R^Fs of the construction industry in general (R^F = 0.24). The results suggest that the safety performance of the HZMB-HK project is worse than that of the public work contracts and the construction industry in general. This calls for stronger efforts to improve the safety performance of this large-scale public infrastructure project.

[Insert Fig. 2 around here]

[Insert Fig. 3 around here]

As Fig. 2 shows, a total of nine fatalities occurred in the HZMB-HK project during the studied period. The lethality rates (R^Ls) of fall, caught in/between, and struck-by accidents were 5.2, 2.5, and 0.7, respectively, implying that fall is the deadliest type of accident in the HZMB-HK project, followed by caught in/between. Moreover, struck-by accidents accounted for 40% of all accidents, whereas fall accidents accounted for 35% of all accidents. The high frequency and lethality rates of fall accidents in the HZMB-HK project should be a major concern not only for this project but also for other similar projects.

Descriptive Characteristics of Fatal Accidents

Table 2 summarizes the demographic information of the decedents and the situational features of the fatal accidents. In Cases 3, 4, and 7, the fatal accidents occurred during night hours and weekends. This might be because night-shift workers typically suffer from increased fatigue and low visibility owing to darkness, and as such can make errors that could lead to accidents (Shapira and Lyachin 2009; Costa 1996). Working on weekends may also cause fatigue in workers (Lingard et al. 2010), which could negatively affect the safety performance of a project (Lingard et al. 2008). The research finding provides argument and support for construction practitioners and stakeholders to eschew working at night or on weekends. However, if certain tasks need to be performed in the night or on weekends, then there should be proper supervision.

[Insert Table 2 around here]

Hertz and Emmett (1986) argued that unfamiliarity with the type of work to be carried out increases the likelihood of accident occurrence. This may explain the reason why the highest accident and fatality rates of the HZMB-HK project were experienced within the first year of the project. Seven of the nine decedents were 40 years old or above. Moreover, it is worth noting that even though some of the decedents had over 20 years' working experience within the construction industry, they had less than 1-year experience in the HZMB-HK project (see Cases 3 and 4, for example). This might imply that there is a need for effective safety trainings for new workers on the project. Furthermore, three of the decedents were non-locals (Cases 7 and 8), and they died from fall accidents. Previous research has shown that ethnic minorities are more prone to accidents than their local counterparts (Tutt et al. 2013; Dong et al. 2009). A number of factors, including safety unawareness, language and communication barriers, inadequate safety training, and insufficient organizational support (Chan et al. 2015; Chan et al. 2017), could explain this phenomenon. Because of the ageing and labor shortage problems facing the Hong Kong construction industry (Legislative Council 2012), the demand for ethnic minority workers may rise in the future. Therefore, it would be useful to direct more attention towards improving the safety performance of ethnic minority workers (Chan et al. 2016).

Incident Sequence

Table 3 shows the incident sequence of each fatal case. Working above or near the sea represents a major challenge to achieving safety in the HZMB-HK project, as evidenced by the drowning fatalities (Cases 2, 4, 7, and 8). While the natures of deaths in Cases 2, 4, 7, and 8 were similar, the working surfaces in these cases were dissimilar (Table 2). In Cases 2 and 4, the decedents worked on barges, whereas in Cases 7 and 8, they worked either on a bridge deck or a working platform above the sea. Cases 1, 3, and 8 are cases that involved the collapse of either a working platform or a lifting frame system (agents). Due to the collapse of these agents, some workers fell from heights, while others were struck by falling objects. Accordingly, each of the three cases (Cases 1, 3, and 8) comprised at least one fatal injury and more than one nonfatal injuries. Cases 4, 5, and 6 involved heavy equipment operations in which many accidents occurred. Accidents that occurred within these cases included “rollover” (of an excavator into the sea) accident (Case 4), “struck-by” (a falling hook) accident (Case 5), and “caught between” (objects) accident (Case 6). McCann (2006) indicated that rollover, struck-by, and caught in/between are the most fatal heavy equipment operation-related accidents.

[Insert Table 3 around here]

As shown in Table 3, the eight fatal cases involved three types of accidents, which are fall (Cases 1, 2, 3, 4, 7, and 8), struck-by (Case 5), and caught between (Case 6) accidents. The fall accidents consisted of fall (from height) onto land (Cases 1 and 3), fall (from height) into water (Cases 7 and 8), and fall (from a barge) into water (Cases 2 and 4). While land-based fall accidents have attracted much attention from researchers, research considering sea-based fall accidents is very lacking. Five out of the nine decedents died from drowning (Cases 2, 4, 7 and 8). The result indicates that working above or near the sea poses a high risk of drowning to construction workers. As yet, however, research on construction-related drowning fatalities is limited. Thus, identifying the causes of the drowning fatalities that occurred in the HZMB-HK project is crucial; the findings could help in preventing the recurrence of similar fatalities.

Causes of Drowning Fatalities

This study identifies the causes of the drowning fatalities that occurred within Cases 2, 4, and 8, as these were the only cases with accident investigation reports outlining the causes of the drowning fatalities, and were accessible. As mentioned previously, the identified causes were grouped into immediate causes, safety management failures, and underlying factors (Table 4).

[Insert Table 4 around here]

Case 2

In this case, a drowning fatality occurred. The decedent was a handyman who was working on a barge. Certain unsafe behaviors caused him to fall into the sea and drown. The handyman had to transport a heavy metal stanchion from the barge to an artificial island. Owing to a long distance between the barge and the artificial island, he stood outside the fenced area of the barge deck (Marine Department 2014) to throw the stanchion onto the artificial island. In the process, he lost balance and fell into the sea. According to the Marine Department (2015a), the lack of a lifting gear for lifting operations within this case might explain the behavior of the handyman. A lifting gear is pivotal for eliminating manual handling of heavy construction materials. Eliminating manual handling of heavy construction materials is central as manual handling can negatively affect workers' postural balance and cause accidents (Pan et al. 2003). Lipscomb et al. (2006) reported that 11.5% of the slip and strip accidents in construction were due to manual handling of loads. Slip and trip accidents that occur on barges ought to be prevented to prevent possible fall-into-water accidents (Labor Department 1999). Aside from the aforesaid causes, the handyman wore a damaged life jacket; thus, the life jacket could not assist him to keep afloat in the water. The accident investigation report (Marine Department 2015a) indicated that the life jacket was not regularly inspected and maintained. Besides, it was identified that the handyman wore the life jacket wrongly (OSHC 2015). In conclusion, it can be stated that manual handling of a heavy load, improper use of PPE, and lack of regular inspection and maintenance of PPE were the major causes of the drowning fatality in this case.

Case 4

This represents another case in which a drowning fatality occurred, and it involves a rollover of an excavator into the sea. Lingard et al. (2013) and Edwards and Holt (2010) identified that factors such as ground conditions, weight of the load, and operator's competence and errors typically cause rollover of excavators. Their finding has been reinforced by the present study. The immediate causes of the excavator rollover within the present case were identified as follows: unsafe working surface, improper operation, and windy weather. This case involved the operation of an excavator on a barge. The operator was operating the excavator for loading public fill (from the barge) into a truck (Marine Department 2015b). The presence of the public fill on the barge created an uneven working surface that contributed to increasing the likelihood of the excavator overturning. In addition, "a northeasterly wind of force 4 on the Beaufort scale caused the barge to rock" (*ibid.*). Likewise, as the excavator was not properly secured on the barge prior to operating it, it – together with the operator – fell into the sea as a result of (1) the rolling motion of the barge caused by wind, and (2) shifting of the center of gravity of the excavator (OSHC 2016). Although the operator was eventually rescued, he was found dead. Another issue that should be highlighted is that the operator did not have proper safety training, and hence did not hold any relevant safety training certificate (Judiciary 2016), which may be the underlying personal factor behind the accident.

Case 8

This case comprises two drowning fatalities that occurred as a result of a temporary working platform (over the sea) collapsing. In summary, the decedents were engaged in dismantling a temporary working platform that was suspended by two lifting systems on a bridge deck. Each of the lifting systems consisted of a lifting beam, two hydraulic jacks, supports for both the lifting beam and hydraulic jacks, and a set of fiber rope slings. The accident was such that the temporary working platform, along with three workers, fell into the sea, resulting in two fatalities (Labor Department 2017b, c). Numerous possible causes of this accident have been identified. For example, it was identified that one of the lifting beams collapsed, causing two fiber rope slings to break (Labor Department 2017b). Additionally, there was no independent lifeline or an anchorage point for workers' safety harnesses. This may reflect that the safety harnesses (PPE) were improperly used. Chi et al. (2005) also found that improper use of PPE was a major cause of fall accidents. Other possible causes of the accident in the present case have been identified to include the lack of an approved method statement that sets out safe working procedures for dismantling the platform, inadequate risk assessments on major work processes, and inadequate safety information and training for workers.

To summarize, this study found (1) unsafe working conditions above or near the sea, (2) improper use of PPE, (3) use of damaged PPE, (4) inadequate safety supervision, training, instructions, and information, and (5) deficiencies in work design to be the major causes of the drowning fatalities that occurred in the HZMB-HK project. Based on this finding, suitable measures can be formulated and implemented to prevent the reoccurrence of similar drowning fatalities in construction projects that involve working above or near the sea.

Preventive Measures

In this research, 20 accident prevention measures were identified through reviewing relevant accident investigation reports. These measures were then categorized into administrative, engineering, and behavioral controls, as explained earlier. Table 5 shows the 20 preventive measures as well as their categories and cases. It could be inferred from the frequencies that more emphasis was placed on the administrative controls. Generally, the frequencies for the administrative controls were high, compared with those for the engineering and behavioral controls. The top five administrative controls were "conduct comprehensive task-specific risk assessments", "establish effective safety monitoring and control systems", "establish task-specific safe working procedures", "appoint competent persons to plan, design, control, and supervise the safety of the work environment", and "establish and maintain a safe work system with comprehensive method statements". Additionally, "provide and maintain safe means of access and egress" was identified as a crucial engineering control. This engineering control should be implemented when: working between vessels (Case 2); working at height (Case 1); and operating heavy equipment (Cases 5 and 6). Furthermore, "provide adequate safety training, information, and instructions" was highlighted as a crucial behavioral control. Implementing this control is key for workers to ensure their safety at work (Labor Department 2017b).

[Insert Table 5 around here]

Risk assessment is an essential part of any safety management system (Fung et al. 2010). According to Gadd et al. (2004), one of the key pitfalls in risk assessment is using generic risk assessment rather than specific (e.g., site- and task-specific) risk assessments. This study suggests that a key measure to prevent accidents in large-scale infrastructure projects, like the HZMB-HK project, and improve their safety performance is to "conduct comprehensive task-specific risk assessments". As discussed earlier, the Labor Department (2017b) revealed that one of the potential causes of the drowning fatalities that occurred in "Case 8" was inadequate risk assessments on major work processes. Therefore, conducting thorough and efficient task-specific risk assessments could help prevent fatal and costly accidents. This is due to the fact that such risk assessments can greatly help to identify and eliminate safety hazards associated with a task. Goh and Chua (2009) also agree that risk assessment "is an important process that can prevent costly accidents." However, stakeholders and practitioners should be advised that the efficacy of risk assessment is largely dependent on the risk knowledge and experience of individuals and the risk assessment team (Hillson and Murray-Webster 2007). Hence, for an effective risk assessment, it is critical to employ competent individuals and teams to perform the risk assessment. These individuals and teams could utilize past knowledge and experience in the form of past risk assessment and accident cases (such as the cases analyzed in this study) to improve the quality and effectiveness of new risk assessments (Goh and Chua 2009). Also, the utilization of artificial intelligence tools is advised in order to improve the quality of the task-specific safety risk assessments for large-scale infrastructure projects (*ibid.*). Artificial intelligence tools can improve the risk assessment quality through facilitating the retrieval of past knowledge and experience.

The provision of adequate safety training, information, and instructions would be another useful means to prevent accidents in large-scale infrastructure projects (Table 5). This is a key behavioral control that can influence the safety knowledge, awareness, and attitude of workers (Goldenhar and Schulte 1994; Huang and Hinze 2003). Safety trainings can focus on ensuring that workers are familiar with established safe working procedures. Additionally, they should introduce workers to PPE, such as safety belt and life jacket, and educate them on why PPE is necessary and how to use PPE properly. While employers should assume the responsibility of providing PPE and independent lifelines for workers (Labor Department 2017c), they should also be aware that regular inspection and maintenance of PPE is as well critical for preventing fatal accidents. Within the "Case 2", for instance, the handyman who died from drowning wore a damaged life jacket. With regular inspection and maintenance of PPE, the reoccurrence of similar incidents could be prevented. Moreover, employers should ensure that workers have the needed safety training, evidenced by their holding of relevant safety training certificates.

Even though the accident investigation reports analyzed in this study did not mention this preventive measure, assessing workers' swimming abilities might be a useful way to identify and engage those who could rescue themselves should they accidentally fall into the sea. This might be especially important in cases where the construction works need to be done above or near the sea. In essence, it can lead to reducing drowning fatalities. Nevertheless, emergency rescue measures must be in place (Labor Department 2016). Marine construction, in particular, requires implementing emergency rescue measures as a safety practice (Gudmestad 2013).

Limitations of This Study

Despite achieving the objectives, this study has some limitations. As fatality rate and accident rate measure the absence of safety, they may not be very reliable indicators to measure safety performance (Lingard et al. 2017). The absence of incidents does not necessarily mean better safety performance (Cadieux et al. 2006; Mengolinim and Debarberis 2008). For instance, the fatality rate of the HZMB-HK project varied during the studied period, and the absence of fatalities in 2013 might not mean better safety performance, given the occurrence of fatalities after 2013. By considering the severity of nonfatal injuries that result in hospitalization and lost working time, future research could improve the safety performance measurement. Also, this study analyzed eight fatal cases based on relevant accident investigation reports. However, from the accessible accident investigation reports, this study could identify the causes of the fatalities that occurred in only three of the cases. Additionally, future research is required to explore the interrelationships between the preventive measures proposed in the present study. In this respect, quantitative data on the proposed measures could be collected and quantitative data analysis techniques, such as the structural equation modeling, could be utilized to explore the interrelationships.

Conclusions

This study analyzed the construction accidents occurring in the HZMB-HK project, which is a large-scale public infrastructure project in Hong Kong. The unique feature of this project is that it involves construction works carried out above or near the sea, making the study of its safety performance important. Quantitative and qualitative approaches were used to analyze the accidents that occurred in the project from 2012 to the first half of 2017. In conclusion, it was identified that the safety performance of the HZMB-HK project was worse than that of public work contracts and the construction industry in general. The practical implication is that project stakeholders should implement measures to improve the safety performance of the HZMB-HK project. As this project is still ongoing, improving its safety performance is key to preventing future accidents and concomitant injuries and deaths. Additionally, fall and caught in/between were identified as the deadliest types of accidents in the project. This highlights the need for stakeholders and practitioners to pay special attention to how to curb these types of accidents in large-scale infrastructure projects like the HZMB-HK project. In this respect, this study identified and proposed a number of accident prevention measures. Moreover, the findings of this study indicated that working above or near the sea poses a high drowning risk to construction workers.

As Chua and Goh (2004) advised, "in order for the construction industry to improve its safety performance, it needs to learn from its mistakes and put the lessons learned to good use." Goh and Chua (2009) also stressed the importance of knowledge of past incident cases in improving the quality and efficiency of new construction safety risk assessment, which is an important construction safety planning function. Thus, the lessons from the present study, when properly used, would definitely help policy makers and practitioners improve the safety performance of large-scale infrastructure projects worldwide. The key theoretical contribution of this research is the analysis of accidents in a large-scale infrastructure project that involves both land- and sea-based construction works.

Data Availability Statement

This study utilized data on the HZMB-HK project, which were obtained from various entities. The data on the workers and man-hours of the workers were obtained from the Highways Department of HKSAR. Those on the industrial and marine accidents were obtained from the Labor Department and Marine Departments. Those on the accident and fatality rates of public work contracts and the construction industry in general were gathered from the Annual Report on Accident Statistics and Analyses for Public Work Contracts, published by the Development Bureau. The Concise Investigation Report, the Work Safety Alert, the Marine Accident Investigation Report, the Marine Department Notices, the Judgment, and the Green Cross were publicly available. Demographic information of decedents were gathered from the WiseNews database.

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