Ocean & Coastal Management 141 (2017) 43–54

Contents lists available at ScienceDirect

Ocean & Coastal Management

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

Cyclone risk mapping for critical coastal infrastructure: Cases of East Asian seaports

Jasmine Siu Lee Lam [a,*], Chang Liu [b], Xueni Gou [b]

[a] School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
[b] Maritime Institute, Nanyang Technological University, Singapore

ARTICLE INFO

Article history:
Received 7 July 2016
Received in revised form
14 February 2017
Accepted 21 February 2017

Keywords:
Cyclone
Critical coastal infrastructure
Port
Risk mapping
Natural hazard

ABSTRACT

Seaport is a critical coastal infrastructure serving important economic purposes but at the same time is exposed to a wide range of natural hazards including tropical cyclones. Mapping of cyclone risk for seaports is a primary step in risk planning and mitigation which remains a gap in the literature. Since East Asia is among the most affected areas of cyclone risk, and also the region where the world's top container ports are located, cyclone risk mapping for major seaports in East Asia is carried out. The objective of this paper is to develop a scientific methodology of cyclone risk mapping for critical coastal infrastructures, taken East Asian seaports as illustration. The risk maps are created by the integration of cyclone hazard maps showing historical cyclone tracks, wind intensity distributions and frequency distributions, with port container throughout data map. Results show that there were a considerable number of cyclone events, especially along the coastal seas extending from Vietnam to Japan. In South East Asia, cyclone risk is generally low in terms of both wind intensity and frequency but not completely zero. The ports of Shanghai, Kaohsiung, and Keelung are more exposed to cyclone risk in North East Asia.

1. Introduction

With increasing concern of natural hazards and associated disasters, the need to investigate coastal exposure to natural risks has been rising. Coastal infrastructures are particularly prone to various natural hazards (Hoby, 2015). In addition, coastal infrastructures in developing countries are most vulnerable and most lacking in their resilience to withstand the various disaster impacts (Asariotis and Benamara, 2012). Among them, seaport is a critical coastal infrastructure, which serves important economic purposes but at the same time is exposed to a wide range of natural hazards. Marine cargoes are growing in terms of both volume and value. The increased concentration of goods, combined with greater exposure to hazards and even catastrophes, makes ports more vulnerable than ever before (Lam and Su, 2015). All compounding factors including sea-level rise, increased storms, monsoons, earthquakes and tsunami, may cause damage to coastal structures and trigger off coastal disasters, leading to coastal inundation, flooded assets and disrupted port operations (Hanson et al., 2011; Khew et al., 2015; Rahman and Rahman, 2015).

Tropical cyclone varies by name such as hurricane, typhoon, tropical storm, cyclonic storm, tropical depression and cyclone, depending on its location and strength (NOAA, 2015). It is a rapidly rotating storm system characterised by a low-pressure centre, an organised system of clouds and thunderstorms originating over tropical or sub-tropical waters. To be classified as such, maximum sustained winds of 74 miles per hour (66 knots, 34 m/s, 119 km/h) or higher should be reached. The major effects associated with tropical cyclones include strong winds, rain, high waves, storm surge/tide and tornadoes. Coastal regions are particularly vulnerable to damage from a tropical cyclone, as tropical cyclones normally weaken rapidly when moving over land with a cut-off from the primary energy source (NOAA, 2015). According to Shi and Kasperson (2015), East Asia is one of the most affected areas by tropical cyclones.

Past hurricane events in North America and their impact on seaports have been widely noticed and documented as well. These included Hurricane Hugo in 1989 hitting into the port of Charleston in South Carolina, Hurricane Katrina in 1995 hitting the ports of Gulfport and New Orleans, Hurricane Sandy in 2012 hitting the port of New York-New Jersey, etc. (Lloyd's List). Gujarat Cyclone in 1998 hit the port of Kandla in India, which caused extensive damage to port structures and facilities, as well as widespread impact on ships

* Corresponding author.
E-mail address: sllam@ntu.edu.sg (J.S.L. Lam).

http://dx.doi.org/10.1016/j.ocecoaman.2017.02.015
0964-5691/

and cargoes (Lloyd's List, 1998). The most famous case in East Asia was the Typhoon Maemi in 2003 which hit the port of Busan, caused severe damage to 11 quay cranes and had the container yards flooded (Lloyd's List, 2003). This event had also caused a 91-day closure of the port that significantly affected maritime transport in the region (Lam and Su, 2015). Several other typhoon events also led to disrupted port operations in this region, although no significant physical damage had been incurred. Typhoon Kalmaegi on 12 September 2014 forced closure of container ports in Hong Kong (News24, 2014). Typhoon Halong on 9 August 2014 caused a shutdown of the major container terminals in Kansai, including the Hanshin ports of Kobe and Osaka on 9 and 10 August. Cargo terminals in Hong Kong and Shenzhen shut down their services at the time of Typhoon Megi heading toward the southern Chinese coast on 21 October 2010 (Lloyd's List, 2010). Hong Kong suspended port services again in 2011 when Typhoon Nesat was issued the No.8 Gale or Storm Signal on September 29 (Terra Daily, 2011).

The high impact and uncertainty of exposure to cyclone risk of coastal infrastructures and seaports dictate that the assessment of cyclone hazard is important and meaningful. There is a pressing demand to prepare the ports for cyclone risk. Mapping of cyclone risk for major seaports is a primary step in risk planning and mitigation which remains a gap in the literature. Furthermore, there is no available literature providing a methodological approach in cyclone risk mapping for coastal infrastructures. Since East Asia is among the most affected areas of cyclone risk, and also the region where the world's top container ports are located, cyclone risk mapping for major seaports in East Asia is carried out in this research.

The objective of this paper is to develop a scientific methodology of cyclone risk mapping for critical coastal infrastructures, taken East Asian seaports as an illustration. The findings will be useful for East Asian seaports. The proposed concept and methodology can also easily be adapted for other geographical areas, thus facilitate future research. The rest of the paper is structured as follows. Section 2 reviews the significance of critical coastal infrastructures, including seaports, and highlights their vulnerability to natural hazards. It particularly highlights research demands in careful natural hazard analysis and risk planning/preparation. Section 3 describes the scientific methodology of cyclone risk mapping for seaports. Section 4 presents the risk maps and analysis. Section 5 concludes this paper and highlights its contribution.

2. Literature review

Natural hazards are viewed as the potential occurrence of a natural physical event which may cause injury, loss of life, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources (IPCC, 2012). They include earthquakes, landslides, tornadoes, hurricane wind and storm surge threats, floods, and many other natural events. The concept of natural hazards has also been expanded to include climate change and variability since the initial IPCC report (IPCC, 2001).

Natural hazards often lead to disasters. The geo-physical and climatic characteristics of any region determine the likelihood of natural disasters occurrence (Guha-Sapir et al., 2004). Overall, there has been a steady increase in the number of natural disasters and catastrophic events (UNSIDR, 2009; IPCC, 2011; OECD, 2012; WEF, 2013; EMDAT, 2015). Economic losses associated with these disasters are also increasing (IPCC, 2011; EMDAT, 2015).

Coastal zones, as the interfaces of land, sea, and air, are susceptible to a wide range of natural hazards (Yoo et al., 2011). Their vulnerability is compounded by increasing concentrations of population and economic systems. A large part of the global population lives in coastal regions, and the trend of growing density is expected to continue (Hugo, 2011). Many coastal zones have exhibited higher growth rates in population and GDP than their national averages, as well as significant urbanisation (McGranahan et al., 2007; Seto et al., 2011). Most of the world's megacities are also located in coastal areas (Brown et al., 2013). Important economies and economic assets including buildings, transport infrastructures, utility infrastructures, and energy infrastructures are therefore subject to the increasing concerns of natural hazards (Lam and Lassa, 2017; Munich Re, 2004).

While assessment of the impact of natural hazards on critical infrastructures is widely carried out as part of homeland security and emergency management, the research on their impact on critical coastal infrastructures has been limited. In fact, the impact of natural hazards and climate extremes on critical coastal infrastructures represent serious challenges due to significant growth in exposure (Hanson et al., 2011). Natural hazards are imposing more severe risks on coastal areas (Grant-Smith, 2014). It has been shown that the probabilities of failure as a system for the coastal structures are higher than that of other civil works (Hoby, 2015). Many critical infrastructures are also located in coastal zones, including energy and transport networks. Large-scale energy generation plants such as oil refineries and nuclear power plants often require coastal locations for either transportation and/or water supply for cooling purpose (Brown et al., 2013). Airports, and more often seaports, are usually located in low-lying or reclaimed coastal areas. Relocation of these critical coastal infrastructures is very costly, if not impossible at all, especially in the near-to medium-term (Brown et al., 2013). Therefore, proper study of the potential hazards and the associated risk is essential in preparation and planning.

Among the critical coastal infrastructures, seaports are focal points as a critical facilitator in international trade and logistics. The key function of seaport by connecting sea and inland transportation across continents and regions makes itself an essential component in the trade flow. Seaports are also important in acting as key nodes in global supply chains (Lam and Gu, 2016). As such, the impact of natural hazards on any major seaport will have significant economic consequences at the regional and national levels as well as internationally (WEF, 2010). Moreover, seaports are strategic infrastructures for rescue mission and materials distribution at the time of any natural disaster. Destroy of a seaport or disruption to its key functions can easily increase the risk of secondary disasters (Hsieh et al., 2014).

The impact of natural hazards on seaports can be well illustrated by the recent earthquakes and tsunami in Japan, cyclones and floods in Australia (UNCTAD, 2011). The great Hanshin-Awaji Earthquake in 1995 caused disastrous damage to the port of Kobe, which included direct repair costs of $5.5 billion and an estimated economic loss of $6 billion (Werner et al., 1997). The 2004 Indian Ocean Tsunami in Asia and the 2011 Great East Japan Earthquake and Tsunami have severely damaged/destroyed many ports, and caused significant interruptions to world trade and economy (Lloyd's List, 2011a, 2011b). An analysis of port disruption events since 1900 has revealed that natural disaster was one of the main causes and associated with the highest severity in terms of affected cargo volumes for Asian ports (Lam and Su, 2015).

Based on the records from 1900 to 2014, the number of occurrences of natural disasters, the number of total affected and total damage in East Asia all showed clearly increasing patterns (CRED, 2015). Regarding the vulnerability to natural hazards, a study concluded that the developing countries in Asia have the least capacity to adapt to climate change (Yusuf and Francisco, 2009). Anticipating the trend of climate change in the coming decades, coastal areas and maritime infrastructure will be exposed to rising