Chapter 1

Introductory Chapter: A General Overview of Tsunami and Effectiveness of Early Warning System

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1. Introduction

Confirmed tsunami events from 1610 BC to AD 2014 are 1212 events from which 245 were deadly. The geographical distribution of these events is 76% in the Pacific Ocean, 9% in the Indian Ocean and Red Sea, 6% in the Atlantic Ocean and Caribbean Sea and 9% in the Mediterranean Sea. Concerning the sources for generation of the tsunamis, 87% are from earthquake, 8% from underwater volcanic eruptions, 4% from major ocean landslides and 1% from other sources [1].

In recent years, world has experienced few mega-tsunamis, which have caused extensive loss of life and properties. The most destructive ones were in December 2004 in Sumatra causing more than 290,000 death and March 2011 in Japan, creating a nuclear accident [2]. The event of 2004 has triggered many global initiatives, such as a new tsunami detection system, more detail coastal modeling, tsunami compatible coastal developments, integrated approach for regional early warning system (EWS) and public educations, awareness and preparedness.

Early warning system (EWS) can play an important role in risk reduction, using the effective development of national and local capabilities. However, it must be emphasized that national risk reduction strategies must not only be based on the EWS. If risk considerations are not adequately factored into national development strategies, disaster occurrence and loss will continue to increase, with or without the improved EWS capabilities. EWS should thus be seen as a last line of defense for dealing with unmanaged risks. EWS should be developed as vital element of much wider national risk management and reduction strategies. If the EWS is developed as stand-alone systems, it may contribute to generate a false sense of security leading to indifference and passivity in vulnerable groups and sectors as well as among national disaster management agencies and systems.

2. Tsunamis

2.1. Tsunami sources

The recent advances in tsunami study has lead the scientist for better understanding of the cause of tsunami, its propagation and most importantly the system of warning ahead of tsunami arrival to the vulnerable coastal area. In addition, now the secondary sources for strengthening the devastating effect of the tsunami, for example, the splay faulting, landslide caused by the parent earthquake sources, have been advancing [3].

The main source for tsunami generation, however, has been identified as being the earthquake. Due to this, we will discuss here two case studies, namely the Makran (Indian Ocean) and Great East Japan earthquake and tsunami Pacific Ocean.

The other sources are classified as meteorological effects, meteotsunami. This has been discussed fully within this book on Chapter 1, and the underwater volcanic eruption as other tsunamigenic sources also being better documented and investigated on Chapter 2 of this book.

Tsunamis can also be generated by a submarine landslide, which typically occurs as a result of an earthquake [4]. A submarine landslide, rock fall or ice fall can trigger a tsunami by displacing large amounts of water. As a result, the water level rises generating tsunami.

The Papua New Guinea tsunami of July 1998 is a good example of relatively small deepwater submarine landslide, which caused devastating local tsunamis. This was triggered by a magnitude 7.1 earthquake [5]. The multibeam bathymetric study is a very useful tool in identifying this type of potential submarine landslide offshore.

The other sources of major risk contributors are the onshore earthquake events rather close to sea. The thick sediments at Oman Sea provide conditions for submarine landslides and slumps that can generate small tsunamis in the region. Heidarzadeh and Satake [6] showed that the tsunami observed in the northwestern Indian Ocean following the 23 September 2013 Pakistan inland earthquakes was generated by a submarine landslide.

In addition, the splay faults mapped offshore Makran can also play an important role as tsunami strengthening factor after the major tsunamigenic event has occurred, but not as independent tsunami source [7–9].

It is very important to note that the coastal area can be affected by both local and remote-source tsunami. In the case of a local earthquake, the impact of the earthquake can be greater than the tsunami. The main tsunamigenic earthquake may cause damages to buildings and infrastructure before the arrival of the tsunami wave, with potential loss of life. Therefore, in the near coast (local) tsunami-prone area, both tsunami and earthquake effect must be considered.

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2.2. Tsunami due to earthquake

2.2.1. Makran

From seismotectonic view point, the Makran subduction zone is characterized by the subduction of the oceanic part of the Arabian plate beneath the Eurasian plate [8] and extends along the Gulf of Oman from the Zendan-Minab fault system near the Strait of Hormuz in the west to the Baluchistan volcanic arc in the east. It has one of the largest accretionary prisms in the world with a thick (7 km) unconsolidated sediments [10, 11], lying above a shallow dipping decollement (**Figure 1**).

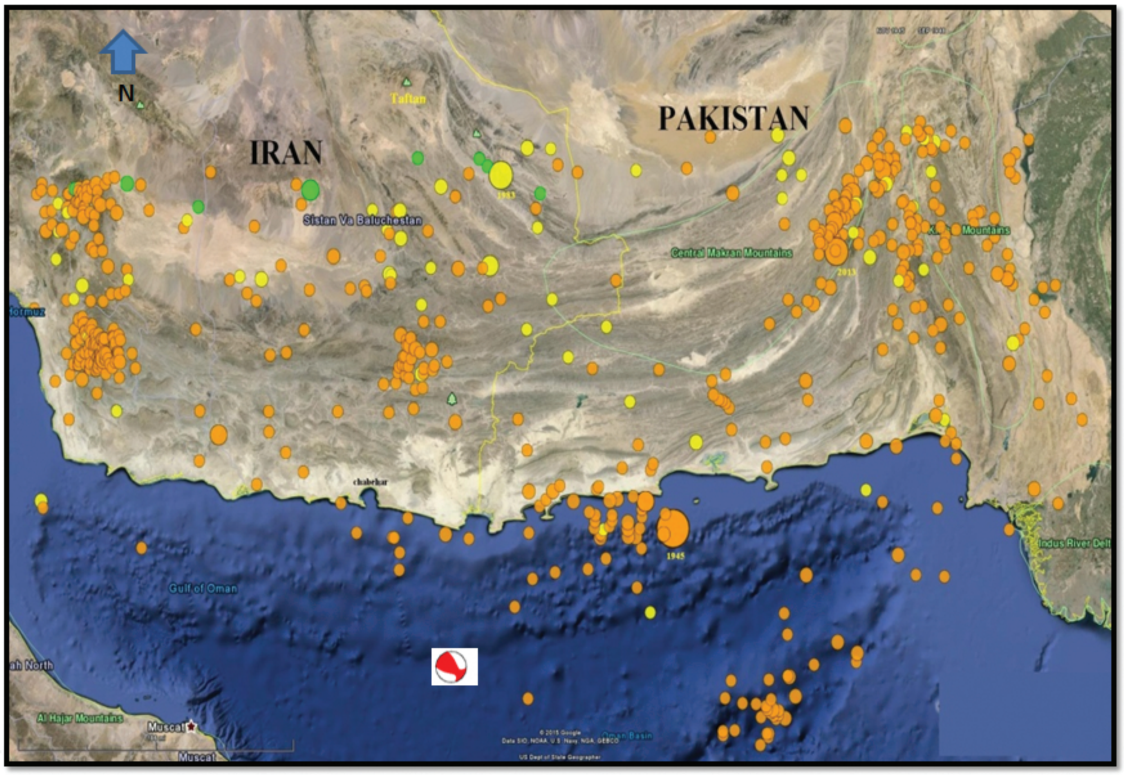

Figure 1. Makran seismicity 1940–2015, based on USGS catalog, the location and Focal Mechanism solution of 2015 earthquake also being indicated on the figure.

From seismicity point of view, compared with other similar zone in the world The Makran subduction area has been considered as having low seismicity. But based on data from 1945 tsunami, the affected area has been classified as a tsunami-prone region [11, 12].

2.2.2. Great East Japan earthquake and tsunami

The Pacific plate is subducting along the Japan Trench beneath Eastern Japan, whereas the Philippine Sea plate is subducting along the Nankai Trough beneath Western Japan [13]. The Philippine Sea plate is subducting along the Sagami Trough beneath the North American plate. The Pacific plate is converging with and subducting beneath the Okhotsk plate at about 40 mm per year, resulting in frequent and large earthquakes [13]. The Japan Trough has a long history of large events, including the 869 Mw 8.3 Jogan, 1896 Ms 7.2 Meiji Sanriku and 1933 Mw 8.4 Showa Sanriku events, all of which produced large destructive tsunamis [13].

On 11 March 2011, an earthquake with magnitude of 9.0 off the northeastern coast of Japan triggered a tsunami [6]. The waves reached up to 40 m high and penetrated up to 5 km inland. It caused a great loss of life (~20,000), strong environmental damage and infrastructural destruction. The tsunami has also severely affected the Fukushima nuclear power plant, causing serious risks of contamination from radioactive releases.

2.2.3. Tsunami major disaster effects

One of the major disaster effects that require an especial attention is the environmental damage at the coastal area due to transportation of sediments and debris from ocean to coast and vice versa. For example, during 2004 Sumatra tsunami, the sediment transport and coastal subsidence associated with the tsunamis had a major impact on urban communities and also in ecosystems. Unfortunately, these types of impact have not been adequately studied because they may have long-term effects both on environment and on the regional economy.

2.2.4. Factors strengthening the tsunami disaster

Several case studies indicated that splay faults are associated with subduction zones in the world [3, 11]. They develop within the sedimentary sequences as sediments being added from the upper plate. The superimposed effect of splay faulting on tsunami wave heights in the near-field has been observed in many mega-tsunami events. In this respect, the 1946 Nankai, 1960 Chilean and 1964 Alaskan earthquakes and tsunamis [8, 14] and the most recent case of the 2004 Sumatra-Andaman could be mentioned.

Thus, splay faults can play an important role, in particular, as local hazard, and thus their identification is important.

At this stage, we do not believe that these faults individually are capable of producing tsunami, but as indicated above, they can play an important role in strengthening the tsunami hazard effect during megathrust ruptures. So, we strongly suggest that this factor should be accounted for a comprehensive tsunami hazard analysis. These factors in addition to the above-mentioned items, if are not implemented accurately, will make the design of an effective tsunami early warning system problematic [15].

2.2.5. Mud volcano (example from Makran)

Mud volcanoes are known from onshore, where erupted water often is methane saturated. These are the result of progressive compression and dewatering of the deep undercompacted, overpressured sequences (at decollement). The world's most notorious mud volcano, Indonesia's Lusi, destroyed a town in 2006.

Offshore Makran (Northwest Indian Ocean), numerous mud volcanoes have been mapped. There is a direct relationship between mud volcanoes and transform faults. Not all mud

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intrusions reach the seabed (**Figure 2**). In places, there is clear evidence of mud intrusions in the shallow part of the sedimentary sequence. The mobilized overpressured sequences have clearly used the fault zones as conduits to reach low-pressure areas and the surface.

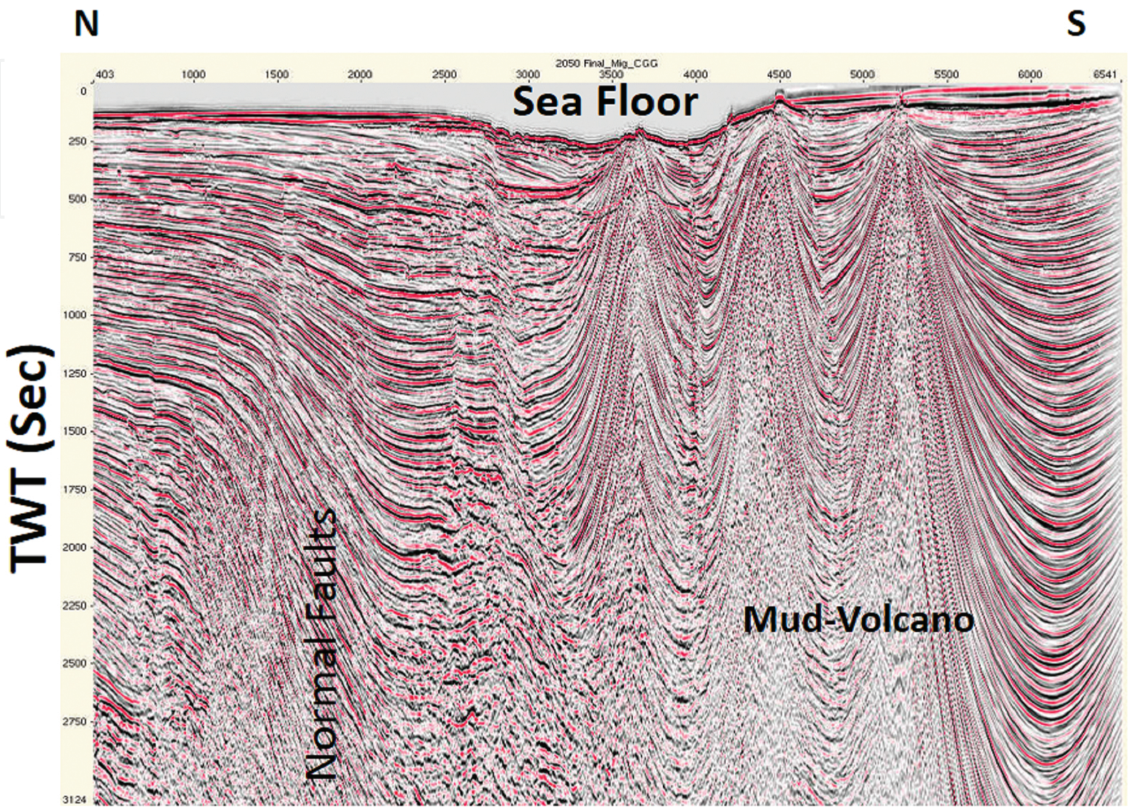

Figure 2. Seismic expression of mud volcanoes in the Makran subduction zone area, Oman Sea (belong to National Iranian Oil Company).

The offshore mud volcanoes, as the onshore once, have limited lifetime, and eroded tops have been observed.

On 24 September, a shallow 7.7 magnitude earthquake occurred in Pakistan. At least 300 people died and thousands of houses collapsed in Balochistan Province. The earthquake was felt as far as Oman and India. The earthquake appeared to be a strike slip event. An amazing effect of the earthquake—in roughly 40- km distance— is that a new island appeared few hundred meters off of Gwadar offshore. The island is about 18–21 meters high, up to 91 meters wide and up to 37 meters long [16].

3. Tsunami early warning system

The main elements that are required to be considered before any decision to set up an early warning system are frequency, severity, lead time, accuracy, response costs, loss reduction and early warning system cost. A feasibility study needs to be conducted with great precision taking into account also the public education and their awareness to full response.

The current tsunami preparedness policy, which is oriented toward warning and evacuation, needs to be revised worldwide. Coastal cities, ports and marine constructions at tsunami risk are growing and becoming more and more vulnerable to a tsunami impact. Today, we cannot ignore an increasing risk of cessation of sea-port operation, oil platform destruction or coastal devastation. The safe and stable function of sea ports, coastal oil or gas tanks, cold storage, fisheries and other facilities becomes more significant for the economic development of coastal communities. Economic risk management is an important goal, which has to be solved for coastal urban and industrial areas at tsunami risk. Therefore, it is important to engage in day-to-day efforts to improve public awareness, preparedness and regional cooperation to deal with marine natural disasters.

4. Discussion and conclusions

In some areas, such as Japan's coast, the tsunami knowledge is high but other areas such as Indian Ocean region in particular Makran region is less advanced, and even some of the most important earthquake source parameters are less understood and require collection and analysis of more seismological and seismotectonic data. In this regard, it is important to note that in the recent years some progress is underway in the Makran region, for example, acquisition of some deep active seismic profiling using both explosion and air gun as seismic sources aimed at better understanding of the crustal structural elements and model to be used on tsunami hazard assessments.

In recent years, tsunami early warning systems are being established in the region. One of the essential parts of an effective warning system is the tsunami (earthquake) detection. It is important to consider how modern technology and lessons learned from past tsunamis worldwide can be combined to create safer coastal communities with tsunami aware populations.

For people living in coastal areas, protection awareness and education are other important elements in everyday lives, and through the professional responsibilities, understanding the disaster risk also increases the effectiveness of early warning system and policy implementation.

In this respect, the current tsunami preparedness policy, which is oriented toward warning and evacuation, needs to be revised worldwide. Coastal cities, ports and marine installations at tsunami risk are growing and becoming more and more vulnerable to a tsunami impact. Today, we cannot ignore an increasing risk of termination of sea-port operation, oil platform destruction or coastal devastation. The safe and stable function of sea ports, coastal oil or gas tanks, cold storage, fisheries and other facilities becomes more significant for the economic development of coastal communities. Economic risk management is an important goal, which has to be solved for coastal urban and industrial areas at tsunami risk. Therefore, it is important

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