Chapter

Introductory Chapter: The Lessons Learned from Past Tsunamis and Todays Practice

Mohammad Mokhtari

1. Introduction

It is always the history that gives us prospects to plan the future, based on past experiences, to make it better. Similarly, to apprehend the future losses from disasters like earthquakes and tsunamis, studying past events using geological evidence gives us the best opportunity to plan the mitigation. Especially in the case of trans-oceanic tsunamis, which are rare, the only evidence we found earlier in many cases is historical documents. The past occurrence of such large tsunamis is usually preserved by geological features/structures at coasts. The geological evidence not only gives insight into the past to understand what has had happened, but it also helps us prepare for the future, including the fine-tuning of standard operating procedures for unexpected events and planning and designing of infrastructure for the development of a particular region. The long-term geologic records provide opportunities to assess tsunami hazards more copiously. A more refined understanding of the long-term variations in time and the recurrence of giant tsunamis is essential for producing realistic vulnerability assessments for coastal communities.

The recent instrumental observations from geodesy and seismology together with the historical earthquake and tsunami data have a profound impact on the understanding of rupture patterns of large earthquakes and tsunami events. Nonetheless, the devastation caused by the 2004 Indian Ocean tsunami and the later major tsunamis made it clear that estimates of earthquake size and tsunami potential are woefully inadequate. Therefore, a more refined understanding of the long-term variations in timing and recurrence of giant tsunamis is essential for producing realistic vulnerability assessments for coastal communities. For example, if an earthquake similar to 1945 Makran occurs again, it will cause huge destruction at rapidly growing coastal cities of Iran, Pakistan, India, North of Oman sea, Yemen and UAE. During recent years, several studies in Oman, Pakistan, India, and Indonesia focused on North West Indian ocean tsunamis but Makran is one of the noted places which has deficient in data on tsunami size and frequency. No large-magnitude earthquake is known in the western Makran where the recorded seismicity is sparse. By contrast, large-magnitude and frequent earthquakes characterize the eastern Makran. This geographical dissimilarity in seismicity is attributed to a hypothetical segmentation of the subduction zone or to a locked plate boundary that experiences great earthquakes with long repeat times in the west [1].

2. Tsunami sources

Knowledge of tsunami sources is important in tsunami warning and mitigation. Where tsunami detectors should be deployed and maintained? What incoming tsunami heights should modelers assume in making inundation maps? Which coasts have the greatest need of mitigation measures? The answers depend on estimates of tsunami size and frequency, which in turn may vary from one tsunami source to the next.

Let's now look at the case of the Indian Ocean. There are two major tsunamigenic sources in the Indian Ocean region. One is the Andaman-Sumatra subduction zone and the other one is the Makran subduction zone. The results of the studies show that the Andaman-Sumatra subduction zone being affected by many major tsunamis in the past. However, the Makran subduction zone, which located between Iran and Pakistan to the north of the Arabian Sea, neither there is many historical records nor any long-term studies. Though recent studies established the fact that Oman, Pakistan, Iran, and India were repeatedly hit by tsunamis in historical times, it is still unclear how strong were these events and what was the height of the tsunami waves. For example, the investigation found that boulder deposits and fine-grained sediments from the north coast of Oman are evidence for much larger pre-historic tsunami events in the region. It is interesting to note that the seismicity differs in the eastern and western parts of the Makran subduction zone, with a boundary at about the Iran/Pakistan border. No large-magnitude earthquake is known in the western Makran where the recorded seismicity is sparse, raising the question of locked or aseismic? By contrast, large-magnitude and more frequent earthquakes characterize the eastern Makran. However, the evidence found from the Oman coast is in contrast to the theory of division of the Makran subduction zone in two. Therefore, the earthquake might have at least partially ruptured the western Makran, which would imply that the western Makran is not completely unlocked. Consequently, the hazard scenarios prepared based on historical data underestimate the tsunami threat in the Northern Arabian Sea. Keeping in view the indistinct structure of the Makran subduction zone as well as inconsistent historical tsunami records. To help the situation a Paleo-tsunami studies can play an important role in further assessment of the region. In this case the dated deposits can allow us to estimate the times and recurrence intervals of past tsunamis. The obtained result can guide the mitigation efforts and may reduce major losses due to future tsunamis. This study now being initiated and it will happen in a regional context which would reduce the uncertainty where a repeated location would be investigated. Parallel to above in the Makran region the onshore part is also important for better understanding the structural framework of the area, so the following work has been conducted and shown the result is unique.

3. Recent active seismic data

To improve a better understanding of the Makran subduction zone structural model recently, three active seismic profiles (**Figure 1**) have been acquired onshore west Makran. Each profile was about 200 km long, with a shot-point interval of 20 km and the receiver interval of 700 m [2]. **Figure 2** shows the results of the model analysis. The high signal to noise ratio and resolution is exclusively valuable, which give an exclusive evidence on layering of the accretionary margin and also the oceanic Moho with rather high resolution. The offshore continuation of these

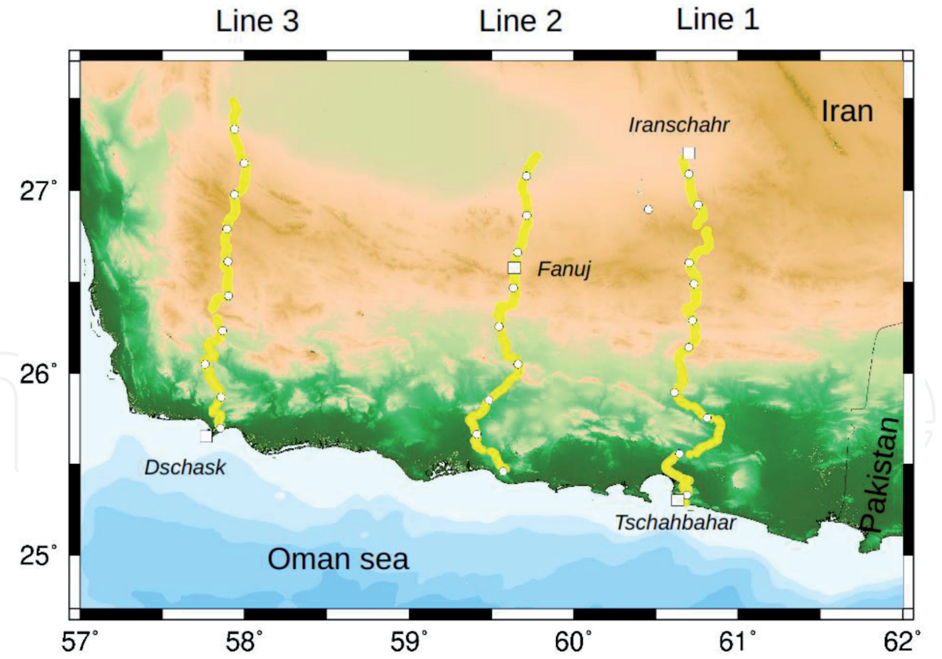

Figure 1.
Location of onshore active seismic data in the West Makran. The yellow lines indicate the lines. The open circle on the lines indicate the shot point locations.

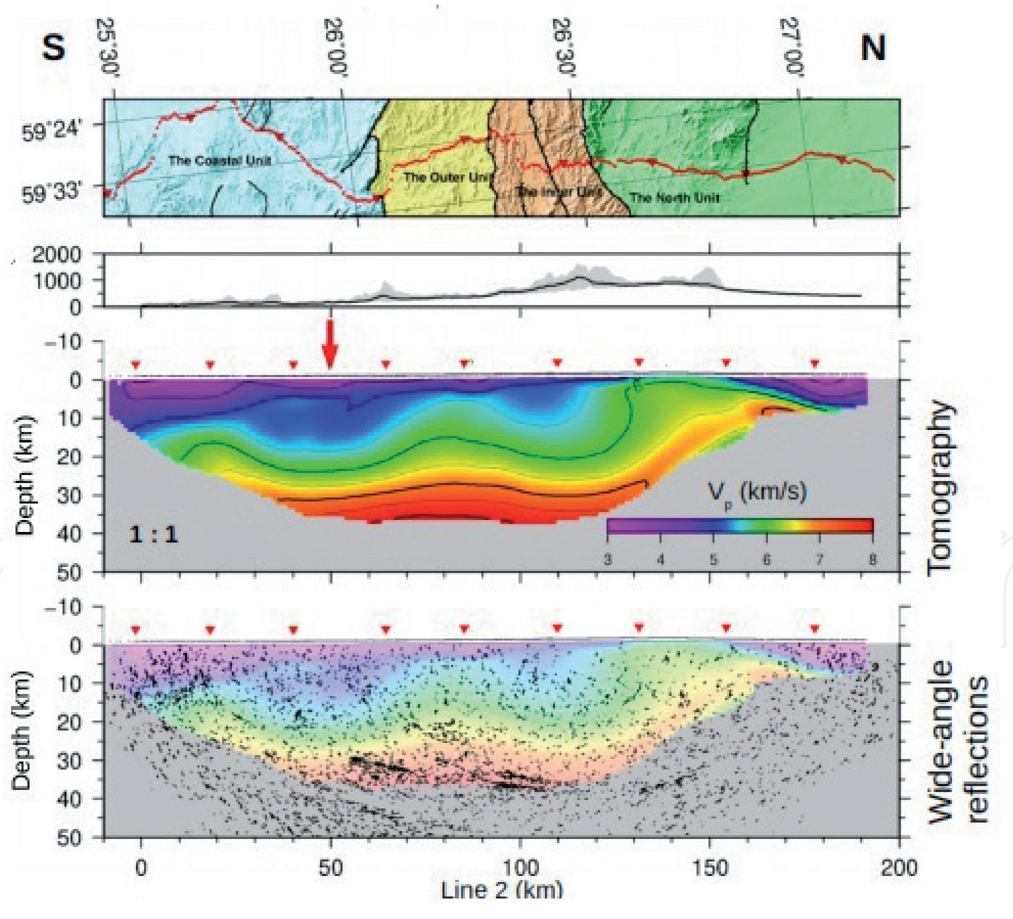

Figure 2.
Results for seismic profile (Line 2). P-wave velocity (Vp) of tomographic inversions are color coded; unresolved regions are clipped; contours are Vp with labels in km/s. Shot locations are indicated by red inverted triangles. Line-drawing elements (black dots, point out reflective bands) migrated with tomographic Vp model are overlaid on Vp model. Tectono-structural units of Makran (M) is indicated on top of panel.

lines is ongoing and hope soon we will cover with high resolution the entire wester Makran margin. These will provide the major parameters of future Makran mega-thrust fault.

4. Tsunami risk reduction measures

4.1 Early warning system

Following the Sanriku Tsunami in 1933 the first tsunami early warning system was established in Japan. Tsunami warning center was established in 1946 after Unimak tsunami in Hawaii. After the 1964 Mw 9.2 Great Alaska earthquake and Tsunami the Pacific Tsunami Warning Centre, and in the 1960 Valdivia Mw 9.3–9.6 earthquake and tsunami in Chile have been established [3]. Tsunami early warning systems had not been established in the Indian Ocean at the time of the 2004 Indian Ocean Tsunami. Again, it was only following the major disaster that the regional tsunami early warning systems were established in the Indian Ocean. Recently Indian Ocean Tsunami Warning and Mitigation System, IOTWS; the North-eastern Atlantic and the Mediterranean Sea (North-eastern Atlantic, the Mediterranean and Connected Seas Tsunami Warning and Mitigation System, NEAMTWS), and the Caribbean region (Caribbean and Adjacent Regions Early Warning System, CARIBE-EWS) has been established. Additionally, national tsunami early warning systems were established in the Indian Ocean (e.g., Indonesian Tsunami Early Warning Systems, Ina-TEWS) [4].

In the Makran region using different earthquakes and tsunami, the estimated time for tsunami waves to hit the coastlines of Iran and Pakistan and Oman is between 15 and 20 minutes. This strongly suggests a major need for the establishment of a tsunami early warning center in the region. It should be mentioned at the present there two national early warning systems one in India and the other one in Oman. It is strongly necessary that these centers to be task as waring dissemination in the region as well till a new center with task region being established for the here we should add 4.

4.2 PTHA modelling

As there are different causes for tsunami generation (earthquakes, landslides, volcanic activity, meteorological events, and asteroid impacts) number of geophysical assessments should be in principle conducted. It is important to mention one the mythology that can be used in understanding a tsunami hazard and risk reduction measures is the application of Probabilistic Tsunami Hazard Analyses (PTHAs) among other methods in the world in a global, regional, and local scales. Tsunami hazard assessment methodologies are not standardized and recent destructive tsunamis It is difficult to quantify the hazard of Hazard assessments need to consider how the tsunami hazard information will be used, the relevant tsunami sources, the propagation, and inundation models, and whether the assessment is probabilistic or scenario-based. The determination of maximum earthquake magnitude is difficult. For example, the magnitude range for the Sunda Arc is 9.0–9.6 whereas the range for the Makran subduction zone is 8.1–9.3. Predictions of tsunami inundation are influenced by earthquake characteristics, models, bathymetric and topographic data resolution, land cover roughness, and tides. Tuning models to historical events can increase accuracy and return periods can be calculated from pre-historic tsunamis. Can help modelers and end-users to agree on methodologies and how to best deal with uncertainties. Before the occurrence of the 2004 Indian Ocean Tsunami, only a few PTHA's were carried out. However, the PTHA method gained momentum due to the many tsunami hazard assessments which included the deterministic hazard studies; to inform the risk reduction to the stakeholder and government authorities. The development of modern PTHA techniques being done by Geist and Parsons [5], and some-more studies using the methodology followed later.

The unexpected measure of the disaster caused by the 11 March 2011, Tohoku earthquake and tsunami in Japan in a country that has invested much effort on tsunami preparation, again showed that our understanding of tsunami hazard and risk is being been limited. In essence, this event highlighted the need for incorporating more complex phenomena such as variable slip and quantification of source uncertainties in PTHA analysis.

5. Conclusion and future work

The recent observations from geodesy and seismology in combination with historical tsunami data have a profound impact on the understanding of rupture patterns of large earthquakes and its consequent tsunami events. However, the 2004 Indian Ocean tsunami which caused a devastating effect made it clear that estimates of earthquake size and tsunami potential are woefully inadequate. So, some powerful methodology requires to reduce this short come. Among this which recently has gained momentum is the Probabilistic Tsunami Hazard Assessment or simply PTHA. It should be noted that many aspects of PTHA need to be revised for the future application of this methodology. Despite a major advance in the PTHA methods, the standards on how to conduct PTHA assessments is lacking now and in addition, the probabilistic risk assessments need to be revisited. The lack of systematic data for building the models for earthquake sources for example shallow megathrust zone close to the trench. It should also be noticing the inclusion of landslide and splay faulting [6] as other hazard strengthening elements due to the lack of an instrumental record of occurrence has proven. [7, 8] have noticed that tsunami risk combines the calculations of PTHA, exposure, and fragility. So, the tsunami risk calculations will include both human populations and the main infrastructure. Thus, the development of future probabilistic risk assessments will rely critically on developing tsunami fragility curves and systematic standards for PTHA calculations. The use of the logic tree framework in PTHA is gaining momentum. It should be noted due to the ease of technical implementation of the logic trees being used frequently. It is a powerful tool to organize the way of thinking in situations where alternative models, in which the analysts have different degrees of confidence, might apply. The end product can greatly enhance tsunami risk reduction efforts. Finally, it is important to mention Paleo tsunami researches is a powerful tool that can lead to a better constraining Mmax and the rate of large tsunami events.

Author details

Mohammad Mokhtari[1,2]

1 IOC/IGC UNESCO, Australia

2 TERC at The University of Hormozgan, Iran

*Address all correspondence to: m7mokhtari@gmail.com

References

[1] Mokhtari et al. (2019). A review of the seismotectonics of the Makran Subduction Zone as a baseline for Tsunami Hazard Assessments. Geosci. Lett. DOI: 10.1186/s40562-019-0143-1

[2] Haberland C, et al. (2020). Anatomy of a crustal-scale accretionary complex: Insights from deep seismic sounding of the onshore western Makran subduction zone, Iran: Geology, v. 48, DOI: 10.1130/G47700.1

[3] Abe K. (1979). Size of great earthquake of 1837-1974 inferred from tsunami data. Journal of Geophysical Research. **84**:1561-1568

[4] Lauterjung et al. (2010). The challenge of installing a tsunami early warning system in the vicinity of the Sunda Arc, Indonesia. Natural Hazards and Earth System Sciences. **10**(4). DOI: 10.5194/nhess-10-641-2010

[5] Geist EL, Parsons T. (2006). Probabilistic Analysis of Tsunami Hazards. Natural Hazards. *37*:277-314. DOI: 10.1007/s11069-005-4646-z

[6] Mokhtari M. (2014). The role of splay faulting in increasing the devastation effect of tsunami hazard in Makran, Oman Sea. Arabian Journal of Geosciences. **8**. DOI: 10.1007/s12517-014-1375-1

[7] Løvholt F, Kuhn D, Bungum H, Harbitz C, Glimsdal S. (2012). Historical tsunamis and present tsunami hazard in eastern Indonesia and southern Philippines. Journal of Geophysical Research. **117**. DOI: 10.1029/2012JB009425

[8] Løvholt F, Glimsdal S, Smebye H, Griffin J, Davies G. (2015). Tsunami Methodology and Result Overview. Technical Report, UN-ISDR Global Assessment Report. Geoscience Australia: Canberra. p. 2015