Numerical Modeling of Tsunami Waves Associated With Worst Earthquake Scenarios of the Makran Subduction Zone in the Jask Port, Iran

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Abstract

The recent studies show that the past researches may have significantly underestimated earthquake and tsunami hazard in the Makran Subduction Zone (MSZ) and this region is potentially capable of producing major earthquakes. In this study, the worst case possible earthquake scenarios of the MSZ are simulated using fully nonlinear Boussinesq model to investigate tsunami hazards on the Jask Port, one of the most important southern coastal areas of Iran. The 9.1Mw and 8.7Mw earthquakes which respectively, represent the rupture of about full and half length of the MSZ plate boundary, have been considered in the modeling. The global and local numerical simulation were conducted based on 1-minute and 3-arc sec resolution bathymetry data, respectively, in order to capture tsunami generation, propagation and inundation at the Jask Port. Results show the water subsidence is firstly observed along the Jask Port coastlines just after the earthquake occurrence, which can alert residents as a natural warning sign. Model results also reveal that due to the 9.1Mw earthquake and the 8.7Mw western Makran earthquake, the most coastal areas around the Jask Port are inundated by tsunami waves. However, the tsunami run-up is not observed when the 8.7Mw earthquake occurs at the eastern segment of the MSZ because the tsunami waves almost propagate in the north-south direction, perpendicular to the Makran fault and it causes a little effect of the tsunami attack on the western coast of Makran. Therefore, the most crucial factor that determines the tsunami risk at the Jask Port is the location of earthquake focal points in the Makran region.

Keywords: Makran Subduction Zone, Tsunami, Jask Port, Numerical model, Inundation

1. Introduction

Following the catastrophic Indian Ocean tsunami in December of 2004, which resulted in fulmination to more than 225,000 humans live and homelessness of more than one million people (Geist, Titov et al. 2006) and 2011 Japan tsunami which caused indescribable damage and casualties, paying more serious attention to this phenomenon and to assessing the vulnerability of different coasts around the world, especially for marginal Indian Ocean countries like Iran, is required. Definitely, Makran tsunami in 1945 and powerful tsunami of Indonesia in 2004 are not the first or the last such occurrences in the region. Indeed, the behaviour of three Eurasian, Indian and
Arabian tectonic plates indicates that the recurrence of tsunami in this zone is quite conceivable (Ambraseys and Melville 1982). Tsunami hazard assessment in any particular region and its irreparable losses requires the compilation and analysis of past tsunami records. Naturally, a better understanding of the tsunami vulnerability of any region will not only be crucial for all aspects of regional development, including land-use and urban activities, but also for estimating associated social and economical losses in the aftermath of such events (Heidarzadeh et al. 2008). Therefore, cataloguing the history of tsunami occurrences around the world is a well-heeded international practice.

Although tsunamis can be generated by variety of different sources like earthquakes, submarine landslides, volcanic eruptions and meteorite impact, but subduction zones earthquakes are known as the most common source of tsunamis. However, it should be noted that usually earthquakes that take place along the interface between the tectonic plates can lead to tsunami formation. For example, the 2012 huge earthquake occurred close to epicentre of the 2004 Indian Ocean earthquake was out of subduction zone and did not cause considerable disturbance at ocean surface; while the 2004 Indian Ocean earthquake occurred inside the subduction zone, between Sunda and Indian plates, generated huge tsunami that devastated the surrounding region and caused about 230,000 losses of lives.

The Makran Subduction Zone (MSZ) is a tsunamigenic narrow region extended from the Strait of Hormuz at the end of Zindan-Minab fault in Iran to the Ornach-Nal fault near Karachi in Pakistan. It is stretching about 900 km (Heidarzadeh, et al. 2008) due to reconstructions occurring among three tectonic Eurasian, Indian and Arabian plates (Fig.1). The rate of convergence along the Makran boundary increases slightly from the west towards the east (DeMets, Gordon et al. 1990), and the mean subduction rate at the MSZ is about 19.5 mm/y (Vernant, Nilforoushan et al. 2004). According to other subduction rates related to different zones, such as the Tonga Subduction Zone between Fiji and Pacific plates equalling 160 mm/y (Bevis, Taylor et al. 2002), Japan Subduction Zone among Pacific and Eurasian and Philippine plates at 80 mm/y (Kawasaki, Asai et al. 2001), Sumatra Subduction Zone among Australian, Indian and Eurasian plates amounting to 65 mm/y (Gahalaut and Catherine 2006), the MSZ is characterised as a relatively slow moving subduction zone. From the seismicity point of view, in the MSZ large and shallow earthquakes are common which can be regarded as a partial evidence for the tsunami generation potential associated with order of magnitude 8 earthquakes with an approximate average return period of 100 to 250 years (Ambraseys and Melville 1982; Heidarzadeh et al. 2008).
Few references based on historical reports document that quite a number of tsunamis have occurred associated with different sources until 1945 A.D. in the MSZ. Heck (1947) provides a list of global tsunamis generated from 479 B.C. to 1946 A.D., some of which were related to tsunami occurrences in the Arabian Sea and adjacent regions. Berninghausen (1966) presents another list of tsunami events including three from the West coast of India and the Arabian Sea. As an important tsunami resource, Page (1979) describes existing evidence for the recurrence of large-magnitude earthquakes along the MSZ and predicts that the 1945-type earthquakes can occur with a return period of about 150 to 250 years within the Eastern Makran. Ambraseys and Melville (1982) submitted the results of studies related to the historical earthquakes inside Iran. Another list compiled by Murty and Rafiq (1991) used a variety of sources in the Indian Ocean region from 326 B.C. to 1974 A.D., as well as Byrne et al. (1992), which treated great thrust earthquakes along the plate boundary of the MSZ. The threshold tsunami generation potential of the region was studied by Pararas-Carayannis (2006) along the MSZ.

The results of recent studies carried out based on thermal modeling of the MSZ by Smith et al (2013), shows that past assumptions may have significantly underestimated the earthquake and tsunami hazard in the MSZ; and it is potentially capable of producing major earthquakes, up to Mw 8.7-9.2. Therefore, the probability of recurrence of earthquake and tsunami in the Makran zone is relatively high and the tsunami can be considered as an obvious hazard for neighbouring countries, like Iran and Oman.

Among the existing approaches to study tsunamis, the use of Paleotsunami data, historical tsunami records, online DART systems, local tide gages and numerical modeling, using historical data and numerical modeling due to being economically advantageous are predominant to investigate tsunami behaviour after occurrence. Numerical modeling of tsunami in the MSZ provides insight into past events and simulates possible future scenarios. Recently, some numerical works have established in the MSZ to study the generation and propagation of the tsunami waves (Heidarzadeh et al., 2009; Heidarzadeh and Kijko, 2011). In particular, the determination of the potential run-up values and areas prone to inundation via numerical modeling from a local or distant tsunami is recognized useful, since data from past events is usually insufficient (Rafi and Mahmood 2010).

The Jask Port is one of the most important coastal areas of Iran, regarding its resident population and strategic situation. It is located at the west of Makran zone and can be affected by possible tsunamis. In recent years, within the national development plans of Iran, major ongoing port construction activities have been undertaken for expansion of the Jask Port as a portal on the transit corridor. Hence, the tsunami hazard assessment is important in this region for future development. In order to assess tsunami hazard, the impact and run-up of the MSZ seismic tsunamis on the Jask Port is simulated in this study. However, the certainty of tsunami occurrence is undeniable in the MSZ, and therefore, any substantial investment in the development of the port facilities is contingent upon a thorough investigation of potential tsunami impacts.

The current study present the results of the performed numerical modeling of tsunami propagation as well as coastal zone inundation around the Jask due to proximity to the MSZ based on evaluating three plausible tsunami scenarios of varying consequences. In the defined scenarios for tsunami modeling, earthquakes having moment magnitude of 9.1Mw and 8.7Mw are considered; which are equivalent to the rupture of about full and half length of the plate boundary in the MSZ. For this purpose, the open source numerical model, GEOWAVE is applied as a comprehensive numerical model. GEOWAVE is a combination of TOPICS and FUNWAVE models, in which the tsunami generation is simulated by TOPICS and then tsunami propagation and run-up are simulated by FUNWAVE. Unlike previous simulations of Makran tsunamis (Rajendran et al, 2008; Neetu et al., 2011), containing just one large-scale global model, in this study one high resolution local model is defined around the Jask Port in order to capture tsunami run up accurately.
2. Numerical Model

Numerical modeling is an impressive approach to studying the events of tsunami, particularly for the future hazards. Numerical modeling of seismically induced tsunamis may be organized into the following three phases: generation, propagation and run-up (inundation). The generation phase involves modeling an underwater earthquake source and translates its effects into an initial free surface water-level displacement and an associated velocity field. The second phase consists of propagating the generated tsunami across Deep Ocean/Sea. Finally, inundation associated with the run-up phase simulates the shallow ocean zone behaviour of the tsunami in order to predict coastal flooding and inundation. The interaction between the waves and the shoreline is considered for calculating wave propagation over dry land.

The achievement of tsunami studies depends on the combination of precise tsunami sources, an advanced tsunami propagation and finally inundation model. As yet, many numerical models have been modified or lately developed to impressively and carefully study the generation, propagation, run-up and inundation of tsunami. In this study, one of the tsunami models, GEOWAVE, is adopted to study the generation, propagation and inundation of potential tsunami generated from MSZ. GEOWAVE is formed by merging the Tsunami Open and Progressive Initial Conditions System (TOPICS) with the Fully Nonlinear Boussinesq water wave model FUNWAVE. An accurate run-up and inundation by using a slot method and wave breaking with a dissipative breaking model were implemented in the model. This model has capability of simulation of the whole life range of tsunami from generation, propagation till inundation. This model has been validated with analytical solutions and experimental studies (Wei and Kirby 1995; Wei et al. 1995; Chen et al. 2000; Kennedy et al. 2000), and also benchmark problems related to several historical events including the 1946 Unimak, Alaska; the 1946 Skagway, Alaska and the 1998 Papua New Guinea (Watts et al., 1999; Watts et al. 2003, 2005; Waythomas and Watts 2003; Day et al. 2005; Ioualalen et al. 2006; Grilli et al. 2007) and indicated satisfactory achievements in comparison with either field or satellite observations and tidal gauge measurements. Figure 2 shows the global and local domain of tsunami modeling. The data of the Makran 1945 tsunami event authorize us to validate the numerical model of the tsunami propagation. Because of the lack of persistent sea-level measurements of the tsunami, the sea-level observations of the Makran 1945 tsunami from the tide gauge at Karachi in Pakistan is presumed for numerical model validation. The maximum wave height of tsunami recorded at Karachi was 44 cm in which compatible with the existent numerical model that calculated 50 cm wave height at the same station. Compatible with the reports by Neetu et al. (2011) and Rajendran et al. (2008), the present model result indicates the wave height of 250 cm in Pasni.

![Fig. 2: Bathymetry of studying domains for Global (a) and Local (b) models](image)
2.1. Model Grids

According to the long wavelength of tsunami waves, especially in deep water which is usually in order of tens of kilometers, generation and propagation of waves can be simulated based on coarse hydrographic data, typically in the order of kilometers; but accurate calculation of tsunami run-up requires much finer topography and hydrographic data since the behaviour of tsunami waves strongly depends on the bathymetric and topographic features near the coastal area.

The present numerical modeling is performed in two distinguished grids of bathymetric and topographic data; The global type grid (refers to global model) which covers the entire region of Oman Sea where the fault plane is located, with 1-minute grid resolution, and the local type grid (refers to local model) covers the entire Jask port and its surrounding areas with 90 m grid resolution. The high resolution bathymetric and topographical data was achieved from Community Model Interface for Tsunami (ComMIT) database which is approved by NOAA, and used to obtain the applicable details of run-up and inundation in the Jask area for possible tsunami events. The initial wave of tsunami is generated in the global model and then it propagates from MSZ to the coastlines. The local model used when the waves reach to areas that have high significance for calculation of tsunami run-up. When the waves enter to the vicinity of local models, the global model is stopped and the local model is begun. Free surface elevation and water velocities which are achieved at the final time step of global model, are constrained to the local model as the initial conditions.

2.2. Governing Equations

According to the Wei et al. (1995), the fully nonlinear Boussinesq equations with considering breaking, bottom friction and shoreline moving boundary effects have been applied in this study. The governing volume conservation and momentum equations are as follows,

\[
\beta \eta_t + V_h \cdot M = 0 \tag{1}
\]

\[
u_{at} + (u_{at} \cdot V_h) u_{at} + gV_h \eta + V_1 + V_2 + R_f - R_b = 0 \tag{2}
\]

in which \( \eta(x, y, t) \) is water surface elevation, \( h(x, y) \) is the local mean water depth; \( V_h \) is horizontal gradient and \( M \) is depth-integrated horizontal volume flux which is given by Eq. (3).

In Eq.(3), \( u_{at} \) is horizontal velocity at an elevation \( Z_a \) taken to be \( Z_a = -0.531h \). Eq.(4) and Eq.(5) represent dispersive effects, \( V_1 \) and \( V_2 \). The forces related to the wave breaking and bottom friction are explained by \( R_b \) and \( R_f \) respectively. \( A \) and \( B \) are functions of velocity given as Eq. (6) and Eq. (7).

\[
m = \lambda \left[ u_a + \left( \frac{Z_a}{2} - \frac{1}{6} (h - \eta + \frac{1}{2}) \right) V_h A + \left( Z_a + \frac{1}{2} (h - \eta) V_h B \right) \right] \tag{3}
\]

\[
V_1 = Z^2 V_h A_t + Z_a V_h B_t - V_h \left[ \frac{h^2}{2} A_t + \eta B_t \right] \tag{4}
\]

\[
V_2 = V_h \left[ (Z_a - \eta) (u_a, V_h) B + \frac{1}{2} (Z^2_a - \eta^2) (u_a, V_h) A \right] + \frac{1}{2} V_h \left[ (B + \eta)^2 \right] \tag{5}
\]

\[
A = V_h \cdot u_a \tag{6}
\]

\[
B = V_h \cdot (hu_a) \tag{7}
\]

For moving boundary condition in the shoreline, a porous slot method was implemented by inserting factors \( \beta \) and \( \Lambda \) as follows;

\[
\beta = \begin{cases} 1, & \eta \geq Z^* \\ \frac{\delta (1 - \delta) e^{-\lambda (\eta - Z^*)/h_0}}{\lambda}, & \eta \leq Z^* \end{cases} \tag{8}
\]

\[
\Lambda = \begin{cases} (\eta - Z^*) + \delta (Z^* + h_0) - (1 - \delta) h_0, & \eta \geq Z^* \\ \delta (\eta + h_0) + (1 - \delta) h_0, & \eta \leq Z^* \end{cases} \tag{9}
\]

Here, \( h_0 \) is the slot layer depth which must be deeper than the depth of maximum wave rundown during a simulation. The selection of \( Z^* \) is explained by Kennedy et al. (2000). According to the number of tsunami run-up events investigated by Watts et al. (2003), Day et al. (2005) and Grilli et al. (2007),
parameter values $\delta = 0.08$ and $\lambda = 25$ are used for run-up calculation.

The major advantage of a Boussinesq wave propagation model over nonlinear shallow water wave model is considering the horizontal velocities and also vertical acceleration variations along depth (Watts et al., 2003). Moreover, the equations include eddy viscosity terms to model the dissipation caused by wave breaking.

3. Tsunami Simulation for Different Scenario Magnitudes

3.1. Earthquake Scenario

Earthquake scenarios (magnitude and source zone) must be defined for any tsunami simulations. For the 9.1Mw earthquake, the MSZ should experience the full rupture to obtain relevant seismic moment; while in order to produce the moment magnitude of 8.7Mw about half of the plate boundary should be faulted. In the latter case, the western or eastern part of the MSZ can be faulted, according to the earthquake epicenter. Since estimation of future earthquake place is impossible, the 8.7Mw earthquake is considered in intended scenarios both at the western and eastern segments of the MSZ. So, for modeling of Makran tsunamis three scenarios are considered totally, as presented in Table 1. In each scenario the source parameters, defining dimensions of faulted area, are estimated using empirical relationships presented by Wells and Coppersmith (1994) based on source parameters of 244 historical earthquakes. After initial estimation, the source parameters are modified slightly to satisfy the relation between moment magnitude and seismic moment (Eqs. 10 and 11).

$$M_w = \frac{2}{3} \log_{10}(M_0) - 6 \quad (10)$$

$$M_o = \mu \Delta LW \quad (11)$$

Where $M_w$ is moment magnitude (dimensionless number), $M_o$ is seismic moment in N m, $\mu$ is rigidity of the earth (assumed $3 \times 10^{10}$ Nm$^2$), $L$ and $W$ are fault length and width respectively and $\Delta$ is the displacement on the fault surface.

3.2 Source Models

The determined source parameters are inserted to TOPICS, tsunami generator model of GEOWAVE, and it calculates initial disturbance of ocean surface using Okada’s elastic deformation source model (Okada, 1985). Calculated free surface elevations actually are seabed vertical displacements transferred to ocean surface identically, because of instantaneous generation of seismic tsunamis. As expected, maximum values of the initial wave crest and trough are observed during scenario 1 in which the 9.1Mw earthquake leads to about +8m uplift and -6m subsidence of the ocean surface (Fig.3a). Due to variation of the fault strike between western and eastern part of the MSZ (Byrne et al, 1992), the full rupture of the MSZ in scenario 1 is divided to two separated segments.

<table>
<thead>
<tr>
<th>Scenario number</th>
<th>Earthquake moment magnitude</th>
<th>Faulted area</th>
<th>Source parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fault length (km)</td>
</tr>
<tr>
<td>1</td>
<td>9.1</td>
<td>All part of the MSZ</td>
<td>900</td>
</tr>
<tr>
<td>2</td>
<td>8.7</td>
<td>Western part of the MSZ</td>
<td>500</td>
</tr>
<tr>
<td>3</td>
<td>8.7</td>
<td>Eastern part of the MSZ</td>
<td>500</td>
</tr>
</tbody>
</table>
3.3. Global Model

Free surface elevations obtained from TOPICS feature initial wave of tsunami and provide initial condition of the tsunami propagation model, FUNWAVE; which is based on fully nonlinear Boussinesq equations developed by Wei et al. (1995). The major advantage of a Boussinesq wave propagation model over nonlinear shallow water wave models is that horizontal velocity variations along depth and also vertical acceleration are considered (Watts et al., 2003). Moreover, FUNWAVE equations include eddy viscosity terms to model the dissipation caused by wave breaking. The governing equations are solved first at global model grid points having 1-arc min resolution. Thus, the propagation of tsunami waves from source to near the coasts is simulated, as illustrated in Fig. 3. It is observed that the tsunami waves dissipate firstly, at the beginning of propagation; but they amplify again approaching the coast due to water depth reduction and shoaling effect. The waves propagate perpendicular to the faulted area mainly in the north-south direction, unlike landslide tsunamis propagate radial and identically in all directions (Soltanpour and Rastgoftar, 2011). Figure 3 also shows that along the coastlines locating north of the MSZ falling water is first observed and then main waves of tsunami arrive; while southern coastlines of the MSZ, like Oman, first receive tsunami positive waves.

3.4. Local Model

Free surface elevation and water horizontal velocities of global model are transferred to the local model as the initial conditions (Fig. 4). It should be noted that the initial conditions of global model also include water velocities, but they are set to zero; because no initial velocities are assume for the
earthquake tsunamis.

After providing the required initial conditions, the Boussinesq equations of FUNWAVE are solved at this time in the local model domain. The total number of grid points in the local model area is 554,238 (751×738) according to 3-arc sec (about 90 m) bathymetric data extracted from ComMIT model data bank. The time step of the local model is determined 0.23 s to satisfy the stability conditions; it is clear that the global model has greater time step (2.43 s) according to larger mesh size. Finally, the free surface elevation and horizontal velocities are calculated for all time steps and the run-up of tsunami on coasts of the Jask Port is computed (Fig. 5).

![Fig. 4: Local model initial conditions for scenario-1; (a) free surface elevation, (b) longitudinal velocity and (c) latitudinal velocity](image)

![Fig. 5: Tsunami induced inundation at Jask coasts for scenario-1 at times t= 18, 20, 22, 24, 26 and 28 min after the earthquake](image)
4. Results and Discussion

Three virtual gauges were deployed along the Jask Port coastline to extract the time series of tsunami. The location and water depth of the gauges are presented in Table 2. The gauge 'H' located at western coast of the port around the harbor, while the gauges 'S' and 'A' are at the eastern coast near the soccer stadium and the airport, respectively (Fig. 6). Figure 7 shows the wave heights time series extracted during the scenarios 1 and 2; while the time series of the scenario 3 are presented in Fig. 8.

Table 2: Locations of virtual tidal gauges

<table>
<thead>
<tr>
<th>Gauge No.</th>
<th>Longitude (°E)</th>
<th>Latitude (°N)</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>57.8000</td>
<td>25.6516</td>
<td>0.5</td>
</tr>
<tr>
<td>H</td>
<td>57.7672</td>
<td>25.6460</td>
<td>0.6</td>
</tr>
<tr>
<td>S</td>
<td>57.7720</td>
<td>25.6439</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Fig. 6: Location of virtual tide gauges 'A', 'H' and 'S' for wave height time series analysis (filled circles)

Fig. 7: Modeled time series of water surface elevations at various locations along the Jask coast for the Mw 9.1 (solid line) and the Mw 8.7 western Makran (dashed line) tsunamis
Figures 7 and 8 demonstrate, as expected, the maximum wave heights are observed in scenario 1 that represents the largest earthquake. During scenario 3 tsunami waves appear at all the gauges much smaller than two other scenarios. For example, the gauge 'S' has recorded about 14 and 10-meter height waves in scenario 1 and 2, respectively; but in scenario 3 the maximum wave height observed in this gauge is less than 0.4 meter. The reason is that when earthquake occurs at the eastern part of the MSZ, the tsunami waves reaches slightly along the western coasts of the Makran zone, like Jask Port; because the tsunamis caused by earthquakes spread perpendicular to the source fault in the north-south direction in the MSZ.

Figure 7 reveals that in scenarios 1 and 2 the time between earthquake occurrence and arrival of tsunami waves is about 20 minutes. This shortness of time makes the tsunami warning process for the Jask Port very difficult. On the other hand, the negative wave of tsunami is first observed along the Jask Port coastline and the sea bottom becomes visible at shallow areas when the negative wave height is more than the water depth. This situation can be seen in Fig. 7 where there are no data displayed, mostly at the beginning of the time series. Residents of the port can use this natural warning sign and be aware of the event before arrival of the destructive waves. The figure also shows the gauges 'S' and 'A' have recorded the waves having approximately the same height, whereas the gauge 'H' has experienced waves with smaller heights. This can be attributed to the location of gauge 'H' that is at the western coast of the port and so receives the diffracted tsunami waves.

Maximum tsunami heights recorded during scenarios 1 and 3 are presented in Fig. 9. This figure also displays the tsunami inundation extent for all the scenarios (The tsunami inundation in scenario 2 has been specified by bold line). It is observed that the waves due to the 8.7Mw eastern Makran earthquake (scenario 3) cannot run-up on the Jask Port at all. However, the waves caused by the 9.1Mw earthquake (scenario 1) and the 8.7Mw western Makran earthquake (scenario 2), not only inundate the port completely, but also capture on farther inland areas. Therefore, it can be concluded that the most crucial factor determines the tsunami risk in the Jask Port is the location of the Makran earthquakes. In the other words, the huge earthquakes occur at east of the MSZ can be considered as small hazard for the Jask Port, while the occurrence of earthquakes having less magnitudes at west of the MSZ leads to the high waves devastate the port seriously. While it was previously thought that the tsunami effect depends essentially on the earthquake magnitude. According to Fig. 9, the inundation extent of tsunami is a function of the maximum tsunami height. In scenario 3, where no inundation takes place, the maximum water level around the coastline of the Jask Port is less than 1m; whereas it is between 10 m and 15 m in scenario 1.

Although the most coastal areas around the Jask Port are inundated by the tsunami waves in scenarios 1 and 2, but there are regions where are safe against the tsunami waves. These regions are shown by circle in Fig. 9. As adjacent areas of the Jask Port are considered for development in future plans of the Makran zone, the estimated safe regions seem advisable regarding to tsunami threat.
5. Conclusions

Largest possible earthquakes of the MSZ were simulated to investigate tsunami hazards on the Jask Port. The 9.1Mw and 8.7Mw earthquakes, featuring respectively the rupture of about full and half length of the MSZ's plate boundary, were assumed in defined scenarios. The smaller earthquake was considered both at the western and eastern segments of the MSZ. GEOWAVE numerical model was employed to simulate tsunami generation, propagation and inundation. Unlike previous studies, containing just one large-scale global model, in this study a small-scale local model was also defined based on 3-arc sec resolution bathymetry data, in order to capture tsunami run-up on the Jask Port.

The results show that during critical tsunamis there is a short time between earthquake occurrence and arrival of tsunami waves (about 20 minutes). But, along the coastlines locating north of the MSZ, like the Jask Port, falling water of tsunami was first observed. Residents of the Jask Port can use this natural warning sign and vacate the port before arrival of the destructive waves.

Model results also reveal that due to the 9.1Mw earthquake and the 8.7Mw western Makran earthquake the most coastal areas around the Jask Port are inundated by the tsunami waves. However, the tsunami run-up is not observed at all when the 8.7Mw earthquake occurs at the eastern segment of the MSZ. When 8.7Mw eastern Makran earthquake occurs, the tsunami waves reach slightly along western coasts of Makran zone; because seismic tsunamis propagate perpendicular to the source fault, in north-south direction in the MSZ. Therefore, unlike previously thought, the tsunami risk at the Jask Port depends more on the location of focal points MSZ earthquakes than their magnitudes.

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