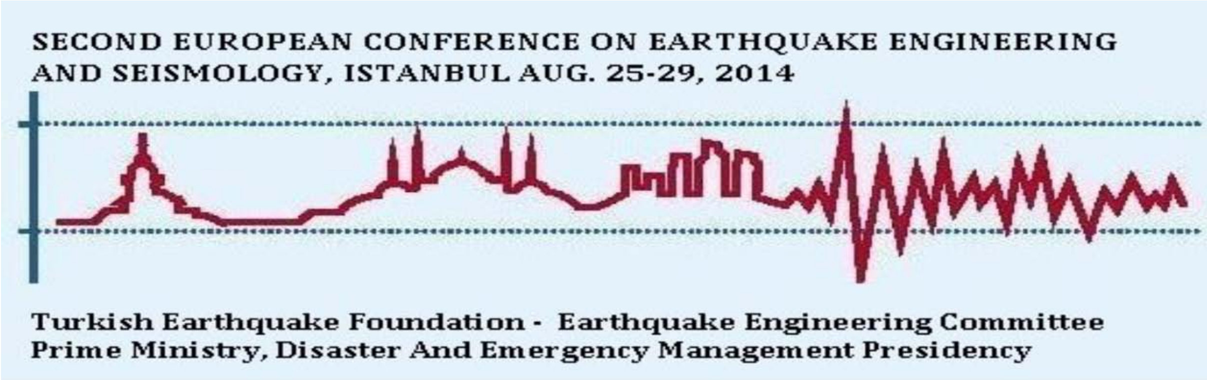

SEISMIC AND TSUNAMI HAZARD IN THE SHORELINES OF KHARK ISLAND;PERSIAN GULF, IRAN

Mehdi ZARE[1]

ABSTRACT

The most conservative scenarios are determined in this study for possible earthquakes within the Khark zone (Persian Gulf) based on experimental relations between the fault length, magnitude and displacement, which are parameters for determining tsunamigenic sources.. Subsequently, the maximum height of tsunami waves are calculated based on the specifications of the seismic source and its distant from the shore, as well as the coastal slope. A zoning map of tsunami hazard is finally presented. The maximum calculated wave height is 3.5 m. No serious hazard is posed to the structure by sources 1 and 3 due to the shallow depths at these sites. The maximum potential wave height are 30 and 60 cm, respectively. A far distance source produces waves heights of almost 1.5 m along the shore lines of Khark Island, despite. This is due to the expected magnitude of this source as well as its location in the deep waters of the Oman Sea.

INTRODUCTION

In this article the assessment of the seismic hazard is explained first, based on the determination of seismic source zone. Secondly, we calculate of the possible water wave height along the shorelines of the Khark Island, caused by any probable tsunami in the Persian Gulf. The deterministic approach applied in this study is based on the approach laid out by the Iranian Oil Terminals Company (OTC), who will be the end user of this study. The specification of the present report is focused on the tsunami hazard analysis for the shorelines of the Khark Island, which is one of the first attempts to quantify the tsunami hazard in the Persian Gulf. The Bathymetry map of Khark Island is shown in (Figure-1) in which the water depth in the shorelines around the Khark Island is presented. This bathymetric condition is considered in the potential of tsunami hazard around this Island in this article.

Determination of the event probability is critical in all comprehensive hazard analysis. This is especially true in tsunami risk. Previous attempt have been performed using the deterministic method and using scenarios (Yanovskaya et al., 2003, Soloviev, 1970, 1978, Murty, 1977).

Probabilistic tsunami hazard analysis (PTHA) is established based on probabilistic seismic hazard analysis (PSHA) and combines two calculating and experimental methods of historical run-ups. The main difference between PTHA and PSHA is that far sources are considered in the latter. The calculating methods are mainly based on the numerical modeling of tsunami wave distribution.

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With the exception of the west side of Khark Island, water depth studies show that the island slopes gently to a depth of 3 m. The width of this slope extends outward from the shore for ~500 m from the shore and reaches to its maximum in the northeast and south shores (Figure-1). Along the western coast the slope is steeper than elsewhere on the island, reaching depths of 20 m at a distance of 200 m from the shore and a depth of 40 m at a distance of 1 km. The deepest points around the island are 30-40 m and lie west of the island (Figure-1).

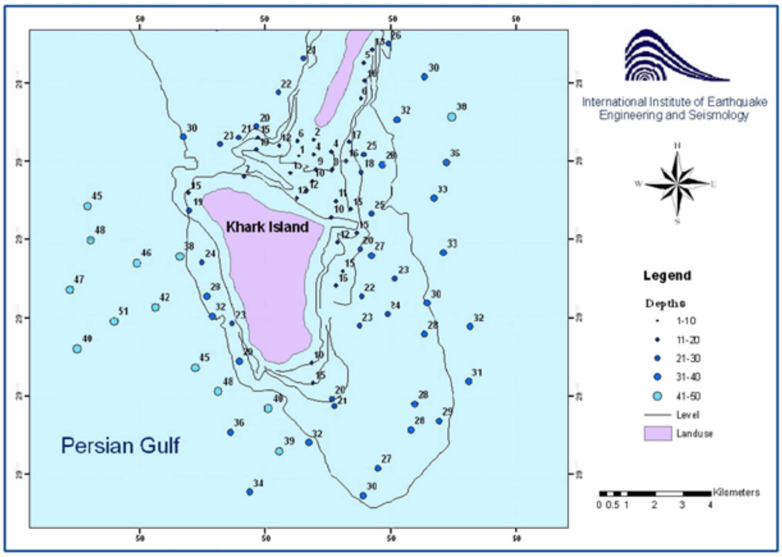

Figure-1: Bathymetry map of Khark Island, the numbers on the points give the estimated depth in meters.

DETERMINATION OF SEISMIC SOURCE ZONES:

The faults and tectonic trends of the study area are investigated using geological maps and relevant available published research. This information was compiled into a single structural map (Figure-2).

The Kazeroon-Borazjan, Khark-Mish and Hendijan faults are considered the potential tsnamigenic sources due to their proximity to Khark Island. Although the Makran subduction zone was far from the study site, it was considered in the calculations due to its seismic significance and being the interpreted source of a tsunami on 27 November 1945 (Ambraseys and Jackson 1988) (Figure-3).

Following digitization of the faults, the expected magnitudes for these structures was calculated using empirical relationships defined by (Zaré, 2003; Mohajer-Ashjai and Nowroozi, 1978; Ambraseys and Jackson, 1998; Nowroozi and Mohajer-Ashjai, 1985; Wells and Coppersmith, 1994). The maximum and median probable slip of these faults is obtained by applying the relations of Wells and Coppersmith (1994) and Liu-Zeng et al. (2004) (Table 1).

Table 1. Magnitude and slip variables for each potential tsunamigenic fault.

Source		Magnitude *M*					Slip *S*/m		
Name	Length/km	Wells & Coppersmith (1994)	Nowroozi & Mohajer-Ashjai (1985)	Ambraseys & Jackson (1998)	Mohajer-Ashjai & Nowroozi (1978)	M_{av}	Wells & Coppersmith (1994)	Liu-Zheng et al. (2004)	S_{av}
L_1	151	7.2	7.3	7.2	7.3	7.4	0.8	4.5	2.7
L_2	169	7.3	7.4	7.3	7.3	7.5	0.9	5.1	3.0
L_3	245	7.5	7.6	7.4	7.5	7.7	1.1	7.3	4.2
L_4	690	8.2	8.1	7.9	7.9	8.3	1.5	20.7	11

The relation between the wave heights (*H*) in the source and coast is as follows:

$$H_c = f(H_s, r, h_c, h_s, \alpha),$$

where H_c is the height of wave in the coast, H_s is the height of wave in the source, h_c is median depth of the coast, h_s is the depth of source, r is the distance from coastal point to the source, and α is the slope of coastal profile.

Near the coastline, the water depth decreases and the wave length increases, which is referred to as “Run-up”. For shallow depths the linear theory of the waves is shown as (Ward, 2002):

$$S_L(\omega, \mathbf{r}) = \sqrt{\frac{u(\omega, h(\mathbf{r}))}{u(\omega, h_s)}}$$

Where S_L is the shallow depth factor, where its value depends on the difference between the group velocity of the waves at the tsunami source (u(ω, h(r)) and at the coastline (u(ω, h_s)). In uniform water depth, the shallow depth factor (S_L), similar to the geometric expansion factor, G(r), will be 1. The short period coastal waves (~10 s) show <50% increase in amplitude. However, tsunami waves with the periods of 100 to 2000 s have shallow wave factors between 3 and 6. For the water waves with a period of more than 250 seconds, we have

$d_C >> h$ $(u(\omega,h)=(gh)^{1/2}$
$u(\omega,h_s)= (gh_s)^{1/2}$.

Consequently, the shallow depth factor (S_L) will be
$S_L=(h/h_s)^{1/4}$.

Based on Green’s law, the shallow water factors, h_c and h_s become

$$H_c / H_s \approx (h_c / h_s)^{0.25}.$$

Due to the geometric distribution, the attenuation differs from r^{-1} distant for short waves to $r^{-0.5}$ for long waves. The minimum wavelength of tsunami is three times as long as the water depth on the source and its maximum depends on the dimension of rupture.

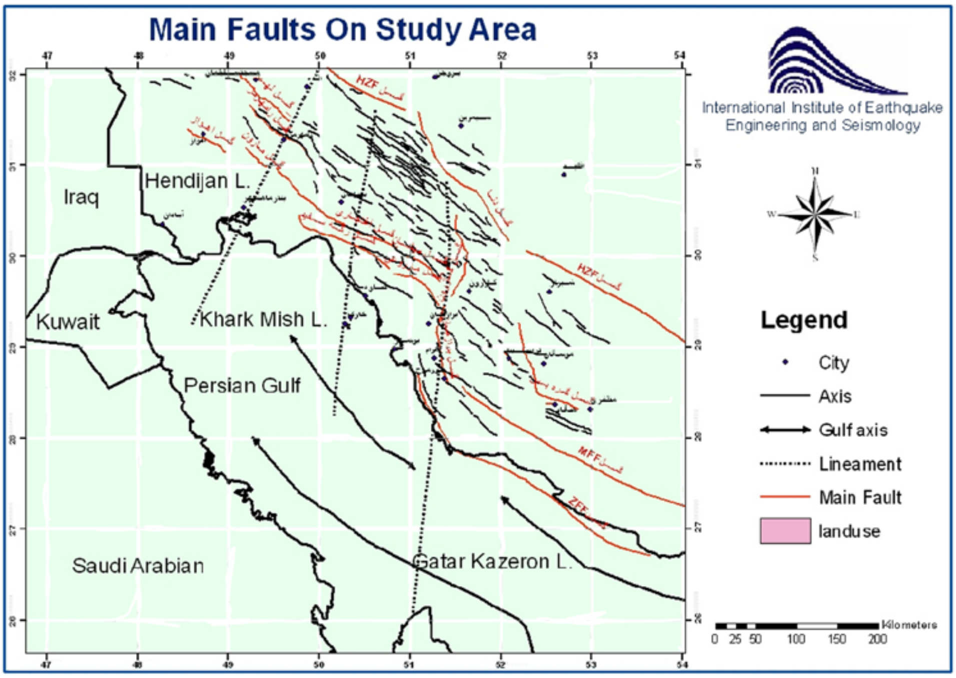

Figure-2: Tectonic map of main faults in Khark island area.

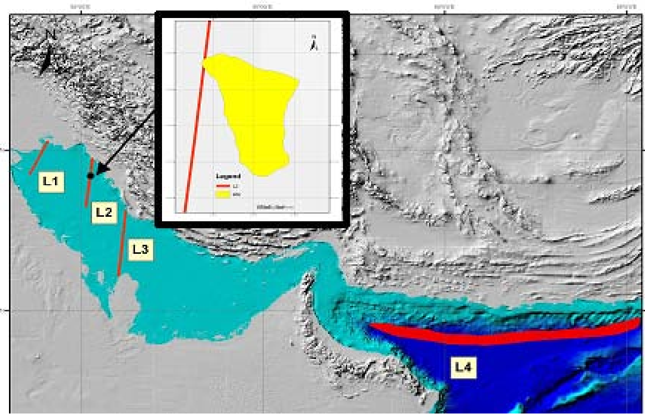

Figure-3: The map of sources as compared with the situation of source L2.

The maximum wavelength of tsunami could not be determined for these sources due to a lack or unavailability of data. Therefore, the type of tsunami wave has been determined based on the assumption of direct relations between the tsunami wavelength and the causative earthquake magnitude. Takahasi (1961) studied the earthquakes and their consequent tsunamis and concluded that the dominant tsunami per minute periods had a close relationship with the magnitudes of the triggering earthquake. Ward (2002) presented the attenuation curves of tsunami waves versus distance for different magnitudes using the previous achievement as well as the relation between attenuation and wavelength.

Tsunami magnitude is $m = \log_{10} 2 \times H$, where H is the maximum run-up height measured at a coast 10–300 km from the tsunami source (Murty, 1977). Soloviev (1970) pointed out the inappropriateness of the term 'tsunami magnitude'. "If seismological terminology is applied to description of tsunamis, the grades of the Imamura-Iida scale must be designated as the intensity of the tsunami and not its magnitude. This is because the latter value must characterize dynamically the processes in the source of the phenomenon and the first one must characterize it at some observational point, the nearest point to the source included."

RESULTS

Concerning the model structure, a code has been written in MATLAB software for calculating the height of a tsunami wave for each of the mentioned sources. The necessary input data are zone basin, geographic locations of coastline and the specifications of sources. Bathymetry data are obtained by converting the geographical ordinates into UTM and using the codes in the form of x, y and z. The same was done for the ordinates of coastline and used as x and y.

The specifications of the sources are presented in two Files: (1) the initial and ultimate coordinates, digitizing of source length into 100 metric intervals; (2) median depth, source length, earthquake magnitude and the height of the wave coming from the source (based on the calculations of previous section).

The height of tsunami wave from a particular source was calculated at certain coastal point using all above information. Repeating these calculations for the entire coastline, the map of tsunami wave height is obtained for each source. The output of the program was the coastline ordinates and the wave height (x, y, z) of each point, which can be used in all preparing and plotting map software.

The items used for zoning are: the height of 0–0.5 m (non sensible); 0.5–1 m (the wave height less than human being, sensible, low hazardous); 1–2 m (water height almost as human being tall, hazardless); over 2 m (the height higher than human being and comparable with structural height, critical) (Table 2).

Table 2: Height range used for preparing zoning map.

Wave height/m	**Hazard Degree**	**Used color**	**Description**
0–0.5	0	Blue	Non sensible
0.5–1	1	Green	Wave height less than human tall, sensible, low hazardless
1-2	2	Yellow	Wave height almost as human tall, hazardous
>2	**3**	Red	Wave height more than human tall, comparable with the heights of structures, critical

The map of wave height was also prepared for each seismic source. The coastal hazard zoning maps have been prepared using the data of wave height in the shore based on the mentioned height range. The assessment of possible tsunami height is performed based on Source L1 to be ~1 m. These heights are assessed to be 3 m for source L2, 1 m for source L3, and 2 m for source L4. The maximum height for tsunami hazard levels is assessed and presented (Figure-4), which was obtained from the co-weighted averaging of the wave height caused by different scenarios. It should be mentioned that the width of the coastline has no physical meaning in the maps and serves only for better perspective.

CONCLUSIONS

With regards to the obtained results, the hazard distribution along the coastline and the hazard levels of each source are summarized as follows:

1) The maximum calculated wave height is 3.5 m.
2) No serious hazard is posed to the structure by sources 1 and 3 due to the shallow depths at these sites. The maximum potential wave height due to sources 1 and 3 are 30 and 60 cm, respectively.

3) Source 4 produced waves heights of almost 1.5 m at the site understudy, despite its far distance,. This is due to the expected magnitude of this source as well as its location in the deep waters of the Oman Sea.

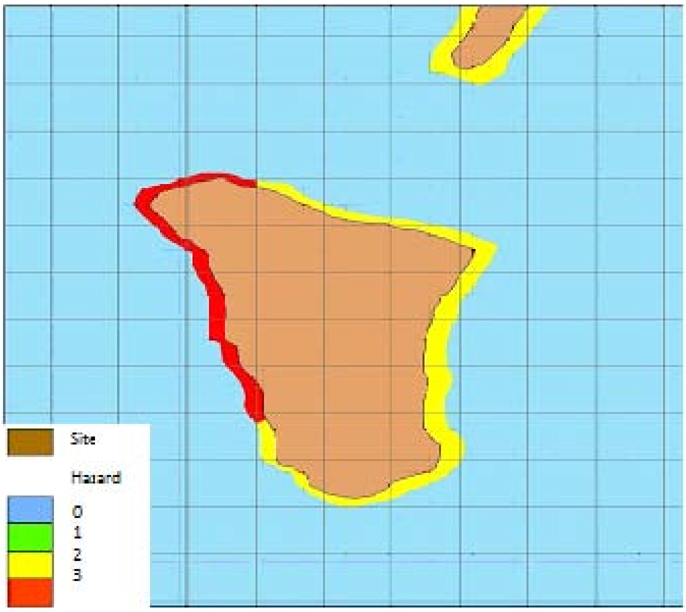

Figure-4: The map of maximum expected hazard level, from the co-weight averaging the height of waves caused by different scenarios

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