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Would Makran tsunami skip Mumbai, India? No it would reach 8 minutes later than Ratnagiri

Kirti Srivastava*, V.P. Dimri, V. Swaroopa Rani, R. Krishna Kumar & Likhita Narain
CSIR-National Geophysical Research Institute Uppal Road, Hyderabad 500 007, India
[Email: kirti@ngri.res.in]

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Tsunami from Makran subduction zone in the northern Arabian sea are seen to arrive at Ratnagiri (16°56´24.00˝N, 72°40´12.00˝E) along the west coast of India 8 minutes earlier than Mumbai (18°59´24.00˝N,71°52´12.00˝E) in spite Ratnagiri being 244 km down south of Mumbai. This can give rise to a false signal and could be interpreted as tsunami skipped Mumbai and is traveling towards south. However, this advance information at Ratnagiri could be used for quick evacuation of densely populated coastal areas of Mumbai. Reasons for later arrival of tsunami at Mumbai is mainly due to a wide shelf of greater than 250 km whilst at Ratnagiri the shelf suddenly becomes half that of Mumbai. The importance of shelf width along the west coast of India which plays a great role in the arrival of the tsunami waves and the wave heights at different locations are conferred in the present study

[**Keywords**: Tsunami, Makran, Ratnagiri, Mumbai, Wave height, Shelf width]

Introduction

Quantifying the arrival times for the tsunami waves at different locations in the vicinity of the source is of vital importance in the estimation of the coastal hazards. Makran subduction zone in the southern part of Pakistan is seismically active and there have been several historical tsunamigenic earthquakes from this region e.g. in 1765, 24th Jan 1851 and 27th Nov 1945. This is one of the world's largest forearc region and the age of the deformation front is around 70-100 Ma and is divided into two segments by Sistan suture zone based on morpho-tectonic features, contrasting seismicity patterns and the varying rupture histories[1].

The 1945 Makran earthquake of magnitude 8.1 had generated destructive tsunami which travelled all along the west coast of India causing large scale damage to life and property and was studied by several researchers[2-6]. Seismicity of this region too has been studied in detail[7-8]. Shelf in the western margin of India is highly varying from north to south. The tectonics of the western continental margin is typically passive, continental margin of the Atlantic type and is highly complex hosting a number of deep seated faults, rift systems, basement highs and NW–SE trending ridges such as Laccadive ridge, Laxmi Ridge, Prathap ridge etc.

Materials and Methods

TSUNAMI-N2[9] based on finite difference technique has been used to model the tsunami wave propagation. The formulation uses the central difference staggered leap frog method with a second order truncation error and which is developed in linear and spherical system. Non-linear Long wave equations are for a set of initial and boundary conditions. At the open sea the boundary condition is assumed to be free transmission of the wave and the boundary condition on land is assumed to be a perfect reflector. The initial deformation at the source has been computed using Mansinha and smylie[10] method.

Bathymetry and topography of the study region and the earthquake source characteristics are important controlling parameters. Bathymetry is most often described with a grid covering a rectangular area and for any tsunami wave propagation reasonable simulation a good coverage of bathymetry and topography information with uniform vertical and horizontal spacing is needed. In the present study we carried out tsunami propagation for potentially large tsunamigenic earthquakes in the eastern Makran subduction zone. The west coast of India also gets tsunami from the Sumatra subduction zone which has been studied by several researchers[11-14].

Data

In this study we have modeled a possibly large tsunamigenic earthquake from the Makran subduction zone and computed the tsunami arrival times along the west coast of India[15]. The shelf width is however not uniform along the west coast of India. We have considered several gauges located at important cites from north to south along the west coast of India. They are Dwarka, Mumbai, Ratnagiri, Panaji (Goa), Bhatkal, Udipi, Mangalore, Thalessary, Calicut, Cochin and Thiruvanthapuram (Figure 1). Distance between epicenter to Mumbai is about 1060 km, to Ratnagiri about 1300 km, to Cochin about 2100 km and to Thiruvanthapuram around 2300 km.

The bathymetry data is taken from the General Bathymetric Chart of the Oceans GEBCO 1 arc minute (1834 m) and the topography data is from *Shuttle Radar Topography Mission SRTM 3arc* sec (93 m) which is available online. The source characteristics for a possibly large tsunamigenic earthquake of magnitude 9.0 (epicenter: 25°09´N, 63°28´48´´E) in the eastern Makran subduction zone are taken as: fault length = 377 km, width of the fault = 190 km, focal depth = 25 km, angle between N & fault axis = 265 º, dip angle = 7 º, slip angle = 90 º, displacement = 11 m. The fault length, width and slip on the fault have been computed using the empirical relationship of the seismic moment. Using the formulation of[16], and the scenario discussed in the note the initial deformation is obtained and then the tsunami propagation is modeled.

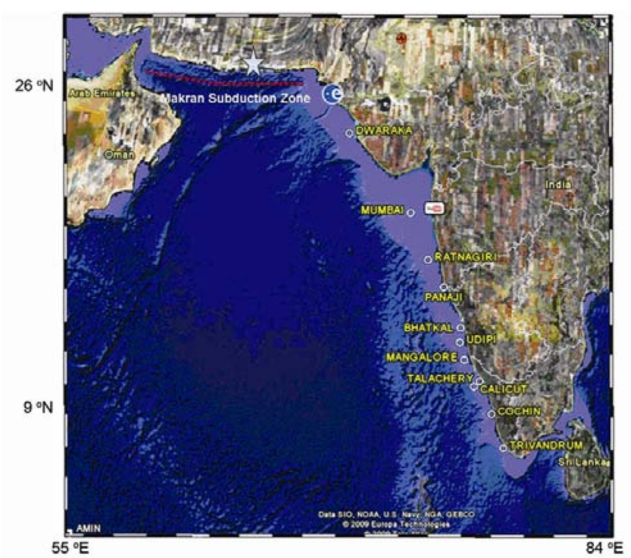

Figure 1—Tectonic map the Makran subduction zone along with the various gauge locations along the west coast of India.☆ denotes the epicenter of the earthquake

Results and Discussions

Figure 2(a) shows the arrival times of the tsunami at various locations along the west coast of India. From the figure it is clear that the tsunami arrives at Dwarka after 106 minutes, at Mumbai after 180 minutes, at Ratnagiri after 172 minutes, at Panaji (Goa) after 181 minutes, Bhatkal after 213 minutes, Udipi after 209 minutes, Mangalore after 196 minutes, Thalessary after 250 minutes, Calicut after 204 minutes, Cochin after 234 minutes and Thiruvanthapuram after 241 minutes. We observe that the tsunami reaches Mumbai and Panaji (Goa) almost at the same time.

The most interesting point to be noted is that it has reached Ratnagiri about 8 to 9 minutes earlier which is about 244 km down south of Mumbai (Figure 3). The reason for this is that the shelf is narrower at Ratnagiri and the wave has travelled faster in deeper ocean. The shelf here is about 125 km almost half of that of Mumbai and it slowly becomes narrower as we go down towards south. The varying nature of the water column depth due to changing width of the shelf in this region is responsible for the variation in the arrival times of the tsunami along the west coast of India. The 8 minutes difference of advance arrival of the tsunami at Mumbai and then Ratnagiri is seen to be independent of the magnitude of the earthquake due to $v= \sqrt{gt}$ where v is speed, g is acceleration due to gravity and t is depth to water column, as well as the epicenter as worked out from several scenarios that have been simulated for different controlling source parameters. Similar observation has been noticed between Thalessary and Cochin because of the depth to water column varying with width of the shelf. Also we observe that the shelf at Bhatkal is about 131 km and at Udipi it is 117 km. The wave has reached Udipi after 209 minutes but it takes almost 213 minutes to reach Bhatkal. It shows that the wave has reached Udipi earlier due to the narrow shelf width. Similarly the shelf at Cochin is smaller than at Thalassery and the tsunami arrives at Cochin almost 16 minutes earlier. The wave reaches Calicult much earlier as the shelf is very small compared to other regions as seen in Figure 2(a).

Once a tsunamigenic earthquake of magnitude greater than 7 has occurred in the Makran subduction zone and the tsunami has traveled to a nearest location an alert can be given saying that the tsunami is arriving. It is important to note that once the tsunami reaches a further point down of Mumbai, say at Ratnagiri, the concerned authorities should not think

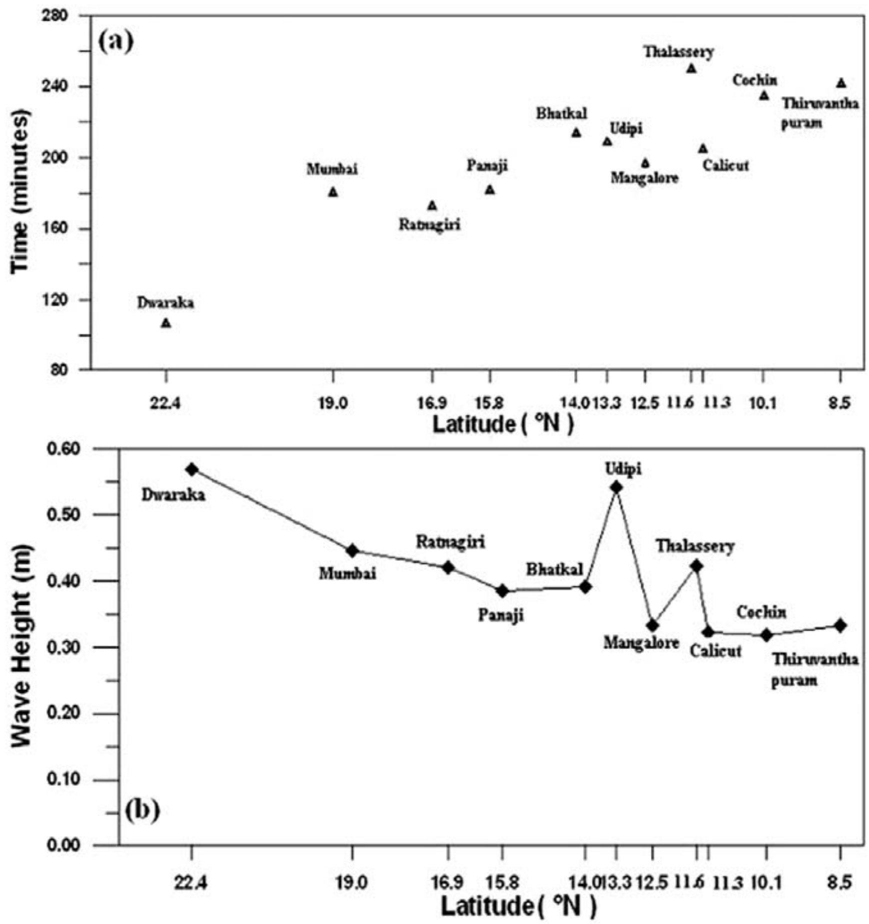

Figure 2—(a) Arrival times of tsunamis at various gauge locations from North to South on the west coast of India for a possibly large tsunamigenic earthquake of magnitude 9.0 . (b) Wave heights recorded at various gauge locations at the onset of the tsunami at that gauge suggesting that the wave height depends on the local bathymetry.

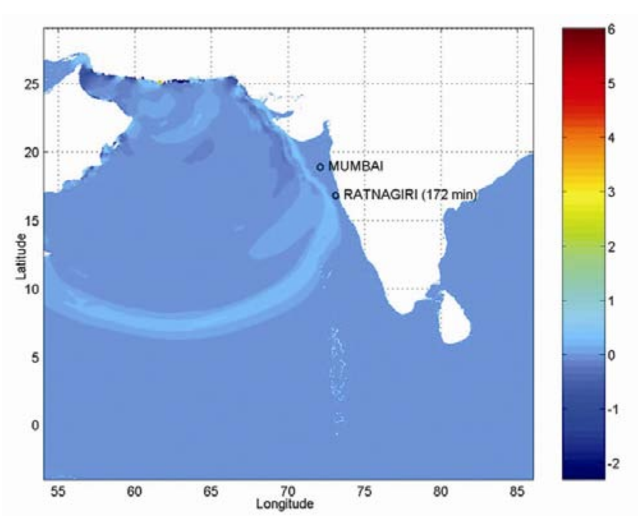

Figure 3—A snap shot of Tsunami reaching Ratnagiri at 172 minute and still far away from Mumbai coast.

that the tsunami has skipped Mumbai and it is safe. Our analysis shows that it is coming and is little later say by 8 minutes and this time difference is sufficient to alert the people of Mumbai where thousands of people live on the coast and have properties and businesses. In Mumbai large parts of the city is located on reclaimed land which is highly vulnerable to disasters due to tsunami.

The wave heights at the various gauge locations have also been computed and we observe that the wave height is maximum at Dwarka and Udipi. The shelf at Udipi is narrower and steeper and though Udipi is more than 1000 km down south of Dwarka we find that the wave heights are almost similar (Figure 2(b).

The continental shelf is about 300 km in Kutch-Saurashtra area and gradually narrows down to 50 km in the south towards Cochin and Thiruvanthapuram[2].

Conclusions

The Makran subduction zone has generated many significant earthquakes which have produced great tsunamis. In this paper we are quantifying the tsunami arrival times at different locations along the west coast of India Our analysis shows that (1) tsunami wave is reaching first to Ratnagiri and then to Mumbai, with 8 min difference, and (2) tsunami arrival time for Mumbai and Panaji, which are separated by about 350 km is almost same.

References

1 Minshull, T. A., R. S. White, P. J. Barton, & J. C. Collier. Deformation at Plate Boundaries around the Gulf of Oman, *Marine Geology.,* 104(1992) 265-277.

2 Pendse, C. G., The Makran earthquake of the 28th of November, 1945. *Sci. Notes.* Indian Meterol. Dep 10(1948) 141-145.

3 Ambraseys, N., & Melville, C. A. History of Persian Earthquakes. Cambridge University Press, New York Earthquakes in the Islamic period, Beer, A & Stag, J.M. Seismic Sea Wave of November 27th, 1945. *Nature.,*158(1982) 63-64.

4 Byrne, D. E., A. R. Sykes and D. M. Davis. Great Thrust Earthquakes and Aseismic Slip along the Plate boundary of the Makran Subduction Zone*. J. Geophys. Res.,* 97(1992) 449-478.

5 R.Ramachandran., Waves from the past. *Frontline.,* 22 (2006) 2.

6 Carayannis, G.P., Potential of tsunami generation along the Makran subduction zone in the northern Arabian Sea, case study: the earthquake and tsunami of November 28, 1945. *Science of Tsunami Hazard.,* 24(2006) 358-384.

7 Quittmeyer, R.C., and Jacob, K.H. Historical and modern seismicity of Pakistan, Afghanistan, northeastern India and southeastern Iran. *Bull. Seismol. Soc. Am., 69*(1979) 773-823.

8 Swaroopa Rani V., Kirti Srivastava, D. Srinagesh & V.P. Dimri. Spatial and temporal variations of b-value and fractal analysis for the Makran region. *Marine Geodesy* 2009 (accepted).

9 Imamura, F., Review of Tsunami Simulation with a Finite Difference method, Long-Wave Run-up Models Edited By H.Yeh, P. Liu And C. Synolakis, World Scientific (Isbn981-02-2909-7) 1996 , pp. 25-42.

10 Mansinha, L., & Smylie, D.E. The displacements fields of inclined faults. *Bull. Seismo .Soc. Am.,* 61(1971) 1433-1440.

11 Kirti Srivastava, Swaroopa Rani V., D. Srinagesh & V.P. Dimri. Could the 12 Sept, 2007, earthquake of southern Sumatra, Indonesia, have generated a large Tsunami causing damage to the east coast of India? *Current Science.*, 93(2007) 1228-1229.

12 Srivastava, K., & Dimri, V.P. Tsunami propagation of the 2004 Sumatra earthquake and fractal analysis of the aftershock activity. *Indian J. Mar. Sci.,* 36(2007) 128-135.

13 Chidambaram,S., A. L. Ramanathan, M. V. Prasanna, D.Lognatan, T. S. Badri narayanan, K. Srinivasamoorthy & P. Anandhan. Study on the impact of tsunami on shallow groundwater from Portnova to Pumpuhar, using geoelectrical technique - south east coast of India. *Indian J. Mar. Sci.,* 37(2008) 121-131.

14 Bhattacharya, G.C., & Chaubey, A.K. Western Indian Ocean- A glimpse of the tectonic scenario. In The Indian Ocean- A Perspective, R Sen Gupta and E. Desa (Editors) Oxford-IBH, New Delhi 2001, pp. 691-729.

15 Uda, T., Numerical simulation and experiment on tsunami run-up, *Coastal Engineering In Japan*., 31 (1988), 87-104.

16 Okada, Y. Surface deformation due to shear and tensile faults in a half-space, *Bulletin of the seismological society of America*., 75(1985), 1135-1154.