Tsunami simulations for Karachi and Bombay: Sensitivity to source parameters of the 1945 Makran earthquake

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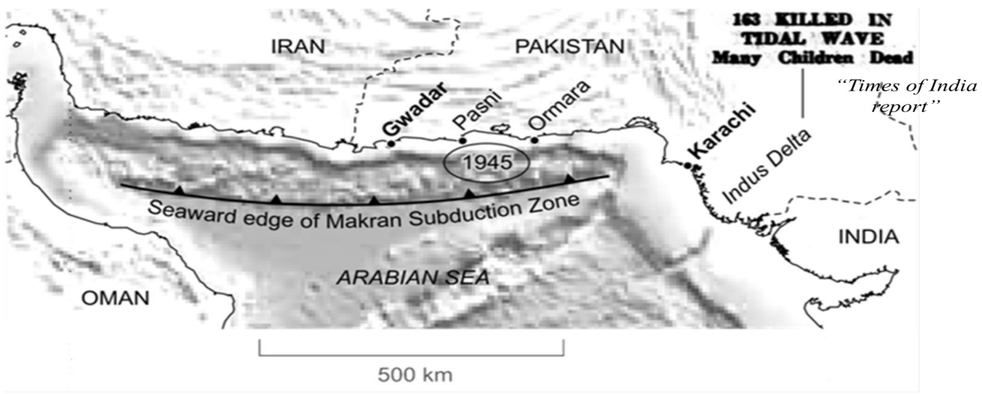
Conclusions

- A sensitivity analysis for the source parameters was carried out.
- The wave amplitudes and arrival times at Karachi compared well with observations, however unlike within the observations, the first wave is the highest and not the fourth.
- Moreover, the observations at Bombay harbour did not match the simulated results.
- These discrepancies may be because of a number of factors:
  1. Some of this may be sloshing in the harbour and since the fourth wave is the largest, it may be that edge waves were trapped on the continental shelf that propagate back and forth and one of these later waves is interacting with the sloshing in the harbour or reflections from other coastlines to give a larger resulting wave.
  2. Wave-wave interaction due to a secondary source such as a sub-marine landslide may also be a possibility. As arrival times for the highest wave is around the same at Bombay, Karachi and reports from Pasni also suggest the same, the profiles at Bombay suggest that the slip was closer to Bombay then any of the other locations mentioned.
  3. Finally it could also be the coastal vertical deformation due to the source. Reports suggest that there was 2m uplift at Ormara with none at pasni[7], however, this is not the case in the present study, where the maximum coastal deformation of approximately 2 m lies in the vicinity of the epicentre.



Objective and Methodology

- The Markan earthquake was widely recorded worldwide and the tsunami registered on tide gauges at Karachi and Bombay, however, compared to modern standards the quality of earthquake source data was of poor standards, which lead to the calculations of source parameters in the early 90's.[1]
- Subsequent studies have utilised this data to model tsunamis[9] and have tried to interpret results with available scant historical and eyewitness records together with uplifts of 2m reported at Ormara and none at Pasni.
- More recently, studies have tried to reanalyse the source[3] after publishing of the 1945 tide gauge data[6].
- Because so much is unknown about the 1945 earthquake and tsunami, we use an open-source code, Geoclaw, for a sensitivity analysis of alternatives to the source parameters.
- With this analysis we are attempting to determine whether the source of the 1945 tsunami was tectonic deformation only, or whether submarine slides could have played major roles.

	Source Parameters	*fault width*	*fault length*	*slip angle*	*dip angle*	*strike direction*	*Dislocation*	*epicentre latitude*	*epicentre longitude*	*focal depth*	***Ormara uplift***
	Byrne et al. (1992)	100 km	150 km	89°	7°	246°	7 m	25.15°N	63.48°E	27 km	**0.1187m**
A		**50 km**	150 km	89°	7°	246°	7 m	25.15°N	63.48°E	27 km	**0.0829m**
		150 km	150 km	89°	7°	246°	7 m	25.15°N	63.48°E	27 km	**0.1377m**
B		100 km	**100 km**	89°	7°	246°	7 m	25.15°N	63.48°E	27 km	**0.0494m**
		100 km	**200 km**	89°	7°	246°	7 m	25.15°N	63.48°E	27 km	**0.2554m**
C		100 km	150 km	**84°**	7°	246°	7 m	25.15°N	63.48°E	27 km	**0.1063m**
		100 km	150 km	**94°**	7°	246°	7 m	25.15°N	63.48°E	27 km	**0.1303m**
D		100 km	150 km	89°	**4°**	246°	7 m	25.15°N	63.48°E	27 km	**0.1209m**
		100 km	150 km	89°	**10°**	246°	7 m	25.15°N	63.48°E	27 km	**0.1149m**
E		100 km	150 km	89°	7°	**236°**	7 m	25.15°N	63.48°E	27 km	**0.0956m**
		100 km	150 km	89°	7°	**256°**	7 m	25.15°N	63.48°E	27 km	**0.1450m**
F		100 km	150 km	89°	7°	246°	**2 m**	25.15°N	63.48°E	27 km	**0.0339m**
		100 km	150 km	89°	7°	246°	**12 m**	25.15°N	63.48°E	27 km	**0.2036m**
G		100 km	150 km	89°	7°	246°	7 m	**25.12°N**	63.48°E	27 km	**0.1219m**
		100 km	150 km	89°	7°	246°	7 m	**25.18°N**	63.48°E	27 km	**0.1151m**
H		100 km	150 km	89°	7°	246°	7 m	25.15°N	**62.96°E**	27 km	**0.0169m**
		100 km	150 km	89°	7°	246°	7 m	25.15°N	**64°E**	27 km	**1.0657m**
I		100 km	150 km	89°	7°	246°	7 m	25.15°N	63.48°E	**15 km**	**0.0397m**
		100 km	150 km	89°	7°	246°	7 m	25.15°N	63.48°E	**39 km**	**0.2037m**

Scenarios

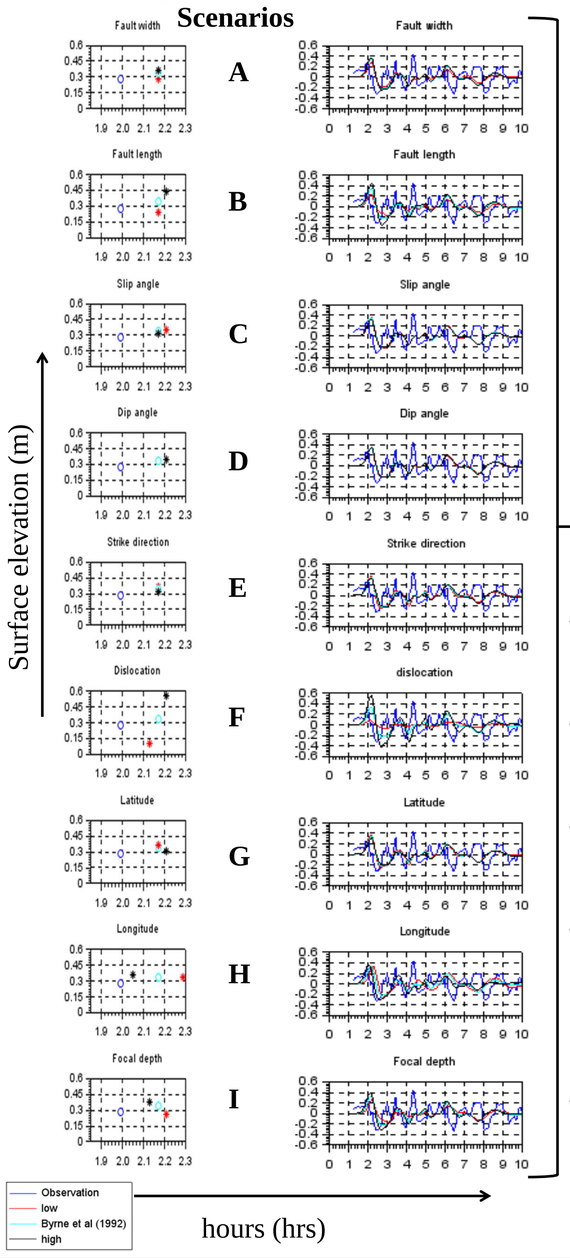
Location and Type of Tide Gauge

- A float-type tide gauge at Karachi Port Harbour was installed before 2nd January 1924 within the channel along the shore of Manora Island malfunctioned due to the tsunami but was repaired thus kept on recording the surface elevation during the event.[6]
- A similar tide gauge was located in Bombay Harbour with its location offshore of Apollo Bunder according to PSMSL (Permanent Service for Mean Sea Level)

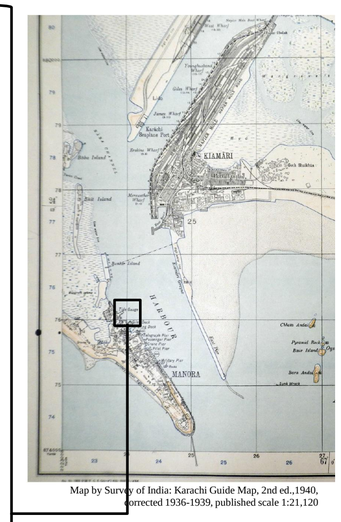
Numerical Model

- Geoclaw[5] uses finite-volume methods to solve the two-dimensional nonlinear shallow water equations that are standard in modeling tsunami propagation and inundation. Some of the key features are:
  - Adaptive mesh refinement (AMR) which allows for efficient solution of modeling problems.
  - The code allows parallel processing to attain additional speed.
  - Digital elevation models (DEMs) for bathymetry and topography can be provided arbitrarily at different resolutions.
  - Arbitrarily complex topography and shorelines can be incorporated without the need for mesh generation.
  - Time-dependent sea-floor motion can also be incorporated in the model.

Results



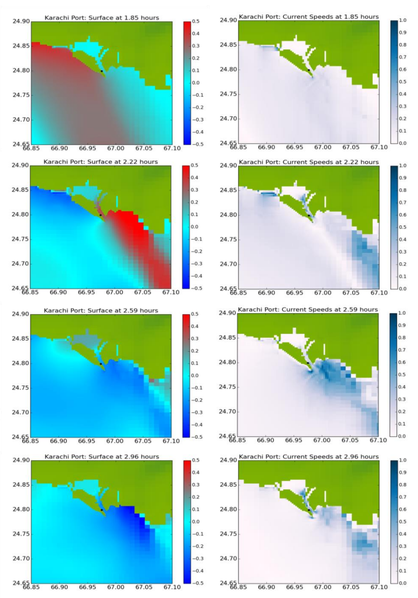
Karachi Harbour



Map by Survey of India: Karachi Guide Map, 2nd ed.,1940, corrected 1936-1939, published scale 1:21,120

- Results for the original 1945 source parameters, shows the initial wave at Karachi having an amplitude and wavelength similar to observations though later do not seem to be well captured by the model.
- This behaviour is also evident in the sensitivity analysis of the source parameters with wave heights having the most effect due to variations in dislocation.
- Observations show the fourth wave is the highest, which is not the case for the model runs.

- The last wave, which was the highest, generated strong ebbing currents of 4-5 knots (2-2.6 ms^{-1})[8]
- The receding wave is reported to have caused damage within the Karachi harbour.[7]
- The model shows the maximum current speed for the first wave in the harbour to be in the vicinity of 1 m/s.
- Even though, the model does not predict the fourth wave to be the largest but considering the result from the first wave the estimated speed for the last wave observation would have been the same.
- These estimates are important and more work is needed on causes of death and damage in the harbour.

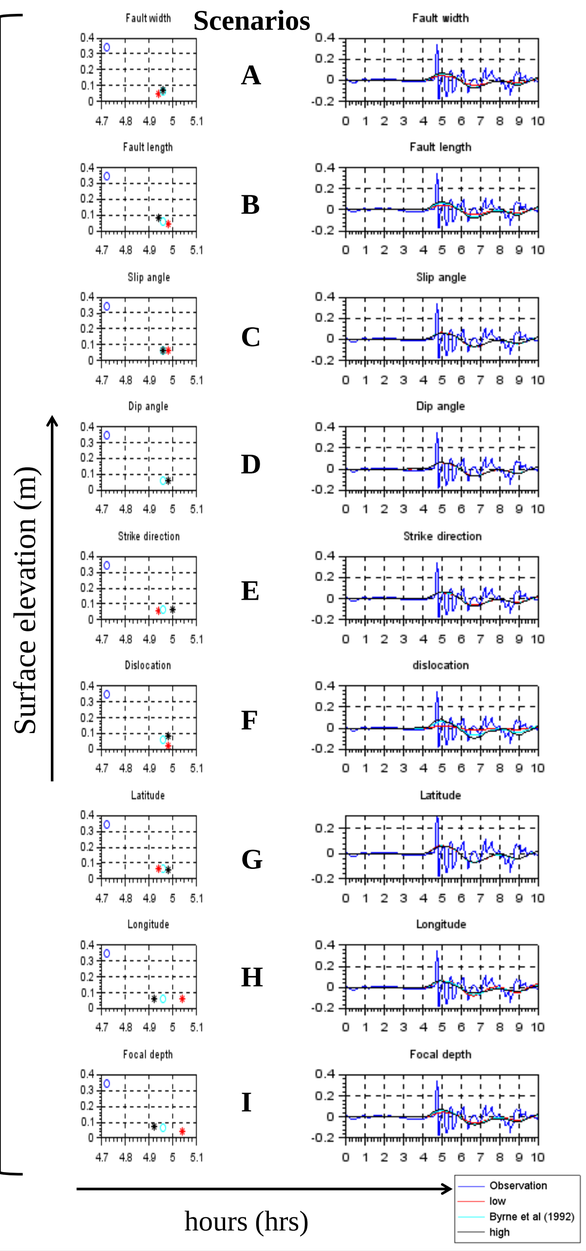


Bombay Harbour

Map by Survey of India's 1933 Bombay guide map, scale 1:25,000, updated through 1932

Tide gauge (72.833333,18.916667) ref: PSMSL

- Limitations in the DEM does not allow placing the tide gauge at Mumbai exactly at the same location.
- The amplitudes and the wavelength do not compare at all well with the tide gauge data of Bombay.
- However, if the oscillations in the observed tide data is smoothed out, there might also be a component at the frequency observed in the simulation.



Background

- Pakistan's tsunami threat, like Japan's, is posted by near-field waves.
- The Makran Subduction Zone, where Eurasia overrides the floor of Arabian Sea, produced a magnitude-8 earthquake offshore Pasni on 28th November 1945[1].
- The ensuing tsunami took hundreds to probably thousand of lives in what is now Pakistan with large populated cities like Karachi and Bombay (Now Mumbai) were not spared either.
- The Bombay Chronicle reported certain adjoining compounds of the oil installations at Keamari being flooded with the wave damaging the 400 ft. in length which was constructed of 177,591 tons of stone and built 1861-1863.[2] Several deaths were also reported along the Bombay coast.

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