Field surveys and modeling of the 1999 Izmit tsunami

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Abstract. A tsunami was generated in Izmit Bay and affected the coastline extensively following the 17 August 1999 Izmit Earthquake. The effects of the tsunami were documented by four different field surveys, which started a few days after the earthquake. Based on eyewitness reports and run-up and inundation measurements, the sea was reported to have receded first along northern and southern coastlines of Izmit Bay. This information provides valuable information on the generation mechanism of the tsunami waves, for it implies that there was subsidence(s) near and/or at the shoreline, possibly caused by a step-over mechanism. Local peaks in tsunami run-up along the northern and southern shorelines of the central basin hint that the underwater slumps and/or subsidences may have been the source of the tsunami. Here, the coastal and offshore evidences obtained from the field surveys are summarized. The source mechanism of this tsunami is investigated by the model studies to satisfy the tsunami characteristics determined by field surveys.

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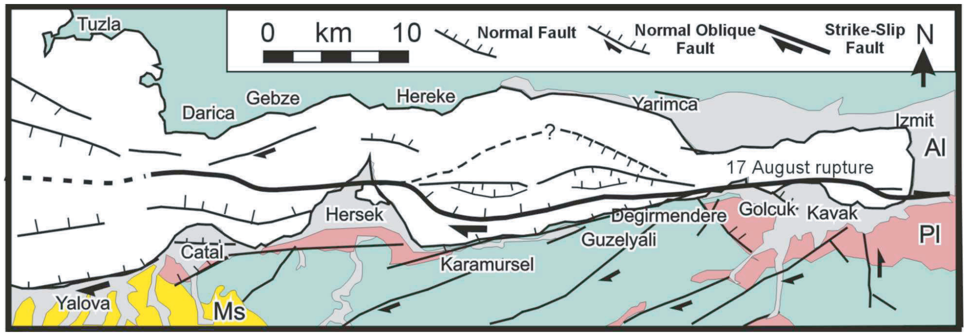

Figure 1: A diagram showing the tectonic setting of Izmit Bay (modified from Alpar and Yaltirak, 2000; Lattice *et al.*, 2001). Thick line represents the master fault activated during the 17 August earthquake.

1. Introduction

The Izmit earthquake (00:01:39.80 UTC, 17 August 1999) of magnitude $M_w = 7.4$ occurred with a macroseismic epicenter near the town of Golcuk (40.702°N, 29.987°E). The earthquake mainly caused a right-lateral strike-slip movement along the main fault crossing the Izmit Bay, which is a 53 km long and 2–10 km wide tectonically active basin with three small tectonic basins (Fig. 1). These basins covered mainly by fine-grained continental siliclastic material resulting from fluvial and littoral processes (Alpar, 2000). The field observations indicated that the earthquake, with a focal depth of 17 km, produced at least 125 km of surface rupture and dextral offsets as large as 4.2 m (Altinok *et al.*, 1999; Barka *et al.*, 2001).

Different field surveys had been performed for determining tsunami wave characteristics, which had been observed in Izmit Bay after the earthquake. Tsunami run-up measurements were taken using watermarks and sea born debris. More than one hundred eyewitnesses were interviewed. Overall the tsunami damage was small, but quite extensive spatially (Yalciner *et al.*, 1999; Altinok *et al.*, 1999; Yalciner *et al.*, 2000).

In order to determine the source mechanism of this tsunami, the mathematical model *Two-Layer,* which was developed at the Tohoku University Disaster Control Research Center, is used. Several scenarios for the initial wave and propagation of a tsunami is tested. One of the results which satisfies the field data is presented.

2. Coastal Evidence of Izmit Tsunami

According to field data from field surveys, the characteristics of the Izmit tsunami have been described in detail by Yalciner *et al.* (1999), Altinok *et al.* (1999), and Yalciner *et al.* (2000). Along the northern coast of Izmit Bay, in the central basin between Hereke and Tupras Industrial Plant, the tsunami had the form of a leading depression wave. Tadepalli and Synolakis (1994, 1996) first described these waves. The run-up heights ranged from

1.5 to 2.6 m, and decreased to high water levels within 4 km east of Tupras and 10 km west of Hereke. The first wave arrived along the north coast a few minutes after the earthquake, and had a period of about 1 min. The hardest hit areas were Sirinyali, Kirazliyali, Yarimca Korfez, and Tupras. The wave carried mussels into houses and damaged doors and windows. At the locality Korfez near Yarimca, the inundation distance ranged up to 35 m. There were clear watermarks on the wall of the police station in Hereke, and at the Denizkosku restaurant near Korfez. Eyewitnesses reported that the wave arrived at Kirazliyali from the southeast and at Korfez from the south.

Along the southern coast between Degirmendere and Guzelyali, run-up heights were measured in the range of 0.8 to 2.5 m, and decreased to high water levels within 6 km east of Golcuk, location 20, and 10 km west of Guzelyali. The tsunami was observed as a leading depression wave to the west of Kavakli up to Guzelyali. The wave was noticed immediately after the earthquake. There was significant coastal subsidence in addition to slumping of the Cinarlik Park near Degirmendere. The subsided area extended 250 m along shore and 70 m perpendicular to shore, and included two piers, a hotel, a restaurant, a coffeehouse, and 14 large trees. The sea was observed receding about 150 m in less than 120 s near Degirmendere. When the sea came back, it flooded up to 35 m inland, as indicated by the mussels and dead fish left in this inundation area.

3. Offshore Evidence of Tsunami Source

Izmit Bay is a tectonically active depositional area. Seismic profiles show that the asymmetric geometry of the bay is a result of half graben formation. Sediments in the basin are thickest in the deepest part of the graben and gradually thin southward. The average sedimentation rate is 20 cm per 1000 years, with a maximum of 150 cm per 1000 years for the deepest parts (Alpar, 2000). East–west compressional and north–south tensional forces created three basins in the bay and resulted as a response to the kinematical block displacements at active zones (Barka and Kadinsky-Cade, 1988).

Shallow seismic studies following the 1999 Izmit Earthquake showed a master fault crossing the Izmit Bay (Alpar, 1999; Sengor *et al.*, 1999). Northward bending of this master fault causes en echelon faults and open tectonic basins of Izmit Bay as releasing bend basins (Alpar and Yaltirak, 2000). Secondary faults low-angle oblique to the master fault are the products of the dextral shearing mechanism. The tectonic setting of Izmit Bay is shown in Fig. 1.

In order to understand the tsunami generation, modeling is believed to be the most convenient tool. In order to define the source mechanism, the generation, propagation and coastal amplifications of this tsunami in Izmit Bay are modeled by using different scenarios.

4. Modeling

Until recently it was common to choose a water surface deformation as the initial condition for mathematical models for tsunamis. As a recent development of tsunami modeling, the model *Two-Layer* was created in Tohoku University Disaster Control Research Center in Japan (Imamura and Imteaz, 1995). *Two-Layer* can use the wave due to fault break as the initial condition and can also employ landslide motion for the wave generation. It is applied to simulate the Izmit tsunami in this study.

The computation domain is chosen as bounded by the longitudes 28.49°E and 29.96°E and the latitudes 40.67°N and 40.81°N. The spatial grid size is taken as 50 m. Several tsunami scenarios related to tectonic settings are tested by *Two-Layer*.

According to seismic reflection surveys, the pure strike slip fault extends to west with bending in the basins, but mainly parallel to coastline. Its lateral offset diminishes westward at west of Ulasli. Depending on the bending structure of the buried master fault, there are some short but significant normal and normal oblique faults developed at some localities. One of them is seen clearly to the east of Golcuk on land. There are also some tensional surface ruptures near Yarimca and Tupras along the northern shores (Altinok *et al.*, 1999). An eyewitness who was awake and watching the sea while sitting in his 5th floor balcony in Degirmendere felt a slight tremor for a very short period of time before the great earthquake and observed the receding of the sea before the earthquake (Altinok *et al.*, 2001, in press). Therefore, it can be said that the Izmit tsunami was started by the recedence of the sea, triggered by the main fault. It is highly possible that the tsunami was superimposed by the motion of coastal landslides along the southern coast, and subsidence on the sea bottom. By considering this information, several scenarios have been tested.

As one of the applications, coastal subsidences at Degirmendere Cinarlik park (west of Golcuk) and Kavakli village (east of Golcuk) are used. It is found that the tsunami generation related to these subsidences is not sufficient to satisfy the arrival time to the north coasts of the central basin and the measured run-up values. There must be other subsidence type sources of tsunami in the bay near the north coast to satisfy leading depression wave and arrival time.

The scenario that assumes the secondary synthetic faults and tension cracks near the north coast and fault break along the south coast is simulated. The initial wave of the generated tsunami is shown in Fig. 2. The distribution of maximum water surface elevations along the north and south coasts are shown with the measured run-up data. In Fig. 2 the maximum water surface elevations computed at each grid point in the bay are also shown.

As seen from Fig. 2, the source of 1999 Izmit tsunami is mainly related to the water surface subsidence. The computed distribution of the maximum water surface elevations near the shoreline along north and south coasts are in agreement with the distribution of measured run-up values (Fig. 2). Since the finite difference technique cannot compute the run-up values exactly

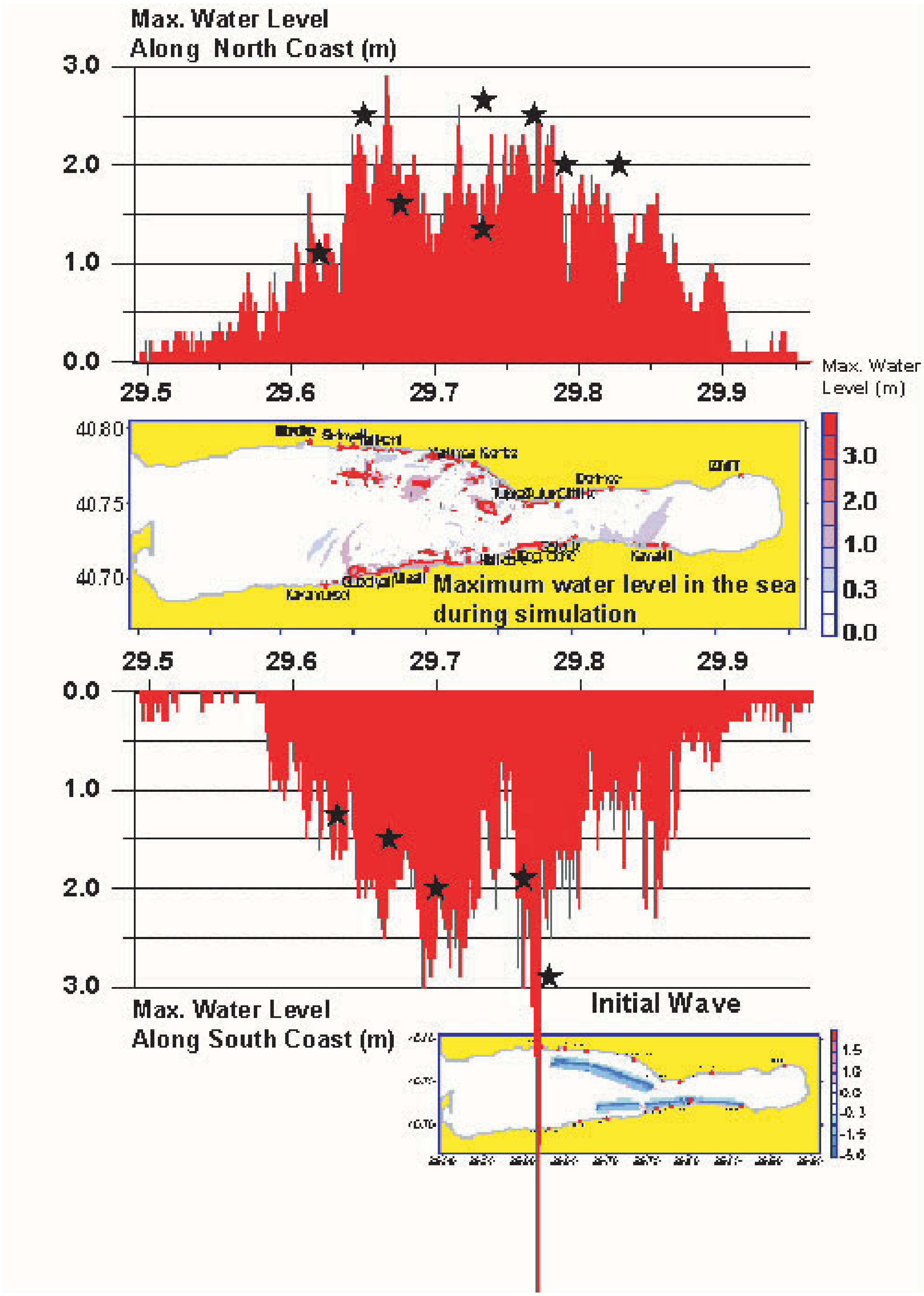

Figure 2: The distribution of maximum water surface elevations in Izmit Bay for the scenario of the 1999 Izmit tsunami and the comparison with measurements along the northern and southern coasts.

because of its fixed spatial griding technique, the slight underestimation along the north coast and slight overestimation along the south coast are in acceptable limits.

5. Discussion and Conclusion

The coastal and offshore evidences of the 1999 Izmit tsunami are summarized. The model *Two-Layer* is applied by using different source mechanisms related to geophysical data. The scenario, which considers the water level subsidence along the secondary fault parallel to north coast together with the water level subsidence along the south coast, can simulate the behavior of tsunami reasonably and the results are in agreement with the field data.

Acknowledgments. USC Professors James Dolan and Jean Pierre Bardet, Prof. Yalcin Yuksel from Yildiz Technical University, and California's State Lands Commission engineers Martin Eskijian and John Freikman are cheerfully acknowledged by the authors for their contributions in the field work, the latter particularly for their help in assessing the damage to port facilities. This study was supported by Professor Nobuo Shuto of Iwate Prefectural University of Japan, Dr. Cliff Astill of the National Science Foundation of the United States, the Istanbul University Research Fund (Projects O-467/280998, 1268/050599, O-803/31052000, and O-947/01022001), TUBITAK (YDABCAG-60, INTAG-827), JICA, GNDT (Gruppo Nazionale Difesa dai Terremoti), the University of Southern California, the Middle East Technical University, Tohoku University's Disaster Control Research Center, the University of Bologna, and the General Directorate of Disaster Affairs Turkey. KISKA A.S, E. Bortolucci, A. Armigliato, civil engineer Salih Saygili, and the Municipality of Degirmendere are also acknowledged for their valuable assistance.

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