Tsunami Waves in Izmit Bay

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15 authors, including:

Ahmet Cevdet Yalciner
Middle East Technical University

Yıldız Altınok
Istanbul University

Costas E. Synolakis
University of Southern California

Jose C Borrero
University of Southern California

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Kocaeli, Turkey, Earthquake of August 17, 1999 Reconnaissance Report

TECHNICAL EDITORS
T. Leslie Youd
Jean-Pierre Bardet
Jonathan D. Bray

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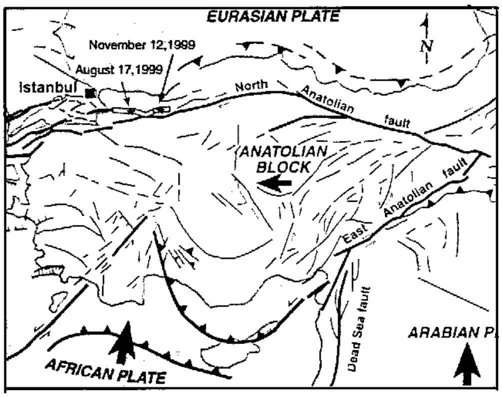

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3 Tsunami Waves in Izmit Bay

INTRODUCTION

Following the Kocaeli earthquake of August 17, 1999, unusual water wave motions affected the coastline of Izmit Bay. The effects of these water waves were systematically documented by field surveys a few days after the earthquake, within the limited time window available for finding and interpreting the watermarks from small tsunamis in densely populated coastlines. Here, the results of the tsunami field surveys after the Kocaeli earthquake are summarized, and historical tsunamis in the region are briefly reviewed.

EVIDENCE OF TSUNAMI TRIGGERED BY THE KOCAELI EARTHQUAKE

Tsunamis are long water waves generated by geophysical events of the seafloor, landslides, volcanoes, and asteroid impacts (Prager et al. 1999). The understanding of tsunami generation mechanisms remains an unresolved scientific problem. Even when seafloor bathymetry is measured following an earthquake, the bathymetry prior to the event is seldom known with enough resolution to infer the actual seafloor displacement that triggered tsunamis. Geophysicists rely on field survey data of inundation heights and inland penetration distances and on eyewitness observations about the characteristics of the leading wave (Tadepalli and Synolakis 1994 and 1996) and arrival times for attempting to identify the source motion.

In the days following the Kocaeli earthquake, contemporaneous press accounts described extensive flooding of coastlines of Izmit Bay but made no mention of tsunamis. Given the predominantly strike-slip nature of the fault rupture system, there was an urgent need to determine whether a tsunami was generated or whether the flooding was attributable solely to tectonic subsidence. Four separate surveys were performed in the affected area around Izmit Bay and the Sea of Marmara. The first took place between August 22 and August 30, 1999, and was followed by three more in September and October 1999.

RESULTS OF FIELD SURVEYS

Tsunami run-up measurements were taken using watermarks and seaborne debris (see figure 3.1). Run-up refers to the elevation difference between the most inland penetration point of the wave and the shoreline, at the time of the event (Synolakis et al. 1995; Kawata et al. 1999). When it is impossible to measure run-up directly, the elevation difference between watermarks and the shoreline is used as a substitute. The two are seldom identical, and the former is usually smaller than the latter. During the Kocaeli field survey, more than one hundred eyewitnesses were interviewed. The surveys were performed at the locations shown in figure 3.2 and listed in table 3.1 (Altinok et al. 1999). Overall the tsunami damage was small but quite extensive in area.

As shown in figure 3.2, along the northern coast of Izmit Bay, in the central basin between

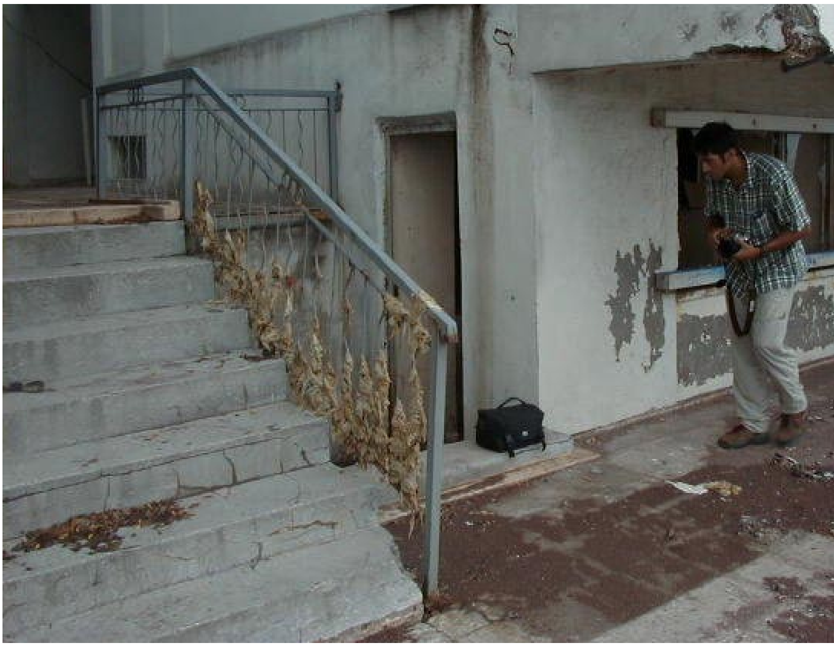

Figure 3.1. The tsunami wave left behind seaborne debris (seaweed) hanging on the staircase railing at Kirazliyali (location 8 in figure 3.2).

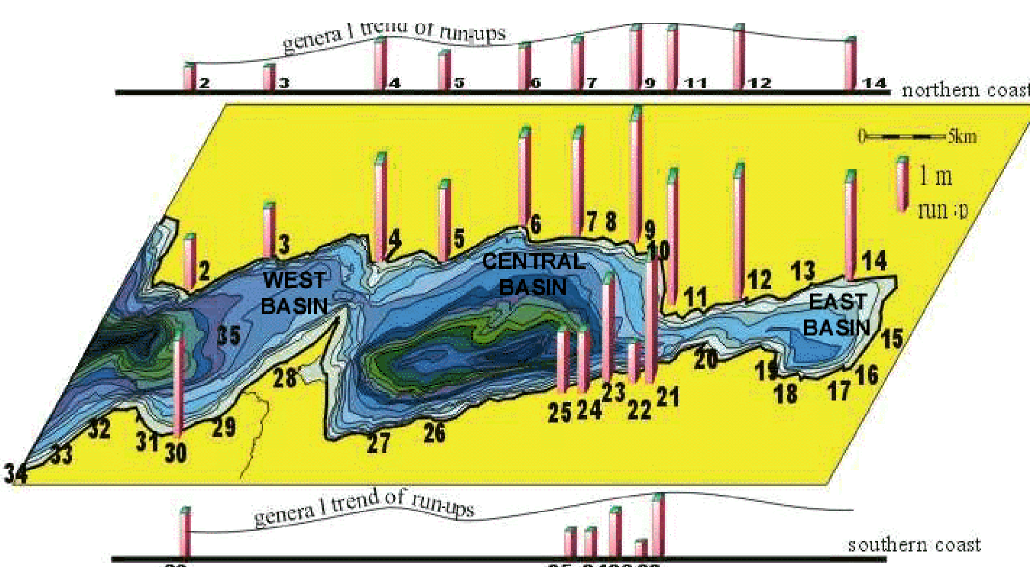

Figure 3.2. Bathymetry of Izmit Bay, locations of tsunami field surveys, and measured values of run-up heights (Altinok et al. 1999).

Table 3.1. Data compiled from eyewitness accounts and interpreted measurements of run-up heights, inundation, and receding distances of the tsunami after the Kocaeli Earthquake (Altinok et. al. 1999; and Yalciner et. al. 1999). Note: * refers to the inundation distance due to coastal subsidence.

No	Locality	Run-up (m)	Inundation Distance (m)	Receding Distance (m)
2	Darıca	1+	4	
3	Eskihisar	1+	15	
4	Dilovası	2		
5	Tavsancilar	1.5	25,30	
6	Hereke	1.80	30	
7	Sirinyali	1, 2.5	15	
8	Kirazliyalı	2.5		
9	Yarımca	2.5	35, 60	15, 20
10	Körfez	2.5	100	15
11	Tüpras	2.5		
12	Derince Port	2-2.5		
13	Çene Suyu	2	60	80
14	Izmit, Marina		25	40
17	Seymen		50	2
19	Kavaklı		300*	
20	Golcuk			
21	Degirmendere	2.5	35	150
22	Halidere	0.8	60	15
23	Ulasli	2	5+	
24	Eregli (Güzelyalı)	1.25	4	15
25	Defne Mahallesi	1.5	4	
26	Karamürsel	1.25		
27	Kaytazdere		15	
28	Hersek		30+	
29	Havuzdere			
30	Topçular	1+		
35	Offshore Topçular			

Hereke and Tupras industrial plant, the tsunami had the form of a leading depression wave. These waves, which were first described by Tadepalli and Synolakis (1994 and 1995), caused transient exposure of the seafloor near the shoreline. It is now common knowledge that most near-shore tsunamis manifest themselves as leading depression waves, also referred to as LDNs. The run-up heights ranged from 1.5 to 2.6 meters 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 one minute. The sea withdrew during the earthquake in the port at Tavsancilar, and the elevation wave that followed flooded up to 25 meters inland and invaded the first floor of houses (see location 5 in figure 3.2). Henceforth the location numbers refer to the vertical bars in figure 3.2.

The hardest hit areas were Sirinyali, Kirazliyali, Yarimca, Korfez, and Tupras (locations 7 to 11). The basements of waterfront apartments were flooded, and the sea rose to the second floor of some houses near Kirazliyali. The wave carried mussels into houses and damaged doors and windows. At the Yarimca Yachting Club (location 9), the sea first receded 15 to 20 meters, and the following elevation wave lifted up a motor yacht and moved it 50 meters inland. A second wave inundated the same shore to 30 meters inland. At Korfez, the inundation distance ranged up to 35 meters. There were clear watermarks on the wall of the police station in Hereke (location 6) and at the Denizkosku restaurant in Korfez. Eyewitnesses reported that the wave arrived at Kirazliyali from the southeast and at Korfez from the south. At the Izmit Marina (location 14), the sea receded about 40 meters. At Seymen (location 17), the waves were observed to come from the northwest.

Between Degirmendere and Güzelyali, run-up heights were measured in the range of 0.8 to 2.5 meters and decreased to high-water levels within 6 km east of Gölcük and 10 km west of Güzelyali (location 24). The tsunami was observed as a leading depression wave to the west of Kavakli

Figure 3.3. At Cinarlik Park near Degirmendere (location 21 in figure 3.2.), a hotel, restaurants, shops, and trees along the shoreline subsided into the sea, at the place where the seawater changes to a lighter color. The divers on the boat were looking for a car dragged into the sea by the wave.

Figure 3.4. A view from the sea of the subsided coastal area at Kavakli, west of Gölcük (location 20 in figure 3.2).

(location 19, figure 3.3) along the southern coast up to Güzelyali. The wave was noticed immediately after the earthquake. As shown in figure 3.4, there was significant coastal subsidence in addition to slumping of Cinarlik Park near Degirmendere (location 21). The subsided area extended 250 meters along shore and 70 meters perpendicular to shore and included two piers, a hotel, a restaurant, a coffeehouse, and 14 large trees. The sea was observed receding about 150 meters in less than 120 seconds near Degirmendere. When the sea came back, it flooded up to 35 meters inland, as indicated by the mussels and dead fish left in this inundation area.

At Halidere (location 22), the sea receded 10 to 15 meters and flooded up to 50 meters inland, as inferred from the depositions of sea moss and jellyfish. At Ulasli (location 23), the sea receded and inundated at least 5 meters. Seven people were swept into the sea when a waterfront restaurant subsided; only two survived. The building of the Ulasli municipality and its open-air parking area near the coast sank into the sea, together with cars, construction equipment, and boats (Altinok 1999). In the port at Güzelyali, the sea withdrew and boats were stranded outside the breakwater at the onset of the earthquake. The inundation distance was about 5 meters. At Karamürsel (location 26), the sea receded; sea moss and dead fish were found along a 70– to 100-meter zone at the Aksa Textile Industrial Complex at Kilic Delta, west of location 30.

At Küçükçekmece Inlet, Atakoy Marina, Yenikapi, Bosporus, Bostanci, Pendik, Tuzla, Yalova, Çinarcik, Bandirma, and Erdek, strong currents and abnormal water-level changes were also reported, but of much longer periods. In Atakoy Marina, abnormal long-period water-level changes and strong currents were observed by the staff of the marina until 6:00 A.M. the following morning.

ABNORMAL SEA LEVEL CHANGES AS REPORTED BY SEAMEN

Along the northern coasts of Izmit Bay, at Dilovasi, Korfez, Derince, and Izmit (locations 4, 10, 12, and 14, respectively), several boat captains reported abnormal sea level changes.

At the onset of the earthquake at Dilovasi Port (location 4), the 2,000 gross-ton (GT) tanker *Nazan,* with a draft of 4.5 meters, along with *Empros* and *Bora Mete,* suddenly descended and then was uplifted as much as 3 meters. At the port of Derince (location 12), loading cranes derailed due to horizontal and vertical movements of the caisson as large as 40 cm. Two large, heavy, and powerful tugboats, boarded alongside a ship moored at port, descended violently on their bows as a result of the LDN and were then uplifted 2 to 2.5 meters.

The boat *Korfez-1* was moored at a fisherman's wharf at Korfez at around 3:00 A.M. on August 17, 1999. The LDN caused the boat to hit the seafloor, and then *Korfez-1* drifted back to the sea. In less than half a minute, the boat rose with the rising water and drifted toward a fisherman's wharf. From this observation, the period of the wave (time distance between crest to crest) was inferred to be less than one minute. In Izmit Marina (location 14), the moored boats dropped by more than 2 meters before recovering.

Along the southern coast of Izmit Bay at Degirmendere, Halidere, and Ulasli, the captains experienced violent wave motions. The 375 GT 50-meter-long passenger ship *Ataturk* was moored to the Degirmendere Pier, next to the 300 GT 36-meter-long fishing boat *Kircillioglu-4*. The captain of the fishing boat *Abonoz,* which was nearby, reported that *Kircillioglu-4* was uplifted more than 10 meters relative to *Ataturk* and sank, while *Ataturk* was dragged to shallower depth. At the Halidere pier, the 349 GT 4-meter-draft *Tatlisu Ship* fell down more than 1 meter below the pier, hit bottom, and damaged her shaft and propeller. At the Ulasli port, the ship *Kirat* broke her ropes off and fell down below the pier. All these short-term near-shore events, which depend on local seafloor bathymetry and marina geometry, are an indication of the water pandemonium that followed the earthquake.

A less credible but nonetheless interesting report was from the captain of the ferryboat *Okmeydani,* which was sailing at 1 knot within 90-meter-deep water from Topcular to Eskihisar (locations 30 and 3), 2.6 miles from Topcular. The captain reported seeing a 30- to 40-meter-high wave about 100 meters away from her bow. He observed that the wave progressed toward Eskihisar (Altinok et al. 1999).

HISTORICAL TSUNAMIS IN THE SEA OF MARMARA

The tsunami waves observed after the Kocaeli earthquake are not the first ones to have occurred in the Sea of Marmara; ten historical tsunamis were reported between A.D. 975 and A.D. 1962 (Ambraseys 1962). The Osmanli (Ottoman) official archives (Kuran and Yalciner 1993) report that the September 14, 1509, earthquake triggered a tsunami that flooded the regions behind the city walls of Istanbul near Yenikapi and Galata (located to the west and east of Bosporus, respectively) and the residential areas in Hereke, near the northern coast of Izmit Bay. The July, 10, 1894, earthquake generated a tsunami that affected Prince's Islands west of Bosporus and the coasts from Bakirköy to Kartal (north of the Sea of Marmara). The passenger ship *Eser-i Cedit* was dragged to shallower depths, and many boats of various sizes were thrown up onto the land near Büyük Island. The sea receded about 50 meters at Cam Harbor of Heybeli Island (Kuran and Yalciner 1993). The September 18, 1963, earthquake (M=6.1), which was widely felt over a 70,000 km^2 area, triggered a tsunami. Sea waves washed over the seawalls and caused panic at Bandirma, an important port city 120 km away from the epicenter near the south coast of the Sea of Marmara. Local residents vacated port facilities, businesses, and coffeehouses close to the shoreline. The same tsunami reportedly deposited seaborne debris far beyond the high-tide line along the coast of Mudanya Bay (Kuran and Yalciner 1993). Based on historical references, Altinok and Ersoy (1996) and Altinok, Ersoy and Yalciner (1999) reported tsunamis in Izmit Bay and its vicinity to have occurred in A.D. 120 or 128, 325, 358, 447, 488, 553, 555, 557, 715, 740, 1754, April 1878, May 1878, and September 18, 1963.

SUMMARY AND CONCLUSION

Based on eyewitness reports and run-up and inundation measurements, the tsunami generated after the Kocaeli earthquake had a period shorter than a minute and arrived a few minutes after the earthquake on the northern coasts and about a minute after on the southern coasts. The sea 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 a large subsidence near and/or at the shoreline, possibly caused by a stepover between two strands of the strike-slip fault system. The fairly consistent reports of approximately one-minute wave periods rule out bay oscillations as the source of the flooding and indicate that regions of subsidence may have been localized (Alpar 1999; Guneysu 1999). Tsunami waves may have also been generated by sediment slumping within the bay, in addition to tectonic subsidence. Local peaks in tsunami run-up along the northern and southern shorelines of the middle basin hint that these slumps may have generated waves near Degirmendere.

The Kocaeli earthquake generated only small tsunami waves that caused no extensive damage to coastal structures. The tsunami hit close to highly populated areas, however. This is a cause of substantial concern, as there are hundreds of houses, hotels, and cafés within tens of meters of the coastline. Future earthquake hazard mitigation programs in Izmit Bay and the Sea of Marmara need to consider the hazards of tsunami waves, which may result from coseismic seafloor motion, underwater landslides, slumps, and subsidence.

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CHAPTER CONTRIBUTORS

Coordinators

Ahmet Cevdet Yalciner
Middle East Technical University and University of Southern California

Yildiz Altinok
Istanbul University

Costas E. Synolakis
University of Southern California

Other Contributors

Jose Borrero, *University of Southern California*

Fumihiko Imamura, *Tohoku University*

Sukru Ersoy, *Istanbul University*

Ugur Kuran, *General Directorate of Disaster Affairs, Ankara*

Stefano Tinti, *University of Bologna*

Martin Eskijian, *California State Lands Commission*

John Freikman, *California State Lands Commission*

Yalcin Yuksel, *Yildiz Technical, Istanbul*

Bedri Alpar, *University of Istanbul*

Philip Watts, *Applied Fluids Engineering Company*

Utku Kanoglu, *Applied Sciences Laboratory, Inc.*

Jean-Pierre Bardet, *University of Southern California*