THE 21th JULY 2017 GOKOVA EARTHQUAKE AND TSUNAMI; PRELIMINARY REPORT OF POST TSUNAMI FIELD SURVEY IN THE SOUTH COAST OF BODRUM PENINSULA, TURKEY

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PRELIMINARY REPORT

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1. INTRODUCTION

A strong earthquake happened in Gokova Bay on July 21, 2017 causing strong wave motions and damages at some small bays at South of Bodrum peninsula (SW of Turkey). The earthquake and wave motions have also been felt in Kos island Greece. A quick tsunami field survey along the coasts of Bodrum Peninsula was organized and performed by METU and KOERI in collaboration with Turkish Chamber of Civil Engineers (TCCE) on July 22 and 23, 2017.

The main objectives of this survey were to document the variation of the tsunami effects along the coast, to obtain any available data on the wave height and to understand the event in detail for the scientific studies of tsunamis. According to our field survey and eyewitness reports, there was almost no significant water motion at western face of Bodrum peninsula. The tsunami effects are observed at south coast of Bodrum peninsula only from 27.255E to 27.528E. The major runup was about 1.9 meter observed at the mouth of small dry stream (27.407924E 37.029879N) at Gumbet Bay. This report briefly presents the observations, measurements and discussions/interpretations of eyewitness interviews. The report will be updated with further info when obtained.

2. EARTHQUAKE INFORMATION

The earthquake happened in Gokova Bay on July 21, 2017 at 01:31 local time (22:31 UTC) at 36.9620N 27.4053E (KOERI), with the moment magnitude of M_w=6.6 (M_l= 6.2) at a depth of 5km. The epicenter is about 12km ENE of Kos, Greece and 8 km SSW of Bodrum, Turkey. The earthquake was highly felt in Southwestern Aegean Region, especially in Mugla Province. The fault mechanism calculations reveal that the earthquake occurred with a normal faulting and many aftershocks were recorded after the main shock having the maximum moment magnitude of M_w=4.8.

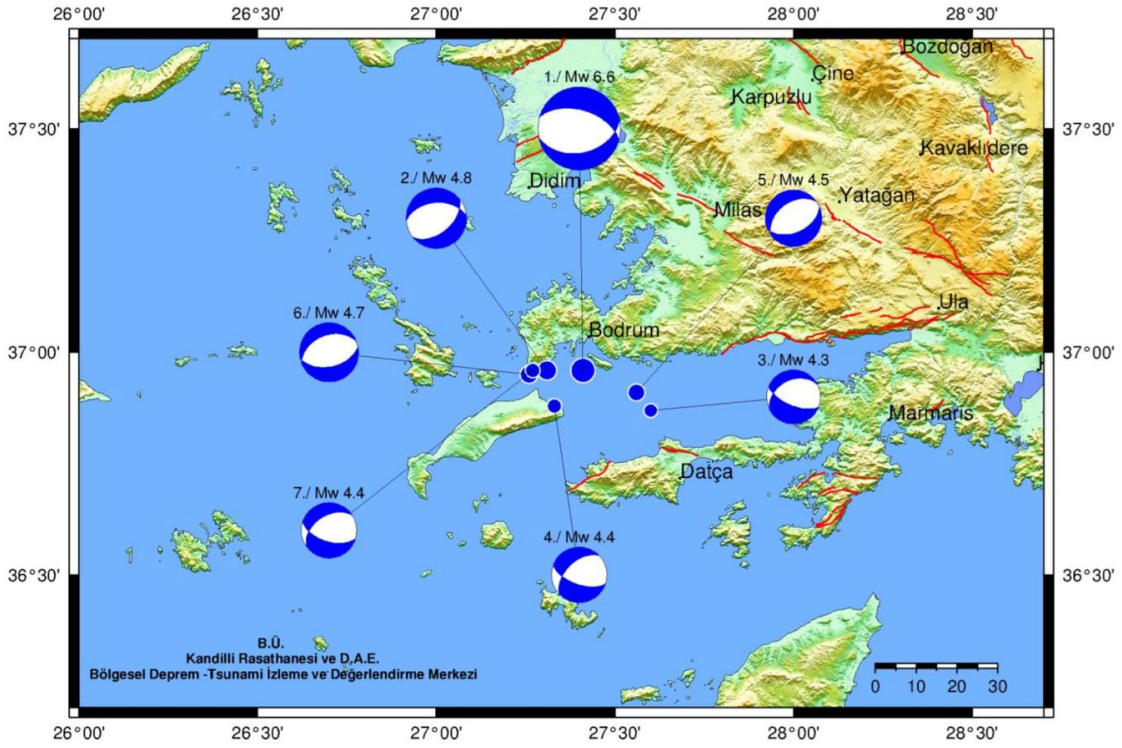


Figure 2.1: Fault mechanisms of main shock and aftershocks by KOERI

According to the first intensity maps produced by ELER in KOERI, the earthquake intensity in Bodrum was VII which indicates that the perceived shaking was very strong while the potential damage was moderate. The earthquake intensity in Kos Island, Bodrum Peninsula and North of Datça Peninsula was VI representing strong perceived shaking and light potential damage.

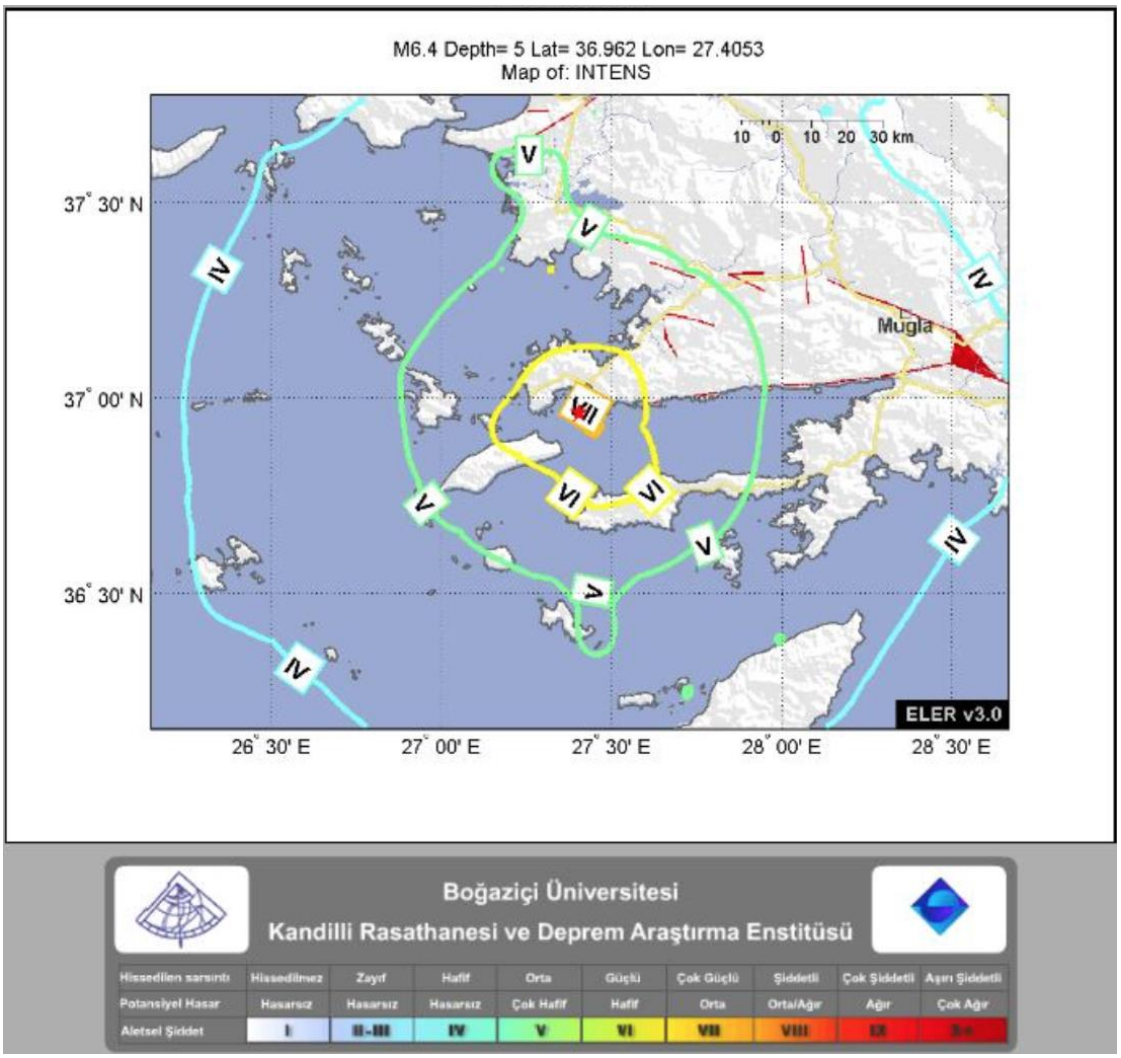


Figure 2.2: Earthquake Intensity Map produced by ELER (KOERI) (M6.4)

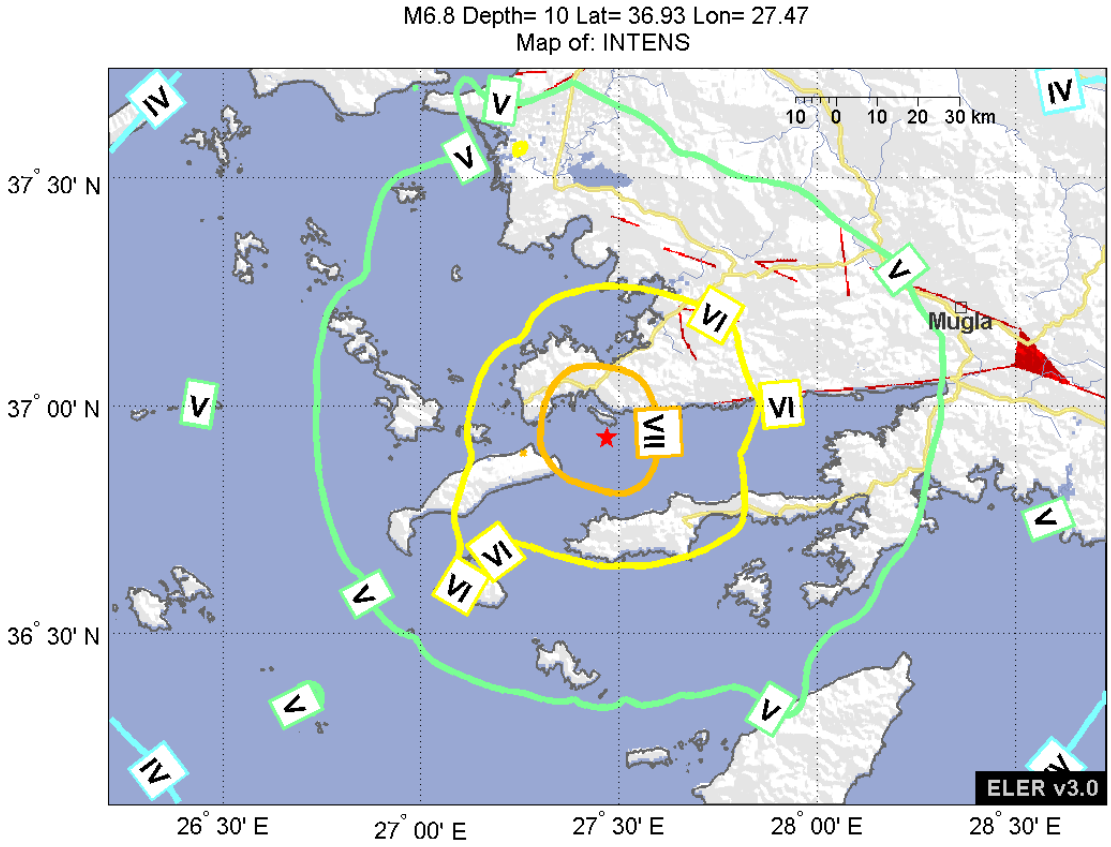


Figure 2.3: Earthquake Intensity Map produced by ELER (KOERI) (M6.8)

3. FIELD OBSERVATIONS ON TSUNAMI

The field survey is performed on July 22 and 23, 2017 along the southern coasts of Bodrum Peninsula in between 27.255E 37.000N (Turgut Reis Marina) and 27.528E 36.992N (Yaliciftlik region). Figure 3.1 shows the survey locations on which the numbers indicate coastal sites where local authorities were contacted and observations on the tsunami waves are obtained. In Table 3.1, a complete list of these coastal sites is given. (The ID numbers in the figure are the same as in Table 3.1.).

Figure 3.1: Location map showing the distribution of the observations of the tsunami waves, obtained from locals.

Table 3.1: List of the surveyed places local people inquired to describe the effects of the tsunami

	Place	Region	Lon. E	Lat. N	Locals inquired
1	Turgut Reis D-Marin	Turgut Reis	27.257491	37.001613	Chief of the marina
2	Olivia Restaurant	Fener Beach, Akyarlar	27.264562	36.964772	Restaurant manager
3	Kilavuz Motel Beach	Akyarlar Bay	27.29093	36.967359	Fishermen and summerhouse residents
4	Balmahmut's Place	Karaincir	27.300496	36.972961	Restaurant manager
5	Aspat Beach	Aspat Bay	27.312356	36.979592	Beach workers
6	Camel Beach	Kargi Bay	27.330562	37.013582	Beach and restaurant workers
7	Bitez Beach	Bitez Bay	27.383582	37.025615	Beach and restaurant workers
8	Whole Bay including municipality cafe	Gumbet Bay	27.405322	37.030868	Fishermen, visitors and other locals
9	Bodrum Marina	Bodrum Center	27.424827	37.035808	Marina workers and visitors
10	Yali Café	Yaliciftlik	27.527908	36.992786	Café workers

The observations of the post event started on 22th of July, 2017 on Saturday at Gumbet Bay **(8)** which seems the most hit area by the tsunami waves in Bodrum Peninsula. Waves first receded 5min after the earthquake and then the first wave arrived 12-13 minutes after the earthquake. Figure 3.2 describes the motion of the wave according to the observations.

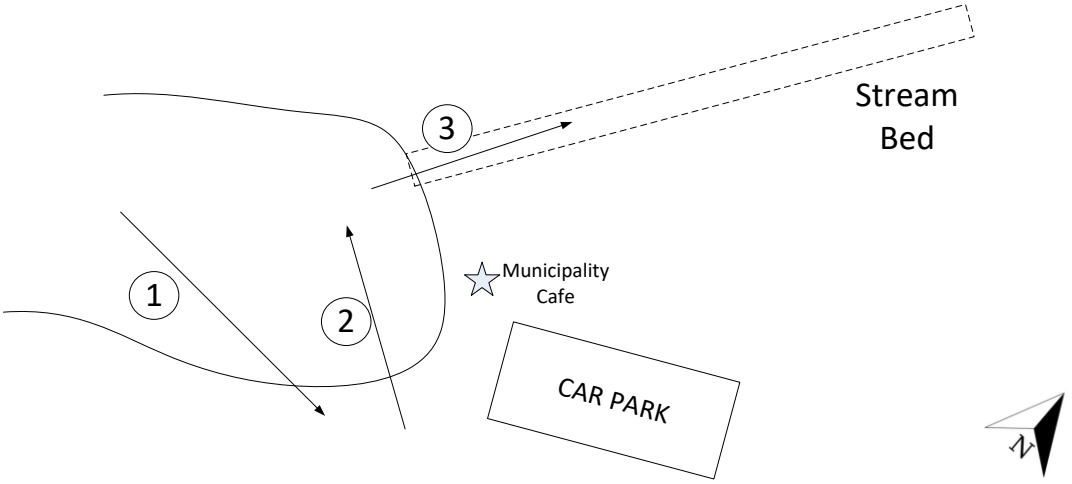


Figure 3.2: The motion of tsunami at eastern end of Gumbet Bay (Municipality café is at 27.408503E 37.029732N)**.**

It is stated by the workers that approximately 20m of inundation is observed near the municipality café. Waves dragged the parked cars near the shoreline on the concrete bed of dry stream. Totally 12 cars have been dragged and all were collected in the same location (37.031137N 27.406882E) away from the shore at the stream and concrete planters in front of these car parking area. Eyewitnesses from the sea front restaurant staff reported successive waves (sea withdrawal and advancing) until the sun rise (about three hours after the earthquake). In the next morning after the earthquake, water level was decreased about 2m in vertical (Figure 3.3). People have found dead fish mostly near and around the stream bed, and all along the coastline of the bay. Besides, they observed remarkable increase in the number of rare insects in last couple of days on the ground.

Figure 3.3: View of sea withdrawal in Gumbet Bay about three hours after the earthquake

The waves mostly penetrated through the dried stream bed (used as a road and parking place) near Ayaz Hotel (Figure 3.4). The width of the road is 3.3 meters (5.7 meters with side walls). The waves penetrated through this stream bed, accelerated as flowing in a channel and reached up to 100m away from the shoreline. The maximum flow depth in the stream bed was about 1 m (Figure

3.5). According to the security camera records of a hotel, waves reached to the entrance door of hotel about 13min after the earthquake. The tsunami inundation distance is about 60 meters and flow depth reached up to 50-60cm. Waves flew in strong current in hotel front.

Figure 3.4: Penetration of the waves through the dried stream bed near Ayaz Hotel

Figure 3.5: Observer showing the flow depth by his foot (37.031412N 27.406703E**)**

Figure 3.6: View of the stream bed that the tsunami inundated (27.407821E 37.029761N**)**

In the last 15 days before the earthquake, there were anomalies in the sea (eyewitnesses reported that at some time the water temperature dramatically increased in some locations of Gumbet bay (Nagi beach club, 27.403552E 37.031463N) in the last 2 weeks before the earthquake. Some eyewitnesses reported the sea bottom topography was changed in two weeks before the tremor. Abnormal currents have been felt by some people when they were swimming in Gumbet Bay. An amateur fisherman (an Australian tourist) reported that about two weeks before the earthquake while he was fishing in his boat at a location (40m water depth) between Kara Ada-Black Island (27.423E, 36.9958N) and Aquarium bay at Adabogazi (27.3875E, 37.0003N), he observed that water uplifted like a pumping up. The waves dispersed away. The coordinate measurements and related observations along Gumbet Bay are given in Table 5.1 in Appendix.

At the eastern most part of Gumbet bay (27.407621E, 37.037478N), the small boats berthed at shallow region. Tsunami dragged all boats together and moved them away from the shore to the location (27.405029E, 37.0281.33N) in the bay. More than 30 boats were damaged and more than 10 boats sunk in this location. The boat captains reported that there was very strong swirling water motion at three locations in the bay. Approximate locations are i) 27.405029E, 37.0281.33N, ii) 27.400399E, 32.029001N, iii) 27.403934E, 37.030043N.

Figure 3.7: View of damaged boats and coastline of Gumbet Bay

Figure 3.8: Damaged minibus and advertisement board

On the second day of the survey (July 23, 2017), the survey team started to collect information from Yaliciftlik Bay **(10)** which seems the most probable boundary for significant inundation at the eastern end of Southern coastline of Bodrum Peninsula. Any major damage is not reported in the bay and the boats in the dockyard were toppled due to the earthquake effect). Limited inundation was observed along the coast and it is noted by the locals that the sea is not shallow along this coast and the sea slope is steep). No inundation was also observed along the stream. Big holes which can be

seen in Figure 3.9 might have appeared due to liquefaction and/or collapse of the sand material placed on the rubble material. The coordinate measurements and related observations along Yaliciftlik Bay is given in Table 5.2 in Appendix.

Figure 3.9: Big hole appeared at Yaliciftlik Bay after the earthquake (27.527908E 36.992786N)

The survey continued at D-Marin **(1)** at Turgut Reis area which is located at western coast of Bodrum Peninsula. According to the chief of the marina, strong currents were observed along the circulation channels on the breakwater. On the other hand, no run-up is observed or reported. The marina chief states that ±50cm is the normal tide and they did not observe any additional sea level change. The chief also got information from the captains of the yachts moored at Kalimnos Port and Vathi bay. According to indirect information, the water level decreased first just after the earthquake and the boats sat on sea bed at Kalimnos. Currents occurred at Vathi bay 4 hours after the earthquake. Kalimnos Port had major damage due to the earthquake effect.

Fener Beach **(2)** which is located at the corner of western and southern coasts of Bodrum Peninsula is the most probable boundary for significant inundation at the western end of Southern coastline of Bodrum Peninsula according to the information obtained from Olivia Restaurant workers (Figure 3.10). However, information on Meteor Beach which is at the western nearby of Fener Beach shows approximately 40cm water level change. Locals state 2-2.5 m water drawdown at first and then 1-2m inundation. The coordinate measurements and related observations at Fener Beach is given in Table 5.3 in Appendix.

Figure 3.10: Boundary of the tsunami observation at the western end of the Southern Coastline of Bodrum Peninsula according to eyewitnesses (27.264562E 36.964772N**)**

Approximately 10 meters of inundation distance is observed along the coast of Akyarlar Bay **(3).** One of the summerhouse residents observed that the small hole at 10-15m distance from the coast was all washed up by the waves. He stated that the flow depth was about 50cm. The port in this bay is at a safe location by the natural conditions, therefore no damage observed by the waves in the port. According to the fisherman observations in the port, the sea level first decreased and then rising was observed. Also, strong currents were observed at the nose of the breakwater, one of the fishermen said *''it was flowing like stream water at the entrance of the port''.* The dock height was measured as 80cm. The water level rise at the harbor was 120 cm according to the eyewitnesses. (Figure 3.11). Waves affected the part up to Kilavuz Motel if one considers a perpendicular line to the coastline from the head of the breakwater. Furthermore, local people have reported that the sea temperature highly increased in last 2 days before the earthquake in Dogu Beach at Akyarlar Bay. The coordinate measurements and related observations along Akyarlar Bay is given in Table 5.4 in Appendix.

Figure 3.11: Schematic view of wave motion in Akyarlar Bay (27.290930E 36.967359N**)**

The field survey continued at Karaincir, Balmahmut's Place **(4)**. Inundation is reported approximately 60m near Atakan Beach, water drawdown is approximately 20m and the motion was like tidal wave according to the observers. Inundation in the stream bed (width: 2.5m) is around 250m and 150m in the road (width: 6m) (Figure 3.12). The observers state that water level was first decreased and then rised up resulting in a total wave oscillation of +1.5m -1.2m. The incoming wave washed away cars along the road. The visualization of the inundation can be described in Figure 3.13.

Figure 3.12: Maximum inundation distance in Karaincir Bay along the streambed

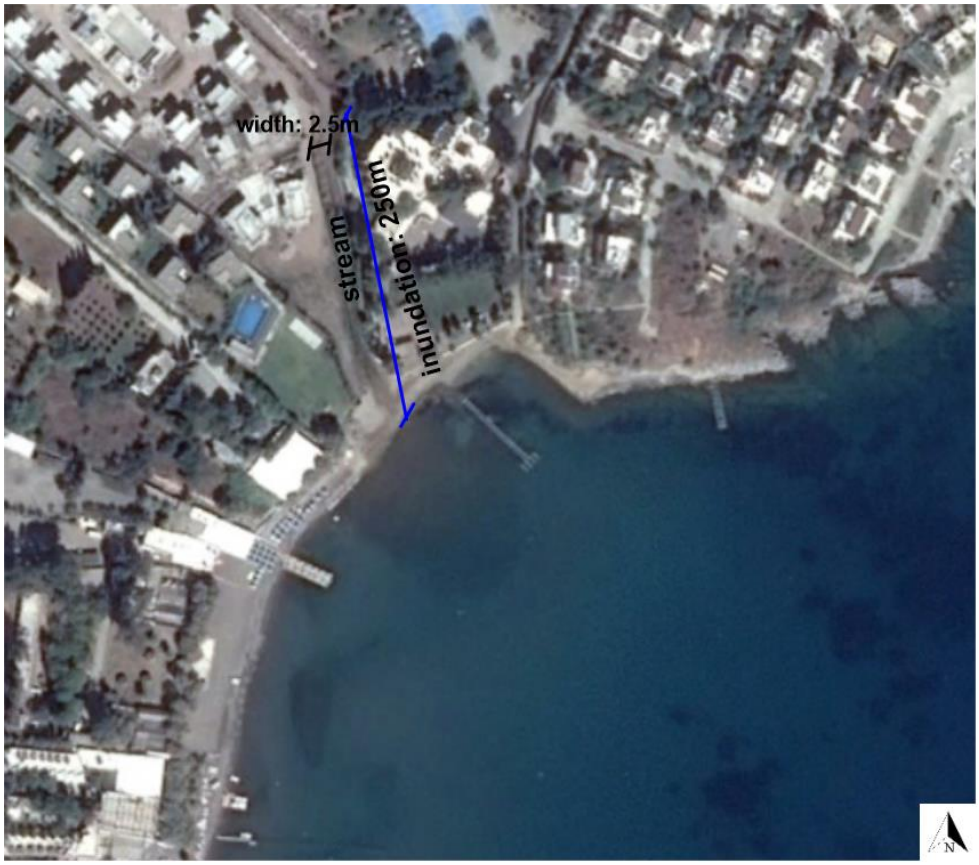


Figure 3.13: Schematic view of the inundation at Karaincir Bay (27.300496E 36.972961N**)**

In Aspat Bay **(5),** the run-up height is reported as 100cm (75cm elevation of stream wall + 25cm overtop) and the inundation distance is observed as approximately 60m. Azmak stream rised up and flooded according to the observers. The pier in the coast is also damaged due to the earthquake effect (Figure 3.14). The coordinate measurements and related observations at Aspat Bay is given in Table 5.5 in Appendix.

Figure 3.14: Damaged Pier in Aspat Bay (27.312356E 36.979592N**)**

Camel Beach in Kargi Bay **(6)** is another affected area after the earthquake and the tsunami. According to the inquired beach and restaurant workers, the first wave came after approximately 10 minutes later than the earthquake and the second wave came at 02:48 (77 minutes after the earthquake). The first motion of the sea was drawdown and then rising. The run-up height is reported as approximately 40-50cm whereas water level decrease is 120cm. The inundation distance is also reported as 7-8 meters.

The field survey ended at Bitez Bay **(7)** of Bodrum where the first motion of the sea is reported as drawdown of 3m, 10-15 minutes after the earthquake. The inundation distance is stated as approximately 10m in the middle of the bay but the eastern part of the bay is more affected by the waves (inundation distance is approximately 30m in this part) due to the location (Figure 3.15). Flow depth is reported as nearly 50cm and no strong current was observed in the bay.

Figure 3.15: Schematic view of wave inundation at Bitez Bay (27.383582E 37.025615N**)**

4. TSUNAMI NUMERICAL MODELING

The nearest tide gauge which is located at 27.420E 37.029N (near Bodrum Marina entrance) recorded the water level change (Figure 4.1)

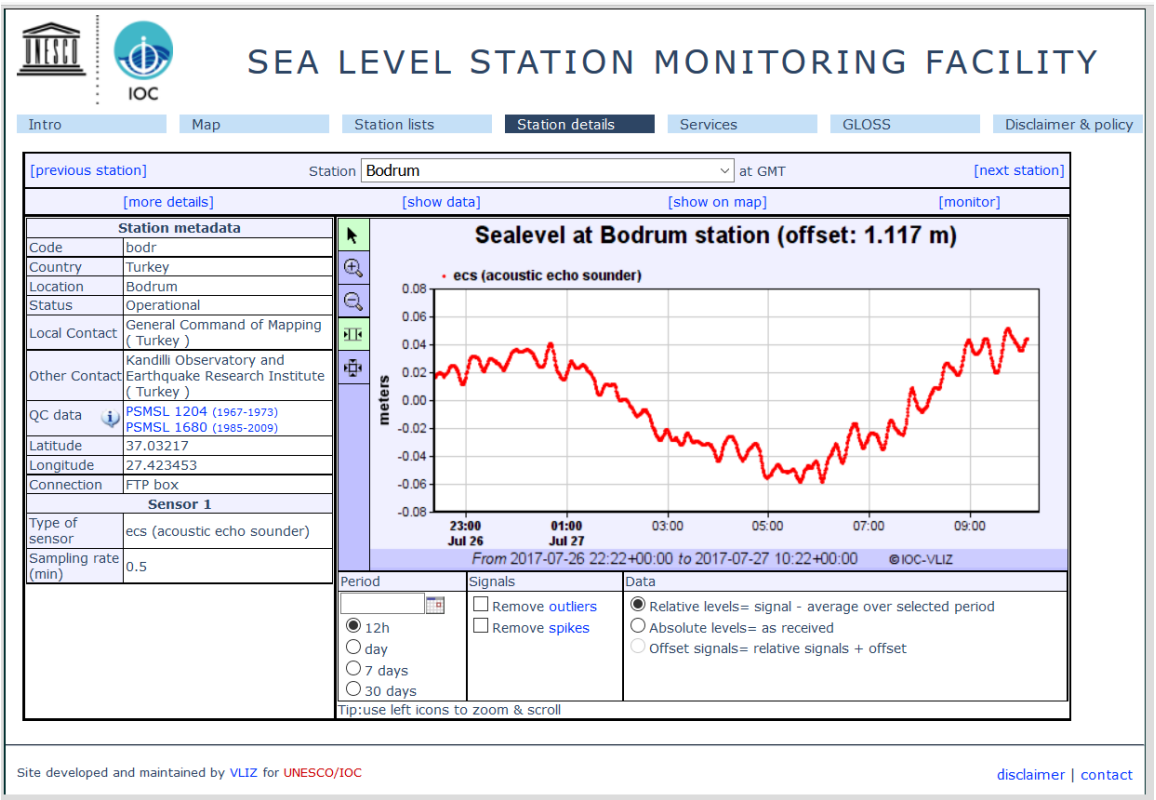


Figure 4.1. Tide gauge record at Bodrum

http://www.ioc-sealevelmonitoring.org/station.php?code=bodr

Tsunami Numerical Model NAMI DANCE is used in modeling of July, 21, 2017. The model solves the Nonlinear Shallow Water Equations (NLSWE) with a bottom friction term using the Leap-Frog numerical scheme (Imamura, 1989; Shuto et al., 1990). The model takes an input tsunami source from either a defined rupture, pre-determined wave form, or time history of water surface fluctuation at a grid boundary and computes propagation, coastal amplification, and inundation (e.g. Ozer Sozdinler et al., 2015, Dilmen et al., 2015, Aytore et al, 2016, Cankaya et al.,2016,). The GPU version of the model is used in this study (Yalciner and Zaytsev, 2017).

The bathymetric data is obtained GEBCO and digitized from Navigational charts. The land elevations are obtained from ASTER (https://gdex.cr.usgs.gov/gdex/). The study domain is selected in the boundaries 27.25E and 27.54E along E-W direction and 36.805012N and 37.037N along S-N direction. The land topography at Gumbet bay has been obtained from Bodrum Municipality. The grid size is 10m (Figure 4.1). The simulation duration is 90 minutes after the earthquake.

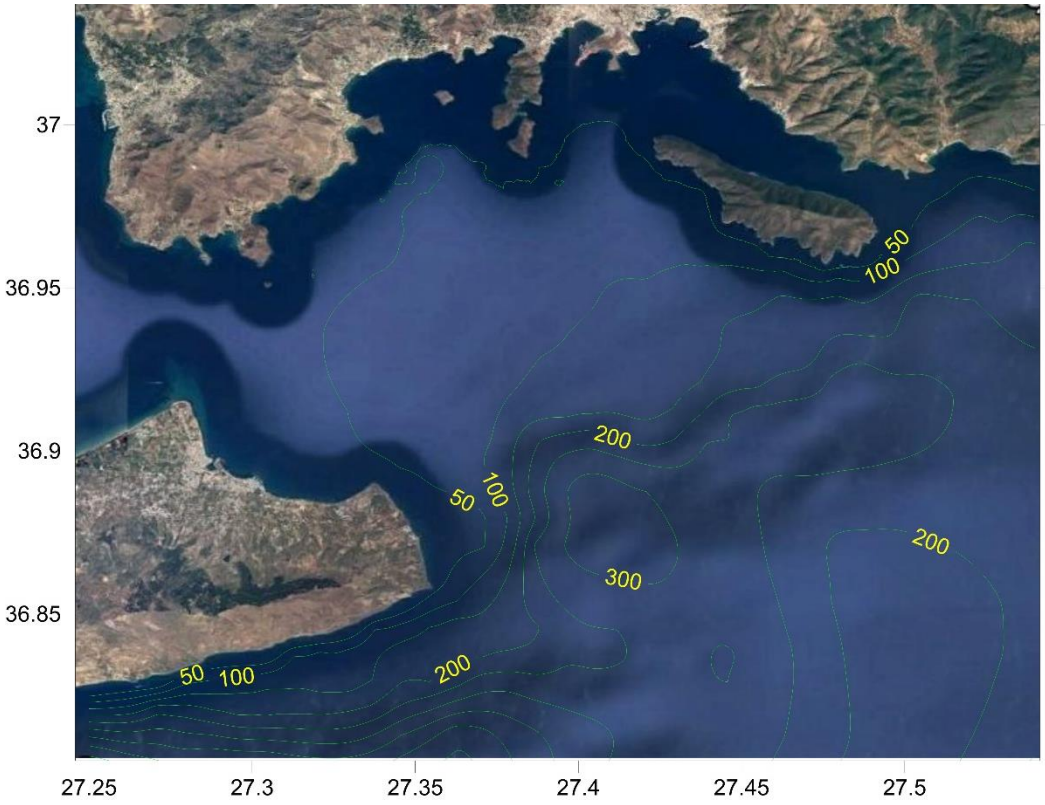


Figure 4.2 The study domain and bathymetry for numerical modeling

According to observations the wave receded almost all coast around the epicenter which indicates the tsunami source was generated by the subsidence of the sea bottom. In the preliminary simulations, two sources are selected for comparisons with the observations.

Source 1: Elliptic Subsidence

Center coordinate 27.423E 36.923N. Length of major axis is 12km and length of minor axis is 6km. The major axis is along he direction 121-degree CW from North. The subsidence is assumed as semi ellipsoid with the 0.4m subsidence along the major axis and zero at the boundaries of the ellipse. The elliptic source and distribution of maximum water elevations after 90-minute simulation are shown in Figure 4.3.

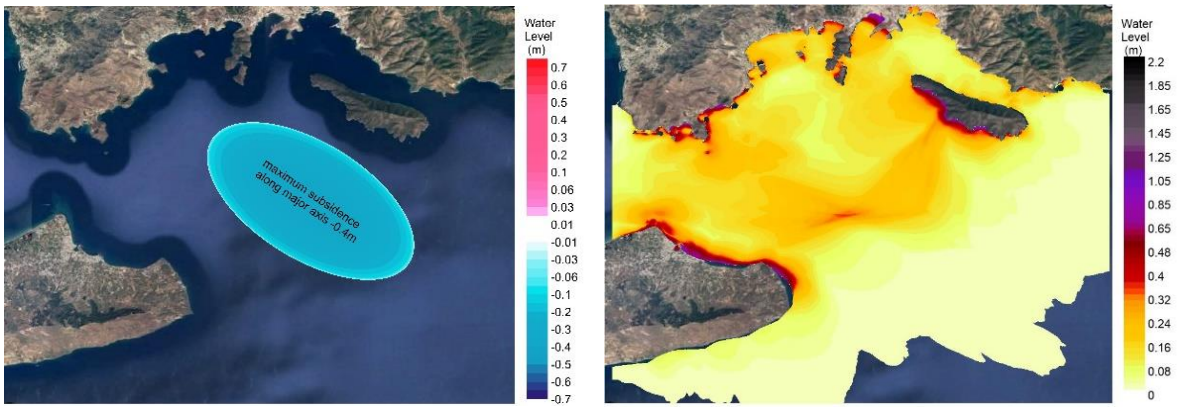


Figure 4.3. Elliptical source and distribution of maximum water wlevations after 90 Minute simulation

Source 2: USGS NP-2

Epicenter 27.415E 36.923N, Length 14km, Width 6km, Strike angle 285 (deg. CW), Focal depth 7km, Dip angle 39 degree, Rake angle -73 degree, Slip displacement 2.2 m. According to Okada solution the maximum subsidence at the sea bottom (water level subsidence) is 0.3827. The source based on seismic data and distribution of maximum water elevations after 90-minute simulation are shown in Figure 4.4.

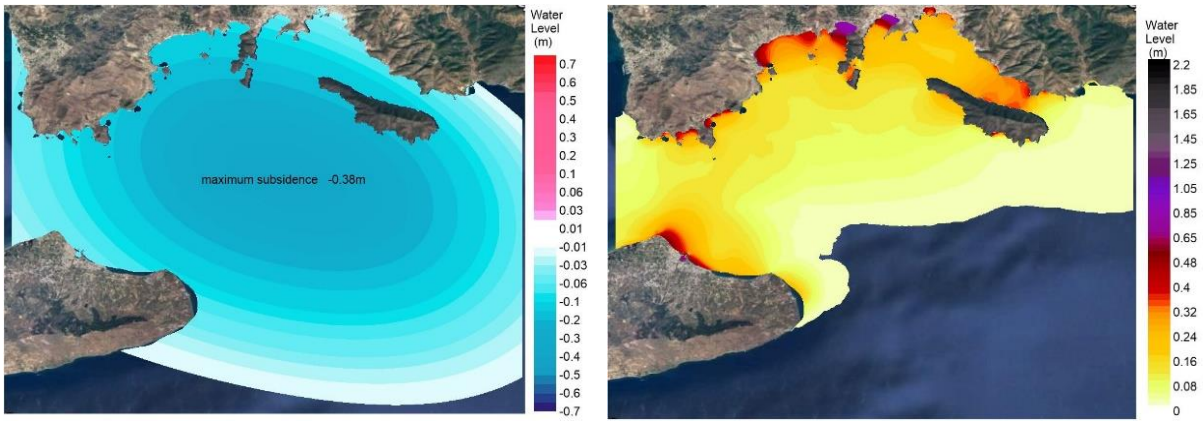
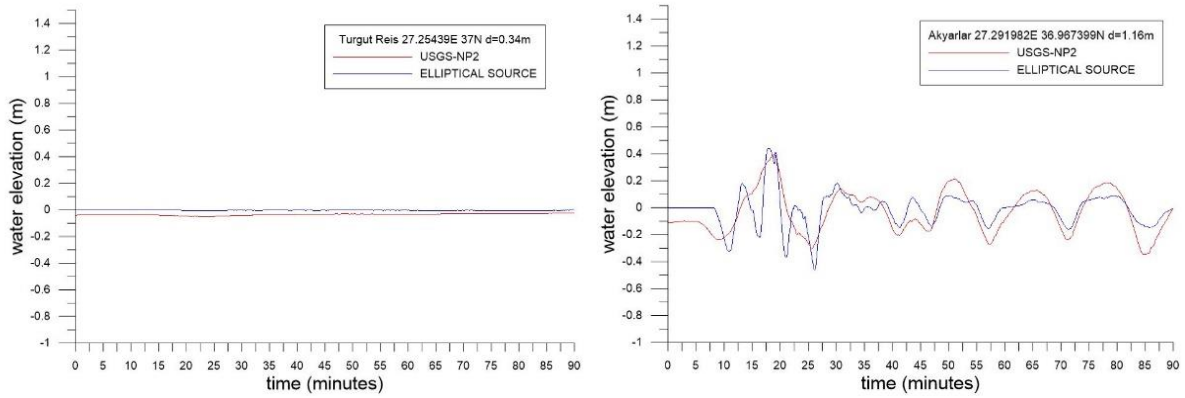


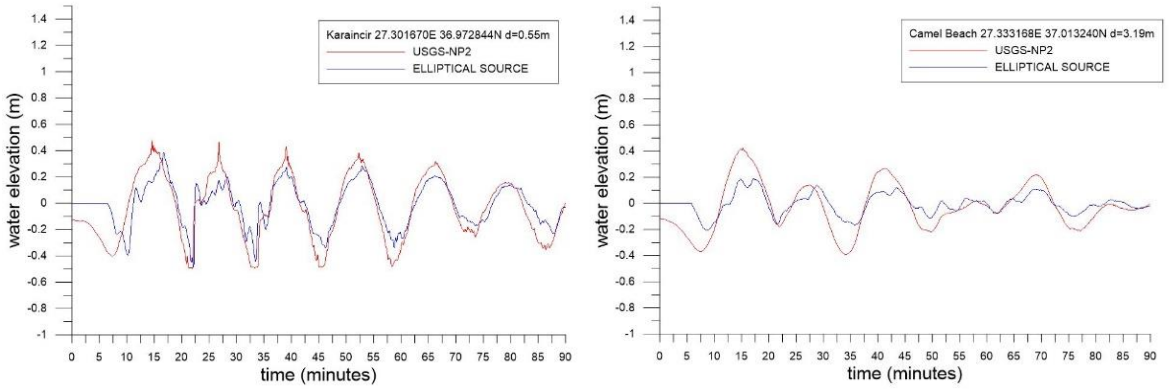
Figure 4.4. Tsunami source computed from USGS data and distribution of maximum water elevations after 90 Minute simulation

(https://earthquake.usgs.gov/earthquakes/eventpage/us20009ynd#executive)

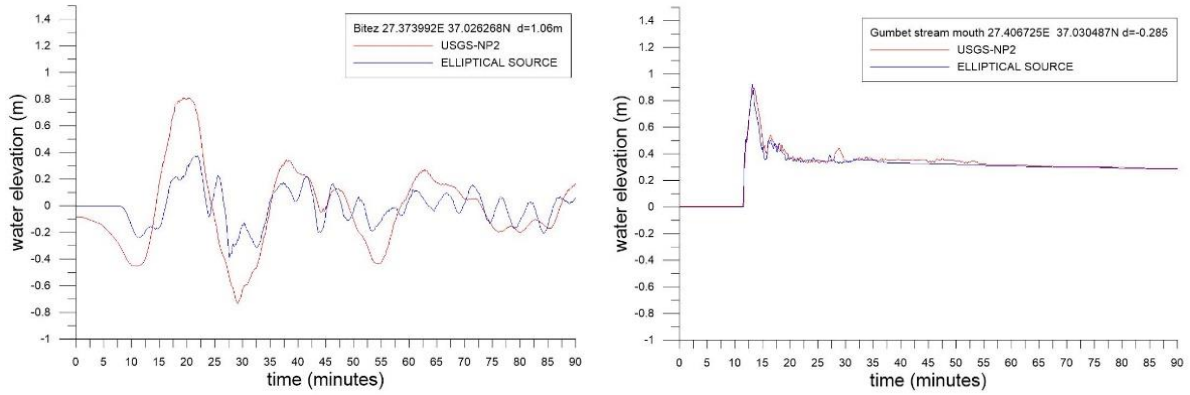
The time histories of water surface elevations at different locations are plotted in the following for the comparison of computed of water elevations with observations.



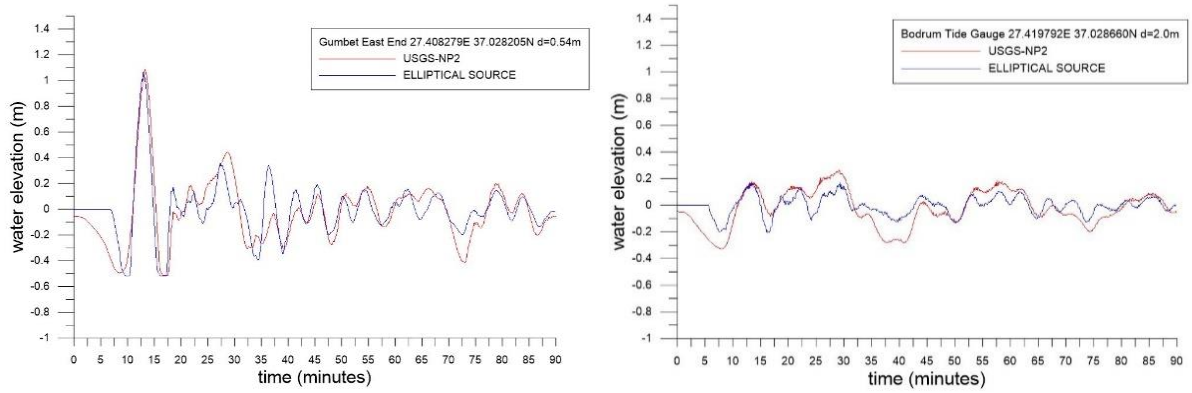
At Turgut Reis marina there is no significant wave motion. At Akyarlar, the maximum elevation fits with the observations.



At Karaincir and Camel beach, the maximum elevation exceeds 0.4m as observed.

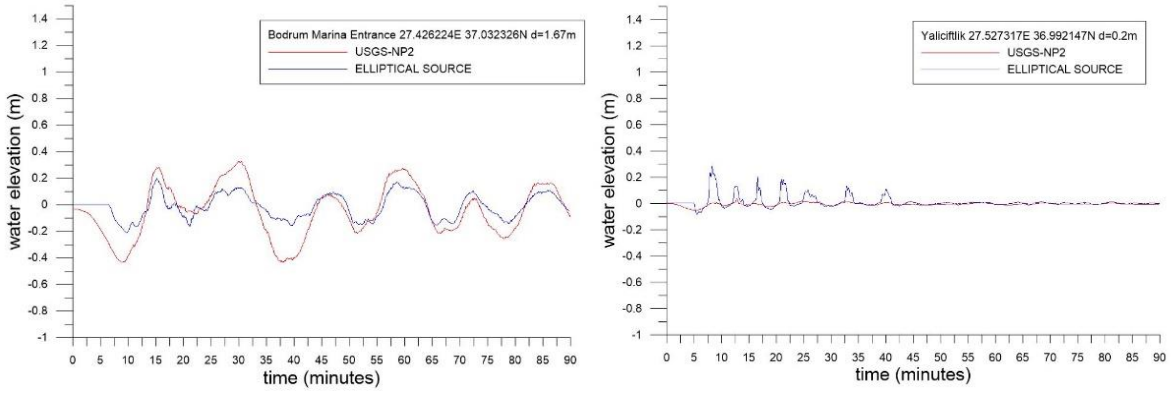


At Bitez bay (west of Gumbet bay) the water elevation reached 80cm. At Gumbet at the dry stream bed (where the cars are dragged), the water elevation reached 1m.

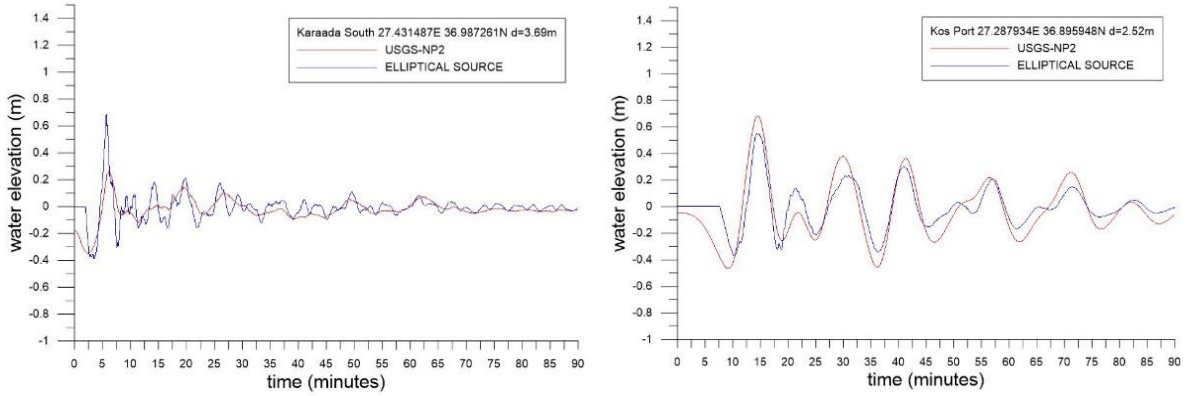


At eastern end of Gumbet bay (where the boats dragged and some of them sunk), the water elevation reached 1.1m. The computed arrival time of initial withdrawal at Gumbet bay fits well with the arrival time extracted from camera recordings (5min). The computed arrival time of advancing wave also fits well with the arrival time extracted from camera recordings (13min)

At the tide gauge, elliptic source cause ± 18cm water level change. Seismic source cause -30cm initial subsidence and +18cm water uplift.



The water level change in Bodrum Marina is in between -40cm and +30cm. It is seen that the wave amplitude at Yaliciftlik (eastern most location) decreases.



At Karaada (nearest coast to source) the maximum elevation reached up to 80cm at the gauge point. The maximum elevation of water in front of Kos port at the gauge point reached 70cm.

5. DISCUSSIONS AND CONCLUSIONS

The 21 July 2017 Gokova earthquake and tsunami was quite a strong event that caused damage to southern coasts of Bodrum Peninsula. Considering the importance of collecting tsunami data in affected coastal areas, it is necessary to perform surveys as soon as possible in order to observe the tsunami traces and deposits before they are altered or removed. A day after the Gokova event, a field survey was organized, and undertaken by a team who were able to survey the area within few days. The team surveyed the southern coasts of Bodrum Peninsula, took some rough measurements and interviewed people obtaining a picture of the phenomenon. Regarding the measurements, the team focused on an estimate of the height reached by the seawater as well as its horizontal inundation. As to the second work, the team tried to understand the time evolution of the event through eyewitnesses. There is a lack of data along some portions of the coast, such as the small peninsula of Bitez Bay and some places on the eastern part of the southern coasts of Bodrum Peninsula due to the fact that there is no settlement in these areas.

Regarding the collected information, Gumbet Bay is the most hit and damaged region of Southern Bodrum Peninsula by the tsunami with more than 1m of flow depth and the inundation distance reached up to 60m at some places. Seawater penetration is much higher wherever any stream beds exist in the bays such as in Karaincir and Gumbet Bays. The observations and eyewitness reports reveal that in Gumbet the maximum inundation distance reaches up to 280m. According to

the preliminary elevation measurements performed by topographical engineering division of Bodrum Municipality, the maximum runup was determined as 1.7m in Gumbet Bay. Furthermore, Fener Beach seems the most probable boundary for significant inundation at the western end of Southern coastline of Bodrum Peninsula whereas Yaliciftlik Bay is the most probable boundary at the eastern end.

6. ACKNOWLEDGEMENTS

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8. APPENDIX

Table 5.1: Coordinate Measurements at Gumbet Bay:

#	Coordinates	Accuracy of the GPS Signal (m)	Note
1	37.030487N 27.406725E	5	Cars drifted in the stream bed. Coordinate of the car park.
2	37.031137N 27.406882E	5	Cars drifted from Point 1 to this location.
3	37.031412N 27.406703E	5	Flow depth reached 85 cm at this point.
4	37.032087N 27.406866E	10	Flow depth 85 cm in front of the car (Brand: Fiat – Kartal in the photos)
5	37.032310N 27.406834E	5	Flow depth reached 98 cm in front of the headwall.
6	37.032802N 27.406801E	5	Maximum inundation distance (mandarin in the photo taken at the taxi station)
7	37.032466N 27.406865E	5	- Flow depth reached 1.1 m near the sides of the headwall. - For scaling, height of the side of the headwall: 1.05m (at the right hand side, concrete wall in the photo)
8	37.031579N 27.404888E	5	Maximum inundation distance along the road near Sami Hotel (White BMW)
9	37.027047N 27.407369E	5	Damaged yachts in the Gumbet Bay
10	37.031424N 27.399539E	5	Maximum inundation distance is about 25 m.

Table 5.2: Coordinate Measurements at Yaliciftlik Bay:

#	Coordinates	Accuracy of the GPS Signal (m)	Note
1	36.992786N 27.527908E	5	Location of one of the holes in Yalıçiftlik
2	36.991411N 27.532678E	5	Most probably boundary for significant inundation at the eastern end of Southern coastline of Bodrum Peninsula.

Table 5.3: Coordinate Measurements at Fener Beach:

#	Coordinates	Accuracy of the GPS Signal (m)	Note
1	36.964772N 27.264562E	5	Most probably boundary for significant inundation at the western end of Southern coastline of Bodrum Peninsula.

Table 5.4: Coordinate Measurements at Akyarlar Bay:

#	Coordinates	Accuracy of the GPS Signal (m)	Note
1	36.967359N 27.290930E	5	Maximum inundation along the bay is near here.

Table 5.5: Coordinate Measurements at Aspat Bay:

#	Coordinates	Accuracy of the GPS Signal (m)	Note
1	36.979592N 27.312356E	5	- Maximum inundation from the stream in Aspat Bay. - Maximum inundation from the sea is at 50 m South of this point