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BYTNet AND DATNet: TWO RECENT STRONG MOTION ARRAYS IN WESTERN TURKEY

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SUMMARY

Two strong motion arrays comprising 22 stations have been installed in the west of Turkey under the NATO Science Program. This paper describes the justification and sites of the arrays and presents samples of records recovered from them.

INTRODUCTION

The NATO Science Program funded project described in this paper has been motivated by the inadequate patchwork of isolated strong ground motion records were recovered during the two major earthquakes in Turkey in 1999. The two major events that occurred in the Sea of Marmara region in Turkey during 1999 rank among the largest earthquakes to have occurred in the eastern Mediterranean Basin during the last 100 years. In terms of their visible effects (such as ground deformation patterns, widespread damage and economic losses) these earthquakes established new thresholds. The first one with M_w7.4 struck on August 17, 1999, and the second M_w7.2 on November 12, 1999, and yet the number and quality of strong motion records recovered from the main shocks might have been much better if there had been properly deployed arrays in the region. With instruments located usually inside institutional buildings there was contamination of the ground acceleration traces caused by the buildings. The instruments were mostly stand-alone devices, a combination of analog and digital types, and were triggered independently, making it difficult to study wave propagation effects.

Earthquakes with magnitude larger than 7 occur at intervals typically measurable in several hundred years even in high seismicity areas, so missing proper recording of the ground motions they produce represents loss of much valuable and irreplaceable scientific data. High density strong motion networks are justified because when effects of this seldom occurrence are recorded, they provide much valuable insight as to what to expect in the future in terms of the damaging power of similar motions.

The national strong ground motion network in Turkey is owned and operated by the General Directorate of Disaster Affairs, which is part of the Ministry of Public Works and Settlement. The system has been initiated in 1973, but currently it stands only at the very modest total of 140 instruments (this number includes instruments acquired through this project) about evenly divided between analog and

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digital types. Concerns over safety and ease of access, maintenance and phone link-up have been the reasons for locating them inside government buildings. A small number of professionals within GDDA is charged with the duty of operating the system.

The application to obtain funding from the NATO Science Program for the establishment of two separate arrays comprising twenty instruments in two tectonically different regions in western Turkey was made in the Fall of 2000. Currently, both of these arrays have been successfully launched, and are operational. The paper describes the tectonic environment for the arrays, agreed principles of operation, and presents samples of ground motions already recorded by sensors in them.

DESCRIPTION OF THE ARRAY SITES

Geology and Tectonics of the Array Sites

BYTNet

BYTNet is a roughly linear network that is 60 km long between Yalova and Bursa. Based on the hypothesis that the twentieth century westward migration of earthquake epicenters along the North Anatolian Fault (NAF) will continue, the probability of the western extension of the segment that ruptured during the August 17, 1999 earthquake to rupture further is an astounding 62 percent for the next 30 years [1]. The bulk of the transform movement along NAF occurs in the northern strand [2], but the two southern strands of NAF are also potentially capable of nucleating destructive earthquakes. The following description has been excerpted from Barka [3].

The North Anatolian fault separates into two main strands west of Bolu (Figure 1). The southern strand passes from the southern shore of İznik Lake and extends towards Gemlik. Further west, it is composed of several parallel segments dominated by either strike-slip or normal movement. While the southern section of these parallel lines continues to the Aegean Sea passing from Edremit Bay, the northern section passes from Bayramiç and reaches the Aegean Sea. The large seismic events that took place in the last two centuries associated with the southern and western strand of the North Anatolian Fault are:

> 28 February 1855 and 11 April 1855 (both with Intensity IX), causing damage in and near the city of Bursa
>
> 6 October 1964, M = 6.6, rupturing the segment between M. Kemal Paşa and Manyas
>
> 18 March 1953, M = 7.2, associated with the Yenice-Gönen segments

The northern half of the Marmara is characterized by pull-apart basins (active grabens) about 1,200 m deep, bounded by E-W trending normal faults and separated by NE-SW trending strike-slip faults (ridges). These form basically the eastern, central and western basins, shown as A, B and C in Figure 1. Microseismic activity and frequent moderate to large earthquakes with $M < 7$ are mostly associated with the pull-apart basins. The strike-slip segments have the capacity to produce less frequent but $M > 7$ earthquakes, Barka [4].

The first array site comprising 14 instruments has been designated as BYTNet (meaning <u>B</u>ursa-<u>Y</u>alova, <u>T</u>urkey <u>net</u>work) for easy reference. It is shown in Figure 1.

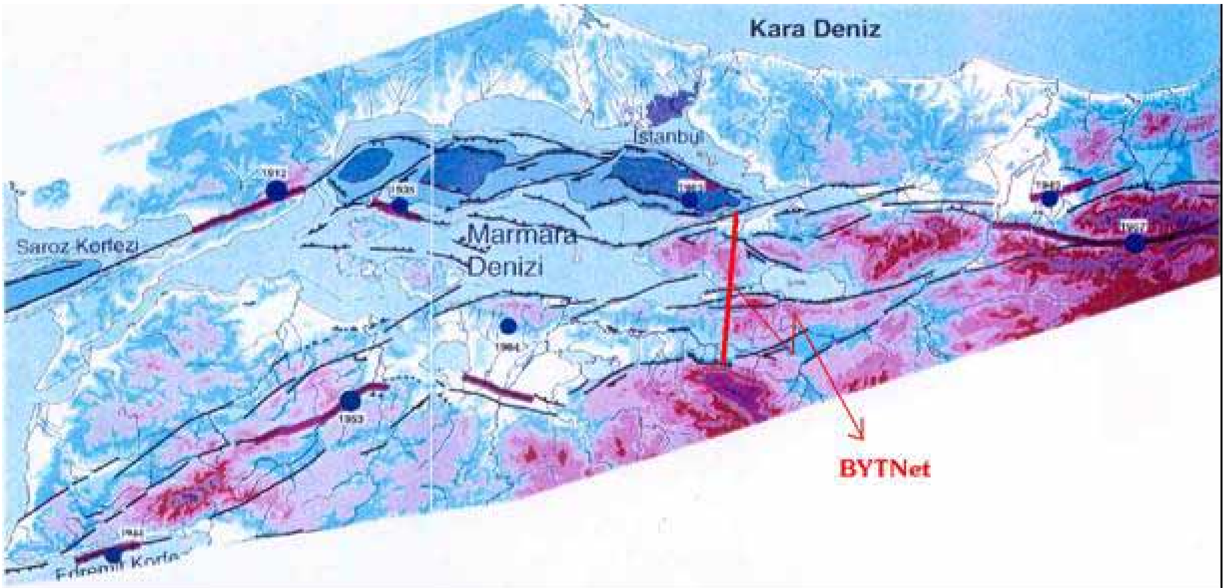

Figure 1. BYTNet Location

DATNet

The second array is situated along the Menderes river graben in the Aegean region of western Turkey. The Aegean Region is one of the most rapidly moving and seismically active parts of the Alpine-Himalayan Mountain Belt. Based on global positioning measurements, McClusky and others [5] show that east of 20ºE the motion between Africa and Eurasia does not result from one-plate boundary, but it is confused by the rapid motion of two small plates, the Aegean and Turkish (Anatolian) plates. The Aegean plate is bounded at the north by the southwestern extension of the North Anatolian Fault. The southern boundary of the Aegean plate passes through the Hellenic Trench, south of Crete and Rhodes. The northeastern boundary of the Aegean plate is a diffuse boundary located in the region of extensional faulting in western Anatolia, in the vicinity of the Buyuk, Menderes, and Gediz grabens. In this boundary region, the net motion between the Aegean and Anatolian plates is 10-15 mm/yr extension. This provides a very satisfactory explanation for the larger number of earthquakes near the Aegean coast of Turkey, and for the focal mechanisms of shocks in southwestern Turkey and the eastern Aegean. The general features of the gps measurements in the Aegean region are shown in Figure 2. The sharp change in direction and magnitude of the slip that occurs in southwest Anatolia, from west to southwest, is evidence for the plate boundary that runs through that region.

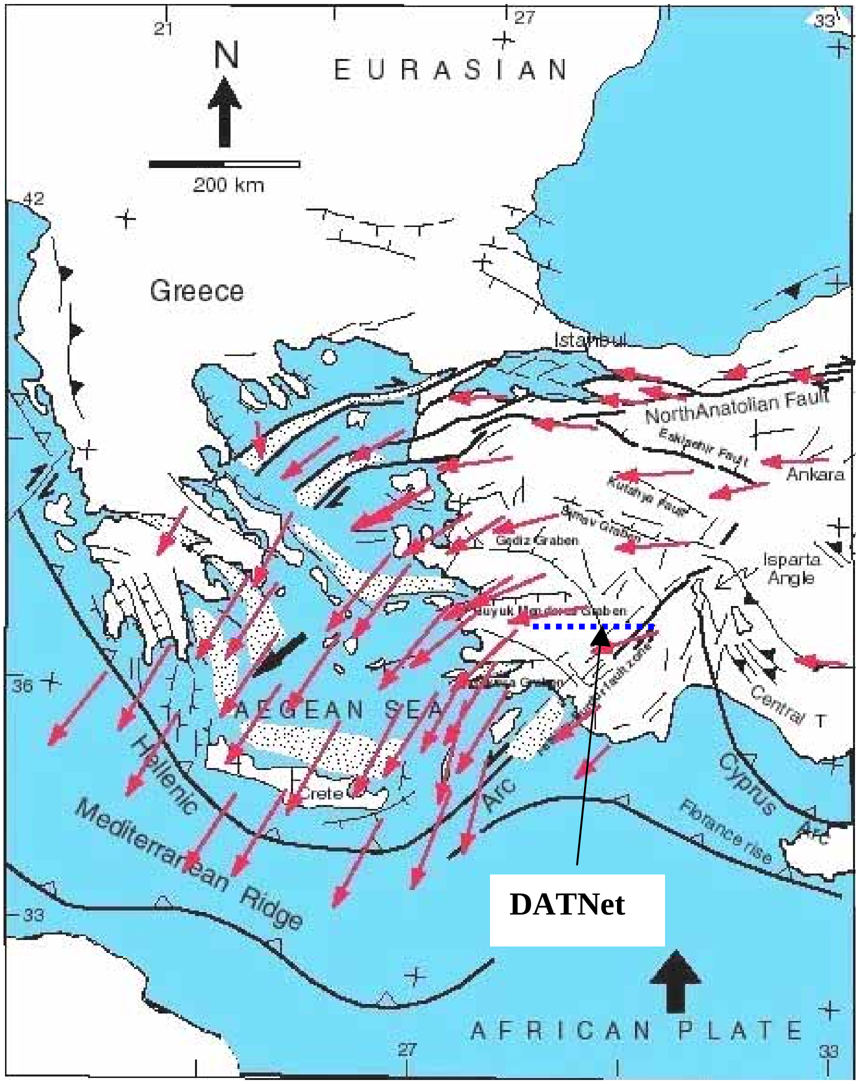

Figure 2. Tectonics of the Aegean region. Lengths and directions of arrows in red indicate the slip rate relative to Eurasia. The location of DATNet is shown. Adapted from [6].

The main deformation between the Aegean and Anatolian plates is observed along E-W and WNW-ESE trending grabens and normal faults of western Anatolia. Investigations have shown that, numerous graben systems have been forming in the E-W and WNW-ESE directions due to the N-S substantial extension in Western Anatolia. Gökova, Büyük Menderes, Küçük Menderes, Gediz, Bakırçay, Kütahya, Eskişehir and Simav Grabens constitute the main tectonic structure of the region together with Fethiye-Burdur, Tuzla and Bergama-Foça fault zones that are trending in NE–SW directions. A number of major normal faulting events have occurred along these faults. NW to SE striking normal fault systems mostly occur the in southwestern Aegean such as Pamukkale, Dinar and Yatağan-Muğla faults. The overall extension rate for the source zones in Western Anatolia is about 10-15 mm/yr, where most deformations are the result of the activity of the Menderes and Gediz Grabens. Thus these are very active fault zones, and are uniquely important locations to be instrumented to record ground motions from earthquakes with normal faulting mechanisms.

Our second array (DATNet) is situated along the 120 km long section between the cities of Denizli and Aydın. It consists of 6 newly established stations that have been incorporated with two that existed as part of the national system operated by the General Directorate of Disaster Affairs.

Site Characterization

Engineers and seismologists must know the local soil conditions at seismograph stations because these have an important influence on many of the characteristics of the motions that are recorded with the instruments in these stations. During destructive earthquakes buildings and other facilities experience strong ground motions that are closely linked to the local soil conditions. A major drawback in the interpretation of records from the existing national strong motion network in Turkey is that this information is not available. To overcome this deficiency we contracted the task site investigations at each station site of the two arrays to qualified soils firms according to terms of reference decided by

METU. The fourteen stations comprising BYTNet are shown in the map in Figure 3. Table 1 lists the names and coordinates of these stations.

Description of the site characterization for the stations has been accomplished through data obtained from geophysical surveys and geotechnical tests. The former group has yielded the P and S wave velocities at the sites (generally to a depth of at least 30 m, unless rock formations were encountered at shallower depths). Laboratory tests within the second group have established soil unit weight, depth to the water table, shear strength and soil classification. A sample is shown in Figure 4.

Figure 3. BYTNet stations. Red lines are the northern and Gemlik strands of North Anatolian Fault. Gulf of Izmit lies in the upper part of the picture, and the oval body of water is the Lake of Iznik.

Table 1. BYTNet stations

Sta. Code	Lat. N	Long. E	Station Location
BYT01	40.18249	29.12966	General Directorate of Rural Services 17th Regional Office
BYT02	40.28599	29.07522	Bursa Emergency Management Center
BYT03	40.27360	29.09611	Demirtas Town. Kirantepe
BYT04	40.36322	29.12221	Kurtul Village. Garden of the Mosque
BYT05	40.39431	29.09811	Gemlik Military Veterinary Training Command
BYT06	40.41039	29.17993	Umurbey Town. Celal Bayar Medical High School
BYT07	40.42510	29.16659	Gemlik Industrial Crafts Vocational School
BYT08	40.42223	29.29090	Cargill Agricultural Industries Factory
BYT09	40.44975	29.25869	Gedelek Medical Services Building
BYT10	40.49440	29.29976	Orhangazi Basic Education School
BYT11	40.56413	29.30600	Dogus Meat and Milk Company, Sugören
BYT12	40.59648	29.27140	Sogucak Post Office
BYT13	40.65069	29.27900	Yalova Nursing Home
BYT14	40.65753	29.24722	Yalova Agriculture Station

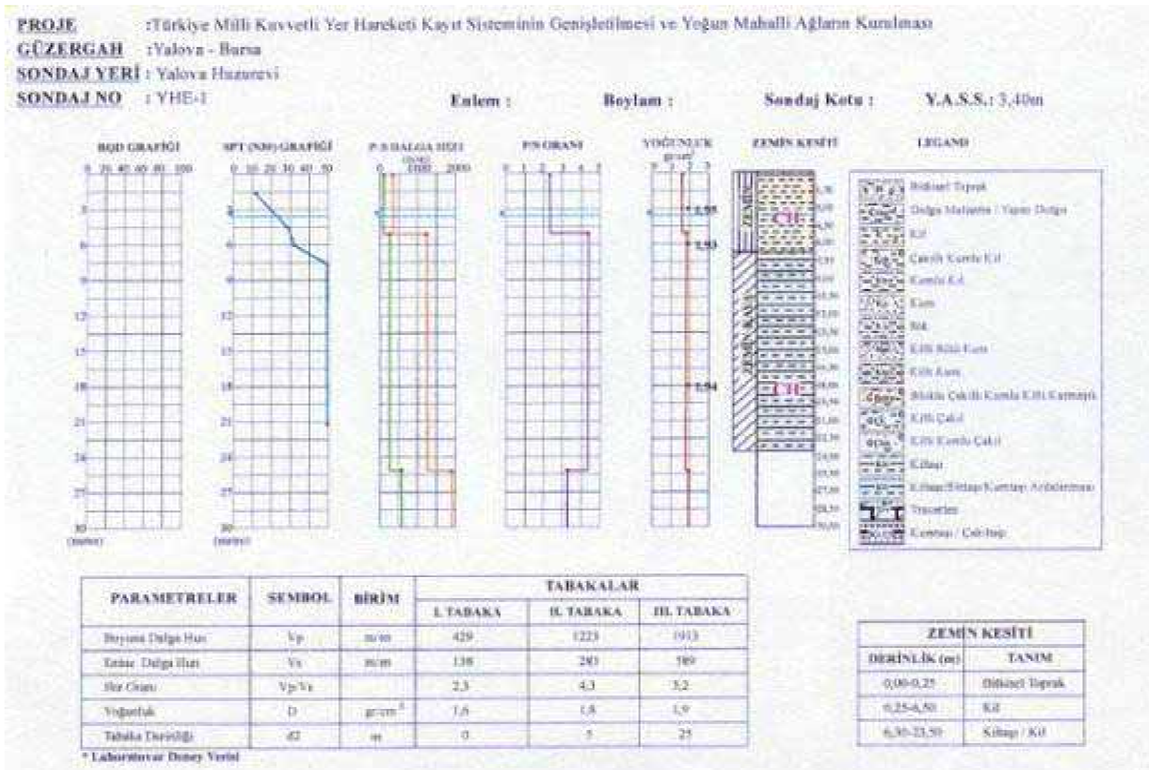

Figure 4. Local Soils Information for Station BYT13

The choice of the Menderes river valley as the sites of the stations comprising DATNet has been motivated by the desire to record future earthquake ground motions from a tectonically different seismic environment. In contrast to BYTNet where horizontal movements in the right-lateral sense occur during earthquakes, ground deformations in the Aegean region of Turkey have significant vertical components because the causative faults are of the normal type. The stations in DATNet are shown in the map in Figure 5. In additions to the 6 instruments that have been emplaced along the route from Denizli to Aydın, the two instruments that were already located in those cities combine to form an eight-instrument array. The names and coordinates of stations in this array are listed in Table 2.

Station Description

Recording stations in both arrays are the small masonry huts with concrete roof slab constructed according to the plans shown in Figure 6. The masonry huts were designed as stand-alone containers for the instruments, and checked for their structural integrity during earthquakes compatible with their location. Care has been exercised to locate each hut at a distance at least equal to the height of the nearest adjacent building. A typical station is shown in Figure 7.

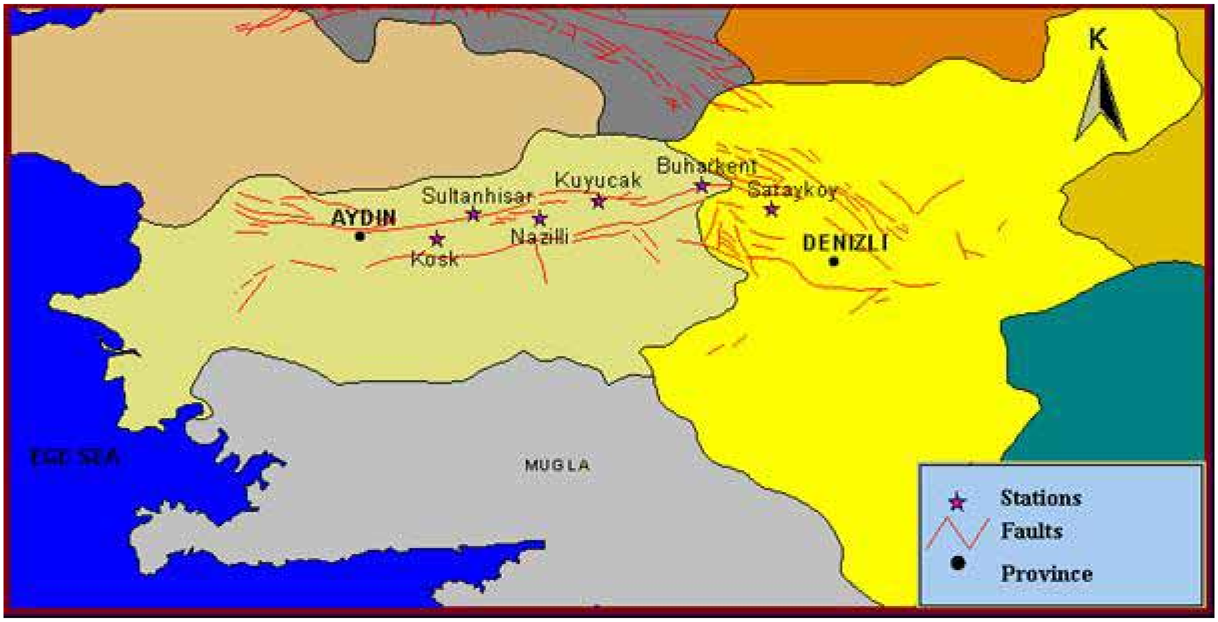

Figure 5. DATNet stations

Table 2. DATNet Stations

Sta. Code	Lat. N	Long. E	Station Location
DNZ*	37.8123	29.1142	Denizli, Provincial Branch of MPWS
DAT01	37.9325	28.9229	Denizli, Sarayköy Geothermal Energy Development Works Staff Housing
DAT02	37,9738.	28.7463	Buharkent Electric Power Distribution Station
DAT03	37.9116	28.4655	Kuyucak Local Health Clinic
DAT04	37.9132	28.3431	Nazilli Meteorological Observation Station
DAT05	37.8841	28.1506	Sultanhisar Meteorological Observation Station
DAT06	37.8572	28.0502	Köşk Local Health Clinic
AYD*	37.8371	27.8384	Aydın Livestock Hospital Facility

* These two national network stations existed before installation as part of DATNet.

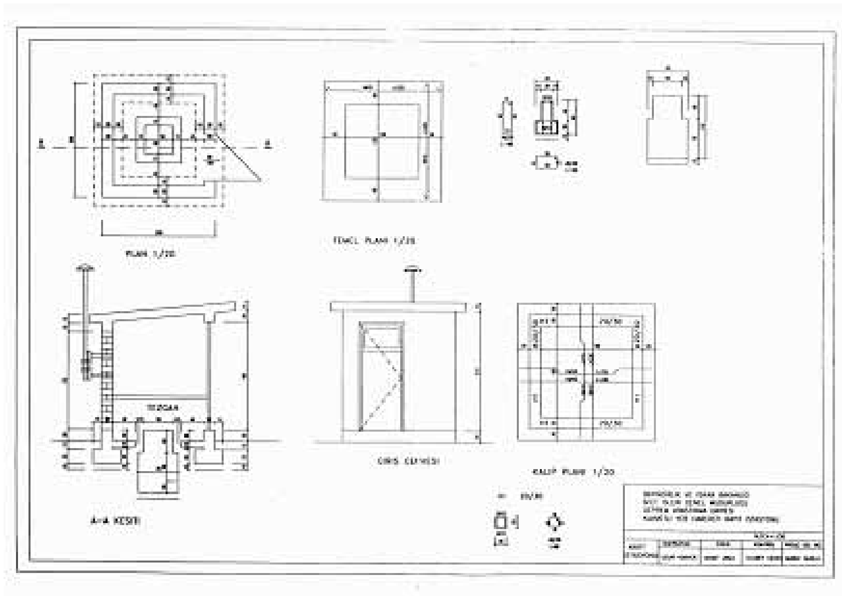

Figure 6. Station plans

Figure 7. DATNet station in Nazilli

All 20 stations in the two arrays have been built by GDDA through contracts awarded to local builders. GDDA has also let out the contracts for the soils investigations at each station site, and provided all of them with telephone connections for regular or as-needed interrogation from Ankara. All instruments are Kinemetrics Etna devices.

PERFORMANCE

As of 2004 the systems have been operational for about two years, and already recordings from small magnitude regional earthquakes have been made. To date some 100 records have been made, but most of these are of low engineering relevance. Figures 8 and 9 display epicenters of events that triggered at least one station in BYTNet and DATNet, respectively. These figures show that DATNet environment has experienced greater seismicity, and indeed the earthquake that shook the town of Buldan, Denizli, on July 23, 2003 has yielded the largest acceleration in our data set to date. This event even triggered one BYTNet station. A subset of selected events that were recorded by either array is reproduced in Table 3.

Among objectives of the project the derivation of more reliable attenuation relations applicable to different regions in Turkey and updating the seismic hazard map for the country were defined as goals whose achievement will likely extend beyond the formal end of this project. The free dissemination of seismograms through the Internet will enable both domestic and international researchers to interpret and utilize those results for their specific needs. The records are currently being made available to the research community worldwide from www.dmc.metu.edu.tr.

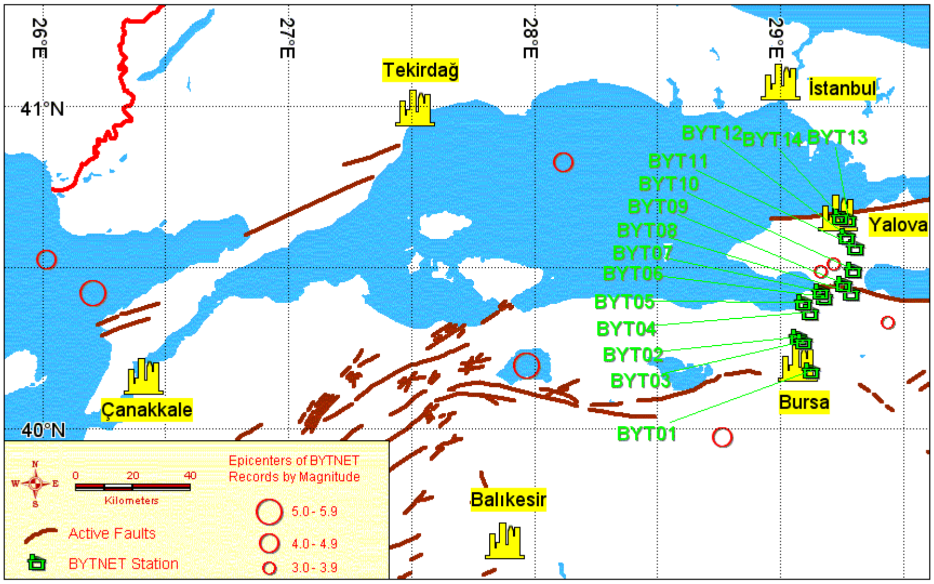

Figure 8. Seismic events in the vicinity of BYTNet

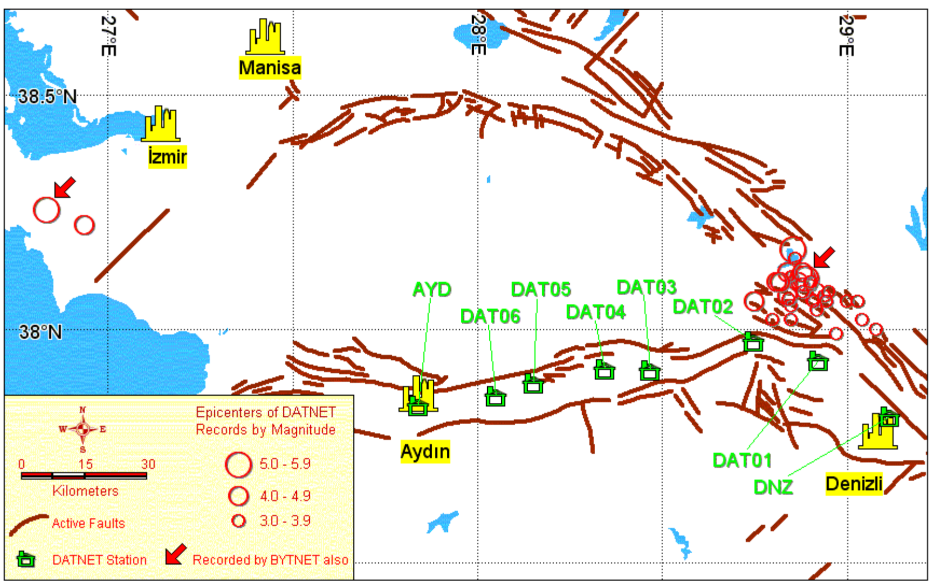

Figure 9. Seismic events in the vicinity of DATNet

Table 3. Selected Earthquakes from BYTNet and DATNet

				Epicentral Coordinates					
Station No:	Event No:	Date	Mw	N	E	Depth (km)	R(km)	Comp.	PGA (mG)
BYT-05	4	04.10.2003	6.0	38.2568	26.8345	15.8	307.19	L	2.8934
								T	2.7156
								V	1.1199
DAT-01	4	04.10.2003	6.0	38.2568	26.8345	15.8	186.29	L	4.7157
								T	4.5812
								V	1.7655
DAT-05	4	04.10.2003	6.0	38.2568	26.8345	15.8	122.47	L	8.4352
								T	7.3001
								V	2.8944
DAT-06	4	04.10.2003	6.0	38.2568	26.8345	15.8	115.33	L	7.7417
								T	5.8208
								V	3.1321
BYT-02	4	04.10.2003	6.0	38.2568	26.8345	15.8	296.81	L	3.1335
								T	2.6462
								V	1.7569
BYT-06	4	04.10.2003	6.0	38.2568	26.8345	15.8	313.05	L	1.0386
								T	0.9494
								V	0.4182
BYT-07	4	04.10.2003	6.0	38.2568	26.8345	15.8	313.6	L	2.7854
								T	3.3019
								V	1.4701
BYT-08	4	04.10.2003	6.0	38.2568	26.8345	15.8	320.27	L	1.3468
								T	1.5621
								V	0.9596
DAT-4	4	04.10.2003	6.0	38.2568	26.8345	15.8	137.45	L	10.9913
								T	6.6428
								V	3.0987
DAT-01	11	23.07.2003	5.2	38.1718	28.8533	5	27.35	L	90.1585
								T	123.2295
								V	60.6828
DAT-03	11	23.07.2003	5.2	38.1718	28.8533	5	44.62	L	21.7283
								T	19.9022
								V	13.1054
DAT-04	11	23.07.2003	5.2	38.1718	28.8533	5	53.15	L	23.0677
								T	25.9445
								V	11.8649
DAT-06	11	23.07.2003	5.2	38.1718	28.8533	5	78.6	L	7.695
								T	8.3406
								V	6.0432
DNZ	11	23.07.2003	5.2	38.1718	28.8533	5	45.97	L	22.1863
								T	45.8374
								V	19.989
DAT-01	17	26.07.2003	5.0	38.12	28.84	5	22.13	L	47.5435
								T	34.462
								V	36.2482
DAT-03	17	26.07.2003	5.0	38.11	28.88	5	40.18	L	10.5331
								T	11.224
								V	5.6031
DAT-04	17	26.07.2003	5.0	38.11	28.88	5	49.25	L	10.2267
								T	16.8304
								V	6.8045
DAT-06	17	26.07.2003	5.0	38.11	28.88	5	75.16	L	3.042
								T	3.3522
								V	2.7874
DAT-01	20	26.07.2003	5.6	38.11	28.89	4.3	21.1	L	107.506
								T	121.1164
								V	153.9724
DAT-03	20	26.07.2003	5.6	38.11	28.89	4.3	43.83	L	26.2926
								T	19.9361
								V	11.5104
DAT-04	20	26.07.2003	5.6	38.11	28.89	4.3	53.16	L	26.9711
								T	27.158
								V	13.588
DAT-06	20	26.07.2003	5.6	38.11	28.89	4.3	79.21	L	10.4511
								T	8.4844
								V	8.1096
BYT-07	20	26.07.2003	5.6	38.11	28.89	4.3	257.41	L	1.2851
								T	1.3442
								V	0.4871

The 5.2-magnitude earthquake near Buldan, a district center 44 from Denizli on July 23, 2003 caused damage in that township, with cracked walls in many masonry houses. The closest station to the epicenter is DAT02, but its sensor had been recently struck by lightning, and was inoperative when Event No. 11 occurred. We show the seismograms from DAT01, DNZ, DAT03, DAT04 and DAT06 in Figure 10 with the trigger times at a common origin.

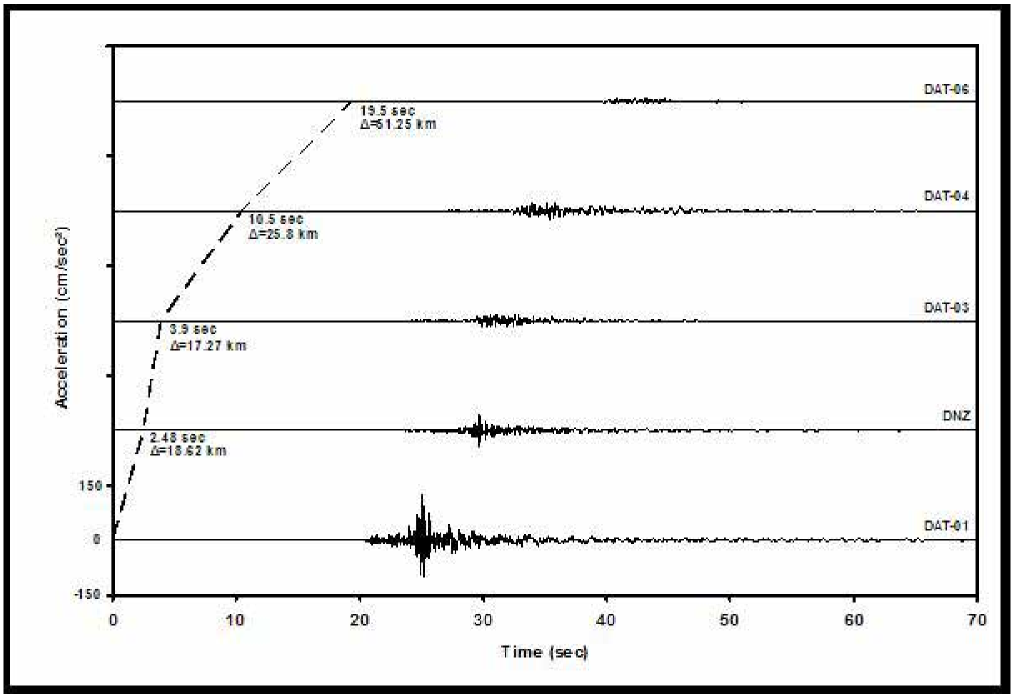

Figure 10. Buldan earthquake records of July 23, 2003. The component shown is E-W

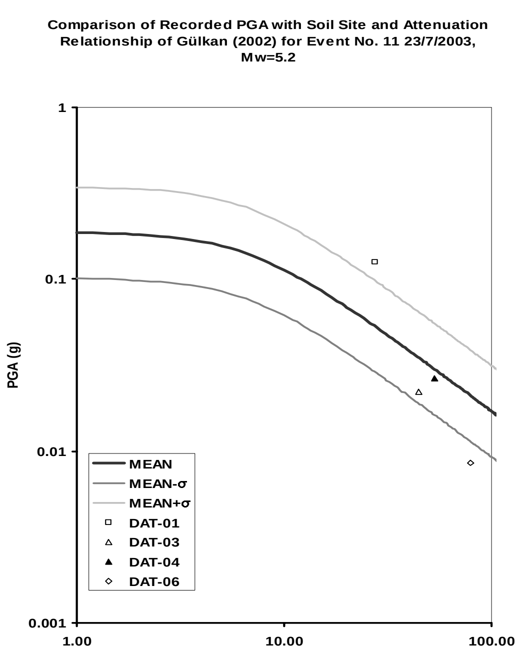

Figure 11. Attenuation prediction for Event 11 from Table 3

The comparison of recorded peak accelerations with the attenuation curves developed by Gülkan [7] for these four stations is described in Figure 11. Each station has been characterized by the code that conforms to NEHRP site description that was then transcribed to the format required in [7].

Buldan and its vicinity were shaken at close intervals during July, 2003. The intensity of the event that occurred at 08:36 on July 26 (Event 20) surpassed that of Event 11, and was even recorded by one of the BYTNet stations. In Figures 12 and 13 we show the acceleration and displacement response spectra for the N-S component of the motion recorded at DAT01.

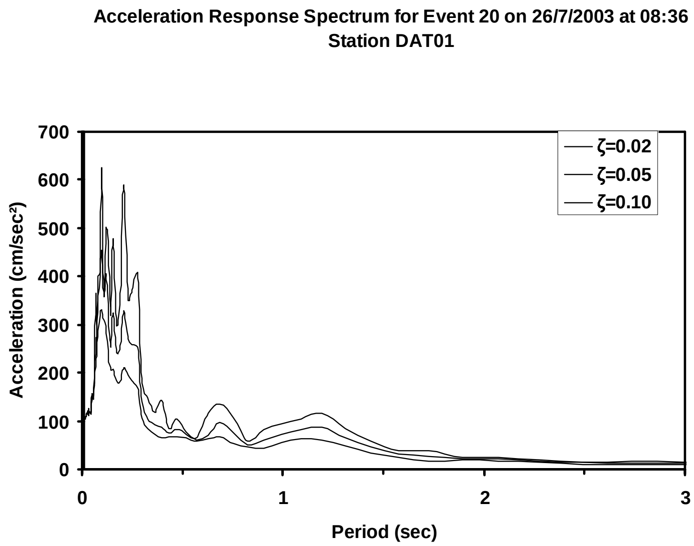

Figure 12. Spectral acceleration for the N-S direction at DAT01, event 20

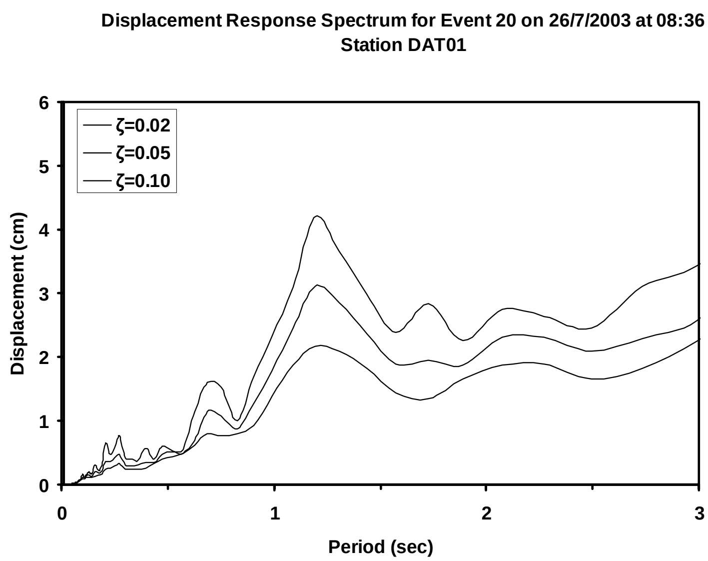

Figure 13. Spectral displacement for the N-S direction at DAT01, event 20

CONCLUSIONS

The two arrays described in this paper hold much promise for Turkey's research and implementation in the area of strong motion seismology. The country's national strong motion network is operated by the General Directorate of Disaster Affairs, and consists of about 150 accelerographs. The long-sought goal of increasing the total number of accelerograph stations in the country to one thousand has not been reached. Most instruments are located in major population centers in the seismically active areas. The sites for the sensors have been selected by engineers with a view toward ease of random access for the older generation of instruments and their safety. The stations of the national network are therefore generally in the basements of public buildings not taller than three stories. Site characterization for these locations has not been made except on the basis of fragmentary information.

Because the stations have been solitary, it has been hitherto difficult to interpret the records. A single seismogram at a particular point discloses little information about the generation, transmission, and modification of ground motion. This inability to correlate it with motions in close-by, referenced points with well-known local site properties has bedeviled the research community in Turkey.

The two arrays code-named BYTNet and DATNet described in this paper will help in reducing the chances of missing important seismological information when major earthquakes with return periods of tens of years occur in Turkey. The arrays consist of modern digital instruments that are routinely interrogated per phone. Their operation to date has been satisfactory, and the information recorded is immediately released to the research community.

A national program, supported by the Scientific and Technical Research Establishment of Turkey, is currently underway to create a third array with 18 stations between Maraş and Antakya in southern Turkey. This program runs parallel with another one that sets to select retrofitted buildings in the country for strong motion instrumentation.

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