ENHANCEMENT OF THE NATIONAL STRONG MOTION NETWORK AND ESTABLISHING SEISMIC ARRAYS IN TURKEY

Revised Proposal Submitted to
NATO Science Programme, Science for Peace Sub-Programme
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ONGOING AND OTHER PROJECTS

Currently there are three earthquake related international collaborative research projects where SfP key personnel are involved. These are summarized below.

1. Analysis of Dinar Earthquake accelerograms and correlations with damage.

   Project initiation : September 1997
   Project duration : 3 years
   Funding agency : NATO Scientific and Environmental Affairs Div.
   Reference no : CRG 970579
   Amount of grant : 254 000 BEF
   SfP key personnel involved : Haluk Sucuoğlu, John G. Anderson

2. Seismic risk mitigation in Turkey in the wake of the 17 August 1999 M=7.4 Kocaeli Earthquake.

   Project initiation : September 2000
   Project duration : 2 years
   Funding agency : U.S. Agency for International Development Office of Foreign Disaster Assistance
   Amount of grant : 250 000 USD
   SfP key personnel involved : Polat Gülkan, Haluk Sucuoğlu, Mehmet Çelebi

3. Development of a database from the Düzce-Bolu region in Turkey relating building damage to structural, geotechnical and geological parameters.

   Project initiation : June 2000
   Project duration : 1 year, subjected to extension
   Funding agency : U.S. National Science Foundation
   Amount of grant : 75 000. USD (first year)
   SfP key personnel involved : Polat Gülkan, Haluk Sucuoğlu

The University of Nevada, Reno team has previous experience with operation of a strong motion network in an international setting. Since 1985, John Anderson has been a principal investigator on a project funded by the United States National Science Foundation to operate a strong motion accelerograph network in Mexico. The most recent of these grants separates the project into an operations grant and a research grant as follows:

4. Guerrero Accelerograph Network Operation

   Duration: Sept 15, 1995-Aug 31, 1999
   Funding Agency: NSF CMS-9506675
   Amount of Grant: $150,000

5. Guerrero Accelerograph Network

   Duration: July 15, 1996 – June 30, 2000
   Research Pis: J. G. Anderson and Y. Zeng.
   Funding Agency: CMS 9528517
   Amount of Grant: $ 180,000

BACKGROUND AND JUSTIFICATION

Background

Safeguarding the life and property of the public is a major task facing many governments. Each year enough destructive earthquakes occur in many parts of the world to bring this problem into renewed focus. In spite of increased awareness and universal agreement that the fundamental technology exists to prevent much of these losses, earthquakes continue to claim lives and cause property losses partly because modern societies have more of their assets exposed to the seismic threat, and partly because urban growth forces settlements to be located closer to sources of seismic hazard. Safe and economical structures can be designed and constructed in many parts of the world only if we understand the nature of the ground motion that these systems may experience during their service lives. This understanding can only come from direct measurement and subsequent analysis of the strong ground motion recorded during actual earthquakes.

Strong ground motions from earthquakes are recorded by special instruments called strong motion accelerographs. The early generation of these instruments were analog based until 1970's. New generation instruments are digital, and they have high sensitivity so that they can record weak motions from low magnitude earthquakes. Strong motion instruments deployed over an area may either form an array or a network. An array is a dense composition of instruments deployed in the neighborhood of an active fault having a high probability of generating earthquakes in the near future. The ground motion data retrieved by an array is essential for understanding the effects of fault characteristics, wave propagation paths and local site conditions on the distribution of ground motion intensity. Networks cover a much wider region where seismicity is influenced from a variety of active faults. Hence each earthquake in the region triggers a limited number of instruments in the network, not all of them. Ground motion attenuation relations are derived by using the network data from a number of earthquakes in time. These relations are in turn used to predict the ground motion intensity distribution approximately. The variability of their prediction is inherently very high. Attenuation relations are not sensitive to near field effects in short distances to the fault, source characteristics of the faulting and site conditions. The reliability of their prediction can only be improved by increasing the instrument density in the network.

Strong Motion Arrays

An International Workshop on Strong-Motion Instrument Arrays was convened in May 1978 in Hawaii (Iwan, 1978)[1]. The recommendations and conclusions of this workshop included the following:

[1] Iwan, W.D., Ed. 1978. Strong-Motion Earthquake Arrays. Proceedings of the International Workshop on Strong-Motion Arrays, May 2-5, 1978, at Honolulu, Hawaii. Pasadena: California Institute of Technology.

1. The International Association for Earthquake Engineering, in collaboration with the International Association of Seismology and Physics of the Earth's Interior (should) form an International Strong Motion Arrays Council (ISMAC)[2] to facilitate the establishment of strong-motion arrays.

2. Earthquake threatened countries (should) individually and collectively initiate the immediate installation of minimal arrays of 10-20 strong-motion instruments at the sites identified by this workshop.

3. High priority (should) be given to the design and installation of more elaborate source mechanism, wave propagation and local effects arrays, particularly at the six critical sites identified. (One of those sites was Varto in Turkey, but no array was established there.)

4. A mobile strong-motion instrument array capable of making source mechanism, wave propagation and local effects measurements (should) be established and maintained for deployment immediately following the occurrence of a major earthquake for recording aftershocks.

Since the first strong motion accelerograph was developed and deployed in the Los Angeles area in 1932, the number of these instruments has increased exponentially. It is estimated that there are currently some 15,000 instruments in operation worldwide today. The sites for these instruments are selected by engineers whose primary concern is for buildings and other traditional structures. As a consequence most strong motion instruments are located near population centers. Even today, the number of integrated arrays consisting of strong motion sensors deployed over a wide enough area for the purpose of collecting information concerning the generation, transmission and local modification of earthquake waves is sparse.[3] This is the case also for Turkey where currently no array is in operation. One objective of this proposal is to address this deficiency by establishing array type accelerometer networks in two locations in Turkey.

Array Types

The ground motion experienced at a given site depends both on the nature of the earthquake source mechanism and the many factors affecting the way in which the waves propagate from the source to the site. A better understanding of the physical processes involved in the generation and transmission of seismic energy is possible if data is obtained from dense arrays of strong-motion instruments deployed within the near source region. Different configurations have been suggested or implemented for these arrays. This constitutes the area of strong motion seismology that has emerged within approximately the last quarter century. Pioneering work in this field has shown that collaboration between engineers and seismologists lead to fruitful results, and produces safer, rationally designed structures.

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[2] ISMAC remained in existence until early 2000 when IAEE disbanded it because it had served very capably its intended function, and fulfilled its expected mission.

[3] Iwan. W.D. 1979. The Deployment of Strong-Motion Earthquake Instrument Arrays. Earthquake Engineering and Structural Dynamics, Vol. 7, pp. 413-426.

For sites with a predominantly strike-slip mechanism, comb shaped arrays consisting of approximately 50-100 instruments deployed along one or several lines on either side of the fault for several tens of km might be considered. Care should be exercised to make sure that the operational safety of no sensor is compromised by being located within the likely rupture zone. Some of these instruments could also be deployed along legs perpendicular to the fault for a more complete picture. Instruments extending away from the fault rupture are intended to measure the wave attenuation away from the fault to a distance comparable to the fault depth. The longer legs are intended to provide information on path effects and rupture mechanisms.

For sites with a predominantly dip-slip source mechanism, two dimensional arrays consisting of approximately 50-75 instruments with spacings from 1 to 5 km may be recommended. In thrust or subduction type source mechanisms, fewer instruments arranged in several lines and deployed along the fault at a spacing of several km may be planned.

In addition to these permanent arrays designed for source mechanism and wave propagation investigations mobile arrays for deployment shortly after large earthquakes to measure the ground motions generated by aftershocks. This way, more precise information on local effects can be recorded when these may have been caught in less than crisp detail by the national network.

Strong ground motion arrays have additional engineering uses. A full description of earthquake generated ground motions involves more than the characterization of motion at a particular point, or along a definite set of geometrically arranged points. Many engineering applications stand to benefit also from descriptions of gradients of motion between closely spaced points, leading to rocking, twisting and relative motion between them. The precise nature of differential motions between adjacent points is affected by both source mechanisms and by a combination of subtly interacting factors. These include local topographic and geotechnical features, soil-structure interaction effects, liquefaction, etc. Further applications are possible by placing sensors on engineering structures so that their response can be recorded during strong shaking, and matched against predictions based either on computer models or extrapolated from laboratory specimens.[4] These are current research topics on their own right, and they do not form an integral part of this proposal.

Strong Motion Network in Turkey

The concept of establishing a national strong motion accelerograph network in Turkey was initiated in 1973. This network is operated by the General Directorate of Disaster Affairs. Initially, analog acceleration records were installed as they were the then-available technology.[5] Later the system has been supported by the addition of digital instruments. As of October, 2000, this system is comprised of some 130 instruments, about evenly divided between analog and digital types. The instruments are placed inside institutional buildings such as meteorology stations or local ministerial offices for safety and ease of maintenance. Figure 1 shows their locations.

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[4] Proceedings of a Workshop on Interpretation of Strong Motion Earthquake Records Obtained in and/or near Buildings. UCLA Report No. 8015, April, 1980.
[5] İnan, E. et al. 1996. Catalog of Earthquakes between 1976-1996 with Acceleration Records. General Directorate of Disaster Affairs, Ankara.

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Figure 1. Locations of Strong Motion Instruments in Turkey

Additional instruments are deployed in Turkey by other agencies and universities. For example, a number of historic religious structures in İstanbul such as the Saint Sophia Museum, Süleymaniye Mosque have been instrumented because of their cultural importance. A recently ended program managed jointly by the General Directorate of Disaster Affairs and Japan International Cooperation Agency has established a network in nine provinces in northeastern Turkey between Ankara and Samsun on the Black Sea coast. The purpose of this network is to arrive at quick estimates of losses and casualties if a major earthquake should strike the subject area. The suspension bridges across the Bosphorus have been the subject of health monitoring, and have been outfitted by accelerographs operated by the General Directorate of State Highways. The Scientific and Technical Research Establishment of Turkey (TÜBİTAK) has funded research programs that have enabled the setting up of small local networks or distributed single instruments designed for specific purposes. Small, specific-purpose clusters of instruments deployed by İstanbul Technical University (İTU) or Boğaziçi University (BU) operate as stand-alone systems in the İstanbul metropolitan area. The General Directorate of State Hydraulic Works (DSİ) operates single strong motion recording systems in or near major dams they have built. None of these clusters of instruments constitutes an array in the sense we propose to establish here. More importantly, the choice of their location is either along major fault zones as in Fig. 1, or established in conformance with other criteria in mind. Clearly, the number of instruments is very meager for a country with the size and seismicity of Turkey.[6] For this reason, an "improved"

[6] The General Directorate of Disaster Affairs is planning to expand the existing system by at least 100 percent in 2000. This will be achieved in several ways. One is the procurement of additional digital three-component sensors for a denser network, or expanding the network into cities that have so far been excluded. The other is to combine the existing national network and the prototype JICA network into a unified "Disaster Information System."

assessment of the seismic hazard in Turkey has had to rely on ground acceleration attenuation relations derived from other sources.[7]

Justification

A patchwork of isolated strong ground motion records were recovered during the two major earthquakes in Turkey in 1999. As noted earlier, the national strong ground motion network in Turkey is operated by the General Directorate of Disaster Affairs (GDDA). While the records were useful, the instruments lacked precise clocks. Their haphazard locations (instruments are placed in institutional buildings, such as meteorological stations) limited their usefulness. The deployment of the instruments in the epicentral area is shown in Fig. 2. We note that the near-field instruments were actually several km removed from the actual fault trace. Further, all were stand-alone devices, and were triggered on their own. The mixture of analog and digital sensor outputs introduced another source of dissimilarity into the records recovered. In current hazard maps it is common practice to express the ordinates of ground motion spectra at specific periods such as 0.3 and 1.0 s, corresponding to low, stiff buildings and medium height buildings of about 8-10 stories, respectively. Such maps depend on the availability of ground motion records at a variety of distances from the epicentral area, and at well documented site conditions. Unfortunately, this critical information is still lacking, so improvement of the current map can not be attempted with confidence.

Earthquakes with magnitude larger than 7 occur at intervals typically measurable in one or 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 if 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.

[7] Gülkan, P. et al. 1993. A Seismic Zones Map of Turkey Derived from Recent Data. Earthquake Engineering Research Center Report No. 93-01, Middle East Technical University, Ankara (in Turkish).

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Figure 2. Location of Near-Field Strong Motion Instruments That Triggered during the Two Major Earthquakes in Turkey in 1999

CURRENT STATUS

The current status of strong motion instrumentation in the Partner country and worldwide is very difficult to summarize briefly. The first strong motion instruments were installed in the United States in 1932 as a result of the efforts of John Freeman, and the first significant records came from the Long Beach, California, earthquake on March 10, 1933. The early instruments all used an analog recording device. In the late 1970's, the first digital instruments were placed into service. These were mostly using 12 bit analog-to-digital converters. In the 1990's, "24-bit" a-d converters came into use, enormously expanding the dynamic range of the instruments. These instruments actually give about 19 bits above the noise level at the present time. For an instrument set to record a maximum acceleration of plus or minus 2g ($1g=980cm/s^2$), this means that the instrument can resolve accelerations as low as 0.007 cm/s^2. This allows these modern instruments to easily record local earthquakes down to magnitudes below 2.0. The original analog instruments, even in an area with high seismicity, would only record fewer than one earthquake per year. Because the number of earthquakes increases by a factor of 6-12 for each decrease of one magnitude unit, the modern instruments will record large numbers of earthquakes per year, and become a useful supplement to seismic networks if they are equipped with an accurate clock. The Guerrero accelerograph network, described below, uses all digital instruments, and over 14 years the average instrument has recorded 4 events per year. The original equipment in Guerrero used 12-bit a-d converters. The increase in the number of records in later years is due to gradual conversion to 16- or 19-bit recording.

Another issue is the numbers of instruments that are deployed. In California alone, the California Division of Mines and Geology maintains a network of strong motion instruments that is about ten times the size of the network in Turkey. The state of the art is defined by the Trinet project in southern California, in which several hundred digital strong motion instruments are being set up to communicate recordings in near real time to the central station. The results are being used to develop "shake maps" nearly immediately after the earthquake, and which will be used for guiding emergency response to the most strongly shaken areas quickly after the earthquake.

Guerrero Accelerograph Network Operations

The Guerrero accelerograph network was first installed with NSF support by John Anderson and Jim Brune, in collaboration with scientists in Mexico, in 1985. The principal objective of the network is to record an anticipated magnitude 8 earthquake in a seismic gap near Acapulco, Mexico. Although the earthquake has not yet occurred, the network has recorded large numbers of other earthquakes. The following table gives the most recent statistics:

Table 1. Numbers of events recorded, by magnitude and by year

				Magnitude					
Year	Events	Records	Rec/Ev	<3	3-3.9	4-4.9	5-5.9	6-6.9	>7
1985	39	75	1.9	1	18	10	3	0	2
1986	48	83	1.7	5	19	14	5	0	1
1987	47	118	2.5	2	30	14	0	1	0
1988	52	119	2.3	5	30	13	4	0	0
1989	80	219	2.7	3	38	30	4	1	0
1990	62	172	2.8	0	15	34	6	0	0
1991	57	141	2.5	8	18	17	0	0	0
1992	55	137	2.5	0	5	32	7	0	0
1993	34	111	3.4	0	4	21	5	2	0
1994	23	85	3.4	0	4	12	2	2	0
1995	55	101	1.8	2	14	33	3	0	3
1996	86	183	2.1	17	14	48	5	1	1
1997	99	226	2.3	34	12	44	6	2	1
1998	126	277	2.2	60	12	46	7	1	0
1999									
Total	693	1707	2.5	137	232	369	57	11	7

Data from this project is available on the web site of the Nevada Seismological Laboratory (www.seismo.unr.edu), and is described in a series of data reports, many of which are now also posted on the web. The most important earthquake so far occurred in the first year of full operation of the network (Anderson et al, 1986),[8] but significant earthquakes have been recorded on the network while we wait for the gap-filling earthquake (e.g. Anderson et

[8] Anderson, J. G., P. Bodin, J. Brune, J. Prince, S. Singh, R. Quaas, M. Onate, and E. Mena. 1986. Strong ground motion and source mechanism of the Mexico earthquake of Sept. 19, 1985, Science 233, 1043-1049.

al, 1995).[9] The continuing operation of this network demonstrates the experience of the principal investigators in long-term operations of a major facility (the network operations have been renewed four times), and in operations under difficult field conditions.

Guerrero Accelerograph Network Research and Related Studies

This is one of several NSF and Southern California Earthquake Center (NSF Science and Technology Center) grants that has supported research by the University of Nevada group. We highlight research on two aspects: site response and modeling strong motions.

Site response: Stations in the Guerrero network are all nominally sited on the hardest rock available, consistent with the other objectives of the network (station distribution, security, power, etc.). All but one site is in a location where the dominant geomorphic process is one of erosion with soil formation on top of bedrock. Nearly all of the sites are on rock where the erosion processes are so little advanced that the outcrop is hard rock. Still, those stations exhibit distinct site response functions (Castro et al., 1990[10], Humphrey and Anderson, 1992[11]). Some of the stations exhibit fairly strong resonance peaks that may be due to the weathering layer. For instance, the station at Xaltianguis shows a peak in its site response at 10-15 Hz, even though site appears to be very hard granite kept clean by sheet runoff of rainwater. This demonstrates that rock sites selected by seismologists for seismic network operations also may have unexpected site response effects that ought to be characterized before the sites are used for comparison with basin sites.

The characteristic of the problem of determining the site response in Mexico is that the stations are widely separated compared to the separation of the source from the stations. Su et al (1996)[12] demonstrate that in southern Nevada, the results of that approach give results that are similar to the approaches used by Castro et al (1990) and by Humphrey and Anderson (1992).

Modeling strong motion seismograms

Analysis of Accelerations from the Dinar, Turkey Earthquake. The Dinar earthquake, 1 October 1995, was a moment magnitude 6.2 earthquake in southwestern Turkey. The earthquake has a normal faulting mechanism. The earthquake caused 90 deaths, over 200 injuries, and a large amount of damage. What makes this event unique is that it was recorded by seven strong motion accelerographs, including four stations within 100 km. One of these,

[9] Anderson, J., R. Quaas, S. K. Singh, J. M. Espinosa, A. Jimenez, J. Lermo, J. Cuenca, F. Sanchez-Sesma, R. Meli, M. Ordaz, S. Alcocer, B. Lopez, L. Alcantara, E. Mena, and C. Javier. 1995. The Copala, Guerrero, Mexico earthquake of September 14, 1995 (MW=7.4): a preliminary report, Seismological Research Letters 66, No. 6, 11-39.

[10] Castro, R. R., J. G. Anderson and S. K. Singh. 1990. Site response, attenuation and source spectra of S waves along the Guerrero, Mexico subduction zone, Bulletin of the Seismological Society of America 79, 1481-1503.

[11] Humphrey, J. R. Jr. and J. G. Anderson . 1992. Shear wave attenuation and site response in Guerrero, Mexico, Bulletin of the Seismological Society of America 82, 1622-1645.

[12] Su, F., J. G. Anderson, J. N. Brune, Y. Zeng. 1996. A comparison of direct S-wave and coda wave site amplification determined from aftershocks of the Little Skull Mountain earthquake, Bull. Seism. Soc. Am. 86, 1006-1018.

at Dinar, is on the edge of the surface projection of the fault. The record from Dinar is possibly unique in its proximity to the causative fault for this type of mechanism. The Dinar site is in a small, stiff building on soft sediments with a shallow water table. The peak acceleration was 0.32g on the horizontal component perpendicular to the fault trace.

The earthquake was caused by rupture on the Dinar fault, which is a normal fault trending generally towards the south-southeast, with the down dropped hanging wall on the west. The Dinar earthquake caused surface rupture along about a 12 km segment of this fault. The Dinar strong motion station is at the south end of the fault, under one kilometer from the nearest surface trace. The hypocenter was at the south end, beneath Dinar, with rupture propagating towards the north and away from the strong motion site. We found a composite source model, as described by Zeng et al (1994)[13], to match the statistical characteristics of the strong motion records.

OBJECTIVES

This proposal sets to establish two seismic arrays that will serve as models in Turkey for the future, and to increase the density of instruments in the national strong motion network at selected urban zones. This proposal is limited only to describing a small part of a wider system that will be enhanced mainly through Turkish national resources. The successful initiation of these arrays that will record ground motions from both small- and large-magnitude earthquakes will serve as leverage for similar arrangements at other suitable locations. The arrays will become incorporated into the national system in operation in Turkey, and serve to enhance its utility. A national strong motion arrays council consisting of experts in this field should establish the national objectives, and promote the idea nationally. We plan to form this council quickly so that their counsel is available during the planning and installation stages.

With heightened odds for a renewed major earthquake near the western end of the North Anatolian Fault estimated to affect İstanbul, one of these arrays would be near Yalova, a city 40 km to the southeast (see Figure 3 below), and extend linearly to Bursa, about 65 km to the south-west of Yalova. (The rupture of the 17 August 1999 earthquake did not reach Yalova, but it is reasoned that the next segment to break will include it.) The vicinity of Aydın-Denizli, 100 km east of İzmir along the Menderes river valley, is considered for the second array. These two locations are in transform and normal fault mechanism regions, respectively. Yalova, Bursa, İzmir, Aydın and Denizli are the candidate cities for deploying instruments to complement the currently existing isolated ones.

Among significant objectives is also the training of young seismologists and engineers in the design, installation, and maintenance of these array as well as utilization of the data that may be recorded on them. Most of these younger staff are part of the Earthquake Research Division of the Turkish General Directorate of Disaster Affairs, the national agency responsible for the operation of the national system. Qualified young academicians from METU and ITU will also be trained for strong motion instrumentation and operation. With the US planning to spend $175 million to establish an Advanced National Seismic System

[13] Zeng, Y. and J. G. Anderson. 1995. A method for direct computation of the differential seismogram with respect to the velocity change in a layered elastic solid: Bull. Seismol. Soc. Am. 85, 300-307.

that will require $47 million annually to maintain, the global importance of protection of lives and infrastructure against the seismic peril is confirmed. Investment in these instruments may pay off for decades with the knowledge to build safer structures. Large earthquakes that are not properly recorded are irreplaceable, missed opportunities that can result in delays of decades before a similar earthquake is recorded. The practice of risk management in the country will benefit from the information that could be generated from these arrays.

METHODOLOGY

No one can be sanguine that any array will capture its intended information immediately after being established. Forecasting of earthquakes is rife with much uncertainty, and an early maxim in strong motion seismology stated that earthquakes tended to cease occurring in areas that had been instrumented to record them! In spite of this seeming initial setback many arrays have been created in many different countries, and useful data recorded for the benefit of the world community of scientists and engineers. There must be a reasonable expectation that an earthquake can be recorded within a meaningful length of time, and that the records will be representative of the seismic environment that produced them.

Some current research indicates that there exist plausible grounds to expect heightened odds for a major earthquake to affect İstanbul, the largest city in Turkey, and the principal seat of the country's financial institutions.[14] This forecast considers earthquakes on the North Anatolian fault system in the Sea of Marmara during the past 5000 years, and tests the resulting catalog against the frequency of damage in the city during the preceding millennium. If the time-dependent effect of stress transferred by the 1999 $M_w = 7.4$ İzmit earthquake to faults nearer to the city are considered, then there appears to be a 32 percent probability of strong shaking to occur within 50 km from İstanbul during the next decade. The ground rupture during the 17 August 1999 earthquake appears to have terminated beneath the Marmara Sea to the east of Yalova, thus increasing the stress and the likelihood of a triggering there. Yalova shown as a square in Fig. 3 is 40 km to the south-east of İstanbul. There are no seismic faults within the immediate vicinity of İstanbul. It is therefore prudent to set up the first array in the area of Yalova, containing the urban boundaries from east to west, but extending beyond them transversely and longitudinally.

Another objective is to enhance the urban strong-motion coverage. Currently, each city along major faults is equipped with only one instrument. With at most one record from each location recorded in a major earthquake, it is not possible to correlate observed damage with the strength of the ground motion. With several records from cities in hazardous areas, and certainly in the proximity of the proposed arrays, this deficiency should be addressed. It is proposed that sample urban settlements including Yalova, Aydın, Denizli, Bursa and İzmir should be equipped with five additional instruments each for a better coverage. The number of such cities and the instruments there may further be expanded with those procured by GDDA through their own program.

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[14] Parsons, T., et al. 2000. Heightened Odds of Large Earthquakes near İstanbul: An Interaction-Based Probability Calculation. Science, April.

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Figure 3. Space Image of the Marmara Sea Region

The other location envisioned for an array deployment is the Menderes Valley shaped by a graben with the same name. The valley extends from the ancient city of Miletos near the Aegean coast in the west first toward the north-east, and then directly to the east to Sarayköy. Its length is some 200 km, and width varies between 10-25 km. Major urban settlements such as Söke, Aydın, Nazilli and Denizli are part of this zone. Damaging earthquakes occurred in Söke (1955), Aydın (1966) and Denizli (1963 and 1976). The first strong motion record in Turkey was recovered from the 1976 Denizli event. This tectonic structure is part of the West Anatolian intermountain range shaped by a succession of rising and falling basin and range formations in the east-west direction. Geologists calls this the Aegean graben system. The entire area falls in the highest hazard zone of the building code.

Examination of space-time diagrams of earthquakes in the Aegean system between 1900-95 associated with surface ruptures shows that successive events occur on adjacent segments, suggesting a similar triggering mechanism, with one earthquake setting up the next, may again be at work as on the North Anatolian Fault.[15] The pattern has not been exhaustively studied, but it carries many of the characteristics of normal faulting.

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[15] Demirtaş, R., and Yılmaz, R. 1996. Seismotectonics of Turkey. Turkish Ministry of Public Works and Settlement, Ankara.

Earthquakes in the Aegean graben system are episodic. The period between 1900-10 is quiet, but the following two decades are very active, followed again by three decades of subdued activity until 1960. The magnitude-7 earthquake that levelled Gediz in 1970 was again a part of an increased activity period. The last important earthquake in the area occurred in Dinar in 1995.

Deliverables

The work contained in this proposal will be implemented in two stages. We believe that the installation of the first array near Yalova should be done first before repeating for the Aydın array. This way, the learning process from the first leg will shorten the second stage of work.

1. Study of the local geology and topography in the area betweenYalova and Bursa. This step is necessary to ensure compatibility between the intended instrument layout and possibility of physical deployment. Currently, we plan to locate most of the instruments at the ground level. In addition to the precise coordinates of each sensor, borehole data should be gathered for soil characterization. With GDDA involvement it is planned to provide borehole data to 30 m, and sample tests for each deployment.

2. A related activity will be the selection of the cities and locations for instrument deployment in order to enhance the existing strong ground motion accelerograph network. This will be achieved through the creation of the Turkish National Strong Motion System Advisory Council whose counsel will be sought for the two arrays. Site-specific surveys at sites of the existing instrument stations will remove a source of uncertainty for the complementary information that may be obtained in the future.

3. Instrument procurement, training of personnel to install, utilize and maintain devices.

4. Installation and testing.

5. Installation of the second array in the vicinity of Aydın.

6. Web site design.

7. Advanced research institute/workshop organization.

8. System maintenance and operation.

We anticipate that with the funding that can be available if this proposal is accepted, about 15 modern accelerographs can be purchased. With 9 of these a linear array deployed in the N-S direction between Yalova and Bursa can be designed (see Figure 3). This array will then traverse several branches of the North Anatolian fault that are considered likely by seismologists to rupture within the next 30 years. The remaining instruments will be deployed over a similar distance in the E-W direction between Denizli and Aydın.

Both arrays will become incorporated into the existing national system maintained by the General Directorate of Disasters. When an expansion is enabled through other resources, then planning and deployment of these will be performed according to the recommendations of the national strong motion arrays council that this proposal will establish.

PROJECT STRUCTURE

Project Milestones, Deliverables and Schedule

The work leading to the establishment of two arrays and their successive startup is planned over a three-year period. Careful prior planning is necessary to locate the networks optimally. This has considerations for operability, maintenance, and safety. Ideally, when waveforms from a given earthquake are recorded on the system, recovery and processing of the data should be done as quickly as possible so that it can be placed on the Internet for researchers the world over to access and utilize. With data transmission modalities undergoing the rapid changes it has seen during the last decade, this requires the crafting of a system that will preserve its functionality for the foreseeable future, and not become obsolete and inaccessible because its design had been made according to fading technology. This will be the major challenge of the program. The objectives stated under the section titles "Activities" should not be taken to imply that this will only be an equipment procurement project. Its training and manpower capacity building components will accrue over time.

Each program activity is scheduled as follows.

1. Study of the local geology in Yalova-Bursa : Months 1-6
2. Selection of new station locations : Months 3-6
3. (a) Instrument procurement : Months 6-12
   (b) Training : Months 9-12
4. Installation and testing : Months 12-18
5. Second array in Denizli-Aydın : Months 19-30
6. Web site design : Months 30-33
7. Advanced research institute/workshop : Months 22-28
8. System maintenance and operation : Months 30-future

For ease of presentation, these tasks have been converted into an activity chart in Fig. 4.

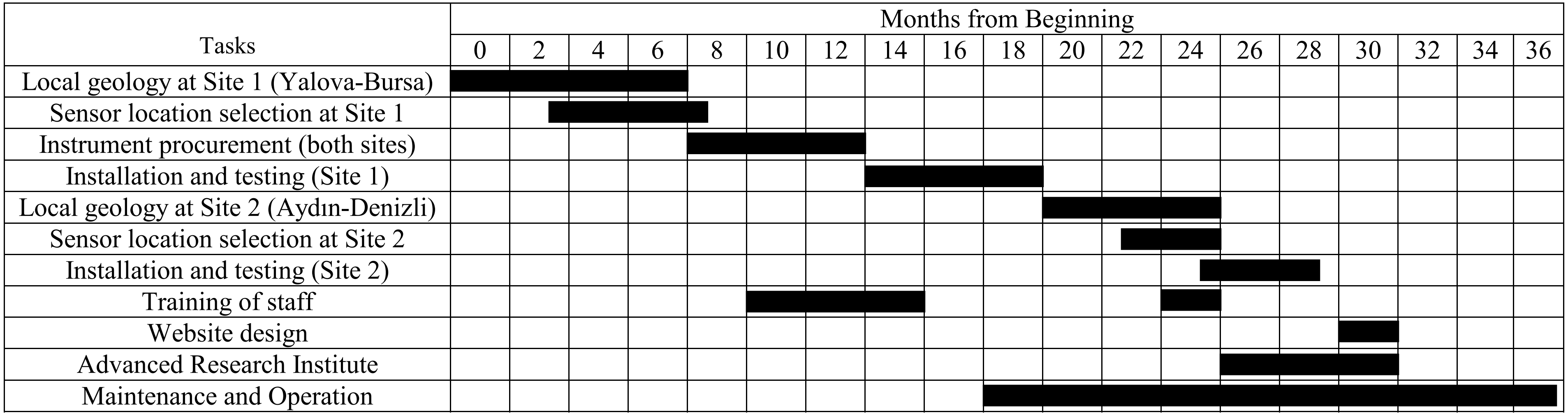

Figure 4. Barchart of Program Activities

Organization and Management

The organizational and management structure of the project is shown in Fig. 5 and summarized in Tables 2 and 3. It is noted that we foresee the establishment of a steering committee consisting of six persons, with a virtual seat at METU. No one partner assumes primacy in dealing with any other. METU assumes responsibility in performing much of the coordination and background work. The General Directorate of Disaster Affairs will contribute manpower from the Division of Earthquake Research that already operates the national accelerometer system. The Scientific and Technical Research Council of Turkey Information is represented by two entities: The Marmara Research Center (MAM) and its Earth Sciences Unit as well as the Technologies and Electronics Research Institute (BİLTEN).

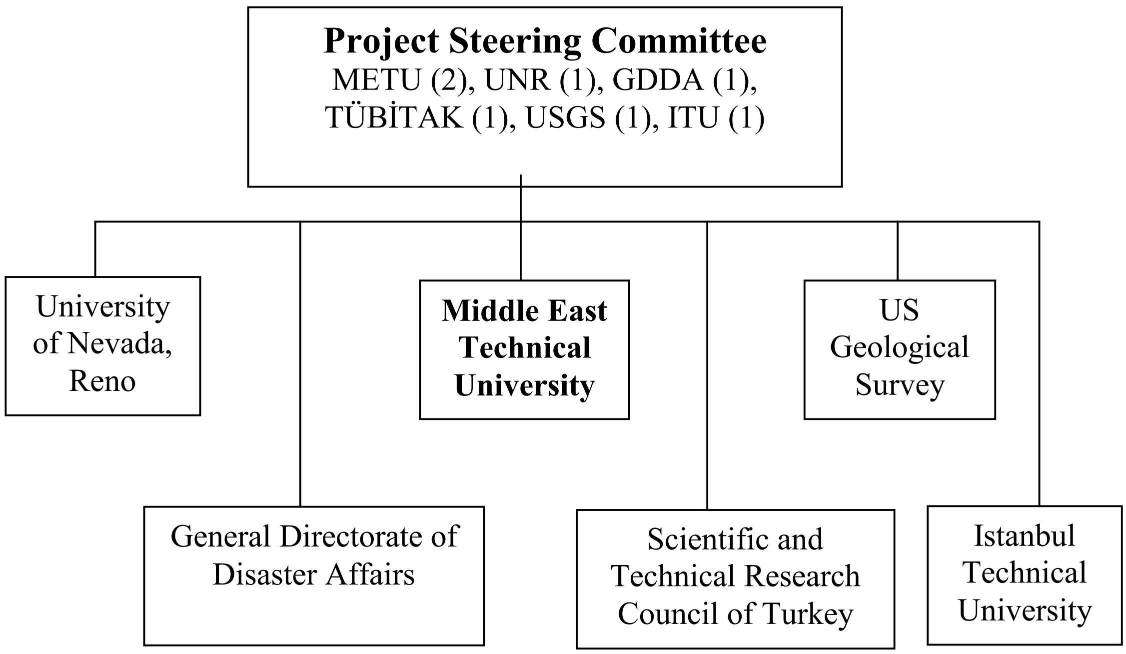

Figure 5. Organizational Arrangements

Table 2. Sharing of Duties among Tasks

Participating Group	Task
METU	Coordinate, schedule site selection, instrument procurement, installation and testing, web site design, ARW, maintain system
GDDA	Local geology, site selection, send personnel for training, installation and testing, system maintenance and continued operation
TUBITAK	Selection of station locations, instrument procurement (additional), installation and testing, ARW
USGS	Local geology, site selection training junior scientists, ARW
UNR	Local geology, training young scientists, selection of sites, installation and testing
İTÜ	Site selection, installation and testing, ARW

ARW: Advanced Research Workshop

Table 3. Organizational Arrangement

	Name of Participant and location	Affiliation	Position	Involvement Percent Time	Task
1	Prof. Polat Gülkan, Ankara, Turkey	Middle East Technical University (METU)	Earthquake engineer, senior researcher	30	Co-PPD; site selection, procurement coordination, visits to UNR
2	Prof. Haluk Sucuoğlu, Ankara, Turkey	METU	Earthquake engineer, senior researcher	30	Co-PPD; site selection, procurement coordination, visits to UNR
3	Mr. Sinan Akkar, Ankara, Turkey	METU	Ph.D. student	80	Development of software for data retrieval and processing; training at UNR under Prof. Anderson
4	Mr. Tolga Yılmaz, Ankara, Turkey	METU	Ph.D. student	75	Development of software for data retrieval and processing; training at USGS under Dr. Çelebi
5	Mr. Altuğ Erberik, Ankara, Turkey	METU	Ph.D. student	75	Development of software for data retrieval and processing; training at UNR under Dr. Anderson
6	Ms. Zahide Çolakoğlu, Ankara, Turkey	General Directorate of Disaster Affairs	Staff geophysicist, end user	50	Manage data download and maintenance at data center, train at UNR under staff
7	Mr. Uluğbey Çeken, Ankara, Turkey	General Directorate of Disaster Affairs	Staff geophysicist, end user	25	Manage array operability, develop and maintain data processing capability

8	Dr. Erol Tunalı, Ankara, Turkey	Scientific and Technical Research Council of Turkey	Electronics engineer, researcher, data transmission expert	25	Design communications requirements, manage array operation
9	Prof. Tuncay Taymaz, İstanbul, Turkey	İstanbul Technical University	Seismologist	30	Co-PPD; site selection, procurement coordination, visits to UNR
10	Prof. Haluk Eyidoğan, İstanbul, Turkey	İstanbul Technical University	Seismologist	15	Participate in site selection and array design
11	Prof. Mustafa Aktar, İstanbul, Turkey	Scientific and Technical Research Council of Turkey and Kandilli Earthquake Center of Boğaziçi University	Geophysicist	10	Participate in site selection and array design, supervise domestic training
12	Prof. John Anderson, Reno, Nevada, USA	University of Nevada	Director of Seismological Laboratory	5	NPD, design of array, site selection, supervise training of Mr. Akkar and Ms. Çolakoğlu
13	Dr. Roger Borcherdt	US Geological Survey	Research Engineer	10	Array and data transmission and processing of Mr. Yılmaz
14	Dr. Mehmet Çelebi, Menlo Park, California, USA	US Geological Survey	Research Engineer	10	Array and data transmission and processing, supervise training of Mr. Yılmaz and other Turkish young scientists to be named.

15	Matt Purvance Nevada, Reno	University of Nevada	Graduate Student in Seismology	50	Conduct graduate work under Prof. Anderson, coordinate training and visits
16	Name to be determined	Middle East Technical University	Graduate student in structural engineering	50	Conduct graduate work under Prof. Gülkan
17	Name to be determined	General Directorate of Disaster Affairs	Staff scientist	75	Receive training at USGS, ensure continuity of array operations
18	Name to be determined	General Directorate of Disaster Affairs	Graduate student in earthquake engineering	50	Conduct graduate work under Prof. Sucuoğlu
19	Aasha Pancha	University of Nevada	Graduate student in seismology	50	Conduct graduate work under Prof. Anderson
20	Name to be determined	İstanbul Technical University	Graduate Student in Seismology/ geophysics	50	Conduct graduate work under Prof. Taymaz

IMPLEMENTATION OF RESULTS

When strong ground motion data is retrieved in an array, it represents a valuable source of information for both the engineering and the seismological/geophysical communities. Recorded ground accelerations and the response spectra of past earthquakes provide a basis for the rational design of structures to resist earthquakes.[16] When the precise array geometry and the local geotechnical characteristics of the recording sites are known, it becomes possible to correlate the strength of the ground shaking with fault physics. Surface and downhole records enable validation of ground amplification theories. Comparison of simultaneous acceleration traces from many instruments makes it possible to correlate path dependent effects on structural response. Analysis of individual records leads to improved ground motion attenuation relations. When these traces are processed in further detail it becomes possible to differentiate period-dependent spectral effects more precisely. These results combine to permit better assessment of seismic hazard nationally. Ground motion data, if it can be captured by the proposed arrays, will continue to serve as the information source from which improved design and analysis procedures for a safer environment worldwide will be derived.

[16] George W. Housner

We plan to establish an Internet site with information and news displayed regularly. An advanced Research Workshop on "Strong Motion Arrays" organized approximately two years after program inception will serve as an appropriate forum whose outcome can serve as a further tool for better system design. Through the explicit association with USGS, the arrays will become a link in a global network. We also plan to become associated with COSMOS[17] (http://www.cosmos-eq.org/links.html). The consortium was recently established as a non-profit corporation with headquarters located at PEER, the Pacific Earthquake Engineering Research Center, Berkeley, California, USA with its major mission being " To expand and modernize significantly the acquisition and application of strong-motion data in order to increase public safety from earthquakes."

The main product of the project is the strong ground motion recordings retrieved from specially selected environments. Although the magnitude of an earthquake, which is calculated by using the recordings of sensitive seismographs is a popular parameter for scaling the size of an earthquake, it has no use for expressing the effects of the earthquake on the built environment. Another type of seismic instruments, the strong motion accelerographs are capable of recording the strong ground shaking during an earthquake at a given location, which are in turn employed to express the ground shaking intensity at that location. Currently the strong ground motion accelerograph network in Turkey consists of 130 instruments located sparsely in cities in the first and second priority seismic zones. This network is operated by the Directorate of Disaster affairs, which is a partner and an end user in the proposed study. A smaller network in the Marmara region consisting of 10 instruments is operated by the Kandilli Observatory of the Boğaziçi University, which is designated as another end user. Such quantities of strong motion recorders are extremely insufficient in Turkey considering the size of the earthquake prone regions and the high level of seismic activity being observed in these regions. Due to the insufficiency of strong motion instruments, there is only one instrument in each city in the active seismic regions of Turkey. However it is well known that the distribution of ground motion intensity and the consequent seismic damage is closely related with the local site characteristics, the type and the directivity of the fault rupture during the earthquake. The peculiar distribution of damage within various cities during the 1999 earthquakes in Turkey has clearly demonstrated that the variation of strong ground motion intensity in the built environment is significant. This variation has to be captured by an increased number of instruments in larger cities, and by specially designed seismic arrays in selected locations, as planned in the project proposal presented herein. The enriched strong ground motion data retrieved as a product of the proposed research program during the probable earthquakes in the near future will enhance understanding of the seismic vulnerability of urban settlements in seismic regions.

The chief end-user, the Directorate of Disaster Affairs is an active participant in the project. The end results of the project will be implemented basically in improving the damage-loss estimations and in developing the seismic intensity attenuation relations, which is in turn connected to the earthquake scenario studies for urban zones. The designated end-users in the project proposal are the research institutions which carry out such studies. They will have direct access to the retrieved strong motion data through the interned media. Besides, all geological, topographical and geotechnical information pertaining to the deployed instrument arrays and stations will be made freely available to the end-users. Training and capacitation of the staff at this agency will become the primary benefit enjoyed by Turkey.

[17]International Consortium of Organizations for Strong-Motion Observation Systems

The most practical way of disseminating the information and knowledge gained during the project is to establish an Internet web site and provide free access to all interested parties and communities worldwide. A more specific plan for opening the end results to the discussion of the international scientific community can be achieved by organizing a workshop or a study institute towards the ending phase of the program. A NATO Advanced Study Institute or Advanced Research Workshop Program fits very well for assembling such a broad scientific discussion platform. The operators and end users of all similar strong motion networks and arrays in earthquake prone countries will perhaps be the prospected participants of the platform.

We envisage this to serve as the founding block for deriving a near-real-time shake map, like the one in southern California. That could be a significant improvement in response to earthquakes as one would know immediately at the central point where the shaking was strongest.

CRITERIA FOR SUCCESS

In the kind of work that is proposed herein, the criteria for success have an element of irony. For the system(s) to be declared successfully functioning scientific tools, earthquake ground motions need to be recorded on them. This means the occurrence of an earthquake, and perhaps loss of life and property. The installation of an array network, and enhancement of existing instrumentation in urban environments in areas close to the array locations are important milestones in themselves. This system must be crafted in such a way that advances in communications and Internet technology will not adversely affect the operability of the system. Training of eight young engineers and scientists in array design and management, and evaluation of processed information for the design of safer built environment are among other potential outcomes. Table 4 is a summary of the criteria for success.

Table 4. Criteria for Success

Criteria for Success	**Relative Weight**
1. Select suitable sites	15
2. Install systems successfully	15
3. Train young scientists	15
4. Organize ARW/ASI on Strong Motion Arrays	6
5. Set up Website	3
6. International publications in journals and conferences	6
7. Networks obtain accelerograms[18]	10
8. Derive reliable attenuation relations	5
9. Improve national hazard maps	10
10. Improve loss estimation and disaster management practices	15

[18] With suitable array sensitivity, ground motions caused by at least minor earthquakes should be available for Tasks 8-10. Even small earthquakes would help to ensure that the system functions A preliminary listing of the accelerograph requirements is given as Annex 5.