INTRODUCTION

The twenty-seven-station digital short-period (1 Hz) Syrian National Seismological Network utilizing a combination of radio-frequency (RF) and land-line (LL) telephone telemetry was installed and has been operational since 14 January 1995. Augmenting the seismic network is a twenty-station network of three-component digital accelerographs commissioned at the same time as the seismic network. The spatial distribution of both networks covers most of western Syria from north to south. The network’s design criteria were to monitor all discernable earthquake activity along the Dead Sea fault system (DSFS) and its related branches in Syria and nearby Lebanon (Figure 1).

This major fault system is characterized by relatively high seismic activity and, as the Program for Assessment and Mitigation of Earthquake Risk in the Arab Region (PAMERAR) initiative proposed in 1981 concluded, poses a significant seismic hazard to the densely populated areas surrounding it. The most recent and truly devastating large earthquake (deaths estimated at 20,000) along this fault system occurred in the Bekaa Valley within the large restraining bend on 25 November 1759 and had an estimated magnitude of greater than $M, 7.3$ (Ambraseys and Barazangi, 1989).

FIELD TELEMETRY STATIONS

In 1985 the General Establishment of Geology and Mineral Resources (GEGMR), responding to an initiative proposed by PAMERAR, started the design and implementation phases for the construction of the Syrian National Seismological Network (SNSN). The primary focus of the SNSN was to study local and regional earthquakes to evaluate earthquake hazard and subsequently to implement a strategy to mitigate seismic risk in the region. Topography as well as lack of adequate telephone cable (LL) connections mandated that a combination of RF and LL telemetry be employed. Digital technology had limited availability at the time, so the system in place is frequency-modulated (FM) analog. Figure 2 shows the geographical distribution of the Syrian National Seismological Network, Strong Ground Motion Network and Sub-centers location.
Figure 1. Map showing the major tectonic boundaries of Syria and the surrounding region. Large historical earthquakes (after Ambraseys and Barazangi, 1989) are also shown.

Figure 2. Map showing the geographical distribution of the Syrian National Seismological Network and Strong Motion Network.
The nine seismic stations of the southern subnetwork became operational in late 1994 and early 1995. The remaining eleven stations of the northern subnetwork followed the next year to complete the twenty stations of the western SNSN. Table 1 gives the detailed coordinates, starting operational date, and other technical specifications for each station of the SNSN. The seven eastern stations (21–27 in the table) were added in April 2002; two were three-component seismic stations. The signals are routed to and multiplexed in Raqqa and then sent via two phone lines to a Damascus central recording station where all network data are processed. The topographic and communication study was executed by the technical specialist of the Syrian center, while the installation and initial operation was by experts from Kinemetrics and UNESCO, approved and accepted by GEGMR.

Since there is a very limited history of instrumental seismic data within Syria, a network of digital strong-motion accelerographs, as proposed by PAMERAR, was designed and installed to augment the broadband seismic network. The instrument package used exclusively throughout the 20-station strong-motion network includes a Kinemetrics SSA-1 digital accelerograph with a predetermined threshold availability between 0.1% to 10% of its full-scale value of 2 g. All SSA-1’s are triaxial and have been located on dam structures, in multistory buildings, and in some vaults of the seismic network. This strong-motion network not only enhances the overall dynamic range capability of the classical seismic network but also provides an important, previously nonexistent data set that is useful to the Syrian civil engineering community in the development of revised building code standards and seismic zonation maps.

### TABLE 1
Parameters of the Syrian National Seismic Network (SNSN)

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Station Code</th>
<th>Long. E (°')</th>
<th>Lat. N (°')</th>
<th>Altitude (m)</th>
<th>Beginning Date</th>
<th>Gain (dB)</th>
<th>Filter Corner (Hz)</th>
<th>Number of Components</th>
</tr>
</thead>
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<tr>
<td>1 Tel Chehab</td>
<td>TCHB</td>
<td>35°58.13′</td>
<td>32°40.15′</td>
<td>458</td>
<td>February 1995</td>
<td>48</td>
<td>0.1</td>
<td>1</td>
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<tr>
<td>2 Sala</td>
<td>SALA</td>
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<td>32°42.68′</td>
<td>1670</td>
<td>February 1996</td>
<td>48</td>
<td>0.1</td>
<td>1</td>
</tr>
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<td>3 Zaif</td>
<td>ZALF</td>
<td>37°20.05′</td>
<td>32°55.33′</td>
<td>532</td>
<td>December 1995</td>
<td>54</td>
<td>0.1</td>
<td>3 (July 1996)</td>
</tr>
<tr>
<td>4 Dj Badran</td>
<td>BDRN</td>
<td>36°18.57′</td>
<td>33°20.45′</td>
<td>965</td>
<td>December 1994</td>
<td>54</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>5 Dj Barbar</td>
<td>BRBR</td>
<td>35°57.05′</td>
<td>33°24.68′</td>
<td>1834</td>
<td>December 1994</td>
<td>48</td>
<td>0.1</td>
<td>3 (July 1996)</td>
</tr>
<tr>
<td>6 Qussion</td>
<td>QASN</td>
<td>36°16.57′</td>
<td>33°31.97′</td>
<td>990</td>
<td>December 1994</td>
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<td>0.1</td>
<td>1</td>
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<tr>
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<td>KOOC</td>
<td>36°45.80′</td>
<td>33°39.55′</td>
<td>1120</td>
<td>December 1994</td>
<td>54</td>
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<td>3 (July 1996)</td>
</tr>
<tr>
<td>8 Ras Al Marah</td>
<td>MARH</td>
<td>36°28.90′</td>
<td>34°01.57′</td>
<td>2640</td>
<td>December 1994</td>
<td>48</td>
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<td>1</td>
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<tr>
<td>9 Abou Rabah</td>
<td>RABH</td>
<td>37°12.33′</td>
<td>34°26.13′</td>
<td>738</td>
<td>December 1994</td>
<td>48</td>
<td>0.1</td>
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<tr>
<td>10 Dj Warideh</td>
<td>WRDH</td>
<td>36°24.72′</td>
<td>35°30.48′</td>
<td>730</td>
<td>April 1995</td>
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<td>0.1</td>
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<td>September 1995</td>
<td>48</td>
<td>0.1</td>
<td>3 (September 1996)</td>
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<td>12 Al Bida</td>
<td>BIDA</td>
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<td>35°00.83′</td>
<td>930</td>
<td>November 1995</td>
<td>42</td>
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<td>1</td>
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<td>13 Dj Alarnab</td>
<td>ARNB</td>
<td>35°58.43′</td>
<td>35°50.62′</td>
<td>810</td>
<td>April 1995</td>
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<td>0.1</td>
<td>3 (August 1996)</td>
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<td>SLNF</td>
<td>36°13.37′</td>
<td>35°35.73′</td>
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<td>December 1994</td>
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<td>1</td>
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<td>35°12.75′</td>
<td>650</td>
<td>December 1994</td>
<td>42</td>
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<td>1</td>
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<tr>
<td>16 Batraich</td>
<td>BTCH</td>
<td>36°27.55′</td>
<td>36°02.25′</td>
<td>803</td>
<td>April 1995</td>
<td>48</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>17 Darouich</td>
<td>DRWC</td>
<td>36°40.00′</td>
<td>36°37.27′</td>
<td>920</td>
<td>April 1995</td>
<td>48</td>
<td>0.1</td>
<td>1</td>
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<tr>
<td>18 Dj Al Wahab</td>
<td>WHAB</td>
<td>37°33.12′</td>
<td>35°55.03′</td>
<td>930</td>
<td>April 1995</td>
<td>54</td>
<td>0.1</td>
<td>3 (September 1996)</td>
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<tr>
<td>19 Al Salmeh</td>
<td>SALM</td>
<td>37°56.10′</td>
<td>36°12.47′</td>
<td>520</td>
<td>April 1995</td>
<td>54</td>
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<td>20 Al Jahlan</td>
<td>JHLN</td>
<td>38°26.47′</td>
<td>35°40.35′</td>
<td>459</td>
<td>April 1995</td>
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<td>21 Al Saraym</td>
<td>SRYM</td>
<td>39°37.04′</td>
<td>34°38.44′</td>
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<td>22 Al Bishri</td>
<td>BSHR</td>
<td>39°29.23′</td>
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<td>23 Darb Al Tahta</td>
<td>DRBT</td>
<td>39°29.23′</td>
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<td>597</td>
<td>April 2002</td>
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<tr>
<td>24 Al Mazarekh</td>
<td>MZRK</td>
<td>40°39.12′</td>
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<td>25 Kbs Dag</td>
<td>KBSD</td>
<td>40°32.30′</td>
<td>36°59.35′</td>
<td>526</td>
<td>April 2002</td>
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<td>SFYN</td>
<td>40°06.30′</td>
<td>36°24.20′</td>
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<td>April 2002</td>
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<td>27 Al Monkr</td>
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<td>35°55.52′</td>
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<td>April 2002</td>
<td>54</td>
<td>0.1</td>
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</table>
GENERAL DESCRIPTION OF THE SYRIAN TELEMETRY NETWORK

Responding to the PAMERAR initiative of 1982, the initial spatial design of the national network was undertaken in 1985 by a select group of Syrian geophysicists, engineers, and geologists in cooperation with technical and scientific staff from Cornell University. Factors such as topography, accessibility, and property rights influenced the site selection but did not compromise the final design. Site noise (natural and artificial) and radio-frequency interstation path-viability studies were contracted to Kinematics experts aided by Syrian engineers and were reviewed and approved by GEGMR.

Each site consists of:
- Detailed geographic and topographic survey of the immediate area and exact vault location verified using GPS data.
- Protective security fence around the total land parcel.
- Careful excavation of vault area down to consolidated bedrock sufficient for installation of 2–3-m-tall prefab steel vault enclosures.
- Cylindrical steel vault cemented to bedrock surface, as can be seen in Figure 3.
- Concrete antenna mast base (support) and anchors poured, mast erected.
- Power, data cable raceways, and lightning protection grounding grid dug in and backfilled.

An ingenious seismic vault concept was used by civil engineers from GEGMR to allow for portability to difficult remote site locations and vertical flexibility to accommodate various depths of bedrock overburden encountered. The design was as follows: 1-m-tall flanged steel cylinders (approximately 1.5-m diameter) that could be easily bolted together, compressing a rubber interface gasket. The internal flanged joints also served as electronic cabinet support fixtures. Use of multilayered ethafoam planking provided thermal (extreme heat or extreme cold) insulation to the seismic sensor and system electronics area. Removable ladder access was provided at all sites. A zero-vertical-profile clamshell-type vault opening eliminated considerable wind-shear noise and allowed for easy entrance under difficult meteorological conditions.

The circular 1.8-m² instrument pier surface allows for installation of three SS-1 type seismometers, a strong-motion accelerograph, and sufficient floor area to service instrumentation and access the electronics cabinet. Figure 4 shows a detailed cross-section of the vault that became a recommended standard for other national seismic networks by an international seismological agency (Bormann, 2002).

The voltage (proportional to earth velocity) generated by the SS-1 seismometer is selectively (switch control) filtered and amplified by AM-2 amplifier filter module and then converted from voltage amplitude variations to a center frequency modulated in proportion to those variations using an OM-2 voltage control oscillator. This FM signal is input to a very low-wattage RF transmitter for transmitting via six elements horizontally or vertically polarized Yagi antenna to a matched at the receiver central station, repeater site. The CM-2 module contains an automatic calibration internal clock and switch circuits for independent daily step-function calibration of the whole system.

Each field station includes:
- SS-1 seismometer (single- or three-component 1 Hz with calibration coil).
- Electronics enclosure, housing.
- Supply battery (12 V truck type).
- TH-11 box containing power supply board, AM-2 amplifier filter module, OM-2 voltage controller oscillator module, CM-2 calibration module, PP-13 power, and I/O input/output board.
- The metal tower on which the horizontally or vertically polarized VHF or UHF RF Yagi antennas are mounted also support the solar panels capable of charging system batteries even in the event of many cloudy or overcast days.

NOISE AND SIGNAL CONDITIONS AT SNSN STATIONS

One important aspect of satisfactory operation of a seismic telemetry network involves the initial and periodic calibration of the overall system. Without calibration and first-order time control there is no basis for quantitative comparison of results from observatories throughout the region.

During systemization of SNSN’s hardware and electronic components at the manufacturer’s facility, very precise
system calibration was performed and detailed data sheets were provided. Since field calibration within Syria, either
dynamic (sinusoidal signal through the seismic band pass) or
via daily step-function pulses, cannot match the quality of the
factory calibrations, both the above-mentioned methods are
used for periodic assurance that the initial installation param-
eters remain somewhat constant (±5% of factory certifica-
tion). Response curves and magnification values for each
component (vertical and orthogonal horizontals) therefore
should remain reliable.

The site selection and noise study were conducted by
Kinemetrics, Inc. (Kinemetrics, Inc., 1994) using a SS-1 seis-
mometer and PS-2 Portable Analog Recorder System. We
present here the digital noise level of some stations, illustrat-
ing the best site, ZALF; an average station, BIDA; and the
worst site, JHLN (Figure 5), in comparison to the new seis-
ic high- and low-noise model proposed by Peterson (1993),
as well as the response curve for BIDA.

THE CENTRAL STATION

The central station is located in Damascus, at 36:18:18°E
and 33:31:42°N, 700 m above sea level. It receives all trans-
mitted signals from:

- The southern network consists of nine stations (1–9 in
  Figure 2) transmitting on four VHF frequencies to the
center by multiplexing station signals.
- The northern network consists of eleven stations (10–20
  in Figure 2). Signals are processed and transmitted to the
town of Hama on five frequencies. All signals are sent via
three phone lines from Hama to Damascus.
- The eastern network consists of seven stations (21–27 in
  Figure 2). Signals are processed and transmitted to
Raqqa central station via three frequencies. All signals are
then sent via two phone lines from Raqqa to Damascus.

Incoming signals at the central station are discriminated in
real-time and recorded in both analog form on five dual-pen
recorders and digital form via a 16-bit A/D digitizing
board on the hard disk of the server and two removable hard
disks. Data are not time-coded at the network stations. Preci-
sion network timing for both analog and digital data sets was
provided at the central station via LORAN transmissions to
True Time’s Omega digital timing receiver until 31 August
1997; from 1 February 1998 until the present a multisatellite
GPS time-code receiver and encoder system (True Time) has
been used exclusively. The data management and analysis are
done by center specialists using a computer net system con-
sisting of a server and many computers (Figure 6). This work

▲ Figure 4. Cross-section through a seismometer vault of the Syrian National Seismological Network field stations.
Figure 5. Noise spectra for ZALF, BIDA, and JHLN stations from the SNSN. Sample time is 60 seconds at 100 sps for all three stations. NLNM and NHNM are the new low- and high-noise models respectively proposed by Peterson (1993). Included is response curve for BIDA.

Figure 6. A schematic showing recording and analog display earthquakes data system operating in the main center at Damascus (Kinematics, Inc., 1995).
started in 1995, and the system used is Seismic Work Station (SWS), which is discussed in the following section.

**DATA ANALYSIS**

**Seismic Work Station (SWS):**
The SWS software is an integrated set of seismic data-analysis programs designed to provide maximum analytical capacity using standard IBM-compatible PC hardware. The software is modular, and most application programs are written in FORTRAN. Three types of software are needed with the workstation: interface, application, and commercial. Interface software is used to retrieve data and bring them into the seismic workstation. Once the data are in the system, the application software can be used for general editing or for doing specific analytical tasks. All workstation users need the Time Series Editor to perform data format conversion and edit data prior to the use of other applications. These include strong-motion data analysis software, vibration survey software for Fourier transforms and spectral analysis, and seismological data analysis software, which is a valuable tool for analyzing data recorded by seismic SNSN stations. Source code is optional for all applications. Commercial software is used to edit and modify the application software.

**System Software**
The seismic network application software (SNAP) implements a flexible central event recorder for an on-site or telemetered array of up to 64 channels. User-selectable parameters include:
- Digital sample rate (up to 100 sps for 64 channels).
- Number of channels recorded.
- Continuous or triggered recording.
- Trigger algorithms ratio or difference of STA/LTA, (short-term average/long-term average).

The effectiveness of the SNSN stations can be demonstrated by comparing Figure 7 with Figure 8, which show the difference between ISC locations and SNSN locations during the same periods of time and geographical coordinates. Figure 9 shows earthquakes recorded by SNSN during the period from 1995 to June 2003.

The field stations were internationally coded, and the phase readings are published and distributed regularly to all regional and international seismological centers. The network has been designed to be a technologically sophisticated system and fundamentally adequate to meet important needs for qualification of seismic hazards and risks associated with natural earthquakes. The data from the SNSN are freely available to researchers who might be interested in scientific cooperation projects directly with SNSN.
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▲ Figure 7. Earthquake activity in the area documented by International Seismological Centre recordings from 1 January 1995 to 3 March 2001.
Figure 8. Earthquake activity in the area documented by Syrian National Seismological Network recordings from 1 January 1995 to 3 March 2001.

Figure 9. Earthquake activity in the area documented by Syrian National Seismological Network recordings from 1 January 1995 to 31 June 2003.
CONCLUSIONS

The Syrian National Seismological Network is equipped with suitable hardware and software for digital data acquisition and processing. It is capable of interactive computer-assisted data analysis and evaluation. This allows extraction of both seismic event parameters and waveform data according to internationally recommended standards, and subsequent use of the data for various seismological research efforts. The SNSN covers a significant portion of the north Arabian Plate, including the Arabian-African plate boundary along the seismically active Dead Sea fault system (DSFS).

ACKNOWLEDGMENTS

We thank the General Establishment of Geology and Mineral Resources for providing us information and data for this paper. We are appreciative of a helpful review and suggestions provided by Muawia Barazangi. We also acknowledge the Syrian National Seismological Network staff, especially Lina Jbour for her excellent English review.

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General Establishment of Geology and Mineral Resources
Damascus
Syria
(R.D., M.M.)

Higher Institute of Earthquake Studies and Research (HIESR)
Damascus University
Damascus
Syria
fax : +963 11 2137161
m-daoud@scs-net.org
(M.D.)

George Hade
Institute for the Study of the Continents
Cornell University
Snee Hall
Ithaca, NY 14853
U.S.A.
(G.H.)