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DISSEMINATION OF EUROPEAN STRONG-MOTION DATA, VOLUME 2

Nicholas N. AMBRASEYS[1], John DOUGLAS[2], Ragnar SIGBJÖRNSSON[3], Catherine BERGE-THIERRY[4], Peter SUHADOLC[5], Giovanni COSTA[6] and Patrick M. SMIT[7]

SUMMARY

This paper describes a new CD ROM of European and Middle Eastern strong-motion data that has just been released. The CD ROM contains corrected acceleration, velocity and displacement time-histories of 462 triaxial strong-motion records from 110 earthquakes and 261 stations in Europe and the Middle East. In addition, it also contains linear elastic response spectra, inelastic (elastoplastic) constant strength spectra and inelastic (elastoplastic) constant ductility spectra. The associated earthquake, station and waveform parameters of these 462 records are also present on the CD ROM so that full use can be made of the data. These data were selected using strict selection criteria and so they are the Eurasian data for which most information exists. All of these data can be viewed and analyzed using the Strong-Motion Datascape Navigator (SMDN) software provided on this CD ROM. SMDN allows you to export the time-histories, spectra and the associated parameters of records to ASCII files in a standard format. SMDN can also be used to view and analyze data downloaded from the Internet Site for European Strong-motion Data (www.isesd.cv.ic.ac.uk).

INTRODUCTION

The Internet Site for European Strong-motion Data (ISESD, http://www.isesd.cv.ic.ac.uk) [1,2] provides a platform for the dissemination of large amounts of strong-motion data and associated parameters to any interested parties. However, because of the large quantities of data on ISESD it is not possible to

[1] Dept of Civil & Environmental Eng., Imperial College London, UK, Email: n.ambraseys@imperial.ac.uk
[2] Dept of Civil & Environmental Eng., Imperial College London, UK. Email: john.douglas@ukonline.co.uk
[3] Earthquake Engineering Research Centre, University of Iceland, Selfoss, Iceland, Email: ragnarz@afl.hi.is
[4] Institut de Radioprotection et de Sûreté Nucléaire, Fontenay aux Roses, France, Email: catherine.berge@irsn.fr
[5] Dipartimento di Scienze della Terra, Universita degli studi di Trieste, Trieste, Italy, Email: suhadolc@dst.univ.trieste.it
[6] Dipartimento di Scienze della Terra, Universita degli studi di Trieste, Trieste, Italy, Email: costa@dst.univ.trieste.it
[7] Currently at National Emergency Operations Centre, Zürich, Switzerland, Email: smp@naz.ch

individually correct each record using individually-selected filter parameters. Nor is it possible, at present, to provide users of ISESD with the additional information on earthquake, path and site characteristics that exist for some of the records in the database. In addition, the search facilities on ISESD are limited to geophysical criteria.

Therefore a new CD ROM has been produced that provides a selection of 462 Eurasian strong-motion records including extra information currently not given on the Internet site, such as shear-wave velocity profiles, photos of stations and extra source parameters. The strong-motion records are individually corrected with a rigorously selected correction procedure and cut-offs and a correction for the instrument response is applied. It is hoped that this CD ROM is a good source of records for most engineering investigations, especially in industry, which need a smaller number of high-quality engineering-significant records with good associated parameters. In the summer of 2002 we conducted an email survey of people who use the original CD ROM [3] and/or ISESD [1,2] to ask what features they would like to see in a new CD ROM. Many of the features included in the navigator on this CD ROM were requested during that survey.

Strong-Motion Datascape Navigator (SMDN) provided on this CD ROM allows you to access the archived information via a user-friendly environment. Numerous types of graphs can also be plotted. SMDN also allows you to plot code design spectra so that they can be compared with the observed response spectra. The codes that can be plotted are those from: Eurocode 8 [4], the Uniform Building Code 1997 [5] and the International Building Code 2000 [6]. In addition, user-defined code spectra can be plotted to compare with the observed spectra.

BACKGROUND

The first accelerograms were recorded during the Long Beach (11th March 1933) earthquake in California. Accelerographs were not installed in Europe and the Middle East until later. The first accelerogram recorded in Europe was of an earthquake on 2nd December 1967 recorded at Debar (Macedonia) on a Teledyne AR-240. In 1992 it was estimated that about 2,400 permanent and temporary strong-motion instruments were then in operation in the Eurasian region run by about 200 different organizations [7].

The routine collection of strong-motion data at Imperial College started in 1971 and included the installation of Kinemetrics SMA-1s in Ghir (Iran) in 1972 and in Peshawar (Pakistan) in 1975. Bommer & Ambraseys [7] provide details of the VAX-based database and databank system operational at Imperial College during the 1990s. In 1998, this database and databank was converted to a Microsoft Access system running on a PC. As part of this process a new file format and slightly different database concept were adopted.

In 2000, a CD ROM containing 1,068 mainly triaxial strong-motion records was released [3]. The CD ROM provided a snapshot of strong-motion data then available from Europe and the Middle East but since the amount of strong-motion data is continually increasing, it no longer fully represents the current state of strong-motion data in Europe and the Middle. Also some of the associated parameters of the time-histories archived on the CD ROM have been re-evaluated because new information has become available.

In order to overcome some of the short comings of the original CD ROM, an Internet site, known as the Internet Site for European Strong-motion Data (ISESD, http://www.isesd.cv.ic.ac.uk) was established from which users can freely download strong-motion data and associated parameters. Due to the nature of the Internet and of the relational database underlying the site, new data can be easily added to the databank and changes to the associated parameters can be made. As was stated in the introduction, the actual design of ISESD does not allow complex searches and also the data archived on ISESD is of varying quality. Consequently a new CD ROM has been developed in order to overcome these problems, which is strongly linked to ISESD.

DATA SELECTION

The main purpose of this new CD ROM is to provide practising engineers with a set of strong-motion records whose associated parameters are complete and reliable and which are of high-enough quality to be used for most engineering applications. Since additional records can be obtained from ISESD and imported into SMDN for analysis the data selection criteria for the data provided on the CD ROM is quite strict. The criteria adopted are given below.

1. Estimate of seismic moment, M_0, is available.
2. Estimate of surface-wave magnitude, M_s, is available.
3. Estimated focal mechanism in terms of strike, dip and rake (or equivalently the orientation of the P, T and B axes) is available.
4. Estimated fault geometry is available if M_w>5.5.
5. Detailed site description or near-surface shear-wave velocity of recording station is available.
6. Uncorrected acceleration time-history is available.
7. Natural frequency and damping are available if the instrument is analogue.
8. All three (two horizontal and one vertical) components are available.
9. Acceleration time-histories are of high quality.

Figure 1 shows the distribution of records selected for the new CD ROM in terms of magnitude and distance. It shows that the distribution is reasonably uniform but that, as is often true, there is a lack of records from large magnitude earthquakes especially at near-fault distances. This is partly caused by the lack of instrument characteristics and local site conditions.

In total 462 records were selected of which 111 have an associated photograph of the recording station and 137 have an associated near-surface shear-wave velocity profile.

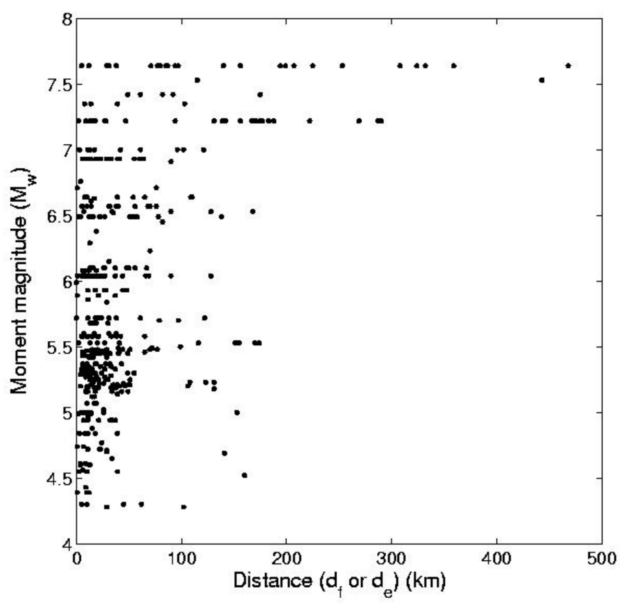


Figure 1: Distribution of selected records in terms of magnitude and source-to-site distance

Correction technique

In order to provide corrected acceleration, velocity and displacement time-histories that are reliable a correction procedure was adopted that used individual filter cut-off frequencies for each record. The correction technique implemented in the Basic Strong-Motion Accelerogram Processing (BAP) software [8] was used for the correction of all of time-histories contained on this CD ROM. This method consists of: interpolation to 200 samples a second; a correction for the instrument response, when the required characteristics are known, and high-cut filtering, with a cosine transition from the roll-off frequency to the cut-off frequency; followed by low-cut bidirectional Butterworth filtering of the acceleration after padding the time-history with zeros. The main problem with filtering strong-motion records is the selection of appropriate cut-off frequencies for the high-cut and, particularly, low-cut filters. For this CD ROM a method based on the estimated signal-to-noise ratio of each record was used.

Time-histories from digital instruments often include long-enough pre-event portions to use as an estimate of the noise. Therefore for those records with pre-event portions the Fourier amplitude spectrum of this noise estimate was computed as was the Fourier amplitude spectrum of the rest of the signal and the ratio was calculated. The low cut-off frequency was chosen from this spectrum as the frequency at which the signal-to-noise ratio becomes less than two. The instrument-corrected and filtered displacement time-history was then plotted and the cut-off frequencies altered slightly if the displacement trace did not look realistic. The cut-off frequencies often did not need changing.

It is more difficult to choose cut-offs for records from analogue instruments because often estimates of the noise do not exist. Most films from analogue instruments feature a fixed trace, which record the position of light beams reflected from mirrors attached to the instrument case [9]. Since these traces do not record the ground motions, if they were digitized in the same way as the ground motion traces they would provide the best estimate of the recording and digitization noise. Unfortunately, however, they are not often digitized or disseminated; only 123 records in the complete Imperial College strong-motion archive (of about 8,000 records) have an associated digitized fixed trace. For those time-histories that have such a digitized fixed trace they were used to select the low cut-off frequency in the same way as was done with the records with pre-event portions.

For those records from analogue instruments with no available fixed trace, the upper edge of the average hand digitization noise estimate from Figure 8 of Trifunac & Todorovska [10] was used as an estimate of the noise. This estimated noise spectrum may be too high for many records that were digitized on automatic or semi-automatic digitizing tables but because the digitization procedure is unknown for most records it was thought to be a conservative estimate. This signal-to-noise ratio spectrum and the signal's Fourier amplitude spectrum were used to estimate the low cut-off frequency. The Fourier amplitude spectrum was examined following the suggestion of Zarè & Bard [11] that Fourier amplitudes that do not tend to zero at low- and high-frequencies are evidence for noise. The estimated cut-off frequency were often varied if it was found that the displacement traces were not realistic or if it was found that a less strict cut-off frequency could be used and still obtain a realistic displacement trace. Even with the techniques adopted here for the selection of cut-off frequencies for records from analogue instruments with no digitized fixed traces there is still some subjectivity in the process.

After choosing the appropriate cut-off frequency for each component (two horizontal and one vertical) of a strong-motion record a single cut-off frequency was chosen for all three components for consistency. The choice of this single cut-off was difficult for some records because the generally lower amplitude vertical ground motions imply that often the appropriate low-frequency cut-off for vertical components is higher than for the corresponding horizontal components.

The high-frequency filtering was accomplished using the commonly-chosen roll-off frequency of 23 Hz and a cut-off of 25 Hz for records from analogue instruments and a roll-off of 50 Hz and a cut-off of 100 Hz for records from digital instruments [e.g. 8]. Since most digital instruments have natural frequencies of about 50 Hz, and some of those with lower natural frequencies correct for the instrument response automatically, the effect of instrument correction is not large and therefore the requirement to apply a high-cut filter is less than for records from analogue instruments.

STRONG-MOTION DATASCAPE NAVIGATOR

New software, called Strong-Motion Datascape Navigator (SMDN), was written to select, view and analyze data provided on the new CD ROM. This program was written using Matlab 6.5.1 from Mathworks and then compiled (using Matlab Compiler 3.0.1) to create a stand-alone program that can be used on PCs with or without Matlab installed.

Figure 2 shows a screenshot of the main window in SMDN. This window lists all the currently selected records grouped by earthquake in ascending date order. Under a header line for each earthquake giving the main parameters for the earthquake (name, date, time, location, magnitude and mechanism), the associated waveforms for this earthquake are listed along with their main parameters (station, source-to-site distances, local site category and a selection of strong-motion parameters). Earthquakes and records can be selected by clicking on their entries in this list.

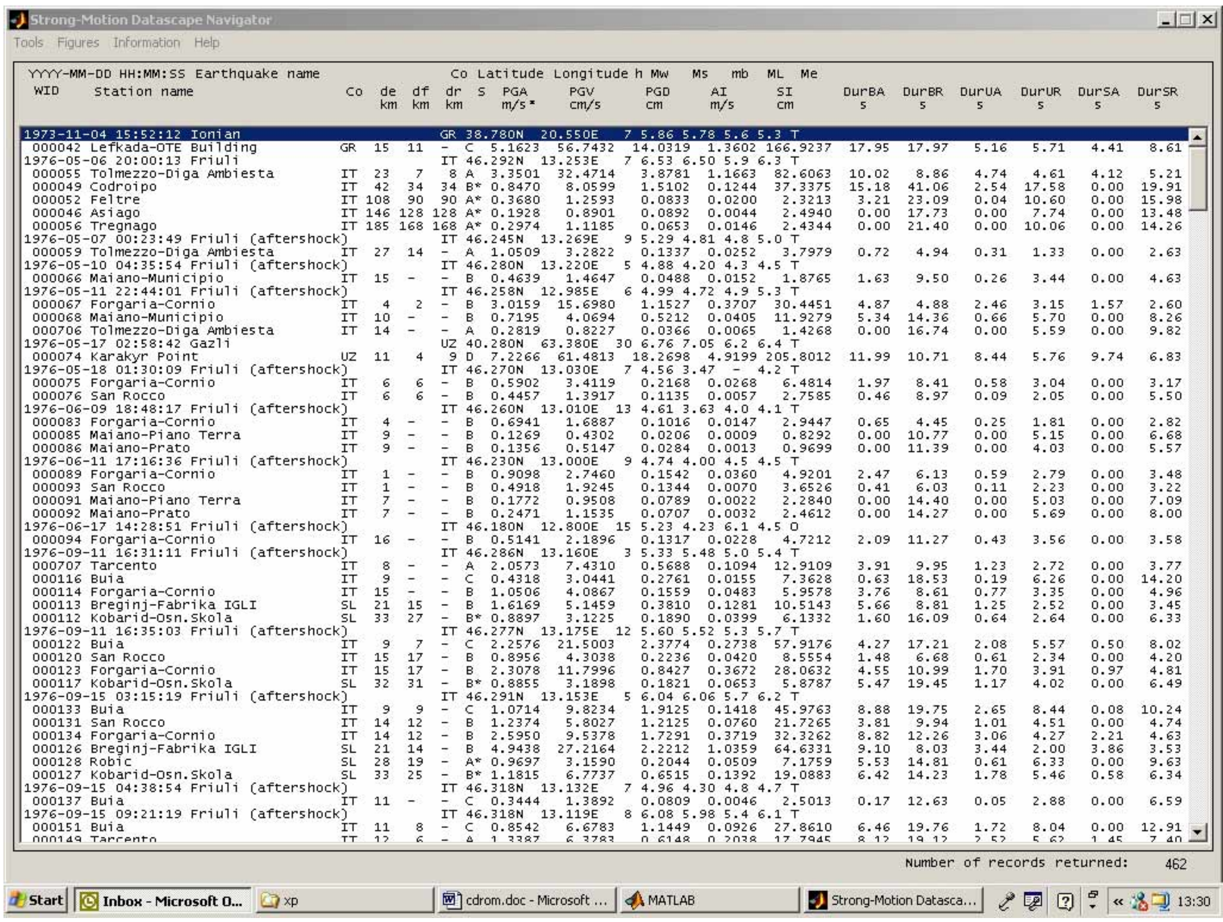


Figure 2: Screenshot of main window in SMDN showing main characteristics of available records.

SMDN calculates a large number of strong-motion parameters, many of which can be used as search criteria (see below). Also it allows the user to plot the following graphs that are useful for strong-motion analysis:

1. acceleration, velocity and displacement time-histories;
2. linear elastic response spectra;
3. normalized linear elastic response spectra;
4. linear elastic response spectra using the tripartite representation;
5. pseudo-spectral acceleration versus spectral displacement;
6. inelastic ductility demand spectra;
7. inelastic strength demand and inelastic spectral velocity spectra;
8. strength demand versus ductility demand for a given natural period and damping;
9. Husid plot, i.e. Arias intensity versus time;
10. normalized energy density versus time;
11. absolute Fourier amplitude spectra (these can be smoothed);
12. horizontal to vertical ratio of the Fourier amplitude spectra (including user-defined smoothing);

All of these graphs (except number 1) can be plotted for a number of records simultaneously, thereby aiding comparison of different records. Graphs displaying linear elastic response spectra can be plotted to also display a chosen design spectra.

Maps showing the locations of the strong-motion stations that recorded accelerograms during a particular earthquake can be drawn using SMDN. These maps also show the epicentre and if known the location of the causative fault. On these maps the recorded acceleration, velocity and displacement time-histories can be plotted to aid understanding of the spatial variability of the strong ground motions. An example of such a map is shown in Figure 3.

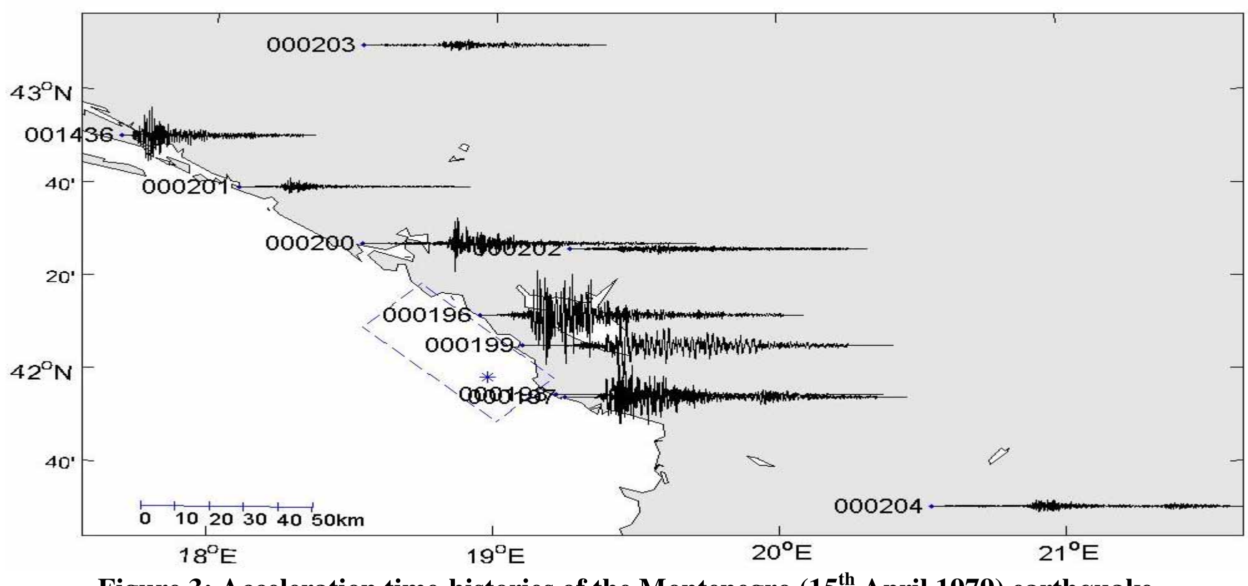


Figure 3: Acceleration time-histories of the Montenegro (15th April 1979) earthquake.

If there is a photograph of a recording station then this is displayed when the station information is viewed. Also, if available, the shear-wave velocity profile of the recording station is also shown.

Knowledge of the crustal structure in the region where an earthquake occurred can be useful in analyzing the recorded strong motion. SMDN gives the user the possibility to plot the crustal structure at the epicentre and at the station by utilizing the CRUST2.0 [12] model. An example of the station information page, displaying the near-surface velocity profile, the crustal structure profile and the photograph of the recording station is shown in Figure 4.

In addition to selecting, viewing and analyzing data provided on the CD ROM SMDN allows the user to import data from ISESD and use the data in a similar way. Since ISESD does not provide all the associated parameters as provided for the inbuilt data, nor does it provide constant strength or constant ductility inelastic spectra some features are disabled when SMDN is used with ISESD data.

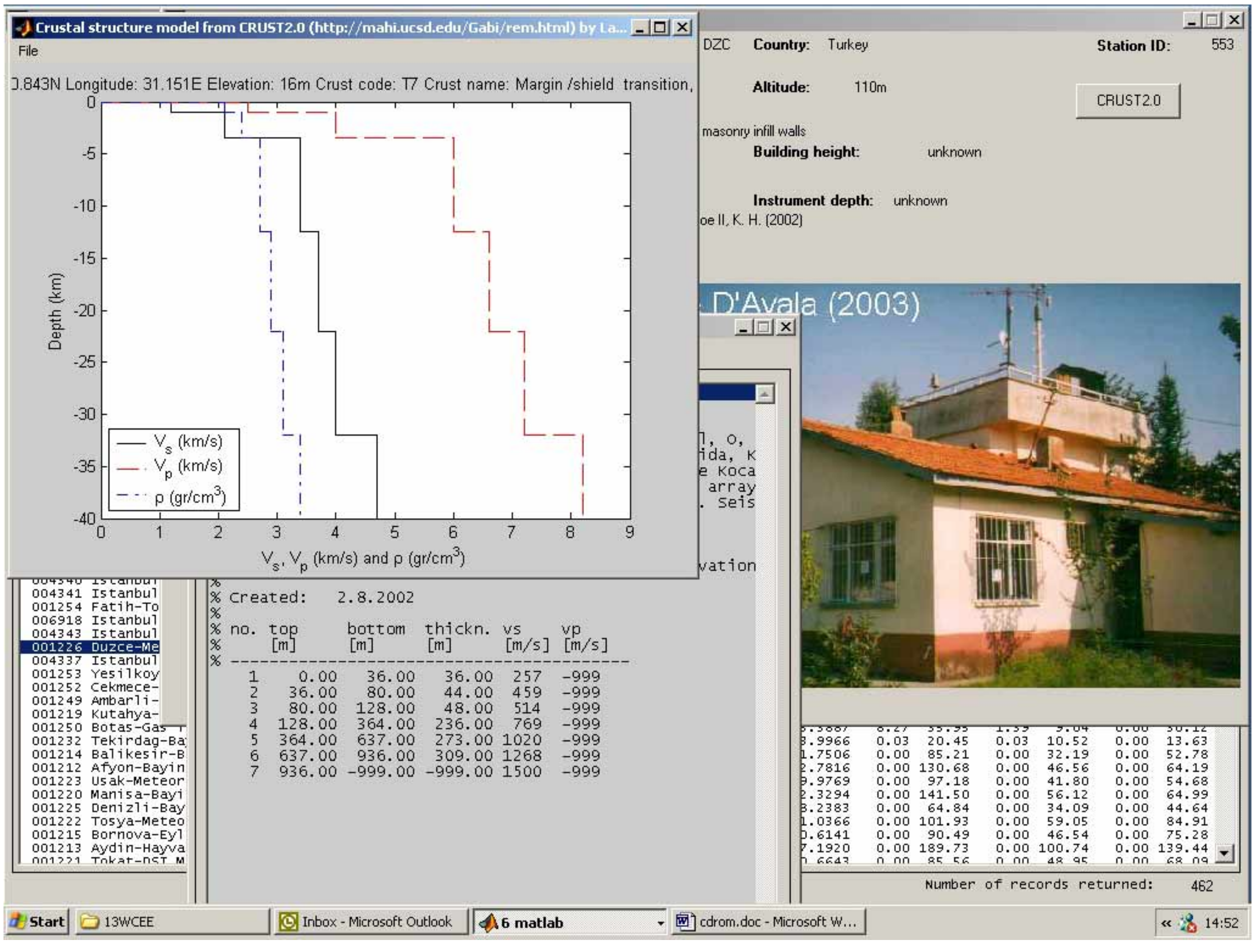


Figure 4: Screenshot showing an example of the station information window in SMDN.

IMPORTING DATA FROM ISESD

One inherent problem with CD ROM collections of strong-motion data is that it is always a snapshot of the data available at the time when the data is released. Consequently additional data cannot be added and the associated parameters of the records cannot be changed. Internet sites, such as ISESD, do not suffer from this problem, since additional data can be added reasonably easily and changed made. However, as was mentioned above, it is difficult to provide tools for making complex searches and plots on Internet sites and therefore data must be downloaded and imported into separate programs for viewing and analysis. SMDN provides such a tool.

When a user selects data from ISESD, the uncorrected and corrected time-histories and the linear elastic response spectra files are available for download and an email is received from ISESD with a parameter file attached. The user must then uncompress all the downloaded files and place them on their computer for easy access. Once SMDN is started the user is asked whether data from ISESD is to be analyzed. Once this choice is made SMDN reads in the downloaded data into the memory using the parameter file from ISESD to make the connections between earthquakes, stations and waveforms. These data can then be viewed and analyzed in the same way as the in-built data can be.

SEARCHING

In previous CD ROM strong-motion data collections [e.g. 3, 13] and on Internet sites providing strong-motion data (e.g. ISESD and COSMOS, http://db.cosmos-eq.org/) the search criteria that can be used are limited to geophysical parameters such as earthquake magnitude, source-to-site distance and local site category and possibly a handful of simple strong-motion parameters, such as peak ground acceleration. Such criteria, although useful, do not allow the user to find records that match criteria defined in terms of strong-motion parameters, which are often the only parameters researchers or designers know. For example, if a user wants a selection of time-histories to use to test a structure with a given natural period and damping subjected to shaking specified by a seismic design code then the spectral ordinate for that given period and damping is known and not the magnitude and distance of the target event. Therefore, in this new CD ROM the geophysical and strong-motion parameters specified in Table 2 can be used as search criteria.

Table 2: Allowable search criteria in SMDN

Geophysical	Source	Path	Site
	Name Country Date Location (Lat. & Long.) Focal depth Magnitude (M_w, M_s, m_b & M_L) Mechanism	Epicentral distance Hypocentral distance Fault distance Rupture distance	Name Country Location (Lat. & Long.) Site class $V_{s,30}$
Waveform	Amplitude	Duration	Frequency
	PGA Effective PGA PGV PGD Arias intensity Spectral intensity	Absolute bracketed Relative bracketed Absolute uniform Relative uniform Absolute significant Relative significant	Spectral intensity Spectral shape

The thresholds and limits, for example those used for the computation of the absolute bracketed duration or the spectral intensity, used for the different strong-motion parameters can be altered by the user.

SPECTRAL MATCHING – CASE STUDY

One option for searching that is useful in current earthquake engineering practice is to find time-histories that match a specified design spectra such as that specified by a building code. The selected time-histories can then be used for detailed nonlinear analysis of the proposed structure.

In the literature there does not seem to be any clear guidance as to how spectral matching should be performed. Therefore, in SMDN the following method is proposed and is used. Since no observed response spectra will exactly match the required spectrum this browser will return those records whose spectrum matches the specified spectrum to a certain user-defined degree. We define the average root-mean-square deviation of the observed spectrum from the target spectrum, D_{rms}, defined at user-specified frequencies, as the square of the mean sum of squares difference between the normalized observed and target spectra. The user can specify a maximum value for this quantity and then the browser returns those time-histories with D_{rms} values less than that specified. This spectral matching can be combined with the other search criteria specified above. For a discussion of spectral matching using this and other techniques see Bommer & Acevedo [14].

As an example of this technique, the CD ROM was used to find a selection of records that fit the median elastic response spectrum for M_s=5 and d_f=10km at a rock site estimated using the equations of Ambraseys et al. [15]. The target response spectrum from these equations was computed at ten equally-spaced periods from 0.1 to 1.0s and the normalized spectral shape (i.e. the estimated spectral accelerations divided by the estimated peak ground acceleration) was computed. This was input into the browser using the search window (see Figure 5).

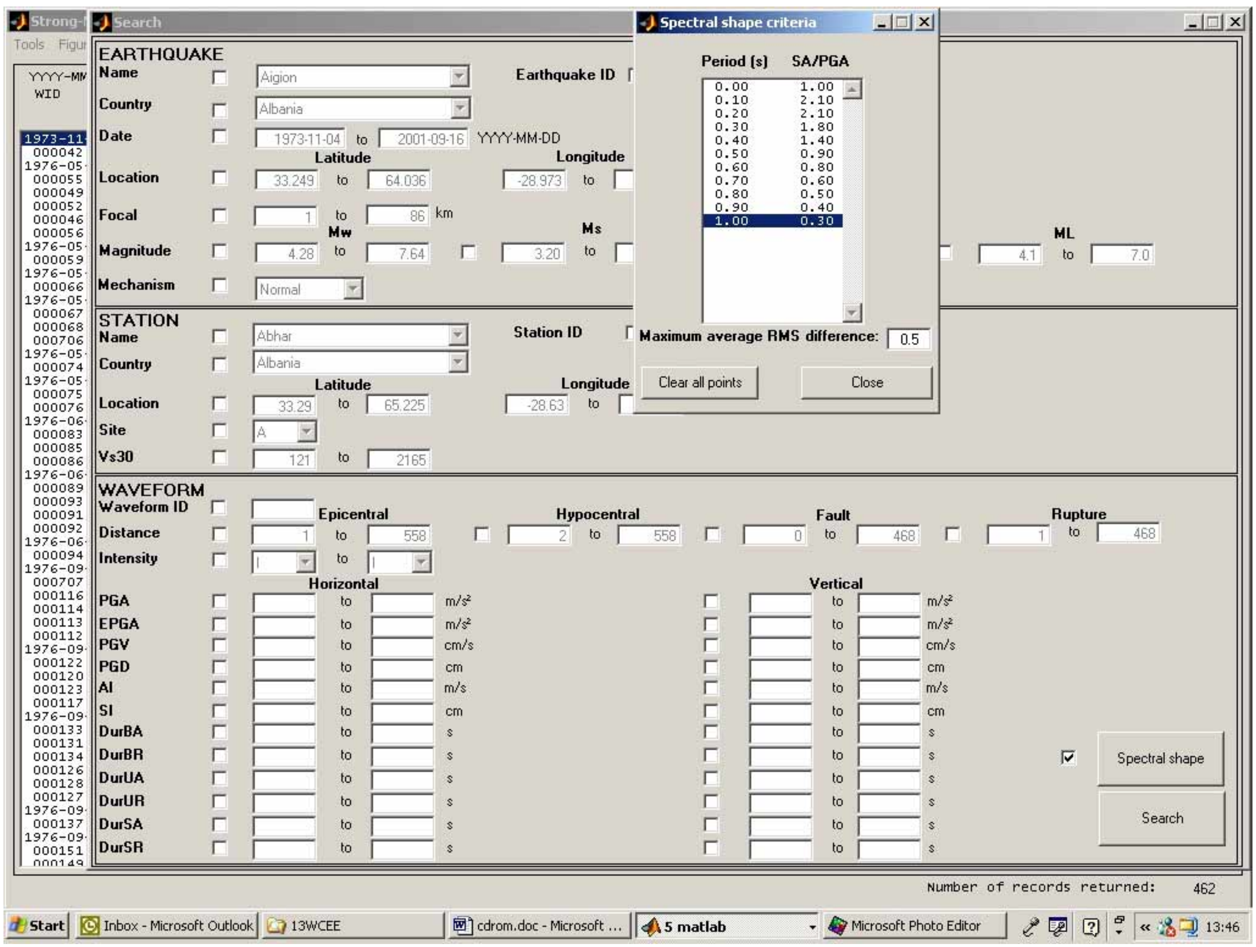
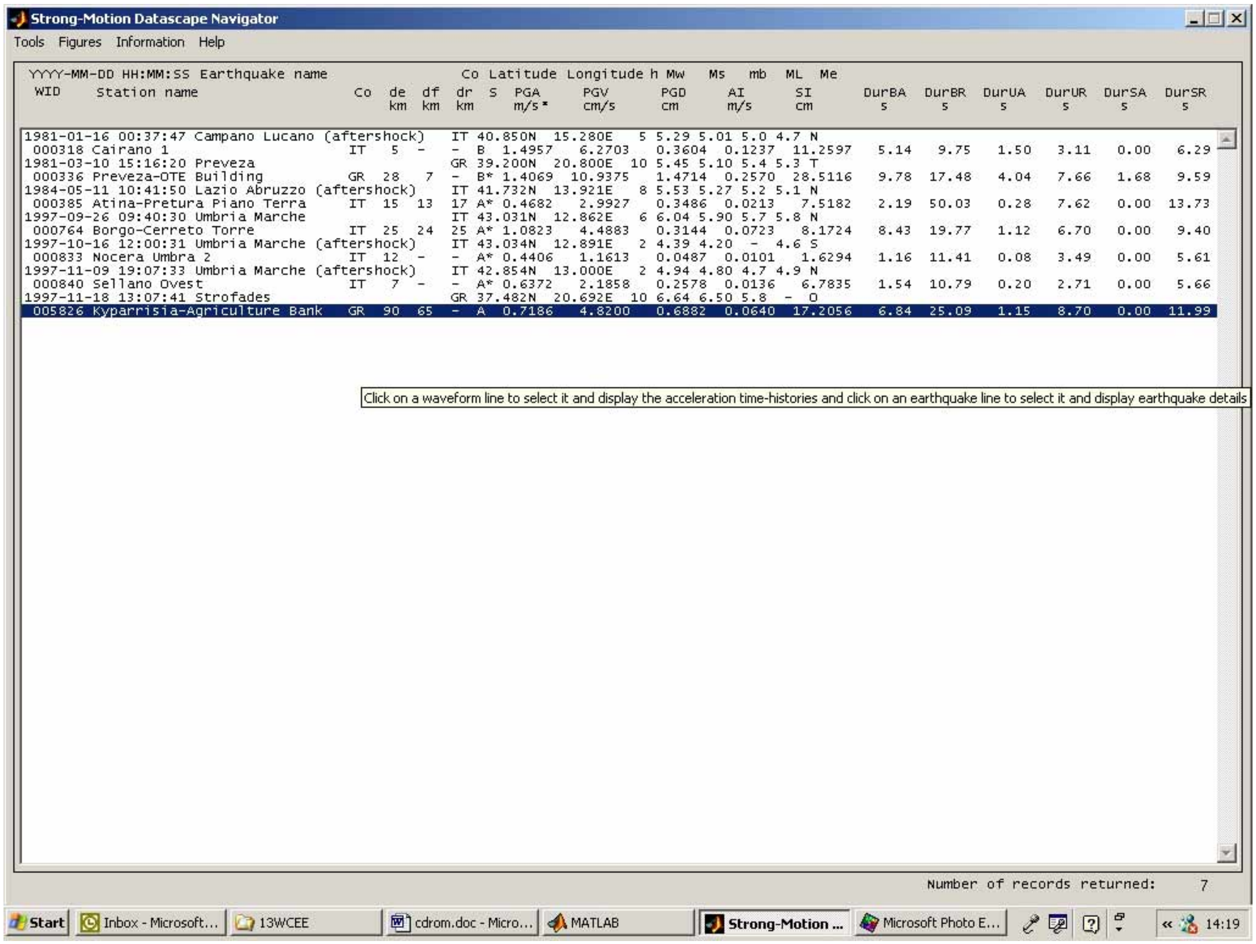


Figure 5: Screenshot showing inputting of normalized spectral shape into SMDN.

Firstly, a maximum root-mean-square deviation of the observed spectrum from the required spectrum, D_{rms}, of 0.5 was selected. This returned 259 records. To reduce this number, D_{rms}, was changed to 0.25. This lead to 41 records being selected. One suggestion about scaling acceleration time-histories is that the scaling factor should not be less than 0.5 or greater than 2.0. Therefore this was used as a further selection criterion in the search window by limiting the search to return records with PGAs between 0.42 and 1.68ms^{-2} (the predicted PGAs given by the equations of Ambraseys et al. [16]). This further reduced the number of records returned to 18. Time-history analysis often requires only a handful of records, therefore the maximum D_{rms} was reduced further to 0.2. This gives a final selection of seven time-histories. A screenshot displaying the characteristics of these seven records is shown in Figure 6.

Figure 7 displays the normalized spectral shape of the selected records as well as the target spectral shape. As can be seen the selected records match the target spectral shape reasonably well although there is still a significant amount of mismatch.

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YYYY-MM-DD HH:MM:SS Earthquake name            Co Latitude Longitude h Mw   Ms   mb  ML  Me
 WID    Station name                 Co  de  df  dr  S  PGA     PGV      PGD     AI      SI       DurBA  DurBR  DurUA  DurUR  DurSA  DurSR
                                         km  km  km     m/s*    cm/s     cm      m/s     cm       s      s      s      s      s      s
1981-01-16 00:37:47 Campano Lucano (aftershock)  IT 40.850N  15.280E   5 5.29 5.01 5.0 4.7 N
 000318 Cairano 1                    IT   5  -   -  B  1.4957   6.2703   0.3604  0.1237  11.2597   5.14   9.75   1.50   3.11   0.00   6.29
1981-03-10 15:16:20 Preveza                      GR 39.200N  20.800E  10 5.45 5.10 5.4 5.3 T
 000336 Preveza-OTE Building         GR  28   7  -  B* 1.4069  10.9375   1.4714  0.2570  28.5116   9.78  17.48   4.04   7.66   1.68   9.59
1984-05-11 10:41:50 Lazio Abruzzo (aftershock)   IT 41.732N  13.921E   8 5.53 5.27 5.2 5.1 N
 000385 Atina-Pretura Piano Terra    IT  15  13  17 A* 0.4682   2.9927   0.3486  0.0213   7.5182   2.19  50.03   0.28   7.62   0.00  13.73
1997-09-26 09:40:30 Umbria Marche                IT 43.031N  12.862E   6 6.04 5.90 5.7 5.8 N
 000764 Borgo-Cerreto Torre          IT  25  24  25 A* 1.0823   4.4883   0.3144  0.0723   8.1724   8.43  19.77   1.12   6.70   0.00   9.40
1997-10-16 12:00:31 Umbria Marche (aftershock)   IT 43.034N  12.891E   2 4.39 4.20  -  4.6 S
 000833 Nocera Umbra 2               IT  12  -   -  A* 0.4406   1.1613   0.0487  0.0101   1.6294   1.16  11.41   0.08   3.49   0.00   5.61
1997-11-09 19:07:33 Umbria Marche (aftershock)   IT 42.854N  13.000E   2 4.94 4.80 4.7 4.9 N
 000840 Sellano Ovest                IT   7  -   -  A* 0.6372   2.1858   0.2578  0.0136   6.7835   1.54  10.79   0.20   2.71   0.00   5.66
1997-11-18 13:07:41 Strofades                    GR 37.482N  20.692E  10 6.64 6.50 5.8  -  O
 005826 Kyparrisia-Agriculture Bank  GR  90  65  -  A  0.7186   4.8200   0.6882  0.0640  17.2056   6.84  25.09   1.15   8.70   0.00  11.99
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Figure 6: Screenshot showing the seven records selected based on spectral shape and PGA.

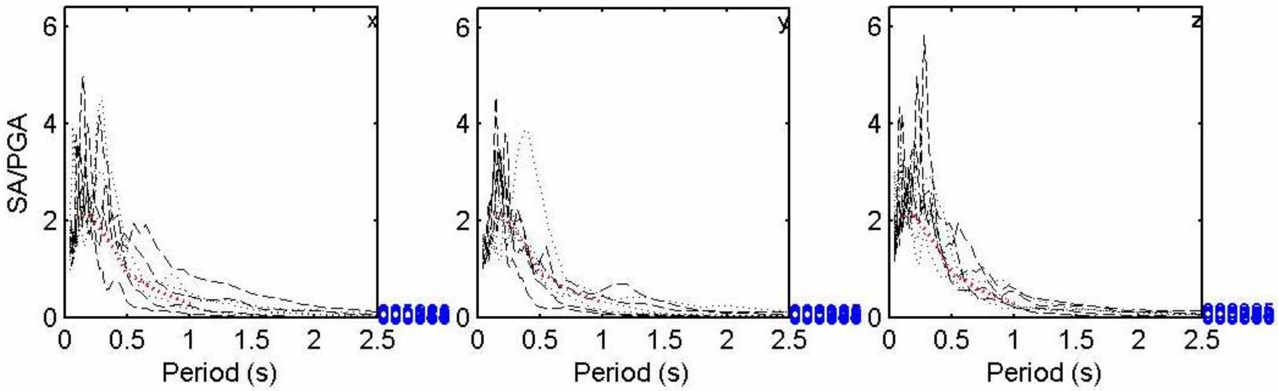

Figure 7: Normalised spectral shape (black) and target spectal shape (red) of selected records for all three components.

CENTRAL AMERICAN CD ROM

SMDN has also been used to disseminate strong-motion data from central America collected by NORSAR in two projects in the early 1990s but not disseminated until now [16]. This CD ROM contains 308 triaxial strong-motion records from 145 earthquakes and 72 stations in Costa Rica (169 records), El Salvador (87 records) and Nicaragua (52 records). The authors of this paper would be interested to hear from organizations that are interested in using SMDN to disseminate their strong-motion data.

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