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An earthquake strong-motion databank and database

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ABSTRACT: A pilot project has been carried out to make strong ground-motion data available to engineers. A databank of several thousand earthquake strong-motion records in a standard format and a relational database of associated seismological, geophysical and engineering parameters have been developed. More than 700 shallow earthquakes in the Eurasian region have been identified as having generated strong-motion records and their source parameters, including re-calculated surface-wave magnitudes, have been re-evaluated. For 863 strong-motion records from this region, source-site distances and site geologies have also been determined and entered to the database.

1 FORMATION OF DATABANK AND DATABASE

The protection of life and property from the destructive effects of earthquakes is an urgent world-wide problem. An understanding of the nature of strong earthquake ground motion is of crucial importance in solving this problem, and therefore the retrieval, uniform processing and publication of strong ground-motion data is essential for the development of building codes and design methods for large engineering structures, and also for the development of near-field seismology.

1.1 The need for a databank of earthquake strong-motion records

The effective earthquake resistant design of structures and lifelines requires knowledge of the dynamic properties of foundation and structural materials and also of the expected nature of the ground motions that future earthquakes will produce. A large, reliable and easily accessible databank of real strong-motion records could obviate the need to generate synthetic time-histories, which are associated with many uncertainties.

In order to address this need, the most urgent task is to retrieve and compile the existing strong-motion data that has already been recorded. Thousands of strong-motion records have been obtained throughout the world, at considerable expense, and these records are an invaluable resource to those involved in seismic risk mitigation. Large amounts of existing strong-motion data remain unexploited and unavailable, denying the engineering community the opportunity to benefit from the unique insight that they provide into the nature of real earthquake-induced motions. Sophisticated dense and three-dimensional arrays have been established and the technology of strong-motion recording and processing has advanced enormously. Nonetheless, there is still a scarcity of strong-motion data from near the source of destructive earthquakes and the published data is insufficient to meet the requirements of planners and engineers.

1.2 The formation of a strong-motion databank

One of the problems that leads to the situation described above is that strong-motion records are invariably acquired from networks operated by a multitude of agencies, institutions and national research establishments, and they remain inaccessible or little known to end-users. The digitised records obtained are stored in a standard format on a networked VAXstation 3100, which allows easy access and manipulation. Provided that the origin time of the earthquake and the identification of the recording station are known, then the record will be included in the databank, even if it is of doubtful association and quality; all strong-motion data is useful, even if only to provide better understanding of the problems associated with recording and processing of accelerograms.

A general policy has been to obtain records in an uncorrected state whenever possible. This means that the record is obtained as digitised, scaled in time and acceleration and with a straight baseline fitted. The reason for this is that there are often errors present, other than the noise usually associated with analogue records and their digital conversion. Examples of such non-standard errors include arbitrary shifts in the baseline and the inclusion of spurious pulses. Each record in the databank needs to be individually inspected to check for the presence of such errors so that they can be eliminated at source. Standard processing techniques will generally conceal these errors, but not actually remove them.

All of the records will be processed using state-of-the-art techniques to compensate for the dynamic characteristics of the instrument, provided that the instrument constants are reliably known, and for the high- and low-frequency noise. The details of the correction procedure applied will be recorded since they strongly influence the nature of the time history.

1.3 The design of an earthquake strong-motion database

In order to interpret and qualify the strong-motion records in the databank it is necessary to establish a catalogue containing information about the records and also about the earthquakes and recording stations that produced them. The ideal tool for the organisation of such a catalogue is a relational database, which minimizes the repetition in storage of information and allows efficient retrieval of data.

A number of databases have been developed for earthquake strong-motion data at different centres, but it was considered worthwhile to develop a new system tailored to the specific requirements of the Imperial College databank, (Bommer 1991). The database performs two simultaneous functions. Firstly, it is a cataloguing system for the records held in digital form, and secondly, it is a catalogue for records which have been identified, and for which peak recorded accelerations are known, but which are not yet in the databank.

The relational database system chosen is Rdb/VMS 3.1, which is run on the VAXstation operating under VMS 5.4. Instead of using Structured Query Language (SQL), which is the most common way of accessing databases, a menu-driven interface has been developed to allow the user to browse, add, delete and update information, and to perform structured searches of the data and to extract the recovered information. The interface is written in VAX Fortran and uses a novel technique that allows the operator to make structural changes to the database without the interface program requiring any modification. This is achieved using screen management routines that create virtual displays whose size can be adjusted as changes dictate; in this way the program only uses the amount of memory that is needed for the data being presented, (Eleftheriadis,1988). The disadvantage of this approach is that only ASCII text can be written to the virtual displays, so other types of data stored in the database need to be converted using internal WRITE statements, but the flexibility obtained is well worth the penalty in running time.

The database is organised into six main relations which are connected via key fields, which are usually alphanumeric codes, (Figure 1). The EARTHQUAKE and STATION relations contain the information about the source and the recording site, respectively; the TRIGGERING-EVENT relation contains information pertinent to each triaxial record, such as distance from the source and local intensity, and the COMPONENT relation contains the information specific to each of the three components, such as the azimuth, sensitivity, natural frequency and damping of the transducer; the RAW and FINAL relations then contain data, such as peak values and durations, on the uncorrected component records and the processed versions, respectively. These last two relations also contain the names of the files under which the component records are stored . For those records that are not in the databank and for which only peak accelerations have been obtained, information is stored only in the EARTHQUAKE, STATION and TRIGGERING-EVENT relations. There are also four other relations which contain names of countries, models of instruments and intensity values and scales, which are entered as numerical codes, which serve as key fields, in the main relations.

1.4 Selection of database parameters

Other than the fields that are included to connect the relations and to catalogue the databank, the most important parameters to be stored in the database are those that characterise the earthquake source, the source-to-site path and the site of the recording station. The following criteria were established for the selection and definition of these parameters:

1. The parameter should have a real physical significance as far as the nature of the strong-motion is concerned.
2. The parameter should be concise, so that it can be used in searches; comments and text should not be included in the database.
3. The definition of the parameter should be such that it is possible to reliably determine its value for a significant proportion of the records.
4. It should be possible to consistently determine the parameters, using primary sources and systematic calculations.
5. The parameters should be expressed to an accuracy consistent with the level of uncertainty in their determination and if possible an indication of the uncertainty should also be included.
6. Since the parameters will be used in the selection of records for use in design situations, it should be feasible for the engineer to assess the value of the parameter a priori, although other parameters, not normally used in seismic hazard analysis, may also be included for research purposes.
7. If a parameter takes distinct levels rather than values over a continuous range, then it is preferable to use a branching structure. The first character, for example, could take one of two values, and then these can be subdivided by subsequent characters. In this way the field need not remain blank if the available information is limited.

The source is characterized by a number of magnitudes: local magnitude, M_L, either from seismographs or accelerograms; body-wave magnitudes from short-period, m_b, and intermediate-period, m_p, teleseismic readings, and surface-wave magnitude, M_s, uniformly re-calculated using the Prague formula (Vanek et al 1962) according to the procedure of Karnik (1969). The seismic moment, M_o, is also included. The most reliable epicentral co-ordinates and an estimate of the focal depth, expressed as a 5 km range, define the location of the source, and the mechanism, where known, is classified as thrust, normal, strike-slip or oblique, with an indication of whether surface rupture was observed.

The travel path is defined by the distance from the epicentre, and where it is possible to determine, the shortest distance from the recording station to the surface projection of the fault rupture. The rupture is defined by surface faulting, aftershock locations and fault plane or centroid moment tensor solutions.

The recording site is defined by three parameters. The first distinguishes the geology as either 'rock' or 'alluvium', according to the superficial deposits, regardless of depth. The second site parameter defines the foundations of any structure as 'small' or 'large', and the third classifies any structure at the site as 'light' or 'heavy'; a free-field station would be entered as small foundation and light structure.

1.5 Records of uncertain association and non-triggered instruments

Information about strong-motion records is culled from the literature and from reports of the network owners, and all the data are entered to the database. However, in some cases there is reason to suspect that the record, as reported, has been wrongly associated with a particular earthquake, either when absolute time has not been recorded and the record is attributed to one of several events in the period between visits to the instrument, or else absolute time has been recorded but correlates only approximately with the origin time of an event in the region; it is possible that the instrument was in fact triggered by a smaller, but very close, event which was not detected teleseismically, or else by electrical storms, human intervention or trickle-charger malfunction. These records are still included in the database but are marked as being of doubtful association.

Where information is available that positively identifies operational instruments within the felt region of an earthquake that did not trigger, then their locations and distances from the source are also included, as useful 'negative evidence'.

2 ASSESSMENT OF THE EUROPEAN STRONG-MOTION DATABASE

The formation of a global databank is an enormous undertaking and the project has concentrated to date on the formation of a databank for the Eurasian region, from the Azores in the west to Pakistan in the east, encompassing the Maghreb, the Middle East, the western Soviet Union and Scandanavia. This serves as a useful pilot project, and forms a kind of feasibility study for the formation of the global databank.

2.1 Identification of the Eurasian database

Some strong-motion data sets are well-known and easily accessible, particularly that from California, and these are widely used in earthquake resistant analysis and design. It is important, however, that strong-motion data be obtained for each seismic region so that its particular characteristics can be assessed. It may be the case that Californian data is adequate for use in risk analysis in Europe and adjacent regions, but this needs to be confirmed by a thorough comparison of data from the two regions. It is also important that the approach adopted is not too parochial - there is no need to exclude data from across a political border if the tectonics are the same.

Through extensive literature reviews, correspondence with network operators and also through concerted efforts under the auspices of the EAEE Working Group on Strong-Motion Studies, the state-of-the-art of strong-motion recording in Europe and adjacent regions has been identified. Strong-motion recording began in the region much later than elsewhere, with the first European strong-motion record being obtained in the Soviet Union in January 1966, more than 30 years after the first accelerograms were obtained in California. It is estimated that about 2,400 permanent and temporary strong-motion instruments are now in operation in the region, run by about 200 different organisations.

2.2 Seismological parameters for Eurasian strong-motion records

The initial search identified more than 700 shallow earthquakes in the Eurasian region that have triggered strong-motion recording instruments, as well as about 30 events of intermediate focal depth, (Ambraseys 1990; Ambraseys & Bommer 1990). The magnitude scale selected for use in analysis of the Eurasian strong-motion data is M_s, since it is the scale most often employed in hazard analysis in the region. M_s is determined from more teleseismic readings with better azimuthal distribution than the other scales, and is associated with an average standard deviation of 0.25 compared to at least 0.4 for body-wave magnitudes. It has been possible to determine M_s values for 67% of the Eurasian earthquakes. For 208 events the focal mechanism has been determined, although for half of these this has been based on the assumption of aftershocks having the same mechanism as the main shock.

2.3 Path and site parameters for Eurasian strong-motion records

For 442 of these shallow earthquakes, some basic information has been recovered about the 863 triaxial accelerograms that they generated, (Ambraseys & Bommer 1991). Distances from the surface projection of the fault rupture are always selected in preference to epicentral distances, and these can differ significantly for large events. For instance, the accelerograph that recorded the Tabas (Iran) earthquake of September 1978 was situated 54 km from the epicentre but only 3 km from the source area. The source distance has been determined for most events of magnitude greater than 6.0, but for none smaller than 5.5, although the source dimensions of these smaller events are generally no greater than the uncertainty in the epicentral location.

The parameter most often considered in the attenuation of strong-motion other than magnitude and distance is the superficial geology of the recording site. This suggests that it is important to obtain more detailed information about the site conditions at Eurasian stations, but the availability of this data is limited. The superficial site geology has been identified for about 90% of the Eurasian database. The site classification used, based only on the general nature of the surface deposit regardless of

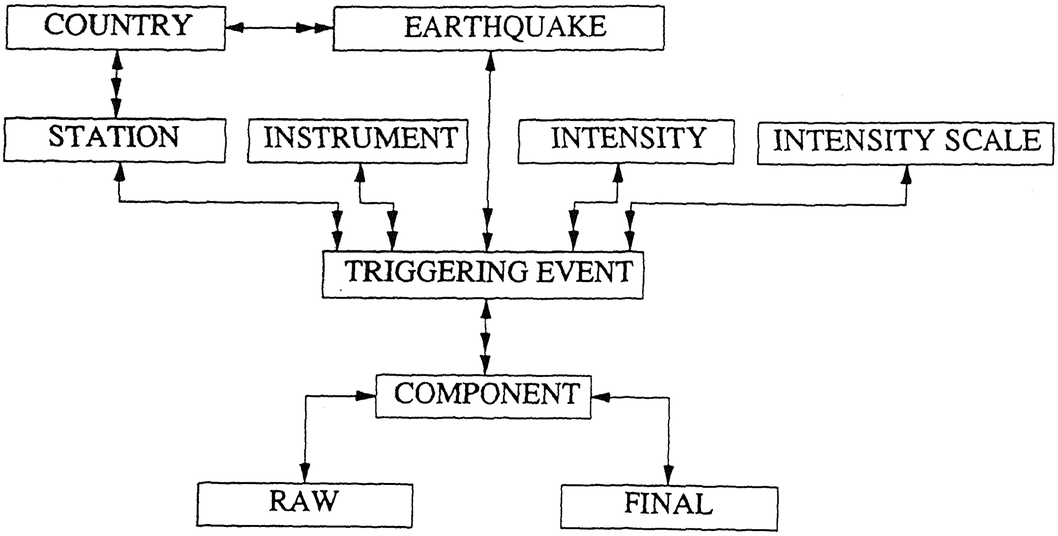

Figure 1. Data model showing relationships of earthquake strong-motion database. Single arrows represent one-to-one relationships and double arrows one-to-many relationships.

depth, is probably insufficient to reveal the influence of the geology on the strong-motion. However, detailed data on the stations in the region is scarce and this classification is consistent with condition 3 listed in Section 1.4. If the categories were to become more detailed then the best approach, consistent with condition 7, would be to break down the two classes of rock and alluvium into two or three sub-groups, depending on depth and stiffness.

2.4 Distribution of Eurasian data in magnitude-distance space

The data set that has been analysed to date excludes all earthquakes of magnitude less than 4.0 and focal depth greater than 25 km. The distribution of the data set with respect to magnitude and distance is fairly uneven, with 70% of the records coming from distances of less than 40 km, and with small magnitudes predominating; 74% of the records have peak horizontal accelerations of less than 0.10 g. The coefficient of correlation between magnitude and the logarithm of the distance is 0.51.

The capacity of the data set to reveal the true nature of the distance dependance of the attenuation depends on the distribution of the data with respect to distance and the inclusion of several earthquakes recorded at a number of stations over a large range of distances. The Eurasian data set includes many earthquakes recorded at very few stations: more than half of the earthquakes are recorded at only one station, and only 10% of the earthquakes triggered more than four instruments.

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