Bull. Ind. Soc. Earthq. Tech. Paper No. 255 Vol. 24 No. 2 June 1987, p.p. 77 To 86

MEASUREMENT AND ANALYSIS OF STRONG EARTHQUAKE GROUND MOTION

A.R. CHANDRASEKARAN*

ABSTRACT

The basic data that is needed in the design of systems located in an earthquake environment is the way the ground particle moves in all camponental directions during a pastulated earthquake. For this purpose a data bank of records of actual strong earthquake is necessary in order to study their statistical behaviour and influence of various parameters for the purpose of predicting design earthquake.

This paper highlights the development and deployment of strong motion measuring instruments particularly in India. A description of processing the data from analag medium in the form of photographic paper/film is also given.

Except for the significant records obtained at Koyna (a hydro-electric project in Western Ghats of India) no major event has been recorded so far in the existing network and array of strong motion accelerographs.

STRONG MOTION ACCELEROGRAPH

Even though instruments to monitor earthquakes in the form of seismographs were deployed from the middle of Nineteenth century, impetus for the development of instruments to measure strong motion in epicentral region came after studying the disastrous earthquakes of Kanto, Japan in 1923 and Long Beach, California, U.S.A., in 1933. Upto almost 1970 most of the significant strong earthquakes in the world have been recorded on United States Coast and Geodetic Survey (USCGS) accelerographs or of similar design except in case of Japanes earthquakes which were recorded on their SMAC accelerographs. Details of the instrumentation are available in published literature [Hudsons (1959, 1974)].

INDIAN SCENARIO

In India, prior to 1960, there was negligible instrumentation for strong motion measurements. Authorities of river valley projects gave impetus to strong motion studies particularly due to repeated tremors in the vicinity of Koyna Dam site. The Department of irrigation, Government of Uttar Pradesh

* Professor, Department of Earthquake Engineering, University of Roorkee, Roorkee.

sponsored the design and development of strong motion accelerograph by the Department of Earthquake Engineering, Roorkee. The Indian Standards Institution brought out IS : 4967 in 1968 entitled "Recomendations for Seismic Instrumentation for River Valley Projects". The code suggests installation of accelerograph at the base as well as top of the dam. In addition, one accelerograph is to be installed at mid-height if the dam is more than 100 m. tall. The specifications of the accelerograph are as follows:- (i) Three accelerometers to measure motion in all three components and having natural period 1/15 to 1/20 sec, damping 60-70 percent, range unit gravity and sensitivity with an amplitude of 4 cm on paper. The recording speed is not less than 10 mm/sec. The starting mechanism is to come automatically into operation when the ground motion begins and automatically stop not less than 5 sec. after the last contact The instrument is to be operated by storage batteries which are to be charged continusly by a trickle charger.

Except for the accelerographs located in some projects in Western India, bulk of the instruments in various projects are those which have been fabricated at the University of Roorkee. These instruments are known as RESA which is an acronym for Roorkee Earthquake School Accelerograph are a modified version of USCGS accelerograph, The current model of RESA uses as a recording medium photographic paper roll of 22 5 cm. width which is cut from a 45.7 cm. roll of R90 Agfastate paper and is the only variety of photo medium available in the country. The accelerometers are torsion type with a coil acting as mass. Permanent magnets provide damping and control of damping is through a shunt resistor. There are two mutually perpendicular horizontal pendulum starters. The take-up and give-up spools are light tight and can be daylight loaded. The control of functions is through solid state circuitry. The equipment is powered by Nickel-Cadmium batteries.

28 such instruments are located in various river valley projects in the country and a few in multistoreyed buildings.

INDIAN NATIONAL STRONG MOTION INSTRUMENTION NETWORK (INSMIN)

RESA instruments are also now located covering a network in the two severe seismic zones of the country. 42 such instruments are located as shown in Fig. 1. This project is sponsored by the Department of Science and Technology, Government of India. Though the network looks sparsely spaced due to vastness of the country, it is hoped that some instruments would trigger in the event of the next strong earthquake.

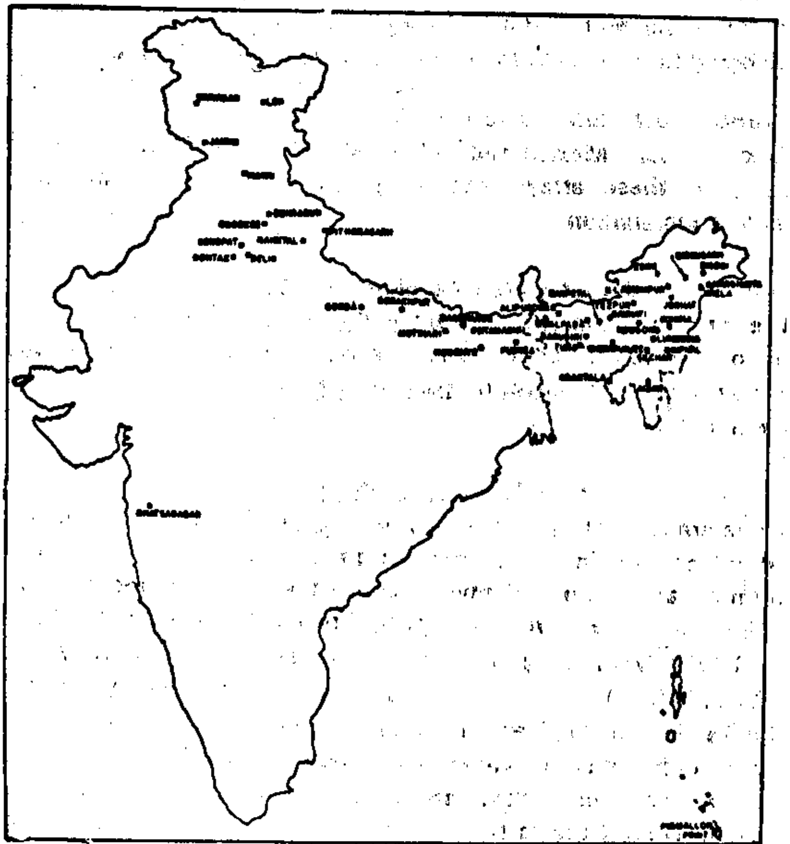

FIG 1. MAP SHOWING ACCELEROGRAPH (RESA) STATIONS COVERED UNDER INSMIN PROJECT

STRONG MOTION ARRAY

As a recent development of studies in strong motion seismology, setting up of instruments in the form of dense arrays in the epicentral region of strong earthquakes have been recommended by an International workshop (Iwan, W.D., 1978). The array is expected to provide information on Source Mechanism, Wave Propagation and local effects. The instruments in array differ from that of network in the important aspect of recording absolute time. The suggested instrument characteristics are as follows : The individual station is to have a bandwidth from 0.1 to 30 Hz and dynamic range (using gain ranging) of 10°. The sensors should be capable of recording three components of motion linearly over this bandwidth with a maximum acceleration 2g. Internal clocks should have a drift rate not exceeding 10^{-7}. These clocks must be able to be reset from an external, portable master clock so that the precise relative timing can be obtained periodically. The sample rate should be 100 Hz to allow for reliable recording of 30 Hz signals after anti-aliasing filtering. There should be a minimum of 45 minutes of recording time. In case of digital accelerographs, pre-event memories of 2 sec should be provided.

Since 1980, such array have been installed in U.S.A (in California), Japan, Taiwan, China, Mexico and India. Significant records have been obtained from all these arrays except in India where there is no major activity since their installation.

The instruments in the array are of analog or digital type. The digital type is costlier but has superior characteristics in the form of per-event memory and larger dynamic range. The analog instruments in array have the additional provision of absolute time recording as compared to those installed in network.

There are two arrays in India, one in the Kangra region of Himachal Pradesh which contains 50 analog instruments. and the second in Shillong region on North-Eastern India which contains 45 analog instruments. The analog instruments are all of identical make (SMA - 1 with TCG of M/S KINEMETRICS, U.S.A.). In addition 5 digital instruments (A 700 of M/S TELEDYNE, U S.A.) have been procured for rapid deployment to record aftershocks in an epicentral region. The funding for the procurement and deployment of the array has been provided by the Department of Science and Technology, Government of India and National Science Foundation, U S.A. and the arrays are managed by the Department of Earthquake Engineering, University of Roorkee.

Figure 2 shows the deployment of the array in Kangra region where the instruments had been installed in 1983. Figure 3 shows the broad tectonic features and location of past epicentres. The biggest shock recorded in the region was in 1905 with an estimated magnitude of 8^+.

Figure 4 shows the deployment of the array in Shillong region where the installation would be completed by Dec. 1985. Figure 5 shows the broad tectonic features and location of past epicentres. The biggest shock recorded jn the region was in 1987 with an estimated magnituede of 8.5.

The entire Himalayas is considered to be tectonically active and with this new plan of instrumentation it is expected to yield valuable data of great interest to the scientific and engineering community.

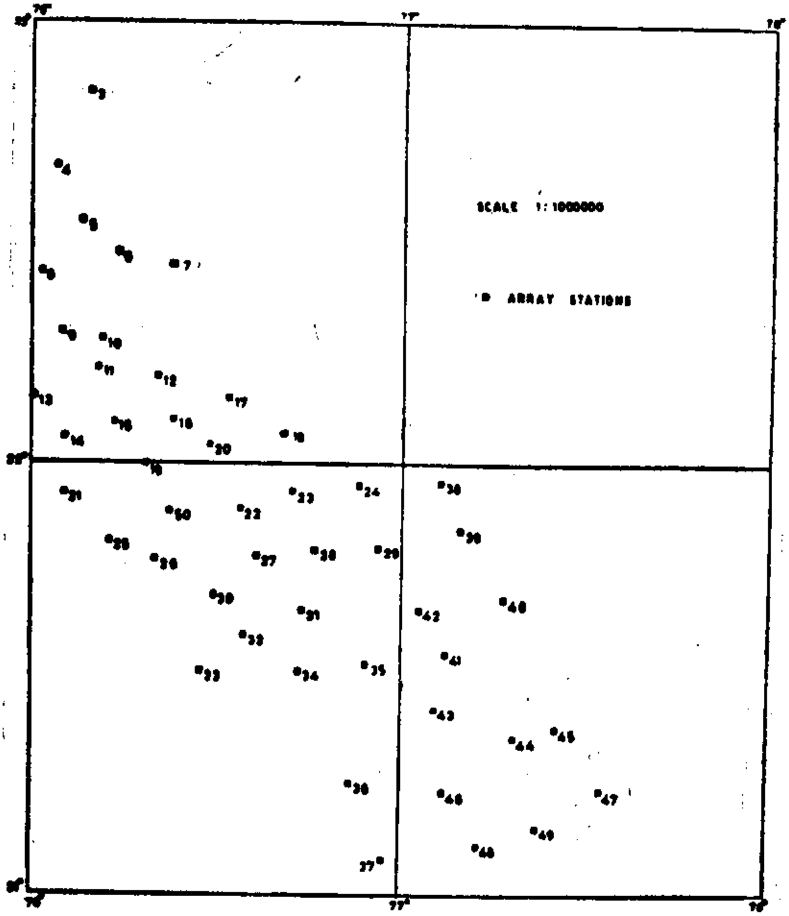

Fig. 2- Map Showing Location of Strong Motion Array Stations Around Kangra.

ANALYSIS OF DATA

Analog instruments of either network or array record on 70 mm films or on photographic paper say of 22.5 cm. width. A typical accelerogram would consist of six to seven traces. The minimum number of traces has to be four corresponding to three component of ground motion and one relative time marks in the form 2 or 4 pulses per second. In the case of array instruments, one of the trace must be an absolute time code. In addition, there are usally two fixed traces whose records are used for correcting for certain types of spurious motion and are useful for the detailed computer processing of the accelerograms.

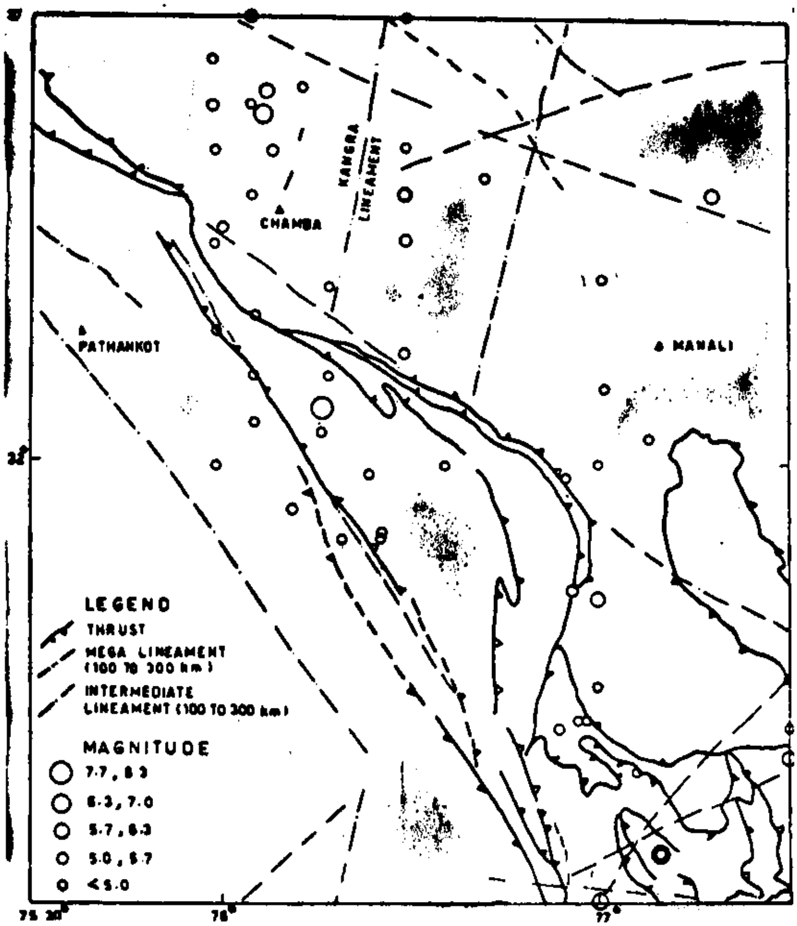

Fig. 3- Map Showing Various Tectonic Features And Historic Seismicity In The Region Around Kangra

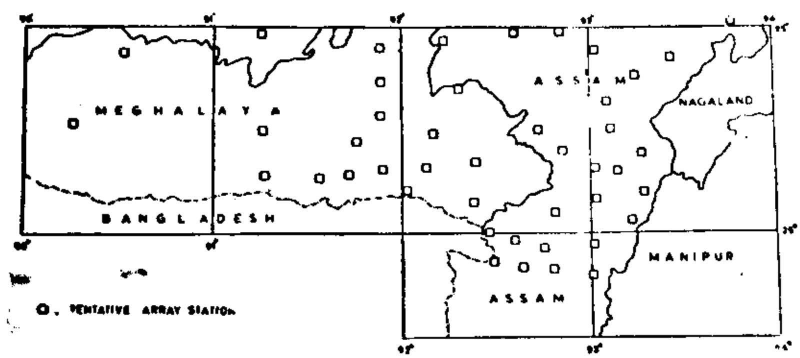

Fig 4- Map Showing Tentative Strong Motion Array Stations In N E India.

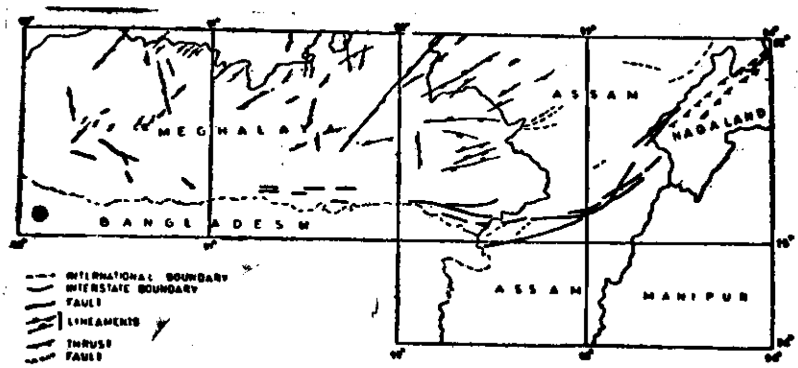

Fig. 5- Map Showing Tectonic Features Of N-E India

Preliminary information that can be obtained from the accelerogram by usual inspection and simple scalling without digitization or further processing is as follows : (1) peak acceleration of the three components of ground motion (2) time duration of ground shaking (3) frequency of predominent waves and (4) if vertical starter is used, approximate distance from recording site to earthquake hypocenter.

Accelerogram Digitization

In order to derive useful information from accelerogram, the analog records have to be digitized and then the raw digitized data is subsequently processed. Nowadays, the record is processed by a semi automatic digital data acquisition system or by fully automatic system. For the purpose of exchange of data, only copies of the original record are sent as the original is kept in the safe custody of the owner. Since the copy could have some distortion introduced by the process of copying, it is disirable to exchange the digitized raw data of the original accelerogram.

In the semi-automatic method, the record is placed on the surface of the digitizer and a cursor is aligned on the trace point to be digitized. A press of a switch or button activates the data acquisition system and the x & y coordinates with respect to a datum axis is displayed on a screen or printed. Nowadays such data acquisition system have atleast a minicomputer system attached to it such that the data could be recorded on a file which could be transferred to a transportable medium like floppy disk or magnetic tape. However, in the semi - autometic system, the cursor has to be aligned successively at all trace points of interest. This could introduce errors in digitization which depends on the care of the operator.

In the automatic system, which is of course expensive, the errors of digitization are considerably minimised.

In adition to digitzing the three components of ground motion, the relative time marks and the fixed traces are also digitized. If there are no fixed traces, then the relative time marks could also act as a reference fixed trace. Digitization of relative time mark is essential as the time base may not be constant due to variable speed of movement of particular paper records as compared to film records.

The records may be digitized on an unequal time basis to give the best definition of the trace for a given number of data points. All significant peaks, points of inflection, etc. are to be picked, along with as many intermediate points as are needed for an accurate definition of shape. The average number of points per second of record in the most rapidly oscillating sections of the accelerograms may be about 50. Uniform time data can be derived by a simple interpolation technique.

The fixed traces could depart measurably from straight lines, usually involving log period components to be ascribed to paper distortion, motions of the paper in the drive mechanism etc. The fixed traces are digitized at intervals of the order of one second, smoothed by a weighted averaging over every three consecutive points and subtracted from accelerometer traces as first step in the data processing.

For fitting a base line to the acceleration function, the time axis is translated and then rotated for a small angle, so that the integral of the accceleration function is equal to zero for the whole length of the record. In principle, this is equivalent to minimising the sum of squares of the ordinates of the acceleration. In all cases the minimum RMS acceleration values are recorded as a significant parameter of the record.

The above procedure was first proposed by, Hudson and his group (Trifunac and Lee, 1973) and is now adopted as a standard to obtain basic "uncorrected data" as it represents the minimum interference with the basic data consistant with the definition of unambiguous numerical values.

PROCESSING THE UNCORRECTED DATA

The raw data must be corrected to obtain a more true value of base acceleration versus time. The corrections fall in two main classes. The first accounts for high frequency errors and instrument corrections. This work was pioneered at the California Institute of technology, Pasadena, U.S.A. (Trifunac, 1970 and Trifunac, et. al. 1971). There are a few other modifications to the above procedure (Shyam Sundar, 1980 and April Converse, 1983).

Once the corrected accelerogram is derived from raw data, other information like ground velocity, ground displacement, response spectra can be obtained using standard procedures (Trifunac and Lee, 1973).

STRGNG MOTION DATA ACQUISITION SYSTEM

As a part of the Indo-US project, with funds provided by the National Science Foundation, U S.A., the University of Southern California had assembled a data acquisition system which is now located at University of Roorkee. The system comprises a CALCOMP 9000 digitizer with a working area of a 48 inch ×36 inch With the help of a cursor with cross-hair, an accuracy of 1000 points per inch can be achieved. In an off-line mode, a micro-processor based controller links the digitizer with LA 34 printer giving an X-Y output when a button of the cursor is pressed. In an on-line mode, the micro-processer controller is connected to a PDP 11/23 system comprising a VT 103 terminal cum processor, RX02 floppy drive and a HP-7470 Colour plotter. The operating system is RT-11 SJ. The application software for Strong Motion Data Processing that been installed is the 1984 version of program of Trifunac and Lee of University of Soutern California, U.S.A.

CONCLUSIONS

Two arrays, one in Kangra region and other in Shillong Region have been set up in India. There is also a network of instruments covering the severe seismic zones of the country. A data centre has been set up in India. There is also a network of instruments covering the severe seismic zones of the country.A data centre has been set-up for digitization of analog record first into raw (uncorrected) digitized data and subsequent data processing in a standard format.

ACKNOWLEDGEMENTS

The Department of Science and Technology, Govt. of India is the main sponsor of Strong Motion Instrumentation in India. The National Science Foundation, U.S.A. gave full financial support to the installation of first array and data centre in India. E.C. Lindvall of M/S Lindvall, Richter and

Associates, Los Angeles, California is the Principal Investigator of the INDO-US project from USA side and auther is from the Indian side. Several individuals have contributed to the successful implementation of the project, notably among them being Prof. Jai Krishna of India and Prof. Donald Hudson of U.S.A both past presidents of the International Association of Earthquake Engineering.

REFERENCES

Coverse, April (1983), a compilation of "AGRAM: a series of Computer Programes for Processing Digitized Strong Motion Accelerograms" United States Department of the Interior, Geological Survey, open-file Report 83-276.

Hudson, D.E., (1959), "Ground Motion Measurements in Earthquake Engineerng", Earthquake Engineering, Seminar Series No. 1, University of Roorkee, Roorkee, India.

Hudson, D.E., (174), "Ground Motion Measurements in Earthquake Engineering" in Earthquke Engineering (Jai Krishna Volume), Sarita Prakashan. Meerut, India.

IS : 4967-1968, "Recommendations For Seismic Instrumentation for River Valley Projects", Indian Standards Institution, Manak Bhawan, New Delhi.

Iwan, W.D , (1978) Ed., "Strong Motion Earthquake Instrument Arrays", Proceedings of the International Workshop on Strong Motion Earthquake Instrument Array, Honolulu, U.S.A.

Shyam Sundar, (1980), "On the Standard Processing of Strong Motion Earthquake signals" Dept. of Civil Engineering, Report R80-38, M.I.T., Massachusetts, U.S.A.

Trifunac, M.D., (1970), "Low Frequency Digitization Errors and a new method for Zero Baseline Correction of Strong Motion Accelerograms, EERL Report No. 70-07, CALTECH, Pasadena, U.S.A.

Trifunac, M.D., et, al., (1971), "High Frequency Errors and Instrument Correction of Strong Motion Accelerograms", EERL Report No. 71-05, CALTECH, Pasadena, U.S.A.

Trifunac, M.D. and V. Lee (1973), "Routine Computer Processing of Strong Motion Accelerograms", EERL Report No. 73-03, CALTECH, Pasadena, U.S.A.