DEVELOPMENT AND DEPLOYMENT OF RADIO TELEMETERED SEISMIC NETWORK AT BHATSA

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ABSTRACT – *An indigenously built, eleven station radio (wireless) telemetered seismic network (WITSEN) was commissioned at Bhatsanagar, Shahapur Taluka, Thane District, Maharashtra State, early in 1988 to study the reservoir induced seismicity (RIS) of the region. This paper discusses the development of this network in general and in particular the technical details of various laboratory and field equipments developed and deployed. Various illustrations of signals from local micro-seismic events, events occurring in about few hundred kilometers and teleseismic events acquired by the network are provided. Comparison is made with different types of systems for acquiring micro-earthquake data which were adopted by different local institutions in the past. Future research and development efforts required to improve the capabilities of such network are also discussed.*

REQUIREMENT OF MICRO-SEISMIC NETWORK

Micro-earthquake data from a local region would permit drawing conclusions about the seismicity of the region, location of seismically active regions, properties of earthquake source zone, evaluation of attenuation characteristics of the site region thus providing valuable information for future estimates of the seismic hazards which is particularly useful in siting a nuclear power plant. Other uses of micro-earthquake data are in the location of active faults and to study reservoir induced seismicity (RIS). This can be achieved by monitoring the micro-earthquakes around the reservoir region before and after the impoundment of the reservoir. The study of induced seismicity in gas storage and other artificial deposits in the region can be monitored in similar fashion[1].

The need for a WITSEN within the country is evident. In the past various institutions had procured equipment, systems from foreign manufacturers and deployed these at various places. These instruments include, various types of micro-earthquake recorders (MEQs)[2] and very sophisticated multichannel telemetry systems[3]. The development of this system indigenously should provide a good facility to upgrade instrumentation required for various purposes as mentioned above.

BACKGROUND OF THE PROJECT

Bhatsa Dam (19 30'N, 73 25'E) is situated about 90 kms north east of Bombay across river Bhatsa near village Sakivali in Shahapur Taluka of Thane district, Maharashtra state. Impoundment of the reservoir started in 1977. The earthquakes were felt from May 1983 to August 1984 causing some damage in Khardi and nearby villages. From October 1983 the project authorities and NGRI (National Geophysical Research Institute, Hyderabad) established a network of 8 seismic stations in the area[2].

Seismological studies of Bhatsa region was initiated by BARC in 1984–85, following the recommendation of Science Group, constituted by different organisations engaged in geophysical studies. Developments of various subsystems such as multichannel seismic data acquisition system, timing system, multichannel waveform display system, telemetry system etc. were taken up by BARC and all these systems were thoroughly tested at Seismic Array Station, Gauribidanur, Karnataka State where a 20 element cable telemetered seismic array is operating for the last 25 years. An experiment was also conducted to check the dynamic range of FM telemetry system. This was found to be in the order of 75 to 80 dB and at par with that of the cable telemetry system[4].

EXPERIMENT FOR TESTING LINE OF SIGHT

Location map of Bhatsa Khardi area is provided in figure 1. In May 1986, an experiment was conducted to test line of sight for UHF transmitted signal between probable field stations and Bhatsa, logistics of which were better suited for establishing master receiving station (MRS) and central recording laboratory (CRL). Two walkie-talkie sets operated in UHF band, together with telescopic aerial were utilized. One set was operated from the top of a 20 meter high water tank, situated at Bhatsanagar and the other was carried in a moving vehicle which visited all probable sites. All sites provided good communication with Bhatsanagar indicating good line of sight for wireless telemetry in UHF band. Although the testing could not be carried out for a longer duration, it was then assumed that the reception of signal on 24 hours would be feasible when the telescopic antennas are replaced by the corner reflected type (which provides antenna gain of 12 dB approx.) and the path attenuation for transmitted signal can be reduced by about 25 dB when product of antenna height is raised from 20 meters (when operated at ground level) to about 200 meters (antenna mast heights for transmitter and receiver of 10 meters and 20 meters respectively) in the final operating form[5].

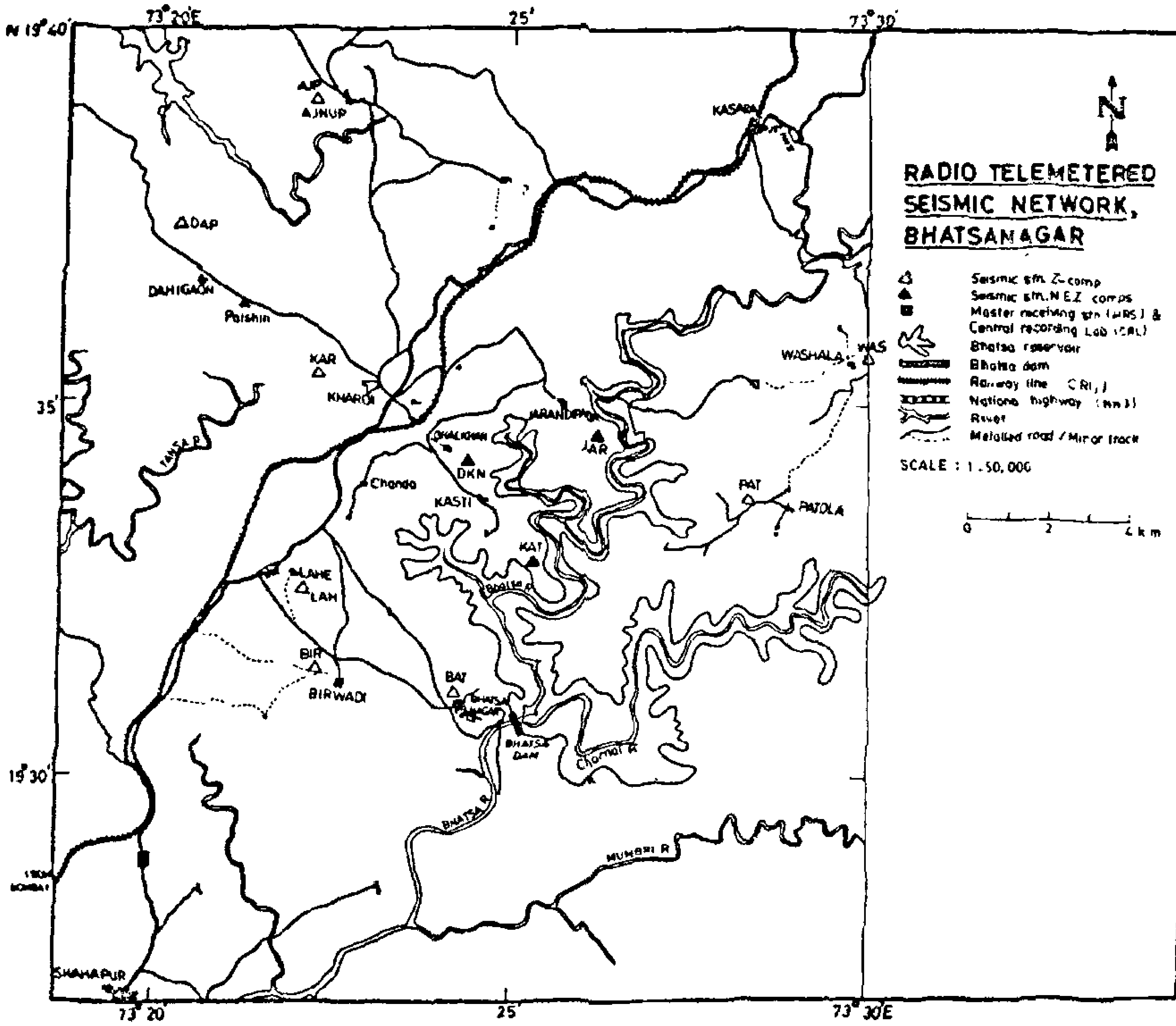

FIGURE 1. A map illustrating the location of field stations and CRL of the telenet operating at Bhatsanagar.

INSTALLATION OF SEISMIC NETWORK

The installation of seismic telenet at Bhatsanagar began in the last week of December 1987. We coordinated the activities with Bhatsa Dam Division No. 1 (BDD1) who provided good support particularly in the preparation of civil structures in the field, and conditioning of laboratory room, battery room and antenna tower. The MRS was installed at the top of the water tank building. The CRL was completely set up in early April 1988 and the last of the field station at Kasti was installed in the second week of May 1988.

SEISMIC TELENET AT A GLANCE

Seismic tele-network at Bhatsa comprises of a total of eleven stations spread over an area of about 400 sq. kms. covering the catchment area surrounding Bhatsa reservoir. Of these eleven stations, ten stations are operating with single vertical seismometers and the station at Khardi is providing three component (to record earth motion in X, Y and Z planes) seismic data.

FIELD SYSTEM

The system at each field station comprises of a seismic sensor acting as a velocity transducer followed by a signal conditioner consisting of a balance amplifier with a gain of 1000, a band pass filter (1 to 30 Hz, roll off of 6 dB per octave beyond 10 Hz) and a frequency modulator (Fc = 2160 Hz, deviation +, −40% for −, +2 Volts input). A calibrator is also included which provides 2 Hz sinusoidal signal (duration 8 sec.) to the calibration coil of the seismometer once every 24 hours. The FM signal is given to a UHF transmitter which operates at spot frequency in the band of 461·5 to 462·0 MHz. Eleven spot frequencies are allotted to eleven field stations by the Ministry of Wireless and Communication. The supply to the entire field system is through a 12 Volts 90 AH lead acid battery which is trickle charged by a 32 Watts solar panel through a charged regulator during the day time and makes up for the amount of discharge during the dark period. The housing for sensor, electronic sender unit (amplifier, FM modulator etc.) charge regulator and battery, is a clamshell which is an iron cylinder with a diameter of 700 mms and concreted to the bedrock below ground level. An iron lid is bolted on the top surface and also provided with locking arrangement. The solar panel is placed in a fixture on top of a 30 feet high pole. The corner reflect antenna and transmitter unit (housed in a water tight enclosure) are mounted below the panel. The cables from the solar panel and transmitter are run through the GI pipe which is clamped to the pole and then are run below the ground up to the clamshell situated about 20 meters away. The transmission of data is in analog frequency modulated form and on a 24 hour basis. The entire field system is modular designed to ease servicing. The block diagram of the field setup is illustrated in figure 2. Figure 3 provides a view of a typical field station.

MASTER RECEIVING SYSTEM AND CENTRAL RECORDING LABORATORY

The MRS and CRL are located at Bhatsanagar. Although this is not the central point of the network (as can be seen from figure 1), the maximum distance from any of the field stations is not more than 25 kms and is well within the range of a half Watt UHF transmitter.

A 70 feet high water tank tower is available at Bhatsanagar and the top of the water tank tower is utilized for erecting all receiver antennas. The receivers are also mounted on each antenna pole in a water tight enclosure. The supply to all receivers are provided through a 12 Volt battery which is trickle charged through the mains supply. Outputs of all these receivers are the signals in frequency modulated form which are cable telemetered to the central recording laboratory situated at the feet of the water tank tower. A view of the antenna tower is provided in figure 4.

At CRL all eleven FM signals are shaped and demodulated and fed to an event data acquisition system. In this system the analog data is multiplexed, digitized at 100 samples/channel/sec. (12 bit word) and sequentially stored in a circular buffer memory with a capacity of a total of 32 K words. In this memory, data for 20 seconds duration for each channel is sequentially stored and overwritten by new data in serial order. The demodulated signals which represent signal conditioned field data are also fed to a trigger circuitry. This circuitry detects an event onset in online mode based on the comparison of Short Term Average (STA) and Long Term Average (LTA) derived for a total of eight of eleven channels, individually and utilizing time window algorithm[6]. When an event is detected, the delayed data from the memory bank is serialised, phase encoded and recorded on a single track of magnetic tape in real time for a minimum duration of 1 minute and is extended up to 4 minutes depending on the code length of the event[7].

Multichannel seismic data with real time throughput rate of 1600 words/sec. (19·2 Kbaud rate) is recorded at a tape speed of 3 3/4"/sec. This results in packing density of 5120 bits/inch/track and total tape capacity of 70 million words. Edited data of about 600 events which may occur in about three to four weeks, are recorded on a single tape spool.

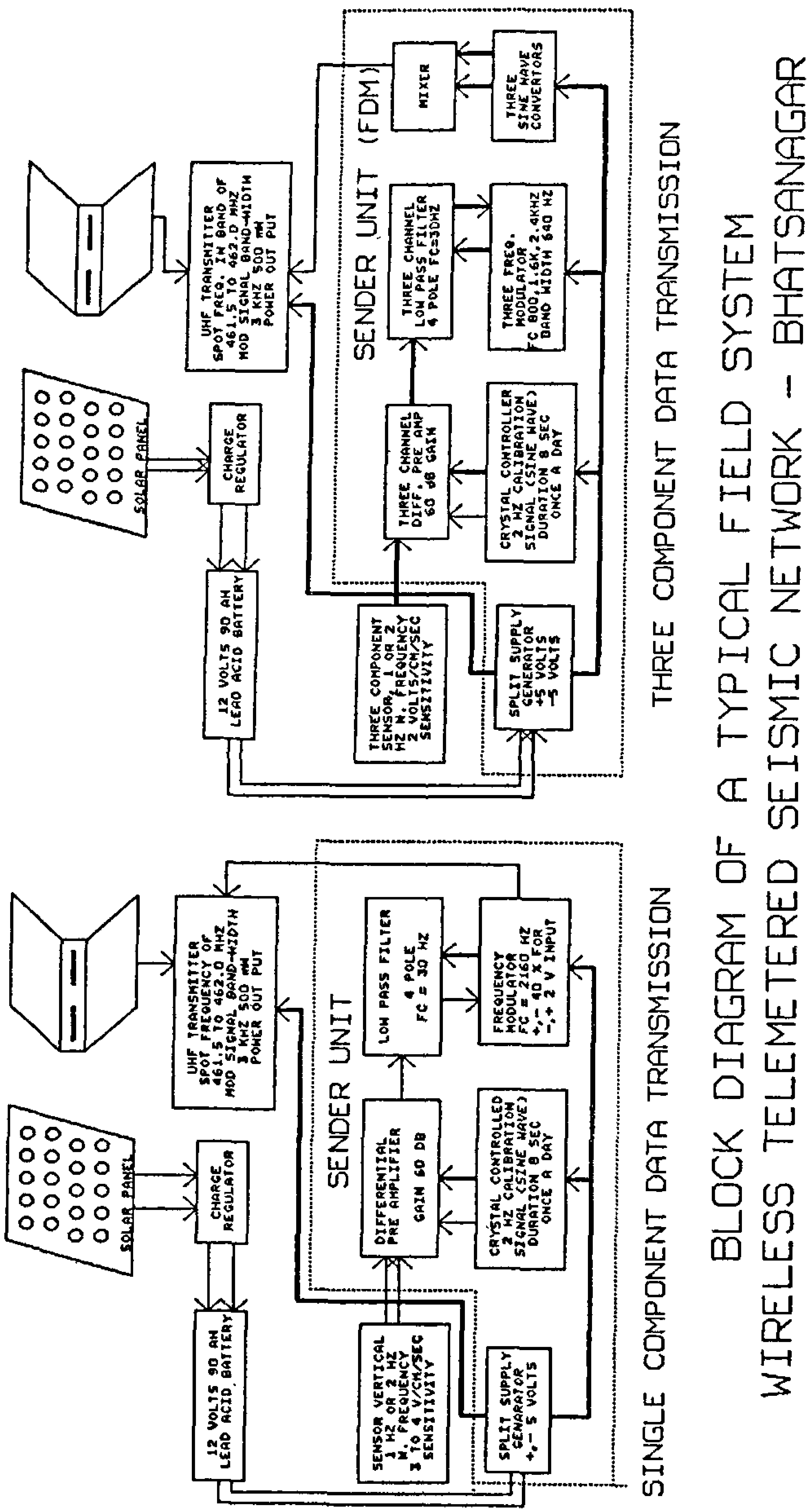

Figure 2. A block diagram of a typical field system.

Figure 3 A view of a typical field set up (Birwadi).

Figure 4 *A view of the master receiving system erected on top of the water tank building at Bhatsa.*

Online detection and recording of only edited portions of event data is preferred to continuous recording of multichannel data. In a similar system operated at Gauribidanur array, the detection of even very small events were found to be very efficient and reliable[6]. This method also economises on tape length and manual labour required for extracting and processing event data is drastically reduced.

Time indexing to event recording system is provided by a serial time code with pulse repetition rate of 5 pulses per second and time frame of 10 seconds, within which the BCD (binary coded decimal) information of the counters in the chronometer, for days of the year, hours, minutes, seconds, year, event number and elapsed time, is encoded. This time code is illustrated in figure 5. While reproducing the event data from the recorded tape, a time code reader associated with the system decodes this time code and provides display of time information[8].

A multichannel waveform display system[9] incorporated in the total set up, provides display of 8/16 steady waveforms on a general purpose single channel oscilloscope screen refreshed from digital data stored in the memory (64K). About 5 to 25% of this data is suitably displayed on the screen at a time. This system features,

- Display of 8 or 16 waveforms from up to 32 input channels in turns.
- Forward and reverse movement of displayed signals in slow and fast mode.
- Variable trace length, trace separation and gain control.
- Compensates for average DC component in each of the displayed channel to ensure uniform spreading of waveforms on the screen.
- Facilitates display of multichannel data with 100 kHz bandwidth and 72 dB dynamic range which is outside the scope of any galvanometric strip chart recorder.

This system helps to monitor the functioning of the field channels in on line mode and replay of event data in on line as well as in off line mode. Illustration of an

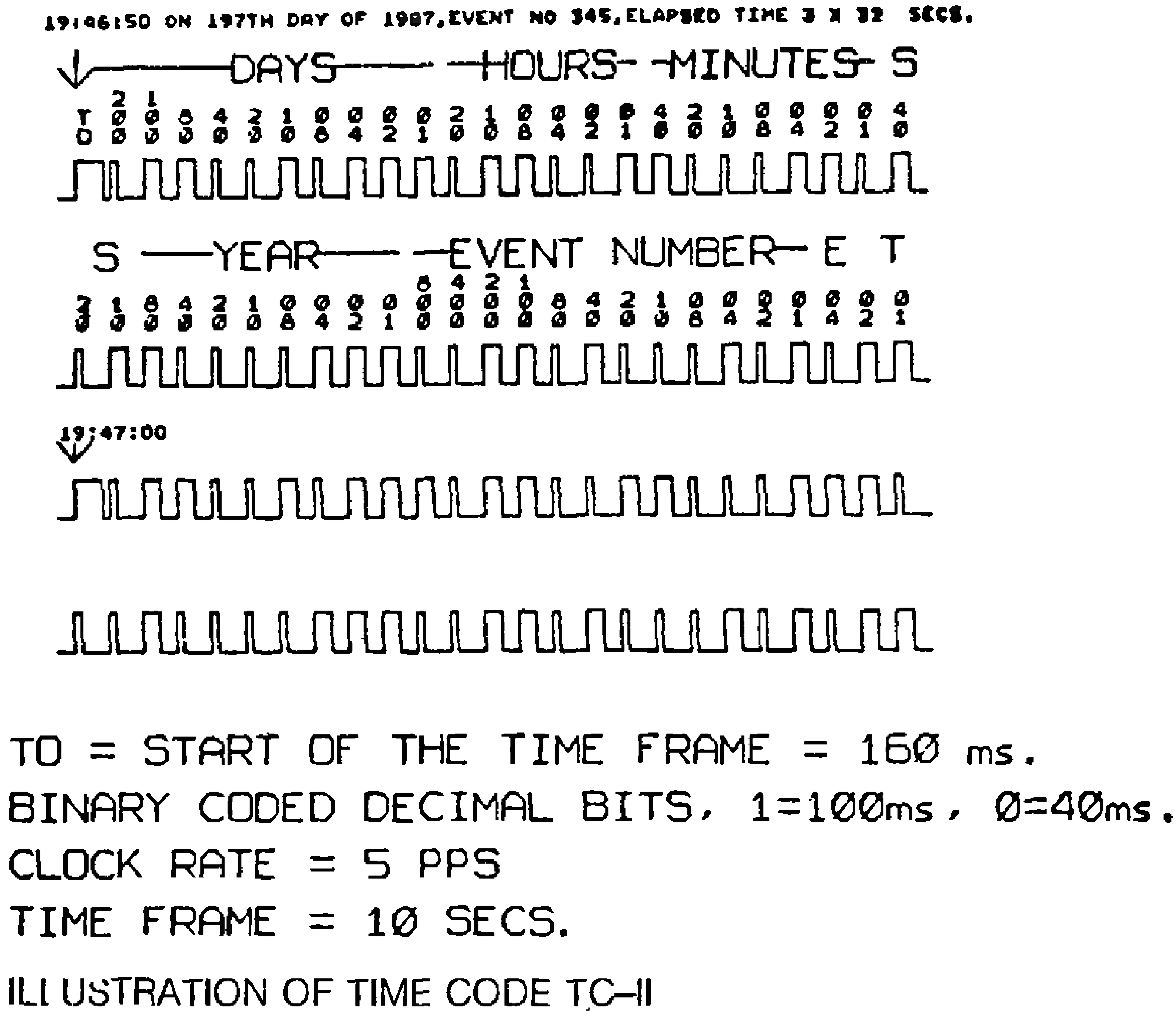

FIGURE 5 Illustration of a time code used in the data acquisition system.

event recorded at Gauribidanur array and monitored by this display system is provided in figure 6.

Two of the eleven channels are continuously monitored on two separate helicorders which are run at a speed of 60 mms/sec. Each of them provides a record for 24 hours duration on a paper sheet of size 100cms × 40cms. These records merely serve as the first hand information for the events recorded by the network. A specimen of the record is illustrated in figure 7.

The on line set up comprises of UHF receivers, FM demodulators, event data editing and recording system, tape deck (operated in interrupt mode) and timing system, is powered through 500 VoltAmp UPS (Uninterrupted Power Supply) and is capable of keeping the system functioning for a minimum of 48 hours during continuous absence of mains supply. A kerosene generator set of 1·5 KVA capacity is also operated in the event of mains failure.

The entire system described above runs on a 24 hour basis, is fully automated and requires minimal attendance. The block diagram of the laboratory system is illustrated in figure 8. Figure 9 gives the view of the data acquisition system at CRL.

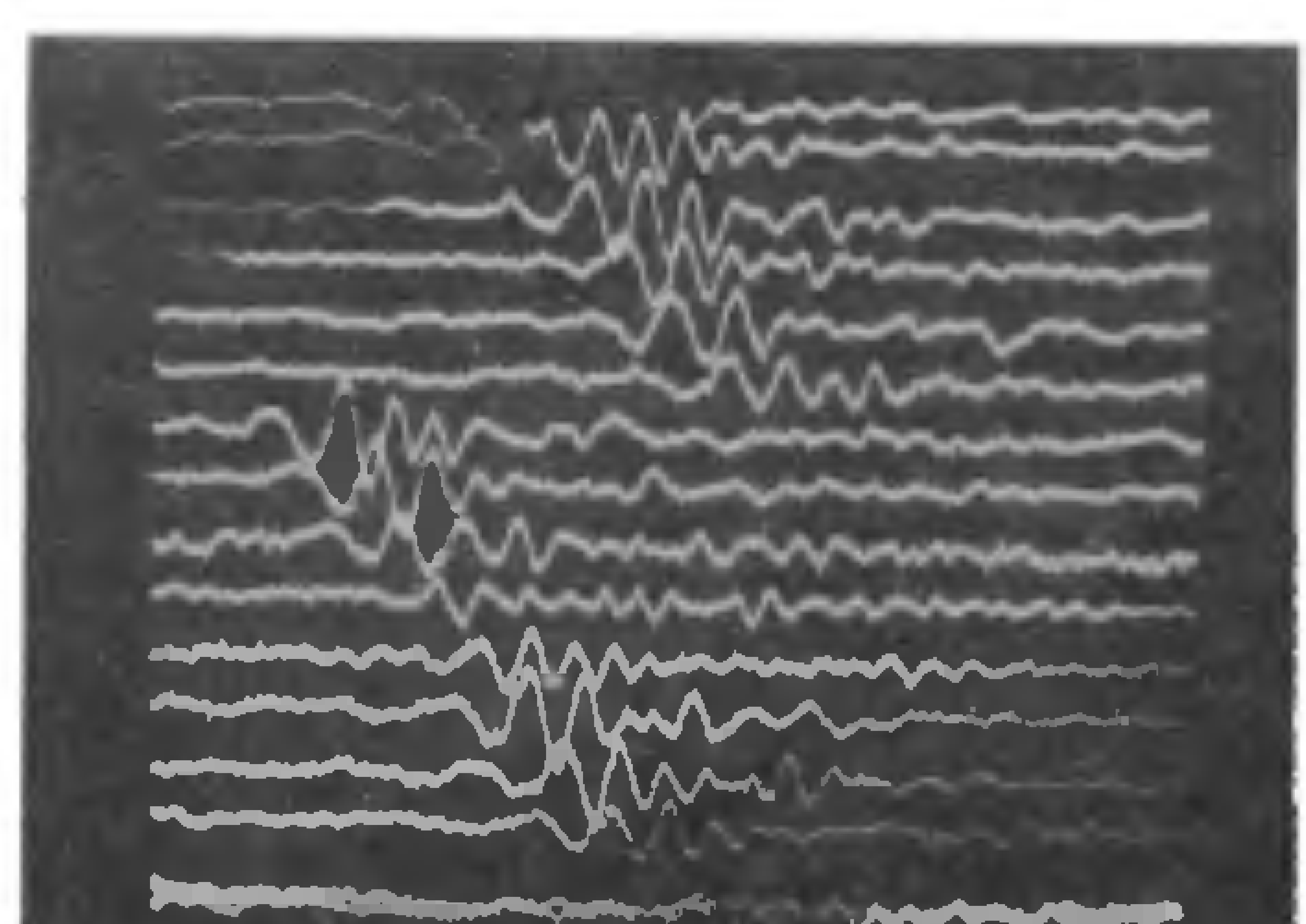

FIGURE 6 Multichannel waveform display of an event signal detected by Gauribidanur array.

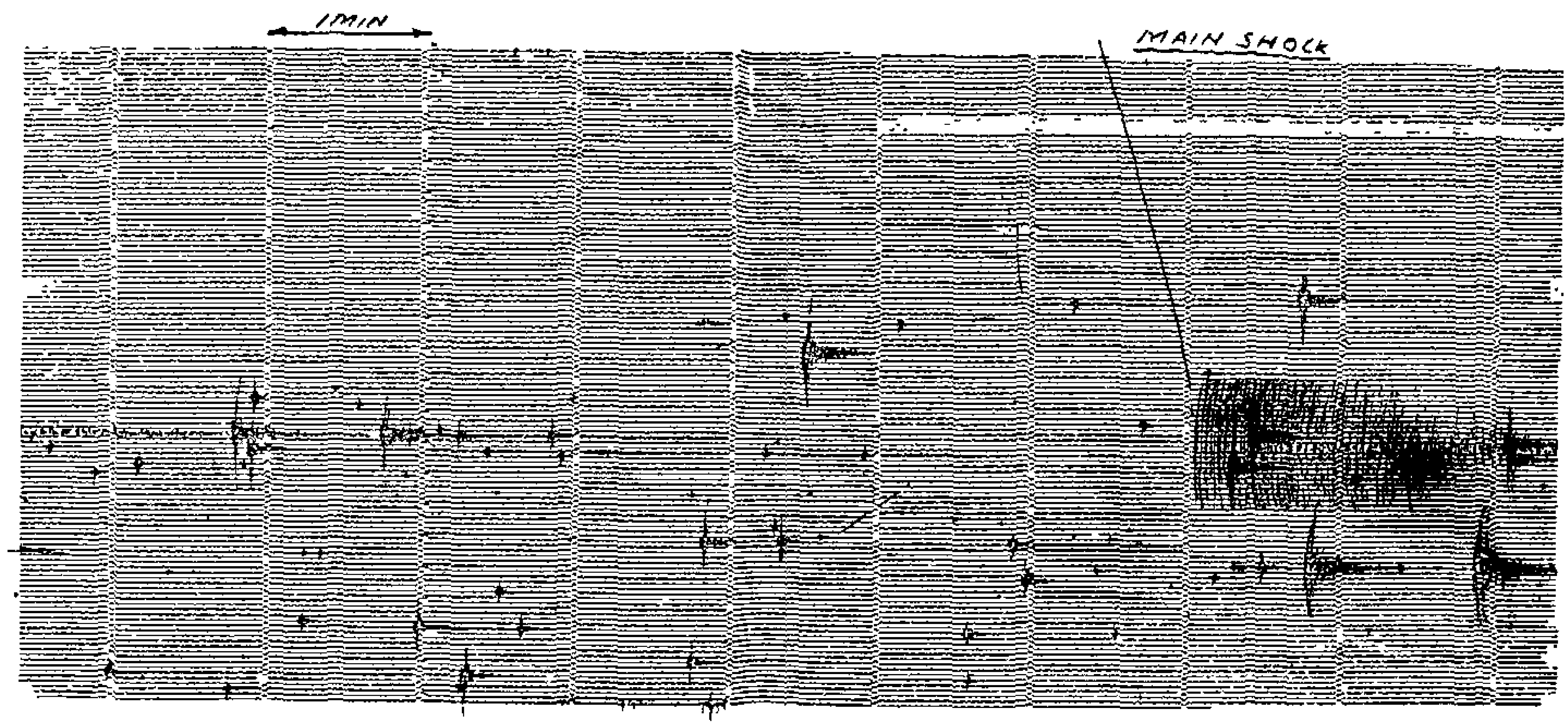

FIGURE 7 A specimen helicorder record of June 2, 1990. (stn–Ajnup)

GENERAL APPROACH MADE FOR BUILDING A SEISMIC NETWORK

The WITSEN at Bhatsa is the first of its kind built indigenously. However in the past, a requirement of seismic network was generally met by installing a number of micro-earthquake recorders (MEQ) at convenient locations in the required area. In this kind of configuration, each station comprises of a vertical sensor followed by a signal conditioner with selectable gain setting, a timing system and a helical drum recorder. A specimen of a day record would be similar to that illustrated in figure 7. The data recorded in this form on all individual MEQs is then analyzed at a central place and event parameters are evaluated.

The Individually Operated Seismic Station Network (INDOSEN) as described above however suffers from various disadvantages as listed below.

- For accurate determination of earthquake parameters, time synchronisation of all individually operated stations is very important. However accuracy of time setting achieved is limited to about +, −1/4 seconds due to manual error.
- The recording speed of the chart paper is limited to around 1 mm/sec., providing a very poor resolution in determining onset time of different phases of an event, accurately.
- Each station is required to be attended everyday. This is normally achieved by a resident operator or by sending a person from central place every day. This calls for adequate man-power and/or good infrastructure which has to be maintained. Instant, quick analysis of any important event is possible only if data from all station sites is rushed to the central place.
- The dynamic range of the signal recorded on the paper chart in this fashion is limited to around 30 dB. Sometimes a very small signal is not seen properly on the record whereas a big signal often provides saturated record and estimation of signal strength becomes impossible.

To achieve higher dynamic range and higher resolution, the event portion of the data from single or triaxle seismometer is edited and recorded on a digital cassette recorder. In this case, the data from a weaker event is not guaranteed to be recorded at each individual station in the network. The system may often get triggered due to local disturbance such as animal or vehicle movements which may result in running over of the cassette, early.

- The analog data obtained on a paper chart in this form cannot be processed through computer.

ADVANTAGES OF WITSEN SYSTEM OVER INDOSEN SYSTEM

The WITSEN system overcomes all the above problems. The synchronisation of time to the world time is a secondary issue as far as monitoring the local area is concerned. Relative time accuracy of a higher order (in milliseconds) for different phases of an event on multiple channels is an important factor and is achieved by recording multichannel data on a common

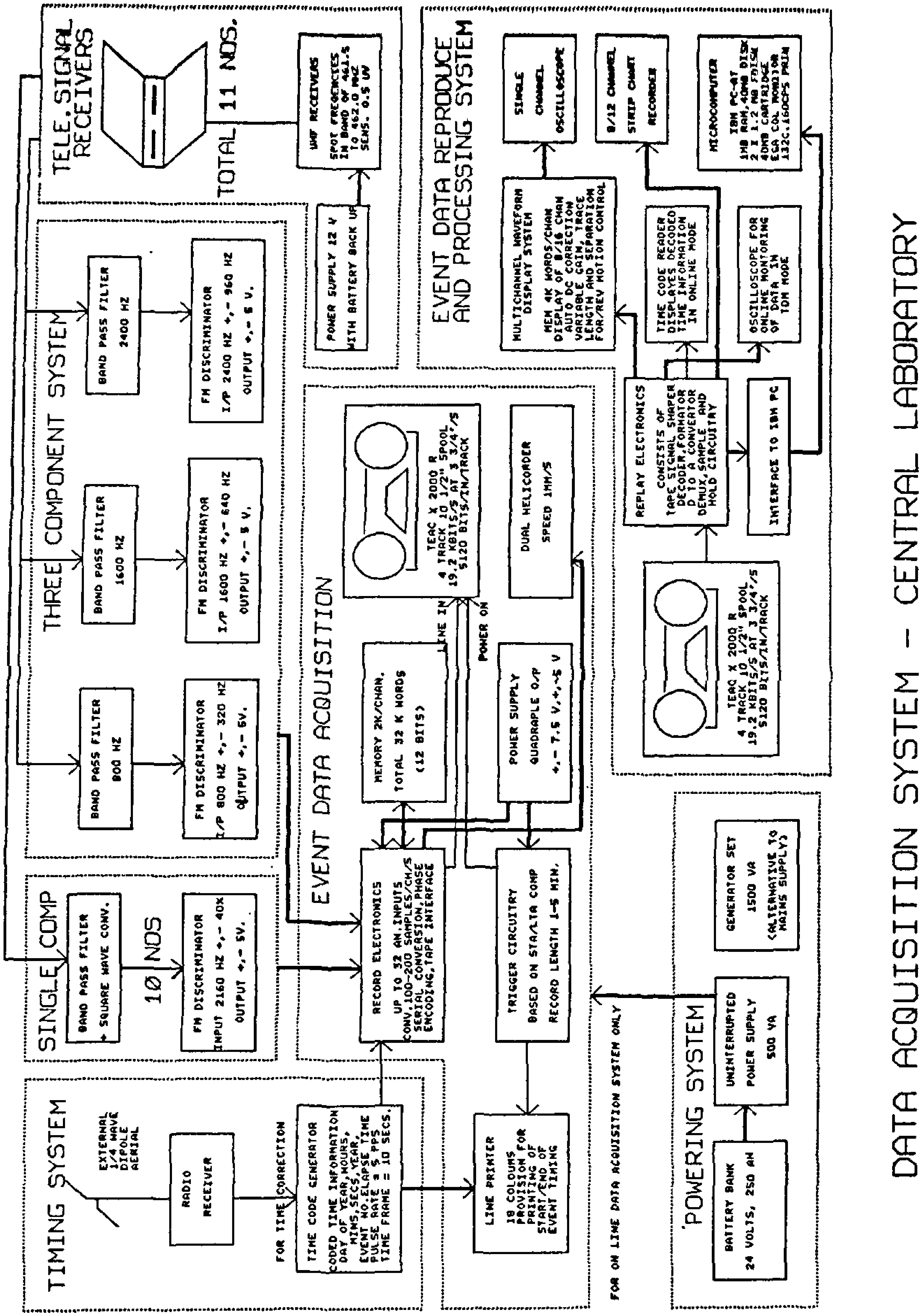

FIGURE 8 A block diagram of the laboratory system (Event data acquisition system)

FIGURE 9 *A view of the data acquisition system at CRL.*

time base. The data recorded on the magnetic tape can be reproduced on to a strip chart recorder at any desired speed and sensitivity to determine delay time intervals for different phases. Figure 10 and figure 11 illustrate events recorded on helical recorder at a speed of 1 mm/sec. and also on a magnetic tape together with other data channels from the network. These figures demonstrate clearly the advantages of the WITSEN system over the INDOSEN system in terms of accuracy with which onset times for different phases on different channels can be read. The amplitudes and period of different phases can also be measured precisely.

The dynamic range achieved (72 dB) in the WITSEN system is higher than offered by the INDOSEN system by a factor of 100. This enables one to magnify a smaller signal and to attenuate a larger amplitude one, to a readable level while replaying event data from a magnetic tape.

In the WITSEN system, the recording of event data at CRL is based on the detection of event onset in the majority of the channels and the events are reliably detected and recorded. As can be seen from the illustrations in figures 10 and 11, in the majority of shallow focus micro-earthquakes the energy release is so small that P (longitudinal) and S (shear) phases cannot be distinctly identified in all channels and a very weak surface phase is only noticed in distant channels.

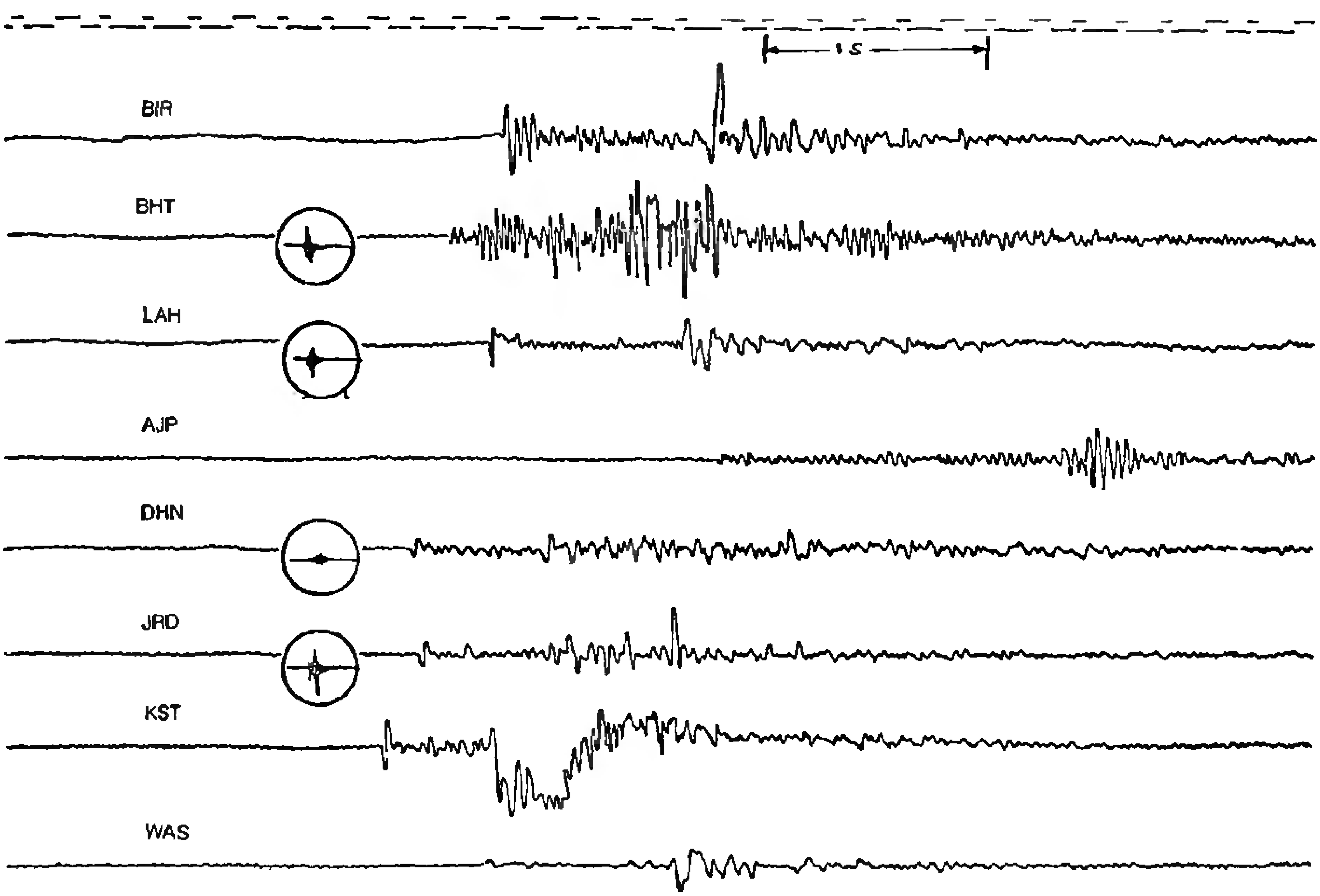

FIGURE 10 An example of a micro-earthquake recorded at Bhatsa. Onset time of 22:59:42 on 142nd day of 1989. Corresponding signal traces on helicorders for four monitored channels are shown in circles.

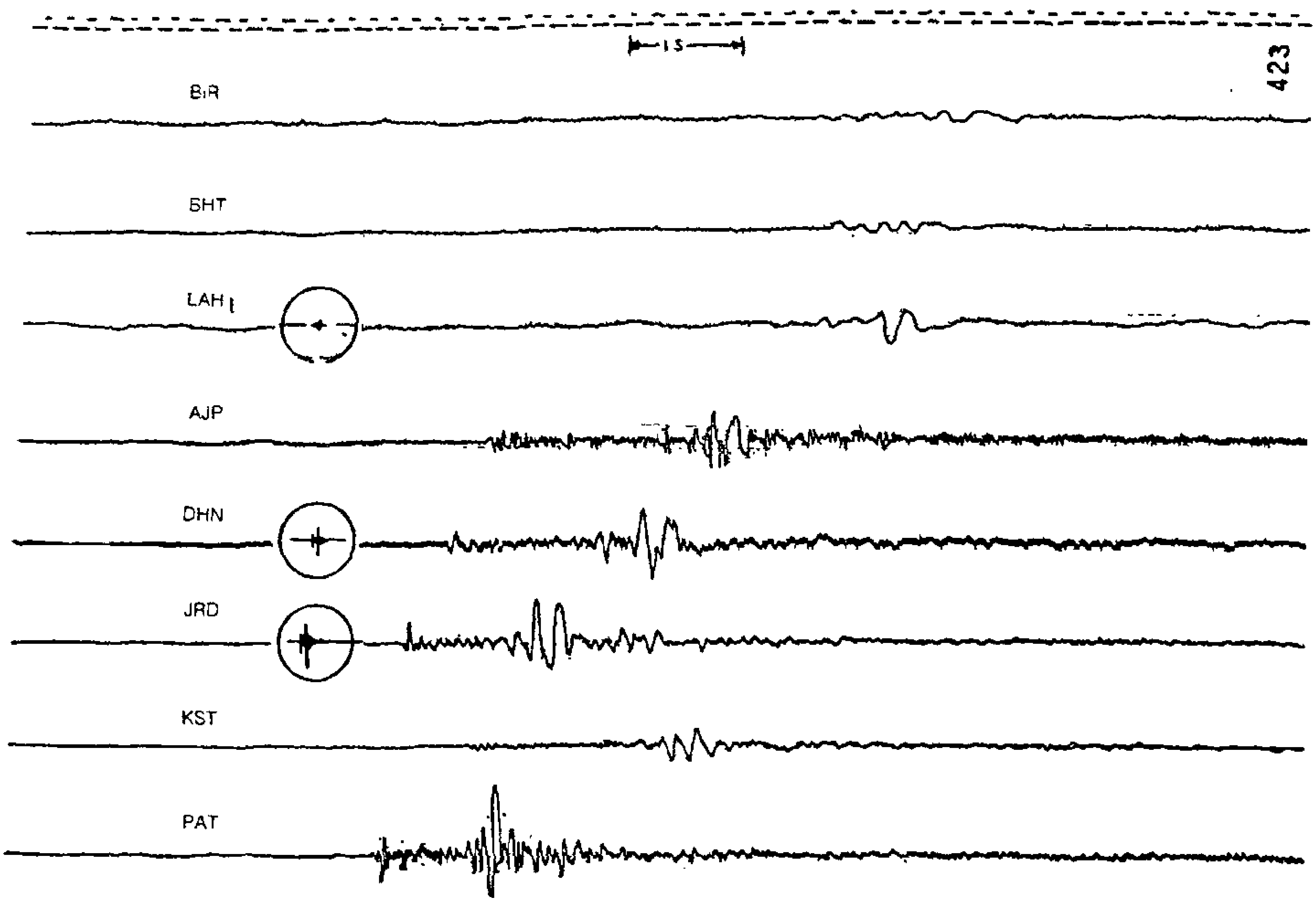

FIGURE 11 An example of a blast signal recorded at Bhatsa. Onset time of 02:09:51 on 142nd day of 1989. Corresponding signal traces on helicorders for three monitored channels are shown in circles. Note the weak signal traces from Birwadi, Bhatsa and Lahe stations.

Such small events may not be reliably recorded in all digital cassette recorders operated in the INDOSEN system.

In the WITSEN system, manual labour is drastically reduced. Any field station is required to be attended once in 2–3 months, at the most, only for the sake of preventive maintenance like checking the condition of the battery, cleaning the solar panel etc. The system at CRL is fully automated. Other routine work like checking the functioning of the channels, tape changing, tape head cleaning, event data replay etc. would take about a couple of hours in a day for a single operator.

The data recorded on a magnetic tape in the WITSEN can be extensively processed on a computer.

PERFORMANCE OF THE TELENET

All the telemetry system and the system at CRL have been functioning round the clock for the last 3 years. No major technical failure has taken place so far. However due to erratic mains supply, the UPS system failed 5 to 6 times. Long interruptions were encountered by deploying the stand-by UPS into operation.

In the field, there were few problems of non technical nature. Solar power module (PM645 of M/S Central Electronics) rated for 32 Watts, provided only about 40% efficiency and failed to keep the battery charged during rainy season. These were replaced by a more efficient one (PM648) which could provide sufficient charge to the battery for uninterrupted operation of the stations in all seasons. Due to cultivation and very rough road conditions two stations namely Kasti and Ajnup could not be accessed during the monsoon. In the recent past, both these stations and the station at Lahe were frequently hit by vandalism. Stations at Kasti and at Lahe are being moved to other safer locations. During the non monsoon period, on an average 10 stations have functioned satisfactorily at a time, and have provided good data.

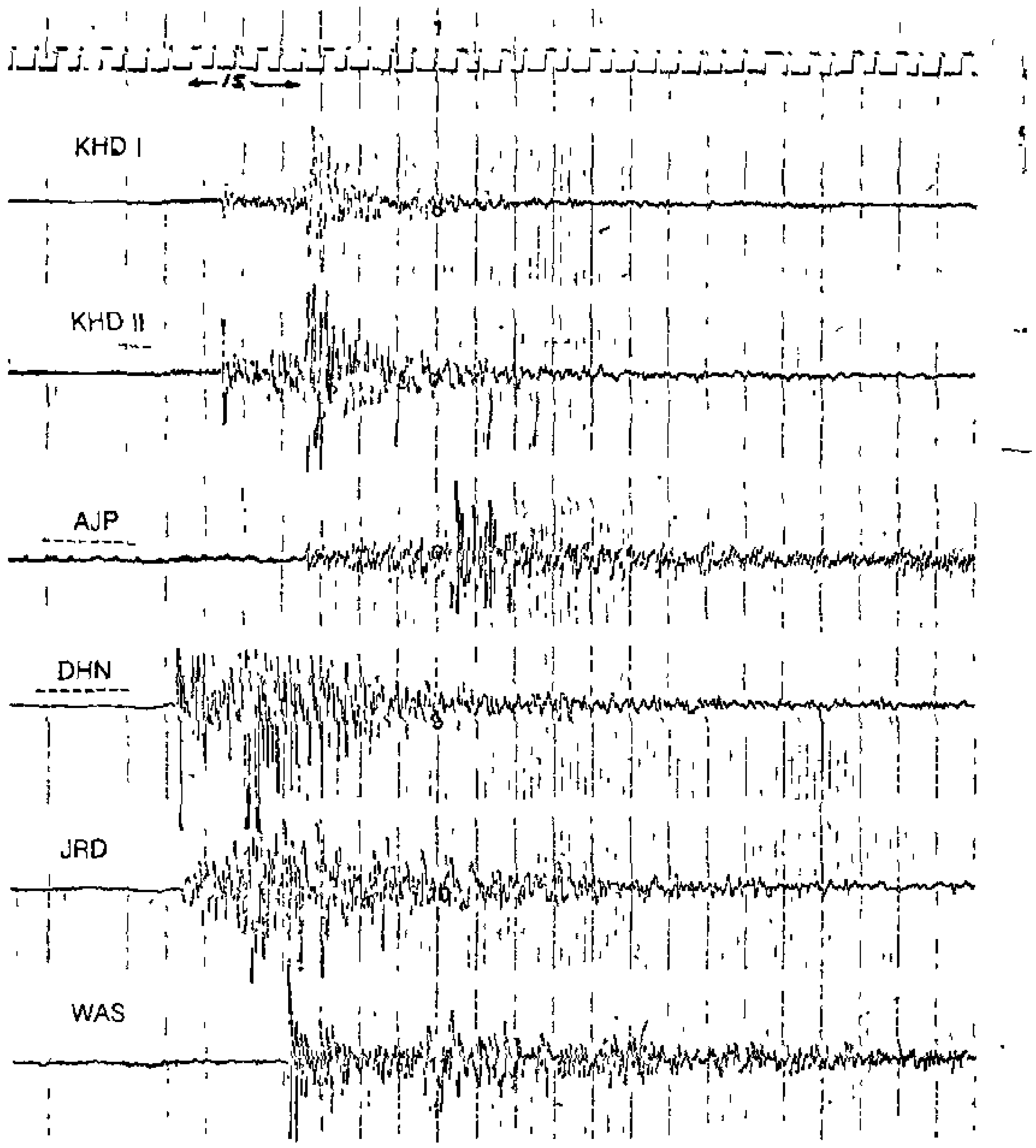

FIGURE 12 A foreshock with onset time of 16:28:35.6 on 2nd June 1990.

During the operation of the network in the last three years, the system gathers data for hundreds of local and teleseismic events. This region had not experienced any major seismic activity since it had subsided in the year 1985. During the first two years of operation of the network occasional minor micro-earthquakes (duration magnitude of −1, −2) were recorded. However a swam of micro-earthquakes was recorded in the first week of June, 1990. About a dozen foreshocks were recorded in six hours before the main shock which occurred at 17:35:04 (GMT) on 2nd June with a magnitude of 3·9. Hundreds of aftershocks were recorded within the next 72 hours. Analog data from Ajnup station for 2nd June, recorded on helicorder is illustrated in figure 11. Records of multichannel signals for a foreshock and for an aftershock is illustrated in figures 12 and 13. Epicenters for these events lie close to Jarandipada and Dhalkan stations. A detailed study of these swarm of earthquakes is underway.

The Bombay-Nasik rail track runs through the area under investigation and is a very busy track. Many a times stronger signals from moving trains were detected even by far off stations like Ajnup and Patola which are located 8 to 10 kms. away from the track. An illustration of a moving train signal is provided in figure 14.

Local events from distances of 2 to 3 hundred kms. are very prominent. All events of magnitude above 2·2 from Koyna region and also from north-west region (Gujrat), have been faithfully recorded. A typical event is illustrated in figure 15. All these event data is useful considering there is no other network operating in the vicinity, providing high quality data.

This network is also acquiring data for a number of teleseismic events and thus contributing a great deal in monitoring global seismicity. A typical teleseismic event is illustrated in figure 16. General microseism (background natural seismic noise prominent in the band 0·2 Hz to 0·5 Hz) is found to be in the same order as in Gauribidanur (few nanometers), although this network is situated just 50 kms (approx.) from Arabian Sea.

The multichannel event data in digital form is

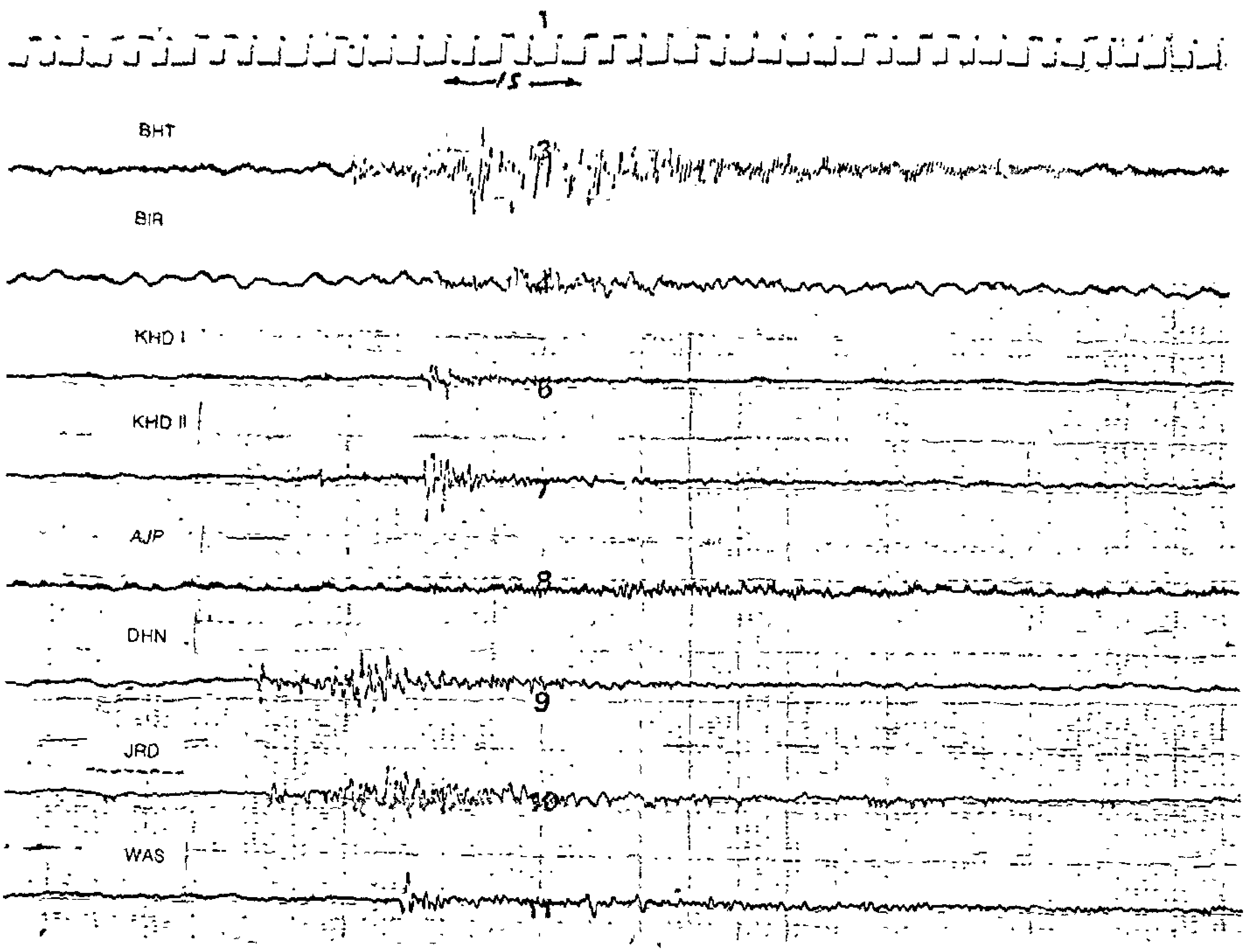

FIGURE 13 An aftershock with onset time of 18: 41:12.6 on 2nd June 1990.

extensively processed using HYPOGEL program to provide epicentral locations, focal depth and velocity parameters of each event. Magnitude and energy release for each event are also computed separately[10].

SOME RESULTS OF THE PROJECT

This is the first ever radio telemetered seismic network built indigenously and operating satisfactorily. The total system cost around 22 lakhs of rupees including total laboratory and field systems, all civil structure, and laboratory furniture. Foreign exchange requirement may be 1/3rd of this cost. This cost is very much less than any foreign system, for which the equipment cost may alone run into 30 to 50 lakhs of rupees (FE).

A write up has been prepared to provide guidelines based on our experience in Bhatsa for realising a network of similar specifications which can be systematically commissioned in about two months at any place in the country. This write up also enlists the infrastructure requirements of the field and laboratory system, requirement of manpower, cost structure and time schedule for building a similar network[11].

CONCLUDING REMARKS

In the application of monitoring micro-earthquakes, it is necessary to acquire data with a higher dynamic range. A very large signal can be generated from a closely located sensor even from a low intensity micro-earthquake. A dynamic range of 72 dB (from 12 bits digital system) may not be adequate in this case. This can be increased to about 96 dB by employing 16 bit ADC in each field system and employing the digital

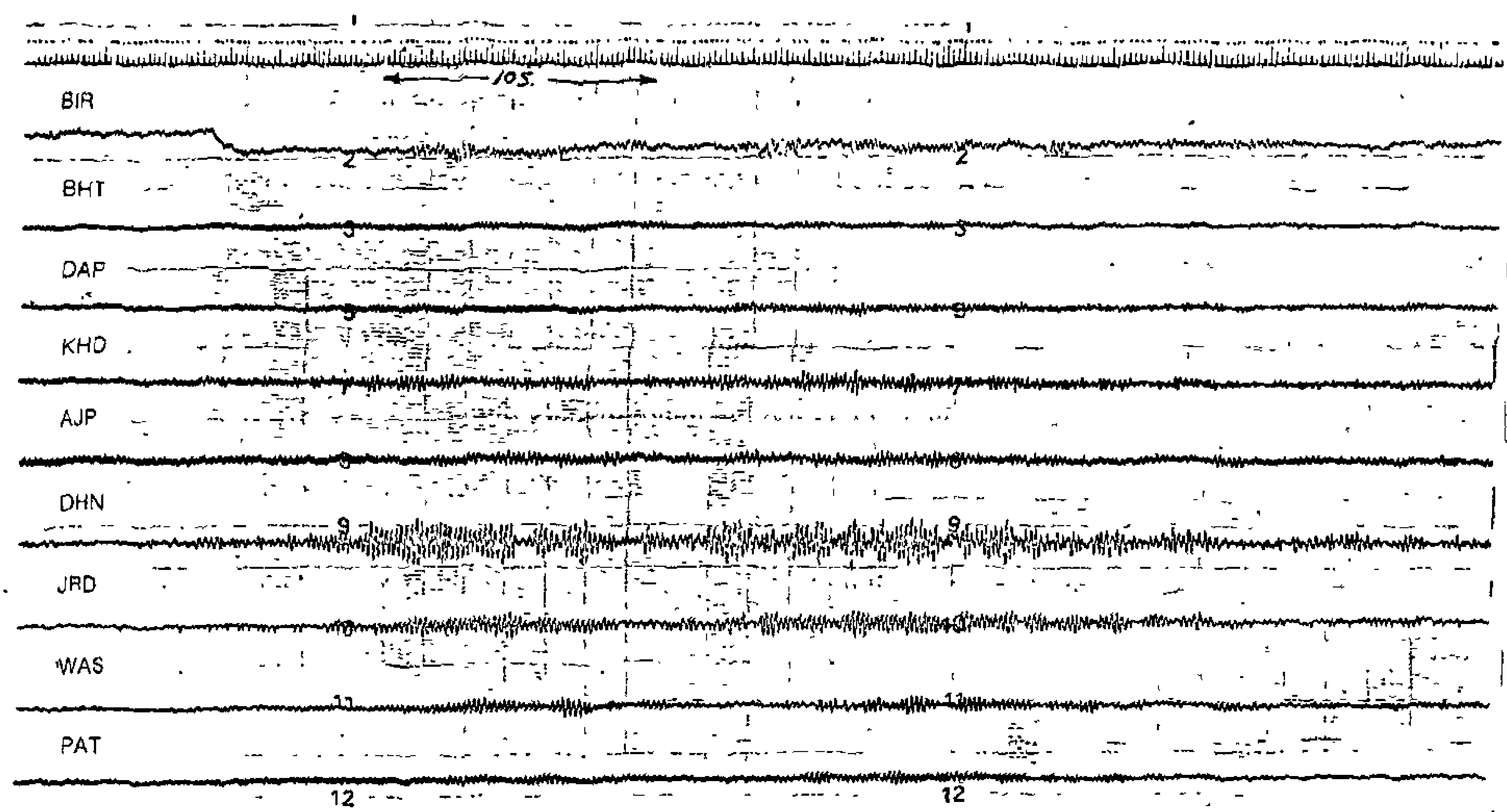

FIGURE 14 An illustration of a typical train motion picked by all stations.

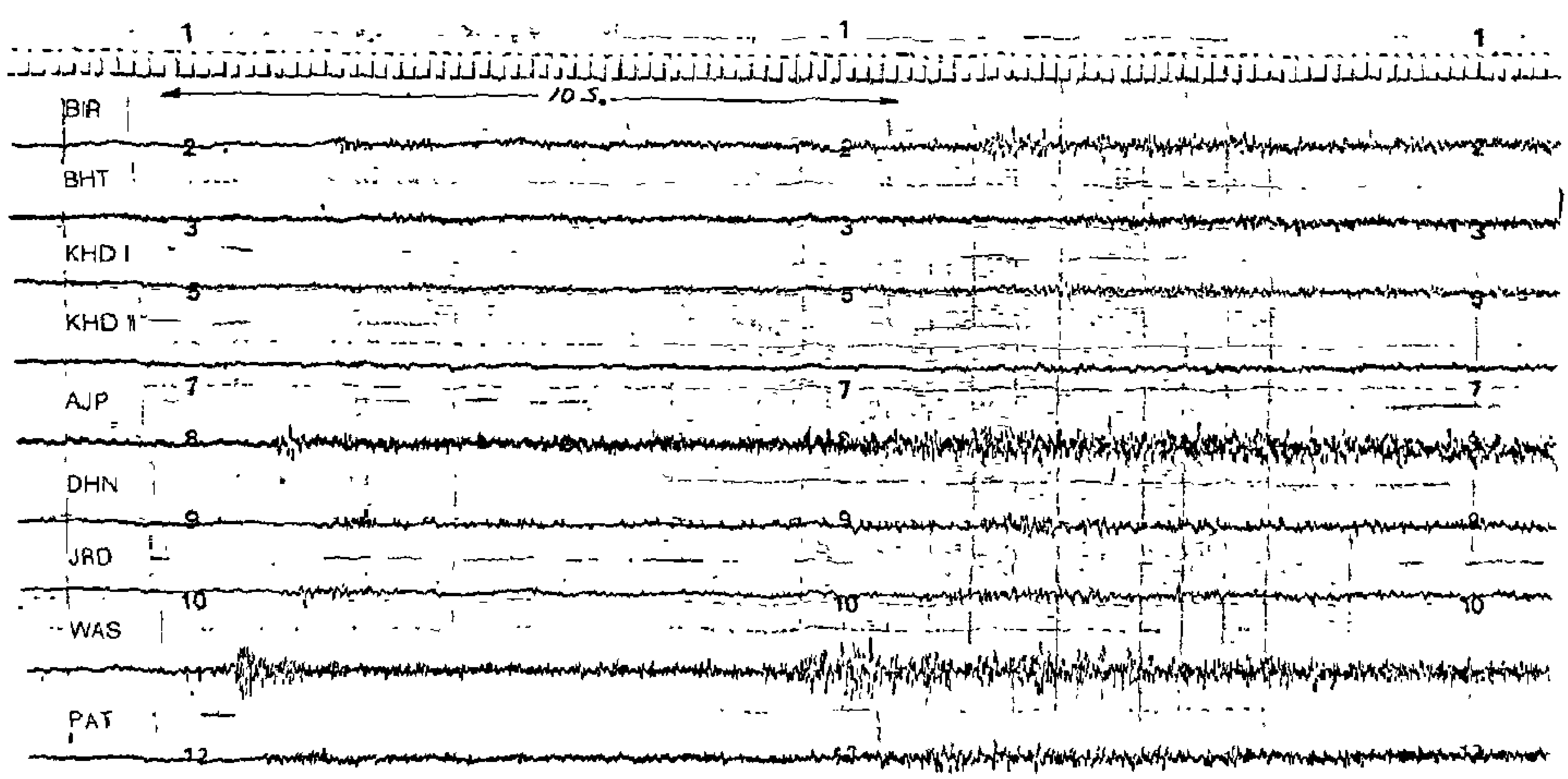

FIGURE 15 An event from north-northeast direction with P & S difference of 12 sec., onset time of 08.24.05.1 on 241st day of 1990.

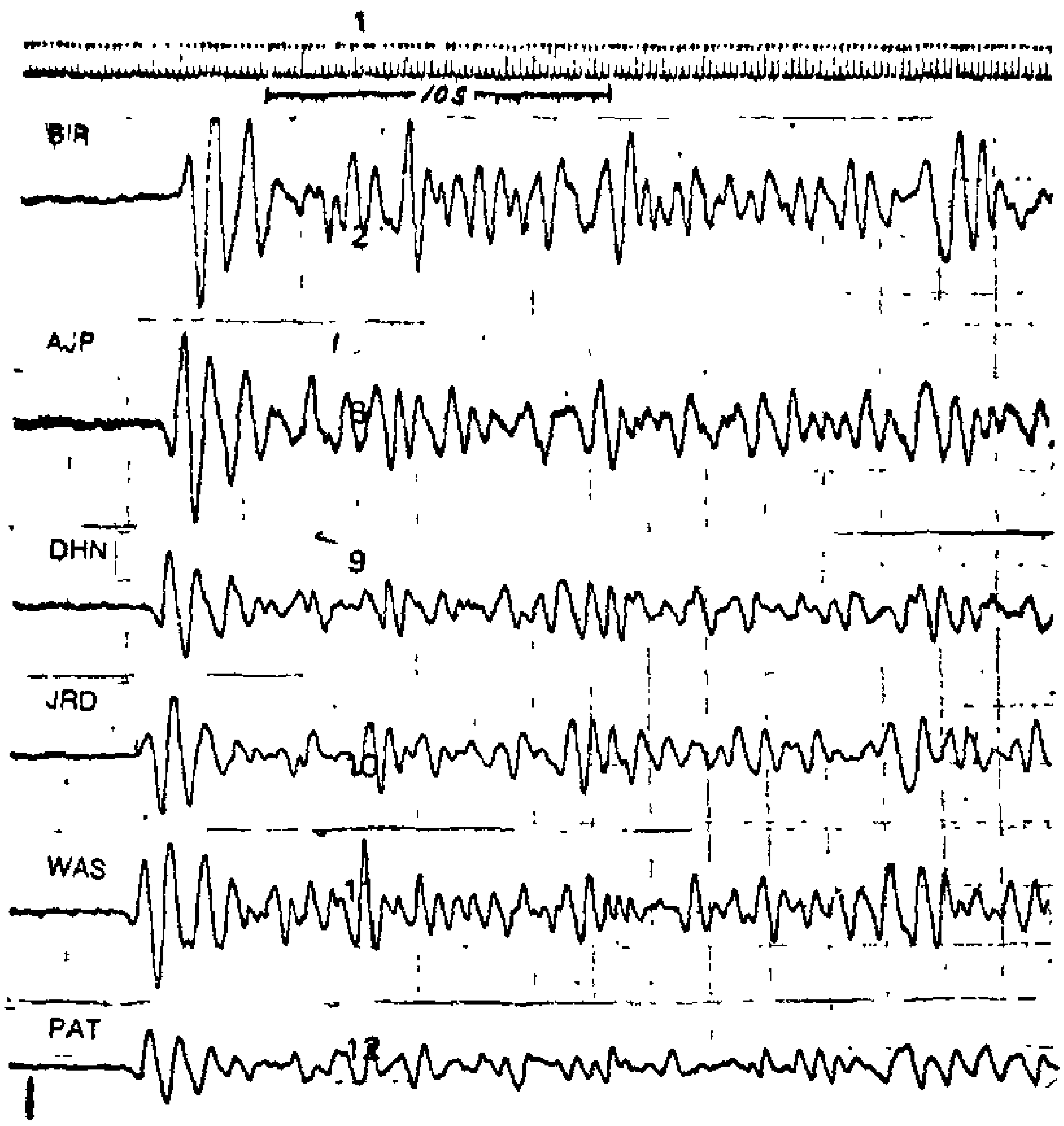

FIGURE 16 A teleseismic event with onset time of 16:19:06 on 239th day (5th Dec.) of 1990, Origin time 16:08:52.7, Lat = 5.25S, Long = 131.4E, Depth = 89 kms., Mb = 5.9, Location, Banda Sea, (Information from GEDESS).

telemetry system. Design of such system is under development.

As discussed earlier WITSEN provides tremendous advantages over INDOSEN system and it is hoped that in any future applications in the country, WITSEN would be preferred to INDOSEN.

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