REPORT
ON THE PROJECT

IMPROVEMENT OF AGROMETEOROLOGICAL

AND

SEISMOLOGICAL SERVICES

IN

BANGLADESH

UNDER

**BANGLADESH METEOROLOGICAL DEPARTMENT
GOVERNMENT OF THE PEOPLE'S REPUBLIC OF
BANGLADESH**

CONSULTANT: **DR. H. N. SRIVASTAVA**

GLOBAL SUPPLIERS LIMITED
63, MOHAKHALI C/A
DHAKA – 1212
BANGLADESH

PROJECT REPORT
On the

Establishment of seismic network in Bangladesh under Bangladesh Meteorological Department

Through Global Suppliers Limited, 63, Mohakhali C/A, Dhaka – 1212.

Consultant. **Dr. H. N. Srivastava**

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CHAPTER – I

EARTHQUAKES IN BANGLADESH

PREFACE

Under the project entitled "Improvement of Agrometeorological and Seismological services in Bangladesh Meteorological Department (BMD) Government of Bangladesh invited Global tenders for seismological consultancy services in April 1999.

The Department decided to award the contract to the Global Suppliers Limited supported by Dr H. N. Srivastava, Phd. FNA.SC a reputed SEISMOLOGIST as the CONSULTANT from India. Sites were selected for new Seismological observatories at Sylhet, Rangpur and Dhaka through joint survey by the consultant and Senior BMD officers. A visit was also made to see the Chittagong Geophysical Observatory. An interim survey report was submitted to BMD on 27.3.2000 followed by submission of final report on 13.4.2000 (which is included as Chapter 11 of this Project report)

The project report has been divided into 12 chapters and designed in such a way as to provide an overall view of seismicity of Bangladesh, modern Seismological practices, instruments, data centers and exchange and the importance of the upgraded network for earthquake hazard assessment in Bangladesh. The tender document has been prepared to match with modern global network of Seismological Stations in different parts of the world

The project document, tender specifications, design of buildings and other requirements of the project have been prepared through active interaction with BMD and PWD officers

The consultant, in particular and the Global Suppliers Limited place their deep appreciation for cooperation and support for the first phase of two months (from 8.3.2000 to 7.5.2000). Special acknowledgements are due to Mr. Ershad Hussain, Director, BMD Mr Md Ashraf Ali Howlader, Mr. S. Karmaker, Deputy Directors and related officers of Rangpur, Chittagong and Sylhet. Any clarification or support required for the project execution will be duly extended by the Global Suppliers Limited, Dhaka

Earthquake in Bangladesh

1.1 Introduction

Earthquakes have been occurring from times immemorial causing huge loss of life and property. As the science of seismology is only about 100 years old, our information about earthquake parameters is based on historical records, books, newspapers and gazetteers. From the description of the damage caused, inferences are drawn about the place of occurrence of the earthquakes and its intensity from the historical records. It often becomes a difficult task even to assess the date or month of its occurrence due to use of different type of calendars or late reporting of information about past earthquakes. It is a subject of research to scan old records and report new earthquakes.

Damage due to earthquakes is caused not only by the local earthquakes but also, distant ones depending upon the distance of the source focal depth and local geology. Thus great earthquakes which have occurred in the Indian and neighboring region have caused earthquakes destruction in Bangladesh. Rapid growth of multistoried buildings and other development projects requires installation of seismological instruments in the country as early as possible to monitor earthquake hazard including after shocks if any.

1.2 Historical Earthquakes upto 1900

Examination of old records and catalogues of earthquakes has brought out the following damaging earthquakes in Bangladesh and neighborhood. The intensity has been assessed in modified Mercalli Scale whose details are given in table 1. Its conversion to magnitude is approximate.

1	2 April 1762	22.0	92.0	XI	7.5	off cost of Chittagong
2	3 April 1822	23.5	91.0	VIII	6.0	Comilla

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2	3 April 1822	23.5	91.0	VIII	6.0	Comilla

3	8 July 1834	25.8	89.4	VIII	6.3	Rangpur
4	21 July 1834	25.8	89.4	VIII	6.0	Rangpur
5.	11 Nov 1842	25	90	IX	6.8	Pabna
6.	6 Aug 1845	24.5	91.8	VIII	6.0	Near Sylhet
7.	18 Oct 1846	24.5	90.4	VIII	6.3	Mymensingh
8	8 January 1851	22.3	91.8	VIII	6.3	Chittagong
9	15 December 1865	22.5	92.0	VIII	6.3	Chittagong
10	30 June 1868	24.9	91.9	VIII	6.0	Sylhet
11	10 January 1869			IX	7.0	Cachar (India)
12	14 July 1885	24.5	89.7	IX	7.0	Sirajgaonj, Khamakhil
13	12 June 1897	25.9	91.0	XI OR XII	8.7	Great Shillong earthquake (India)

The extent of damage due to Chittagong earthquake of 1865 along with the after shocks felt may be assessed from the information published in the Times of India dated 1 February 1866.

After shocks

1st	Friday	December	15th	6-30 P.M
2nd	Friday	December	15th	7-10 P.M
3rd	Friday	December	15th	10-30 P.M
4th	Saturday	December	16th	2-0 A.M
5th	Saturday	December	16th	4-0 A.M
6th	Saturday	December	16th	6-15 P.M
7th	Saturday	December	16th	2-40 P.M
8th	Monday	December	18th	12-0 noon
9th	Tuesday	December	19th	2-0 P.M

10th	Tuesday	December	19th	10-0 P.M
11th	Wednesday	December	20th	2-0 A.M

Of these shocks, the first was very violent, and caused considerable damage to several of the masonry buildings in the station. The sixth was also severe. During the time from Friday evening to Sunday morning there was observed almost continuous motion of the earth.

In thannah Rojao, the earth's surface cracked in several places which was forced with jets of water and a fine dark colour sand in appearance, very much resembling the common medicinal preparation called Grey powder.

"From a memorandum by Mr. Wilson, the joint magistrate, who visited the place of ejectment, it appears that no sand has ever been found in the deepest excavations, so that it must have been forced up from a great depth. Similar jets and fountain appear to have also occurred near a tea garden on the sungeo. It may also be worth mentioning that wells were burning with an igneous gas rising from the surface of the water and igniting in contact with atmosphere, but it gave no indication of more than the ordinary strength, nor did any of them gave indications of internal volcanic action".

Damage due to the great Shillong earthquake of 1897 (magnitude 8.7) extended to several places in Bangladesh. All brick buildings in Sylhet suffered and fissures occurred. Majority of the brick buildings at Dhaka, Rangpur, Mymensingh suffered besides a few buildings at Chittagong.

1.3 Earthquakes after 1900

Table 2 gives the details of earthquakes covering most of Bangladesh and neighbuoring Indian region after 1900 which is based on instrumental data. The accuracy in the epicentral parameters however, improved after 1963-1964 when a world wide standardized network of seismographs was installed by the U.S. Geological survey

Among the recent past, the Shreemongal earthquake of 1918 was very damaging. In Maulvi Bazar masonry buildings were damaged and many destroyed. In Sylhet and Kishorganj all brick buildings were badly cracked. In Dhaka, several buildings were slightly damaged.

In the Dhubri Earthquake of 1930, Lalmonirhat, Rangpur, Kurigram and Gaibandha towns were severely affected. Slight cracks appeared in a few buildings as far away as Calcutta. Earthquakes originating near Bangladesh Myanmar border have occasionally caused minor cracks in some buildings in Chittagong.

A perusal of the catalogue of earthquakes after 1964 shows that the epicentral parameters (latitude, longitude) of a few earthquakes could be determined upto lowest magnitude of 4.Fig 1 shows the distribution of earthquakes in Bangladesh and neighborhood suggesting that northeastern and eastern parts of Bangladesh are seismically more active as compared to the western areas. However, information about lineaments/ faults hidden in alluvium is lacking. Also, the phenomenon of liquefaction is more serious in this region besides amplification of ground motion. Thus there is a need to establish seismological stations in Bangladesh to meet the following objectives:

i. Increase in the detection capability implying larger number of smaller magnitude earthquakes to apply probabilistic methods like return period of earthquakes.

ii. Improved epicentral parameters, in particular focal depth, which is important for defineation of faults in Bangladesh.

iii. Aftershocks monitoring and migration

TABLE I

Modified Mercalli Intensity Scale of 1931

Scale	Specifications
I	Not felt except by very few under especially favourable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations like passing of lorry. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened Dishes, windows, doors disturbed; walls make cracking sound. Sensations like heavy lorry striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc. broken; a few instances of cracked plaster, unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Every body runs outdoors. Damage negligible in buildings of good design and construction; slight to moderately built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars.

IX Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X Some well-built wooden structures destroyed; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed over banks of rivers, etc.

XI Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown upward in the air.

TABLE 2

LIST OF EARTHQUAKES OCCURRING BETWEEN LAT 22.00 TO 28.00 DEG N AND LONG 85.00 TO 92.00 DEG. E FOR THE PERIOD 1901 TO 1998

			Origin (Time)						
Year	M	Day	H	M	S	Lat(°N)	Long(°E)	Dep	Mag
1909	2	17	0	0	0.0	27.00	87.00	0	5.0
1911	12	7	0	0	0.0	23.00	88.00	0.	5.0
1915	11	14	0	0	0.0	26.00	92.00	0.	5.0
1915	12	5	0	0	0.0	26.00	92.00	0.	5.0
1918	7	8	10	22	7.0	24.50	91.00	0.	7.6
1923	9	9	22	3	42.0	25.30	91.00	0.	7.1
1927	8	25	22	56	38.0	22.00	90.00	0.	5.5
1930	7	2	21	3	34.0	25.80	90.20	0.	7.1
1930	7	3	0	19	5.0	25.80	90.20	0.	5.5
1930	7	4	18	54	44.0	25.80	90.20	0.	5.5
1930	7	4	21	34	00.0	25.80	90.80	0.	5.5
1930	7	8	4	32	24.0	25.80	90.80	0.	5.5
1930	7	8	9	43	0.0	25.80	90.80	0.	5.5
1930	7	13	14	0	12.0	25.80	90.80	0.	5.5
1932	3	24	16	8	44.0	25.80	90.20	0.	5.5
1932	11	9	18	30	16.0	26.50	92.00	0.	5.5
1933	3	6	13	5	38.0	25.70	90.50	0.	5.8
1934	1	15	8	43	25.0	26.60	86.80	0	8.3
1934	1	16	4	59	22.0	28.00	86.00	0.	5.6
1934	7	21	0	0	0.0	25.80	89.40	0.	5.5
1935	3	21	0	4	2.0	24.40	89.50	0	6.2
1935	3	21	4	48	8.0	27.00	85.00	0	5.5
1936	2	11	4	48	8.0	27.00	85.00	0.	5.5
1936	5	30	7	8	38.0	25.70	90.50	0.	5.3
1936	6	9	0	2	42.0	27.50	87.00	0	5.5
1936	6	18	14	56	27.0	26.60	90.30	0.	5.8
1936	9	7	2	30	49.0	27.50	87.00	0.	5.7
1937	3	9	20	19	14.0	27.00	92.00	0.	5.7
1938	1	29	4	13	8.0	27.50	87.00	0.	5.8
1938	2	26	12	10	43.0	28.00	90.50	0.	5.7
1938	4	13	1	10	17.0	26.00	91.00	0.	5.2
1940	2	13	11	46	28.0	27.00	92.00	0.	5.7
1940	8	2	3	3	59.0	28.00	90.50	0.	5.2
1941	1	21	12	41	41.0	27.20	92.00	180.	6.8
1941	1	27	2	30	4.0	27.00	92.00	0.	6.5
1941	9	6	3	17	47.0	27.00	92.00	0.	5.8
1942	2	21	21	46	52.0	24.00	90.30	0.	5.9

1943	2	8	21	5	24.0	27.00	92.00	0.	6.0
1945	5	19	5	2	53.0	25.10	90.90	0.	6.1
1947	11	29	17	56	4.0	27.90	91.90	0.	5.9
1948	10	7	1	18	32.0	27.90	91.90	0.	5.5
1949	12	10	19	37	14.0	26.00	89.00	0.	6.0
1950	2	26	3	35	48.0	28.00	90.50	0.	6.0
1950	8	16	12	38	27.0	27.90	91.90	0.	5.5
1950	8	16	17	51	37.0	27.90	91.90	0.	6.7
1950	8	17	23	56	34.0	27.90	91.90	0.	6.0
1950	12	29	22	35	20.0	24.00	91.80	0.	6.3
1951	4	7	20	29	12.0	25.90	90.50	0.	6.8
1952	10	19	10	44	28.0	27.80	85.70	0.	5.5
1954	2	23	6	40	32.0	27.80	91.70	0.	6.5
1956	6	12	3	12	26.0	24.80	90.90	0.	6.0
1958	1	4	0	0	0.0	27.00	92.00	0.	5.0
1958	2	9	9	31	9.0	24.93	90.86	36.	5.0
1960	7	29	10	42	44.6	26.90	90.30	11.	6.5
1960	8	21	3	29	4.9	27.00	88.50	29.	5.5
1961	9	29	22	36	30.0	28.00	87.00	0.	5.5
1961	11	6	7	59	4.1	26.70	91.90	67.	5.0
1961	12	25	11	19	10.0	27.00	90.00	0.	5.5
1962	1	11	3	1	29.0	27.00	85.00	38.	5.5
1963	2	22	1	32	30.0	27.20	87.10	0.	5.2
1963	6	19	10	47	39.0	24.90	90.50	0.	6.2
1963	6	21	0	0	0.0	24.80	90.90	0.	6.2
1964	2	1	11	28	19.2	27.30	87.78	33.	4.8
1964	2	18	3	48	34.4	27.40	91.18	22.	5.3
1964	3	27	23	3	41.1	27.13	89.36	29.	5.0
1964	8	30	2	35	7.3	27.36	88.21	21.	5.1
1965	1	12	13	32	24.1	27.40	87.84	23.	5.8
1965	1	12	13	55	18.1	27.31	87.68	18.	5.2
1966	2	24	0	16	40.8	26.35	91.44	47.	4.7
1967	9	6	1	43	30.0	24.00	91.90	2.	4.9
1967	9	15	10	32	44.2	27.42	91.86	9.	5.8
1967	1	10	6	4	7.0	25.46	91.75	44.	4.7
1967	11	14	0	4	17.0	24.05	91.61	24.	4.9
1968	6	12	4	29	21.7	24.83	91.94	39.	5.3
1968	8	18	14	18	58.0	26.42	90.62	22.	5.1
1968	10	28	17	48	30.1	27.57	86.03	37.	4.9
1968	12	27	14	38	12.0	24.12	91.61	27.	5.1
1968	12	27	14	38	12.0	24.12	91.61	27.	5.1
1969	11	5	20	25	13.7	27.66	90.24	13.	5.0
1970	2	26	19	30	14.5	27.62	85.70	96.	5.0
1970	2	26	23	21	20.0	27.30	85.90	31.	4.7

1970	7	25	1	35	26.0	25.72	88.58	32.	5.1
1970	8	28	1	24	7.4	24.78	91.55	39.	4.9
1971	2	2	7	59	55.8	23.71	91.66	37.	5.4
1971	10	31	15	54	48.2	26.18	90.65	33.	4.7
1971	12	4	8	38	0.2	27.92	87.95	29.	5.2
1972	8	21	14	4	34.2	27.33	88.01	33.	4.5
1972	11	6	10	56	13.5	26.88	88.43	59.	4.4
1973	11	2	12	9	55.4	25.72	91.70	21.	4.6
1974	3	24	14	16	1.1	27.66	86.00	0.	5.4
1974	3	24	16	17	35.3	27.63	86.01	3.	4.7
1974	5	15	3	51	21.8	25.66	91.91	34.	4.5
1974	9	21	6	27	41.8	25.62	91.04	27.	4.7
1975	1	23	1	37	42.6	27.44	88.37	33.	4.5
1975	2	6	6	39	48.7	27.95	87.67	63.	4.7
1975	4	24	1	35	51.2	27.44	87.04	26.	4.9
1975	6	24	15	38	28.1	27.74	87.50	33.	4.8
1975	11	21	13	49	27.9	26.96	86.54	0.	4.9
1976	9	12	15	36	11.9	27.68	85.94	33.	4.5
1977	6	5	19	21	37.4	26.07	88.43	0.	4.7
1978	10	4	13	53	50.6	27.82	85.93	0.	4.8
1978	10	14	18	48	48.9	27.66	87.33	0.	4.8
1979	1	13	3	27	15.4	27.39	91.89	33.	4.4
1979	1	28	6	6	38.3	24.87	91.02	0.	4.9
1979	2	26	6	54	56.0	25.98	91.23	53.	4.3
1979	4	2	1	16	46.5	26.46	90.68	33.	4.4
1979	4	11	16	8	12.6	25.98	88.84	33.	4.7
1979	6	19	16	29	8.4	26.74	87.48	1.	5.2
1979	8	5	1	18	36.6	22.12	85.97	33.	4.6
1979	10	17	1	44	22.2	27.97	87.62	33.	4.6
1979	11	16	19	17	27.4	27.95	88.69	39.	4.6
1980	6	11	5	25	15.4	25.79	90.31	68.	4.9
1980	10	30	5	29	41.1	23.90	91.46	29.	4.6
1980	11	19	19	0	44.5	27.40	88.80	1	6.0
1980	11	25	9	27	5.1	27.87	85.46	33.	4.1
1980	12	22	4	36	8.0	26.67	89.59	33.	4.4
1981	2	9	15	49	21.6	27.20	89.76	16.	4.9
1981	3	26	2	47	10.4	22.35	89.07	0.	4.9
1982	1	28	7	18	7.6	25.47	90.89	33.	4.4
1982	2	26	0	5	47.5	25.79	90.62	48.	4.6
1982	4	5	2	19	41.1	27.38	88.84	9.	5.0
1982	6	20	15	29	19.8	26.24	89.97	33.	4.5
1982	7	6	6	13	32.0	25.88	90.31	8.	5.0
1982	8	18	18	1	7.6	27.04	89.26	51.	4.6
1982	8	31	10	42	45.4	25.38	91.46	32.	4.9
1982	9	21	12	38	27.9	25.15	91.27	43.	4.9

1982	11	18	6	2	26.5	26.38	91.75	0.	4.8
1982	12	30	8	37	16.0	26.01	91.69	61.	4.9
1982	12	30	12	29	27.5	26.25	91.65	33.	4.6
1983	1	19	12	9	33.2	25.46	91.36	10.	4.8
1983	7	23	7	28	34.4	25.37	91.25	58.	4.7
1983	11	17	21	20	12.8	25.15	91.73	41.	4.4
1983	12	23	19	35	44.2	25.87	87.91	33.	4.3
1984	1	25	23	49	44.6	27.49	86.10	11.	4.6
1984	5	21	9	59	5.0	23.66	91.51	12.	5.2
1984	9	30	21	35	25.3	25.44	91.51	34.	5.0
1985	1	7	16	13	5.4	27.14	91.96	12.	5.4
1985	1	7	20	14	44.8	27.20	91.77	33.	4.6
1985	1	11	20	39	28.4	27.13	91.90	33.	4.6
1985	2	17	23	6	55.0	24.67	85.48	11.	4.7
1985	5	25	0	28	18.7	27.60	88.48	33.	4.6
1985	6	7	18	23	59.0	26.87	90.21	33.	4.8
1985	6	17	21	52	49.0	25.65	90.20	22.	4.6
1985	10	2	16	33	50.3	27.19	89.73	45.	4.4
1985	12	23	13	49	45.2	27.65	85.66	46.	4.4
1986	1	6	9	50	42.0	27.85	85.32	34.	4.8
1986	1	7	20	20	0.4	27.40	88.43	41.	4.7
1986	2	2	0	13	50.7	27.92	86.45	33.	4.5
1986	2	19	17	34	23.0	25.10	91.13	7.	5.2
1986	3	17	3	3	35.1	22.87	85.16	33.	4.3
1986	7	16	6	37	49.1	27.60	91.60	33.	4.5
1986	10	14	14	3	2.1	25.03	91.97	33.	4.6
1986	10	25	21	25	30.4	26.12	88.26	33.	0.0
1987	4	23	9	5	56.8	27.93	87.01	48.	4.7
1987	4	25	22	13	47.0	25.30	88.46	10.	0.0
1987	10	22	21	23	56.0	27.07	89.06	19.	4.2
1987	11	25	19	20	40.0	27.70	86.17	33.	4.5
1987	12	6	23	29	44.0	27.00	88.52	42.	0.0
1987	12	11	6	39	40.0	26.04	90.92	57.	4.6
1988	1	19	11	23	51.0	27.80	88.80	33.	4.3
1988	2	6	14	50	45.4	24.67	91.56	33.	5.8
1988	2	28	5	55	49.0	24.72	91.56	22.	4.6
1988	3	27	5	56	30.0	27.10	88.42	70.	4.1
1988	4	11	12	11	31.2	27.57	85.86	38.	4.7
1988	4	20	6	40	25.8	27.02	86.72	55.	5.4
1988	4	25	16	4	3.7	26.90	86.54	79.	4.7
1988	4	30	3	27	51.0	25.90	91.60	33.	4.2
1988	5	7	5	29	44.0	24.70	89.70	33.	0.0
1988	5	10	7	16	16.1	25.32	90.88	33.	4.4

1988	5	26	16	30	5.5	27.45	88.61	42.	4.7
1988	5	28	23	13	12.0	28.00	89.70	33.	0.0
1988	8	20	21	24	8.0	27.90	85.60	33.	0.0
1988	8	20	23	9	10.1	26.72	86.63	65.	6.4
1988	8	20	23	38	56.0	26.90	86.70	38.	0.0
1988	8	21	16	32	59.0	27.80	85.40	33.	0.0
1988	8	22	11	34	34.7	26.61	86.74	33.	4.3
1988	8	24	9	55	34.3	26.77	86.44	41	4.7
1988	8	29	12	12	17.0	26.39	87.50	33	4.5
1988	9	1	22	4	11.3	26.80	86.53	33.	4.5
1988	9	2	6	35	34.3	26.56	86.48	33.	4.3
1988	9	4	8	1	58.0	26.30	91.75	7.	4.4
1988	9	27	19	10	10.0	27.19	88.37	28.	5.0
1988	10	29	9	10	52.7	27.87	85.64	18.	5.5
1988	11	11	14	14	18.0	27.60	85.90	33.	0.0
1988	12	10	15	24	31.4	26.38	86.68	33.	0.0
1988	12	13	6	29	17.3	27.14	87.97	52.	4.4
1988	12	20	9	45	44.4	27.66	91.12	39.	4.9
1988	12	23	14	18	39.0	23.80	88.97	33.	0.0
1988	12	24	13	32	22.0	26.90	88.00	41.	4.4
1988	12	27	2	56	1.8	27.98	87.86	38.	4.6
1989	1	6	13	31	58.0	25.10	91.61	10.	0.0
1989	2	14	15	52	46.0	23.50	89.20	33.	4.1
1989	3	13	13	6	46.0	22.66	92.00	31.	4.1
1989	4	26	13	40	35.8	27.93	85.19	33.	0.0
1989	4	29	12	55	17.0	25.60	91.58	33.	4.3
1989	5	10	23	20	34.0	27.70	87.20	33.	0.0
1989	5	22	19	24	31.0	27.38	87.86	4.	5.0
1989	6	11	13	42	45.7	26.39	90.70	50.	4.5
1989	6	12	23	12	19.0	28.00	85.60	33.	0.0
1990	1	10	23	1	21.7	26.52	86.67	66.	4.4
1990	5	19	2	18	57.0	25.40	90.93	33.	0.0
1990	10	29	12	6	28.0	27.60	89.10	33.	0.0
1991	2	2	0	15	40.0	25.51	91.17	25.	5.0
1991	2	3	13	22	10.0	25.50	91.67	19.	4.1
1991	6	8	18	59	57.8	26.30	90.37	33.	4.0
1991	8	7	11	36	29.1	25.27	88.66	10.	4.7
1991	8	10	13	0	15.2	24.40	90.51	33.	4.2
1991	8	19	22	28	41.0	26.80	90.70	10.	0.0
1991	8	22	3	53	44.3	25.29	91.18	45.	4.7
1991	9	2	17	20	37.0	24.50	90.47	78.	4.5
1991	9	25	19	26	49.3	26.70	88.40	33.	0.0
1991	10	30	13	13	57.0	26.00	88.60	33.	0.0

1991	12	21	19	52	45.1	27.79	87.96	65.	4.7
1992	2	1	4	52	24.4	23.50	90.90	33.	0.0
1992	4	1	13	41	3.9	27.40	87.10	33.	4.3
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1992	5	3	21	11	29.1	23.90	91.10	33.	4.2
1992	5	28	9	53	20.4	23.20	92.00	33.	4.5
1992	6	27	16	58	57.0	22.00	88.00	33.	4.2
1992	8	8	12	7	48.7	25.40	91.90	50.	4.3
1993	2	15	14	29	40.8	25.90	87.50	30.	5.0
1993	3	3	5	17	31.0	25.40	90.20	33.	4.5
1993	5	6	9	5	58.6	23.10	87.00	33.	4.6
1993	7	5	21	41	45.9	28.00	85.00	33.	3.8
1993	7	5	22	11	9.8	27.90	85.10	33.	4.7
1993	7	9	16	23	17.3	26.80	86.00	33.	4.6
1993	7	31	19	29	21.7	27.90	91.90	33.	4.4
1993	9	5	6	5	54.6	27.20	87.30	33.	4.5
1993	12	12	23	54	18.4	27.20	92.00	33.	5.1
1994	1	16	14	22	38.3	26.40	89.10	33.	3.9
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1994	6	25	8	32	42.9	27.60	85.90	33.	4.4
1995	1	1	19	36	13.6	27.80	87.60	33.	4.9
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1995	5	14	19	10	58.0	23.80	88.00	33.	4.1
1995	5	16	8	11	2.0	23.80	88.00	33.	4.1
1995	8	8	16	52	48.8	26.40	90.40	33.	4.4
1995	12	1	20	9	23.0	26.20	91.60	33.	4.5
1995	12	4	17	54	46.0	27.60	92.00	33.	4.2
1995	12	6	0	50	33.0	25.20	91.00	33.	4.5
1995	12	11	9	49	36.0	27.60	87.50	33.	4.0
1996	1	25	7	15	19.3	28.00	87.00	33	5.2
1996	3	23	16	7	34.2	27.20	88.30	33.	4.0
1996	4	26	16	31	3.0	27.80	87.60	33.	5.2
1996	7	17	5	23	47.6	26.00	91.90	0.	4.3
1996	7	26	12	47	35.0	23.80	90.90	0.	3.9
1996	8	18	2	48	0.0	25.80	90.10	0.	4.4
1996	9	13	3	41	8.6	27.00	88.20	33.	4.5
1996	9	24	3	28	1.8	23.30	88.60	36.	4.6
1996	9	25	17	41	17.2	27.40	88.50	33.	5.0
1996	10	25	19	31	26.3	25.40	91.80	61	3.8
1996	12	30	11	8	18.9	27.43	86.63	37.	5.0
1996	12	30	15	16	29.5	27.23	86.50	33.	3.6

1997	1	22	11	12	4.4	25.60	90.30	33.	0.0
1997	1	31	17	9	15.9	28.00	85.20	10.	4.4
1997	1	31	20	2	16.6	27.94	85.10	22.	5.2
1997	1	31	20	55	53.1	27.90	85.10	10.	3.9
1997	1	31	20	55	53.1	27.90	85.10	10.	3.9
1997	2	3	0	43	5.6	27.97	85.00	18.	3.9
1997	2	3	10	38	13.8	27.75	85.00	29.	3.8
1997	2	17	16	48	42.3	24.59	91.65	33.	0.0
1997	3	3	9	29	40.0	27.24	86.00	45.	4.7
1997	3	24	21	28	7.0	26.80	85.30	0.	4.8
1997	4	4	10	8	41.0	25.50	90.80	33.	3.8
1997	4	7	13	0	42.0	27.40	86.50	33.	4.4
1997	5	26	0	45	32.1	27.70	86.90	33.	0.0
1997	8	5	15	59	4.0	23.20	90.98	33.	4.1
1997	10	11	10	11	10.3	27.70	86.40	33.	4.3
1997	11	14	12	30	23.9	25.30	87.70	33.	0.0
1997	11	26	21	56	36.2	27.50	85.78	33.	0.0
1997	11	27	16	11	57.0	27.60	87.34	33.	5.1
1997	11	27	16	55	52.1	27.70	87.76	33.	4.2
1997	12	8	2	3	55.8	27.48	87.17	33.	5.0
1997	12	8	6	37	57.8	27.48	87.16	33.	0.0
1998	1	6	3	9	47.5	26.00	91.80	33.	4.5
1998	2	12	2	40	29.1	26.50	88.10	33.	4.6
1998	2	28	4	59	30.7	27.00	87.50	33.	4.4
1998	3	16	10	35	2.0	26.90	89.68	33.	3.8
1998	3	18	18	12	18.9	27.36	88.33	33.	4.0
1998	5	22	23	13	32.0	22.53	85.28	33.	4.3
1998	6	27	9	5	59.2	27.67	85.56	33.	4.9
1998	7	8	3	44	59.3	27.32	91.02	33.	5.2
1998	8	18	4	10	20.6	27.55	90.98	22	5.2
1998	9	3	18	15	56.5	27.85	86.94	33.	5.6
1998	9	3	18	22	19.2	27.97	87.04	33.	0.0
1998	9	3	18	51	38.6	27.65	86.80	33.	4.4
1998	9	3	18	51	38.6	27.65	86.80	33.	4.4
1998	9	3	21	0	53.5	27.72	86.88	33.	4.1
1998	9	3	23	2	28.3	27.60	86.46	33.	4.6
1998	9	4	0	36	17.9	27.45	86.46	33.	4.1
1998	9	4	1	10	18.4	27.77	86.79	33.	4.2
1998	9	4	21	16	13.7	27.65	86.72	33.	8.0
1998	9	6	21	35	49.4	27.86	86.89	33.	4.6
1998	9	10	22	57	16.9	27.20	88.34	33.	4.7
1998	9	12	5	8	52.1	27.85	86.90	33.	4.2
1998	9	26	20	48	44.1	27.52	86.13	33.	3.9
1998	10	11	22	0	49.9	26.35	86.40	90.	4.4

1998	10	16	10	27	19.4	27.97	85.42	33.	0.0
1998	10	16	22	22	39.2	26.03	91.21	33.	0.0
1998	11	26	10	14	27.6	27.75	87.89	73.	5.1
1998	12	1	5	35	9.2	27.93	87.64	33.	4.8

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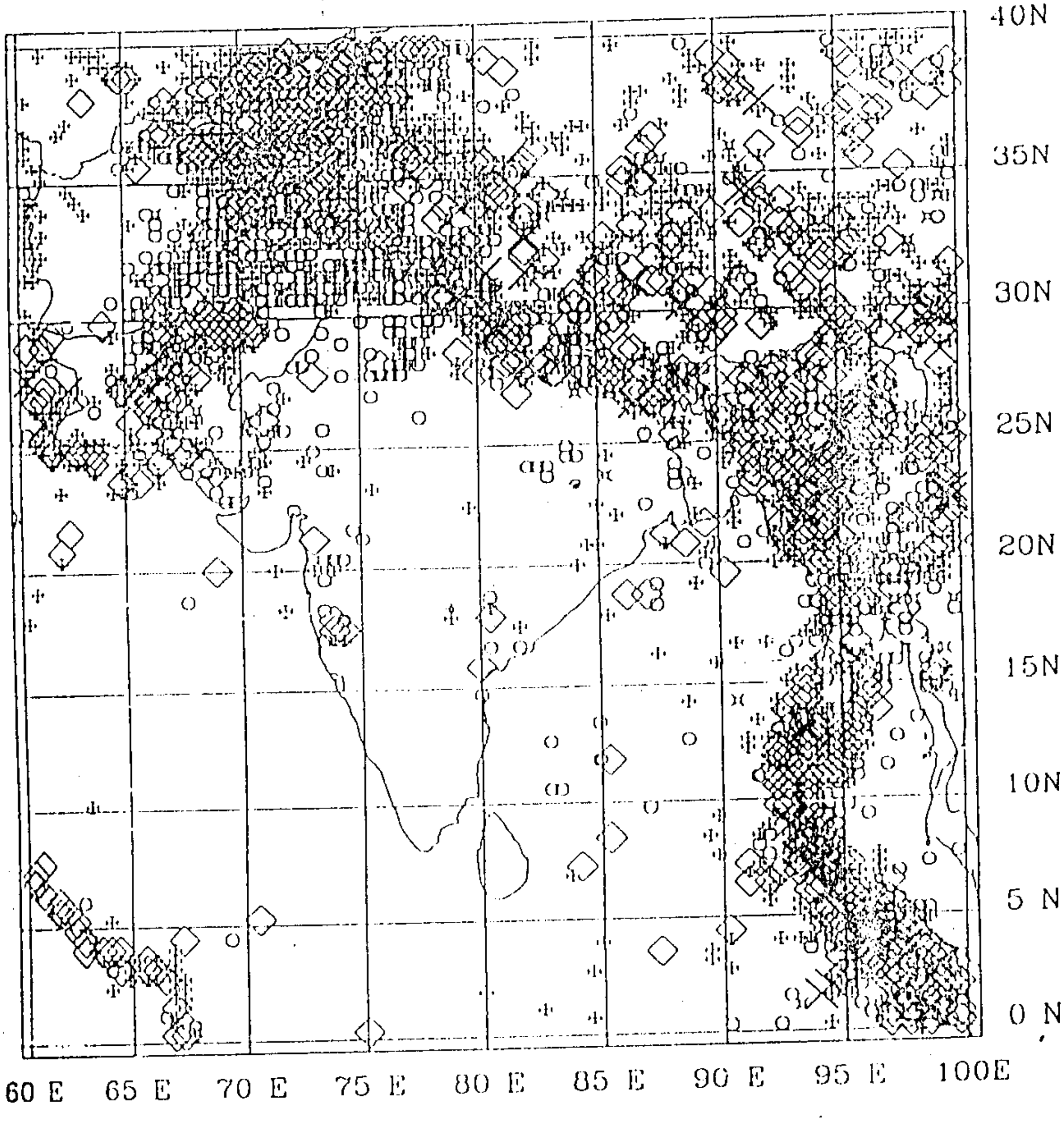
First date: Jan 2, 1964 Last date: Dec 31, 1991



MAGNITUDES:

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U. S. Geological Survey, National Earthquake Information Center
Data taken from the Earthquake Data Base System

FIG. 1

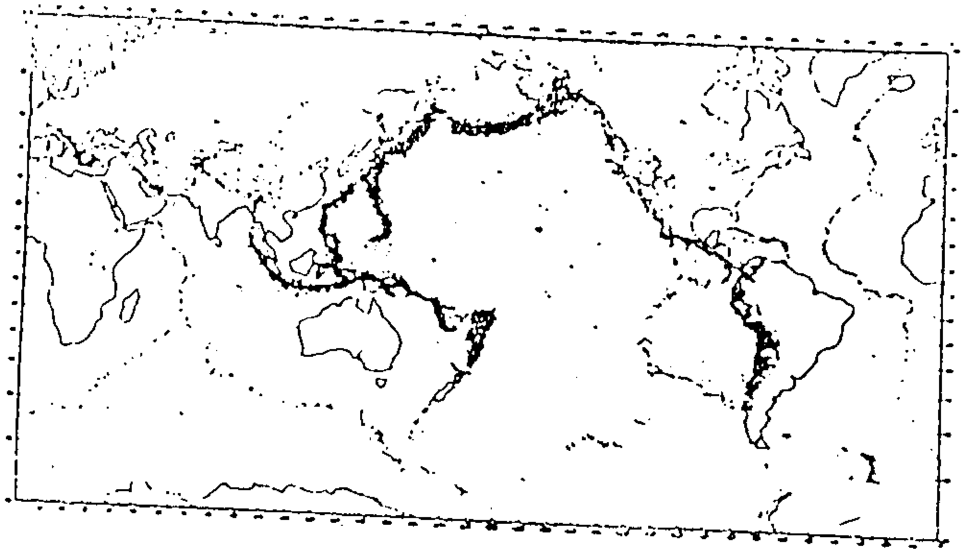
CHAPTER – 2

TECTONICS OF BANGLADESH

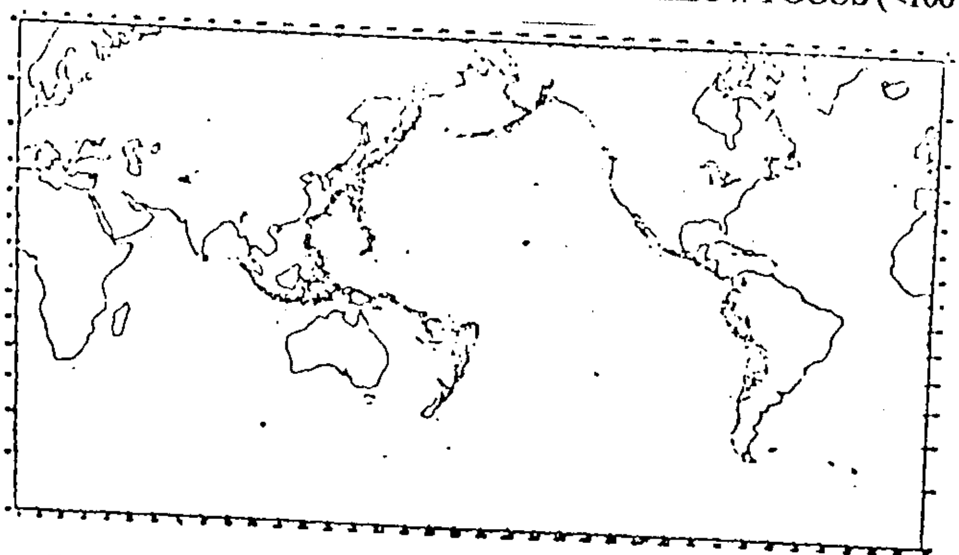
2.1 INTRODUCTIONS

Earthquakes are caused by the forces of Geological Origin

Figure 2.1 and 2.2 shows the epicenters of shallow (less than 100 km) and deep focus earthquakes for the period 1961 to 1967. It may be noticed that there are some well-defined seismic belts. The most spectacular is the 'Ring of Fire' all round the Pacific Ocean called the Circum-pacific Belt. About 75% of the energy is released through shallow earthquakes in this belt. The second well-marked belt called Alpide belt extends from Indonesia through the Himalayas to the Mediterranean where about 20% of the energy release takes place. Seismic belts of minor earthquake activity passing through the oceans generally confined to ridges in the Mid-Atlantic and Indian Oceans are now recognized as centers of ocean floor spreading. Deep focus earthquakes are fewer and mostly confined to the pacific region. The deepest known shock has been reported to have occurred at 720 km which implies that the earthquake activity is confined to crust and mantle of the earth. Comparison of Figs. 2.1 and 2.2 shows that the shallow and narrow seismic belt in the mid-Atlantic Ocean completely disappears in Fig 2.2 due to absence of earthquakes deeper than 100 km in the region. Along the trenches, the foci of earthquakes deepen towards the continental side. All such earthquakes are tectonic and are caused due to gradual accumulation of stress energy of the orders of 10^{20}-10^{25} ergs in the earth's crust which is essential for the earthquakes to occur due to slippage of rock masses across the zones of weakness called faults. These results have given seismological support to the theory of plate tectonics, which enables us to explain systematically the narrow earthquake belts and their peculiar characteristics on a global scale. In addition, it enables identification of the zones of damaging earthquakes in future on long term basis, thus providing basis for earthquake prediction.



2.1 EPICENTRAL BELTS OVER EARTH: SHALLOW FOCUS (<100 KM)



2.2 EPICENTRAL BELTS OVER EARTH: DEEP FOCUS (>100 KM)

2.2 ELASTIC REBOUND THEORY

A large, shallow earthquake is usually accompanied by substantial deformation of the ground over hundreds of kilometers and this is indicative of the volume of rock from which the elastic strain is released. Comparison of geodetic observations in California before and after the San Francisco earthquake of 1906 was responsible for the evolution of the elastic rebound theory of earthquakes as follows:

(a) The fracture of the rock which causes a tectonic earthquake, is the result of elastic strains, greater than the strength the rock can withstand, produced by the relative displacements of neighboring portions of the earth's crust.

(b) These relative displacements are not produced suddenly at the time of fracture, but attain their maximum amounts gradually during a more or less long period of time.

(c) The only mass movements that occur at the time of the earthquake are the sudden elastic rebound of the fracture towards positions of no elastic strain, and these movements extend to distances of only a few kilometers from the fracture.

(d) The earthquake vibrations originate in the surface of fracture; the surface from which they start has at first a very small area, which may quickly become very large, but at a rate not greater than the velocity of compressional elastic waves in the rock.

(e) The energy liberated at the time of an earthquake was, immediately before the rupture, in the form of energy of elastic strain of the rock.

2.3 PLATE TECTONICS

It is well known that the earth's interior consists of three main divisions called the crust, mantle and the core. The crust may consist of two or three layers called grantic rocks (layer) over the basaltic rocks (layer) with an overburden of sediments over the top layer. The crust is thickest under the mountains and thinnest over the oceans (where the grantic layer may be absent). The mantle has been divided into two portions called the lower and the upper mantle. The core is also divided into outer and inner cores. A slightly different classification is followed in defining plates. The top layer known as the Lithosphere, generally includes the crust and upper part of the mantle which has considerable strength. The next layer is down asthenosphere, which extends from the base of the lithosphere to a depth of several hundred kilometers and is weaker. Beyond this lies the mesosphere, which extends to the remaining portion of the mantle and possesses strength.

The word 'Plate' is used to infer the outermost portion of the earth's surface, comprising of the earth's crust and the upper mantle having 50-100 km thickness. The plate is supposed to be rigid with out undergoing buckling except at its end where it may suffer deformation. It is thinner under the ocean as compared to continents. Originally the earth's surface was divided into six large plates called Pacific, Atlantic, Eurasian, Antarctic, Indian and American Plates (Fig 2.3). Subsequently, six smaller plates have been added, as more and more geophysical evidence became available. These plates are constantly in motion relative to each other moving over denser but less rigid parts of the earth's mantle. There can be three types of plate boundaries. First type of plate boundary can be considered as the separation of the plates through the force of magma across the ridge axis. This is the region where the plates are created by adding the material on both sides. Age determinations of rocks near the ridges confirm it. The oldest age of the rock discovered on the ocean floor does not exceed $300 X 10^6$ years, which is much younger than the continents ($3{,}800 X 10^6$ years). As mentioned earlier, the rate of spreading of the main plates at the creating margins can be measured from the distances of the axis of

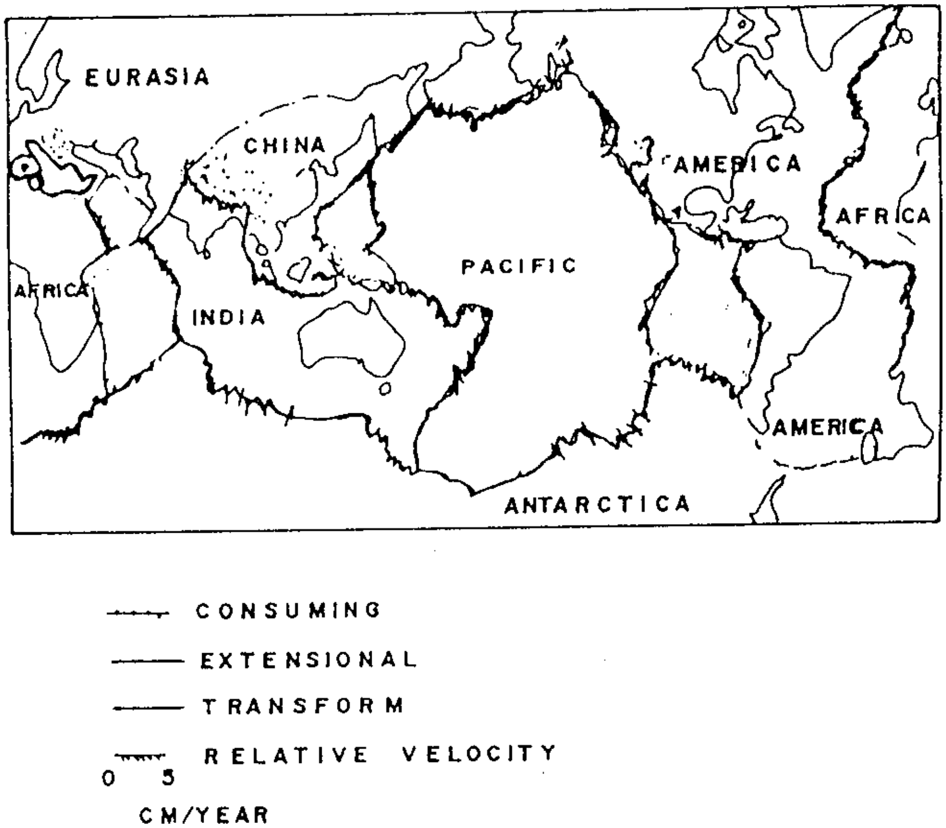


FIG 2.3. MAJOR GLOBAL PLATES OVER EARTH'S SURFACE

adjacent normal and reverse magnetized strips divided by the difference of age between them.

The other type of plate boundary is where the two plates collide or thrust below the other. These are the destructive plate margins across the regions known as trenches. The rate of movement of the plates can be inferred across the boundaries by the total displacement produced by all the past earthquakes over a particular time span of say fifty years. Other methods for determining the velocity of plates are based on paleomagnetic and GPS methods.

A third type of plate boundary occurs along what are known as transform faults. Here the plates move laterally relative to each other and the crust is neither produced nor destroyed. The lateral displacement on one side of the fault is taken up either by formation of new crust along a terminated segment of the mountain range or the ocean trench. Thus transform fault link the mobile belts of the earthquakes into an interconnected network subdividing the earth's surface into a series of rigid plates.

2.4 DRIVING MECHANISM OF PLATES

The driving force for movement of such large and heavy plates presents a major problem. On the assumption of the upper mantle as a viscous fluid, convection currents are generated due to the heating from below resulting in free thermal convection. In the lower mantle, convection may be inhibited by the high viscosity. The plates can be passively dragged along the top of the mantle wide convection cells, provided horizontal dimension of these cells would be very large, almost of the order of the width of an ocean. This appears to be physically impossible and therefore alternatives have been suggested.

The reverse current is a relatively slow migration of material back towards the ridges in the upper mantle. Thus the overlying plates move but the asthenosphere remains nearly stationary. The plates are forced to move apart due to pressure of magma, which is, exerted one the boundaries of the adjacent plates of lithosphere. However the differences between the oceanic and continental regions of the upper mantle are not fully understood and the problem of upper mantle convection is still being investigated.

It may be noticed from Figs 2.1 to 2.3 that the boundaries of the plates are the main regions across which the seismic belts pass. The reliable studies on the nature of faulting and accurate determination of epicentral parameters enable us to understand the mechanism of earthquakes at various kinds of plate boundaries.

2.5 INDIAN PLATE AND ITS FUTURE MOVEMENTS

The whole of India lies on the Indian Plate whose relative motion is generally towards the north-northeast at a velocity of about 5 cm per year. It encounters the adjacent plates in the Myanmar – Andaman Sumatra region in the east, the Himalayan foothills in the north and the Suleman ranges of Pakistan in the west. Great earthquakes in Shillong (1897), Kangra (1905), Bihar Nepal (1934) and Assam (1950) have occurred on the northern boundary of the Indian plate, which is underthrusting the Eurasian plate.

2.6. INTRAPLATE TECTONICS

Seismicity of the Indian Plate assumed more importance after the occurrence of recent earthquakes in Peninsula (Koyna, 1967, 1973; Bhadrachalam, 1969; Broach 1970; Bay of Bengal 1972, 1973, Latur, 1993, Jabalpur 1997). But plate tectonics do not offer a satisfactory explanation for earthquake occurring within the plate itself. Prior to this, the great Rann of Kutch (1819) located far away from the boundary of the Indian Plate could also not be accounted for by the plate tectonics model.

It is remarkable to note that the tear faults in the foothills of Himalayas, namely Moradabad, Lucknow, Patna and Dhubri faults, are oriented roughly along the direction of movement of the Indian Plate. Similar orientation of fractures has been found in the Peninsular India and is attributed to the transmission of stresses from the plate boundary to the interior of the plate.

2.7 TECTONICS OF BANGLADESH

The Bengal basin, comprising Bangladesh and India provinces is extensively covered by recent alluvium and is bounded on the west by the Indian peninsular shield with its Archaean complex and intracratonic Gondwana basins. The eastern side of the basin, bordered by the Lushai-naga folded belt, is a part of the Himalayan – Myanmar belt. In the south, the Bengal basin is open to the Bay of Bengal. On the north lies Shillong Plateau. South of this plateau lies Dawki fault of dextral slip of about 250 km length. The Sylhet fault has been identified through remote sending observations. The earthquakes of 8 July 1918, 9 September – 1923 and 22 July 1930 (with magnitudes >7.0) are located along Kolosib Mureen transform fault. On the eastern side, east west compression has folded the Surma basin sediments into a series of longitudinal folds namely.

(i) Chittaong Tripura fold
(ii) Mizo fold
(iii) Tiddim – Klangklang Flysch zone
(iv) Arkan – chin Axial Belt
(v) Central Burma Molosse zone

It may be noted that the effects of great earthquakes in the main central thrust of the Himalya could have serious impact in Bangladesh. Comparing the similarity in miezoseismal parameters and other factors with that of the great Mexican earthquake of 1985, it is surmised that potential damage could occur in Bangladesh due to the Himalyan earthquakes due to phenomena of liquefaction and amplification of ground motion. Similar impact could be inferred from the great earthquakes in Shillong and neighbourhood, particularly on tall structures. However, earthquakes cannot be predicated as weather and therefore, the only course open for us is to design our structures so that they may resist the forces due to earthquakes. Meanwhile, research is called for to identify hidden faults and lineaments in Bangladesh through remote sensing methods, deep seismic and reflection profiling and micro earthquake surveys using portable seismographs.

CHAPTER – 3

SEISMOLOGICAL INSTRUMENTS AND CALIBRATION

SEISMOLOGICAL INSTRUMENTS AND CALIBRATION

3.1. INTRODUCTION

Earthquakes give rise to three different types of seismic waves which are recorded by Seismographs with frequency response from DC to about 100 Hz. Thus, seismographs are used to record the earthquake motion and other seismic vibrations. They consist of a transducer which is basically an inverted pendulum with a device to damp motion (i.e. applying a force to oppose its motion) to write the movements of the pendulum on a photographic, heat sensitive, smoked or ink writing plain paper, a film or a magnetic tape recorder. An accurate time marking, device usually a crystal clock, is used to impinge the time (hours and minutes) on the records which enable us to find the onset times of various seismic waves from which the epicentral distance of the earthquake, its origin time, magnitude and epicentre can be determined from the data of several stations with the help of electronic computers. With prior knowledge of seismic wave velocities in a region (or a velocity model with detailed crustal structure, etc. from earthquakes or better by calibration of the area with chemical explosions at specified locations), the monitoring of local earthquakes can be considerably improved if there are at least ten stations well distributed in azimuth. Theoretically, only three stations are needed to determine epicentre using elementary theorem of geometry that only one point of intersection is possible through three points not on a straight line. For focal depth determination, at least four stations are needed. For distant events, worldwide data are needed and Jeffreys Bullen Travel time tables are generally used. Focal depth determinations pose great problems, though they can be fairly reliable for a large network of stations close to epicentre or if the depth phases (pP) can be identified on a seismogram or from digital broad band instruments.

3.2. DIRECT RECORDING SEISMOGRAPHS

Simple direct recording seismographs were widely used until 1930. Of these, the torsion seismometer developed by Wood Anderson who led to the definition of local magnitudes in Richter Scale is still helpful for interpretation of other magnitude scales. It consists of a metal fibre suspension held taut by a small weight attached to the side of a copper cylinder, which can rotate about the fibre against the restoring force of torsion. The cylinder is kept in a permanent magnet through which eddy currents are induced in the copper when it moves due to seismic waves. A small mirror is fixed to the copper cylinder on which light falls from a distance. With the passage of seismic waves, there is a deflection of light spot due to twisting of the fibre, which is recorded photographically.

3.3. ELECTROMAGNETIC SEISMOGRAPH

The most widely used seismometer is the electromagnetic type, which is based on the laws of electromagnetic induction. The electromotive force (or voltage) generated is generally proportional to rate at which the lines of force (of a permanent magnet) are cut. The current so produced due to seismic disturbances is passed through a galvanometer with an attenuating network depending upon the ground noise to adjust overall gain, and finally recorded photographically from the mirror of the galvanometer Recent developments in electronics use high gain amplifiers upto dynamic range of 120 dB or more with the electromagnetic or force balance seismometers which may record earthquakes down to magnitude-3. Seismographs have been designed for local earthquakes and teleseisms. For surface waves, long period seismographs, called Press Ewing type were used with seismometer period of 30 seconds combined with galvanometer period of 100 seconds in standardized instruments of US Geological Survey since 1963-64. In the shorter period range, Benioff seismograph which works on the principle of a telephone receiver of variable reluctance type has been in use.

Although the fundamental principles of all seismographs remain the same, a few systems have been developed for specific purposes.

3.4 SEISMIC ARRAYS

If a number of seismometers are placed to form a pattern like the alphabet L or X and their outputs are combined, the resulting system is called a seismic array, which can operate at a very high gain. In its design, advantage is taken of the fact that seismic noise propagates with different speeds than the seismic signals that are usually of interest. By time shifting the output of the various detectors by an amount corresponding to the surface velocity of the desired signal across the array, this signal is further enhanced over the straight summation process as compared to noise (which is random) giving considerable improvement in the signal to noise ratio. The direction of approach of the signal may be determined by comparing the time of arrival of an event at various elements of the array. From the apparent surface velocity and knowledge of the true velocity in the surface layer of the kind of body waves (P or S), the angle of incidence can be derived, providing an added tool for identification of phases, specially crustal phases from regional and local events. Although primarily meant to detect underground nuclear explosions, arrays have yielded valuable data to the seismologists for studying earth's interior down to its core.

3.5. TELERECORDING SEISMOGRAPHS

A set of electromagnetic seismographs called array with a central recording system with multichannel tape recorder is generally used for monitoring micro-earthquakes in difficult terrains such as mountains. Line of sight condition between the seismogrpahs, which have a transmitter operating in VHF range and the central recording system, is essential Seismometers are electromagnetic of force balance type with associated high gain amplifiers. Frequency modulation is used for transmission after which seismic signals are demodulated, amplified, filtered and recorded on ink writing or heat sensitive paper. A Digital Data Acquision system receives data from the telemetry discriminator, converts to digital form and stores them on computers. Triggering arrangements have been incorporated in the system to start the data recorder according to a certain criterion. Solar batteries are used in the system, which overcome the problem of charging conventional batteries in remote areas. Solar panel, antenna and transmitter can be mounted on a metal mast, which can be tied to the trunk of a trimmed tree. The main advantage of this system is that the time base is common for all the stations. Thus the errors in the comparison of clocks at different stations can be eliminated.

Now a days V-SAT are used for data transmission/reception and time is corrected through Global Positioning System (GPS).

3.6. SEISMIC RESEARCH OBSERVATORY (SRO)

Seismic Research Observatory system combines a broad band bore hole seismometer and a computerized recording system. In order to reduce wind-generated noise in the long period band, the seismometers are installed in bore holes at a depth of 100 metres. The characteristics of these seismometers are such that their output is flat in acceleration between 1 and 50 seconds periods which are used to produce both short and long period data and are recorded in analog (on heat sensitive papers) as well as in digital form (using magnetic tapes). The sensors are force balance type with capacitive transducers. The digital recording system consists of filters, analog to digital converter, a station processor, two magnetic tape transports, a digital to analog monitor , a digital clock and a teletype writer. The station processor is a 16 bit mini computer with 16 K or core memory. The analog to digital converter samples the long period channel once each second and the short period channel 20 times per second. Long period digital data are recorded continuously on magnetic tape while short period data are recorded only when event occurs. The digital data are specially suited for studies requiring filtering operations or spectral computations and can be directly used with a computer.

3.7. DIGITAL RECORDING SEISMOGRAPH.

Here all the settings are same as visible recording seismograph upto the amplifier. The amplifier output is however connected to a digital recorder. Thus as a ground displacement, A sin(wt) gives an output of BwGS cos (wt+b) mV from the amplifier. Where w is angular frequency G is Generator constant, b is a constant, t is time, and A is the ground amplitude The output of amplifier then goes to a digital recorder which converts the voltage to counts say, L counts/mV. Thus it records B w GSL cos (wt+b) counts. Thus displacement magnification is I w Generator constant (G) counts/mm and the velocity magnification is I G S L = C.I (T) counts/ (mm/sec). The counts are recorded at equal interval of time i.e sample per second (SPS). The low pass filter is set according to SPS. This sharp (high order) low pass filter is generally 0.4 times the SPS for example if SPS=100 the low pass filter is 40 Hz.

The analogue-to-digital converter (ADC) turns the values into numbers of quantified values. The minimum digitization step is called digit or count. The smallest unit of a digital value or word is Byte (=8 bits). A 16 bit ADC can count values from -32768 to 32768. Thus dynamic range = 20 log10 (32768/1) = 20X4.5 = 90 db.

On the other hand 24 bit counts from -8338608 to 8338608 and this gives dynamic range as 138 db. Increase of dynamic range in digital recording compared to analogue recording gives the advantage to record the ground motion for a very small magnitude earthquake as well as for large magnitude earthquake without saturation.

In an observatory of three component seismograph with 100 SPS in each component and 16 bit (2 byte) recording requires in one day a storage of 3 (comp.) x 100 (SPS) x 2 (byte) x 24 (hrs.) x 3600 (sec) = 51,840,000 = 50 Mb. Although many large storage devices are coming up recently but it is necessary to keep the storing area to a minimum. To achieve this goal, a digital recorder has a few streams of recording; for example, one stream can record at 20 SPS continuously and other stream can record 100 SPS in trigger mode i.e when amplitude of record goes above the normal level. In trigger mode, recording is done only when the ratio of amplitude of short term average (STA) to that of long term average (LTA) is more than a given limit. When this signal to noise ratio crosses this limit, the recorder starts recording from a few seconds earlier to this time and records for some time as set by the operator. The digital recorder (also called Data Acquisition Computer) also maintains the log of this trigger time and signal to noise ratio at the time of trigger. Further for reduction of storing area, compressed techniques are available and this reduces the storing area by half or even less.

Main parameters of digital seismograph are band width, dynamic range and bits used in recording (i.e. 16 bit or 24 bit).

Advantages of digital recording compared to analogue recording.

(i) Generation of seismogram at different frequency band within the recording bandwidth and this helps in identification of phases and helps in determination of magnitude.

(ii) Picking up of arrival time of phases on computer screen in an interactive manner by moving the cursor manually.

(iii) Frequency domain analysis or spectrum analysis can be done in which Aj for frequency wj is obtained. From plot of Aj against wj we can obtain many source parameters.

(iv) Ground motion along any direction can be obtained using the 3 component digital data. In many studies it is necessary to obtain radial and transverse component by vectorial rotation of two horizontal components. Further S-wave is very clear in transverse component.

(v) Drawing particle motion

Many software are readily available which gives the above features. The other advantages are as follows:

(vi) Large dynamic range due to which amplitude does not saturate in case of large ground amplitude in big earthquake.

(vii) Easy to store and disseminate. Database for more scientific research.

3.8 BROAD BAND SEISMOMETER.

During an earthquake, the ground vibrates in the period range approximately for 0.02 sec to 1000 sec depending on how far the earthquake is and on how big it is. As stated earlier a seismological observatory uses analogue records separately for short period range and another for long period range. Further we have seen that the velocity response is flat from a very low period to the period of seismometer. Thus to increase the bandwidth it is necessary to increase the free period of seismometer. However, the increase of free period of a mechanical seismometer causes instability and non linearity. This problem has been solved by using force balance feed back system in the seismometer. This involves a negative feedback loop in which a force is applied to the mass of the seismometer to cancel its relative motion. The force feed-back strategy greatly extends the bandwidth and linearity of a seismometer, because the mass cannot make large excursions that bend the springs and levers. Due to increase of bandwidth, it is called broadband seismometer. Such seismometers are also known as forced-balance seismometer. Most of the broadband digital seismograph use forced-balance seismometer. A typical broad band sensor is shown in the photograph 3.1. . Several versions are available by different manufacturers.

3.9. RESEARCH PROBLEMS IN SEISMOLOGY USING BROAD BAND SEISMOMETERS

(a) Estimates of slip vectors for models of plate motions

(b) Scalar seismic moment – representing earthquake size spatial and temporal centroid of an earthquake

(c) Determination of complete point source solutions to events of smaller size.

(d) Physics of Rupture process

(e) Refinement of earth models : Seismic Tomography

(f) Seismicity patterns preceding earthquakes

(g) Earthquake hazard assessment

(h) Earthquake predictability

3.10. STRONG GROUND MOTION: MEASUREMENT AND ANALYSIS

Loss of lives during earthquakes are caused by strong ground shaking which results into collapse of buildings, bridges and other man made structures. It is, therefore, imperative that for earthquake disaster mitigation, structures be built to resist earthquake induced shaking levels during their lifetime. Strong ground motion records during earthquakes in the form of time history or spectra provide the basic information for earthquake engineering. These records are input for evaluation of seismic hazard of an area, in improving design practices and eventually provide the basics for earthquake engineering research. Analysis of strong ground motion data has accordingly led to a better understanding of the potential effect of strong shaking during earthquakes. The ground motion characteristics determined from strong motion records are studied in various terrain and rock conditions and provide additional inputs for earthquakes parameters. The analysis of data has also helped in the understanding of the soil-structure interaction, vectorial rotation of two horizontal components. Further S-wave is very clear in transverse component.

(v) Drawing particle motion

Many software are readily available which gives the above features. The other advantages are as follows:

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BROADBAND SEISMOMETER

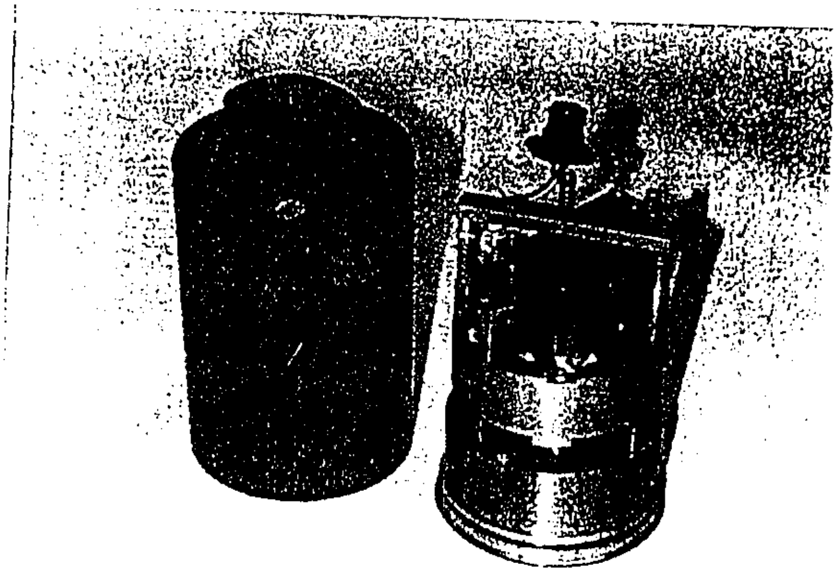


FIG. 3·1

presence of soil deposits and other effects, which are essential for microzonation of an area.

Strong ground motion data provide basic input to define adequately, seismic hazards at national and regional level. Preparation of seismic hazard maps is an important requirement for engineering, insurance and planning purposes in the near future. All seismic hazard studies whether deterministic or probabilistic require strong ground motion data to determine attenuation and seismic source characteristics.
Strong ground motion data are also very important for geotechnical engineers. Records can be used to validate methods used by them to provide site specific ground motion. An understanding of soil-structure interaction and its effect can substantially reduce the cost of construction and retrofitting. Strong motion data has also been used to determine damping and stiffness of ground during earthquake. We can also use these data for study of ground motion of sites during and after liquefaction, study of pile and other types of foundation during earthquakes, which are extremely important for site conditions in Bangladesh.

Strong motion observations have several applications in Seismology like improvement in epicenters, magnitude and source mechanism as discussed later

The latest trend of using strong motion data for early warning systems can be an interesting development in future. In the situation where it is expected that origin of great earthquakes will be about 300 to 400 km away from the populated area, early warning systems can be deployed to give a lead time of one to two minutes to the public to react for the coming disaster. Such systems can broadcast a general alert for earthquakes greater than magnitude 6 and a limited alert for earthquakes between magnitude 5 and 6

3.11. INSTRUMENTATION & PROCESSING TECHNOLOGY

(i) SENSORS

The most commonly used sensors in strong motion instruments are force balance or servo accelerometer (FBA). These sensors have high natural frequency (about 100 HZ) so that a flat frequency response from DC to 50 HZ can be obtained. The damping of the accelerometer are about 70% of critical. The dynamic range of the presently available accelerometers is more that 120 dB. Among the conventional seismic sensors, an accelerometer cannot be used to record the ground motion of micro earthquakes because that the system is too stiff to produce any measurable deflection of the mass. However, in FBA the feed back current, which is the measure of the ground acceleration, can be amplified and measured quite accurately. Thus the scenario has shifted from mechanical measurement of the conventional sensors to electronic control and measurements employing force balance sensors.

(ii) RECORDERS

Analog signals from sensors are amplified to match the full-scale voltage of sensor with that of AD converter and this analog signal is also low pass filtered to remove effect of aliasing during digitization. Accelerographs are using 24 bit delta-sigma AD converters which provide resolution of 18 to 19 bit accuracy at 200 SPS (the accuracy of delta sigma AD converters are dependent on sampling rate). Digital accelerographs use independent ADC chips for each channel of recording so that channel to channel skew are zero (synchronous sampling). The recorders are controlled by microprocessor and each manufacturer of digital accelerograph use microprocessor chips of their own choice.

The digital data is recorded on solid state memory with PCMCIA type flash memory cards which have several advantages over conventional memory chips. These cards can be easily plugged in or taken out by users at the site and can have very large memory with very little additional cost and negligible extra current requirement. PCMCIA is an international standard and have fixed size, pin connections and protocol. Several types of PCs have PCMCIA slots where these cards can be used and read like a floppy (with some additional software).

All the parameters of the recorders like pre event time, trigger threshold, mode of trigger, post event time, post event threshold etc. are software selectable. All such instruments have built-in real time clock and have prevision to synchronize the clock with transmitted standard time signals like GPS, thus giving accuracy of less than 5 milliseconds.

(iii) COMMUNICATION

All the digital accelerographs have RS 232 ports through which they can be connected with a computer having compatible port. Software for communication of computer with the instruments are supplied by the manufacturers generally in DOS and/or Window platforms. The instruments are capable of being connected with modem for remote communication. The software also have option to communicate directly or through modem.

(iv) PROCESSING OF DATA

The recorded data is processed off-line after retrieval on the computer. The processing includes transducer correction, filtering to remove high frequency and low frequency noise, calculation of response spectra, Fourier spectra, velocity history, displacement history etc.

3.12. STRONG MOTION PROGRAMS

Almost all the countries in the world where damaging earthquakes occur have their strong motion instrumentation programs. However USA, Japan and Europe have extensive deployment of strong motion instruments. Mexico also has an excellent network of strong motion instruments.

Taiwan has four different strong motion programs. There is a network of 109 analog type instruments in which records are obtained on photographic film. Most of these are installed at free field sites and some are installed on structures. SMART-2 array has been installed in 1992 in Eastern Taiwan by Institute of Earth Science, Academia Sinica (IESAS). This programme has 45 surface stations and 2 bore hole arrays. The array uses force balance accelerometers and digital recorder with 16 bit resolution. As of 1996, SMART-2 has recorded 5485 accelerograms from 355 earthquakes.

Taiwan Strong Motion Instrumentation Programme (TSMIP) was started in 1991 by Seismological Center of the Central Weather Bureau programme. A free field network evenly covering all urban areas at a density of approximately one instrument per 5 km x 5 km was installed. Currently more than 600 digital accelerographs are in operation in the free field. The accelerographs have 16 bit resolution and many of them are equipped with GPS. TSMIP has instrumented 35 buildings of different height and ground conditons all over Taiwan. Each building has been instrumented with 30 accelerometers located at different points in the building as well as in the free field. TSMIP is also operating a real time network, which works as backbone of a totally automatic Taiwan Rapid Earthquake information system.

To mitigate the disaster in Mexico City due to major earthquakes occurring along the Guerrero Coast (about 300 km from Mexico City), an early warning system was installed in 1991. When two or more stations from the evenly distributed network of 20 sites in Guerrero detect and confirm the occurrence of M>6 earthquake, signal is sent to a center in Mexico City which in turn generates a local alert signal transmitted to schools, government agencies, universities etc. and is also broadcast to public. This early warning system activated on occurrence of M7.3 earthquake of September 14, 1995 and a signal was broadcasted to general public, 72 seconds prior to arrival of strong ground motion at Mexico City. The earthquake struck Mexico City in the morning which is a peak working hour in Mexico. Out of 98 radio receivers of this network, 86 operated during the earthquake. The early warning system triggered alarms in 28 Mexico City public schools, the resulting evacuation was reported to be orderly and well coordinated. The central controls of the METRO Railways received the warning signals and had enough time to stop the trains and open the doors. The audio warning system was reported to have facilities for evacuations from residential colonies.

In India, most of the strong motion instruments India are operated by Department of Earthquake Engineering, University of Roorkee, Central Building Research Institute, India Meteorological Department, Maharashtra Engineering Research Institute Nasik, National Geophysical Research Institute and river valley projects. The programme has been largely funded by the Department of Science and Technology, New Delhi. Excellent results have been detained particularly acceleration data/attenuation characteristics in near field region upto earthquakes of magnitude 6.

3.13 NEW APPLICATIONS OF STRONG MOTION DATA

Improved Epicentre Dharamsala Earthquake of April 26, 1986.

The earthquake of April 26, 1986 (Magnitude ML = 5.4) triggered accelerographs of the Himachal Pradesh Array. Using the absolute arrival times of Pg and Sg waves from this array, the epicentre could be better located as compared to data from seismographs only. Pg and Sg times from six accelerographs could be read in addition to those of Pn and Sn from nearly seismological stations through which the detection threshold has been been reduced to magnitude 2 in Himachal Pradesh. The focal depth of this earthquake was reported by NEIS as 33 km while the results based only on the strong motion data gave the focal depth as 5 km. Using a combination of larger data base from nearby seismological stations as well as strong motion records, the focal depth was found to be 13 km with the error parameters, RMS, ERH, ERZ as 0.61, 2.5 and 1.1 respectively. Keeping in view, the depth of the granite layer in the region as 22 km and the clarity with which Pg and Sg phases were recorded at the nearby stations, the depth range of 5 to 13 km (whether based only on strong motion data or in combination with seismographs) narrowed down to a more plausible value than that reported by National Earthquake Information Service (NEIS) as 33 km. This epicentre was also found to be closer to the meizoseismal area.

The P and S arrival times from strong motion records provide valuable data set for the epicentral parameters of earthquakes and may be included by ISC for routine analysis. This recommendation was accepted by the INTERNATIONAL SEISMOLOGICAL CENTRE (ISC), U.K.

(ii) Improved focal depth : Koyna earthquake December 10, 1967

The crustal velocity model deduced by India Meteorological Department and the National Geophysical Research Institute, Hyderabad for Koyna region was compared employing different techniques based on Deep Seismic Sounding data. A focal depth of 8 km for the main Koyna earthquake of December 11, 1967 was found if S-phase from accelerogram data is included instead of about 2 km which could raise a controversy.

(iii) Attenuation characteristics were found to be different in northeast India as compared to western Himalaya.

3.14 CALIBRATION OF SEISMOGRAPH

Calibration means the frequency and phase response of the system for different ground periods.

Dynamic range and bandwidth

The response of a seismograph is described by its dynamic range and bandwidth Dynamic range means a relation between available resolution and (estimated) maximum amplitudes.

Dynamic range (db) = 20 log(10) (maximum amplitude/resolution)
= 20 log(m) (max. ampl. that can be recorded/smallest readable signal amplitude)

For example in MEQ800 visible recorder, smallest readable signal amplitude = 0.2 mm and maximum pen deflection = 25 mm. Thus.

Dynamic range = 20 log (10) (25.0/0.2) = 20 log (10) (125) = 42 db.

Corner periods of a seismograph are defined as the periods where magnification drops by 3 db of peak value (i.e 0.707 of peak magnification). One corner period Tlc is at the lower side of the period and other corner frequency. The on the higher side. The range (Tlc-Thc) is defined as the bandwidth. This gives the width of period within which the seismograph is sensitive to ground motion.

Detailed method of calibration of analogue system is enclosed in the attached note by KINEMETRICS, USA

APPLICATION NOTE

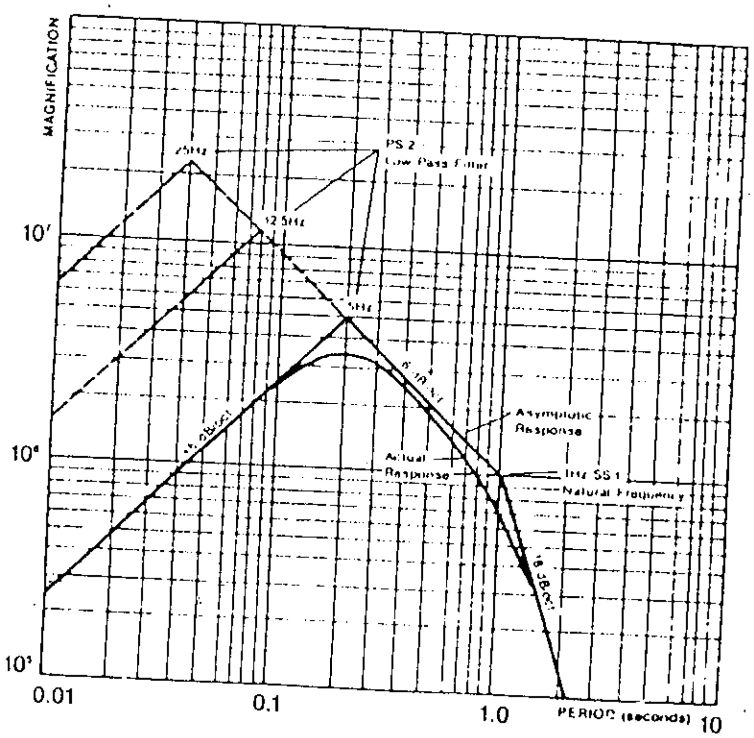
Magnification of the Portable Recorder and Ranger Seismometer

The overall magnification of a seismograph is an important consideration in assuring that useful information is recorded. This Application Note details the computation of magnification characteristics for an SS-1 Ranger Seismometer and a PS-2 Portable Recorder.

To define the magnification of the seismograph, two factors are required:

1. The shape of the period response curve, and
2. The numerical value of magnification at 1 second.

The period response or magnification curve is shown below.



The numerical value of the magnification at the seismometer natural period is given by:

$$M = G_o \left[\frac{R_x}{R_x + R_c} \right] \left(2\pi f_n \right) A_a \cdot S_r$$

Where M = magnification; that is displacement of the recorder pen divided by displacement of the ground.

G_o = open circuit generator constant of the SS-1

R_x = damping resistance for the SS-1

R_c = coil resistance of SS-1

f_n = natural frequency of SS-1

A_a = amplification (or gain) of the PS-2 amplifier

S_r = sensitivity of the PS-2 pen motor

The actual values of G_o, R_x, R_c, and f_n are given on the SS-1 calibration data card. The value of S_r for the PS-2 is 0.25 mm/mV.

Using typical values, the maximum magnification (that is, PS-2 amplifier at 72 dB) at 1 second is:

$$M = \left(345 \frac{\text{volts}}{\text{m/sec}} \right) \frac{5000\,\Omega}{5000\,\Omega + 5800\,\Omega} 2\pi\,(1\text{Hz})(4000)(0.25 \tfrac{\text{mm}}{\text{mV}})$$

$$M = (1000)(4000)(0.25)$$

$$M = 1{,}000{,}000$$

This magnification, however, is calculated at the corner of the asymptotes. Due to the seismometer damping, the actual magnification at 1 second is 0.707 (-3 dB) of the calculated value.

The magnification can be decreased by attenuation. If the PS-2 amplifier is set at other than 72 dB, the resulting amplifier gain A_a is given in the following table.

GAIN		MAGNIFICATION
dB	A_a	at 1 Hz
0	1	250
12	4	1,000
18	8	2,000
24	16	4,000
30	32	8,000
36	64	16,000
42	125	32,000
48	250	63,000
54	500	125,000
60	1000	250,000
66	2000	500,000
72	4000	1,000,000

The magnification at 1 Hz can be verified experimentally by driving the SS-1 calibration coil with a low current sine wave. This can be done by connecting a function generator across GND and CAL at the PS-2 control panel, and measuring the voltage across the 1000 ohm resistor between CAL and CURRENT.

The expected deflection of the recorder pen is:

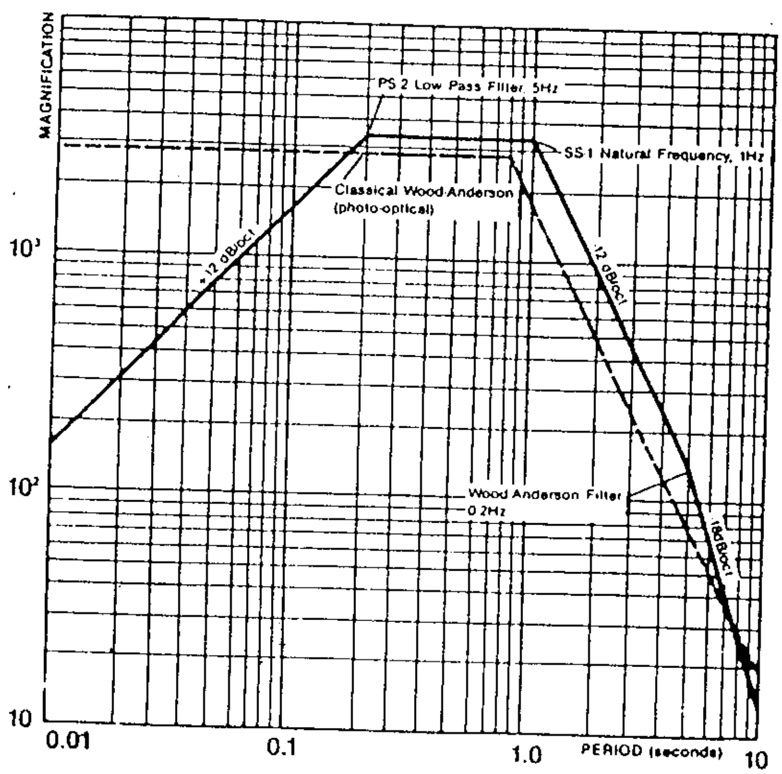
$$D_r = M \frac{(G_{cc})\, i}{(2\pi f_n)^2 m}$$

where G_{cc} = calibratión coil constant of SS-1
= 0.4 newtons/amp;
m = mass of SS-1 = 1.45 kg;
i = current through calibration coil

If the current is 0.05 mA, peak to peak, and the magnification is 63,000 x 0.707, then the pen deflection is:

$$D_r = (63000)(0.707)\left(\frac{(0.4)(0.05)}{(2\pi 1)^2(1.45)}\right) = 16\,\text{mm}$$,peak to peak.

It is also possible to operate the SS-1/PS-2 in a Wood-Anderson mode. The asymptotic magnification curve for the Wood-Anderson mode is shown below. Also shown for reference is the response of the classical Wood-Anderson seismograph.



For frequencies between the SS-1 natural frequency (1 Hz) and the PS-2 low pass filter (usually 5 Hz), the Wood-Anderson magnificat is:

$$M = G_o \left[\frac{R_x}{R_x + R_c} \right] \left(2\pi f_{wa} \right) A_a \cdot S_r$$

where M = magnification

G_o = open circuit generator constant of the SS-1

R_x = damping resistance of the SS-1

R_c = coil resistance of the SS-1

f_{wa} = corner frequency of "Wood-Anderson" filter (0.2 Hz)

A_a = amplification (or gain) of the PS-2 amplifier

S_r = sensitivity of the PS-2 pen motor (0.25 mm/mV)

Using typical values, the magnification is:

$$M = \left(345 \frac{\text{volts}}{\text{m/sec}} \right) \frac{5000\,\Omega}{5000\,\Omega + 5800\,\Omega} (2\pi \times 0.2\,\text{Hz}) (64) (0.25 \tfrac{\text{mm}}{\text{mV}})$$

$$M = 3200$$

Whereas the photo-optional Wood-Anderson could only operate at 28 magnification, the Kinemetrics version can be operated at double, quadruple, or even greater multiples of the Wood-Anderson magnification if desired.

CALIBRATION OF DIGITAL SEISMOGRAPH

The cut off frequencies are dependent upon the scan rate and primary/secondary trigger data decimation. At 200 sps and no decimation, these cut off frequencies are 0.1 Hz and 12.5 Hz; for 50 sps and no decimation, the cut off frequencies become 0.025 and 3.125 Hz. The data in the field is recorded through a laptop computer and processed at the central facility.

Trigger can be accomplished in four different modes; external ratio of STA vs LTA, difference of STA vs LTA, band pass filtered threshold and at pre-programmed time frame called experiment windows.

The true ground velocity is converted from the field data with the help of the Generator constant of the seismometer. SSR-1 when used with SS-1, records the peak voltage (Vpp) which is directly proportional to ground velocity (V).

$$V = \frac{Vpp \times 0.5}{G}$$

Where G is a 70% damped generator constant

$$G = \frac{Go \times Rx}{Rx + Rc} \text{ Volt/meter/sec}$$

Where Go, Rx and Rc can be found in SS-1 calibration data sheet.

Thus,

$$G = \frac{330 \times 4481}{4481 + 5843}$$

$= 143.23$ v/ m/s

3.15 COMMUNICATIONS

V-SAT VERSUS TELEPHONE MODEM

1. Cost is more in VSAT (recurring) but can be reduced if operated in triggered mode

2. Speed of data is faster in V-SAT

3. Readability is better in TDM in V-SAT. With improvement in telephone communication, the field station data is obtained simply by dialing the station like STD and giving the date and timing (hour) for the data required through PC at HQ.

4. At remote places, the speed may be low through telephone modems.

5. Depending upon service satellite, the direction should be without any obstacle for V-SAT.

3.16 V-SAT COMMUNICATION DETAILS

In recent years a new satellite application, known as V-SAT technology has been gaining ground worldwide.

VSATs can be defined as a class of very small aperture (typically having diameter less than 2.4 metres) intelligent satellite earth stations suitable for easy on-premises installations with associated low noise converter for reception and solid state amplifiers for transmission.

V-SAT network provides reliable, efficient and economic services and are particularly suitable for remote and isolated areas. VSATs provide users direct access to satellite links bypassing local telephone exchanges and numerous functions from local exchange.

NETWORK CONFIGURATION

The V-SAT communication system in India is primarily a star network with a central hub station at Delhi and operating with INSAT series of satellites in 4/5 GHz ranges (C-band). With this system data can be exchanged between any two stations by using appropriate address codes. The network consists of (1) Master-Earth Station (MES) at Sikanderabad (U.P.); (ii) Micro-Earth Terminals at user's premises, (iii) Master Earth Station (MES) connected to Delhi Switching Centre by microwave/optical fibre links; and (iv) Host computer connected to Delhi Switching Centre.

All traffic flows from a micro-terminal into the central Hub act as network interface via the satellite. If it needs to be connected to another microterminal, it is processed at the hub, then retransmitted to the same (or another) satellite and thence to the other micro terminal.

In an interactive satellite data network, each micro-earth station is tuned to a specific network outbound (micro-station receive) transponder channel and a network inbound (micro-station transmit) transponder channel through network interface (Host computer and MES). Data packets destined for all nodes are multiplexed on the outbound channel's data stream. This data stream is encoded with a pseudo-random spread spectrum PN code 2,3,4,5 and contains data and control packets which are received by all the micro-earth stations on their outbound channel. Individual and group address bits permit the micro-earth station to identify packets addressed to it for further processing. Each micro-earth station is identified with one individual address and upto 16 group addresses.

Each individual C-200 series micro-earth station (under discussion) has the capability of processing data addressed to it at a maximum average throughput rate of 19.2 kbps.

The return path from the micro-earth station C-200 to the Master Earth Station operates at a maximum data rate of 1.2 kbps. Each C-2000 micro-earth station encodes its transmit data with its own unique pseudo-random spread spectrum PN code. Several C-200 series micro-earth stations share the inbound channel concurrently, without encountering channel congestion or queuing delays, or delays normally associated with a polled network through the use of Code Division Multiple Access (CDMA), also known as Spread Spectrum Multiple Access (SSMA). The network control centre is capable of selectively controlling the transmission flow of each micro-earth station, based on preassinged priorities. This capability prevents an increase in bit error rate resulting from loading an inbound channel in excess of its design capacity. Such flow control is accomplished without loss of data.

MICRO EARTH STATION

Micro Earth Station model C-200 from the remote ends of the data network and are connected directly to the users terminal equipment. Each station contains two basic modules, the antenna and the controller. The antenna module is a 1.067 m X 1.829 m parabolic reflector with offset feed horn, transmit (upconverter/solid state power amplifier) and receive (low noise amplifier/down converter) electronics. It can be easily mounted on a roof or on the ground.

The controller can be placed on a deck or on a shelf near the users terminal equipment and is connected to antenna system with upto 100 meters (maximum) of twin co-axial cable. The low voltage power required for the electronics of the antenna module is provided by the controller through a coaxial cable, eliminating the need for power system at the antenna site.

The controller module has two user ports each of which connects to the user DTE (Data Terminal Equipment) by means of an RS-232C interface, using a standard 25 pin female DB-25 connector. Each port can be operated independently, using the same protocol, in simplex, half duplex or full duplex mode at any data rate upto 19.2 Kbps and appears to the users DTE as conventional modem. The controller contains the power suppliers, transmit/receive, IF circuits control circuits, processors and status monitoring devices.

The maximum transmitted output RF power is 1 watt per micro-earth station, spread over a 5 MHz channel bandwidth, reducing interface to absolute minimum. Spread spectrum technique, which provides a high degree of immunity from interfacing signals, plus high speed forward error correction (FEC) achieve a bit error rate better than 10^{-7} (one in 10 million). Packet transmission capabilities within the network further reduce the bit error rate to less than 10^{-8} (one in a billion) after packet re-transmission. The spread spectrum technology makes it possible to use V-SAT based C-band earth stations to operate as interactive satellite data network.

3.18 GLOBAL POSITIONING SYSTEM (GPS) for clock correction in INSTRUMENTS is shown in FIG. 3.2.

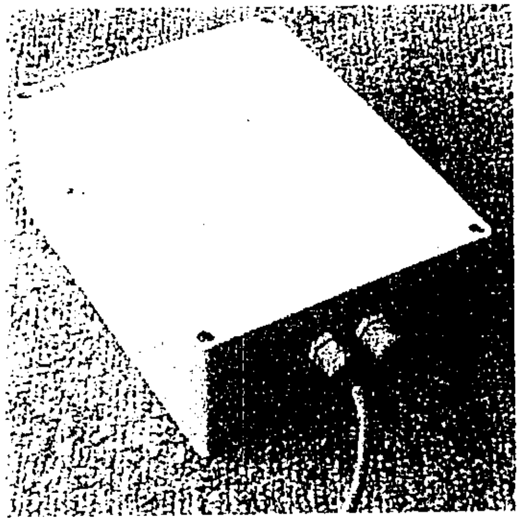
3.19 SOME APPLICATIONS OF DIGITAL DATA:

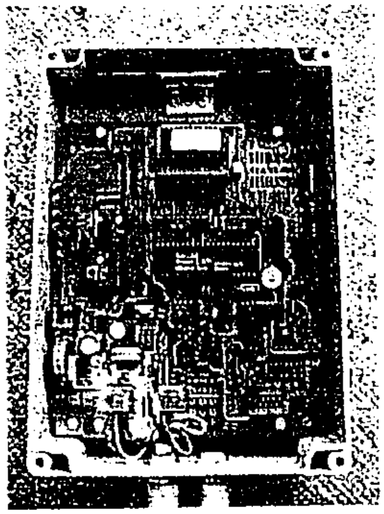
(i) <u>MAGNITUDES</u>

There are numerous quantitative measure of the size of earthquake, such as radiated energy, seismic moment or magnitude. Of these the most commonly used is the earthquake magnitude. Earthquake magnitudes are estimates of radiation intensities of a given wave type at a particular period. General agreement exists by now that body wave magnitude is insufficient to rate the strength of earthquakes on the basis of P-wave and that the radiation intensity of S-wave remains unknown due to its higher attenuation. The body wave magnitudes published by NEIS are based on amplitude observations in the

GPS : Satellite-controlled Time Base with DCF Time Code Generator

FEATURES



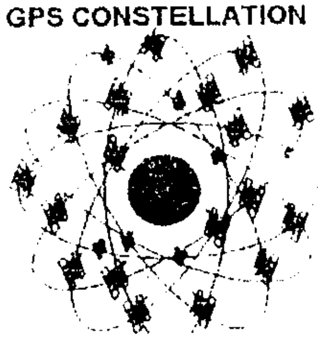


- Operates World-wide.
- Built-in Antenna.
- Optional External Antenna.
- Automatic Setting of UTC Time.
- Time Zone and Daylight Saving.
- DCF-Compatible Time Code output for Master Clocks, Digital Clocks, Recorders, etc...

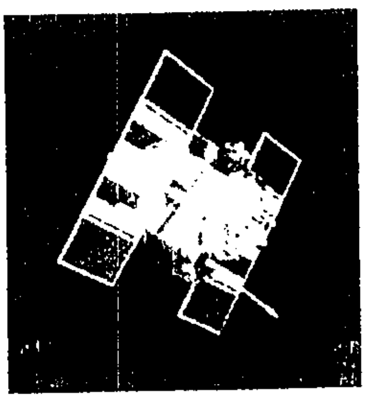
GPS Signals

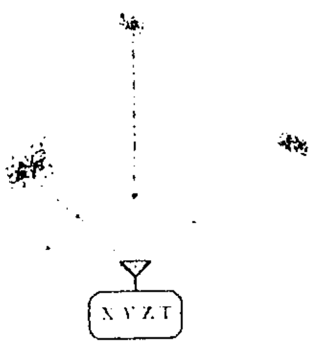
The GPS Global Positioning System of the US Department of Defence, consists of 24 satellites revolving around the earth at an altitude of approximately 20'000 km. GPS receivers use the satellite signals to determine their exact location and altitude on earth. GPS satellites also transmit accurate time and date information, which is being used by the GPS Light.

GPS CONSTELLATION



21 SATELLITES WITH 3 OPERATIONAL SPARES
6 ORBITAL PLANES, 55 DEGREE INCLINATIONS
20,200 KILOMETER, 12 HOUR ORBITS





body wave magnitudes published by NEIS are based on amplitude observations in the period range from 0.1s up to 3 s. Thus it is a quantity which samples and averages the radiation of P-wave over a range of more than four octaves and at the same time at periods usually shorter than that one of the maximum radiation. Also body wave magnitudes which are determined from different instruments with different free periods of oscillation usually yield different magnitude values for a given earthquake.

Broadband records of seismic waves enable one to extend the magnitude definition to bandpass seismograms and to determine a set of magnitudes corresponding to the respective set of seismograms. These magnitudes are called spectral magnitudes. The period corresponding to the maximum spectral magnitude varies between seismic events depending on the source characteristics. The maximum spectral magnitude together with its period is considered as a diagnostic quantity for seismic events.

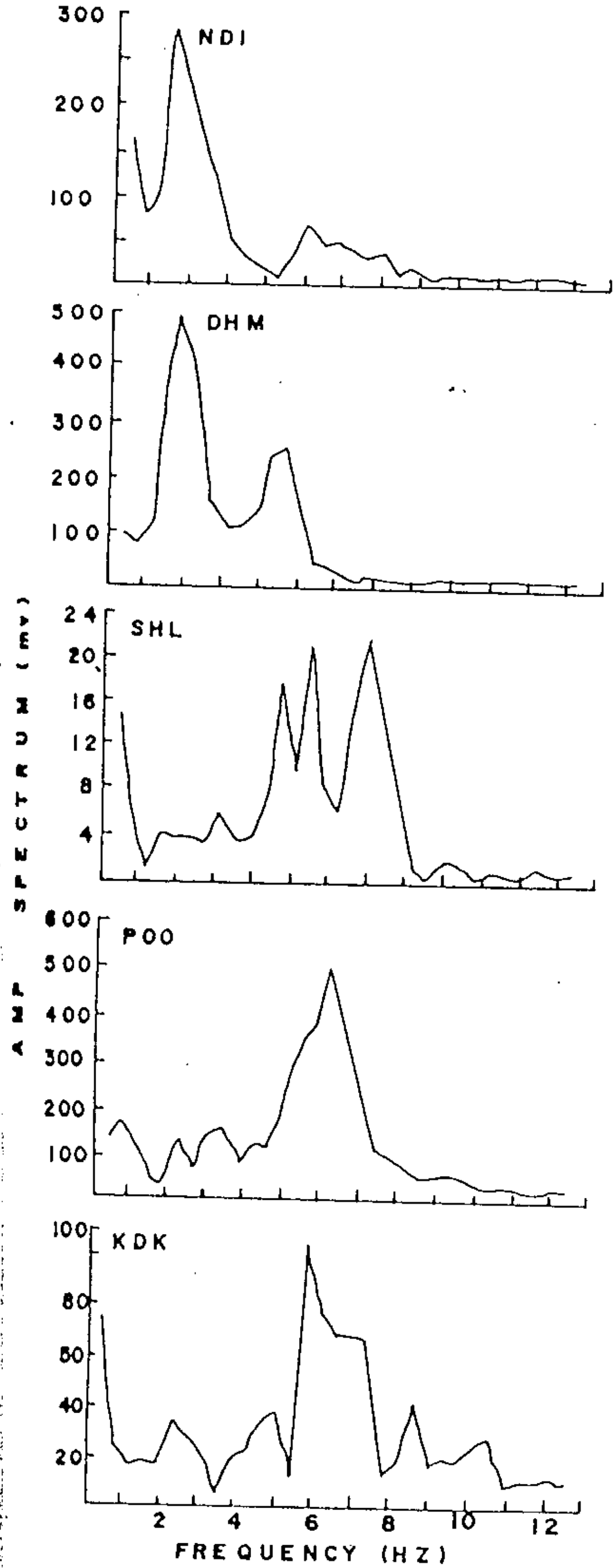
(ii) NOISE SPECTRA.

The spectra of seismic noise mainly aim at estimating the predominant frequency characteristics of the ground at each site. For this purpose, it is necessary to consider a waveform consisting of purely the ambient ground noise only. To start with the time series is tapered by applying a Hamming window to reduce the effect of unwanted frequency components in the spectra arising due to sharp discontinuities. The time series is then subjected to Fast Fourier Transform and spectra obtained over a frequency range of 1-12 Hz. Day time recordings of one event each from all the five stations are considered to obtain the noise spectra presented in Fig 3.3

It may be seen from the spectrum for Delhi that the predominant frequencies occur near 1.6 and 5.0 Hz. Another small peak is also noted near 8 Hz. The spectrum for Dharmasala shows almost a similar pattern. Both these sites are characterized by relatively quiet locations away from main roads and could, therefore, be considered as representative of the basement hard rock with almost negligible surficial cover.

The spectrum for Shillong shows peaks around 3.0, 4.5, 5.5 and 7.0 Hz. The underground vault of the Shillong Observatory is situated almost at the same height as that of a road passing closely (about 100 m) enabling the traffic noise to be effectively transmitted to the seismometer. The spectra of seismic noise from SRO at Shillong also reported a peak around 5 Hz associated with the traffic disturbance. However, the results indicated some peaks between 0.75 and 1.2 sec (which correspond to 1.3 and 0.8 Hz respectively) which was attributed to the rapid decrease of high frequency noise with depth. The spectral peak at 1.3 Hz could therefore, be considered as characteristic of the site implying rocky conditions with a thin surficial layer which has amplified the observed high frequency noise. It may be mentioned that the SRO system is limited by system noise above 4 Hz even at the quietest sites. The spectra also showed a small peak between 4.2 and 4.6 sec, which may be attributed to the microseisms generated from the oceanic areas. This is almost the same range of periods reported corresponding to the secondary microseisms associated with cyclonic storms over the Indian seas.

The spectrum at Pune shows a maximum peak around 6 Hz which may be attributed to the combined influence of the traffic vibrations and the effects of wind on the trees in the close proximity to the site. Smaller peaks are noted at 0.8, 2.3 and 3.5 Hz, which could, be characteristic of the underlying basaltic structure overlain by the traps. On the other hand, vertical spring mass accelerations of road trucks, farm tractors, military transport, vehicles etc have power spectra showing peaks around 1.5 to 6 Hz with additional vibration on fire modes and axle bounce often extending from approximately 3 to 10 Hz. However, at Gauribidanur seismic array located on the Deccan shield over Archeean rocks with unweathered gneiss of 2 m upto the ground surface, the spectral peak has been found to be at 1 Hz with 2 manometers as the median value corresponding to all time, i.e., day and night spectrum. It almost compares with that for Shillong site obtained



 NOISE SPECTRA AT SOME INDIAN STATIONS.

through the bore hole SRO system. In USA, an anomalous peak in the seismic noise spectrum near 2 to 3 Hz has been found to occur at many locations.

High noise stations, as a group, were those sites where recording was on alluvium, while low noise was characteristic of non-coastal stations in western and northwestern United States.

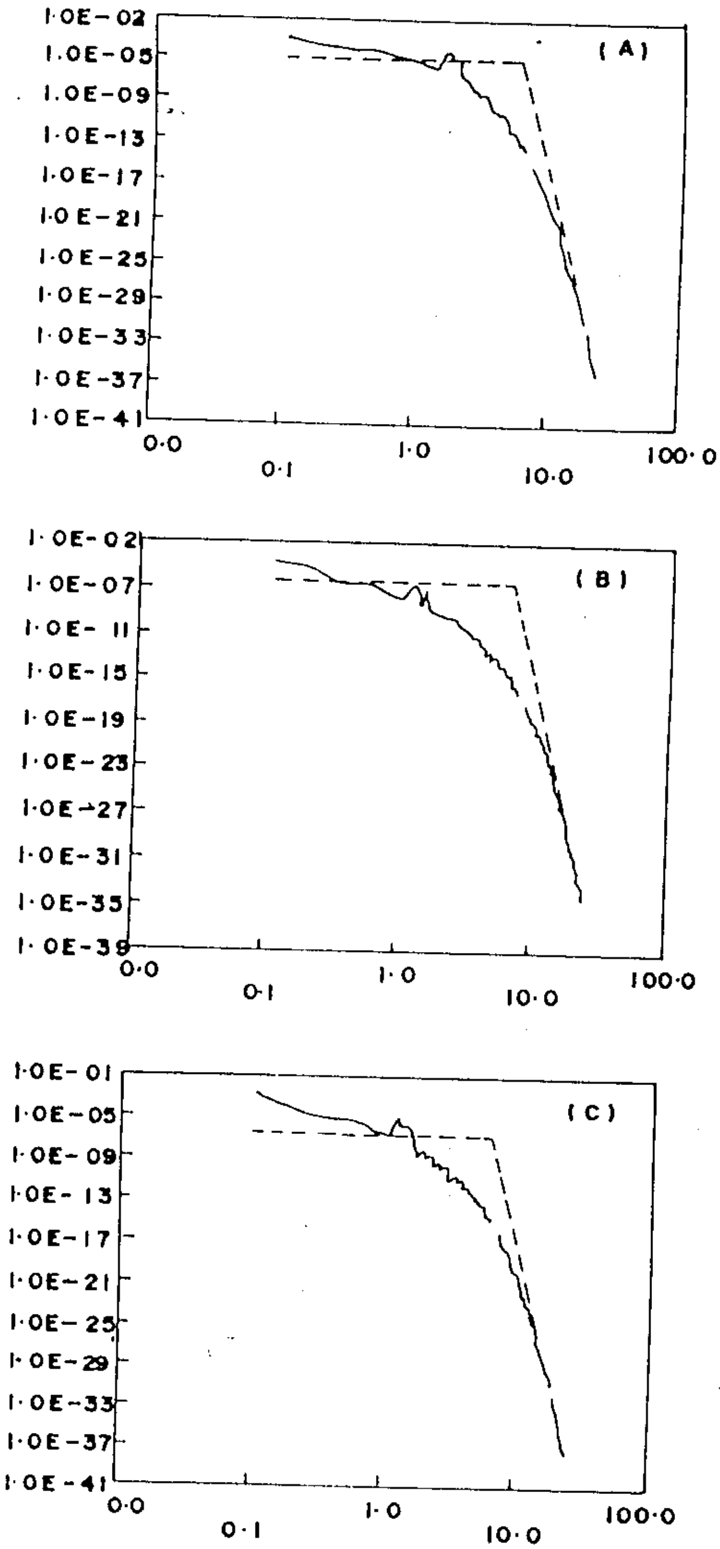
In the Indian region, spectral peak is observed at 2 Hz over Delhi and Dharmasala only, while it occurs near 6 Hz over Pune. Kodaikanal and Shillong, suggesting greater influence of cultural noise at the latter sites. High frequency seismic noise characteristics were studied at the United Kingdom (UK) type medium aperture arrays, namely Eskdalemuir (Scotland), Warramunga (Australia), Yellow Knife (Canada) and Gauribidanur (India). It was found that in general, at all the arrays, the characteristic noise spectrum follows a linear trend above 2 Hz. However, GBA spectrum features flattening above 4 Hz, which is apparently due to locally generated high frequency noise, trapped near the surface. It was surmised that wind generated vibration of large pylons and perhaps small trees in the vicinity could result in high frequency noise.

(ii) P-WAVE DISPLACEMENT SPECTRA AND SOURCE PARAMETERS OF FORESHOCKS AND AFTERSHOCKS

The Uttarkashi region of Garhwal Himalya was rocked by an earthquake of moderate magnitude (m_b=6.6) on October 20, 1991 causing extensive damage to life and property The main shock was preceded by foreshocks and followed by a series of aftershocks which continued for few months. The India Meteorological Department (IMD) is operating five standalone digital seismographs at Delhi, Shillong Kodaikanal, Pune and Dharmashala. The recording system consists of a Seismometer (S-7000), amplifier, analog to digital converter and a digital event recorder (DR-200). The Seismometer with a natural period of 1.0 sec. And critical damping of 0.63 is operated in vertical mode. A seven pole (42 dB/octave) anti-alias low pass filter (frequency 12.5 Hz) is used to reduce the effect of aliasing Accordingly, the recordings are made at a sampling rate of 50 SPS. The digital data recorded in cassettes is retrieved with the help of a digital playback system (DP-260) through a host computer utilising a retrieval software.

P-wave displacement spectra (Fig.3.4) are computed for two foreshocks and aftershocks of Oct. 20, 1991 Uttarkashi earthquake and interpreted using the far field displacement model of Brune. The spectra exhibit a more or less constant amplitude at low frequencies, a well defined corner frequency and an estimated high frequency slope of about – 1.6. The corner frequency, seismic moment, source radius and stress drop for these events vary between 5.1-6.2 Hz, 0.14*10*21-0.85*10**21 dyne-cm, 360-438 metre and 1.3-4.8 bars respectively. The stress drop in the Uttarkashi earthquake sequence decreases from about 10 bars in the mainshock to about 1.7-4.4 bars in the aftershock.

(iii) Focal depth: Broad band digital seismographs have been useful to identify dept phase of Jabalpur earthquake (1997) by Scientists of India Meteorological Department.



(A)
1·0E-02
1·0E-05
1·0E-09
1·0E-13
1·0E-17
1·0E-21
1·0E-25
1·0E-29
1·0E-33
1·0E-37
1·0E-41
0·0
0·1
1·0
10·0
100·0
(B)
1·0E-02
1·0E-07
1·0E-11
1·0E-15
1·0E-19
1·0E-23
1·0E-27
1·0E-31
1·0E-35
1·0E-39
0·0
0·1
1·0
10·0
100·0
(C)
1·0E-01
1·0E-05
1·0E-09
1·0E-13
1·0E-17
1·0E-21
1·0E-25
1·0E-29
1·0E-33
1·0E-37
1·0E-41
0·0
0·1
1·0
10·0
100·0

CHAPTER – 4

EPICENTRAL PARAMETERS

EPICENTRAL PARAMETERS AND ANALYSIS

4.1 INTRODUCTION

The main purpose of the network of seismological stations is to prepare the following epicentral information soon after the occurrence of an earthquake and supply to Government and other agencies:

1. Origin time
2. Latitude, Longitude (Approximate place)
3. Magnitude
4. Focal depth

Sometimes, the press is interested to know the intensity of the earthquake which can be given by converting magnitude into Intensity (modified Mercalli Scale) but better from field survey for which Geological Survey of Bangladesh may be responsible. The duration of shaking is not based on instrumental data and therefore, only an approximate idea can be given from the felt reports.

4.2. EPICENTRAL DETERMINATION

For determination of epicentre of an earthquake, the arrival times of P and S waves are read either from seismographs or through manual pick up by the cursor on a PC where the wave form can be seen. For magnitude determination, the 'coda' duration is noted or the amplitudes of 20 sec surface waves is taken. After the data of all the four proposed stations in Bangladesh is analysed, the data can be fed to another computer and epicentre can be determined making use of local travel times (seismic wave velocities) as an input. Several computer programmes are found useful by different agencies. The programme

HYPO71 by U.S. Geological Survey is quite successful for near earthquakes for this purpose. Other programmes like SEISAN etc are given in Chapter 8. It is however, better to check the results through manual determination of epicentre on a map till sufficient practice is done as computer may give a totally wrong information if the observations have some errors.

4.3 VELOCITY MODEL

Table 4.1 shows the local crustal velocities for a few places in India. For Bangladesh, an approximate model can be prepared making use of results of chemical explosions in Bengal and earthquake data of northeast India. The results of Deep Seismic sounding investigations in West Bengal are given below (published in Geophysics J. Int, 1992, 111,45.66).

"Basement and sub-basement crustal configuration of parts of the west Bengal basin has been delineated from inverse and forward modelling of refraction and wide-angle reflection data obtained along two east-west profiles: (a) Beliator-Burdwan-Bangaon (Profile-1) about 180 km long and (b) Gopali-Tamluk-Port Canning (profile-2) about 140 km long. The study has revealed the existence of four groups of prominent refractors (velocities 1.7-2.1 km/s −1, 2.7-3.2 km/s,3.7-4.2 km/s and 4.6-5.3 km s) overlying the crystalline basement with a velocity of 5.8-6.2 km/s. Rajmahal Traps (velocity 4.6-5.3 km/s, averaging 4.8 km/ s) occur beneath the base of the Tertiary sediments in the middle parts of the profiles. The presence of sub-Trappean Gondwanas is also indicated from the wide-angle reflection modelling supported by deep well lithological information. In general, depth to the basement is found to increase from west to east, with a maximum depth of around 10 to 11 km at the extreme eastern parts of the profiles. A basement upwarp, with a sharp flexure west of Bishnupur on profile-2 in combination with the fault west of Shantipur on profile-1 possibly brings into focus the regionally extending NNE-SSW 'Hinge Zone'. A low velocity layer (LVL) of about 2 to 3 km thickness (velocity

5.6-5.8 km/s) has been inferred in the upper crust in this area. In general the thickness of the upper (including the sedimentary column) and the middle (6.4-6.6 km/s velocity) parts of the crust is found to be larger (thickness varying between 22 and 27 km) than the lower crustal column (interval velocity 6.8-7.0 km s with a thickness of 5 to 10 km). The Moho lies at varying depths of 36 to 26 km along profile-1, with a prominent domal feature of about 40 km width between Satgachia and west of Shantipur. In the middle part of profile-2 the Moho occurs at depths of 32 to 34 km, with a mild flexure east of Tamluk. Configuration of the Moho indicates that the crust is more akin to continental in nature in the western and middle parts of the basin, whereas significantly thinned continental crust is indicated in the eastern and southeastern parts.

Participation of India Meteorological Department in the Deep Seismic Experiments has given the following model:

	Wave Velocity	Thickness
(i)	2.87 km/Sec	1.28 km
(ii)	3.87 km/Sec	3.17 km
(iii)	5.83 km/Sec	

Local crystal velocity models for different parts of India are given table 1.

The trial velocity model by combining the data of northeast India with that of Deep Seismic Sounding results may be given as follows for Bangladesh:

Thickness Km	P Wave Velocity km/sec
0.0	3.37
3.50	5.83

24	6.56
40	8.01

S Wave velocities can be computed by taking Vp ratio as 1.73.

$$\frac{\quad}{Vs}$$

The upper Layers velocities can be improved from the deep bore hole data of oil companies, which can be further improved by using slight variations in velocity and thickness in the computer programs for epicentres.

The model with the least errors in ERH, ERZ and RMS in the HYP071 or other programs is finally adapted.

In future it is suggested that a few calibration chemical explosion shots may be organized and the region calibrated with portable seismographs to finalise a velocity model for Bangladesh.

In case the epicenter is to be determined for earthquakes for which data from Indian, Chinese an other countries are available, the wave velocity model in Table 2 may be used. Now a days, a new velocity model, IASPEI-91 may be better to use.

4.4 Analysis with modern instruments.

Familiarization and analysis with the modern seismographs wave form takes a long time Even reading the onset time of P waves is sometimes difficult since it is directly affected by a slight increase or decrease of amplitude of waves in different frequency bands. The polarity of P waves is, therefore, more difficult which may appear to be compression instead of rarefaction. For this purpose it is necessary to read the onset times of waves from a visible recording analogue seismograph first and then familiarize with the digital wave form data.

Since epicentral determination may be difficult for earthquakes occurring outside the grid of 4 stations in Bangladesh, or near borders with India, it will be of mutual interest if some mechanism of data exchange is established with India on reciprocal basis.

4.5 Measurement Procedures

(i) Polarity measurements of P waves should be made from broadband or long period simulated instruments.

(ii) For secondary phases, long-period or broadband records may be used for onset, amplitude, and period measurements.

(iii) The measurement required on surface waves is the 20 s amplitude, which should be made from either long-period or broadband displacement records.

The following phases may be analyzed daily:

(i) Direct P phase and its polarity

(ii) Depth phases

(iii) Direct S phases at all distances; regional S (Sn, Lg, etc.) is especially useful

(iv) PKP phases need more study (precursors, branches), but are important in eliminating gross errors in focal depth;

(v) PcP and ScP are important phases for research on the core-mantle boundary.

(vi) S/SKS problem: The two phases can't be distinguished by travel time alone polarization analysis may be attempted.

For near earthquakes, all the phases may be searched such as

Pg, Sg

P* S*

Pn, Sn

The amplitude measurements may be reported in nm or microns, which should be in terms of, ground displacement, The analysis may be done daily for the recorded earthquakes.

4.6. Seismological Bulletins

Monthly Seismological Bulletin may be prepared using the data of all the four stations giving complete information of waves onset times, their polarity (for P waves), amplitudes and coda duration in the following format.

Month (Say May, 2000

Date	Station	Time (GMT)	Waves	(S-P) (Sec)	Polarity	Amplitude	Coda
1.	Chittagong		Pg				
			Pn				
			Sn				
			Sg				
	Sylhet		Pg				
			Pn				
			Sn				

	Sg
Rangpur	Pg
	Pn
	Sn
Dhaka	Sp
	Pg
	Pn
	Sn
	Sg

Computer programs can be developed for preparation of seismological bulletin.
Then the next event and go on.

The format used by the International Seismological Centre, U.K. may be adopted which is also being generally followed by India Meteorological Department with more details recorded even for those events where epicentral determination is not possible due to lack of data or distance of the event or errors in observations. A copy of Indian Seismological bulletin may be obtained from

Director General of Meteorology
India Meteorological Department
Lodi Road
New Delhi 110003, India

TABLE - 1

Models for monitoring micro earthquakes in India.

Region	Depth (km)	P-Wave Velocity (km/sec)	S-wave Velocity (km/sec)	Remarks
1. North-east India	0.00	3.95	-	
	2.00	5.58	-	
	24.80	6.55	-	
	46.30	7.91	4.46	
2. Central Himalayan foot hills	0.00	3.40	-	
	4.00	5.72	-	
	6.61	29.00	-	
	8.22	49.00	4.61	
3. Himachal Pradesh (Kinnaur)	0.00	5.60	3.30	
	33.00	6.67	3.65	
	49.00	8.20	4.40	
4. Himachal Pradesh (Kangra)	0.00	5.72	3.29	
	24.00	6.61	3.72	
	45.00	8.22	4.73	
5. Madhya Pradesh (Indore Khandwa (section, Narbada)	0.00	6.01	3.63	
	18.00	6.69	-	
	38.00	8.03	-	
6. Koyna Region	0.00	4.80	-	
	1.5	5.82	3.41	
	17.0	6.61	4.09	
	36.0	8.23	4.60	
7 Bay of Bengal	0.00	6.28	-	
	25.4	8.00	-	

TABLE - 2

Standard velocity models inside earth

Depth (km)	Gutenberg Model Velocity (km/sec) P-wave (1959)	S-wave	Jeffreys Bullen Model Velocity (km/sec) P-wave (1948)	S-wave	Herrin Model (km/sec) P-wave (1968)
0	5.55	3.36	5.55	3.36	6.00
15	6.30	3.55	6.30	3.55	6.75
33	8.16	4.65	7.75	4.35	-
40	-	-	-	-	8.05
100	8.00	4.40	7.95	4.45	8.12
150	7.85	4.35	-	-	8.20
200	8.05	4.40	8.26	4.60	8.32
300	8.50	4.60	8.58	4.76	8.68
413	9.06	5.00	8.97	4.96	9.19
413	9.06	5.00	-	-	-
500	9.60	5.30	9.66	5.32	9.68
1000	11.40	6.35	11.43	6.36	11.44
2000	12-80	6.95	12-70	6.90	12.78
2900	8.08	0	8.10	0	(1894)
4370	9.70	0	9.87	0	-
5120	10.48	0	9.40	0	-
5120	-	-	11.16	0	-
5370	11-13	0	11.21	0	-
6370	11.15	0	11.31	0	-

CHAPTER – 5

GLOBAL SEISMOLOGICAL NETWORKS

GLOBAL SEISMOLOGICAL NETWORKS

INTRODUCTION:

Between the years 1960 and 1967, 120 WWSSN worldwide standardised Seismic network systems were installed by U.S. Geological Survey in cooperation with participating organizations in more than 50 countries. These stations were equipped with six standardized, analog components (15-sec or 30-sec pendulum periods. 100-sec galvanometer periods) and three orthogonal short-period components (1-sec pendulums, 0.75-sec galvanometers). Recording is photographic, with radio-synchronized crystal clocks. These stations are managed by the U.S. Geological Survey (USGS), and the distribution of WWSSN data is handled by the National Oceanographic and Atmospheric Administration (NOAA).

The WWSSN quickly became the most widely used seismological research network in the world. During its first decade of operation, the number of earthquakes routinely located and the precision of those locations, increased by a factor of 3 to 5 with the lowest magnitude upto 4.5 or less. The resulting pattern of global seismicity defined narrow zones of activity outlining the stable lithospheric blocks, including the low-level but nearly continuous seismicity of the mid-ocean ridge crests. This discovery gave a major impetus to the hypothesis of plate tectonics.

Similar advances were made in the mapping of radiation patterns from individual earthquakes, providing seismologists with the focal mechanisms that describe the orientations of fault planes and their slip vectors. WWSSN data reduced inconsistencies in focal-mechanism determinations, which dropped from about 20% to 10%. The new data source were instrumental in the formulation of plate-tectonic concepts and the establishment of the directions of plate motions.

Wave-propagation studies, and the derivation of structural information from them, were also greatly facilitated by the WWSSN, especially in the intermediate-period and long-period bands. Seismologists refined models of earth structure in the mid-mantle transition zone using new theoretical techniques.

Research in seismic discrimination indicated that instruments "tuned" to periods of around 30 seconds would be particularly effective in detecting small events. Also, borehole installation of the seismometers reduced quite significantly the background noise that masked signals of interest. This and other research led to the development and deployment of the Seismic Research Observatory (SRO) network and the upgrade of an existing experimental analog network to become the Abbreviated Seismic Research Observatory stations (ASRO). Late in the 1970's some of the WWSSN analog stations were upgraded by the addition of digital recorders to form the DWWSSN network.

Seismic recordings have conventionally been made in two or more narrow frequency bands because of the dynamic range limits of analog records. With digital recording, it is possible to use broad-band instruments, to yield higher fidelity data.

A more recent initiative to install a global network of broad-band seismometers is the GEOSCOPE project, operated by a consortium of French universities. These stations were equipped with 3 component broad-band instruments and high-dynamic-range digital recording. One such observatory is functioning at Hyderabad (India).

A major drawback of the photographically recorded WWSSN is its low dynamic range, which is only about 44 dB, or a little over two orders of magnitude, so that signals from both very large and very small events are often not usable, even in the center of the instrumental passband. In contrast, modern digital instruments can easily have a total dynamic range of 126 dB, over six orders of magnitude. Hence, IRIS (A consortium of

Universities) programe was developed to deploy wide band digital seismograph systems These are also called GSN stations.

The advantages of GSN are:

i) Epicentral determination of significant earthquakes in near real time.

ii) Availability of digital broad band for research through Internet as well as on floppies on request.

iii) Instruments source parameters of great earthquakes (Mw .8) can be studied without the problem of saturation.

GSN have been established in several countries of the world including USA, India and China. Some initial problems arise due to the availability of large data which is some times lost when dumping the data to tapes or due to quality of satellite and phone line links or due to Y2K Fig 5.1 and 5.2 show the seismological network of stations in India and China (digital).

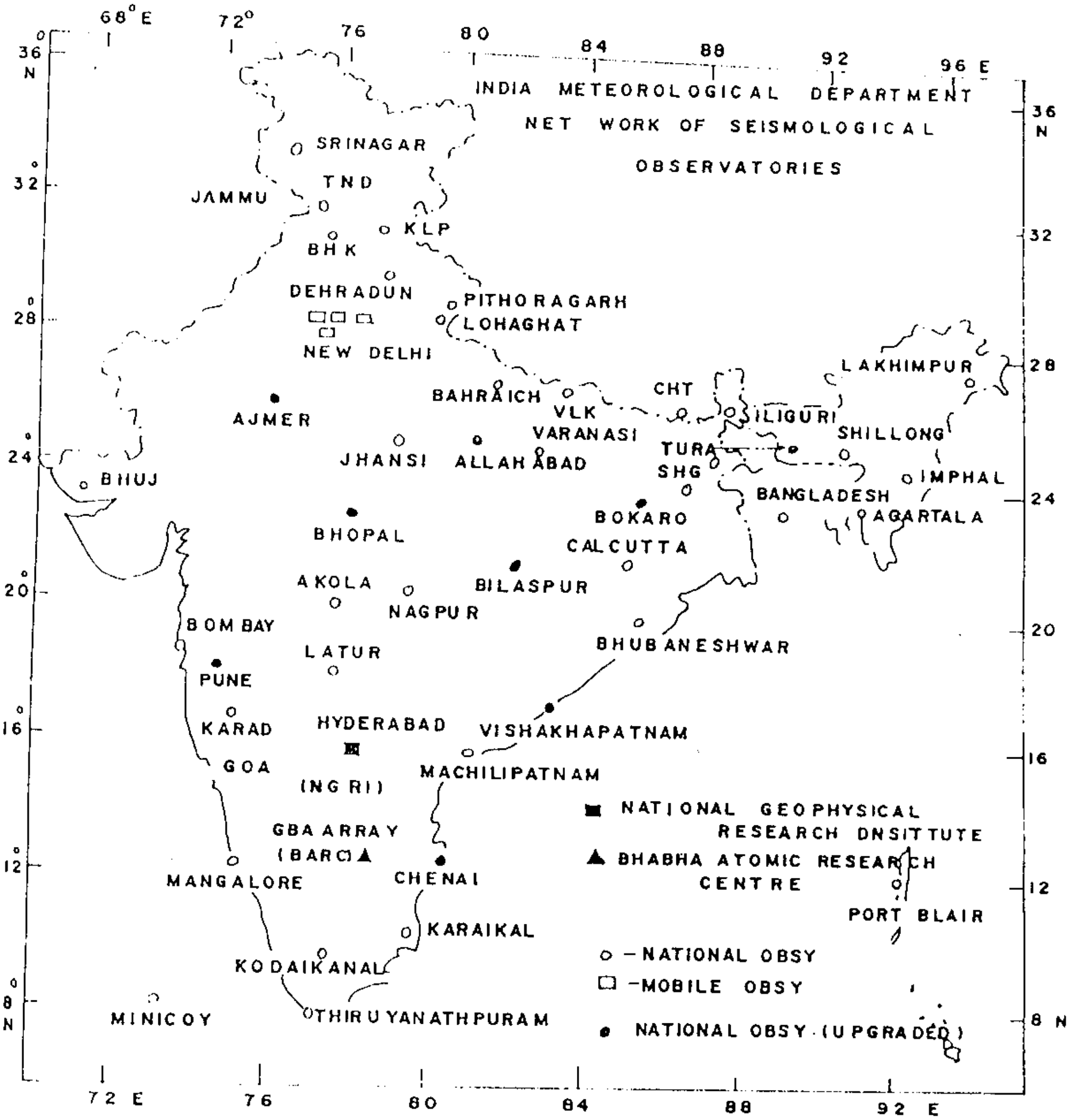


FIG-5.1 SEISMOLOGICAL NETWORK OF INDIA METEOROLOGICAL DEPARTMENT (IMD).

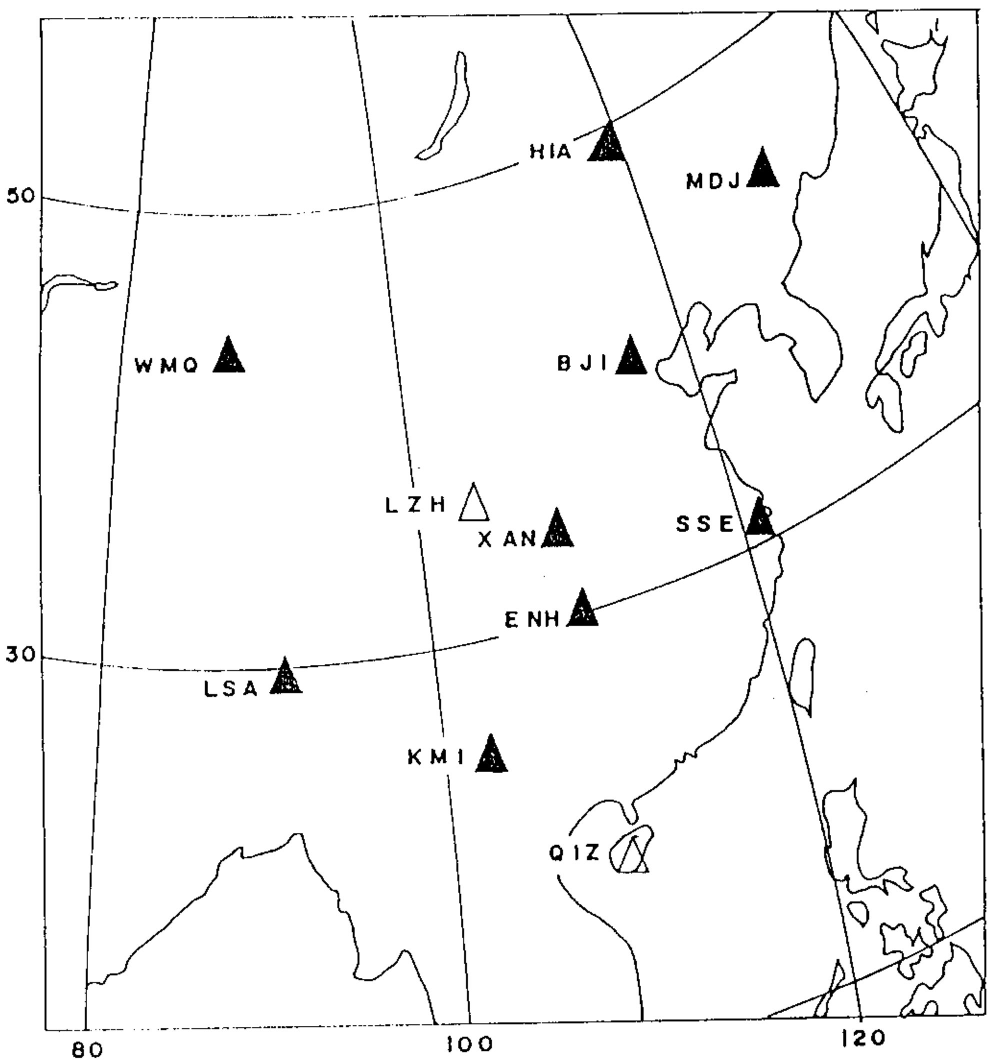


FIGURE 5-2 STATION DISTRIBUTION OF CHINA DIGITAL SEISMOGRAPH NETWORK(CDSN). THE STATIONS ARE SHOWN AS TRIANGLES. FULL SYMBOL REPRESENTS THE NCDSN STATION

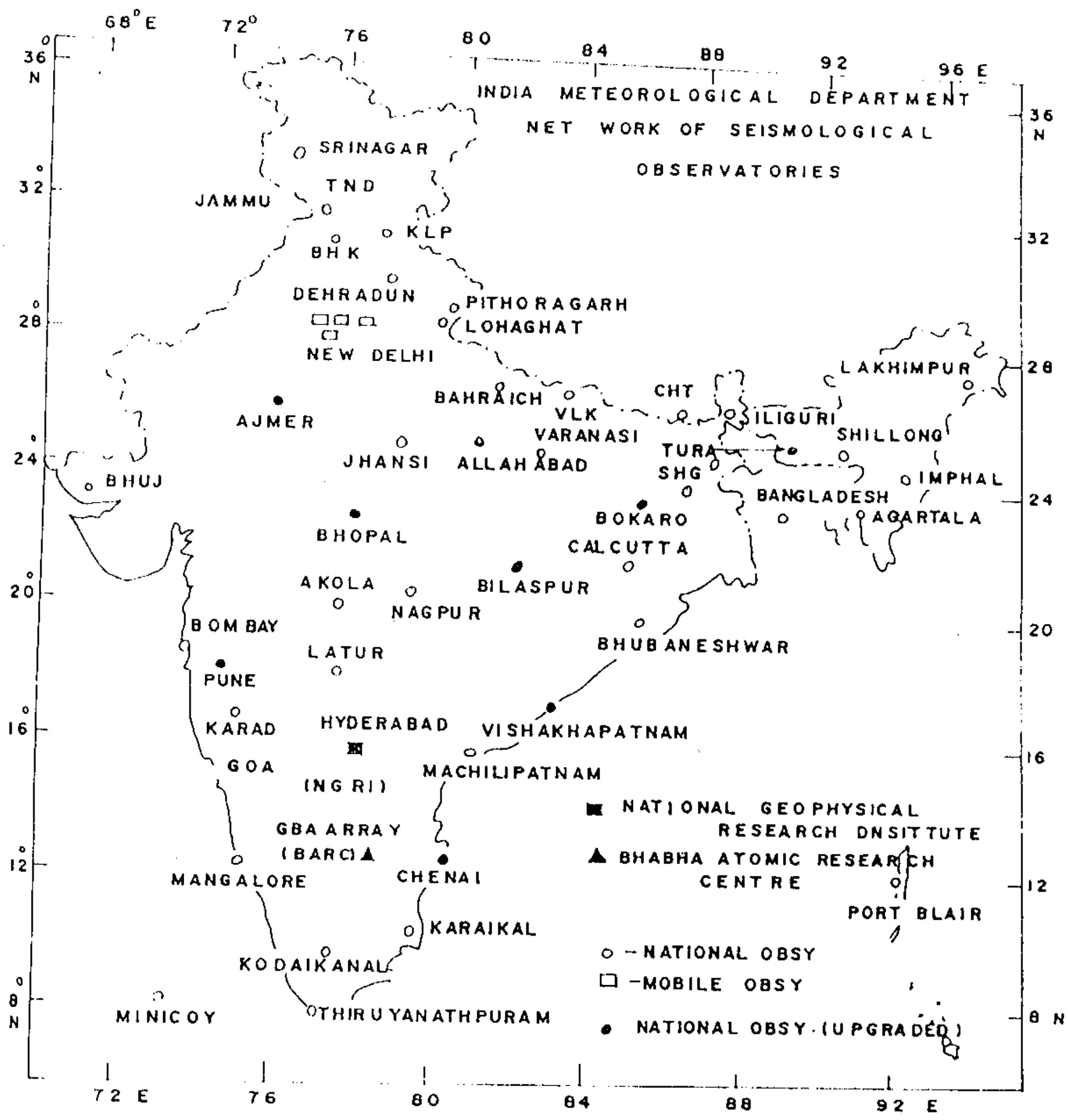


FIG.5.1 SEISMOLOGICAL NETWORK OF INDIA METEOROLOGICAL DEPARTMENT (IMD).

CHAPTER – 6

SEISMOLOGICAL NETWORK IN BANGLADESH

SEISMOLOGICAL NETWORK IN BANGLADESH

6.1 PROPOSED NET WORK

Bangladesh is susceptible to earthquakes of moderate to great intensity. The history of past earthquakes shows that the country is affected not only by earthquakes originating within the country but also from damaging earthquakes in the Indian/Myanmar regions due to:

i. Boundary of Indian Eurasian plates

ii. Faults/lineaments within Bangladesh and extension of faults from neighbouring region.

In order to monitor seismic activity in Bangladesh, the network of seismological stations should be capable of providing the following information for earthquakes:

i. Latitude

ii. Longitude

iii. Focal Depth

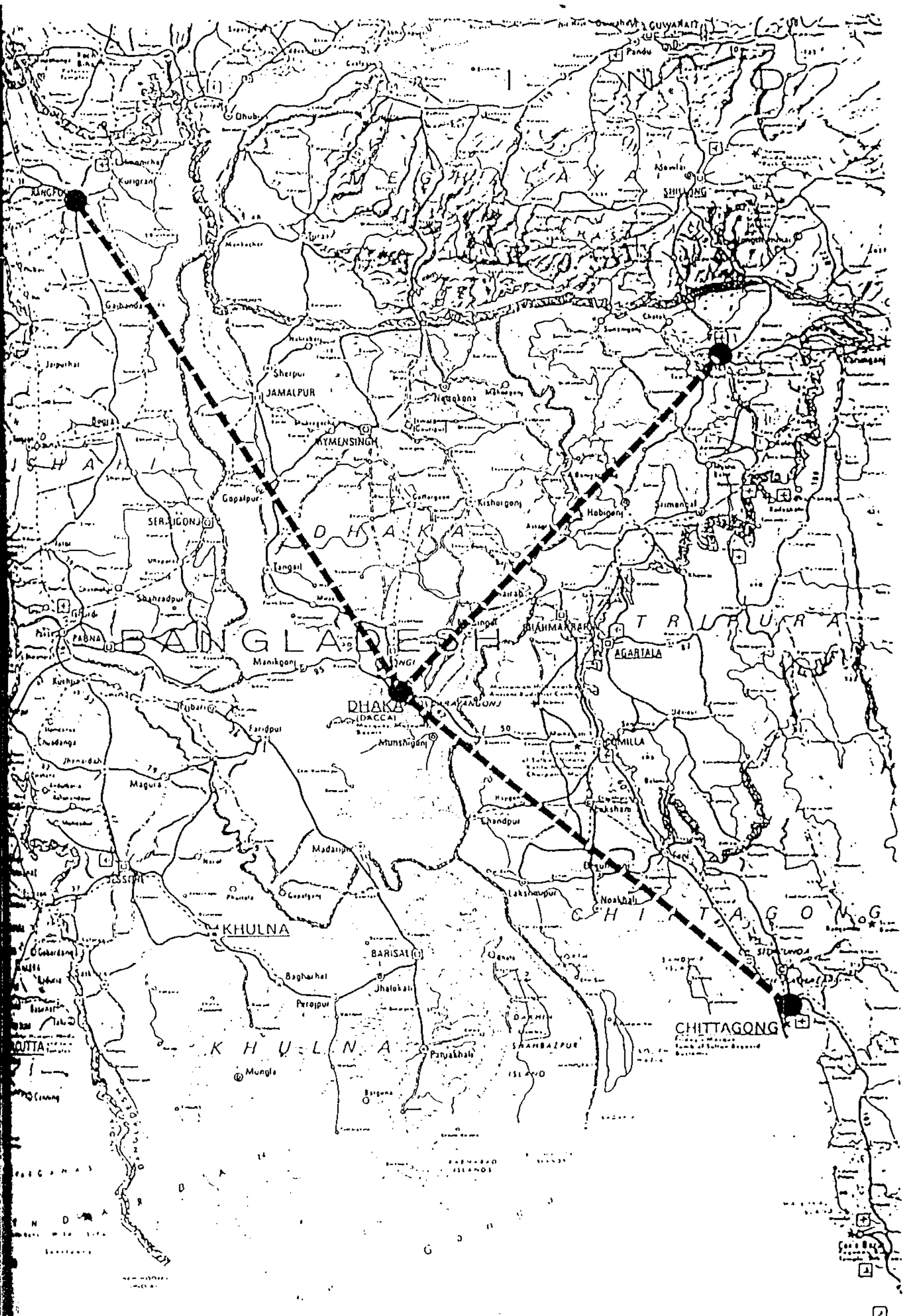
iv. Origin time

v. Magnitude

For this purpose, the regional seismic wave velocities are also needed as an essential input. Thus (I) to (iv) and Seismic wave velocity become 5 parameters for which 5 seismological stations are needed. If we take trial velocity models based on past earthquakes, 4 stations will be the minimum requirements which should cover the maximum geographical coverage well distributed in azimuth. Thus the seismological stations have been proposed by Bangladesh Meteorological Department (BMD) (Fig 6.1) and would be located at

i Dhaka

ii Chittagong



BANGLADESH
DHAKA
(DACCA)
CHITTAGONG
KHULNA
BARISAL
MYMENSINGH
JAMALPUR
COMILLA
AGARTALA
SHILLONG
GUWAHATI
TRIPURA
Sherpur
Gopalpur
Tangail
Manikgonj
Faridpur
Madaripur
Chandpur
Lakshmipur
Noakhali
Magura
Bagherhat
Jhalokati
Perojpur
Patuakhali
Mungla
Kishorgonj
Habiganj
Munshiganj

iii. Sylhet

iv. Rangpur

Of these, Chittagong station has been in operation since 1954. However, the equipment at this station is old and needs to be modernized.

6.2 Future expansion

a) Regional network :

Since errors in observations, detection capability (which depends upon the attenuation of seismic wave due to faults) and need for control in the focal depth of the earthquakes, the network needs to be expanded as early as possible. The new seismological stations may, therefore, be located at

i. Khulna

ii. Rajshahi

iii. Mymensingh

iv. Cox Bazar

This will reduce the inter station spacing and would detect earthquakes of magnitude 4 originating anywhere within the country. (Fig 6.2)

B Local network around Dhaka

Due to rapid growth and urban development of Dhaka Metropolitan City, these are a need to have a network of at least stations in and around Dhaka City to monitor local earthquakes. This will help in

i Detection and activity of faults/ lineaments

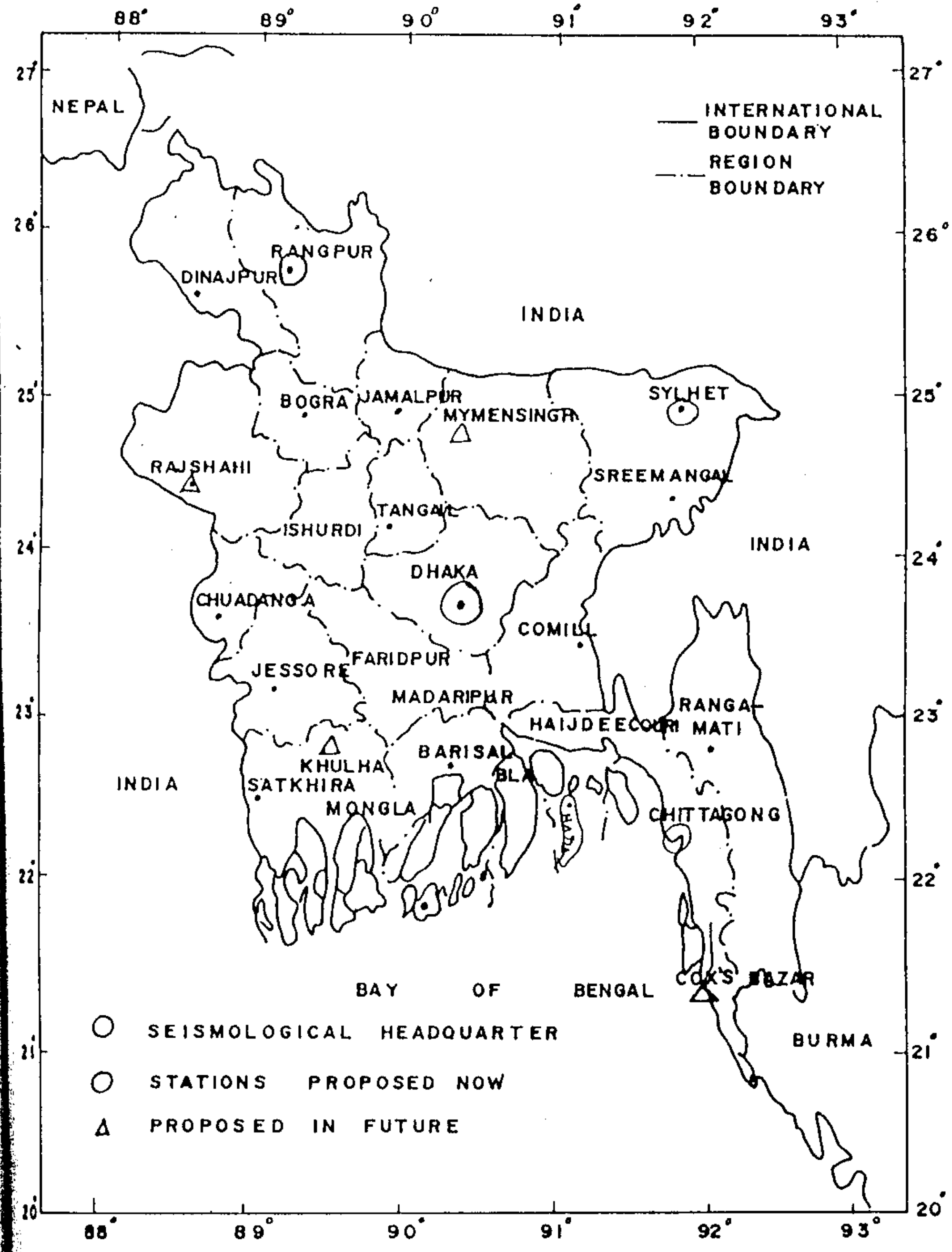


FIG 6.2. SEISMOLOGICAL NETWORK IN BANGLADESH (PROPOSED EXPANSION)

ii. Microzoning

iii. Earthquake risk assessment

These field stations should telemeter data to Central Data processing centre in the BMD campus, Dhaka, making use of VHF/UHF or V-sat facility on real time with GPS timing system

C. STRONG MOTION INSTRUMENTS

(i) Strong Motion Array.

Earthquakes have a tendency to recur along the same fault. Keeping in view the Sreemangal earthquake of 1918, it is better if we may operate an array of 50 strong motion stations through accelerographs to study source characteristics from near field data in that region.

(ii) Strong motion observations need to be taken at 40 to 50 places in Dhaka City due to urban development. Multistoried buildings need to be instrumented at different levels in the city to study the response of structures.

(iii) A national strong motion programme is needed to cover the whole country with 50 accelerographs to study attenuation of acceleration during strong earthquakes to help in earthquake resistant designs.

D. PORTABLE SEISMOGRAPHS

At least 10 portable digital seismographs should be procured and kept ready at Bangladesh Meteorological Department to study aftershocks or earthquake swarms (a group of small earthquakes with explosion sounds creating panic) soon after their occurrence. This set of instruments will also be useful for studying activity of lineaments/faults.

CHAPTER – 7

EARTHQUAKE HAZARD ASSESSMENT

7.1 INTRODUCTION

The importance of seismology lies in development of new techniques for earthquake hazard assessment, thereby reducing loss of life and destruction to dams, power plants, buildings and important structures. The primary input for such studies is obtained through modern seismological instruments, which record weak as well as strong motion due to earthquakes. Proper assessment of earthquake risk evaluation thus provides economical and safer designs.

7.2 BASIC FACTORS REQUIRED FOR SEISMIC DESIGN

7.21 Regional geological setting

- geologic history of the area
- identification of the physiographic features
- description of geological formations (rock types)
- location of major regional geological structural features, lineaments, faults.
- Estimation of the relative degrees of fault activity (rate of displacement) and deformation activity (rate of subsidence) using modern remote sensing and surveying methods.

7.22 Seismic history

- catalogues
- epicenter coordinates (latitude, longitude)
- epicentral intensity
- surface effects: isoseismal contours (map)
- focal depth

- intensity induced at the site (known or estimated)
- quantification of the rate of seismic activity (if possible)

7.23 Seismology

- micro earthquake activity
- focal depth
- focal mechanisms
- strong-motion records (if available)

7.24 Seismotectonic interpretation

- in-situ stress measurements within the region of the site (if available)
- interpretation of the regional tectonic mechanisms and associated types of faulting
- location and descriptions of faults and lineaments able to generate earthquakes

7.3 SELECTION OF EARTHQUAKES FOR ANALYSIS

Earthquake source parameters in the region need to be carefully determined as given below:-

(i) Earthquake Mechanism

Fault plane solutions determined from seismological data includes the orientation of the nodal planes (fault plane or auxiliary plane), the dip direction, dip angle, nature of faulting i.e thrust,, normal or strike slip, the orientation of stresses i.e. pressures and tensions and the slip vector. These parameters are derived from the first motino of P waves recorded at world wide stations well distributed in azimuth using assumed earth's velocity model, the angle of polarization of S waves and the radiation pattern of surface waves. Analysis of spectra of P and S waves enables us to estimate other source parameters namely seismic moment, source dimension, stress drop, average dislocation, apparent stress and the radiated energy, but the accuracy of these parameters is dependent upon the source mechanism like fault geometry, fault orientation and rupture process Recent developments in seismic source theory show that a single source parameter like magnitude is not adequate to define source characteristics adequately. Improved techniques in the digitization of seismograms and development of direct digitizing seismographs allow us to estimate the source characteristics of earthquakes. The displacement spectrum of the radiated shear energy has simple shape, being flat at low frequencies, and failing off as the square of frequency at high frequencies. On a double logarithmic plot, the spectrum is thus contained by two asymptotes, meeting at a corner frequency. The level of the low frequency asymptote is determined by the moment and the corner frequency, Wo has a simple relationship with the idealized source radius The source dimensions can often be estimated also from the distributions of aftershocks, but the rupture velocity, V(B) can not be readily determined.

(ii) FAULT LENGTHS

According to the moving source model, the fault first breaks at one point, usually near one of its ends, and from this point the rupture propagates with a finite velocity Vr (rupture velocity) to the other end of the fault. The length over which the motion extends is called fault length L. For circular sources, the fault length is taken as 2 r (sources radius) which is determined from the spectra of body waves. Fault length can also be computed from surface waves by computing the directivity function which is defined as the ratio of spectral amplitudes of surface waves corresponding to rays leaving the source in opposite directions. It can thus be calculated by taking the ratios of amplitudes of waves recorded at the same station, which have circled the earth in opposite directions or by taking pairs of stations situated 180 DEG apart in azimuth. Fault length can be found after noting the frequencies at which either the first maximum or the first minimum of the observed directivity function occurs. In view of uncertainties in the source parameters, the fault length so computed generally is subject to various errors due to over simplified assumptions in the theory. Recourse is therefore taken to estimate the fault length from aftershock areas, which show various geometrical configurations like ellipse, rectangle, parallelogram or even triangle in shape. In view of spares network of seismological observatories, the errors in the epicentral parameters of aftershocks also introduce uncertainties in determination of their area whose size is larger than that obtained from a closer network of seismic stations well distributed in azimuth. Also, the area of aftershocks tends to increase with time perhaps covering several faults in the vicinity. In general, the aftershocks areas determined from the aftershocks within 24 to 74 hours of the main event gives a better estimate of the fault length. The period for which the aftershocks can be associated with the earthquake is dependent upon the magnitude of the main shock. The longer linear dimensions of such aftershock zone may be taken as the fault length, which gives a better approximation than 2 r on the basis of circular model.

Earthquakes must be defined for analytical purposes so that appropriate seismic evaluation parameters (e.g., magnitude, acceleration, spectral ordinates, duration, etc.) can be selected. The latter process can be accomplished by using either a deterministic procedure, or a probabilistic seismic hazard evaluation.

In a deterministic procedure for choosing seismic evaluation parameters, magnitude and distance should be ascertained by identifying the critical active faults which show evidence of movements in quaternary time; the capability of these faults must be estimated through the appropriate established methods such as the rupture length-magnitude relationship or the fault movement and magnitude relationship or the fault movement and magnitude relationship. The distance of these critical faults from the site should be known to evaluate the other parameters. A probabilistic seismic hazard evaluation quantifies numerically the contributions to seismic motion, at the site, of all sources and magnitudes larger than a designated minimum (typically Richter Magnitude

4, or 5) up to and including the maximum magnitude on each source. The possible occurrence of each magnitude earthquake at any part of a source (including the closest location to the site) is directly incorporated in a probabilistic seismic hazard evaluation.

7.4 TERMINOLOGY

There is no universally accepted terminology for designating the various earthquakes that are used in defining the levels of earthquake motion for which a structure should be designed or evaluated.

Two definitions of earthquakes, for which the structure should be designed or evaluated, are recommended: Maximum Design Earthquake and Operating Basis Earthquake. Both depend on the level of seismic activity, which is displayed at each fault or tectonic province with capability of originating the event.

With each of such earthquake generating features, the notion of Maximum Credible Earthquake (MCE) is linked. This is the largest reasonably conceivable earthquake that appears possible along a recognized fault or within a geographically defined tectonic province. The MCE is generally defined as an upper bound of expected magnitude or as an upper bound of expected earthquake intensity.

To evaluate the Maximum Credible Earthquake it is possible to use a deterministic procedure or a probabilistic approach. If the deterministic procedure is used, the return period of such an event is practically neglected, as the occurrence depends on the seismically capable tectonic features to assess the maximum level of earthquake motion expected at the site. On the other hand, if the probabilistic seismic hazard evaluation is used, then Maximum Credible Earthquake is linked with very long return period for this event (with 50% or higher probability of not being exceeded in a large number of years). Table 7.1 gives the return period of earthquakes in some regions in India.

Maximum Design Earthquake

The Maximum Design Earthquake (MDE) will produce the maximum level of ground motion for which the structure should be designed or analyzed.

TABLE 7.1 Statistical forecasts of damaging earthquakes in India

Region	Return period of earthquakes (years)				Maximum magnitude Of earthquake expected
Magnitude (Richter Scale)	8.0	7.0	6.0	5.0	
Northeast India	50	25	8	-	8.0-8.5
Andaman Islands	75	40	10	-	8.0-8.5
Himachal Pradesh	100	60	15	1.0	8.0-8.5
Nepal Sikkim border	-	40	20	1.5	7.0-7.5
Rann of Kutch region	Insufficient data to compute return period				6.5-7.0
Nepal-India border	-	50	15	2	6.5-7.0
Delhi	-	-	40	5	6.0
Himalayas	40	4	0.5	-	8.0-8.5

DATA INSUFFICIENT TO COMPUTE RETURN PERIOD IN BANGLADESH

7.5 SELECTION OF SEISMIC EVALUATION PARAMETERS

The seismic parameters used for evaluation represent one or several ground motion-related characteristics, such as acceleration, velocity, or displacement values, response spectra, or acceleration time histories. Various combinations of these parameters are often used. For example, several acceleration time histories may define the same MDE. Similarly, an OBE can be represented by a peak ground acceleration and a specified spectral shape.

So far, few attenuation relationships have been developed for peak velocity, which actually may be a better indicator of ground shaking intensity than the PGA especially in the near-field, for peak displacement, or for the vertical component of ground motion. Vertical motion can be quite significant in the near-field and detailed evaluation of such motion is considered for all near-field sites. For intermediate and far-field locations, the vertical PGA may be conservatively taken as two-thirds and one-half of the horizontal PGA respectively.

DURATION

The duration of shaking is one of the most important seismic evaluation parameters, as it has been shown to be directly related to damage.

The durations of earthquakes can be estimated in different ways. Of significance to engineers are the bracketed duration, measured between the first and the last occurrence of acceleration pulses greater than 0.05 g, at frequencies above 2 Hz. Local conditons may also affect the expected duration of earthquake shaking and should be considered on a case-by case basis.

RESPONSE SPECTRA

Response spectra represent the maximum response (in acceleration, velocity, or displacement) as a function of frequency, for a given damping ratio, of a single-degree-of-freedom system subjected to a time-dependent excitation. Response spectra characterizing the MDE and OBE may be determined from peak ground acceleration, velocity and displacement consideration by using site-dependent or site-independent generalized spectral shapes. It is now recognized that the use of generalized spectral shapes remains acceptable when magnitude does not exceed 6.0.

An alternative to spectral shapes are attenuation equations applicable to spectral amplitudes, thereby directly defining spectral response parameters as a function of magnitude, distance, frequency and sometimes soil condition. The level of damping and the number of damping values for which response spectra should be specified to represent the MDE, OBE.

For the purposes of characterizing ground motion and comparing various earthquakes, 5 percent damping is the most commonly used value, mainly because generalized spectral shapes for that damping value are the most available.

ACCELERATION TIME HISTORIES

The definition of seismic parameters by peak values and spectral characteristics is sufficient for many applications. Non-linear analysis techniques require, however, the specification of earthquake motion in the time domain as acceleration time history records. Acceleration time histories may be specified for horizontal and/or vertical motion and should preferably be represented by real accelerograms obtained for site conditions similar to those present at the site under consideration.

Since the strong ground motion data currently available do not cover the whole range of possible conditions, such records can be supplemented by synthetic motions representing any earthquake size and seismotectonic environment. Synthetic earthquakes can be developed by superposition methods, by stochastic processes, or by mathematical simulations of fault rupture. However, strong motion instruments at such sites need to be deployed.

Superposition Methods

The simplest way to produce records of specified duration and peak values is to use several segments of actual earthquake records, scaled in amplitude as necessary by using appropriate factors. This comprises assemblage of portions of real accelerograms intended to simulate the seismic motion, at bedrock level, resulting from the progressive breakage of a fault along successive segments during a large earthquake. Modification of real earthquake records by compressing or expanding the time-scale is possible, but must be done with great care, as the resulting acceleration time history may show an unrealistic phase relationship. Selected phase delays can also represent propagation of the rupture along a single fault. All artificial earthquakes, obtained by superposition or other methods, must be base-line corrected to eliminate long-period drifts in their velocity and displacement records in the same manner as actual recordings are corrected.

Another application of the superposition method is to simulate specific, sustained acceleration and velocity pulses in several near-field records.

7.6 PROBABILISTIC SEISMIC HAZARD EVALUATION

A probabilistic seismic hazard evaluation involves obtaining, through mathematical and statistical processes, the relationship between a ground motion parameter and its probability of exceedance at the site during a specified interval of time. The value of the ground motion parameter to be used for the seismic safety evaluation is then selected after defining an acceptable level of probability for the structure and site considered. Recognized active, or potentially active, faults and seismic provinces are referred to as seismic sources. A seismic province is considered to be an area where the location of active faults is not well known, but where the seismic activity may be reasonably assumed to be randomly distributed. The spatial relationship between the site and the seismic source(s) of concern to the site, and the rates of activity assigned to each seismic source, form the basic elements of the seismic hazard model of the site considered. Such model should be consistent with the geologic and tectonic setting of the area under investigation and with the historic and geologic rates of seismic activity that have been established for the faults included.

7.7. SEISMIC ZONING

Seismic zoning maps indicate a quantitative assessment of the seismic risk in different zones of a region. The preparation of such maps involves a synthesis of the available historical and seismological data, an understanding of the geological and geophysical features.

A seismotectonic approach is adopted to supplement the information contained in the historical and seismological data with geological and geophysical information's, such as, faults, their sizes, and competency; grade of seismogenisity; mechanisms and rate of tectonic differential movements; earthquake mechanisms and tectonic features.

In seismic zoning, seismological data, including magnitude, time of occurrence, epicentre, focal depths of recorded earthquakes and the attenuation laws provide the quantitative basis for estimating seismic risk. The risk analysis may be carried out within a deterministic or a probabilistic framework. Due to a large measure of uncertainty, in each of the above parameters, a probabilistic approach provides a more realistic basis for estimating the seismic risk, provided adequate data is available. This approach is used to estimate the seismic risk, in terms of 100-yr. Return period, peak-ground-acceleration

Seismic Zoning maps have been prepared for different countries. FIG. 7.1 shows three seismic zones for Bangladesh.

7.8. MICROZONATION

Seismic microzonation of a region involves consideration of the variations in the potential for the earthquake hazards due to the effects of local site conditions including soil profile and the topographic features. Identification of the potential earthquake sources around the target region is a primary requirement for microzonation studies.

Several damage survey reports on past earthquakes indicate that the damage pattern in a region is strongly correlated with the spatial distribution and physical properties of the bedrock and the soil cover. The free-field ground motion experienced at different locations in the same region could differ significantly due to the variations in the topography, depth and nature of soil cover, and bedrock profile. The vulnerability of the constructed facilities on these ground motions depends on the dynamic characteristics of the structures as well as the characteristics of the ground motion. Due to growth of urban population centres with different types of constructions taking place, structural designs based on parameters obtained from a seismic zoning map of the country might not be able to ensure the desired level of protection against earthquake induced damage. Thus there is a need for a more detailed zoning procedure or microzonation providing guidelines about the earthquake resistant design parameters as a function of local site conditions and topography over the area of interest. The phenomenon of liquefaction is of great importance in some cities, which may effect the foundations.

An international programme for microzonation of important cities of the world has been taken up which is called RADIUS as per details at the end of this Chapter.

In Bangladesh also, microzoning programme may be initiated due to rapid growth of skyrise structures where tall structures may be affected due to a great earthquakes in the Himalaya/northeast India. Shorter as well as other structures are also vulnerable to local

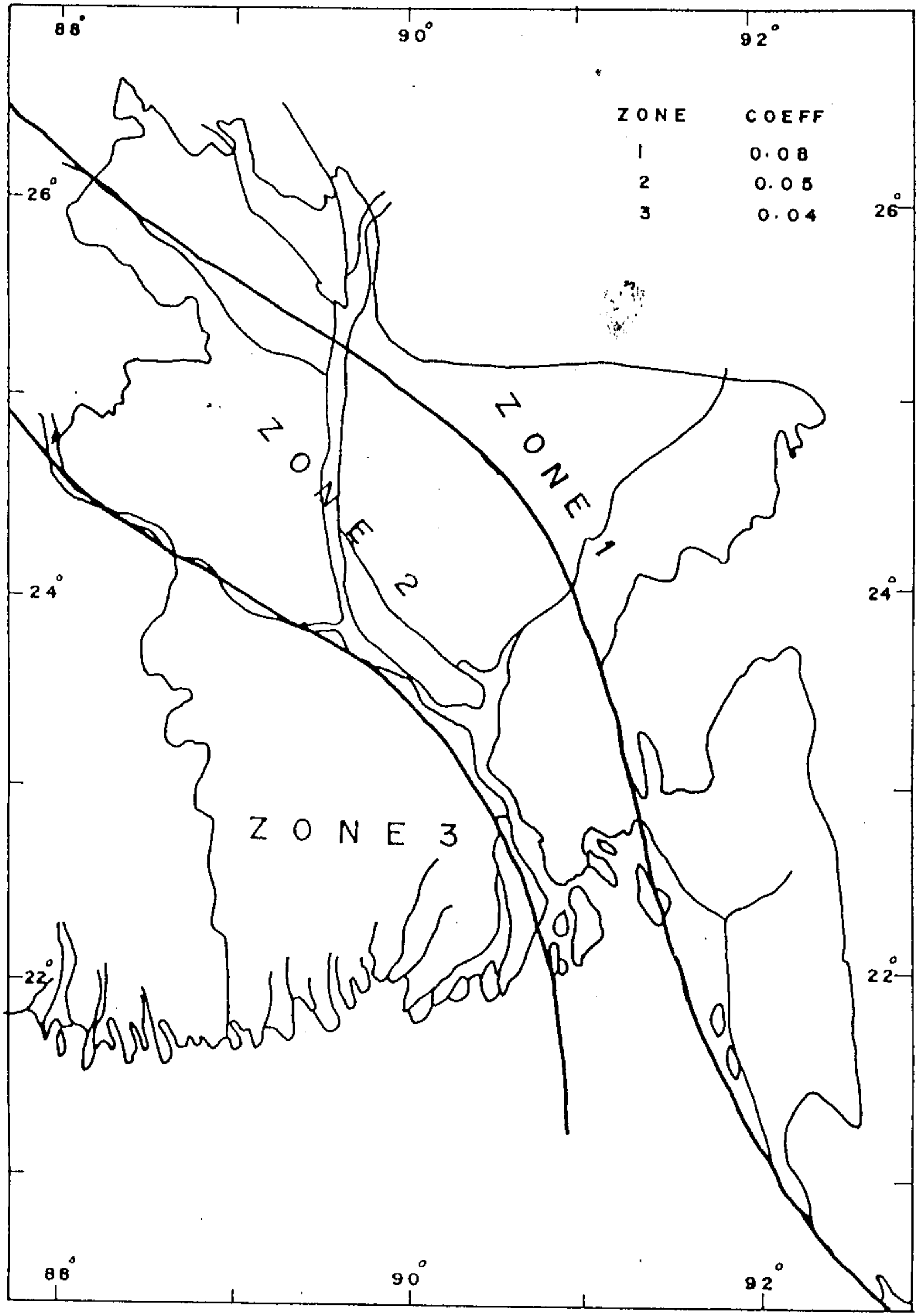


FIG 7.1. SEISMIC ZONING OF BANGLADESH

(ZONE 1: INT IX; 2: INT. VIII; 3: INT. VII) earthquakes in Bangladesh : The extent of damage will depend upon the spectral acceleration (Fig 7.2), duration of shaking and local soil conditions. In order to get acceleration data representative buildings (at different floors) need to be instrumented with accelerographs as early as possible. Also, a network of such instruments in the country will enable to collect the attenuation characteristics of acceleration, which could be more representative for earthquake resistant designs.

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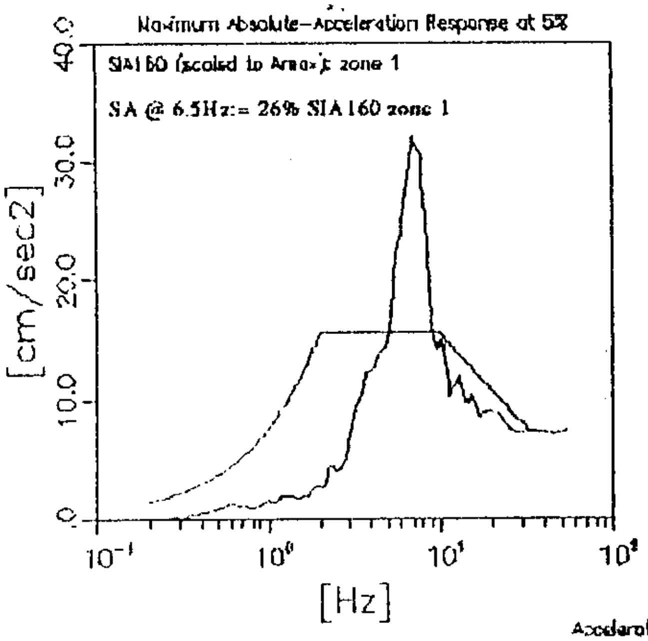
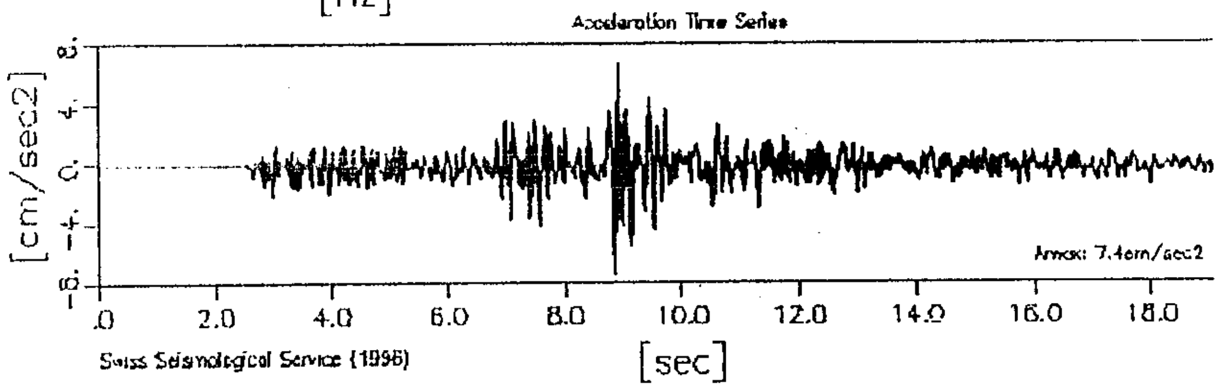


station co-ordinates:	46.194N 6.131E
station elevation:	377m above sealevel
local geology:	soil
local topography:	plain
instrument:	SIG SMACH SM2-CH
recorder serialnumber:	-158
sensor serialnumber:	-158
full scale amplitude:	0.2g
resolution of AD Converter:	12bits
sampling rate:	128samples/s
earthquake:	Meydiet quake (France)
source date:	15. July 1996
source time:	00:13:30.6UTC
epicenter co-ordinates:	45.95N 6.09E
source depth:	5km
magnitude:	5.2ML
epicentral distance:	28km



Swiss Seismological Service (1996)

International Decade for Natural Disaster Reduction

IDNDR

1990 – 2000

Building a Culture of Prevention

RADIUS

Risk Assessment Tools for Diagnosis Of Urban Areas against Seismic Disaster

Join RADIUS as an Associate City!

The IDNDR Secretariat, United Nations, is inviting your city to participate an ASSOCIATE city for RADIUS, a worldwide project for IDNDR on eismic disaster mitigation. The associate cities would have the following rofile:

- cities that have already carried out a seismic risk assessment or are in the process of doing so.

- cities that desire to participate in an interactive program that provides technical information on seismic risk assessment.

UNITED NATIONS

The IDNDR Secretariat has been accepting case study applications from cities for the RADIUS project. The aim of RADIUS is to develop practical tools for the development of seismic risk assessment, based on the analysis of the case studies. The Secretariat will offer financial and technical assistance to about ten case study cities in developing countries. The project has received so far fifty five applications from various cities worldwide. It has also attracted interest from many experts and institutes keen to take part in the project and also to benefit from the information collected. The Secretariat is aiming to select the ten cities by November 1997. The case studies will then start at the beginning of 1998. The cities that will not be selected will be kept informed of the progress made by RADIUS.

The IDNDR Secretariat is now welcoming applications for ASSOCIATE cities. The candidate cities must have carried out a seismic risk assessment or should be in the process of doing so. The associate cities will be integrated into a global network on earthquake disaster mitigation to achieve constructive information exchange. The participation of your city in RADIUS will provide you with state-of-the-art technologies thanks to the participation of international institutes at the forefront of seismic risk assessment research. The associate cities will be able to obtain useful information from other cities and compare their degree of preparedness. The associate cities will also contribute the knowledge they already possess to other cities, particularly in developing countries. Experts from associate cities in developing countries may participate in a training seminar as observers at their own expense. Finally, the associate cities will be invited to present their successful experience in an international workshop where the results of the case studies will be presented. The Secretariat is confident that your city will participate in this vital international cooperation at city level.

We are anticipating that the cities that are not being selected for the RADIUS case studies could carry out a similar study so that they could participate in the project as associate cities. In this connection, we may suggest that national governments, local governments and international organizations, particularly in developed countries, could contribute to a specific case study applicant in the list below, to enable it to conduct a similar study.

List of cities that have applied for RADIUS case studies.

Accra (Ghana),	Addis Ababa (Ethiopia),	Algiers (Algeria),
Ambato (Ecuador),	Amman (Jordan),	Antofagasta (Chile),
Ashgabat (Turkmenistan),	Bandung (Indonesia),	Baoji (China),
Belgrade (Yugoslavia),	Bishkek (Kyrghistan),	Bucharest (Romania),
Cali (Colombia),	Conakry (Guinea),	Cumana (Venezuela),
Damascus (Syria),	Daqing (China),	Dodoma (Tanzania),
Dushanbe (Tajikistan),	Giza (Egypt),	Guayaquil (Ecuador),
Hefei (China),	Istanbul (Turkey),	Izmir (Turkey),
Kathmandu (Nepal),	Kingston (Jamaica),	La Paz (Bolivia),
Lima (Peru),	Mandalay (Myanmar),	Manizales (Colombia),
Medellin (Colombia),	Pasto (Colombia),	Pereira (Colombia),
Petropavlovsk-Kamchatsky (Rus.),	Popayan (Colombia),	Quito (Ecuador),
San Juan (Argentina),	Santiago (Chile),	Shiraz (Iran),
Santo Domingo (Dominican Rep.),	Skopje (Macedonia),	Sofia (Bulgaria),
Tabriz (Iran),	Tangshan (China),	Tashkent (Uzbekistan),
Tbilisi (Georgia),	Tehran (Iran),	Tijuana (Mexico),
Tirana (Albania),	Toluca (Mexico),	Tuscan Region (Italy),
Urumqi (China),	Yangon (Myanmar),	Yerevan (Armenia),
Zigong (China)		TOTAL: 55

RADIUS PROJECT

ASSOCIATE APPLICATION FORM

City (Nation):

Mayor

Address:

Person in charge:

Title:

Address (plus tel. fax. e-mail):

Contact person:

Title:

Address (plus tel. fax. e-mail):

Names of municipalities (if the metropolitan area consists of more than one municipality):

1. Outline of the city

(1) Population (thousands):

(2) Recent annual growth rate of population (%):

(3) Area (square kilometres):

(4) General conditions of buildings and houses (approximate percentages of predominant construction materials and structural types):

2. Urban policy and disaster management

Answer the following questions.

1) Is there an office or department for disaster mitigation in the Municipality? If yes, what is it and what is its role?

The IDNDR Secretariat has been accepting case study applications from cities for the RADIUS project. The aim of RADIUS is to develop practical tools for the development of seismic risk assessment, based on the analysis of the case studies. The Secretariat will offer financial and technical assistance to about ten case study cities in developing countries. The project has received so far fifty five applications from various cities worldwide. It has also attracted interest from many experts and institutes keen to take part in the project and also to benefit from the information collected. The Secretariat is aiming to select the ten cities by November 1997. The case studies will then start at the beginning of 1998. The cities that will not be selected will be kept informed of the progress made by RADIUS.

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Belgrade (Yugoslavia),	Bishkek (Kyrghistan),	Bucharest (Romania),
Cali (Colombia),	Conakry (Guinea),	Cumana (Venezuela),
Damascus (Syria),	Daqing (China),	Dodoma (Tanzania),
Dushanbe (Tajikistan),	Giza (Egypt),	Guayaquil (Ecuador),
Hefei (China),	Istanbul (Turkey),	Izmir (Turkey),
Kathmandu (Nepal),	Kingston (Jamaica),	La Paz (Bolivia),
Lima (Peru),	Mandalay (Myanmar),	Manizales (Colombia),
Medellin (Colombia),	Pasto (Colombia),	Pereira (Colombia),
Petropavlovsk-Kamchatsky (Rus.),	Popayan (Colombia),	Quito (Ecuador),
San Juan (Argentina),	Santiago (Chile),	Shiraz (Iran),
Santo Domingo (Dominican Rep.),	Skopje (Macedonia),	Sofia (Bulgaria),
Tabriz (Iran),	Tangshan (China),	Tashkent (Uzbekistan),
Tbilisi (Georgia),	Tehran (Iran),	Tijuana (Mexico),
Tirana (Albania),	Toluca (Mexico),	Tuscan Region (Italy),
Urumqi (China),	Yangon (Myanmar),	Yerevan (Armenia),
Zigong (China),		TOTAL: 55

3. Availability of data

Describe briefly how the following information is, or supposed to be, available for the seismic risk assessment (on separate sheets and no more than 2 pages). Do not describe data itself.

(1) Historical data

(2) Seismic sources - subduction and faults

(3) Soil conditions and geological features

(4) Conditions of buildings and infrastructure

(5) Population distribution

4. Description of the project that has been or is being carried out in your city

(on separate sheets and no more than 2 pages)

(1) Describe an outline of the project

(2) What information from your city would be useful to other cities?

(3) What do you expect from other cities as well as from the RADIUS project?

The interested cities must send this application form to Mr. Kenji Okazaki, Senior Expert, the IDNDR Secretariat at the address mentioned below, by the end of 1997. He is pleased to answer any questions or comments.

IDNDR Secretariat, UN Department of Humanitarian Affairs,

Palais des Nations, CH-1211 Geneva 10

by e-mail (preferably), fax or mail: *e-mail: kenji.okazaki@dha.unicc.org*

fax:(41-22)733-8695

tel:(41-22)798-6894

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CHAPTER – 8

SEISMOLOGICAL DATA CENTRES

8. SEISMOLOGICAL DATA CENTRES

8.1 INTRODUCTION

Analog media (usually paper) were the sole means of recording seismic data till 1990's. When researchers wanted to exchange this original data, they had to deliver the seismogram recordings or copies. When they needed to describe important information about a recording, they would write the information – such as the station code, starting and ending date and time, time corrections, instrument orientation, dominant frequency pass band, and magnification on a seismogram. To extract information from such data, researchers had to measure a seismogram's parameters by hand.

With the introduction of digital recording, data quality has improved. However they also require new challenges to be met. Many researchers collect digital earthquake data to perform computationally intensive waveform analysis. These analyses require much more auxiliary information such as detailed instrument responses. This auxiliary information is needed in computer-readable form and is sometimes distributed on the same electronic media as the raw seismic data. Some institutions collect and distribute data in various formats, and whosoever receives that data may have to do substantial work to read it. Sometimes the required auxiliary information is incomplete or not even available in computer readable form.

Data exchange has been complicated by different data logger formats, by different computer systems, and by incompatible exchange media. One cannot use, or even visually examine digital data without extensive processing with additional computer hardware and software.

Digital data is opening new areas of research in Seismology. However, due to large volume of data generated, new avenues need to be explored for its archival, dissemination and processing techniques. As the experience is being gained particularly in the developing countries, it is realised that considerable time (several months to years) is needed to exploit the data to the maximum advantage, or even to retrieve the data in digital form on some occasions. Considerable experience in the specific software use is needed for this purpose.

8.2 Main Data Centres : Scope

(i) Computational facility to detect and locate earthquakes
(ii) Large capacity for data storage
(iii) Data distribution methodology
(iv) Data archival facility (long time frame)

8.2.1. SEISMOLOGICAL DATA CENTRE (BMD), Dhaka

The network of four stations will transmit data to the central recording unit at. BMD campus, Dhaka, through telephone modems. Alternatively earthquake data can be called from individual stations through telephone modems from BMD Campus, Dhaka. Here the seismic wave form (in analogue form on PC screen) can be analysed through PC by picking up P, S or other by moving a cursor manually and noting the onset time, amplitude etc or printing it. Data from all the four stations will be them be processed for epicentral determination, in the following modes.

(i) Through a PC where HYPO71 and or HYPO ellipse is loaded, making use of trial velocity model.

(ii) Automatic transfer of triggered data from the stations to the SERVERS, which can be called up for determination of epicentral parameters using SEISAN or other programme at the workstations.

(ii) Taking the floppy from PC containing arrival time data to work station for analysis using SEISAN or other programme. No manual processing should be required except essential minimum commands to the work station/PC The epicentral data should be available through a Printer on real /semi real time mode and shown plotted on a map of Bangladesh.

8.3 Continuous versus Triggered Recording.

The use of triggered recording has been required in the past due to the limitations in the capacity of the recording medium, transmission rates in the case of telemetry, and the ability of the data collection and archival centers to process, store, and distribute a large volume of data at an economically justifiable cost. But triggered recording has some limitations. Signals below the trigger level will not be detected or recorded at an individual station, but if the data from all the stations were combined, the use of array processing techniques might lead to a sufficient improvement in the S/N ratio to detect such signals as in LASA and NORSAR arrays. GSN stations generally provide continuous recording of data. A sampling rate of this order adequately covers the range of frequencies in which deterministic modeling is now feasible. The overall design should be configured to allow both continuous and triggered mode recording.

8.4 Data collection

It has been experienced that the recording of data at the field stations should be continuous. It should work in the triggered mode to transmit the data to the headquarter (HQ)

Alternately, since only a small portion of the available dynamic range is used (rest being earth noise), the data can be compressed through a specialized software. For this purpose, specialised training is needed.

SOFTWARE PROGRAMMES - UTILITY

1. SUDS FORMAT OF IASPEI can be converted into SEISAN

2. GOPHAR – automatic processing in IRIS system

3. PCDSRW – Analysis Progamme in Quanterra

4. SEISNET – Down loading from field station to HQ for GSN stations (automatic and manual)

5. Data in GSN format can be converted into SEISAN format

Some programmes run on PC's under Windows or Windows NT operating system. IRIS DMC realise upon the Oracle Data base management system FIG. 8.1. Software is available at web site.

http://www.iris.washington.edu/NEW/HTM/dms_software. htm. Many programmes need special training at NORWAY or USA.

ANALYSIS PROCEDURE

(i) Main softwares like IASPEI or SEISAN are stored in Work station

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ANALYSIS PROCEDURE

(i) Main softwares like IASPEI or SEISAN are stored in Work station

(ii) Data from field stations is seen on PC and P and S arrival times read. Then they are taken to work station for analysis – epicentre determination.

(iii) Alternately; download the data through SEISNET programme in the workstation itself and directly use SEISAN programme for epicentral determination.

(b) SERVERS

Data storage from all field stations upto 4 GB but should be extendable to 45 GB or more. One server is used as stand by.

© MEMORY SYSTEM

(i) RAM – which should be record/send/rewrite/transmit

(ii) Hard disc or ring Buffer types which can overwrite after it is full.

At central recording station, Trigger mode will transmit data even if disc is full. The recording at the field stations is in continuous mode.

8.5 International Data Exchange

In 1985, the International Association for Seismology and Physics of the Earth's Interior (IASPEI), Commission on Practice, formed a Working Group on Digital Data Exchange to propose a standard for international digital seismic data exchange. Later, the Federal of Digital Seismographic network (FDSN) formed and assumed the responsibility for developing an exchange format. At their first meeting in August, 1987, the Federation working group reviewed a number of existing formats – including standard for the Exchange of Earthquake Data) and a new format was proposed as a starting point for discussion by the US GEOLOGICAL SURVEY for the working group. At a follow-up meeting in December 1987, intensive discussion and numerous clarifications and modifications led to the new format's adoption as a Federation draft standard. The SEED format is oriented towards continuously recording data at the observatory.

The methodology for Data Centres involves the following components.

Data from several sources including the Bangladesh Seismological Stations will be collected at the Data Center through CD's, E-Mail & Internet facilities. Information about earthquakes, received from several centers are also used to populate DIRTS, SPRUT and XTRACT issue SQL to accessDIRTS whle DATA REQUEST UTILITIES

Data within the DIRTS (Data and Information Related to Seismology) database can be accessed by three different utilities. These three methods of accessing data include:

XTRACT, an interactive X Windowing system
SPROUT, a Structured Query Language (SQL) data access method., and
BREQ FAST a batch oriented method of making request for data
(SEE FLOW CHART: data access tools)

Some of the requirements for Data Centre are as follows for SEED SOFTWARE

(i) SUN Work staton

(ii) Laser Printer

(iii) Modem*

(iv) CD writer**

With multi hard disc copier

(v) SEED ** Software

- Modem is important to retrieve the seismological data from different institutions/organizations.

** CD writer is necessary to keep the digital/waveform data on Compact Disks

The computer system proposed for Bangladesh Meteorological Department is at present intended mostly to meet the National requirement. It can be upgraded in future when experience is gained.

NOREWEGIAN AND BRITISH NATIONAL SEISMIC SYSTEMS : SOME EXPERIENCE

The Norwegian and British National Seismic Networks have for some years used the same data acquisition (SEISLOG) and data base and processing system (SEISAN) which have also been used in about 30 other countries. SEISLOG is a standard type data acquisition system similar to the IRIS stations, with the additional capability of being able to use up to 64 channels, and SEISAN does most of the standard routine data analysis needed at an observatory. The current procedures are : to automatically copy all triggered events from the fields stations (phone or ethernet) to a data centre, inspect all data for false triggers, and do the phase picking manually. SEISAN has been streamlined to do the processing with a minimum of operator work

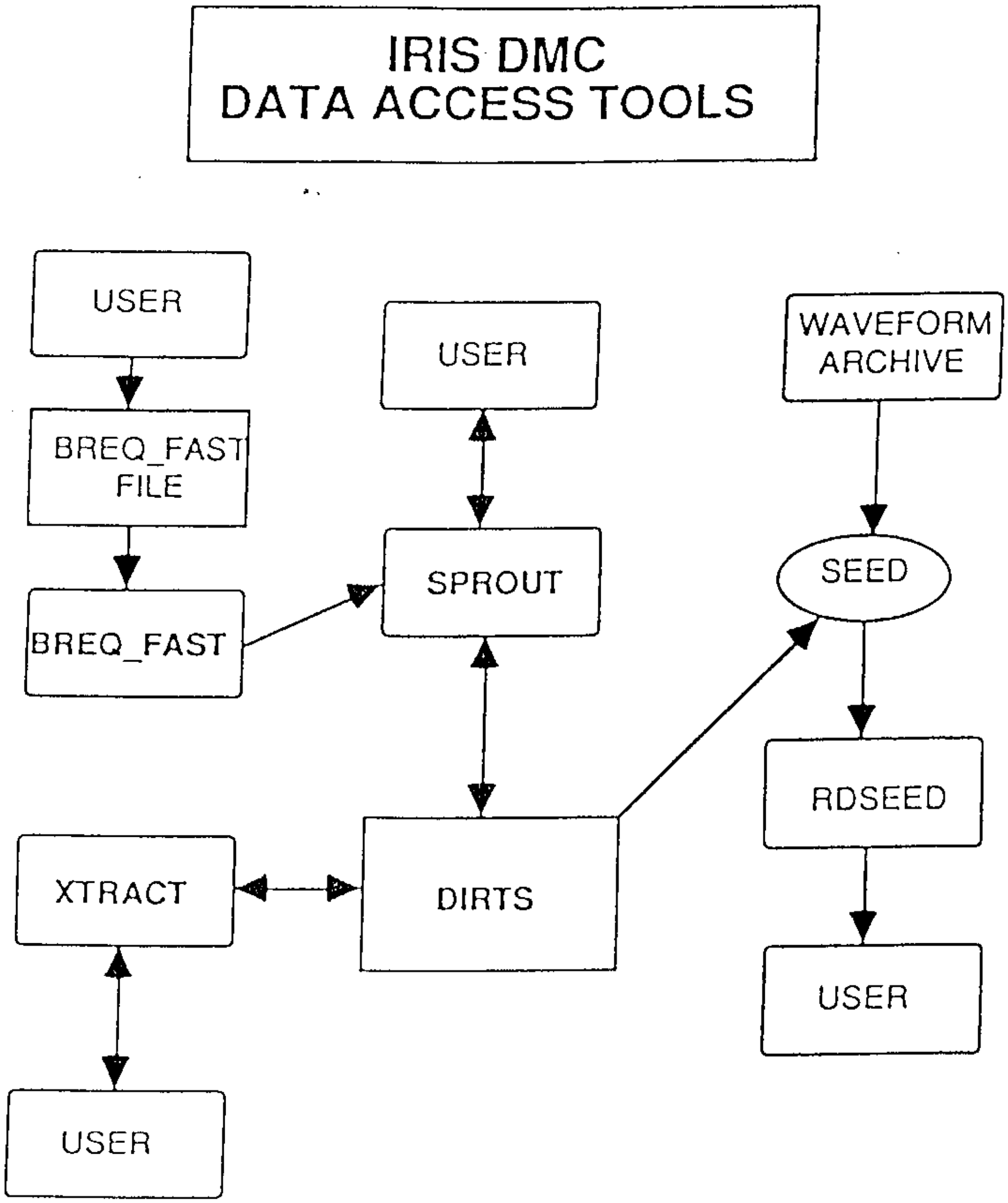

FIG 8.1 IRIS DMC DATA ACCESS

CHAPTER - 9

MANPOWER DEVELOPMENT (TRAINING)

MAN POWER DEVELOPMENT

ManPower Development is very important component for a rapidly growing subject like Seismology and Disaster Mitigation.

It has the following components:

(a) Operational

i. Routine maintenance of Seismological Instruments
ii. Analysis of data
iii. Epicentral Determination
iv. Preparation of Seismological Bulletin
v. Calibration – when required.

(b) Knowledge based lectures covering.

i. Fundamental of Seismology – including Theoretical
ii. Seismic data acquisition and analysis
iii. Determination of the location, magnitude and source mechanism of Seismic events
iv. Seismicity – including reservoir induced
v. After shock surveys
vi. Earthquake hazard assessment
vii. Strong ground motion and microzoning
viii. Earthquake modelling and predictability
ix. Disaster management

Trai... [illegible]

i. Training with manufacturers/suppliers in the countries from where the modern instruments will be purchased for installation, maintenance.

ii. On the job training in the modern instruments in Bangladesh during testing and installation, calibration procedures and their maintenance

iii. Extraction of seismological information from digital data, its analysis from single stations.

iv. Integration of seismological data from network and determination of earthquake parameters using specific SOFTWARES.

v. Exchange of data, its storage and dissemination including compression software based on latest methods

vi. Extraction of information like seismic moment and other source parameters through PC based system/work station/servers.

(d) Training abroad (Additional)

2. It is important that a few officers posted at seismological stations and at Headquarters are trained abroad at one or following institutions to familiarize with the fundamentals of seismology, instrument maintenance and data analysis in the software's purchased. A few such organizations are given below:

i. International Institute of seismology and earthquake engineering Tsukuba, Japan 1 TATEHARA, TSUKUBA-SHI, IBARKI KEN, 305, JAPAN. It offers short term as well as one year training course under different programmes like Colombo Plan etc. One-year course is preferred. It is understood that one officer from BMD has been trained in Japan for short-term course at this institute.

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v. After shock surveys
vi. Earthquake hazard assessment
vii. Strong ground motion and microzoning
viii. Earthquake modelling and predictability
ix. Disaster management

ii. GEO FORSCHUNGS ZENTRUM POTSDAM, Department of Solid Earth Physics and Disaster research

C/o: Dr. Peter Borman
TELEGRAFEN BERG E 428
D-14473 POTSDAM Germany
Fax # 49 331 288 1204
E-mail: course@gfz-potsdam.de

iii. The Abdus Salam, International Centre of Theoretical Physics (ICTP) : TREISTE. ITALY,
Generally short term courses. E-mail: smr1241@ictp.trieste.it

iv. India Meteorological Department, New Delhi – 11003 Short-term courses – under SAARC/Colombo Plan.

v. Participation's in International Symposia/seminar/workshops etc.

Officers may be encouraged to participate in International Seminars/workshop/symposia to know the latest developments in the fast changing scenario:

A few of those are given below as examples:

i. INTERNATIONAL ASSOCIATION OF SEISMOLOGY AND PHYSICS OF EARTH'S INTERIOR (IASPEI) – General Assembly / Regional Assembly

ii. INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS (IUGG) once in four years

iii. World conference on Earthquake Engineering

iv. International Geological congress

(e) update of Library and Training material

Libraries need to be updated with latest books and journals to facilitate research through utilization of data generated by the new network of seismological stations. Manuals for analysis of seismogram may be purchased. In this connection, IASPEI Seismological publication transfer programme of the Committee for Developing countries (IASPEI) is given below:

'As part of IASPEI's outreach effort, the publication transfer program of the Committee for Developing Countries makes available basic texts and publications on seismology and related earth sciences to institutions in need. The IASPEI Secretary General serves as a clearinghouse for requests and offers. Institutions who have publication needs, as well as those with surplus publications, including back runs of journals, should send a list to the Secretary General Requests for payment or reimbursement of reasonable shipping costs can be made to IASPEI.

The current holdings of the IASPEI office are described in the following links:

- AAPG Bulletin
- Bulletin of the Seismological Society of America
- Eos
- Geological Society of America Bulletin
- Geology
- Geophysical Journal International
- Geophysical Journal of the Royal Astronomical Society

- Geophysical Research Letters
- Journal of Geodynamics
- Journal of Geophysical Research
- Review of Geophysics
- Review of Geophysics and Space Physics
- Tectonics
- Tectonophysics

For further information please visit the site; http://www.seismo.com/iaspei/pubtrans. html

IRIS has prepared a Seismic monitor for display of global seismicity and know how about earthquakes. Its details may be seen through the web site http:// www.iris.edu (Full particulars at the end of Chapter enclosed)

Some details of IASPEI software library are given below:

IASPEI Software library volume

(i) IASPEI Software library volume I

This volume (published in 1989) contains programs for real-time operation of a seismic network, and off-line processing and analysis of seismic events. It includes a description of the hardware implementation for a PC-based seismic system, and six computer programs: (1) two realtime programs perform seismic data acquisitino and processing, and (2) four offline programs display waveform data, and perform interactive picking of seismic phases, filtering, spectral and coda Q analysis, and in operation worldwide. A 'beta' version of updates is now available (free of charge) to registered users upon request. Revised edition may be purchased.

(ii) IASPEI Software Library volume 2

The second volume (published in 1990) is a companion to the first volume. It contains twelve computer programs for plotting seismic data on the monitor screen and generating a hard copy. It includes a 3-dimensional data viewing program for rotating, enlarging, or shrinking objects and data points. A new update is now being prepared to include general programs for plotting seismic traces and earthquake epicenter maps on screen and for laser printers. A "beta" version of updates is now available (free of charge) to registered users upon request. Revised edition may be purchased.

(iii) IASPEI Software Library Volume 3

Volume 3 contains two major programs: (1) SeisGram by Anthony Lomax for interactive analysis of digital seisgram, and SYN4 by Robert McCaffrey, Geoffrey Abers, and Peter Zwick for inversion of teleseismic body waves. This volume (published in 1991) is a toolbox for seismological research, especially on broad-band digital seismic data. A "beta" version of updates is now available (free of charge) to registered users upon request. Revised edition may be purchased.

(iv) IASPEI Software Library Volume 4

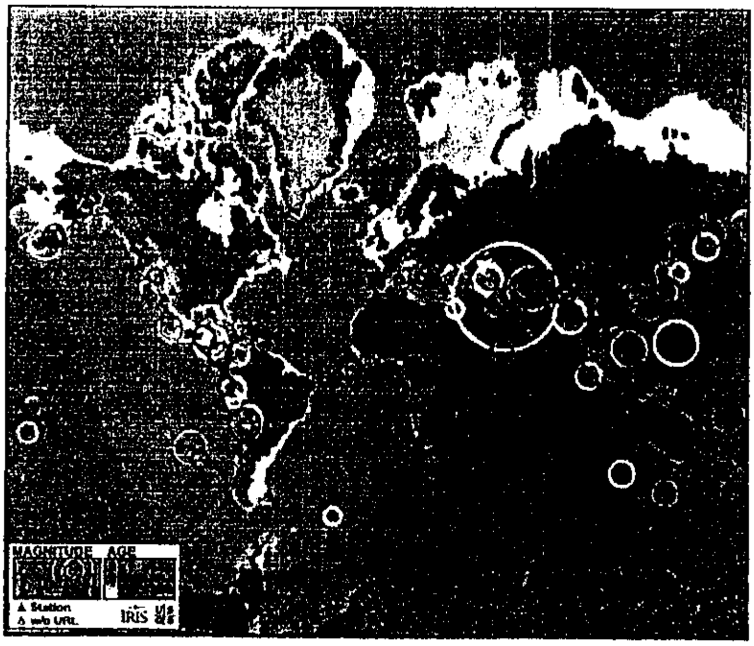
Volume 4 is a toolbox for manging bibliographic information and includes programs to automate the reference preparation in manuscripts and to manage a user's own references. It also includes a database of all articles published in the Bulletin of SSA (1911-1993), and some most frequently cited articles by seismologists. This volume is scheduled for release in February 1994.

(v) IASPEI Software Library Volume 5

Volume 5 is a programmable interactive toolbox for seismological analysis (PITSA) by Frank Scherbaum and James Johnson, and includes a short course on "First Principles of Digital Signal Processing for Seismologists." The manual and PC version code was published in 1992. A version of PITSA for the SUN workstations is available from the authors and from IRIS in the near future.

Watch Earthquakes as they Occur

The Seismic Monitor



[Located at: http://www.iris.edu (Click on the image to initiate display)]

The Seismic Monitor is an interactive display of global seismicity that allows users to monitor earthquakes in near real-time, view records of ground motion, learn about earthquakes, and visit seismic stations around the world.

Monitor Current Earthquakes

Red circles mark earthquakes that have occurred within the last 24 hours. The circles fade from red through orange to yellow in two weeks. After two weeks, the circles disappear and the epicenter remains as a black diamond. After 30 days, the black diamond turns into a pink dot. Pink dots remain for five years. The size of the circle is proportional to the magnitude of the earthquake.

If you click on an earthquake, information about the earthquake such as geographic location, latitude, longitude, and magnitude, will appear. A button at the top of the window connects you to the IRIS SPYDER system, allowing you to view ground motion from the earthquake recorded at seismic observatories around the world, and to learn more about the earthquake.

Visit Seismic Stations

Click on an individual seismic observatory (shown by purple colored triangles) and you can visit the station. Click on the photograph to see the station. Below the photograph is such information as latitude and longitude, types of seismometers, and background noise levels.

View Global Topography and Seismicity

The global display shows the relationship between topography and seismicity. The distribution of seismicity during the past 5 years illustrates how earthquakes define the boundaries of Earth's tectonic plates. Earth's shadow illustrates day/night and seasonal changes.

Seismic Alarm

You will be immediately alerted to important seismic events through the seismic alarm feature. If a significant earthquake occurs within the United States, or if any seismic event is recorded from a known nuclear weapons testing site, the seismic alarm function is triggered.

CHAPTER – 10

DATA EXCHANGE AND COOPERATION

DATA EXCHANGE AND COOPERATION

Earthquakes do not recognize International Boundaries. A moderate earthquake originating in one country may cause some damage in the neighbouring country while a great earthquake may cause extensive damage even a few hundred kilometers away from the epicentre. Great uncertainty arises in the location of earthquakes if there is a gap in the seismological network, which often happens if the earthquake takes place near the border of two countries. Thus, exchange of earthquake data between the neighbouring countries is of utmost importance similar to Meteorology. The seismological network of 4 stations in Bangladesh is just sufficient to monitor earthquakes in the country (The network needs to be expanded to provide higher accuracy in the epicentral parameters of local earthquakes as discussed in Chapter (6). Earthquakes occurring near India Bangladesh / Myanmar border require exchange of data to cover the gap from the neighbouring country. Thus an operational system needs to be designed for quick exchange of data and its dissemination.

Earthquakes are being monitored through seismological observatories in the neighbouring countries of Bangladesh

i. India
ii. Nepal
iii. Pakistan
iv. China

The seismological data for earthquakes in India and neighbouring region is collected at India Meteorological Department at New Delhi, which is exchanged, with the International Data Center U.K and other organisations.

The data is published in the following forms: -

i. Monthly Seismological Bulletin by India Meteorological Department, New Delhi

ii. U.S. Geological Survey – Preliminary Determination of Epicenters (PDE). This is based on world wide data.

iii. Monthly seismological bulletin by International Seismological Centers (ISC). U.K.

This bulletin (ISC) is based on worldwide data using largest number of seismological stations in the World and is published with a time lag of about 18 months. This is the most comprehensive and authentic publication for seismicity and other studies. The details are enclosed in a publication brought out by ISC. The data is also available on CD for direct use by computers disc (shown in ISC pamphlets enclosed).

Modern Data Centre should include:

i) Telecommunications to handle large stream of data
ii) Computational facility to detect and locate events
iii) Large data storage capacity
iv) Data distribution
v) Data archival

The World Meteorological Organisation (WMD) channels for meteorological data exchange is shown in fig. 10.1. It can also be used for limited use in Seismological data exchange.

Lot of IRIS/GSN data can be obtained through Web sites/Internet.

CD-ROMs available from ISC

International Seismological Centre

Pipers Lane, Thatcham, Berkshire, U.K. RG19 4NS
Phone: +44 1635 861022 Fax: +44 1635 872351 email: seismo@isc.ac.uk

ISC Catalogue 1964-1994

724,388 events without station data

International Seismological Centre

Pipers Lane, Thatcham, Berkshire, U.K. RG19 4NS
Phone: +44 1635 861022 Fax: +44 1635 872351 email: seismo@isc.ac.uk

ISC Bulletin 1994

Vol. 5

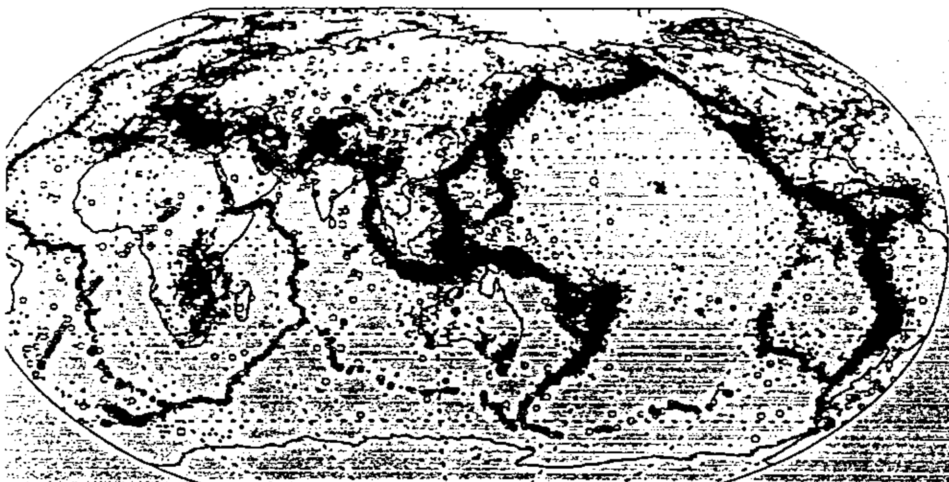
59,257 events and associated station data

Vol. 1: 1964-1977 Vol. 2: 1978-1985 Vol. 3: 1986-1991 Vol. 4: 1992-1993 nternational Seismological Centre

Pipers Lane, Thatcham, Berkshire, U.K. RG19 4NS
hone: +44 1635 861022 Fax: +44 1635 872351 e-mail: seismo@isc.ac.uk

NEW ISC Bulletin 1964-1977

ISC CD-ROM No. 1



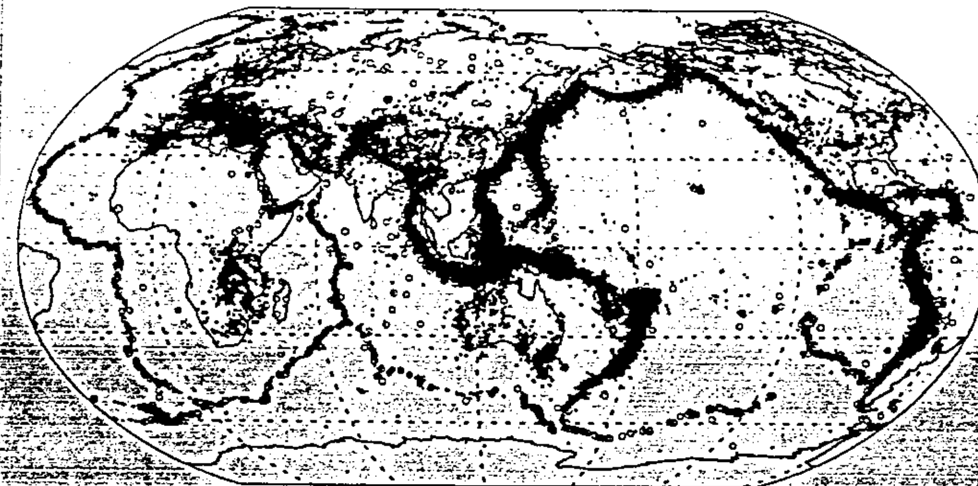
77,191 events and associated station data

International Seismological Centre

Pipers Lane, Thatcham, Berkshire, U.K. RG19 4NS
Phone: +44 1635 861022 Fax: +44 1635 872351 e-mail: seismo@isc.ac.uk

NEW ISC Bulletin 1978-1985

ISC CD-ROM No. 2



172,127 events and associated station data

NEW *CD-ROM No. 5 - Bulletin 1994, Catalogue 1964-1994, Bibliography 1959-1995, SEISAN software*

CHAPTER – 11

SITE SURVEY IN BANGLADESH

SITE SURVEY FOR SEISMOLOGICAL OBSERVATIONS IN BANGLADESH

Introduction:

As per the decision of Bangladesh Meteorological Department, new seismological observatories are to be located at:

1. Dhaka
2. Sylhet
3. Rangpur

Also the existing seismological observatory at Chittagong is to be upgraded with the modern instruments.

Seismographs record the seismic waves produced by earthquakes and other microseismic vibrations from man made or natural sources. Attempts were made to examine sites at the three places namely Dhaka, Sylhet and Rangpur for recording earthquakes

A look at the geological and tectonic features of Bangladesh shows

(i) Vast areas covered with alluvium.

(ii) Chittagong Tripura folded belt in eastern border

(iii) DawKI fault extension towards the northern border

Rivers, Canals, Ponds and agricultural fields are commonly found in Bangladesh.

Standard criteria for a Seismological Station are outlined in a book (1979) published by the International Association of Seismology and the physics of the Earth'sInterior (IASPEI) entitled "Manual on Seismological Observatory Practice". The criteria suggested cannot be adopted in practice except perhaps in isolated places. In practice, the sites have to be selected by keeping in view the following important aspects:

(i) Accessibility
(ii) Availability of power
(iii) Local support
(iv) Watch and ward
(v) Land acquisition considerations
(vi) Time frame for execution in project mode

From the point of view of geology and tectonics, it may be noted that hardly any site can be located for a high gain (large dynamic/gain) seismological station, which can be operated in Bangladesh.

Also microseisms in the Bay of Bengal due to tides, swells predominantly increase during southwest monsoon and cyclonic storms. However, the broad objectives of locating earthquakes (magnitudes 4.5) in Bangladesh can be met with an independent network of minimum 4 stations, although focal depths and azimuthal gaps and errors would require several stations.

RESULTS OF SITE SURVEY

1. RANGPUR

The site survey was done along with the following officers on 10 and 11 March 2000

1. Mr. Md. Ashraf Ali Howlader, Deputy Director , BMD

2. Mr. Shamim Hasan, Meteorologist, BMD.

3. Mr. Md. Abdus Shahid Mithu, Executive, representing Global Suppliers Limited

General features

The city of Rangpur is located on Soft ground (alluvium) with cultivated lands in different parts within as well as out skirts. The Meteorological Department has built a Radar Statons with V-sat facility at Master Para Alam Nagar

Sites

(i) Site No. 1

Main features

This site in the BMD Campus was examined. It was noted that

(a) Main road is about 200 to 300 m away. Approach road is not busy.

(b) These are only a few coconut trees in the vicinity

(c) Railway line is about 1 km away

(d) Cultivated fields are in the neighbourhood.

(e) At present vacant plot of land exists near the back compound wall

(f) A small pond is found in northeast corner.

(g) There is a filled up land of about 2 to 3 m in the vacant place adjacent to office building inside the office compound.

(h) These are H.T. Cables passing over the campus

(i) Generator in the Campus may produce noise during power failure

Site No. 2

The site is located in Taj Zamindar Bari adjacent to the Archaeological Department Taz hut. This place is almost opposite to the Nuclear Agriculture Centre and rice research institute. It was noted that

(a) Main road is about 500 m away

(b) Railway line about 1 km away

(c) More trees as compared to site No. 1

(d) Small pond in the vicinity

Site No. 3

Beyond Medical College Campus on the out skirt of City. The vacant lands were found to be agriculture fields, which were under cultivation but very close to the main road.

Site No. 4

Near memorial of Begum Rokeya, the first educated women of Bangladesh in Pyrabond, similar conditions could be noticed as the other three sites.

Site No. 5

Kar Michael University college, no preference could be noted due to similar candidations as at other sites.

2. SYLHET

The place was visited on 25.3.2000 along with the following officers:

1. Mr. Md. Ashraf Ali Howlader, Deputy Director (BMD)
2. Mr. Sayeed Ahmed Chowdhury, Meteorologist, BMD
3. Mr. Abdus Shahid Mithu, Executive representing GSL

Sylhet has several hilly outcrops. Pieces of weathered rocks can be seen on several hills The sites were surveyed at the following places:

(j) Site No. 1

Hills close to airport

The influence of vibrations produced by the aeroplane and traffic could be picked up. Electricity, water and approach road upto the top of hill will need to be arranged.

(ii) Site No. 2

At this site, Meteorological Office Building is located on the top of a hill at a height of 115 ft. About 7 acres of land is in the possession of Met. Office

Main features

(a) Hill has alluvium deposit interspersed with weathered rock :

(b) Railway line is about 5 to 7 km.

(c) Television Tower is close by on another hill

(d) Main road about 300 meters. Nearest approach road is at the foothill.

(e) Telephone, electricity available;

(f) There is a small pond at the ground level; Tube well for water is close by from where it is taken manually to the met. Office

(g) Some residential houses are constructed near the approach road and in other sides

(h) There are wireless (w/t) poles around the met. Office in triangular configuration

(i) A few trees; more greenery on the pond side.

Site No. 3

Laka Tura Estate Tea Garden

Close to met office. The site conditions almost similar to site No. 2, but the facilities of electricity, approach road and telephone will need to be considered.

Site No. 4

Near hills in M.C. College Area close to Bench Marker. Opposite Principal's Bangallow close to Government Poultry form.

MAIN FEATURES:

(a) Main road is about 30 m, which extends to gas field.

(b) Electricity/water/telephone need to be considered

(c) Approach road over the hill will need to be provided

(d) Site covered with clay (sometimes reddish) interspersed with weathered rock in pieces.

(e) Vacant area more extensive with more trees as compared to site no. 2

4. DHAKA

Dhaka has extensive coverage of alluvium and is a fast growing city with multistoried buildings and other tall structures. Ponds, canals etc. are abundant. The sites in Dhaka were extensively examined on 9th March 2000, 18.3.99 (holiday) and other holidays. The city is about 75 to 100 km from the sea and affected by oceanic microseisms

1. Site No. 1

MAIN FEATURES

The site at the existing Bangladesh Meteorological Department was examined;

(a) The open space between the workshop building and the generator building.

(b) The area is covered with alluvial soil.

(c) 4 storied residential quarters outside boundary wall by the side of workshop

(d) Main road about 100 m from the proposed site

(e) Multi storied buildings in the neighborhood

(f) Extensive open space (garden) on the other side of the main road, opposite BMD Campus

(g) Electricity/water available

(h) Best communication facilities like GTS, telephone

(i) Workshop lathe machines may produce noise when used

(j) Generator may produce noise during power failure

Site No. 2

Dhaka University Campus:

(a) Site covered with alluvium

b) Buildings and roads in the campus with hardly any extensive vacant space

c) Electricity, water, telephones available.

Site No. 3

BMD officers quarters appear to be slightly better although main road is almost at the same distance as the BMD office campus.

Site No. 4

SAVAR

This place is famous for Shiriti Saudh Monument – a war memorial. There is an important institution close by namely Jahangir Nagar University. The site was visited on 18 March 2000 along with Mr. Shaheed of GSL. Some interest of Physics department is noted in earthquake hazard studies (vide IASPEI publication entitled, "Earthquake &

Hazard Assessment"). Another Institution is connected with Atomic Energy. Main features at site are:

(a) Site covered with alluvium

(b) Agricultural fields

(c) Main road on one side of university

(d) Water and electricity available

(e) Less building Activity as compared to Dhaka

Other sites in Dhaka City were seen along Asulia Road (towards Jamuna Bridge) different outskirts were visited on holidays but no special advantage could be seen due to the similar soil water conditions, microseismic sources and other activities.

5. Chittagong

This site was visited on 14 March 2000 along with

1. Mr. S. Karmaker, Deputy Director, BMD
2. Mr. Abdus Shaheed Mithu, representative of GSL

The main objectives were (i) to examine the pillar space and other Infrastructure support like computer room etc for modern seismological instruments

(iii) To check the earthquake records

(iv) To find out if any portable seismograph is available for noise survey

The Geophysical observatory is located at Aam bagar hills and was started in 1954. At the observatory, the following officers were present:

1. Mrs. Keyum Nahar Begum, Meteorologist
2. Mr. Md. Enamul Haque, Meteorologist
3. Mr. Yousuf Chowdhury, Asstt. Meteorologist

The Seismological instruments are located on a pillar inside a room. At present, only one north south component Sprengnether Dyneer visible Seismograph is in operation (30 mm/unit sweep) without time mark . The recorder pen is set at an optimum gain of 2 mv/mm. Microseisms increase if the gain is set at 1 mv/mm. In the past, when analogue instruments were functional with time marks, the data of this observatory was used in the epicentral determination of earthquakes by the International Seismological Centre U K The data was also used for focal mechanism solutions for regional earthquakes. The S-P interval is used to compute the epicentral distance. The records of the observatory were examined which showed many earthquakes with their phases clearly recorded The observatory is getting information about regional earthquakes from the Regional Meteorological Centre, Alibag Calcuta. The seismological Bulletin prepared by the India Meteorological Department is however, not received by the observatory.

At this observatory, the main source of microseisms was found to be due to occasional movement of trains as the Railway line is only about 300 yards. The road is less than 1km but its effect at the gain set for analogue seismogrpahs is less.

Slight seepage of water is noticed in the moat around pillar during the rainy season. which needs to be filled up with sand.

Some improvements in the building for locating computers etc will need to be made for keeping modern seismographs on the existing pillar. New Electrical wiring has to be provided with excellent earthing (copper wire).

11.2 Design of Buildings

General considerations

1. For observatory room in the basement, protection from seepage of water is needed.

2. For GSN/ wide band digital instruments, double wall with 2 or 3 ft. for air gap is required all around the room.

3. The pillar needs to be constructed upto bedrock level. If bedrock is not available, it should be constructed from hard strata (compact clay/ sand) upwards.

4. About 6 to 9" gap is to be left all round the pillar (whose height is kept 2 ½ ft above floor level) and the space is to be filled up by sand to isolate it from floor.

5. The building needs to be provided with excellent earthing with copper wire as the instruments are very sensitive

6. The computer room needs to be provided with UPS and generator (if required) false ceiling and proper layout for cables/wires, protection from rats but easy approach to cables for repair if required.

7. Digitizer AD converters, modems, PC etc are to be kept in AC room and should be kept nearest to the instrument room to reduce the length of the connecting cables.

8. De humidifier need to be provided in observatory room

9. The power should be good quality with least fluctuations in the voltage

10. Pillar is to be constructed continuously from base level upto 2 ½ ft above ground level and not in piece meal. The ratio of cement sand, said and stone is generally 1:2:4 but may change depending upon the depth (psi). Suitable protective covers (shuttering) are to be provided to avoid seepage of water during pillar construction which may weaken the concrete. Shutters may be used made of wood or Iron but should be removed with the setting of concrete. It should be watered for a week.

11. No iron. is to be used anywhere in the pillar construction.

BANGLADESH METEOROLOGICAL DEPARTMENT DECISION ABOUT FINAL SITES AND BUILDINGS

According to the Technical Plan of Incorporated Research Institutes of Seismology (IRIS).

"In some cases, the low noise criteria must be relaxed in order to assure adequate global coverage. At a particular site, the noise environment can usually be improved significantly if the seismometers are emplaced in a bore hole, some hundred meters below the surface. This technique has been demonstrated to reduce greatly the seismic noise generated mostly by the wind at the surface. It also reduces the effects of surface tilts that plague long period horizontal seismometers.

In addition, the other consideration for site selections have been given earlier in this report. Low gain stations with large background noise back have been functioning at

Calcutta, Madras and some other stations with modern wide band digital seismographs. Keeping the above the view, the following is suggested:

A. Observatory sites:

(j) At Rangpur, where the site conditions are equally poor everywhere, the Seismological observatory may be located in the BMD Radar Stations Campus. However, the instrument may be located in a bore hole upto 100 m or more as per expertise/equipment available in Bangladesh for digging deep inside earth.

(ii) Sylhet observatory may be located near the old servants quarter in the BMD campus. The depth of the seismograph pillar may be decided after the bore hole observation are available.

(iii) Dhaka site : The site conditions appear to be slightly better in Savar as campus to Dhaka from where data could be transmitted to BMD Headquarters through VSAT or telephone modem. If it is decided to locate the seismograph in Dhaka, the provision of a bore hole type seismometer may marginally improve the signal to noise ratio at the site near the campus of residential quarters of officers.

B. Noise Survey

Noise survey with a seismograph requires a portable instrument, which is supplied by the concerned department. Efforts were however, made to locate if some instrument could be brought from the Chittagong Geophysical observatory but it was not available there.

Global Suppliers Limited made efforts to get it from USA or India but we are not sure about its availability during the first phase of consultancy. If it does not materialize, survey may have to await for some time till the opening of the tender for its evaluation. For the purpose of tender work, the consultancy period of 15 days from the 2nd phase may be reduced correspondingly out of 4 months.

C. Building Design

(i) Rangpur

Computer room for PC s workstation, digitizers, modems for Data transmission, to Dhaka by telephone, data storage hard disks, (floppies) UPS are required. In addition, rooms for officers, staff need to be provided. A drawing for computer room along with electrical wiring is enclosed.

(ii) Sylhet

An observatory following the GSN type of observatory plan, and electrical wiring with an adjacent computer room for workstation, PC, Digitizer modem to data transmission by telephone to Dhaka, UPS need to be provided.

(iii) Chittagong

Renovation of the main hall into a computer room, new electrical wiring with excellent earthing; construction of another wall in the instrument room about 2 to 3 for away from the side exposed outside. The wall may be erected from outside so that the room size is not reduced. The electrical wiring in the instrument room may be done similar to that recommended for GSN station. UPS & Generator may be provided.

(iii) Dhaka

It is the central recording and analysis Computer centre for earthquake studies in Bangladesh as discussed with Director, BMD. Therefore, the design of building may include.

1. Computers room where earthquake data from Rangpur, Chittagong and Sylhet will be received for epicentral determination on operational basis by telephone modems. The data from the observatory at Dhaka will be included. The data may also be exchanged with other countries through this centre. Thus, the computer centre will have servers, workstations, PC's (including stand by system), UPS. The existing Generator for multi storied building may be utilized for this building also if possible so that ground vibrations may not increase. For the purpose of testing, calibration and training, one basement room is needed where pillar of 3'X6' may be constructed, extending 2 ½ ft above the floor surface. The depth of the pillar would depend upon the results of boring. This pillar will also be utilized for keeping 3 component strong motion instruments and one analogue seismograph with timing system to provide visual information (without any waiting time for processing through digital data) immediately after the occurrence of an earthquake. Stair-case will need to be provided upto the basement room

ALTHOUGH BORE HOLE SEISMOMETER IS DESIRABLE FOR DHAKA OBSERVATORY, THE QUESTION OF ITS LOCATION MAY BE DECIDED BY BMD OR ALTERNATELY TELEMETRY (TELEPHONE OR V-SAT).

<u>It may be impressed upon PWD that all electronic facility are grounded at one and only one point to avoid high potential difference between different sites in the structure</u> at the observatories at all 4 places.

ANGLADESH METEOROLOGICAL DEPARTMENT DECISION ABOUT FINAL SITES ND BUILDINGS

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ALTHOUGH BORE HOLE SEISMOMETER IS DESIRABLE FOR DHAKA OBSERVATORY, THE QUESTION OF ITS LOCATION MAY BE DECIDED BY BMD OR ALTERNATELY TELEMETRY (TELEPHONE OR VSAT).

It may be impressed upon PWD that all electronic facility are grounded at one and only one point to avoid high potential difference between different sites in the structure at the observatories at all 4 places.

CHAPTER – 12

TENDER SPECIFICATIONS FOR SEISMOLOGICAL INSTRUMENTS

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH
BANGLADESH METEOROLOGICAL DEPARTMENT

Technical Specifications for establishment of a Seismological Network

General Information

Bangladesh Meteorological Department (BMD), Government of Bangladesh is upgrading the seismological observatory at Chittagong and establishing new observatories at Sylhet, Rangpur and Dhaka. These are expected to have similar standard as Global Network of Seismological Stations (GSN) in U.S.A. and a few other countries of the World with upgraded systems.

At Chittagong and Sylhet, seismic vault will be available for placing the broad band analogue and strong motion sensors. At Rangpur and Dhaka observatories, space for installation of bore hole will be provided. Also pillars will be constructed for strong motion and analogue systems at these two places. Computer rooms will be provided for keeping Data loggers, modems and other equipment required for the integration of the above systems. Power of 220volt, 50 Hz AC is available for the instruments at all the observatories. At each observatory, two members of the BMD will be deputed for training locally and extending local support as required for the successful bidder during installation/calibration/testing etc. The set up of wide band digital station with sensors and data loggers/processors is shown in FIG. 1.

The Seismological Data Center will be located in the Headquarters of the Bangladesh Meteorological Deportment (BMD), Dhaka where the data from all the four stations (with possible expansion in future) will be acquired. Analysis of data will be carried out at the Headquarters and earthquake parameters will be displayed on a map. Provision of analysis at 3 field stations also needs to be provided. Data from the stations should be available at Dhaka through telephone lines. Facilities to receive the data from neighboring countries using GTS or Electronic Mail should be available. Recorded data should be archived in standard format on mass recording devices such as server. Block diagram of the proposed Seismological Data Center is given in FIG. 2. One terminal is to be provided through Optical fibre link from the Computer Center to the WMO, GTS channels in the main building of BMD Campus. In addition facilities to approach data center through E-Mail also needs to be provided.

It may be mentioned that two sites at Rangpur and Dhaka are located on alluvium and two other stations at Chittagong and Sylhet on hilly folds. All the stations may need to be set for different site parameters particularly during monsoon season due to oceanic microseisms.

LIST OF SOME MANUFACTURERS/SUPPLIERS OF SEISMOLOGICAL INSTRUMENTS

1. Geo SIG AG.
KANALSTRASSE 11
8152 GLÄTTERUGG
SWITZERLAND
PHONE: 411 810 2150
FAX: 411 810 3250
E-mail : info@geosig.ch

2. GEOTECH INSTRUMENTS, LLC.
10755 SANDEN DRIVE, DALLAS
TEXAS 75238-1336
PHONE: 214 221 000
FAX: 214 343 4400

3. GURALP SYSTEMS LIMITED
MIDAS HOUSE, CALLEUA PARK
ALDER MASTON, READING, BERKS
RG7 8EA, U.K.
PHONE: 44 118 9819 056
FAX: 44 118 9819 943
E-mail: sales@guralp.demon.co.uk

4. ISMESSPA
VIALE GIULIO CESARE 29
I-24124 BERGAMO
PHONE: 3935307 111
FAX: 39 35/307 710
TELEX: 301249 ISMESI
E-mail: info@ismes.it

5. KINEMETRICS INC.
220 VISTA AVE.
PASADENA, CA 91107
U.S.A.
PHONE: 626 795 2220
FAX: 626 795 0868

6. NANOMETRICS
250 HERZBERG ROAD
251K2K2A1, CANADA
PHONE: 613 592 6776
FAX: 613 592 5929
E-mail: info@nanometrics.ca

7. QUANTERRA INC.
325 AYER ROAD
HARVAD, MA 01451
U.S.A.
PHONE: 978/772 4774
FAX: 978/772 4645

8. REFRACTION TECHNOLOGY INC.
2626 LOMBARDY LANE, SUIT 105
DALLAS, TEXAS 75220
U.S.A.
PHONE: 212 353 0609
FAX: 212 353 9659
E-mail: info@reftek.com

9. ARAM 24
900, 425-1ST STREET S.W
CALGARY, ALBERTA
CANADA T2P 3L8
PHONE: 403 298 5600
FAX: 403 298 5655

RECOMMENDATIONS

RECOMMENDATIONS

1. The modern updated network of Seismological Stations requires management and interaction at a very high level. It is recommended that a post of Deputy Director may be created exclusively for seismological work.

2. The network of four seismological stations in Bangladesh is just sufficient to determine the epicentral parameters of earthquakes. On many occasions due to errors in observations, the epicentre will be very approximate with hardly any control on focal depth. In order to improve the accuracy of earthquake parameters, it is suggested that at least 4 more stations (one on priority basis) should be established in Bangladesh.

3. Dhaka is a fast growing city covered with alluvium. In order to understand the seismotectonic features of Dhaka and neighborhood, a network of 10 seismological stations around Dhaka within a radius of 100 km needs to be provided with V-SAT data communication facility or UHF/VHF. The data should be received at BMD Headquarters namely Seismological Data Centre and processed on real line.

4. Bangladesh may experience effects of damaging earthquakes. Therefore, due consideration needs to be given for more realistic earthquake designs which can resist earthquake forces in design of structures. For this purpose,

   (i) A network of at least 50 accelerographs needs to be deployed in Bangladesh covering the whole country.

   (ii) An array of 50 strong motion instruments may be deployed near the epicentral zone of great Shreemongal earthquake of 1918 keeping in view recurrence of earthquakes.

   (iii) Accelerometers may be installed in selected floors in tall buildings like UN, BMD, Concord Tower and a few others to understand the response of structures during earthquakes. These instruments require a small space and power.

   (iv) There is a need to install a local network of 10 Tele recording station (VSAT) facility around the epicentral zone of Shreemongal earthquake

5. As discussed with BMD Officers, the equipment and computer requirements have been framed in to take care of future expansion programs in data analysis, dissemination and retrieval. The new data acquired will need sufficiently trained

manpower to take research problems on earthquake hazard assessments and others. In this connection,

(i) Two training courses in Germany and Italy have been brought to the notice of Director, BMD to depute scientists.

(ii) Training courses have been built in the tender documents for maintenance and calibration of instruments as well as software for which suitable Engineers/meteorologists may be deputed.

(iii) Some details of training programs in other countries have been suggested in chapter 9. These may be availed by BMD.

(iv) For specialized software, one or two person may need to be trained at Norway University (Professor Jens Havskov, Institute of Solid Earth Physics, University of Bergen, Norway, Email <jens@ifjf.uib.no>).

(v) Advantage may be taken to depute scientists in India for about two months for training under TC DC program or any other keeping in view that the network of the stations is being upgraded in a phase manner.

(vi) Scientists may be encouraged to participate in International symposia /workshop etc.

6. Four copies of the tender have been given to BMD along with project report BMD may, however, modify or change the draft of the Tender Document as per latest rules in force from commercial angle. Technical specifications may also be modified as required to include more facilities. The list of a few addresses of reputed manufacturers in seismological instruments is given in the Introductory portion of the Chapter 12 (Tender document) to whom tender inquiry may be sent in addition to advertisement.

7. It is clarified that the digital equipment requires considerable experience to maintain and utilize the data for research particularly in poor site conditions such as in Bangladesh. Dedicated scientists may be provided for this purpose. One specialist expert for specific computer programs may need to be invited for 15 days from Norway (Professor Jens Havskov, Institute of Solid Earth Physics, University of Bergen, Norway, Email <jens@ifjf.uib.no>).

8. As a back for analogue seismograph for 4 stations, one horizontal component seismometer (1 to 1.5 sec) designed by India Meteorological Department and one recorder manufactured by the Central Scientific Instruments Organization, Sector 30, Chandigarh, India may be procured. This system worked very well in low gain

noisy station such as Lodi Road, New Delhi. Crystal clock is built in the system for timing. This could be explored through SAARC or any other bilateral arrangement.

9. For developing proper climate for research in Seismology, there will be a need to invite specialists on short term assignments (one or two months) who would guide the team of trained scientists for specialized topics related to earthquake hazard assessment in Bangladesh. It is suggested that BMD may consider to invite.

   Dr. S.N. Bhattacharya
   Deputy Director General of Meteorology (Seismology).
   India Meteorological Department
   Lodi Road, New Delhi 110003
   India.

   Dr. Bhattacharya is the Head of Seismology in that department and an outstanding seismologist and researcher using data of latest broad band digital instruments.

10. Data from neighboring countries is required for good control on epicenters of earthquake particularly those occurring near the borders. Therefore, a mechanism may be set up to exchange data through GTS/E-mail or any other mechanism.

11. Chapter 11 of this Report may be examined for action about sites, design of the building, electrical wiring/AC.

12 Comparison of Broad band sensors as given by the manufacturer of CMG-40 T shows highest noise for this particular sensor (Brochure enclosed). This sensor if quoted by some bidder in TENDER may not be purchased.

13. Free publication may be obtained from IASPEI Secretary Generl as given in Chapter – 9.

14. The following items may be procured locally:

    (i) Automatic Voltage Stabilizer, 15 KVA, 3 phase – One.
    (ii) Computer Tables, Printer racks, equipment cabinet, cabinet for spares and Hard Disk for four stations.
    (iii) Operators' desk – Four sets.
    (iv) Four STD telephones sets with BTTB connection.
    (v) Air-conditioners at four stations as required.
    (vii) Dehumidifier.
    (viii) Any other items as required.

GLOSSARY

Glossary

Accelerograph: A seismograph whose natural period of free vibration is very much shorter than that of the waves to be recorded.

Angle of declination: The deflection from true north of a magnetic needle in horizontal plane.

Alluvium: Sediments deposited by a river or stream.

Bending moment: The accumulative effect of all the flexure stresses on a particular cross-section is called the bending moment at that location and the total effect of the shear stresses is called the "Shear".

Buckling: The reaction of structural member to compressive leading under which the member suddenly becomes unstable, with resulting excessive deflections and structural failure.

Compression and dilation (or rarefaction): Refer to the nature of the motion of P-waves at the recording station. When the ray emerges to the surface, displacement upward and away from the epicenter corresponds to compression, the opposite to dilation. Physically, the volume is reduced in compression while it is increased in rarefaction.

Convection: Transfer of heat from one part of a fluid to another by flow of the fluid from the hotter parts to the colder.

Curie Temperature: The temperature marking the transition between ferromagnetism and paramagnets, or between the ferroelectric phase and the paraelectric phase.

Cyclone: The closed system of air rotating counter-clockwise (in Northern Hemisphere) or clockwise (in Southern Hemisphere) around a centre of relatively low pressure.

Decibels: It is a logarithmic unit which means that amplification increases the power output by the number of decibels attributed to the amplification. In terms of voltage ratio, the gain is 1000 for 60 db and 1,000,000 for 120 db. In terms of power ratio, the corresponding gain is 10^6 and 10^{12} respectively.

Demultiplexing: A process which is used to separate two or more signals that were previously combined by a compatible multiplexer and transmitted over a single channel.

Dip: The inclination of a rock bedding plane from the horizontal.

Dipole: A pair of equal and opposite electric or magnetic charges whose centres are separated.

Discriminator: A circuit in which magnitude and polarity of the output voltage depends on how an input signal differs from a standard or from another signal.

Dispersion: The increase in velocity of observed surface waves with wavelength constitutes dispersion.

Earthquake focus: The region from where the earthquake orginates inside the earth

Earthquake: Vibrations or shakings caused in the earth's crust by sudden tectonic movements or volcanic eruptions.

Elastic rebound: The spring back action of an elastic body when a deforming force is suddenly removed.

Elastic limit: Maximum stain to which an elastic body may be subjected with out permanent deformation.

Epicenter: The point on the surface of the earth lying immediately above the focus of an earthquake.

Fault: A break or shear on which there has been observable displacement of the two parts parallel to the plane of the break.

Fault scarp: Cliff along a fault produced by relative vertical displacement.

Filter: An arrangement for allowing certain frequencies to pass and suppressing the others.

Flora and Fauna: The animal population (Fauna), plant population (flora) of a particular region, geologic period or environment.

Frequency: Vibrations per second. The reciprocal of period.

Frequency modulation: The alternation or regulation of the frequency of an electromagnetic wave.

Geomorphologic: The study of the surface features of earth, primarily their origin and development. Physiography covers much the same subject matter, but according to some authors also includes oceanography and climatology.

Gouge: Rock that has been comminuted by fault movement.

Gravity anomaly: The difference between the observed value of the earth's gravity at a point and the expected value at that point, based on a given earth model.

Ground water: The water held in the pores and crevices of soil and in its underlying bedrock

Hydrophone: Device for detecting sound in water.

Igneous rock: A rock formed bythe solidificaitn of either magma or lava. Granite and baslt are examples.

Ionosphere: The region in the atmosphere, between about 80 and 400 km where the sun's radiation ionizes most of the molecules of gas present.

Isoseismal line: A closed curve passing through points of equal earthquake intensity

Landside. Slipping of a mass of land from a higher to a lower level.

Laser: A device, which is used for light amplification by stimulated enission of radiation

Or

An active electron device that converts input power into a very narrow, intense beamof coherent visible or infrated light.

Lava: A rock formed out of magma when it reaches the earth's surface through a volcano and/or a fissure and allows its dissolved gases to escape into the atmosphere.

Low velocity layer: A layer in the solid earth in which seismic wave velocity is lower than the layers immediately below or above.

Magnification: Ratio of the recorded response of a seismograph to the corresponding quantity in the actual motion of the ground.

Magnetosphere: A belt in which accumulation of electrically charged atomic particles takes place in the vicinity of earth by its magnetic field.

Meizoseismal area: The area within the isoseismals of highest intensity.

Microfracture: The numerous tiny breaks produced in a rock or mineral by application of force.

Multiplexing. A process in which a number of modulating waves or sets of information may be sent simultaneously.

Normal fault: A fault with down throw on the upper or hanging wall side.

Palaemagnetism: Study of natural remnant magnetization of rocks of different geological ages.

Phase: Onset of waves in a seismogram.

Polarisation angle: The ratio of tan-1 SH/SV; SH and SV being horizontal and vertical compoients respectively of the S-waves.

REFERENCES

Bibliography of Seismology 1959-1995

The BIB directory contains 37 annual readable files containing the references included in the bibliography for each year. See the \BIB\README.TXT file for further details.

Issues for the years 1959 to 1964 were prepared at the Dominion Observatory, Ottawa and only the author and title information has been included in this compilation. Issues from 1965 onwards were prepared at the International Seismological Centre (ISC).

A simple program which may be run under MS-DOS (\BIB\ISCBIB.EXE) is provided which will list entries containing specified search strings. The FORTRAN source from which this was compiled is also present in \BIB\ISCBIB.FOR

If the search string contains both upper and lower case letters the case significant, otherwise it is not significant.

e.g.

```
> iscbib Catalonia
```

will list all entries containing an exact match to the string 'Catalonia'.

```
> iscbib 1990 greece
```

will list all entries in the 1990 issue containing the letter sequence 'greece' (case not significant)

```
> iscbib 1970-1980 small earthquake
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will list all entries in the 1970-1980 issues containing the letter sequence 'small earthquake' (case not significant)

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will cause prompts to be displayed requesting the search parameters

67,516 references

SEISAN earthquake analysis software

The SEISAN directory contains the SEISAN analysis software version 6.0

SEISAN is general purpose seismic analysis software for doing many kinds of analysis with seismic data. The software includes a program for reading the ISC 96 column format to convert it to the format used by SEISAN.

The purpose of distributing this software with the ISC CDROM is to make it easy to use the ISC data in various kind of analysis. Among the tasks that can be done when the ISC data have been converted to SEISAN format are:

- Plot hypocenters with sections
- Organize data in a data base and select on different criteria
- Work interactively with the data
- Relocate events with IASP91 model or local crustal models
- Make fault plane solutions
- Calculate b-values
- Calculate seismic hazard

In order to get an idea of what can be done, it is recommended to first print out the manual (file SEISAN\SEISAN.PS, 237 pages).

SEISAN will run on PC (DOS and Windows95), SunOS and Sun Solaris. The distribution contains compiled software for each platform. Copy the software from the CD and follow the installation instructions as given in the manual or the file SEISAN\INSTALL.TXT.

See the file SEISAN\READ.ME for further details.

The ISC thanks Professor Havskov and the University of Bergen for making this package available for distribution by ISC. SEISAN is freely available for non commercial use. All queries regarding SEISAN should be addressed to the editor:

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These files are all available on one CD-ROM.

CD-ROMs previously issued.

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