NATURAL DISASTER MITIGATION RESEARCH

Proceedings
of the
Indo-U.S. Workshop on Natural Disaster
(Earthquake and Wind) Mitigation Research

December 13-16, 1978
New Delhi, India

Sponsored by

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Workshop proceedings on India-U.S. cooperative programs which involve safeguarding life and property from destructive effects of natural hazards (earthquakes and wind-storms) are summarized. The following projects were agreed upon for collaborative research: (1) establishment of a strong motion earthquake instrument array and analysis of strong motion data in the Shillong region of Assam, India; (2) investigation of methods for designing earth and rock-fill dams for earthquake motions; (3) study of generation of strong earthquake type ground motion by high explosive arrays; (4) research in various aspects of wind engineering including measurement of wind speeds in severe tropical storms, risk analysis, preparation of wind zoning maps and wind effects on structures; (5) consideration of areas of mutual interest in strengthening masonry buildings to withstand earthquake forces; and (6) independent creation in India of a shaking table facility of reasonable size with capacity for programmed vibrations simulating earthquake ground motion.

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INDO-U.S. WORKSHOP ON NATURAL DISASTER
(EARTHQUAKE AND WIND EFFECTS)
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DEPARTMENT OF SCIENCE AND TECHNOLOGY, INDIA

and

NATIONAL SCIENCE FOUNDATION, USA

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UNIVERSITY OF ROORKEE, INDIA

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Edited by D. E. Hudson
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WORKING GROUPS

1. Model scale effects – earth and rock-fill dams.

   India: A.R. Chandrasekaran, P. Nandakumaran
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2. Masonry structures.

   India: B. Chandra, P.K. Kandeswamy, G.C. Mathur, A.S. Arya
   U.S.A.: R.E. Klingner

3. Explosive simulation of strong ground motion.

   India: P.N. Agrawal, S.K. Guha
   U.S.A.: C.J. Higgins, H.E. Lindberg

4. Wind effects on structures.

   India: P. Krishna, P.K. Das, P.K. Kandeswamy, N.C. Nigam, P.K. Pande, D.K. Rakshit, B. Venkateswarlu
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5. Strong motion instrument array.

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Summary of Recommendations

The protection of life and property from the devastating effects of earthquakes and wind-storms is an urgent world-wide problem. Large parts of India and the United States of America are threatened by these natural hazards. Considering the importance of disaster mitigation from these effects and the research interest in both the countries, the Indo-US Workshop on Natural Disaster (Earthquake and Wind Effects) Mitigation Research offers the following recommendations:

1) A high priority should be given to the establishment of a strong-motion earthquake instrument array in the Shillong area to collect vitally needed strong motion data from a near earthquake for proper understanding of earthquake mechanisms and to enable a more realistic earthquake resistant design of engineering structures. For this program, full cooperation between the two countries will be not only highly beneficial, but essential.

2) Research work should be immediately initiated on the earthquake behavior of earth and rock-fill dams by means of tests to failure of small prototypes and large models subjected to simulated earthquake motions. Considering the broad interest in the subject and the complementary capabilities in the two countries, cooperative programs in this field will undoubtably be mutually advantageous.

3) Research work on the simulation of earthquake ground motion by the use of conventional explosives in appropriate arrays should be expanded, and applications to the testing of earth and rock-fill dams should be developed. The tests could simultaneously be utilized for dynamic testing of such structures as underground systems, buildings, and bridges. In view of the background work already done in the United States, and the interest in India in numerous practical applications, this subject is especially appropriate for collaborative projects.

4) Research work should be initiated on a collaborative basis in the following aspects of wind effects: a) Measurement of wind speeds in intense tropical storms; b) Risk analysis and preparation of wind zoning maps; and c) Experimental studies of wind effects on structures.

Considerable mutual interest was shown by the representatives from India and the United States in the above four research areas from the point of view of benefit to both countries, and it is strongly recommended that these programs be conducted jointly on a collaborative basis. For the following subjects, the element of collaboration plays a somewhat different role:

5) It is further recommended that in view of the vital importance of saving life and property from the collapse of masonry buildings in future earthquakes, the on-going research work on the earthquake protection of masonry buildings be expanded in both countries and that areas of collaboration be explored to arrive at safe and economical methodologies for strengthening such buildings.

6) It is suggested that for many basic investigations in earthquake engineering, such as tests on structural models, machines, instruments, etc., a shake table facility with a programmed vibration capability is a necessity for India. It is recommended that such a facility be promptly created. Since such facilities already exist in the U.S.A. and the basic technology is already developed, direct collaborative implementation programs were not considered to be necessary.

Editorial Preface

In line with the objective of identifying research programs which would be mutually beneficial to India and U.S.A., the workshop considered a wide range of technical and scientific problems relevant to the basic theme of Natural Disaster Mitigation. These various topics were naturally in widely varying stages of development. Some were subjects in which little research had been done in either country, while others had in one or both countries reached a more advanced state of activity. For this reason, the summaries of the proposed projects, as outlined in the following pages, differ greatly in the amount of detail included. It should be emphasized that the length of the section, or the amount of specific detail given, implies no judgment as to the relative importance of the topic, and no priority assignment. In one way or another, all of the projects are considered to be of great potential importance, and all are worthy of immediate implementation.

In particular, it should be noted that Project No. 1, the Strong Motion Instrument Array in Assam, has a very different status than the other proposed projects. As mentioned in the Introduction to these Proceedings, this Instrumentation Project is a follow-up of a previous meeting, the "International Workshop on Strong-Motion Earthquake Instrument Arrays" which was held in May 1978 in Honolulu, Hawaii. The proceedings of this International Workshop include a detailed consideration of the justification and design of such instrument arrays, and conclude with a strong recommendation that a number of such arrays be installed in various seismic regions of the world. The location which was agreed upon by this international group of experts as representing the highest priority for data acquisition was the Shillong region of Assam, India. This of course brings the subject very much into the scope of the present workshop on India-U.S.A. cooperative programs. In view of these past studies and recommendations, the problem which was presented to the New Delhi workshop on Natural Disaster Mitigation Research was that of reaching certain specific decisions as to the implementation of the instrumentation program. In particular the New Delhi workshop did not review the decisions of the Honolulu Workshop as to the need, justification, priorities, or design details of the recommended strong motion instrument arrays.

In response to the Honolulu workshop recommendations, and as a preparation for the New Delhi workshop, the Earthquake Engineering group at the University of Roorkee prepared a detailed proposal for the installation, maintenance, and data processing aspects of a proposed Shillong array. It was this proposal which was the basis for the discussion at the New Delhi workshop, and which has been in large part reproduced in the appendix material to Project No. 1 in the following proceedings.

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APPENDICES TO PROJECT NO. 1

Introduction

1. BACKGROUND

Safeguarding life and property from the destructive effects of earthquakes and wind-storms is a major worldwide problem, and large parts of India and the United States of America are threatened by these natural hazards. Research work on various aspects of disaster mitigation has been going on in both countries for a few decades. In the field of earthquake engineering, collaboration between India and U.S.A. has been in operation informally for over 20 years between individuals and institutions, particularly between the California Institute of Technology and the School of Earthquake Engineering at Roorkee University. The idea of an expanded collaborative research program in this field was conceived at the time of the Sixth World Conference on Earthquake Engineering in New Delhi in January 1977, through informal discussions between scientists of the two countries. It received the necessary encouragement from the Department of Science and Technology, Government of India as well as from the National Science Foundation, U.S.A. A meeting of representatives of various concerned institutions and organizations in India was convened in April 1978 at New Delhi which recommended a list of problem areas for collaborative research work. A meeting was then arranged at the California Institute of Technology, Pasadena through the sponsorship of the National Science Foundation, with representatives of the NSF and of the two countries.* At this meeting many problems including those recommended by the Indian group were discussed for collaboration. It was considered prudent to begin work with a few problems which were important and urgent and on which at least preliminary work had been done in both countries. The following problems were chosen as a first step:

a) Experimental Investigation of Model Scale Effects with Special Reference to Earth and Rockfill Dams.

b) Strengthening of Masonry Buildings for Earthquake Forces.

c) Generation of Strong Earthquake-Type Ground Motion by High Explosives.

d) Wind Effects on Structures.

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* M.P. Gaus (NSF), D. E. Hudson, and A. K. Chopra from the U.S.A., and J. Krishna, A. S. Arya, and L. S. Srivastava from India.

It was decided to hold an Indo-US workshop at New Delhi between the scientists of the two countries to work out the problems fully and prepare workable proposals on the basis of mutual interest and benefit to both countries.

Another important development was the holding of an International Workshop at Honolulu in May 1978 on Strong Ground Motion Observations under the sponsorship of the International Association of Earthquake Engineering with assistance from UNESCO and National Science Foundation of U.S.A. This international community of scientists and engineers identified 28 regions of the earth which were likely to suffer earthquake disasters in the next decade or so and which were hence favorable locations for installation of strong motion instrumentation. The Shillong area in North-East India was given the highest priority of the six high priority areas. Four of the 28 sites have already experienced a strong earthquake in the last six months thus verifying the basic validity of the site identification by this workshop. This makes it urgent that the Shillong area should be instrumented promptly and adequately so as to record the strong ground motions which would be generated by the probable strong earthquake in the region. It was therefore considered appropriate that this project should also be discussed at the Indo-US Workshop on Disaster Mitigation Research along with the four topics identified above.

The subject of disaster mitigation was also discussed in the meeting of the Indo-US Sub-Commission on Science and Technology held at New Delhi on November 9-10, 1978 in the group on earth sciences. This group took note of the holding of this Indo-US Workshop on Natural Hazard Mitigation Research and made the recommendation that the projects to be identified by the Workshop be included in the Agency for International Development program.

2. OPENING SESSION

The Workshop was opened by Professor M. G. K. Menon, Secretary, Department of Science and Technology, and inaugurated by Dr. Jai Krishna, President, International Association for Earthquake Engineering. In the opening remarks Professor Menon welcomed the participants on behalf of the Department of Science and Technology and highlighted the problem of hazards from earthquakes and wind effects in India. He emphasized the need for Disaster Mitigation Research to arrive at results which will neither lead to over-protection of structures nor any deficiency in them. He welcomed the continuation of the scientific links with the United States which were established several decades back and emphasized that the conclusions of the Workshop should be in concrete terms which could be readily implemented. He indicated that Department of Science and Technology will be willing to allocate funds for the proposals. He also suggested that the capability of building instruments in India should be taken into account while making the project proposals.

In his inaugural remarks Dr. Jai Krishna traced the collaboration which he and the School of Earthquake Engineering, University of Roorkee has been having with the California Institute of Technology for about 20 years and expressed optimism about the outcome of the Workshop. He presented the background of the Workshop, indicating the preparation that had been made in planning the Workshop and inviting the scientists, who had direct interest and expertise concerning the projects for participation. He emphasized the urgency of starting work on some of the projects such as the Strong Motion Observations in the North-East India, understanding of the behavior of earth and rockfill dams under strong earthquakes and the strengthening of dwellings for the common man to withstand earthquake forces, etc. He also hoped that the Workshop would result in concrete proposals for collaborative research with mutual benefit for the two countries.

3. WORKING SESSIONS

The participants of the workshop were divided into groups for each of the five topics. The groups met individually as well as in general sessions to arrive at final proposals for mutual approval. A one-day visit was made by the participants to the Departments of Earthquake Engineering and of Civil Engineering at the University of Roorkee to gain a direct impression of the facilities available and the research work being conducted there.

4. PROJECTS FOR COLLABORATIVE RESEARCH

As a result of the deliberation of the workshop, the following projects were agreed upon for collaborative research:

Project No. 1.	Establishment of a strong motion earthquake instrument array in the Shillong area, and analysis of strong motion data recorded there.
Project No. 2.	A study of the earthquake behavior of earth and rock-fill dams tested to failure by simulated earthquake motions.
Project No. 3.	An investigation of the simulation of earthquake ground motions using conventional explosives in appropriate arrays for testing of earth and rock-fill dams and other structures.
Project No. 4.	Research in Wind Engineering should be initiated on the following aspects: a) Determination of high velocity wind parameters; b) Risk analysis and preparation of wind zoning maps; c) Experimental study of wind effects on structures.

The details of the projects recommended above by the workshop collaboration between India and the United States are given in the following chapters. Project No. 1 on strong motion instrumentation in the Shillong area is fully detailed, including estimates of budget components in U.S. Dollars and Indian Rupees. Since the other projects are in earlier stages of planning, such details could not be included here and will need to be worked out by the participants by correspondence on the basis of further information to be collected in both countries.

5. OTHER RECOMMENDATIONS

Project No. 5	The topic of research work on earthquake protection of masonry buildings was considered of great importance for further expansion of research efforts. However, in view of apparent differences in the types of masonry construction used in India and U.S.A., it was considered that the matter should be further discussed and examined to arrive at areas of collaboration of mutual interest.
Project No. 6	During discussions on various topics, it was emphasized by several of the groups that there was a necessity in India for a shaking table of a reasonable size with capacity for programmed vibrations simulating earthquake ground motion for carrying out tests on models of structures, machines, components and instruments. Such testing facilities already exist in the U.S.A. It was felt that there was no need to plan specific collaboration in the establishment of such a facility in India. It was recommended that the facility be created independently of the cooperative programs considered in this workshop.

6. ACKNOWLEDGEMENT

The present Workshop was jointly sponsored by the Department of Science and Technology, Government of India and the National Science Foundation, U.S.A. The Workshop was organized by the University of Roorkee under the grant from the Department of Science and Technology and the meetings were held at the Indian Institute of Technology, Delhi, by the courtesy of the Director of the Institute. Assistance from all is gratefully acknowledged.

Project No. 1

Strong Motion Earthquake Instrumentation Array in the Shillong Area

1.1 INTRODUCTION

In view of the basic importance of the measurement of strong ground motion in the epicentral region of destructive earthquakes for all investigations in earthquake engineering, a group of participants of the 6th World Conference on Earthquake Engineering at New Delhi in 1977 held a meeting at which it was emphasized that an international effort should be made for initiating a world-wide system of strong motion earthquake instrumentation arrays. Responding to this the International Association for Earthquake Engineering in collaboration with the United States National Science Foundation and UNESCO organized a Workshop on Strong Motion Earthquake Instrument Arrays at Honolulu in Hawaii, U.S.A. from May 2-5, 1978. This Workshop issued a comprehensive report of its recommendations in December of 1978.

The Honolulu Workshop strongly endorsed the idea of a number of large instrumentation arrays and compiled a list of favourable locations of sites for such arrays using the following five principles of site selection:

"1) The need to attain a high probability of capturing a potentially damaging earthquake ($M > 6.5$) within the next ten years. In this regard, consideration has been given to return periods, existence of seismic gaps, current seismicity and occurence of large historical earthquakes.

2) The need to record for some sites the near field ground motion for very large shocks ($M=8$).

3) The need to obtain data from a variety of source mechanisms (strike-slip, thrust, normal and reverse vertical faults) and of geotectonic conditions such as subduction zones, intraplate, and tensional areas.

4) The need for good operational conditions (accesibility to the area, availability of power, technological assistance, existence of strong motion instruments etc.).

5) Where feasible the proximity to important industrial and population centers with structures of engineering significance."

The application of these principles resulted in the selection of 28 sites as promising locations for strong motion instrument arrays. It was also determined that six locations of the 28 representative sites "are extremely promising for the successful deployment of strong motion instruments and arrays in the next few years. These highest priority sites, in order are:

India, Shillong
Mexico, Oaxaca
Taiwan, Taisan, Chia-i
California, Palmdale
Japan, Suruga-Izu,
Turkey, Varto."

It is of interest to note that in the short time from May to December 1978 large earthquakes have occurred at 4 of the 28 sites including one of the 6 highest priority sites. This underlines the major importance of promptness in implementing the deployment of the arrays.

In response to the recommendation of the Honolulu Workshop to install a major array in the Shillong area, a detailed research proposal was prepared by the Earthquake Engineering Group at the University of Roorkee for presentation to the Indo-US Workshop on Natural Disaster Mitigation Research (Appendix I). A sub-committee of the Disaster Mitigation Research Workshop critically reviewed this proposal with the objective of making the specific recommendations necessary for the immediate implementation of the array program.

1.2 INDIA-U.S.A. COLLABORATION

The implementation of the Shillong Strong Motion Instrument Array will be much facilitated by close Indo-US cooperation. From the Indian side, in addition to the availability of the unique highest priority site, there will be a strong and well trained group of technical and professional specialists with the detailed knowledge necessary for the field deployment of the instruments and for processing of the recorded data. From the U.S. side, there will be available highly developed instrument types which have been field tested for many years in large arrays in the U.S. and other parts of the world. Considerable experience in problems of field maintenance collected in the U.S. over a 45 years period can supplement the Indian capability through training and advice.

The advantages to each country are equally clear. For the U.S. the increase in potential availability of data from large earthquakes from a highly seismic region would represent a very significant addition to the capabilities of existing U.S. networks. For India, where the experience has been more in the operation of individual instruments, the experience gained in operation of such large field arrays and instrumentation and in the large scale data processing requirements of such arrays would be most valuable. In this way an effective technology transfer between the two countries would be naturally achieved.

1.3 ORGANIZATIONS FOR IMPLEMENTATION

In India, the Department of Earthquake Engineering of the University of Roorkee which operates the National Strong Motion Instrumentation program for the country, will be the main implementing organization. Many facilities exist there which would enable them to carry out these responsibilities.

The India Meteorological Department operates a number of seismological stations in and near the proposed area. With a long history of seismological observatory experience, they have available the strong professional and research personnel necessary to provide cooperative support. Some array stations can be located as meteorological observatories, and valuable logistic support in the area can be supplied.

A number of other organizations in India will have major interests in the results of the project and can be expected to offer strong cooperative support. The Geological Survey of India, The Survey of India, The Central Water Commission, The Oil and Natural Gas Commission and the River Valley Project organizations in North East India are some examples.

The implementing agency in the United States will be the National Science Foundation. In this field of research, the National Science Foundation had already many connections with the U.S. national organizations and institutions involved in similar studies, including government laboratories, industrial laboratories and universities.

In accordance with the general recommendations of the Honolulu Workshop report, it would be expected that an Array Steering Committee would be appointed containing representatives of major organizations in the participating countries to oversee the implementation program. In addition, it is likely that the National Science Foundation would appoint a small advisory council to assist them in the proper coordination of the implementation program.

1.4 INSTRUMENT TYPES

The most important decision facing the workshop sub-committee on the Shillong Array was the selection of instrument types, and this matter was given detailed consideration. There are two types of surface three-component strong motion accelerographs which are presently commercially available, and would meet the general specifications and time schedule of the project. One of these devices has a mechanical type transducer recording optically on photographic film, and the other has a force-balance transducer and records on digital magnetic tape. These will be referred to hereinafter as the analog and the digital accelerographs. Each of these devices has distinctive advantages and disadvantages for this particular array application, and it was the aim of the subcommittee to balance the number of each type in some optimal way. The local laboratory array and the extended arrays will require down-hole instrumentation as an important component, which will need additional design and development, and for this reason these arrays have been deferred to a later stage in the project.

The Analog Accelerograph:

A. Advantages

1) Fully developed fourth generation device widely deployed over the world. Some 3,000 instruments in the field have produced perhaps a thousand useful strong motion records, many under adverse field conditions. Wide use means assured spare part supply for the life of the array.

2) Basically simple design, easy to check, calibrate, and adjust. Field maintenance problems are well understood because of long experience.

3) Low stand-by power consumption results in relatively simple battery supply problems. Solar cell charging at remote locations is feasible. Repeated earthquakes can be recorded over several months without external power source.

4) Records can provide some essential basic information in the field without the need for specialized data processing devices.

5) Relatively low cost results in more accelerographs for given resources.

B. Disadvantages

1) For complete data processing, a time consuming digitization of the analog record is required. With available semi-automatic digitizers, about one three-component record can be digitized by one person per day. Total data processing time for the whole array using several such digitizers would be of the order of 6 months.

2) Accurate film copies of basic data are relatively difficult to reproduce for wide distribution of data.

3) Absence of pre-event memory may reduce usefulness of data for certain special studies.

4) Possibility of photographic film deterioration in high humidity sites must be anticipated. Film should be replaced on a two month service schedule.

The Digital Accelerograph:

A. Advantages

1) Record is directly available in digital form, and can be quickly transcribed in computer compatible format.

2) Records can be quickly and accurately copied for distribution.

3) A pre-event memory preserves first motions for special seismological studies.

B. Disadvantages

1) As a newly developed first generation instrument, no experience has as yet been obtained on field performance and reliability. No earthquake records are known to have been obtained in the field on such devices as of December 1978. Questions of field servicing, checking, and calibration are as yet unanswered, and the type of training necessary for field personnel not yet established.

2) Relatively high stand-by power requires large battery supply with increased problems of charging and maintenance. Without external power, operating life may be only a matter of hours.

3) Special data processing equipment is needed to read digital tape for field check and calibration as well as for final data treatment.

4) Higher instrument cost reduces size or density of array for given resources.

Considering the two initial arrays - the source mechanism and wave propagation array, and the mobile array - a careful consideration of the above advantages and disadvantages has resulted in a decision for 225 analog accelerographs and 75 digital accelerographs. This is believed to achieve an optimum balance of reliability and cost while retaining some of the advantages of the digital system. In spite of the developmental nature of the digital devices, the above quantities are recommended because (a) there will be a considerable back-up of analog stations should any field problems develop with the digital accelerographs: (b) a number of digital records would be immediately available for copying and distribution, and for complete data processing: (c) to a certain extent sites having favorable environments and accessibility could be selected for the digital accelerographs to minimize maintenance problems: (d) useful information on the field performance of the digital instruments will become available to assist in decisions for extensions of the arrays or for the Indian national network.

1.5 RECOMMENDATIONS

1) The sub-committee concurs in the philosophy of the International Workshop Report that it is essential that the array be placed in operation at the earliest possible time. Should a large earthquake occur at a proposed site before the installation of the array, that site would be virtually removed from consideration for a period of years. In the face of this sense of urgency, the subcommittee has assumed that no instrumentation could be considered that is not immediately available on a commercial basis as of December 1978, and that the major portion of the arrays should be in operation within 2 years from that date.

2) The general location and configuration of the arrays as given in the Disaster Mitigation Research Workshop proposals (Appendix I) are accepted as representing a reasonable balance of tectonic considerations, earthquake history, and accessibility. Minor adjustments of individual site location as dictated by availability and accessibility would be expected.

3) The order of priority of the sub array acquisition and installation should be (Appendix IIa):

   I Source Mechanism and Wave Propagation Array

   II Mobile Array

   III Extended Arrays

   IV Local Laboratory Array

4) The source mechanism and wave propagation array should consist of 200 analog - photographic film strong motion accelerographs plus 50 digital type accelerographs distributed at random throughout the array. This array should be in full operation within two years.

5) The mobile array should consist of 25 analog - photographic film accelerographs plus 25 digital accelerographs. This mobile array should be available in the third year.

6) The instrument types described in the Disaster Mitigation Research proposals (Appendix IIa) for the extended arrays and for the local laboratory array are provisionally accepted, pending review of instrument performance gained from Arrays I and II. These arrays would be expected to be completed within the 3rd or 4th year.

Project No. 2

Investigation into Methods of Designing Earth and Rock-fill Dams for Earthquake Motions

2.1 IMPORTANCE AND BASIC NEEDS

Earth and rock-fill dams compose a large percentage of dams constructed around the world today. A number of earth and rock-fill dams presently exist or are in the construction and planning stage in the highly seismic regions of both the U.S.A. and India. Past earthquakes have revealed in some instances deficiencies in design leading to failure and in some instances evidence of over-design indicating excess cost of the project. Because of the catastrophic consequences of possible failure and the high cost of construction, a better understanding of the behaviour of dams during earthquakes is urgently needed.

In recent years there has been an increasing emphasis in both India and U.S.A. on dam safety. It is believed that a cooperative effort between the two countries would be effective in increasing the understanding of response of earth and rock-fill dams to earthquake ground motions.

2.2 OBJECTIVES

The objective of the recommended investigation is to evaluate current practice in dam engineering and to modify and/or develop analysis and design procedures, as required.

To achieve this objective the topics listed in the next section are recommended for collaborative study by the two countries. It is believed that these topics form a systematic set of research recommendations which when implemented should lead to a more reliable and economical design procedure resulting in increased dam safety and economy.

2.3 RESEARCH RECOMMENDATIONS

It is recommended that research in this area include the following:

1. Critical Study of the State of the Art

   Review the current state of the knowledge concerning the design, analysis and practice in dam engineering and determine the parameters governing the response of earth and rock-fill dams. Following this review, a study of the behavior of embankments will be performed using experimental and analytical techniques.

2. Experimental Studies

An extensive program of testing is recommended on dams of various heights. Some of these dams should be constructed as small prototypes and others as models of small prototypes. Presently it is envisioned that the height of these dams should vary from 3 to 15 m (10 to 50 feet) and that they should be designed and constructed to be marginally safe so that permanent deformations may be achieved during testing as will be discussed later.

To determine the extent to which any of these dams can be considered to be models will require a thorough study of modeling theory. Based on the results of this study a search for appropriate model techniques and materials should be conducted. The possibilities and limitations of the use of models for predicting the response of prototype dams critically depend upon the finding of a suitable model material.

The physical and engineering properties (static and dynamic) of the materials used in various zones (shell, transition, core, etc.) of embankment dams should be determined using experimental techniques. Such techniques include triaxial shear tests, simple shear tests, direct shear tests, mechanical analysis, maximum and minimum density tests, geophysical surveys, standard penetration tests, and other in situ and laboratory tests, as appropriate.

To the extent indicated by the above mentioned studies, tests are recommended using models of different size to investigate the model distortions due to violation of similitude laws.

In order to understand the dynamic behavior of dams during earthquakes, it is proposed that the small prototype and model dams be excited to failure using conventional explosives. The report of Project No. 3 in these proceedings discusses in detail the methods proposed for generating this type of input motion.

3. Evaluation and Improvement of Current Practice

The dams used in this experimental study should be analyzed a priori according to mutually agreed upon appropriate existing methods to predict the dynamic response. A comparison of the predicted and measured response is the key to an evaluation of current practice. In this way it is anticipated that shortcomings of existing procedures can be identified.

Another means of evaluating analysis and design procedures is the dynamic testing of existing prototype dams. Forced vibration tests on dams are recommended to determine their vibration properties (natural frequencies and mode shapes of vibration, modal damping, etc.) at small amplitude motions.

The ultimate test is the actual measurement of the response of existing dams to large earthquakes. Such information is critically needed by the earth and rock-fill dam community throughout the world. To obtain this information, dams in highly seismic areas should be instrumented. This instrumentation should minimally include: accelerographs, slope indicators, pore pressure transducers, and surface surveys including aerial photography.

In all cases an intensive geotechnical investigation of the existing prototype dams and foundations must be conducted.

4. Development of Design Procedures

At an early stage in this investigation it will be necessary to postulate interim design procedures which will be used for the design of the experimental dams. From the results of this investigation the interim design procedures will be improved. The final procedure should be in a simple form that can be routinely used by professional engineers.

2.4 DISSEMINATION AND UTILIZATION OF KNOWLEDGE

The development of orderly, timely and creative means of technology transfer is needed within and between both countries. Possible methods of technology transfer include distribution of publications, workshops, short courses, and seminars.

An open exchange of information and data gathered during the experiments recommended herein is essential to the success of the project.

2.5 CAPABILITIES AND MUTUAL BENEFITS

India offers certain advantages for conducting field tests on small prototype dams and can offer suitable test sites and facilities. The U.S.A. has considerable experience in measurement techniques and available instrumentation. Both countries possess highly qualified specialists in the various fields involved in this program and collaboration would thus be expected to prove very fruitful.

2.6 ORGANIZATIONS AND INSTITUTIONS

Possible organizations in U.S.A. interested in this research include the U.S. Army Corps of Engineers, the Bureau of Reclamation, and the Universities with interest in this area. In India interested organizations include the University of Roorkee, the Research Institutes of the Central Water Commission, and the Irrigation Research Institutes of State Governments.

2.7 IMPLEMENTATION

The next step in the implementation of the above recommendations is the preparation of detailed research proposals including time schedules and budget requirements. Such specific proposals might be initiated in either country, and could in the initial steps be coordinated through correspondence between the sponsoring organizations. This project will be closely associated with Project No.3, and the two programs should be considered jointly in the planning stages.

Project No. 3

Generation of Strong Earthquake Type Ground Motion by High Explosive Arrays

3.1 IMPORTANCE AND BASIC NEEDS

The practical importance of the subject is underlined by the following considerations:

1) There is an absence of significant response data on earth and rock-fill dams during strong earthquakes.
2) Explosive simulation is the only practical method of exciting prototype structures to damaging response levels.
3) Numerous large earth and rock-fill dams exist or are proposed in seismic regions of India and the United States.
4) The results of such high level excitation tests will contribute in a major way to evaluations of the seismic behavior of existing and future dams in India, the United States, and throughout the world.
5) The project will result in improved seismic design methods which will provide higher confidence in dam design, dam safety, and economy of construction.

3.2 OBJECTIVES

The overall objective is the generation of strong earthquake-like ground motion for the field investigation of the response of prototype and large scale models of earth and rock-fill dams and of other important structures. These basic objectives can be achieved through the following research recommendations.

3.3 RESEARCH RECOMMENDATIONS

1) The development of explosive methods for providing adequate excitation of earth and rock-fill dams.
2) The performance of large-scale explosive experiments on earth and rock-fill dams to obtain high amplitude response data.
3) The use of data from large-scale explosive tests for the evaluation and improvement of design procedures for dams.

4) An experimental investigation of the extent to which explosive generated ground motions could be effectively used for simultaneous tests of other structures such as underground cavities, embedded structures, tunnels, retaining walls, masonry structures, and long span bridges.

5) The simultaneous use of large test explosions for geophysical exploration of crustal structure over large distances.

3.4 PROGRAM PLAN

To carry out the above research recommendations the following program is suggested:

1) The identification of possible dam geologies and suitable dam designs.

2) The development of simulation criteria, involving the following points:

   a) Estimation of credible prototype earthquake motion amplitudes and frequencies, and the corresponding response spectra.

   b) Estimation of important dam responses using finite element, finite difference and other current engineering analysis methods (with Project No. 2).

   c) The estimation of ground motion and spectra requirements to achieve desired levels and types of response (with Project No. 2).

3) The Development of Simulation Methods, including:

   a) The development of empirical and analytical prediction methods for explosive generated ground motions and their spectra in different dam geologies.

   b) The selection of appropriate test sites for explosive simulation tests.

   c) The conduct of geotechnical investigations at test sites.

   d) The design and performance of small scale simulation development experiments to verify and/or modify prediction procedures.

   e) The investigation of enhancement procedures as needed to support the simulation criteria.

   f) The performance of development tests on moderate scale models of dams and other selected structures.

   g) The analysis of test data and design of large-scale experiments.

4) The Performance of a Large-Scale Simulation Test:

   a) The selection and investigation of a large-scale test site (with Project No. 2).

   b) The design of the test dam and of other test structures (with Project No. 2).

   c) The preparation of the site and construction of the dam and other test structures (with Project No. 2).

   d) The preparation of an instrumentation plan.

   e) The purchase, assembly and installation of the instrumentation.

   f) The performance of several tests.

5) The Analysis of Data and Preparation of a Joint India-U.S. Report:

   a) The reduction, interpretation and analysis of test data independently by India and the U.S.

   b) The preparation of a joint report on test results.

6) The Evaluation of Dam Design Procedures and Recommendation for Improvements:

   a) The comparison of test results with response prediction from accepted analysis procedures, and recommendation as to improvements needed. (With Project No.2.)

   b) The comparison of prototype response as observed during earthquakes with explosive simulation response.

3.5 CAPABILITIES AND MUTUAL BENEFITS

The United States has unique experience in four technical areas which can contribute to this cooperative program: (a) instrumentation, recording and data reduction equipment; (b) ground motion measurements from point source explosions; (c) design and development of planar explosive arrays; (d) finite element and finite difference computer codes for ground motion and structure response.

The instrumentation includes soil and pore pressure gages, accelerometers, velocity transducers, and structural strain gages.* The most convenient and flexible recording system is multiplexed analog recording on magnetic tape. Data reduction is performed by first digitizing the data by an electronic analog-to-digital converter and then performing all subsequent operations by digital computation.

The ground motion data from point source explosions include measurements in many geologic materials from large (many kilo-tons) and small explosions over a complete range of distances from the explosions. These data provide a basis for fundamental understanding of ground motion from explosions. They also show the limitations of point sources for earthquake simulation and the need for multiple detonation of explosive arrays for this purpose.

Work on design and development of planar explosive arrays is well advanced, but much remains to be done. Successful tests have been performed with single and multiple arrays sequentially detonated. Resulting motions have earthquake-like characteristics and are presently being used to investigate response of nuclear reactor buildings. More advanced simulation will require further development of enhancement techniques to tailor amplitude and frequency content and to modify the type of wave motion (e.g. enhance shear motion). Research is also well underway to minimize the amount of explosive required and hence reduce cost and unwanted disturbance of soil and rock near the explosion by using cannister-contained explosive arrays. This technique also shows promise for motion enhancement by tailoring pressure and frequency at the explosion source.

Finite difference and finite element codes for ground motion and structural response are in an advanced state of development and in large part can be used in existing standard forms. Large-capacity computers are available to perform calculations at reasonable cost for two-dimensional meshes of interest here and for more limited three-dimensional meshes. A wide range of mathematical constitutive descriptions of geologic materials are also available.

Investigators in India have ample experience in: (a) design of earth and rock-fill dams in seismic regions, (b) handling and applications of explosive detonation for various purposes, (c) construction of prototype and models of earth and rock-fill dams and other structures, (d) use of sophisticated data acquisition systems and (e) applications of numerical analysis and finite element methods.

Extensive experience in the analysis and design of earth and rock-fill dams by theoretical and experimental methods exists in India. Very large earth and rock-fill dams are being designed and constructed taking advantage of the indigenously available expertise. The proposed

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*As well as devices requiring more development work, particularly for dynamic applications. This category includes, for example, soil strain gages, soil-structure interface gages, and water pressure transducers.

investigations of the behavior of small prototype dams would provide a very significant addition to the existing knowledge and experience.

Since its inception in 1960, the Earthquake Engineering School at the University of Roorkee has conducted studies of the behavior of ground subjected to blast-induced vibrations for many projects in different seismic zones of India. This has involved study of the distribution of ground motion at short distances and its response spectra, exploration of soil properties and determining the liquefaction potential. A considerable amount of work has been done on somewhat related problems involved in the minimization of seismic effects of explosions that are detonated for other applications such as mining, tunnelling, etc.

Skill and experience exist for the preparation of scaled models of earth and rock-fill dams, and for the conduct of limited experimentation in the laboratory and field. Some of the devices needed in the investigation are indigenously available. A wide variety of test sites varying in geology and lithology are readily available in India.

3.6 ORGANIZATIONS AND INSTITUTIONS

Organizations in the United States with a special interest and background in this field include: U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, U.S. Geological Survey, research laboratories such as the Stanford Research Institute, and a number of Universities.

In India possible organizations include the University of Roorkee, the Central Water and Power Research Station, Poona, and the U.P. Irrigation Department.

3.7 IMPLEMENTATION

The next step in the implementation of the above recommendations is the preparation of detailed research proposals including time schedules and budget requirements. Such specific proposals might be initiated from either country, and could in the initial steps be coordinated through correspondence getween the sponsoring organizations. This project will be closely associated with Project No. 2, and the two programs should be considered jointly in the planning stages.

Project No. 4

Wind Effects on Structures

4.1 INTRODUCTION

Of the two sources of disasters covered in the Workshop, research work on earthquakes has been better organized and more comprehensive in both countries. Although loss to life and property due to extreme wind conditions has been extensive both in United States and India, coordinated research in the area of wind engineering has been limited. In India, the work on wind effects has been confined to a few specific structures and has been carried out largely in aeronautical establishments. Both India and United States are susceptible to extensive damage due to frequent hurricanes (cyclones) and also tornadoes. A comprehensive program of research covering broad spectrum of wind engineering and cooperation in a few areas of mutual interest and importance is therefore considered desirable. The following steps are proposed in this effort.

4.2 OBJECTIVES AND RECOMMENDATIONS

Consistent with the theme of the Workshop of disaster mitigation research, and keeping in view the mutuality of interest of U.S.A. and India, the following projects have been identified for collaboration:

1) Measurement of Wind Speeds in Intense Tropical Storms.

   Design and development of a rugged and reliable anemometer for measurement of high wind speeds, including setting up of an experimental network in the east coast of India for measuring basic parameters of extreme wind and correlation with mathematical models.

2) Risk Analysis and Preparation of Wind Zoning Maps

   Risk analysis based on available wind data for the preparation of zoning maps and recommendations for codes and standards.

3) Experimental Study of Wind Effects on Structures

   Study of wind effects on structures through instrumentation and observations on models and prototype structures.

Some recommendations for specific projects embodying these topics are summarized below, with suggestions for areas of collaboration between India and the U.S.A. (refer to Projects No. 4a, 4b, 4c)

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Two additional recommendations emerged from general discussions of the engineering problem:

1) At the present stage of development of wind engineering in both countries it would be mutually advantageous to encourage an exchange of research workers and literature. This could include support for attendance at conferences, symposia, short courses, etc., in the area of wind engineering.

2) A Wind Engineering Research Council was established in the United States in 1970 to coordinate the national effort in the field of wind engineering. It is proposed that there be established in India a committee at the national level to draw up plans for comprehensive research in the area of wind engineering and to provide interaction with the Wind Engineering Research Council and other organizations and institutions in the U.S.A. Such a committee could include representatives from many groups in India, including those organizations listed below.

4.3 ORGANIZATIONS AND INSTITUTIONS

A number of organizations and institutions exist in both countries with capabilities and potential interest in the subject. Specific examples are: In India, the Indian Meteorological Department, the Indian Standards Institute, the CSIR Structural Engineering Research Center, the Indian Space Research Organization, the Indian Institute of Science-Bangalore, the National Aeronautical Laboratory-Bangalore, the National Building Organization-New Delhi, the Indian Institute of Technology-Kanpur, the University of Roorkee, and Andhra University-Waltair; in the United States, The National Oceanic and Atmospheric Administration, the National Weather Service-Instrumentation Division, the National Bureau of Standards-Center for Building Technology, Virginia Polytechnic Institute, Johns Hopkins University, the University of Florida, the University of Houston, Colorado State University, and the California Institute of Technology.

4.4 IMPLEMENTATION

The three main topics outlined above are described in some detail in the following pages. In each case, the next step in the implementation of the programs would be the preparation of specific research proposals including time schedules and budget requirements. Such proposals might be initiated in either country, and could in the beginning stages be coordinated through correspondence between the sponsoring organizations.

Project No. 4a

Measurement of Wind Speeds in Intense Tropical Storms

4a.1 IMPORTANCE AND BASIC NEEDS

It often happens during landfall of a cyclone, hurricane or similar intense tropical storm that the associated extreme wind speeds go unrecorded. This is often due to the fact that anemometer networks maintained by meteorological services do not provide sufficient coverage of coastal areas. In many cases, however, anemometers and/or their recording systems fail before the maximum wind speed occurs. Notable examples of loss of such data include Hurricane Camille (U.S.A., 1969) and Cyclone Tracey (Australia, 1974). Unless a reliable system for measuring extreme speeds in tropical storms is developed, there will continue to be a critical lack of wind speed data for use in the design of buildings and other structures located in coastal areas.

4a.2 OBJECTIVES

1. The development of performance criteria for a rugged and reliable wind speed recording device for application in coastal networks. These criteria should include: (a) Maximum servicable wind speed; (b) Expected life in harsh environments; (c) Simplicity in fabrication and maintenance; (d) Ease of installation; and (c) Capability for operation without external power source.
2. The design, construction and laboratory test of the device.
3. The installation and maintenance of a pilot network on the East coast of India and the collection of extreme wind speed data.
4. The correlation of basic wind paramcters with mathematical models.

4a.3 CAPABILITIES AND MUTUAL BENEFITS

In India the India Meteorological Department has the capability for design and fabrication of conventional type anemometers that are required for meteorological observations. To achieve the present objective, however, a considerable research and development effort will be required to produce a rugged and reliable anemometer for recording wind information during extreme conditions. The state of the art is not much different in the United States in this regard. The research and development in this direction therefore will be of mutual interest and gain to both the U.S.A. and India for meeting disaster mitigation.

Considerable development work in the design of such rugged and reliable anemometers has been carried out by the Australian Meteorological Service. It is anticipated that visits to such centers by India/ U.S.A. counterparts would be beneficial.

Mathematical models of cyclone and hurricane wind characteristics near the ground surface are largely limited to mean velocity profiles. Very little information exists with which to verify estimates of peak gusts or wind spectra. Collaborative research in these areas would be of mutual benefit, and would result in improved design methods for use in both countries.

Project No. 4b

Risk Analysis and Preparation of Wind Zoning Maps

4b.1 IMPORTANCE AND BASIC NEEDS

An understanding of wind loading on structures is important for their economic design, particularly for modern high-rise, light and flexible structures. Equally important is the problem of safety and protection from extreme wind conditions such as hurricanes (cyclones) and tornadoes. The historical and instrumental data regarding wind speeds provides the rational basis for establishing design wind loads on structures. The information regarding wind speeds is most conveniently depicted through contour maps for a given region. Since there is a large measure of uncertainity about the wind, a statistical treatment of available data provides a rational basis for preparing such maps. An accurate and realistic preparation of zoning maps based on risk analysis and their incorporation in a Code is the most effective insurance against damage to life and property during extreme wind conditions. Availability of wind speed maps based on risk analysis also makes it possible to design structures within a reliability framework with optimum balance between cost and risk.

4b.2 OBJECTIVES

Wind velocity maps based on risk analysis of available data have been prepared in the United States. As more data become available, such maps need to be revised and refined. While mathematical techniques for risk analysis are well developed, the need for a more powerful analytical tool cannot be over-emphasized, particularly in situations where data are limited. In India, the India Meterological Department maintains a large network of wind measuring stations. Some data for mean and extreme wind velocities are available at a limited number of stations spread over the subcontinent. Historical and some instrumental data are also available for cyclones and tornadoes. A systematic risk analysis of this data with a view to prepare return-period maps has not been carried out. It is proposed to assess the available data for the Indian Subcontinent, to perform an appropriate analysis, and to make recommendations concerning the translation of the results into Code provisions.

4b.3 CAPABILITIES AND MUTUAL BENEFITS

Wind data for risk analysis are available for a significant period of time and are being collected at an increasing number of stations continuously in both countries. The expertise for risk analysis and access to large computer systems is available in both countires. Sharing of experience in the mathematical theory of risk analysis, analysis of available data and recommendations for code provisions based on risk analysis will be mutually beneficial. Mixed-distributions based on Indian data will be of special interest to the U.S.A. The scope of the collaboration for this project would be expected to consist mainly in the exchange of research workers and literature.

Project No. 4c

Experimental Study of Wind Effects on Structures

4c.1 IMPORTANCE AND BASIC NEEDS

Safe design of structures against wind requires a reasonably accurate estimate of loads as well as a knowledge of structural behavior when subjected to these loads. For wind loading, some can be obtained through wind tunnel testing of models, supplemented by full-scale studies including a study of failures of structures. Particularly the effect of cyclone and hurricane storms on different structures should be investigated as these lead to extreme load conditions very commonly, both in India and in the U.S.A. Structures which are especially sensitive to wind are flexible structures such as tall towers or wide span structures, e.g. cable bridges or roofs. These are usually expensive projects and can mean considerable loss if failure occurs. Information available on some structures of the above types is either inadequate or requires collection and analysis. Information organization along such lines would be of obvious mutual advantage to both countries.

4c.2 OBJECTIVES

1) The development of boundary layer wind tunnel testing facilities in India.

2) The laboratory testing of structures for which enough basic information is not available, such as suspended structures, towers and cyclone shelters.

3) The conduct of prototype measurements, involving instrumentation of existing structures which have been tested in the wind tunnels.

4c.3 CAPABILITIES AND MUTUAL BENEFITS

1. There are several aeronautical wind tunnels in India, but boundary layer wind tunnels have not as yet been developed there. Several industrial wind tunnels of advanced designs exist in the United States. The development of the whole subject of wind engineering in India would be much facilitated by utilizing this U.S.A. experience in the planning and instrumentation of such tunnels. Such facilities tend to be elaborate and expensive undertakings so that the sharing of existing facilities and cooperative planning of new ones offer attractive mutual benefits.

2. Wind design information for large span structures is in general very limited, and in some aspects almost nonexistent. Long span bridges and masts are being built in both India and the U.S.A. based on this inadequate data. Cable roofs, which are popularly employed in the U.S.A. and offer attractive possibilities for applications in India, are another example of particular structures for which more wind design information would be of direct interest to both countries.

Project No. 5

Strengthening of Masonry Buildings to Withstand Earthquake Forces

5.1 IMPORTANCE AND BASIC NEEDS

Masonry buildings are being constructed in increasingly large numbers in areas susceptible to earthquakes. In view of the loss of life and property that occurs when masonry buildings collapse, it is considered to be of vital importance to design and construct such buildings and houses to achieve a reasonable balance of safety and expense. Masonry construction is the most prevalent type of construction universally on account of its suitability from other considerations as well as economy. It will continue to hold this position, especially for housing the teeming millions all over the world. Hitherto, such masonry structures have not usually incorporated adequate safety requirements as is obvious from the colossal damage and loss of life experienced in many a catastrophic earthquake. Disaster mitigation has assumed greater importance in modern times because of an increasingly heavy concentration of population in many earthquake prone areas.

5.2 CURRENT RESEARCH PROBLEMS

Current research in India is being directed towards the following aspects of the masonry construction problem:

1) Experimental studies of the methods of strengthening new buildings and evaluation of the relative efficiency of each technique.

2) Development of structural systems for improved seismic performance.

Several research projects in the United States are now investigating masonry construction, including the following topics:

1) The National Science Foundation is sponsoring on-going research to develop analytical models for predicting the response of masonry structures, high-rise as well as low-rise, and to develop methodologies for evaluating the safety of existing masonry structures.

2) The Portland Cement Association is investigating the response of minimally reinforced, engineered high-rise masonry.

3) The U.S. Department of Housing and Urban Development is sponsoring research to evaluate and improve the seismic resistance of low-rise reinforced masonry of the type used in residential construction in the U.S.

The National Science Foundation is currently evaluating many other proposals such as the following:

1) Experimental and analytical investigations of the response to lateral load of high-rise masonry shear walls in several configurations.

2) Experimental and analytical investigation of the effects of floor diaphragms on the behavior of high-rise engineered masonry structures.

5.3 CAPABILITIES AND MUTUAL BENEFITS

Both existing and new masonry construction are of vital concern from the point of view of disaster mitigation in all the countries. In India, as well as in the U.S.A., strengthening of existing masonry structures which might be deficient in earthquake resistance, and the safe construction of low-rise masonry buildings present an activity of great research interest. The technological involvement of both the countries in devising appropriate and economical measures to mitigate earthquake disasters presents an area of high priority and of direct interest.

Masonry construction of varied types has been practiced in both the countries for reasons of local availability of different types of building materials at cheap cost and their favorable performance in different climatic conditions. Dissimilarities in the modes of masonry construction are thus not uncommon in India and the U.S.A. Whereas high-rise masonry buildings have become a common feature in the U.S., low-rise masonry structures up to about four stories are increasingly being adopted in India. However, high-rise masonry construction is not precluded there.

5.4 RECOMMENDATIONS REGARDING COLLABORATION

Both countries will mutually benefit by pursuing research evolving appropriate and economical techniques for strengthening the earthquake resistance of prevailing masonry construction. Specific areas of collaborative research should be further identified based on the ongoing research work in both the countries. To achieve this, it is recommended that:

1) Transfer of technology between India and U.S. research organizations and with industry should be developed systematically through improved communication of information and research data.

2) A program for exchange of research workers should be organized to encourage first hand and intimate knowledge of research work in progress in both countries.

3) The research work being undertaken in both the countries in this field should be considerably augmented, and additional mechanisms for translating research results into engineering practice should be developed.

4) Joint research projects, for both analytical and experimental investigations, should be identified by means of further detailed discussions. For example, the possibility of conducting tests on masonry structures using techniques developed under project No.3 above (Generation of Strong Earthquake Type Ground Motion by High Explosive Arrays) should be examined. The construction of suitable test structures in highly seismic regions should be encouraged.

5.5 RECOMMENDATIONS FOR EXPANDING RESEARCH IN INDIA

1) Research work should be initiated for developing methods of evaluating seismic hazards to existing buildings, and practical procedures for repair and strengthening them to improve earthquake resistance.

2) Methods of strengthening which have already been proposed should be evaluated using at least half scale models, more realistic base motions, and more data acquisition points, to derive the maximum information from the tests.

5.6 IMPLEMENTATION

Preparation of specific research proposals will require additional discussions between particular groups within and between the two countries. The next step is the identification of the institutions or organizations, including industrial groups, who would most appropriately initiate and participate in such discussions.

Project No. 6

Programmed Shake Table Facility

6.1 IMPORTANCE AND BASIC NEEDS

For carrying out basic research studies in earthquake engineering involving structural models, equipment safety, instrument development, dynamic soil studies and similar investigations, a shake table of moderate size capable of simulating earthquake type motions is an urgent necessity in India. Several such tables already exist in the U.S.A., Japan and in other countries. Earthquake engineering research work in India could be carried forward much more quickly and at a higher level of thoroughness with such a table. The workshop participants recommend strongly that such a test facility be created in India as soon as possible.

6.2 DESCRIPTION OF THE PROPOSED FACILITY

1) Function: The biaxial earthquake simulation system should be capable of imparting realistic earthquake motions along one horizontal and a vertical axis to a shaking table on which structural models can be fixed. The form of the motion should be controllable over wide limits.

2) Desireable features: Maximum load to be shaken 40 t, 3 vertical actuators each with 14 t force; 2 horizontal actuators with about 30 t force; single piece table; lateral motion restraints; Hydraulic Power Supply; electronic programming for earthquake motion; Reaction mass.

3) System Components

   a. Test table, with a tapped hole matrix for specimen mounting.

   b. Vertical and horizontal actuator assemblies, including servovalves, manifolds, stroke and pressure transducers, and swivel base and heads.

   c. Lateral motion restraints.

   d. Hydraulic power supply including all hoses and service manifolds.

   e. Electronic program and control, including servocontrollers and valve drivers, signal conditioners, master span panel, sweep generators, hydraulic control, safety interlocks, cables, and control console.

f. The reaction mass is a critical part of any vibration system. Performance of the system depends upon the weight, and stiffness of the mass. Allowable vibration transmission to surrounding areas must also be considered, especially when operating through the ground and/or building natural frequencies or its harmonics.

6.3 IMPLEMENTATION

The 1978 cost of the recommended system is estimated to be Rupees 15,000,000 of which about Rupees 12,500,000 would need to be available in U.S. Dollars (approximately Dollars 1,500,000). No specific collaborative project would need to be established, since an adequate input of U.S.A. knowledge and experience can be ensured through existing research links, and since suitable equipment is readily available through commercial channels. Initiation of the program would be by submission of a specific proposal prepared by an appropriate Indian organization.

PROJECT NO.1-APPENDIX I

STRONG MOTION EARTHQUAKE INSTRUMENT ARRAY
SHILLONG REGION (NORTH-EAST INDIA)
DAUKI-HAFLONG FAULT ZONE*

INTRODUCTION

North-East India, comprising the seven states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Nagaland and Tripura, and the adjoining parts of Bangladesh, Bhutan, Burma and China are affected by earthquakes at very frequent intervals. This is one of the well known seismically active regions of the world and offers a unique opportunity to monitor near-field ground motions to study the mechanism of earthquake occurrence and to determine strong ground motion characteristics. This region shows the highest seismic activity in the world and it is highly desirable that a suitable strong motion earthquake instrument array be established in the region to permit studies of earthquake occurrence, a realistic assessment of seismic risks and a correct evaluation of ground motion characteristics. Two great earthquakes** of magnitude 8.7 (12 June 1897 and 15 August 1950) have occurred in the region within the last 80 years causing wide spread damage and loss of life. The occurrence of a large earthquake in the region can thus be expected in the present or coming decades.

GEOTECTONIC FEATURES

Geological investigations in Assam and parts of Manipur, Meghalaya, Nagaland and Tripura have been carried out for almost 90 years in connection with oil exploration in the region, and the knowledge gained is highly reliable being based on geological mapping, drilling and geophysical surveys. Such geological investigations in other parts of North-East India have been conducted only during the last two decades and gradually additional data on the geotectonic features of the region is becoming available. Most of these studies have been carried out by the Geological Survey of India and the Oil and Natural Gas Commission. Figure 1 shows the generalized tectonic map of

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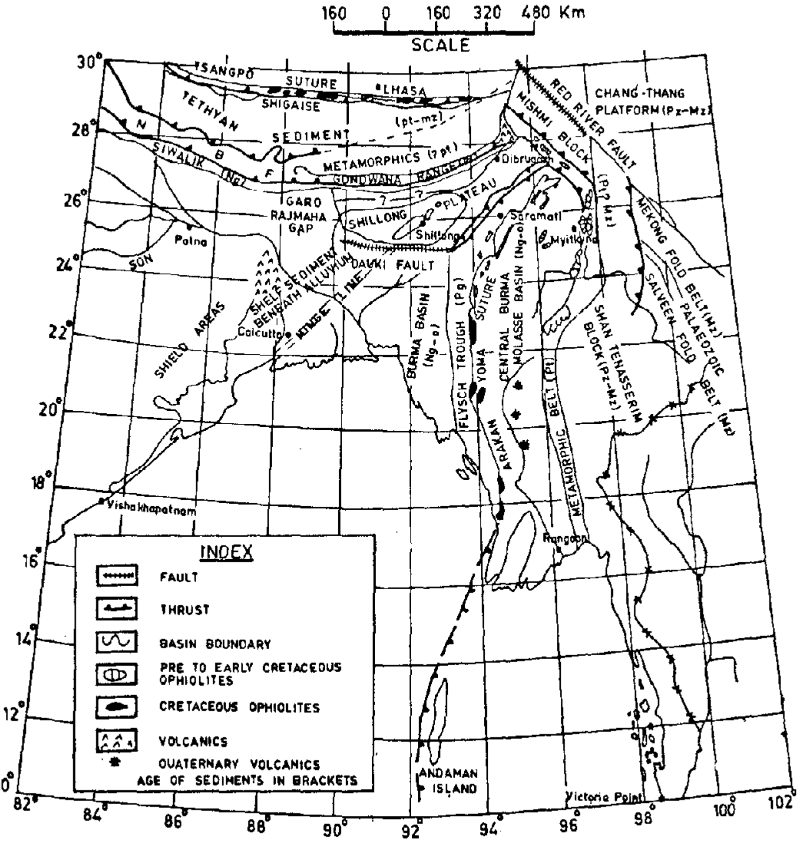
* Prepared by the staff of the Department of Earthquake Engineering, University of Roorkee, Roorkee, India.

** Great earthquakes responsible for devastation over a large area generally exceed magnitude 7.8 and the smallest shock reported felt by persons are near magnitude 2. Earthquakes with magnitude from 2 to 4.5, strongly felt by people but not resulting in damage, are generally classified as minor and those causing damage to weak structure are usually of magnitude around 5. Medium size earthquakes with shallow depth of focus range from magnitude 4.5 to 6.5 and are destructive in regions with structures which are poor in construction or faulty in design. Major earthquakes with magnitudes exceeding 6.5 lead to significant damage and often result in the collapse of well built structures designed without any earthquake consideration.

GENERALISED TECTONIC MAP
OF
NORTH EAST INDIA AND ADJOINING AREAS



After Nandy 1976

FIG.1

North-East India and adjoining areas (Nandy, 1976). The region can be broadly subdivided into four geotectonic units.

1. Arunachal Himalaya
2. Lohit Himalaya
3. The Patkoi-Naga-Lusai-Arakan Yoma (Indo-Burman) hill ranges.
4. Shillong Plateau-Assam Basin.

Arunachal Himalaya (previously described by many workers as the North Eastern Himalaya) are bounded by Siwalik foothills along its southern margins, which are separated by the Permo-Carboniferous (Gondwana) belt towards the north by the Main Boundary Fault. The Gondwana belt farther north is overlain by a discontinuous belt of dolomite orthoquartzite sequence of rocks (Baxa). The higher hill ranges of Arunachal Himalayas occur north of these belts and consist of metamorphic rocks and gneisses with occasional intrusive granites. This "belt is thrust/reverse faulted over the unmetamorphosed Gondwana and/or the Baxas" (Nandy, op.cit.). "The Palaeozoic-Mesozoic Sediments found in Bhutan Himalayas towards west are noted to be absent in Arunachal Predesh" (Nandy, op. cit.). The Main Central Thrust (MCT) of the Himalaya mapped in Nepal and further west, cannot be recognized in Arunachal Himalaya, and may have taken a north eastward swing and passed beyond Indian territory (Nandy, op. cit.). "This thrust delimits the southern boundary of the Palaeozoic-Mesozoic Tethyan basin. Further to the north a narrow belt of Cretaceous flysch and Ophiolites occurs along the east-west course of the Tsangpo (Brahamputra) river..." (Nandy, op. cit.) and this Tsangpo suture is considered by several workers to represent the zone along which Indian Plate collided with the Eurasian Plate by closing the Tethya sea due to north-ward movement of the Indian Plate. Arunachal Himalaya show a general E-W trend in its western part and gradually takes a ENE-WSW to NE-SW trend in its eastern parts. The trend terminates against a NE-SW trending lineament (Siang fracture zone).

The geology of the Lohit Himalaya (Nandy, 1973) differs considerably from that of Arunachal Himalaya and NE-SW trending metormorphic rocks occur along the foothills in contact with the Brahamputra alluvium. Towards the south-east this metamorphic belt is thrust over the Plio-Pleistocene and Miocene formations along the WNW-ESE to NW-SE trending Mishimi thrust and has also overridden the north east trending thrust belt of the Naga-Patkoi hills. The Mishmi thrust is believed to take a westward swing in the Dibang valley and join the Main Boundary Fault. The metemorphic belt is overridden by the Diorite-granodiorite complex of the Mishmi block along the NW-SE trending high angle Lohit Thrust (Nandy, 1976). Across the strike to the north-east, the Mishmi block is structurally continuous with the Chang Thang Platform in China.

The Indo-Burman area consist of a number of distinct compressional structures with N-S to NE-SW trend. These linear geotectonic belts from the Indian shield to the Shan Tenasserin block (Figure 1) consist of (1) Bengal and Assam shelf south-west and north-east of Shillong Plateau respectively, (2) Bengal Basin, (3) Surma Basin, (4) Naga-Arakan-Yoma Flysch Trough, (5) Arakan Yoma Suture Zone with metamorphic and sedimentary Palaeozoic rocks, (6) Central Burman Molasse Basin, and (7) Mogok Metamorphic belts (Nandy 1976). Zone 1 and 3 to 6 take a NE-SW trend to the north and terminate against the metamorphic belt of the Mishmi hills. Bengal basin in zone 2 dwindles towards the north and wedges out along the southern margin of the Shillong Plateau, and the Assam basin north-east of Shillong Plateau is affected by the Naga-Lusai thrust on its eastern borders. Araken Yoma Suture zone with a series of thrust slices (Brunnsschweiler, 1966 in Nandy 1976) forms a complex and tectonically disturbed belt in the Indo-Burman region. According to Nandy (op.cit.) "Eastern sector of Indian Plate (both Oceanic and Continental) collided with the Shan Tenasserin block in a Oceanic crust/island arc/continent setting along this suture and may have been caused due to east-north-eastward movement of the Indian Plate along the Carlsberg ridge".

Shillong Plateau, and its north easternly protruding spur forming the basement of the alluvium and unfolded Tertiary rocks of Assam basin, form a triangular crustal block which is surrounded by Arunachal Himalaya towards north-west, Lohit Himalaya towards northeast, the Indo-Burman fold belt towards south-east, the Bengal-Surma basins on the south, and the Rajmahal-Garo-Sylhat gap towards the west. The boundaries of each of these geotectonic units with the "Shillong Plateau-Assam Basin" area represent a zone of regional thrust-faults, the Great Boundary Fault towards north-west, the Mishmi and Lohit thrusts towards north-east, the Naga Thrust belt towards south-east, the Dauki Tear fault toward south which merges with the Haflong-Disang thrust zone towards east, and the Dhubri tear fault towards the west. "Shillong Plateau-Assam Basin" thus has been affected by major dislocations along its boundary, and the existence of the criss cross pattern of faults and shatter belts in Shillong Plateau and Mikir hills along which straight valleys have been carved out as well as the existenc of a criss cross pattern of faults affecting the Tertiary rocks in Assam basin reveals that the area has suffered great distress due to the northward and eastward movement of the Indian plate. The frequency magnitude analysis of earthquake occurrence in the area as described later indicates the presence of high shear stress and the area thus predictably shows the highest seismic activity of any region in the world.

EARTHQUAKE OCCURRENCE

Though earthquakes are felt almost daily in the various parts of North-East Indian and surrounding areas, so far only two seismological observatories have been established in the region at Shillong and Tocklai. The observatory at Tocklai is equipped with a Wood-Anderson Seismograph at 1000 magnification and that at Shillong is equipped with a set of short period Benioff seismographs under the World-Wide Standardized Seismograph Network (WWSSN) scheme working at a peak magnification 200 K (Choudhury and Srivastava, 1976) in addition to other seismographs. According to Choudhury and Srivastava (1976) analysis of seismograms for events within the epicentral distance of 440km around Shillong show that 2500 earthquakes were recorded during the years 1970-1973. Though the magnitudes of most of these events were too small to be determined by Wood-Anderson Seismographs, the data reveal the high active seismicity of the Shillong plateau. In the absence of a suitable array of short period high magnification seismological instruments such micro-to-medium size earthquakes are not being recorded, and without such data it is difficult to carry out a detailed study of the occurrence, mechanism, size and depth of focus of various earthquakes, evaluate the seismic status of the faults and other tectonic lineaments, estimate the potential seismic risks and design earthquake parameters, and predict the probable location of large size earthquake occurrence in the future.

The available information on earthquake occurrence in North-East India consists of data on medium size to great earthquakes from historical records and instrumental records at various seismological observatories at Shillong and other parts of India and abroad. These data have been analyzed by various investigators to study the mode of earthquake occurrence in terms of epicentral distribution, frequency-magnitude relationships, precursory variation of seismicity rates, energy release, tectonic flux, focal mechanisms, intensity of earthquakes, seismic risks, design earthquake parameters, and seismic regionalization and zoning.

The earthquake frequency magnitude relationship in North-East India has been studied by various workers. It has been well established that the b-value in the earthquake frequency magnitude relationship ($\log_{10} N = a-bM$) can be taken as parameter indicating the level of tectonic stresses operative in the region, and the b-value exhibits significant differences between different earthquake regions as well as between different depth ranges. Choudhury and Srivastava (1976) give a b-value of 1.08 ± 0.24 for North-East India. A similar estimate was given earlier by Evernden (1970, in Choudhury and Srivastava, 1976) for an area within 1000 km of Shillong. These values have been determined by combining the data from different geotectonic units and thus the value is close to the average value (b=1.15) for the earth as a whole. The frequency-magnitude relation of microfracturing in rock as measured in laboratory experiments show lower b-values under high shear stress (Scholz, 1968). Similar conclusions were made by Wyss (1973) based on a study of earthquake occurrence in the Denver region. Khatri, Rogers and Perkins (1978, personal communication) have studied frequency magnitude relationship of the (1) Himalayan belt, (2) "Shillong Plateau-Assam Basin" and Lohit Himalayan zone covering the seismic activity associated with the great 1950 earthquake referred to as the Assam gap, and (3) Indo-Burman belt between Shillong Plateau and Shan Tenasserin Block, based on data on earthquake occurrence from 1825 to 1977. The b-values (Table I) in these three tectonic units are noted to be 0.76, 0.45 and 0.58 respectively, indicating that the Shillong Plateau-Assam Basin-Lohit Himalaya belt possess higher shear stress as compared to the adjacent geotectonic units. Molnar et. al. (1973) had also inferred a lower b-value for the North-East India region and had considered this as one of the indications of higher shear stress in Asia than in most regions.

TABLE I

Frequency-Magnitude Relationship in North-East India

$\log_{10} N = a-bM$

(Khattri, K.N., Rogers, A.M. and Perkins, D.M., 1978, personal communication).

Geotectonic Unit	a (40 year period)	b
Himalaya	5.6	.76
Shillong Plateau-Assam-Basin-Lohit Himalaya	3.8	.45
Indo-Burman belt	4.6	.58

Khattri and Wyss (1977) studied seismicity variations as a function of time in this belt and have noticed that "no major earthquake occurred without an associated anomaly in terms of periods of seismic quiescence. The most remarkable periods of quiescence in this belt lasted 28 to 30 years approximately before the two great 1897 and 1950 Assam earthquakes. Table II shows the periods of anomalously low seismicity preceding major earthquakes in the three zones of this belt (1) "a zone enclosing roughly the meizoseismal area of the Great Assam Earthquake of 1897" (2) a zone defining the gap between the two Great Assam Earthquakes of 1897 and 1950" and (3) a zone covering the seismic activity associated with the Great Assam Earthquake of 1958, with some overlap between the zones".

TABLE II

Precursor Times for Seismicity Anomalies of Assam Earthquakes
(Khattri and Wyss, 1977)

Area	Date	M	Precursor time (Years) decrease	 peak
Meizoseismal area of Great Assam Earthquake of 1897	1897	8.7	28	
	1950	6.7	8	
	1975	6.7	6	10
	1869	7.8	23	
Zone defining the gap between the two Great Assam Earthquakes of 1897 and 1950.	1947	7.9	17	
	?	7.25	8	
Zone of seismic activity associated with the Great Assam Earthquake of 1950.	1950	8.7	30.0	

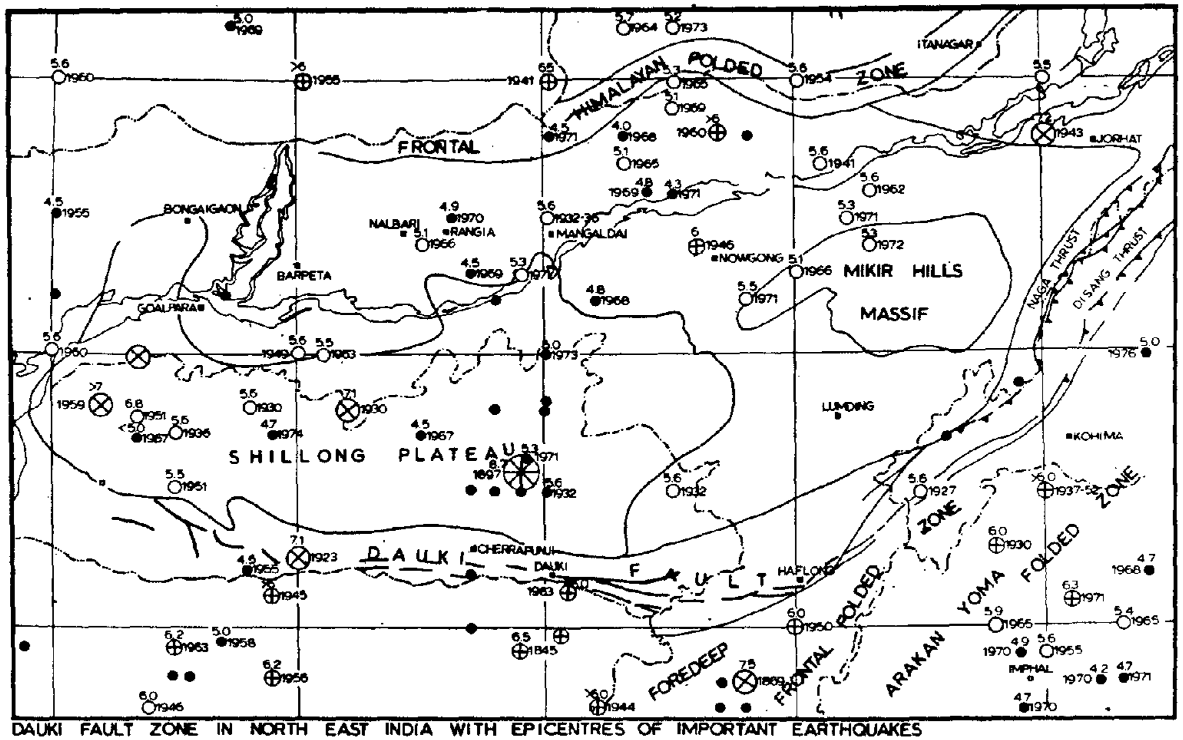
Khattri and Wyss (1977) consider low seismicity periods in this belt to be precursory anomalies indicative of major earthquakes to follow, and have taken the precusor time as the duration from the beginning of the seismicity decrease to the large earthquake terminating the anomalous period (Table II). The precurser times reported by Khattri and Wyss (1977) for this belt "are the longest one reported to date and they are for the largest earthquakes for which precursors have been observed". The area of seismic gap between the two Great Assam Earthquakes of 1897 and 1950 has been relatively quiet since 1950 "not because earthquakes never occur but because the preparatory process for a future great earthquake may have begun" in the area. It may be pointed out "that the data available do not warrant an earthquake prediction," but indicates the probabilities of occurrence of a great earthquake in the future and intensive search for other precursors should be made by carrying out seismicity studies with local seismic instrument networks and magnetic, gravity, geodetic, radon, resistivity and water level measurements. Accordingly a detailed program of geo-seismological investigations for earthquake observation research and search for precursors in North-East India has been prepared and the investigations are likely to be taken up in the near future depending on the availability of funds.

The Shillong Plateau, which was the scene of one of the greatest earthquakes in history in 1897 with a magnitude 8.7 has a seismic activity about as great as any region in the world. The region is bounded by seismically active regional thrust faults, and the Dhubri tear fault forms the Western boundary. The Dauki fault forming the southern boundary of the plateau is the most active fault zone of the region. This fault zone merges with the Haflong-Disang thrust zone forming the eastern boundary of the plateau. Towards the north, the plateau is separated from the Assam basin by east-west trending basement faults. An epicenter map for the Dauki fault zone region is given as Figure (2).

As mentioned above, small earthquakes are felt almost daily in various parts of North-East India. Twenty earthquakes with magnitude greater than 5.8 and ten earthquakes with magnitude greater than 6.5 have occurred along southern and eastern boundary of the Shillong Plateau, east of Dauki and north and northeast of Haflong during the last 70 years. The intervening Dauki-Haflong fault zone has shown medium local seismicity during this period forming a seismic gap along the Dauki-Haflong fault zone. The frequency-magnitude distribution gives an a-value of 3.8 (40 year period value) and a b-value of 0.45. The low b-value indicates existence of high shear stress in the region. The observed precursor times for earthquake occurrence in the past in the meizoseismal area of the great Assam earthquake of 1897 are noted to be 23, 28, 8 and 6 years for earthquakes of magnitude 7.8 (1869), 8 (1896), 6.7 (1950) and 5 (1975). The probability per ten years of ground acceleration greater than 0.2g($M > 6.5$) is thus very high and is estimated at 0.8.

A PROPOSED STRONG MOTION EARTHQUAKE INSTRUMENT ARRAY FOR NORTH-EAST INDIA

At present, only two strong motion instruments are operating in the area described above. The proposed strong motion earthquake instrument array for this area would thus not only be of great significance for evaluation of seismic hazards of the region, but the data obtained would be of



DAUKI FAULT ZONE IN NORTH EAST INDIA WITH EPICENTRES OF IMPORTANT EARTHQUAKES

FIG. 2

great value for scientists all over the world. The design of the proposed arrays follows the recommendations of the Honolulu workshop, and basic considerations may be summarized as follows: (Iwan, 1978).

For a large earthquake the rupture process can extend hundreds of kilometers and may last several minutes. At present the dynamics of the source has been interpreted from observations of long period waves (5-300sec) recorded at great distances from the faults which provide average properties of the source. To obtain information relevant to engineers, a detailed knowledge of the short wave length high frequency nature of the source is needed, which can only be obtained by recording in the near source region. Figure (3) shows a permanent source mechanism and path effect strong motion earthquake instrument array along Dauki and Haflong-Disang fault zones, of approximately 300 km length, designed to monitor strike-slip as well as dip-slip reverse fault mechanisms respectively. A comb shaped array has been designed for the former and a two dimensional array for the latter. This array would answer questions such as: How fast does the fault rupture grow, how smooth is this growth, how does this acceleration vary as a function of azimuth, and is the ground motion maximum at the fault or at some distance away from the fault. A small mobile array is also proposed, which could be moved into the meizoseismal area of a major earthquake in this region within a few days after the event. While the permanent array will stay in the area for many years, the mobile array would record many aftershocks of magnitude 6-7 in the same time period. Thus the information returned would be very high.

It has been observed that geological structure along the wave path and local site conditions introduce considerable complexities in ground motion due to dispersion and interference of body and surface waves, attenuation, reverberations, focussing and defocussing, wave convergence etc. Therefore, a few local effects arrays have been proposed for installation in the region as follows: a) Local Laboratory Array near Lumding over a 2 km diameter flat area with sedimentary formations (shear wave velocity exceeding 100m/sec) with soil cover extending from 30 to 100 mts (shear wave velocity varying from 200 to 600 m/sec) in depth; and b) Simple Extended Array around the proposed high dam across Barak river in Manipur and near Shillong.

The national strong motion instrumentation network of the country would be linked with the above source mechanism and local effects array and strengthened with additional elemental arrays to provide data on local effects and answer questions of engineering significance under various geological, topographical and soil conditions. The elemental arrays being relatively inexpensive would be distributed widely to enhance the chances of picking up data in the national strong motion network. When the proposed arrays are well established the work on installation of special arrays for study of soil structure interaction, liquefaction and behavior of models as well as prototype structures would be initiated.

For successful installation, operation and utilization of data of the strong motion earthquake instrument arrays in order to record strong ground motion of potentially damaging earthquake within the next ten years the following items are of importance: (i) the availability of field tested instrumentation suitable for use under adverse field conditions in a program in which data are obtained infrequently over a ten or twenty year period

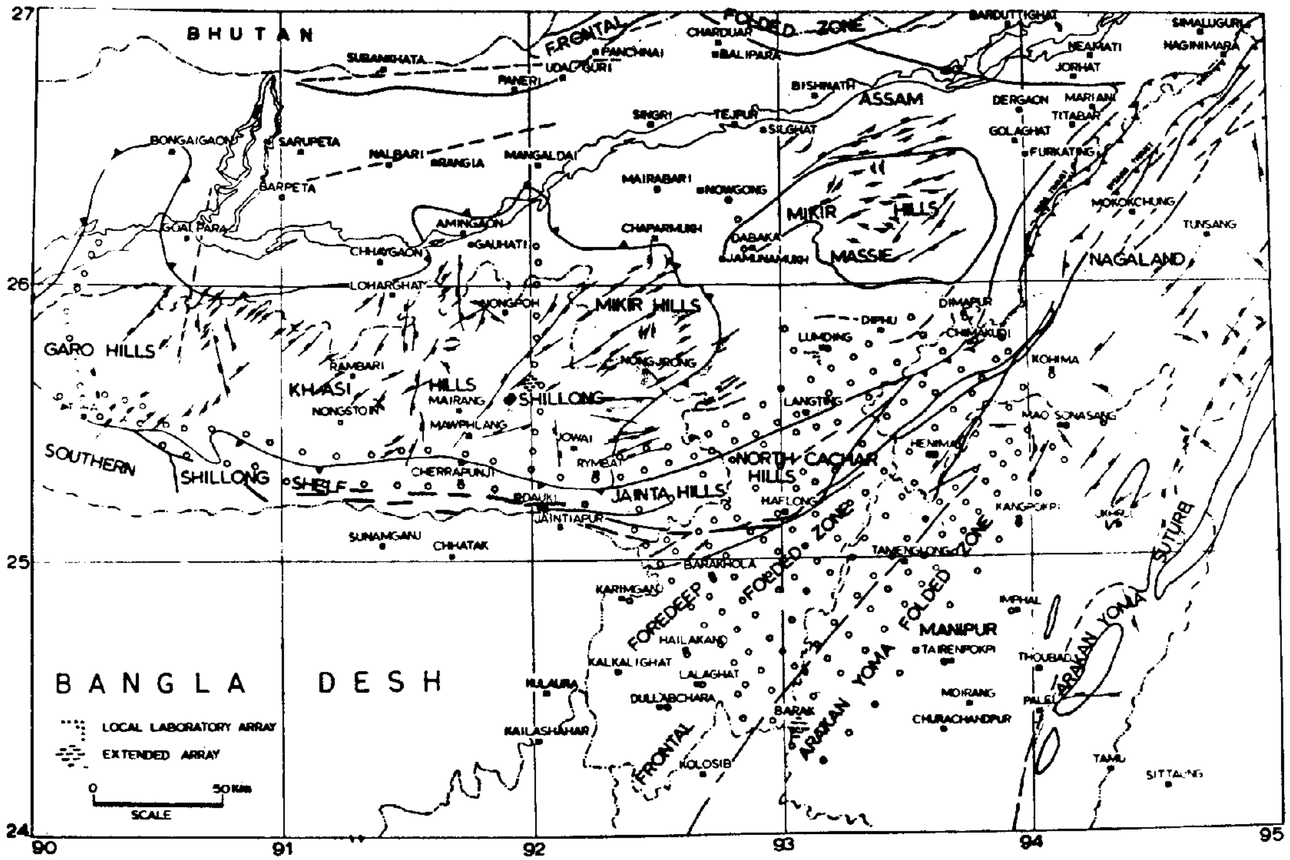


FIG.3_STRONG MOTION EARTHQUAKE INSTRUMENTS ARRAY IN NORTH EAST INDIA SHOWING TENTATIVE INSTRUMENT LOCATIONS

(ii) the cost of establishment and operation of the array (iii) the availability of local personnel to maintain the instruments and (iv) the existance of an organization to act as data center to assemble the data, to process it in a standard manner for interpretation and application, and to disseminate the data for the use of the international community of scientists and engineers.

Development models of accelerographs of a type suitable for the present application have been designed and fabricated by the University of Roorkee. These accelerographs have analog recording of ground motion on photographic paper. The system is triggered by motion exceeding a preset threshold level and continues to record data for the duration of the earthquake with capability of recording numerous events with incoming signals as high as 1g or greater. The instrument gives a time history record of strong ground motion without any pre-event memory and with no standard world time signals. These accelerographs have been designed, fabricated and tested in the laboratory, but they have not yet undergone rigorous field deployment and recording of earthquakes. For the proposed arrays it is highly desirable to install instruments which have had many years of successful field experience. In view of the relatively large number of instruments required, it is also desirable that the accelerographs be available on the open market, and that the recorded data is available in a form that can be widely disseminated, and easily introduced as an input to high speed digital computers.

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PROJECT NO.1-APPENDIX IIa

ESTIMATED EXPENDITURE FOR SHILLONG ARRAY

I Source Mechanism and Wave Propagation Array (Strike-slip and thrust faults)

A. Array

Non-recurring Expenditure	US Dollars (x 1000)	Indian Rs. (x 1000)
(i) Cost Instruments		
a) 200 Analog surface 4500 x 200	900.	-
b) 50 Digital surface 7500 x 50	375.	-
(ii) Cost Site preparation, instrument housing and installation	-	2,500
(iii) Cost of site investigations	-	100
(iv) Laboratory facilities, spare parts, repairs and test equipment	375.	50
(v) Building for control office and central instrument shop at Shillong -300 sq. m.	-	475
(vi) Vehicles 4 No. Rs. 60,000 (Four wheel drive)	-	240
	1,650.	3,365
Recurring Annual Expenditure		
(vii) Personnel	-	900
(viii) Materials and Stores	25.	30
(ix) Travel and Vehicle Maintenance	-	50
(x) Contingent expenditure	-	20
	25.	1,000

B. Data Center at Roorkee

Non-recurring Expenditure		
(i) Equipment for reproduction and copying of recorded analog and digital data	100.	25
(ii) Terminal Facility with computer center	2.	25
(iii) Building including interior preparation for air conditioning and furniture 200 sq. m.	-	200
(iv) Air conditioning of 100 sq. m. of the building in item (iii)	-	250
	102.	500

Recurring Annual Maintenance

(v) Personnel	-	100
(vi) Materials and Stores	-	30
(vii) Travel and contingent expenditure	-	30
	-	160

C. Training of Indian Personnel

(i) Travel	-	60
(ii) Per diem in USA	Included in A(i) and A(iv)	

D. Visits of US Personnel

(i) Travel	To be provided separately
(ii) Per diem in India (excluding salaries)	by NSF

II Mobile Array

Non Recurring Expenditure

(i) Cost of Instruments		
a) 25 Analog Surface 4500 x 25	107.5	-
b) 25 Digital Surface 7500 x 25	182.5	-
(ii) Spare parts etc.	30.	20
	320.	20

Recurring Expenditure

(iii) Contingency Reserve for Array Mobilization	-	100

Recurring Annual Expenditure

(iv) Personnel	Included in I(A) (vii)	
(v) Materials and Stores	7.5	10
	7.5	10

Data Center provided for in Project I will serve for this also.

III Local Extended Arrays at Two Sites

Non Recurring Expenditure

(i) Cost of Instruments		
a) 24 Digital surface 7500 x 24	180.	-
b) 4 Digital Downhole 15000 x 4	60.	-

(ii) Site Preparation, instrument housing and installation	-	320
(iii) Spare Parts etc.	24	-
	264.	320

Recurring Annual Maintenance

(iv) Personnel	Included in I(A) (vii)	
(v) Materials and Stores	5.	10
(vi) Travel and contingent expenditure	-	20
	5.	30

IV Local Laboratory Array

Non-recurring Expenditure

(i) Site Investigations		50
(ii) Instruments including spare parts 7-surface triaxial accelerometer units with recorders (21 channels x $1800)	37.8	-
1 down hole installation, 7 triaxial accelerometer units and recorders (21 channels x $2500)	52.5	-
2 down-hole installations each with 2 triaxial accelerometer units and recorders (18 channels x $2500-1/4)	45.	-
5 down-hole installations each with 2 triaxial accelerometer units and recorders (30 channels x $2500)	75.	-
Data Cable	14.	100
Spare parts and supplies	42.	-
(iii) Installation		
a) Surface	-	70
b) Down-hole	-	830
(iv) Laboratory headquarters building and interior preparation. 100 sq.mts. approx.	-	125
(v) Testing and Maintenance of equipment	50.	-
	316.3	1,175

Recurring Annual Maintenance

(vi) Personnel	-	100
(vii) Materials and Stores	5.	10
(viii) Travel and contingent expenditure	-	10
	5.	120

PROJECT NO.1-APPENDIX IIb

Estimate of Costs

TEN YEAR PROJECT SUMMARY

Priority and Description	1st year total		2nd year total		3rd year total		4th year total		Succeeding year Maintenance	
	US $ (x1000)	Indian RS. (x1000)	US $ (x1000)	Indian Rs. (x1000)	US $ (x1000)	Indian Rs. (x1000)	US $ (x1000)	Indian Rs. (x1000)	US $ (x1000)	Indian Rs. (x1000)
I (Source Mechanism and Wave Propagation Array)										
A. Array	737.5	1,340	750.	2,525	25.	1,000	25.	1,000	25.	1,000
B. Data Center	102.	580	-	160	-	160	-	160	-	160
C. Training (Indians)	-	60	-	60	-	-	-	-	-	-
D. Visits (American)	To be provided separately by NSF									
II Mobile Array	-	-	-	-	327.5	130	7.5	10	7.5	10
III Local Extended Arrays	-	-	-	-	134.	16	137.	350	5.	30
IV Local Laboratory Array	-	-	-	-	161.	185	163.	970	5.	120
	839.5	1,980	750.	2,745	647.5	1,491	332.5	2,490	42.5	1,320

Expenditure for 10 years	US $(x1000)	Indian Rupees(x1000)
First year	839.5	1,980
Second year	750.	2,745
Third year	647.5	1,491
Fourth year	332.5	2,490
Next Six years	255	7,920
	2,824.5	16,626

PROJECT NO.1-APPENDIX III

YEARLY PROGRAM

Work Schedule

Priority	Array Description	1st year	2nd year	3rd year	4th year	Succeeding years
I	(Source Mechanism and Wave Propagation Array)					
A.	Array	1/2 Cost of instrument, lab facilities, spare parts etc. Site investigations Building, Vehicles, 1/2 Annual maintenance	1/2 cost of instruments, lab facilities, spare parts etc. Installation, Annual maintenance	Annual Maintenance	Annual Maintenance	Annual Maintenance
B.	Data Center	-do-	-do-	-do-	-do-	-do-
C.	Training	International travel of 4 scientist/ technicians	International travel of 4 scientist/ technicians	nil	nil	nil
II	Mobile Array	nil	nil	Cost of equipment, spare parts, etc. Annual maintenance	Annual Maintenance	Annual Maintenance
III	Local Extended Arrays (Two Sites)	nil	nil	1/2 cost of instrument spare parts etc. 1/2 Annual maintenance	1/2 cost of instruments, spare parts, etc. Annual maintenance installation	Annual Maintenance
IV	Local Laboratory Array	nil	nil	-do-	-do-	-do-