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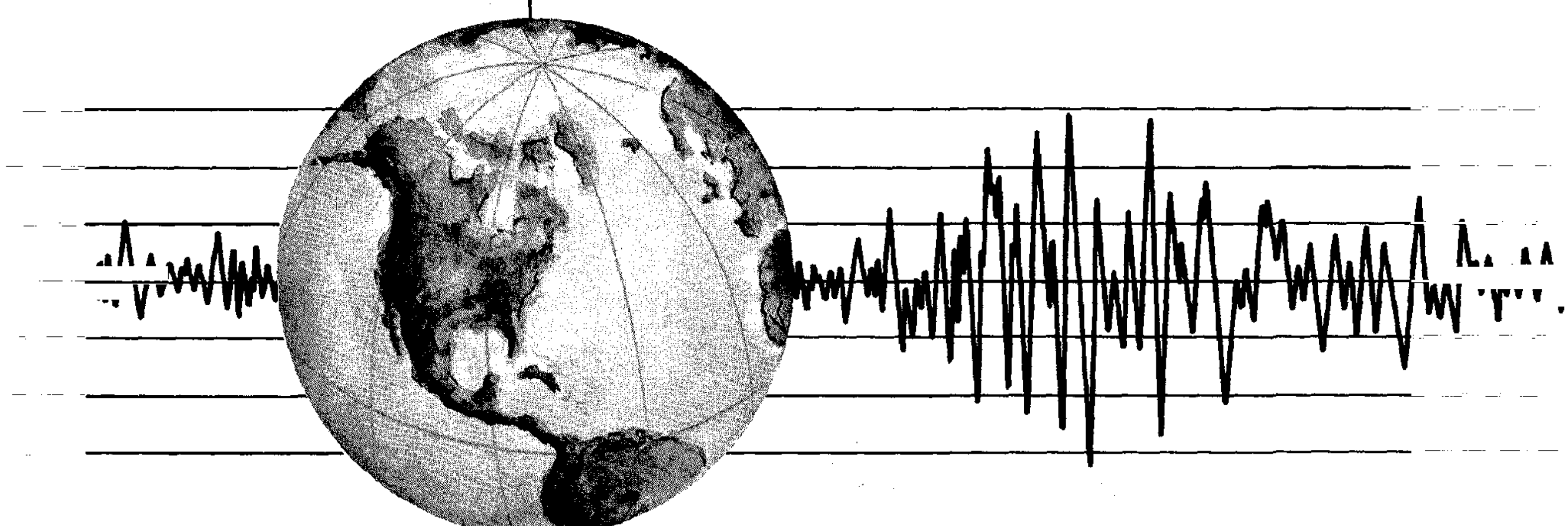
RECOMMENDATIONS FOR A U.S.-JAPAN COOPERATIVE RESEARCH PROGRAM UTILIZING LARGE-SCALE TESTING FACILITIES

by

U.S.-JAPAN PLANNING GROUP
COOPERATIVE RESEARCH PROGRAM
UTILIZING LARGE-SCALE TESTING FACILITIES

Report to
National Science Foundation



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Presented herein are recommendations for one possible U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities to be conducted under the auspices of the U.S.-Japan Panel On Wind And Seismic Effects, U.J.N.R. Program. These recommendations have been prepared by the U.S.-Japan Planning Group, Cooperative Research Program Utilizing Large-Scale Testing Facilities. Section II of this report sets forth the objective of the recommended program, Section III provides background information pertinent to the report, Section IV presents summaries and resolutions of the four U.S.-Japan Planning Group Meetings, Sections V, VI, VII, and VIII describe recommended research related to reinforced concrete building structures, steel building structures, pseudo-dynamic test method, and analytical studies, respectively, and Section IX presents concluding remarks on the overall cooperative program.

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RECOMMENDATIONS FOR A U.S.-JAPAN COOPERATIVE RESEARCH PROGRAM UTILIZING LARGE-SCALE TESTING FACILITIES

to be conducted under
the auspices of

U.S.-JAPAN PANEL ON WIND AND SEISMIC EFFECTS
U.J.N.R. PROGRAM

by

U.S.-JAPAN PLANNING GROUP
COOPERATIVE RESEARCH PROGRAM
UTILIZING LARGE-SCALE TESTING FACILITIES

Submitted to

PROBLEM FOCUSED RESEARCH DIVISION
DIRECTORATE OF ENGINEERING AND APPLIED SCIENCE
U.S. NATIONAL SCIENCE FOUNDATION

Report No. UCB/EERC-79/26
Earthquake Engineering Research Center
College of Engineering
University of California
Berkeley, California

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FOREWORD

Financial support for U.S. participation in the U.S.-Japan Planning Group activities was provided by the National Science Foundation (NSF) under grant No. ENV-76-80835, $94,270, to the University of California, Berkeley. This final report to NSF outlines a recommended cooperative research program which simply reflects the combined views of the planning group in developing one possible program believed to be technically sound with high potential of yielding valuable results of mutual value to both Japan and the United States. It is hoped that this report will be of assistance in the development of other recommended programs.

JOSEPH PENZIEN
Principal Investigator

PREFACE

A U.S.-Japan Planning Group was established in the summer of 1977 to develop recommendations for a cooperative research program utilizing large-scale testing facilities. This group has conducted its activities under the auspices of the U.S.-Japan Panel on Wind and Seismic Effects, United States-Japan Natural Resources (U.J.N.R.) Program over the past two years culminating with the recommendations contained herein. Membership of the planning group consisted of H. Aoyama, University of Tokyo, V. Bertero, University of California, Berkeley, B. Bresler, University of California, Berkeley, G. Corley, Portland Cement Association, R. Hanson, University of Michigan, J. Jirsa, University of Texas, B. Kato, University of Tokyo, S. Kokusho, Tokyo Institute of Technology, E. Leyendecker, National Bureau of Standards, L. W. Lu, Lehigh University, S. Mahin, University of California, Berkeley, A. Mattock, University of Washington, Y. Ohsaki, University of Tokyo, K. Ohtani, National Center for Disaster Prevention, T. Okada, University of Tokyo, T. Okubo, Public Works Research Institute, J. Penzien, University of California, Berkeley, A. Shibata, University of Tohoku, M. Sozen, University of Illinois, Urbana-Champaign, H. Umemura, University of Tokyo, M. Wakabayashi, Kyoto University and M. Watabe, Building Research Institute.

Joseph Penzien
Hajime Umemura

Coordinators
U.S.-Japan Planning Group

ACKNOWLEDGEMENT

The Planning Group expresses sincere thanks and appreciation to (1) the many individuals from the academic community, industry, and government who contributed to the development of the technical recommendations contained herein, (2) the representatives of government agencies, particularly the U.S. National Science Foundation and the Science and Technology Agency and Ministry of Construction of Japan, who actively pursued implementation plans, and (3) the institutions and government agencies in both countries which provided financial support to the planning activities.

DISCLAIMER

Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the Planning Group and they do not necessarily reflect the views of the National Science Foundation.

I. SUMMARY

Presented herein are recommendations for one possible U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities to be conducted under the auspices of the U.S.-Japan Panel On Wind And Seismic Effects, U.J.N.R. Program. These recommendations have been prepared by the U.S.-Japan Planning Group, Cooperative Research Program Utilizing Large-Scale Testing Facilities. Section II of this report sets forth the objective of the recommended program, Section III provides background information pertinent to the report, Section IV presents summaries and resolutions of the four U.S.-Japan Planning Group Meetings, Sections V, VI, VII, and VIII describe recommended research related to reinforced concrete building structures, steel building structures, pseudo-dynamic test method, and analytical studies, respectively, and Section IX presents concluding remarks on the overall cooperative program.

II. OBJECTIVE

The overall objective of the recommended program is to improve seismic safety practices through studies to determine the relationship among full-scale tests, small-scale tests, component tests, and analytical studies. The program has been designed to (1) achieve clearly stated scientific objectives, (2) represent total building systems as realistically as possible, (3) balance the simplicity and economy of test specimens with the need to test structures representing real situations, (4) maintain a balance among small-scale, component, and full-scale tests, (5) utilize previously performed experiments and studies to the extent practical, (6) represent the best design and construction practice in use in both countries, (7) check the validity of newly developed earthquake-resistant design procedures, (8) maintain flexibility to accommodate new knowledge and conditions as successive experiments are completed, and (9) assure the practicability of program results.

III. BACKGROUND INFORMATION

Following the 1968 Tokachi-Oki earthquake in Japan, during which numerous reinforced concrete school buildings of modern design suffered heavy damages, it was apparent that every effort should be made to improve new designs through (1) learning as much as possible from the experience of the Tokachi-Oki earthquake, (2) reviewing and considering possible changes in building codes, (3) improving design and construction practices, and (4) initiating programs of needed research. Responding to this need, a joint seminar under the sponsorship of the U.S.-Japan Cooperative Science Program was held in Sendai, Japan, during the period 21-26 September 1970 for the purpose of (1) reviewing, in depth, the causes of damage sustained by modern school buildings during the Tokachi-Oki earthquake, (2) examining design and construction methods, and (3) identifying and defining needed programs of research which could be conducted more effectively on a cooperative basis. The official participants of this seminar were H. Aoyama, University of Tokyo, R. Hanson, University of Michigan, P. Jennings, California Institute of Technology, H. Kobayashi, Tokyo Institute of Technology, K. Lee, University of California, Los Angeles, K. Ogura, Meiji University, K. Ohno, Hokkaido University, J. Penzien, University of California, Berkeley, J. Roesset, Massachusetts Institute of Technology, T. Shiga, Tohoku University, M. Sozen, University of Illinois, H. Umemura, University of Tokyo, and M. Wakabayashi, Kyoto University. J. Penzien and H. Umemura served as coordinators of the seminar. The proceedings of this seminar (Proceedings of the U.S.-Japan Seminar on Earthquake Engineering with emphasis on the Safety of School Buildings - 466 pgs.) was published by the Japan Earthquake Engineering Promotion Society.

A second joint seminar under the sponsorship of the U.S.-Japan Cooperative Science Program was held in Berkeley, California, during the period 4-8 September 1973 for purposes of reviewing (1) the causes of damages sustained by reinforced concrete structures during the 1971 San Fernando earthquake (2) current research on earthquake resistant design, (3) the safety of existing structures and means of upgrading their resistance, and (4) post-earthquake damage repair. The official participants of this seminar were H. Aoyama, University of Tokyo, V. Bertero, University of California, Berkeley, B. Bresler, University of California, Berkeley, G. Corley, Portland Cement Association, A. Cornell, Massachusetts Institute of Technology, R. Hanson, University of Michigan, M. Hirosawa, Building Research Institute, S. Ikeda, Tokyo Metropolitan University, P. Jennings, California Institute of Technology, J. Jirsa, University of Texas, K. Kubo, University of Tokyo, A. Mattock, University of Washington, J. Penzien, University of California, Berkeley, Y. Ozaka, Tohoku University, M. Sozen, University of Illinois, and M. Wakabayashi, Kyoto University. B. Bresler and K. Kubo served as coordinators of the seminar.

Prompted by informal discussions held at the Sendai seminar, a U.S.-Japan Cooperative Research Program on Earthquake Engineering with Emphasis on the Safety of School Buildings was established under the U.S.-Japan Cooperative Science Program for the period May 1973 - October 1975. The cooperative research in this program was conducted by B. Bresler, T. Okada, J. Penzien, and M. Murakami at the University of California, Berkeley, by A. Shibata and M. Sozen at the University of Illinois, and by R. Hanson and T. Nishikawa at the University of Michigan. J. Penzien and H. Umemura served as coordinators of this program.

A review meeting of the cooperative research program emphasizing the safety of school buildings was held at the East-West Center, University of Hawaii during the period 18-20 August 1975. The official participants of this meeting were H. Aoyama, University of Tokyo, B. Bresler, University of California, Berkeley, R. Hanson, University of Michigan, P. Jennings, California Institute of Technology, S. Kokusho, Tokyo Institute of Technology, T. Okada, University of Tokyo, J. Penzien, University of California, Berkeley, A. Shibata, Tohoku University, M. Sozen, University of Illinois, and H. Umemura, University of Tokyo. The nineteen technical papers presented at this meeting have been published by the Japan Earthquake Engineering Promotion Society (Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings). J. Penzien and H. Umemura served as coordinators of the review meeting.

Based on evidence provided by the presentation and discussion of the nineteen technical papers, it was quite apparent to all participants attending the Hawaii meeting that the cooperative research program had been highly successful. With this experience in mind, a set of RECOMMENDATIONS FOR U.S.-JAPAN COOPERATION IN THE FIELD OF EARTHQUAKE ENGINEERING was drafted and signed by all official participants of the meeting. Recommendations Nos. 2 and 3 read as follows:

RECOMMENDATION NO. 2 -- Establish a Cooperative Research Program in Earthquake Engineering with Emphasis on Large-Scale Testing of Structural Systems under the sponsorship of the U.S.-Japan Panel on Wind and Seismic Effects, U.J.N.R. Program. This program would concentrate on controlled dynamic testing of full-scale buildings in the field and laboratory testing of large-scale building systems using the available specially designed testing floors and associated reaction walls and using a large-sized shaking table. These tests should be designed to provide needed information on force-deformation, energy absorption, and failure characteristics of such systems. Correlative and analytical studies should be made to improve mathematical modelling and computer-oriented dynamic analysis capability.

RECOMMENDATION NO. 3 -- Establish a Task Committee under the U.S.-Japan Panel on Wind and Seismic Effects, U.J.N.R. Program. The assignment given to this Task Committee should be to make detailed plans and recommendations for implementing Recommendation No. 2 which will ensure an effective research program of maximum benefit to both countries within the constraints of the sponsoring government agencies. In view of the time scale for constructing the presently planned test facilities and the major effort required to plan the program, the Task Committee should be appointed by the U.S.-Japan Panel on Wind and Seismic Effects at the earliest possible date. One American and one Japanese should be appointed as co-chairman to head this Task Committee.

Parallel with the above described cooperative activities of university researchers, government delegates on the U.S.-Japan Panel of Wind and Seismic Effects, U.J.N.R. Program, were taking positive steps toward strengthening such cooperative efforts. At the conclusion of its sixth joint meeting held in Washington, D.C. during the period 15-17 May 1974, the panel adopted the following resolution:

"4. that increased effort should be made in the near future to encourage joint research programs, especially in the area of mutual utilization of research facilities and the exchange of researchers."

At the panel's seventh joint meeting held in Tokyo during the period 20-23 May 1975, justification of a cooperative large-scale testing program was well stated in a paper "Earthquake Disaster Mitigation: A Joint Research Approach" presented by C. C. Thiel and J. B. Scalzi as follows:

"2. Large Scale Destructive Testing of Structures
In the area of structural analysis and design we have relied heavily on our technical capabilities with theory and computers to develop concepts for design of structures to resist earthquake forces. Many of these concepts have evolved from post-inspections of earthquake damage and shake table results. As beneficial as these concepts are, there are many factors which cannot be evaluated by inspection or small scale tests.

Among the parameters for which better data is required are: the three dimensional behavior of full size structures and individual components subjected to controlled seismic type forces, the determination of the structural damping characteristics caused by the various elements in a building, the connections of various structural components and equipment, the forces acting on various equipment caused by the interaction of the structure and the equipment, the attachment of non-structural items and other items which are either too large or too cumbersome to be handled on a shake table or confidently by analysis.

A plan to obtain the required data could be formulated by a Joint U.S.-Japan program consisting of: (a) large scale testing of existing structures of various types of materials and construction, (b) pseudo-dynamic tests on full size specimens or structures constructed to obtain specific data, (c) shake table verifications where required for the pseudo-dynamic tests or for specimens which may be considered full size.

At the present time a few projects are underway to investigate the behavior of masonry construction by pseudo-dynamic test methods. Large joint specimens of reinforced concrete frame and shear walls are being analyzed and tested by pseudo-dynamic test procedures.

The results of these tests could be verified by full size structural tests to evaluate the time behavior in a structural system. A program to extend the tests to full size structures to determine the parameters which cannot be evaluated otherwise would be most desirable and beneficial to both countries."

At its Tenth Joint Meeting, Washington, D.C., 23-26 May 1978, the U.S.-Japan Panel on Wind and Seismic Effects again indicated its strong support of the program by adopting the following resolutions:

"3. The Panel on Wind and Seismic Effects recognizes the importance of the U.S.-Japan Cooperative Program on Large Scale Testing and it urges early implementation of the program under the auspices of this Panel."

In January 1976, J. Scalzi of the National Science Foundation encouraged J. Penzien to submit a specific proposal to NSF to implement RECOMMENDATION NO. 3 quoted above, i.e., to establish a Task Committee for the planning of a cooperative research program on large-scale testing. Prompted by this encouragement and the past recommendations for cooperative research, a proposal (UCB-Eng-4227) entitled "Planning a Cooperative Research Program in Earthquake Engineering with Emphasis on Large-Scale Testing of Structural Systems" was submitted to the Research Applied to National Needs (RANN) Directorate of NSF by the University of California, Berkeley. This proposal called for the planning effort to be conducted under the auspices of the U.S.-Japan Panel on Wind and Seismic Effects. NSF responded favorably to this proposal by issuing a Grant (No. ENV-76-80835) in the amount of $85,700 for the period 15 July 1977 - 31 December 1979, with J. Penzien serving as Principal Faculty Investigator.

The planning group consisting of H. Aoyama, University of Tokyo, V. Bertero, University of California, Berkeley, B. Bresler, University of California, Berkeley, G. Corley, Portland Cement Association, R. Hanson, University of Michigan, J. Jirsa, University of Texas, B. Kato, University of Tokyo, S. Kokusho, Tokyo Institute of Technology, E. Leyendecker, National Bureau of Standards, L. W. Lu, Lehigh University, S. Mahin, University of California, Berkeley, A. Mattock, University of Washington, Y. Ohsaki, University of Tokyo, K. Ohtani, National Center for Disaster Prevention, T. Okada, University of Tokyo, T. Okubo, Public Works Research Institute, J. Penzien, University of California, Berkeley, A. Shibata, University of Tohoku, M. Sozen, University of Illinois, Urbana-Champaign, H. Umemura, University of Tokyo, M. Wakabayashi, Kyoto University, and M. Watabe, Building Research Institute, has held four meetings; Tokyo, Japan, 5-10 September 1977, San Francisco, California, 15-19 May, 1978, Tokyo, Japan, 18-23 December, 1978, and Berkeley, California, 9-14 July, 1979. Numerous other individuals from universities, private practice, and government have attended these meetings and have contributed significantly to the planning program.

IV. SUMMARIES AND RESOLUTIONS

A. First Planning Group Meeting

The first planning group meeting, U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities, was held in Tokyo during the period September 5-10, 1977, to discuss future research programs in earthquake engineering utilizing large-scale testing facilities.

During this meeting, the individuals present from academic and government institutions and from private industrial groups exchanged information and views on the following topics:

(1) locations and performance characteristics of existing medium- and large-scale testing facilities in both countries with example tests illustrating capabilities,

(2) locations and performance characteristics of medium- and large-scale testing facilities under construction or planned for future construction in both countries with planned programs,

(3) possible large-scale tests which might be conducted under the recommended cooperative research program including estimates of efforts involved,

(4) implementation of the recommended cooperative research program and level of effort possible considering funding procedures, restrictions, and limitations in both countries, and

(5) selection of large-scale tests and supporting smaller-scale tests to be conducted under the recommended cooperative research program.

At the conclusion of the first planning group meeting, the following resolutions were adopted:

(1) The first major test to be carried out under the recommended cooperative research program should be conducted on a full-size multi-story building to determine its seismic behavior utilizing the Large-Size Structures Laboratory, Building Research Institute, Tsukuba New Town for Research and Education. It is intended that the number of stories on the test structure be the maximum permitted by the facility (8-10 stories), unless the type of construction or building practice requires a lower number of stories.

(2) Six different types of buildings representative of good current practice should be considered for possible testing, namely, a reinforced concrete building, precast and/or prestressed concrete building, a steel frame building, a steel-reinforced concrete building, a masonry building, and a wooden building.

(3) A preliminary design of each building type should be made prior to the second planning group meeting so that a choice can be made at that time as to which type will be tested first.

(4) The building to be tested first should include non-structural elements such as curtain walls, partition walls, piping, etc.

(5) The building should be tested by a pseudo-dynamic procedure so as to develop and define realistic seismic behavior.

(6) After initial testing, the building should be repaired and re-tested to assess the effectiveness of repair procedures.

(7) Complementary tests, such as component and model tests, should be conducted in various institutions prior to and/or parallel with each major full-scale test.

(8) Preliminary long-range plans should be made for a possible full-scale test on the same building type selected for the first major test utilizing the super large-scale two-dimensional shaking table.

(9) Long-range plans should include the possibility of testing large-scale structures other than buildings and experiments to study the effect of wind on buildings and civil engineering structures.

(10) Concerned government agencies in both countries are urged to complete arrangements for implementing the preceding resolutions. It is recommended that the U.S.-Japan Cooperative Science Program and the U.S.-Japan Panel on Wind and Seismic Effects U.J.N.R. Program, coordinate their efforts towards implementing the large-scale testing Program.

(11) The second planning group meeting, U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities, should be held during the period May 15-19, 1978, in San Francisco, California, U.S.A.

B. Second Planning Group Meeting

The second planning group meeting, U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities, was held in San Francisco during the period May 15-19, 1978, to continue planning for future research programs in earthquake engineering utilizing large-scale testing facilities.

After opening remarks by J. Penzien and M. Watabe, preliminary design considerations of full-scale and support tests were presented by H. Aoyama and G. Corley, A. Mattock and T. Okada, R. Hanson and B. Kato, C. Culver and S. Nakata, S. Nakata and A. Mattock, and V.

Bertero and M. Ozaki for building Types 1-6 (No. 1 - Reinforced Concrete, No. 2 - Precast/Prestressed Concrete, No. 3 - Structural Steel, No. 4 - Masonry, No. 5 - Timber, No. 6 - Mixed Steel/Reinforced Concrete), respectively. Extensive discussion toward developing final designs and testing procedures and toward prioritizing structural types followed these presentations. Considering such factors as (1) need based on understanding seismic performance of current construction, (2) need based on developing improved seismic performance in future construction, (3) economic benefits, (4) safety considerations, (5) test feasibility, (6) mutual benefit to both countries, and (7) cost and manpower advantages of conducting full-scale tests on a cooperative basis, it was decided that the immediate future planning should recognize the following priority listing of structural types: No. 1 - Reinforced Concrete, No. 2 - Structural Steel, No. 3 - Precast/Prestressed Concrete, No. 4 - Mixed Steel/Reinforced Concrete, No. 5 - Masonry, and No. 6 - Timber. It was agreed however that detailed planning of the full-scale tests for both the first and second priorities, namely, reinforced concrete and structural steel, should be completed and that plans for component testing involving these and other types should be developed as deemed appropriate. A general flow chart of the first full-scale test project was developed as shown in Fig. 1 below.

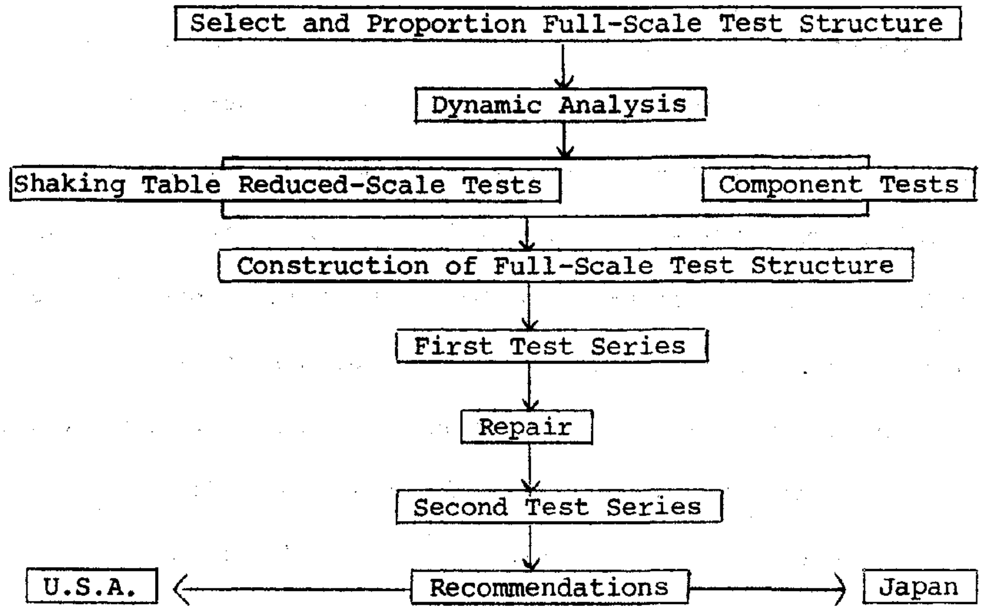


Fig. 1. Flow Chart of First Full-Scale Test Project.

K. Otani and M. Watabe reported on the "Current Status of BRI Facilities" and "Design Earthquake Intensity," respectively, and S.C. Liu and T. Okubo discussed plans for implementing the program under the auspices of the U.S.-Japan Panel on Wind and Seismic Effects, U.J.N.R. Program. It was proposed that the overall program be implemented in accordance with the flow chart shown in Fig. 2, that the U.J.N.R. Panel on Wind and Seismic Effects be used as the implementation and coordination mechanism for the joint program, that the funding agencies have administrative management responsibility for the joint program, and that the program utilize scientists and engineers from academic, government, and industrial organizations in both countries as appropriate to the conduct of specific projects.

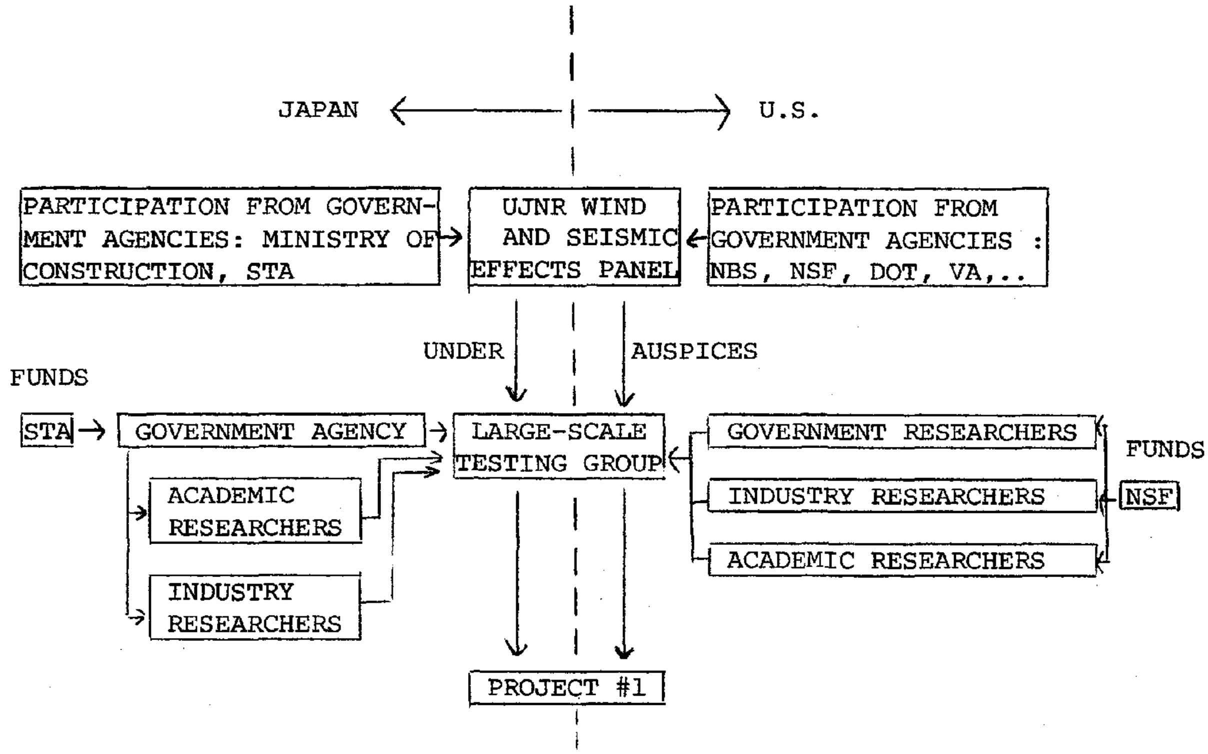


Fig. 2. Flow Chart of Implementation Plan.

At the conclusion of the second planning group meeting, the following resolutions were adopted:

(1) Due to safety and economic consideration, it is urgent that full-scale pseudo-dynamic tests be conducted on various building types for the purpose of verifying and improving seismic performance.

(2) In the interests of improved efficiency and research productivity, it is highly desirable that full-scale pseudo-dynamic tests on buildings be conducted by Japan and the United States on a cooperative basis.

(3) Immediate plans for conducting full-scale pseudo-dynamic tests on a cooperative basis should be developed in accordance with the following priority listing of building types: No. 1 - Reinforced Concrete, No. 2 - Structural Steel, No. 3 - Prestressed/Precast Concrete, No. 4 - Mixed Steel/ Reinforced Concrete, No. 5 - Masonry, and No. 6 - Timber.

This listing should remain flexible, however, to accommodate the availability of test facilities and equipment and to meet other special conditions which may arise prior to and at the time of testing.

(4) Complete detailed structural designs of the reinforced concrete and structural steel buildings should be prepared for presentation at the third planning group meeting. The designs of support tests for both types should also be presented at this meeting.

(5) Because of their great importance, extensive full-scale tests should be conducted on non-structural members together with the structural full-scale tests. Plans for these tests should be developed prior to and be presented at the third planning group meeting.

(6) A subgroup should be established to develop procedures and techniques for laboratory simulation of seismic excitations.

(7) The implementing agencies of both governments should proceed immediately to request funding for the procurement of special test equipment (e.g. hydraulic actuators) and instrumentation still required by the overall proposed test program.

(8) Due to the importance of a balanced exchange of research personnel prior to and during the testing program, every effort should be made on both sides to bring about such an exchange.

(9) Administrative and management arrangements and guidelines for implementing the above resolutions should be completed by the government agencies involved as soon as conveniently possible.

(10) The third planning group meeting, U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities, should be held during the period December 18-23, 1978, in Japan.

C. Third Planning Group Meeting

The third planning group meeting of the U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities was held in Tokyo during the period December 18-23, 1978. The meeting continued discussions to develop future research programs in earthquake engineering utilizing large-scale testing facilities.

The summary and resolutions of the first and the second planning group meetings held in Tokyo in September, 1977, and in San Francisco, in May, 1978, were presented and confirmed.

During the third planning group meeting, representatives from academic institutions, governmental agencies and private industrial firms exchanged information and views. Preliminary design considerations for full-scale tests and their supporting tests were presented by representatives from both U.S. and Japan for four structural types;

No. 1 Reinforced Concrete

No. 2 Structural Steel

No. 3 Precast/Prestressed Concrete

No. 4 Mixed Steel/Reinforced Concrete.

Preliminary discussions were also presented on masonry and timber types.

For the first two of these structural types, U.S. and Japan representatives discussed in depth and reached certain conclusions on experiment designs. In addition to working sessions on structural design, a session on loading procedures for full-scale tests was held. A major discussion in the loading procedures session centered on the feasibility of the pseudo-dynamic test method in which sufficient numbers of electro-hydraulic jacks are used.

At the conclusion of the Third Planning Group Meeting in Tokyo, the following resolutions were adopted:

(1) The goal of the joint program is to improve seismic safety practices through studies to determine the relationship among full-scale tests, small-scale and component tests, and analytical studies.

(2) The joint program shall be designed and conducted to:

(a) achieve clearly stated scientific objectives;
(b) represent total building systems as realistically as possible;
(c) balance the simplicity and economy of test specimens with the need to test structures representing real situations;
(d) maintain a balance among small-scale, component, and full-scale tests;
(e) utilize previously performed experiments and studies to the extent practical;
(f) represent the best design and construction practice in use in both countries;
(g) check the validity of newly developed earthquake-resistant design procedures;
(h) maintain flexibility to accomodate new knowledge and conditions as successive experiments are completed; and
(i) assure the practicality of program results.

(3) This program should be initiated in 1979 jointly and cooperatively in both the U.S. and Japan.

(4) To implement this program, the establishment of the following committees and working subpanels is recommended for inclusion in the governmental MEMORANDUM OF UNDERSTANDING:

(a) Joint Executive Committee for the purpose of providing scientific advice to participating institutions in this program and to appoint subpanels other than stated below to perform tasks as agreed necessary;

(b) subpanel for execution of the full-scale and supporting tests for each structural type; and

(c) subpanel for assessing the feasibility and validity for use in this program of pseudo-dynamic loading techniques.

(5) To implement this joint program, quick and positive response by both governments as to funding and staff arrangements is requested. Strong emphasis is placed on funding the loading systems needed to assure adequacy of the facilities to perform the planned experiments.

(6) The planned order of testing is first the reinforced concrete structure, and second the steel structure. Precast-prestressed concrete structure and mixed steel-reinforced concrete structure are the next priorities. Masonry and timber structures should be studied further for inclusion in this program.

(7) Additional tests and analyses found to be required beyond the planned program should be conducted to assure that research results can be applied in the practical design of buildings.

(8) All activities of the joint program (full-scale tests, support tests, analytical studies, etc.) should be conducted cooperatively with balanced participation from both countries to the extent possible.

(9) The 4th Planning Group Meeting, U.S.-Japan cooperative research program utilizing large-scale testing facilities, should be held in the U.S. during the period July 9th to 14th, 1979.

D. Fourth Planning Group Meeting

The fourth planning group meeting, U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities, was held in Berkeley, California, during the period July 9 - 14, 1979, to finalize recommendations for a cooperative research program utilizing large-scale testing facilities.

After brief introductory comments by H. Umemura and a brief review of the planning group's activities since the third planning group meeting held in Tokyo by J. Penzien and M. Watabe, reports were presented by H. Aoyama and G. Corley on the recommended reinforced concrete building structure full-scale test, by V. Bertero, G. Corley, J. Jirsa, S. Okamoto, K. Otani, and M. Sozen on the recommended reinforced concrete building structure associated tests, by R. Hanson and B. Kato on the recommended steel building structure full-scale test, by R. Hanson, B. Kato, L. W. Lu, S. Mahin, and K. Takanashi on the recommended steel building structure associated tests, by R. Hanson and T. Okada on the recommended pseudo-dynamic test method feasibility studies, by Y. Yamazaki on the acquisition and reduction of full-scale test data, and by S.C. Liu and T. Okubo on past inter-governmental implementation activities for the cooperative program. Informal discussions followed each of the technical presentations with the objective of clarifying the issues raised.

Following presentation of these reports, parallel working sessions were held to develop final recommendations on (1) reinforced concrete building structure full-scale tests and associated tests, (2) steel building structure full-scale tests and associated tests, (3) pseudo-dynamic test method feasibility studies, (4) analytical studies, and (5) implementation. Reports by the working groups were then presented in general session followed by discussion.

Further discussions were held in general session on program cost estimates and schedules, and on developing guidelines for project reports.

At the conclusion of the fourth planning group meeting, the resolutions of the first three meetings were re-confirmed and additional resolutions were adopted as follows:

(1) In view of the importance of improving seismic safety practices through studies to determine the relationship among full-scale, small-scale, and component tests, and analytical studies, the final report of the planning group should be completed and be transmitted to the appropriate agencies of government as soon as possible.

(2) It is recommended that the program of cooperative research as set forth in the planning group final report be initiated in 1979 in both countries.

(3) The level of funding provided to the cooperative research program should permit the fulfillment of goals and objectives as defined in the planning group final report.

(4) To insure successful execution of the recommended cooperative research program, full coordination of all research activities carried out in both countries is essential; therefore, the following committees are recommended:

   (a) Joint Technical Coordination Committee to provide scientific and technical advice to participating institutions in the program. This committee should meet at least once a year during the program.

   (b) Joint subcommittees to provide advice on the execution of research related to reinforced concrete buildings, steel buildings, pseudo-dynamic loading techniques, and other major areas of activity. These committees should meet as frequently as needed.

(5) To assure and enhance the cooperative effort in this joint research program, adequate exchange of research personnel from both countries is needed. It would be desirable for one exchange researcher to be associated with each participating research organization in each country.

(6) Following successful completion of the recommended cooperative research programs related to reinforced concrete and steel buildings, similar investigations should be carried out on other structural types as suggested in previous resolutions taking full advantage of the experience gained in the use of the pseudo-dynamic testing procedure. Appropriate planning for this activity should be initiated at an early date.

(7) Long-range plans should include the possibility of testing large-scale structures and systems, other than buildings, in this cooperative program.

(8) The planning group encourages support of the recommended cooperative large-scale test program by the U.J.N.R. Panel on Wind and Seismic Effects.

V. RECOMMENDED RESEARCH ON REINFORCED CONCRETE BUILDING STRUCTURES

A. Summary

It is recommended that a full-scale seven-story reinforced concrete building structure (including nonstructural elements such as curtain walls, partition walls, etc.) representing good current practice be tested in the Large-Size Structures Laboratory, Building Research Institute, Tsukuba New Town for Research and Education, Japan. The tests should be conducted using a procedure intended to simulate dynamic response to prescribed seismic excitations. A computer-actuator on-line (pseudo-dynamic) test procedure should be considered for this purpose. After an initial series of tests limiting the response to light damage levels, the structure should be repaired and then retested under severe simulated seismic conditions to near collapse conditions. The objectives of this final test would be to assess the effectiveness of repair procedures and to determine the structures large deformation and failure characteristics.

Further, it is recommended that a series of coordinated experiments associated with the full-scale tests be conducted in Japan and the United States on reinforced concrete joint assemblies, walls, and frames, that one-tenth scale models of the full-scale seven-story test structure be tested under simulated seismic conditions using a single horizontal component shaking table, that a one-third scale model (including nonstructural elements) of the same full-scale test structure be tested under simulated seismic conditions using a two-component (vertical and one horizontal) shaking table, and that a full-scale three-story model be tested under simulated seismic conditions using a single horizontal component shaking table.

The results of all associated tests in both countries should be fully correlated with each other and with the results of the tests made in Japan on the full-scale seven-story structure. The objectives of these correlation

studies would be to identify the relative merits of component tests, small-scale tests, and medium-scale tests in predicting prototype performance under medium to severe seismic conditions and to improve structural details leading to improved seismic resistant design.

It should be noted that an investigation of the type described herein represents a first attempt anywhere in the world at carrying out a fully integrated test program having both of the above objectives. It, therefore, should prove of great value in setting long-range priorities for future test programs based on benefit-cost considerations.

Researchers from both Japan and the United States should participate in the full-scale tests, the associated tests, and the correlation studies.

B. Tests On A Full-Scale Seven-Story Building In Japan

The full-scale seven-story reinforced concrete test structure suggested herein represents a portion of a building having dimensions common to earthquake resistant construction in both countries. The lateral load resistance of this building is provided by interacting structural walls and frames. This type of test structure has been suggested so that the test results may be of equal benefit in interpreting performance of that type of building in both countries. Plan and evaluation views of the test building are shown in Figs. 3 and 4, respectively.

Prior to testing the full-scale structure, a thorough analysis of its seismic performance should be carried out in both Japan and the United States using the best available mathematical modelling and computational procedures. In developing the mathematical model of the structure, use should be made of existing component test data in both countries supplemented by the results of associated tests as described in the following sections of this proposal. Through such analyses, seismic excitations to be used in the full-scale tests can be selected.

As previously stated, the pseudo-dynamic test procedure should be considered for the full-scale tests to be conducted in the Large-Size Structures Laboratory, Building Research Institute, Tsukuba New Town for Research and Education. The test structure should be rigidly attached to the test floor of the laboratory. Testing should be carried out at various stages of construction using types and levels of loading consistent with the objectives of individual tests. Both Japanese and U.S. researchers should participate in the development of design details, the planning of instrumentation, and the conduct of all tests. All correlation studies of results should be similarly conducted on a cooperative basis.

DESIGN CRITERIA

1. DESIGN BY 1976 UNIFORM BUILDING CODE
2. CONCRETE STRENGTH-STONE AGGREGATE
   - A. 20.7MPA-SLABS AND BEAMS
   - B. 27.6MPA – COLUMNS AND WALLS
3. REINFORCING STEEL ASTM A615 GRADE 60 $F_Y = 4$

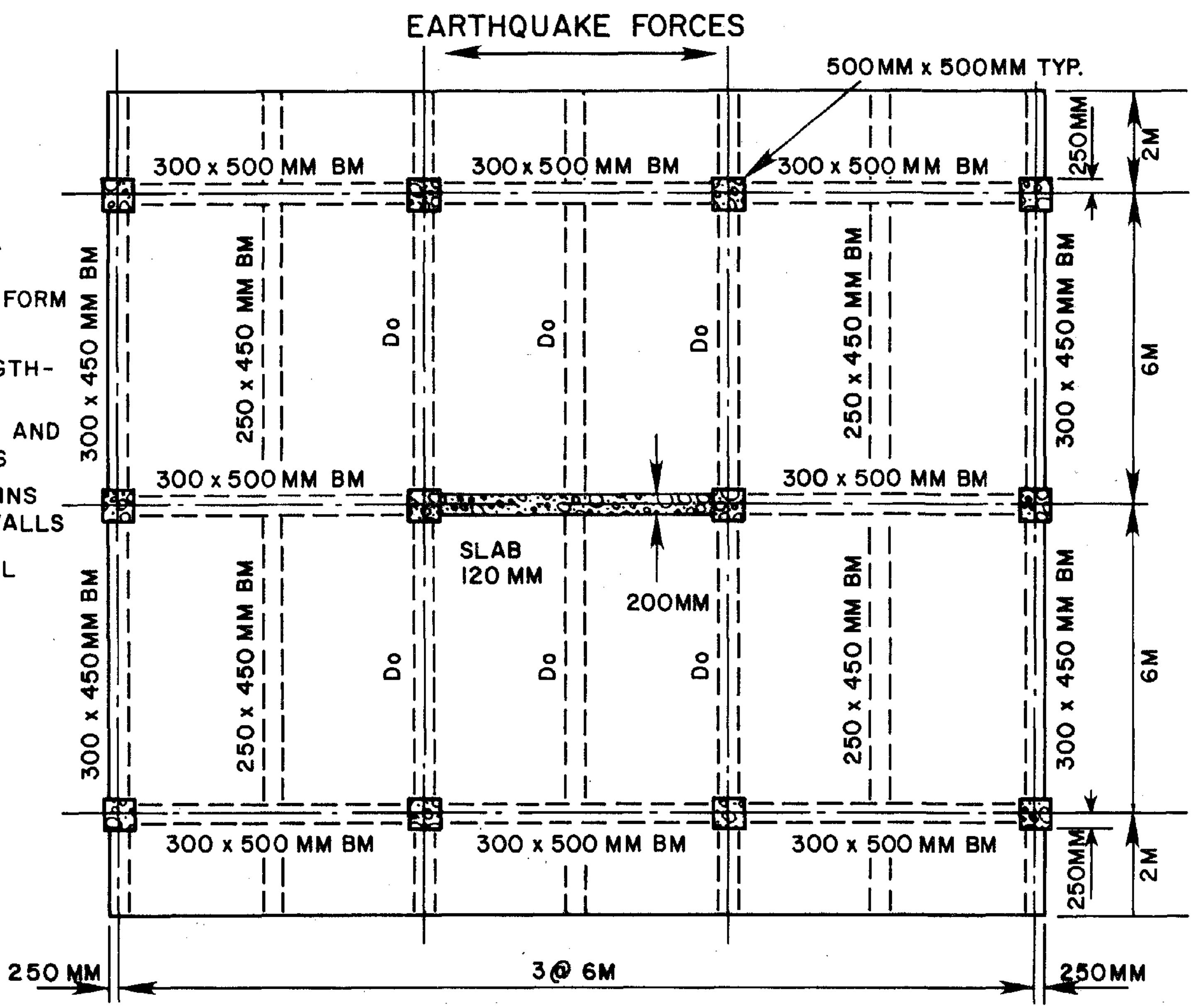


FIG. 3: Plan of Reinforced Concrete Test Structure

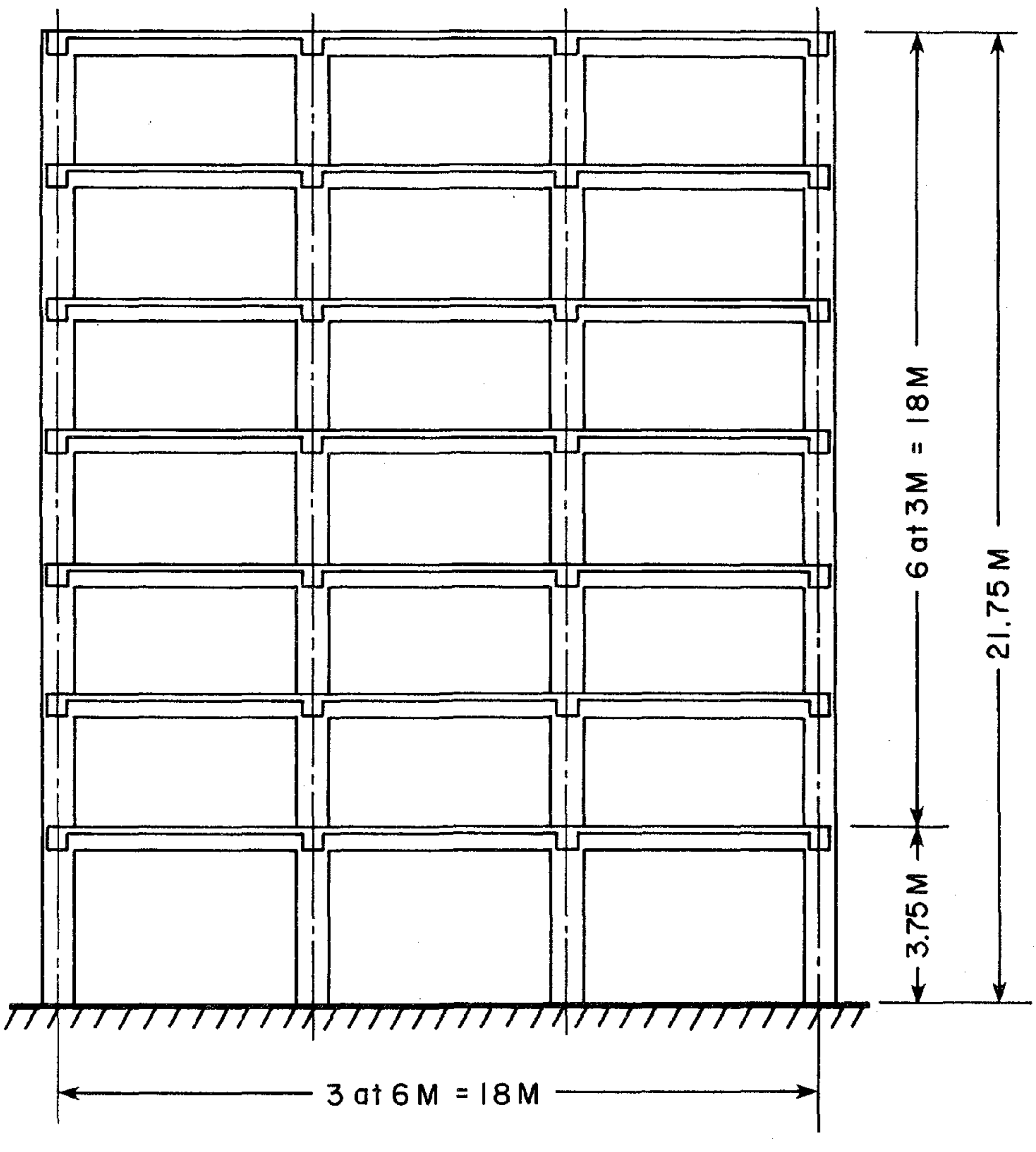


FIG. 4: Elevation View of Reinforced Concrete Test Structure

C. Associated Tests In The United States

1. Quasi-Static Tests On Joint Assemblies

It is recommended that a number of associated tests be carried out on full-scale reinforced concrete joint assemblies as listed in Table 1. Results of these tests will permit correlation between the existing body of experimental data obtained from similar simple test specimens and response of the full-size structure. Results of the correlation will demonstrate the degree of reliability that can be obtained from previously completed laboratory work. The geometries of the joint assemblies should be identical to portions of the full-scale seven-story test structure as indicated in Fig. 5. For reasons of clarity, the floor slab does not show in the drawing of this figure; however, it should form an integral part of the full-scale test building and all associated test assemblies.

a. Exterior column-to-beam assemblies - Three of these assemblies should be tested under a cyclic loading pattern as shown in Fig. 6 (note that again for reasons of clarity, the floor slab does not show in any of the drawings of joint assemblies, i.e., Figs. 6 - 8). Specimen No. 1 should have reinforcing details similar to those originally selected for the full-scale seven-story test structure, Specimen No. 2 may have modified reinforcing details, and Specimen No. 3 should have reinforcing details based on the results obtained from the tests on Specimens Nos. 1 and 2.

Loading of Specimen No. 1 should be applied in groups of three completely reversed cycles. After each group of three cycles, the deformation level should be increased to produce more inelastic behavior. This procedure should be continued until the specimen has lost most of its structural resistance. Specimen No. 2 should be loaded using a controlled deformation pattern similar to that predicted for the prototype structure under seismic conditions. The amount of peak inelastic deformation should be increased with each succeeding pattern until the specimen has lost most of its structural resistance. Specimen No. 3 should be loaded under controlled conditions selected after testing Specimens Nos. 1 and 2.

b. Interior column-to-beam assemblies - Two of these assemblies should be tested under a cyclic load pattern as shown in Fig. 7. Reinforcing details and loading groups for these specimens should be selected following the same considerations and procedures described above for Specimens Nos. 1 and 2 of the exterior column-to-beam assemblies.

c. Wall-to-beam assemblies - Two of these assemblies should be tested under a cyclic loading pattern as shown in Fig. 8. Reinforcing details and loading groups for these specimens should be selected following the same considerations and procedures described for Specimens Nos. 1 and 2 of the exterior column-to-beam assemblies.

2. Quasi-Static Tests On Planar Structures

It is recommended that an isolated wall, a wall and frame combination, and a plane frame as shown in Figs. 9, 10 and 11, respectively, be constructed at medium-scale with portions of floor slab forming an integral part of all three specimens. Nonstructural elements should be built into the plane frame specimen.

a. Isolated wall - The details of this specimen should be similar to those selected for the full-scale seven-story test structure. Loading history applied to the specimen should simulate the corresponding analytically predicted deformations of the prototype structure under prescribed moderate to severe earthquake conditions. The results of this test should be used to verify the validity of mathematical modelling of similar elements in the prototype structure.

b. Wall and frame combinations - The details of this specimen should be similar to those selected for the full-scale seven-story test structure. Loadings of similar types to those described above for the isolated wall test should be applied to the test specimen. Correlation of test results should be made with those obtained from the isolated wall test and they should be used to assist in the verification of prototype mathematical modelling.

c. Plane frame - The details of this specimen should be similar to those of the corresponding frames in the full-scale test structure including the presence of nonstructural elements. Loading types as described above for the isolated wall and the wall and frame combination tests should be used for this specimen. Results of the test should be correlated with the results of the isolated wall and the wall and frame combination tests and they should be used to assist in the modelling of corresponding elements in the prototype structure.

TABLE 1

REINFORCED CONCRETE ASSOCIATED TESTS

TEST ASSEMBLIES						
	Specimen 1		Specimen 2		Specimen 3	
Description	Reinforcement	Loading*	Reinforcement	Loading*	Reinforcement	Loading*
Exterior Column To Beam	Code	Increasing Reversals	Same as Test Structure	Same as Test Structure	To be Determined	To be Determined
Interior Column To Beam	Code	Increasing Reversals	Same as Test Structure	Same as Test Structure	---	---
Wall To Beam	Code	Increasing Reversals	Same as Test Structure	Same as Test Structure	---	---
PLANAR STRUCTURES						
Isolated Wall	Same as Test Structure	Increasing Reversals	---	---	---	---
Wall And Frame	Same as Test Structure	Increasing Reversals	---	---	---	---
Plane Frame	Same as Test Structure	Increasing Reversals	---	---	---	---

* All loads should be applied at rates similar to those commonly used in laboratory work reported in existing literature.

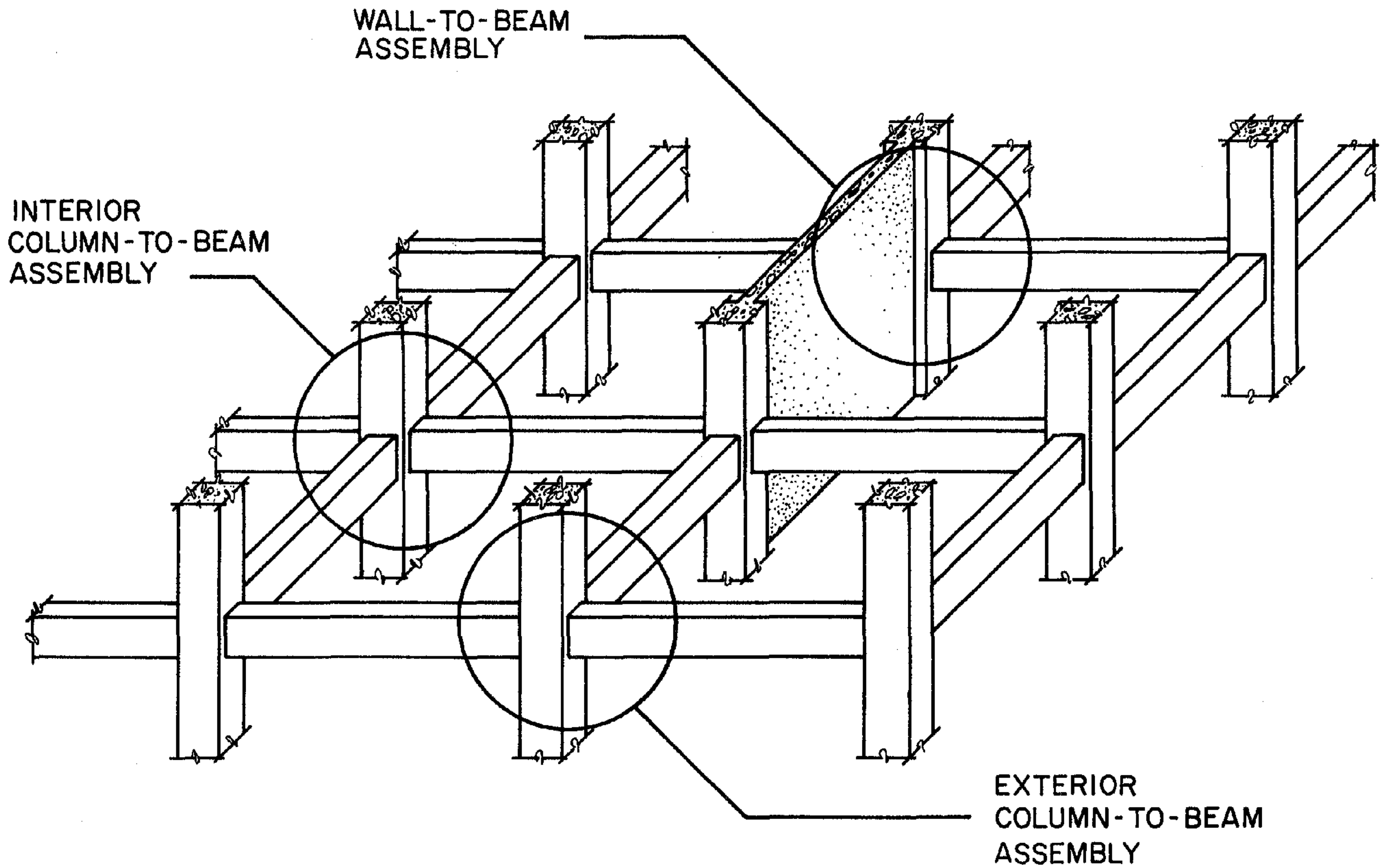


FIG. 5: Portions of Building to be Evaluated in Support Tests

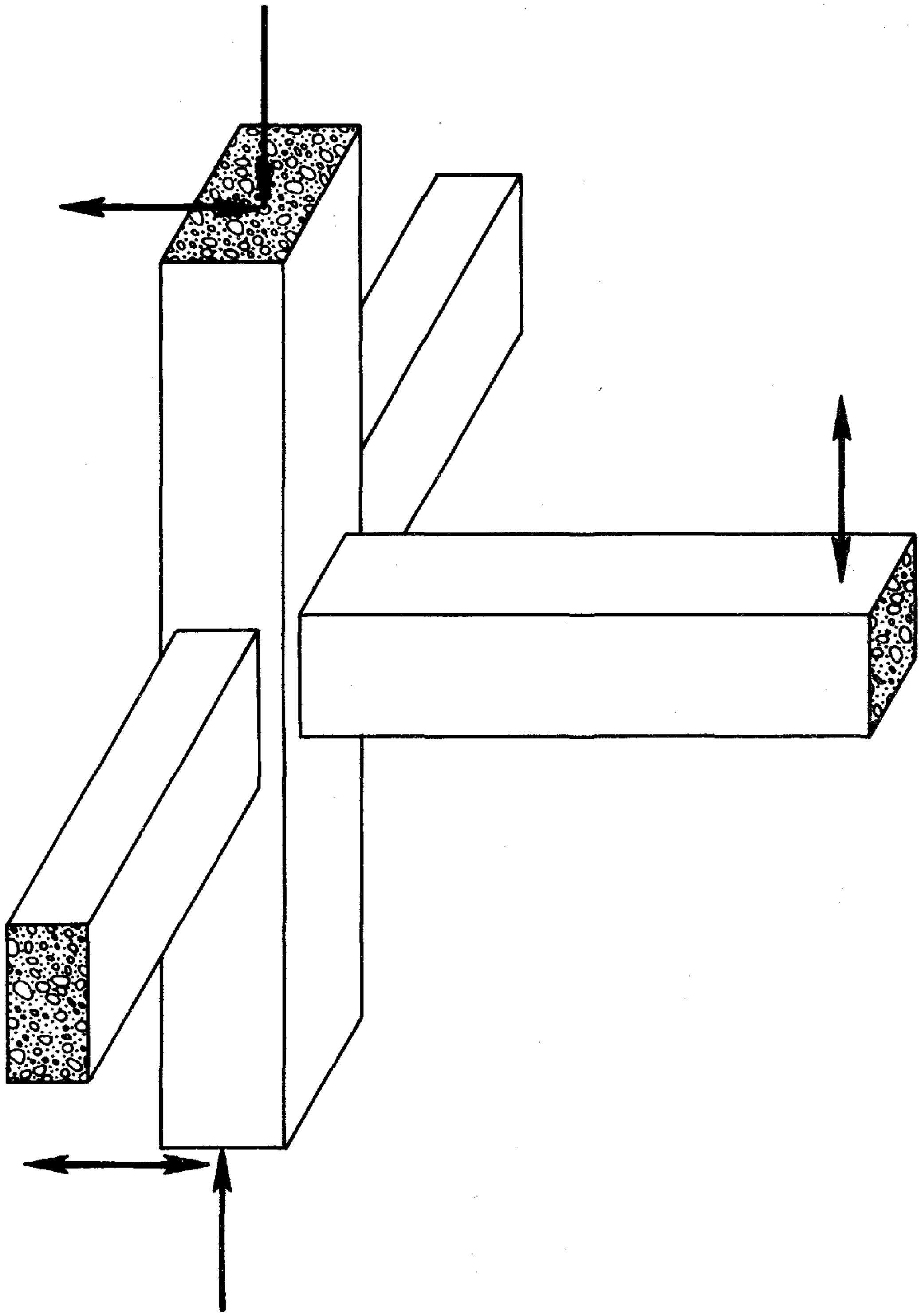


FIG. 6: Exterior Column-to-Beam Assembly

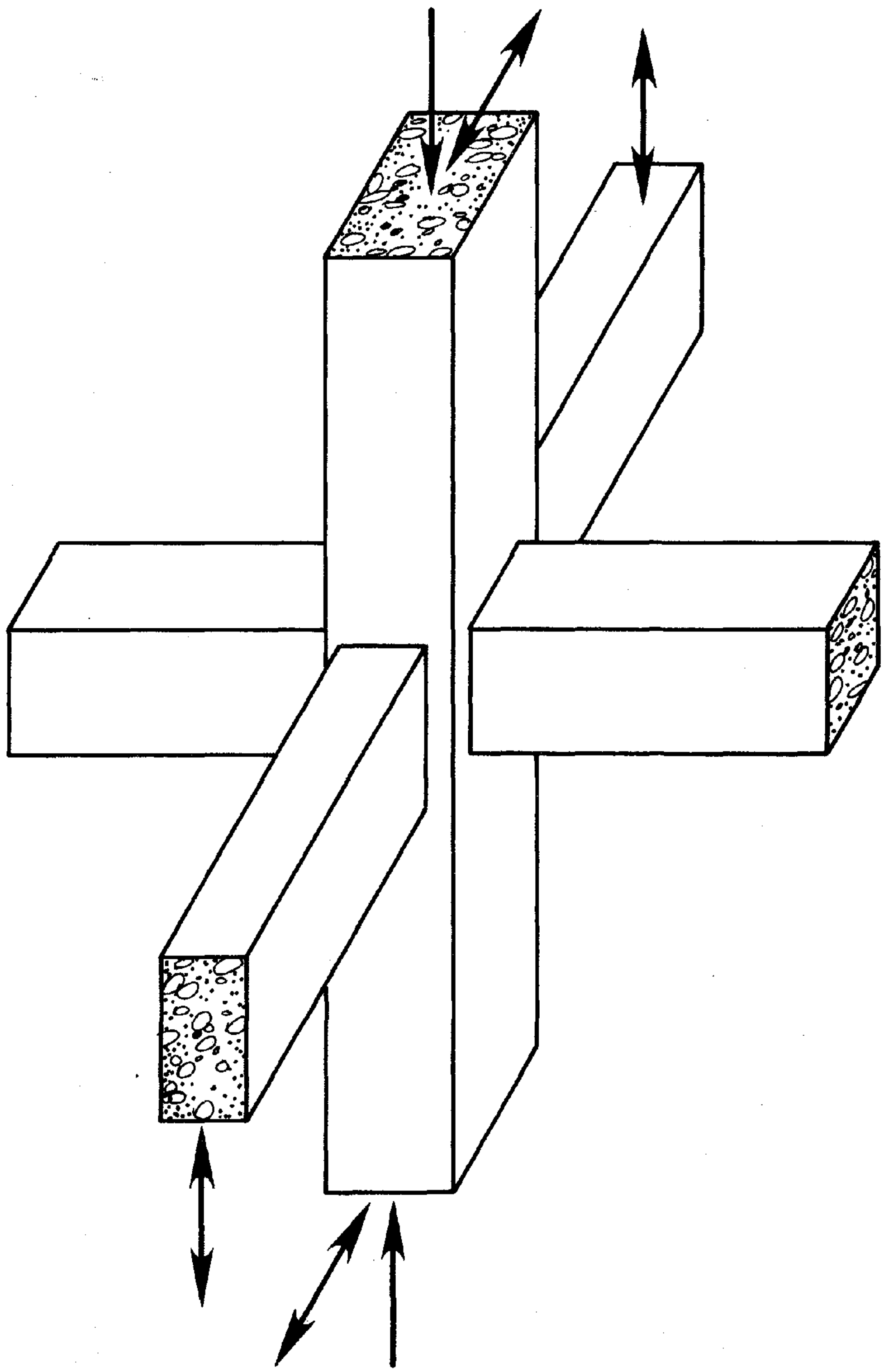


FIG. 7: Interior Column-to-Beam Assembly

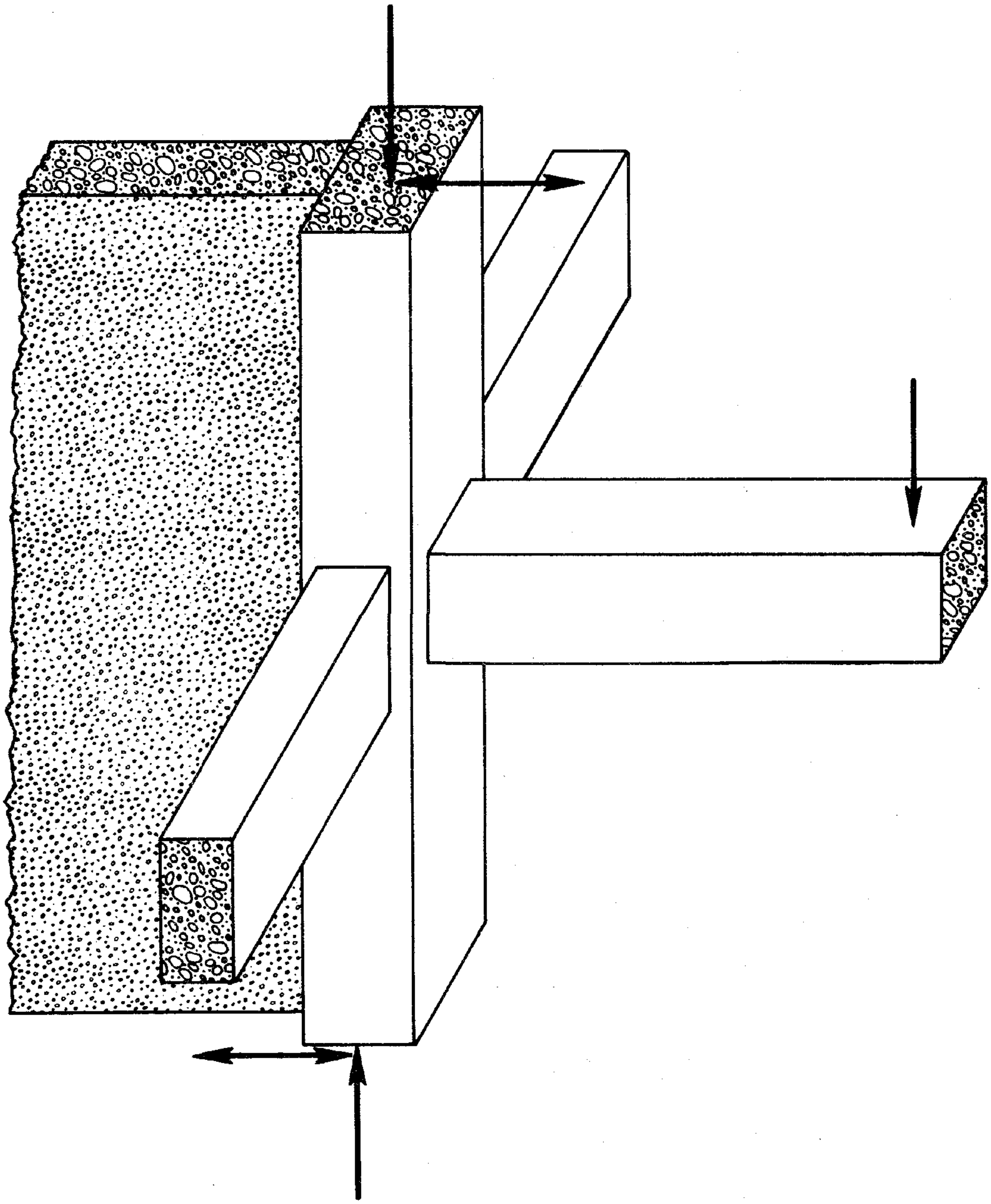


FIG. 8: Wall-to-Beam Assembly

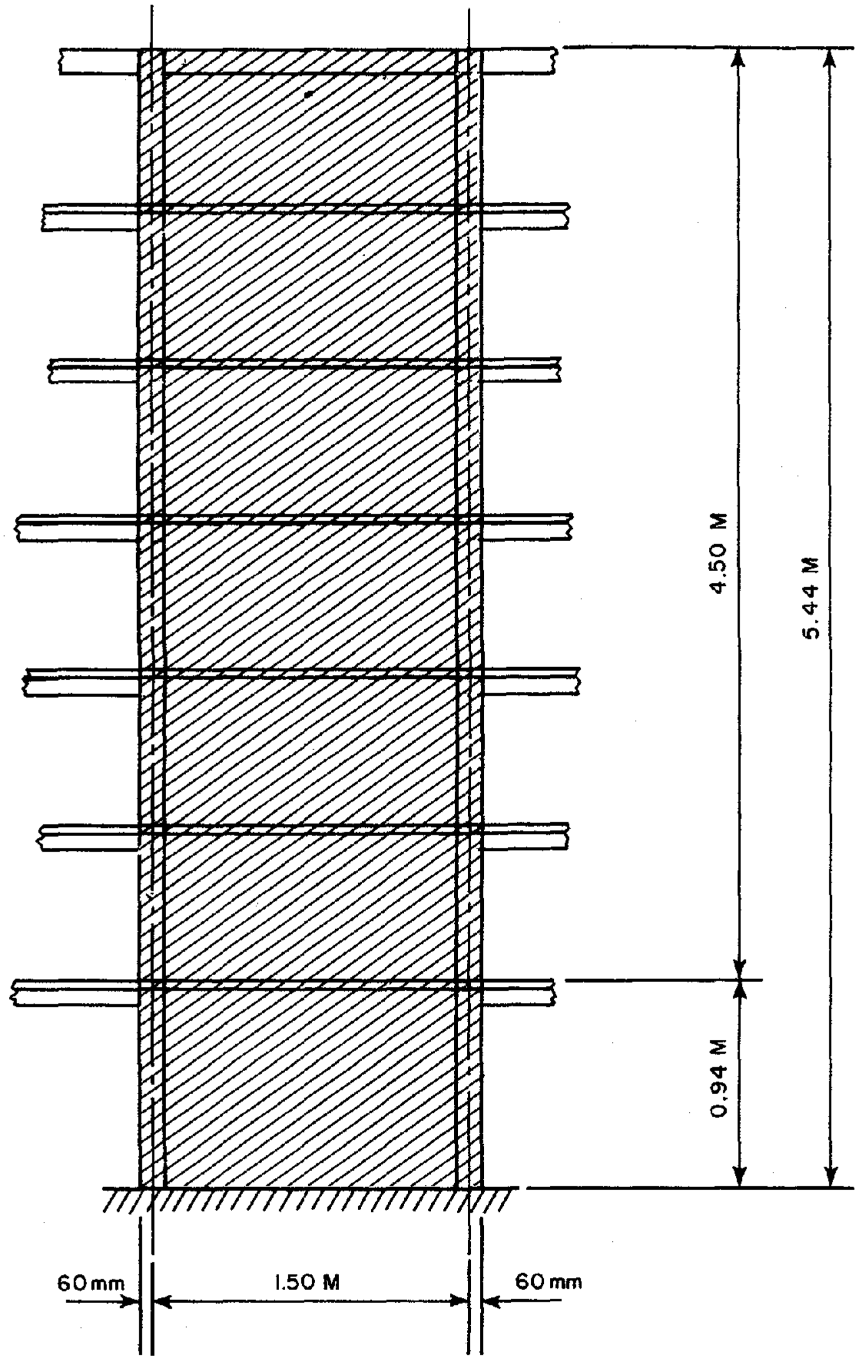


FIG. 9: Isolated Wall

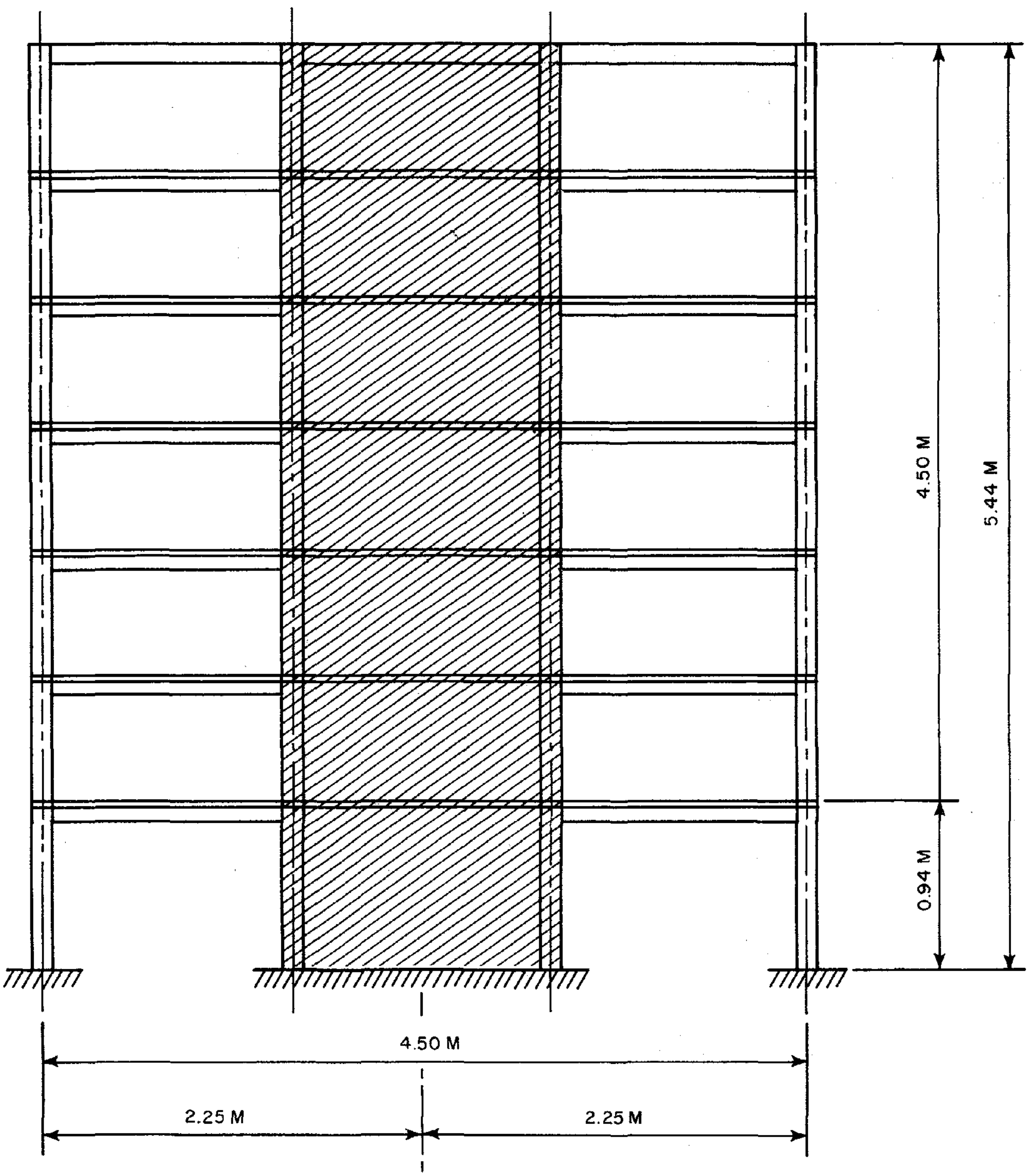


FIG. 10: Wall and Frame Combination

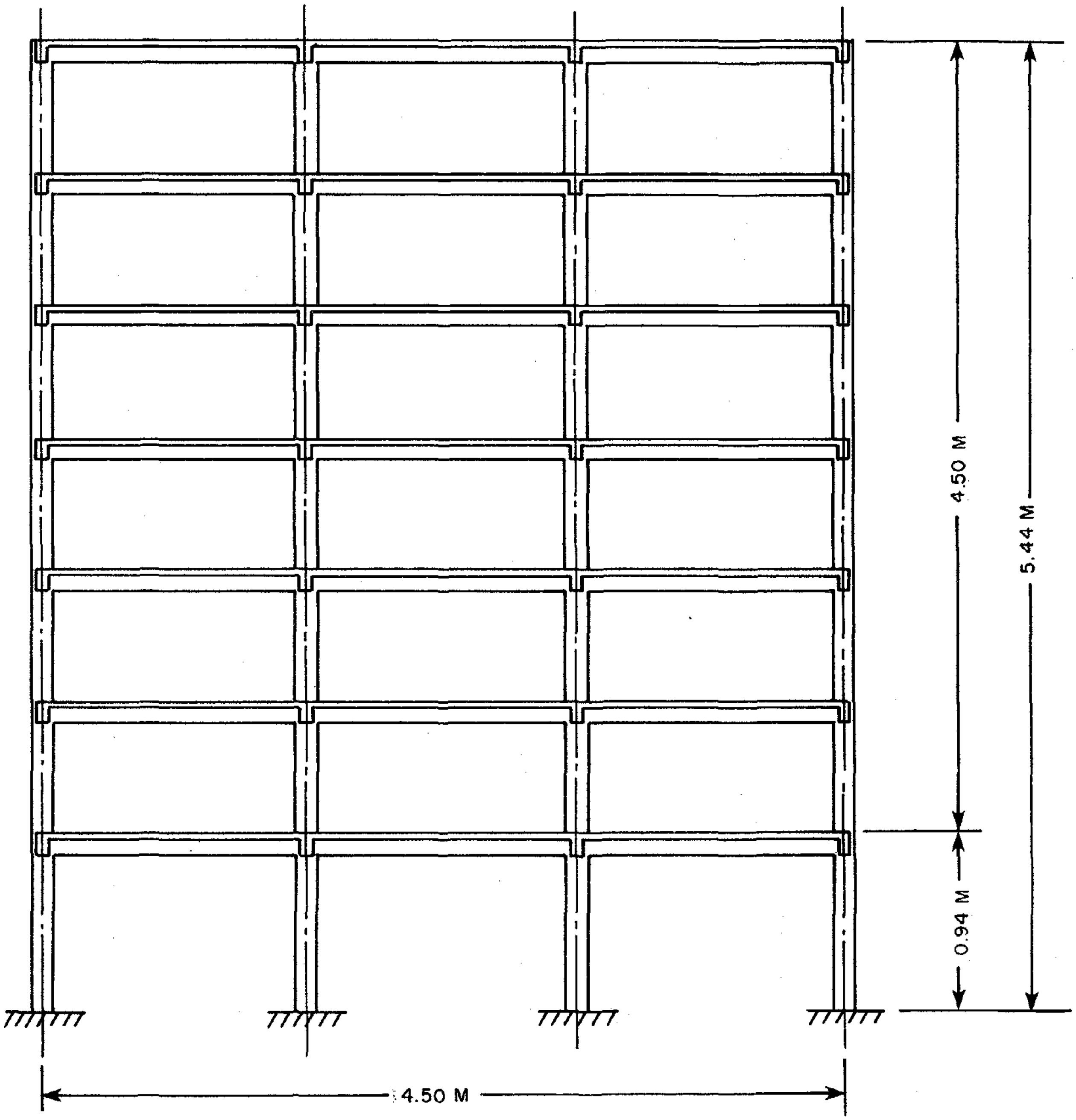


FIG. 11: Plane Frame

3. Shaking Table Tests On One-Tenth Scale Models

Earthquake-simulation tests of one-tenth scale models of the full-scale test structure are recommended (a) to help develop a realistic loading program, representing earthquake response, for the full-scale seven-story test structure and (b) to test the reliability of the small-scale reinforced concrete models in determining the behavior of full-scale structures.

The role of the recommended tests with respect to the first objective is in providing physical tests of the displacement responses calculated for the full-scale test structure using analytical models. Ultimately, the second objective is of greater importance because the studies can be used to establish limits to the use of small-scale reinforced concrete models in experimental analysis of the total response of building structures.

Tests of three one-tenth scale models of the full-scale seven-story test structure are recommended for the experimental program.

The first model structure should be a "bare" structure to be tested to help establish the ranges of response, for prescribed earthquake motions, of the full-scale structure. It is desirable to fabricate and test this model as soon as the detailed features of the full-scale structure have been selected, because the results of the model test may influence the conduct of the tests of the full-scale structure and, if obtained in good time, may influence the final properties and reinforcement details.

The second model structure should include nonstructural components and should be built to correspond closely to the full-scale structure and, more importantly, to the medium-scale (one-third scale) test structure. The nonstructural components included in the model should be only those that are expected to affect dynamic response.

The third model structure should include nonstructural features as well as structural attributes selected to assimilate and help generalize the results from the full-scale test.

a. Small-scale test structures - Recommended dimensions of the model structures are given in Figs. 12 through 14. These dimensions are based on those suggested for the full-scale structure.

   The dimensions of the model structure to the prototype structure should be related in the ratio of 1:10. It is recommended that the model carry masses of approximately 800 kg at each level in order to maintain a ratio of 5:1 between the natural frequencies of the model and the prototype. Consequently, the time scale of the "earthquake motion" should be compressed by five (e.g., a ten-second duration motion in real time will be reproduced in two seconds) such that the relationship between the building frequencies and the frequency content of the base motion will be approximately the same for the prototype and the model.

   The time scale factor of five has been suggested for two reasons: to minimize strain-rate effects in modes affecting structural response perceptibly and to avoid the necessity of lengthy and randomly successful finetuning process required for an earthquake simulator for time-compression ratios of ten or higher.

b. Structural materials and reinforcing details - The reinforcement in the test structures may be cut from bright basic wire annealed to develop a yield stress of approximately 415 MPa. Depending on the reinforcement arrangement finally selected for the prototype, it is anticipated that the wire sizes to be used as main reinforcement in the models will be approximately 2 mm. Elements reinforced with "bars" of this size have been used successfully to simulate moment-rotation characteristics of full-scale reinforced concrete elements.

Because small-scale models are not suitable for investigation of shear failures, faithful modelling of the transverse reinforcement is not essential. Nevertheless, transverse reinforcement should be chosen to correspond to that used in the prototype provided the probability of a shear failure in the model is acceptably low.

The small-scale concrete should be mixed using coarse sand, fine sand, cement and water. Its target strength should be that selected for the prototype, approximately 28 MPa.

In the initial stage of the project, exploratory tests with single- and two-story model frames with filler walls should be conducted to develop a suitable miniature concrete block to be used as "nonstructural" material for the second test structure.

c. Fabrication - Each planar element of the structure may be cast horizontally in one piece using specially designed steel forms. The first model structure should not have transverse elements so that casting the frames and the central wall-frame will not pose any problems. If the transverse structural elements are selected for the second and third model structures, it may be possible to add these "in situ" by building from dowels cast into the planar elements. Because the transverse elements should not contribute substantially to energy dissipation in the direction of the ground motion, unrealistic splicing in their reinforcement would be tolerable.

d. Assembly - The individual planar elements can be assembled on a test platform, as indicated by the plan in Fig. 14. The distances between the individual elements will depend on the design of the story masses. The masses of the first model structure may be connected to the structural elements through steel shafts which fit small cylindrical sleeves cast into the frame joints. The joints can, therefore, be provided with special reinforcement to avoid splitting. An undesirable feature of this scheme is the indeterminacy of the reactions, a condition which will create problems for construction as well as analysis. The load distribution from the slabs to the vertical elements is also indeterminate in the prototype, but there are no explicit "fitting" problems because of the flexibility afforded by cast-in-place construction. The details of the system supporting the masses in the model structures can be changed in a trade-off between realism and convenience, in view of the fact that the first structure will differ in other details too from the prototype.

e. Instrumentation - Instrumentation for the model specimens should include (a) accelerometers oriented horizontally in the direction of motion at all levels, (b) accelerometers oriented horizontally and transversely to the direction of motion at the base and at the top of the structure, and (c) accelerometers oriented vertically at the top of the structure, and (d) LVDT's to measure deflection in the direction of motion at all levels.

Strain gages may not be needed unless a special problem arises in connection with the interpretation of the results from the full-scale test.

f. Test procedure - Each test structure should be subjected to a series of base motions of increasing intensity. The motions should be selected in consultation with all researchers participating in the overall cooperative program. Dynamic response properties of the test structure should also be investigated with the help of free-vibration and/or low-amplitude force-vibration tests in between the earthquake simulation tests.

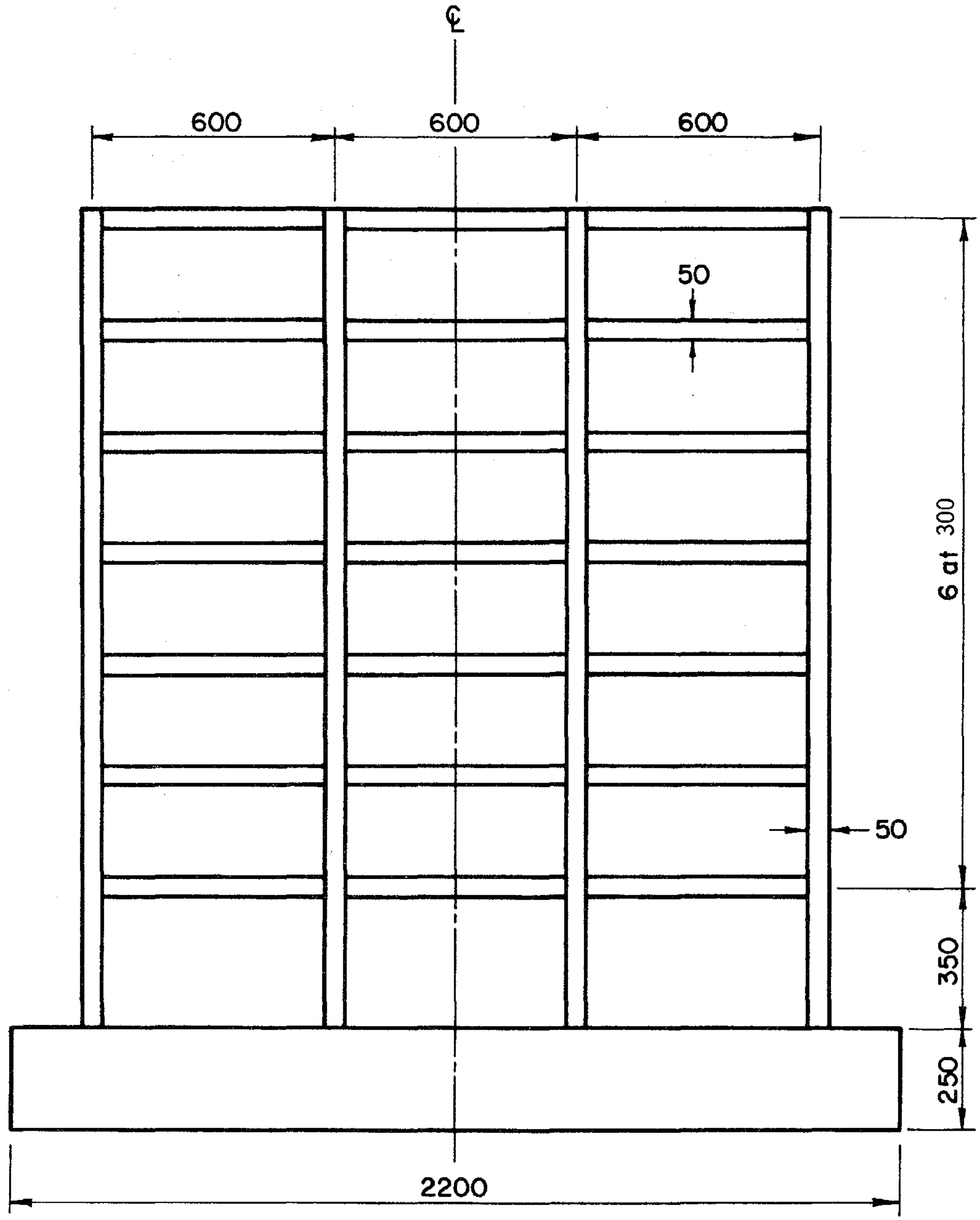


FIG. 12 FRAME DIMENSIONS
(Beams 30*50mm, Columns 50*50mm)

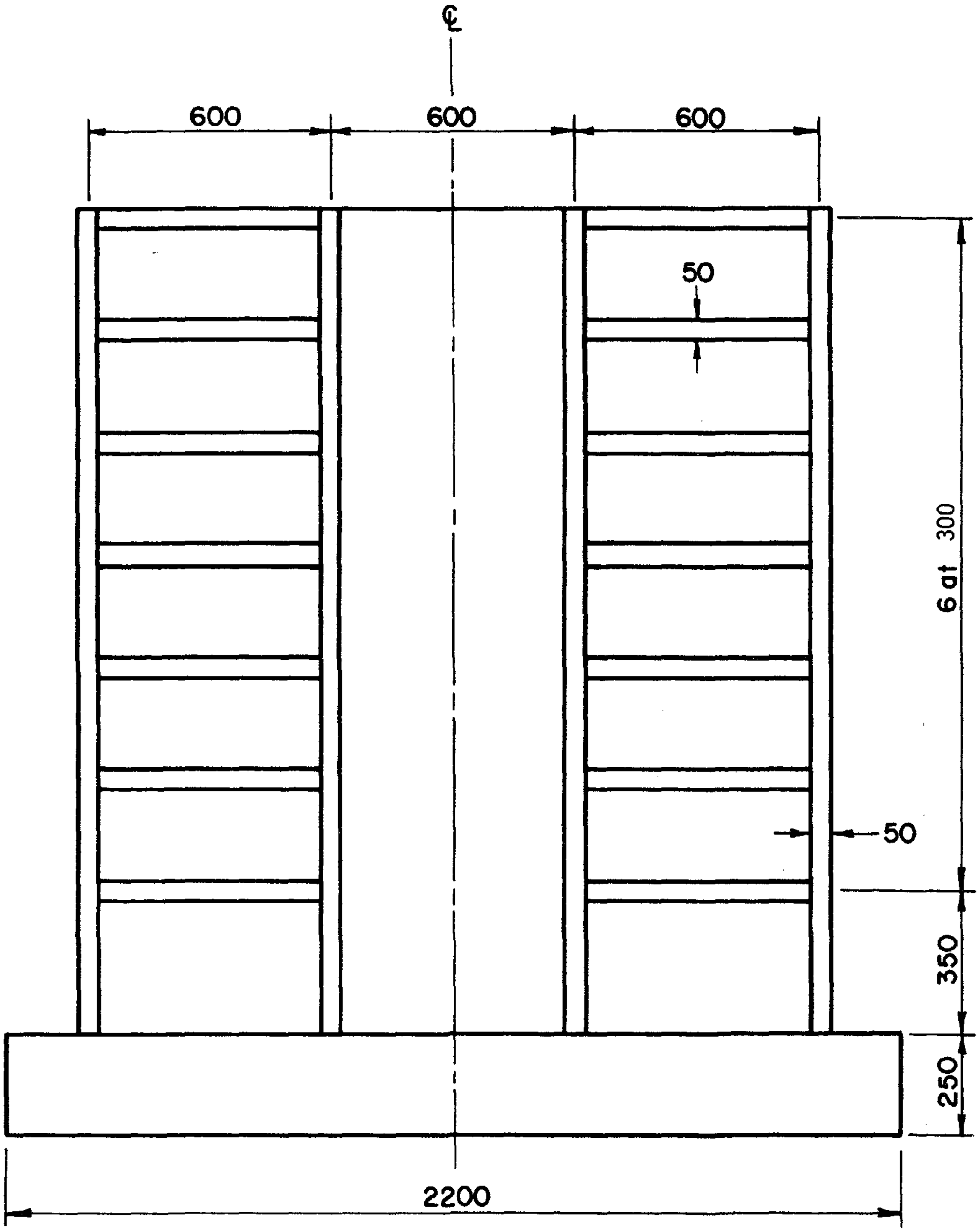


FIG. 13 DIMENSIONS FOR WALL-FRAME
(Beams 30*50mm, Columns 50*50mm, Wall 20 mm thick)

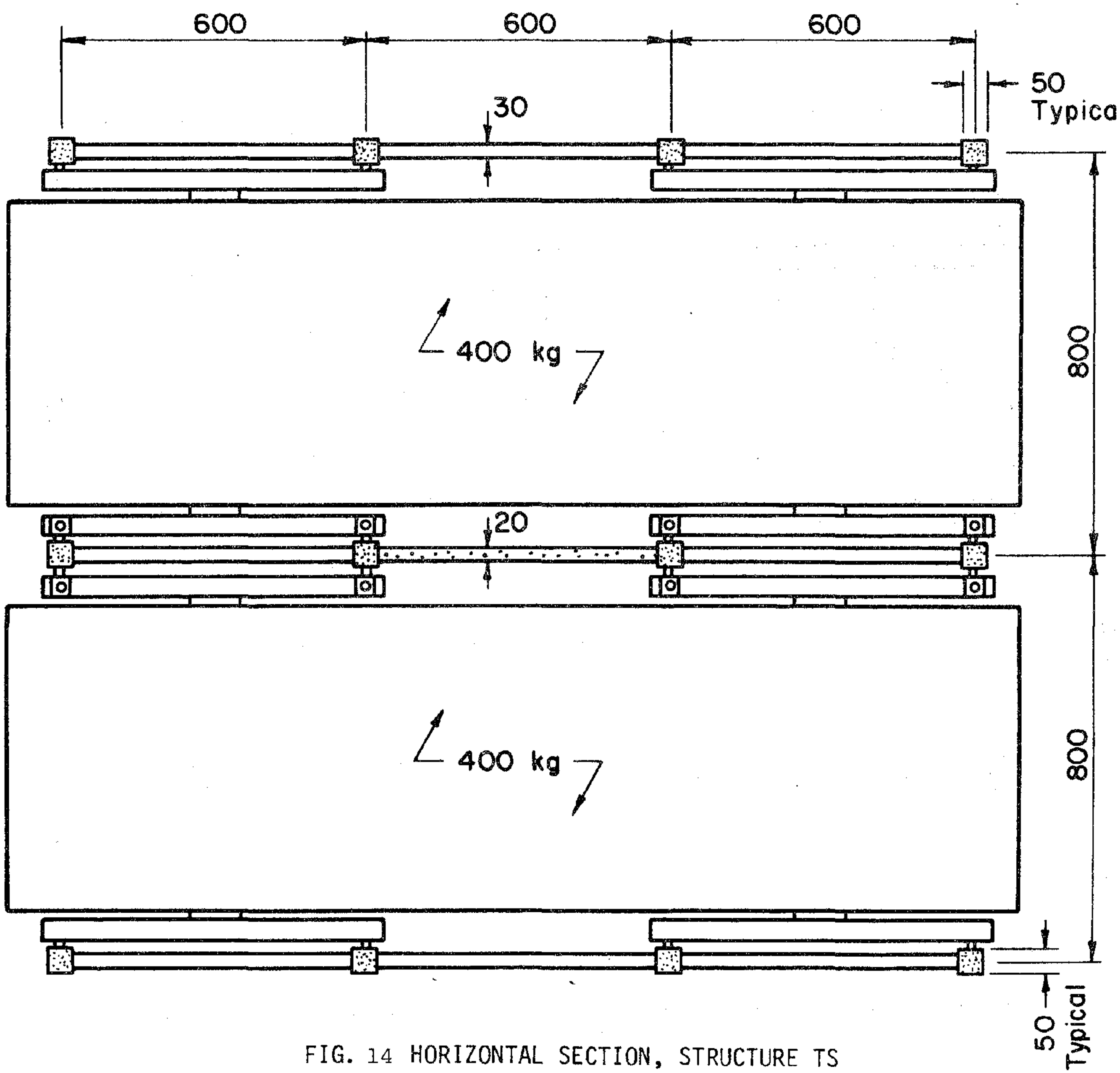


FIG. 14 HORIZONTAL SECTION, STRUCTURE TS

4. Shaking Table Tests On A One-Third Scale Model

As previously pointed out, one of the principal objectives of the overall program recommended herein is to determine the relative merits of component tests, small-scale tests, and medium-scale tests in predicting prototype performance under medium to severe earthquake conditions. The recommended full-scale test representing prototype behavior, the component tests, and the one-tenth scale shaking table tests have been described in the previous sections of this proposal.

While it is expected that the small-scale (one-tenth scale) model tests on a single-component shaking table will provide invaluable information (at relatively low costs) for predicting overall response of the prototype structure, thus greatly assisting in the decision making process of designing and testing the full-scale seven-story test structure, they most likely will be deficient in providing the necessary information for predicting localized prototype behavior. This deficiency can be expected due to the fact that the inelastic behavior of reinforced concrete structures is sensitive to certain factors such as (1) degree of confinement of the concrete, (2) mechanical characteristics of all materials, (3) surface deformations of reinforcing bars affecting bond characteristics, and (4) detailing of the different types of reinforcement. Because of this sensitivity, it is recommended that a medium-scale (approximately one-third scale) model of the full-scale seven-story test structure be tested on a component shaking table. This medium-scale model can be expected to provide much more reliable information for use in predicting inelastic behavior in critical regions of the prototype structure. Also, the results should greatly assist in verifying the accuracy and reliability of the nonlinear analysis computer programs used in various phases of the overall program.

The one-third scale model should be tested first without nonstructural elements under free and/or forced vibration conditions to determine its dynamic characteristics. Nonstructural elements should then be added to the model after which the free and/or forced vibration tests should be repeated. Following these tests, the model should be subjected to excitations simulating service level seismic ground motions. Free and/or forced vibration tests should then be performed to determine changes in the dynamic characteristics. Shaking table tests should again be performed but with the excitation level sufficiently high to induce damage in the nonstructural elements. These damaged elements should then be repaired followed by further shaking table tests with the excitation level even higher than before so that a greater level of damage will be produced in the nonstructural elements. This series of tests would provide valuable information on the effects of nonstructural elements on overall building seismic response. Following even further shaking table tests producing significant, but not excessive, damage in the primary structure of the model, it should be repaired and then retested under severe simulated seismic excitations to near collapse conditions. This final test would assess the effectiveness of repair procedures and would determine the model's large deformation and failure characteristics. Simultaneous, vertical and horizontal components of excitations should be used in the above tests as deemed appropriate.

As discussed in Sec. VIII of this report, the results obtained from one-third scale model tests should be correlated with the results obtained from the full-scale tests, the one-tenth scale shaking table tests, and the component tests.

D. Associated Tests In Japan

1. Quasi-Static Tests On Joint Assemblies

In the course of designing the full-scale seven-story test structure, difficult choices will be encountered due to differences in design and detailing practices between the United States and Japan. Differences in the equation for design shear capacity, differences in column tie detailing, and differences in the requirements for beam-to-column connections are a few examples. In order to determine appropriate choices in the design of the full-scale test structure, it is recommended that the following series of tests be conducted early in the program in Japan.

a. Exterior column-to-beam assemblies - Three half-scale exterior column-to-beam assemblies should be tested under a cyclic loading pattern as shown in Fig. 6. Specimen No. 1 should have reinforcing details as commonly adopted in current Japanese practice. Specimen No. 2 should have additional hoops in the column-to-beam joint based on the shear stress in the joint, and should have reinforcement details different from Specimen No. 1 so that it conforms to current U.S. practice. Specimen No. 3 should be identical to Specimen No. 1, except that it should not have a floor slab. It is intended that these tests would assist in the choice of number of ties within the joint and within the column, would assist in the choice of reinforcing details of the column ties, and would assist in the choice of anchoring details of the longitudinal reinforcement steel in the beams. The third specimen could also serve in correlating its test results with existing test data most of which have been obtained from specimens without floor slabs.

b. Interior column-to-beam assemblies - Three half-scale interior column-to-beam assemblies should be tested under a cyclic loading pattern as shown in Fig. 7. Reinforcing details for Specimens No. 1 and 2 should be selected following the same considerations and procedures described for exterior column-to-beam assemblies. Specimen No. 3 should also have no floor slab. The intentions of these tests are similar to those described above for the exterior column-to-base assemblies. It is possible that a fourth specimen should be tested including nonstructural elements.

c. Exterior top of column-to-beam assemblies - Considerable differences exist between the two countries in the detailing of reinforcement in the upper most column-beam connection. Therefore, two half-scale exterior column-to-beam assemblies representing current practice in both countries should be tested under a cyclic loading condition similar to that shown in Fig. 15. It is expected that these tests would directly serve as a basis for the choice of reinforcing details in the full-scale structure.

d. Walls - Two medium scale (preferably half-scale) walls of three or four stories should be tested under cyclic loading conditions. Specimen No. 1 should have beams in the wall at each floor level reflecting normal current construction practice in Japan. Specimen No. 2 should have no such beams like the full-scale test structure. Each specimen should have a portion of floor slab at each level as an integral part of the structure. The test results of these specimens should be used to verify the suitability of the initial recommendation that such beams be eliminated in the wall of the full-scale test structure.

Using the results of these joint assembly tests, a tentative design of the full-scale test structure should be made. Using the tentative design details, the quasi-static tests on full-scale joint assemblies previously suggested for the U.S. associated test program (Sec. V.C.1) should be carried out. These latter tests can then be used to verify the suitability, and to improve if necessary, the final design of the full-scale test structure.

2. Quasi-Static Tests On Planar Structures

Large-scale models of planar structures have been recommended for testing in the United States (Sec. V.C.2). It is believed that a second set of tests on planar structures would be needed to assist in the interpretation of the results of the tests on the full-scale seven-story test structure, particularly, in determining the time-history distribution of loading carried by each planar structure of the main test building. It is therefore recommended that the following full-scale planar models of identical design to those selected for the main test building be tested in Japan following the tests on the full-scale seven-story building.

a. Wall-frame system - A full-scale wall-frame system of three or four stories, representing the lower part of the control frame of the main test building, should be tested using a quasi-static displacement history identical to that used in the pseudo-dynamic testing of the main building.

b. Plane frame - A full-scale frame, identical to the lower portion of the exterior frame of the main test building, should be tested in a similar manner to that described above for the wall-frame system.

3. Shaking Table Tests On A Full-Scale Three-Story Frame Model

It is recommended that a full-scale three-story frame model having design detailing similar to the main test building, as shown in Fig. 16 be tested on a shaking table located in the Large Aseismic Testing Laboratory, National Disaster Prevention Center, Tsukuba New Town for Research and Education. This model should be provided with sufficient mass so that its fundamental natural frequency is similar to the seven-story full-scale test structure and it should include nonstructural elements such as exterior walls and interior partitions. Various levels of table excitation should be applied to the model so as to determine the interaction effects between the main structural elements and the nonstructural elements. Mathematical modelling and correlation studies should be carried out so as to make the results most useful to the selection of loading levels for the main test building.

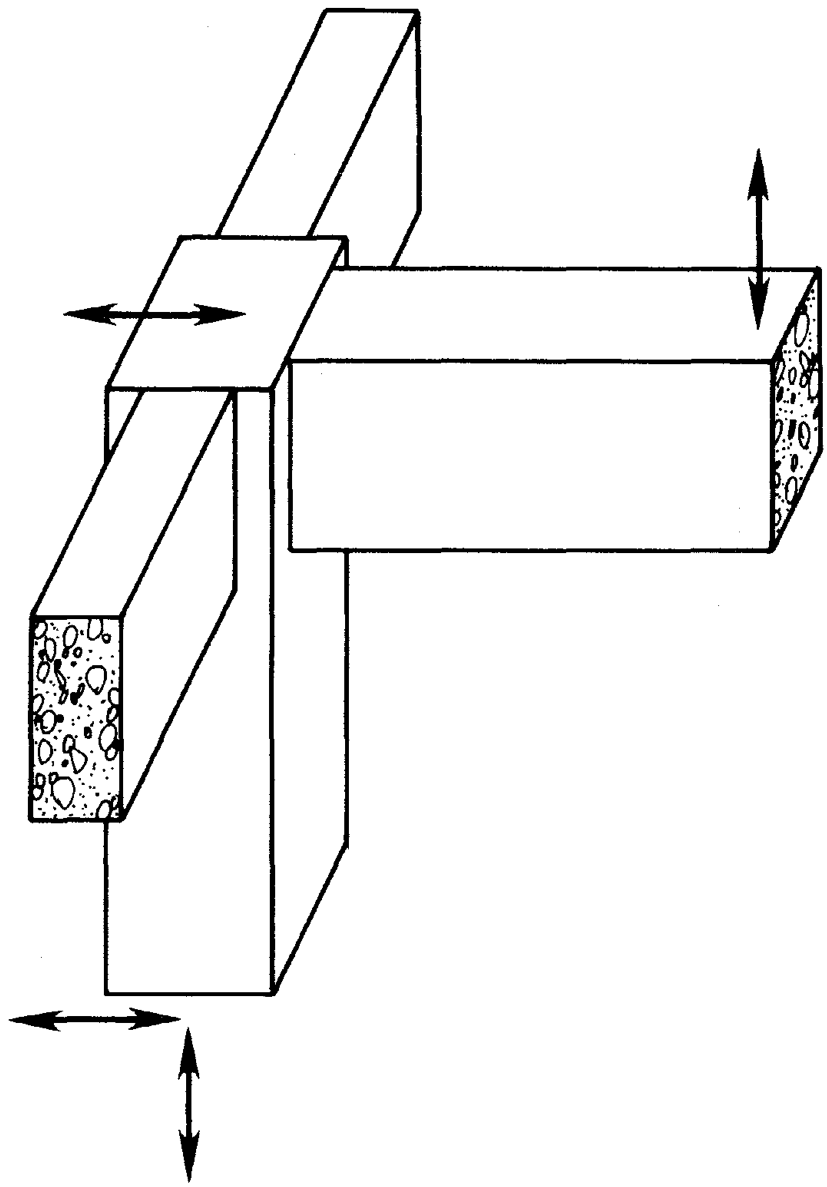


FIG. 15: Exterior Top of Column-to-Beam Assembly

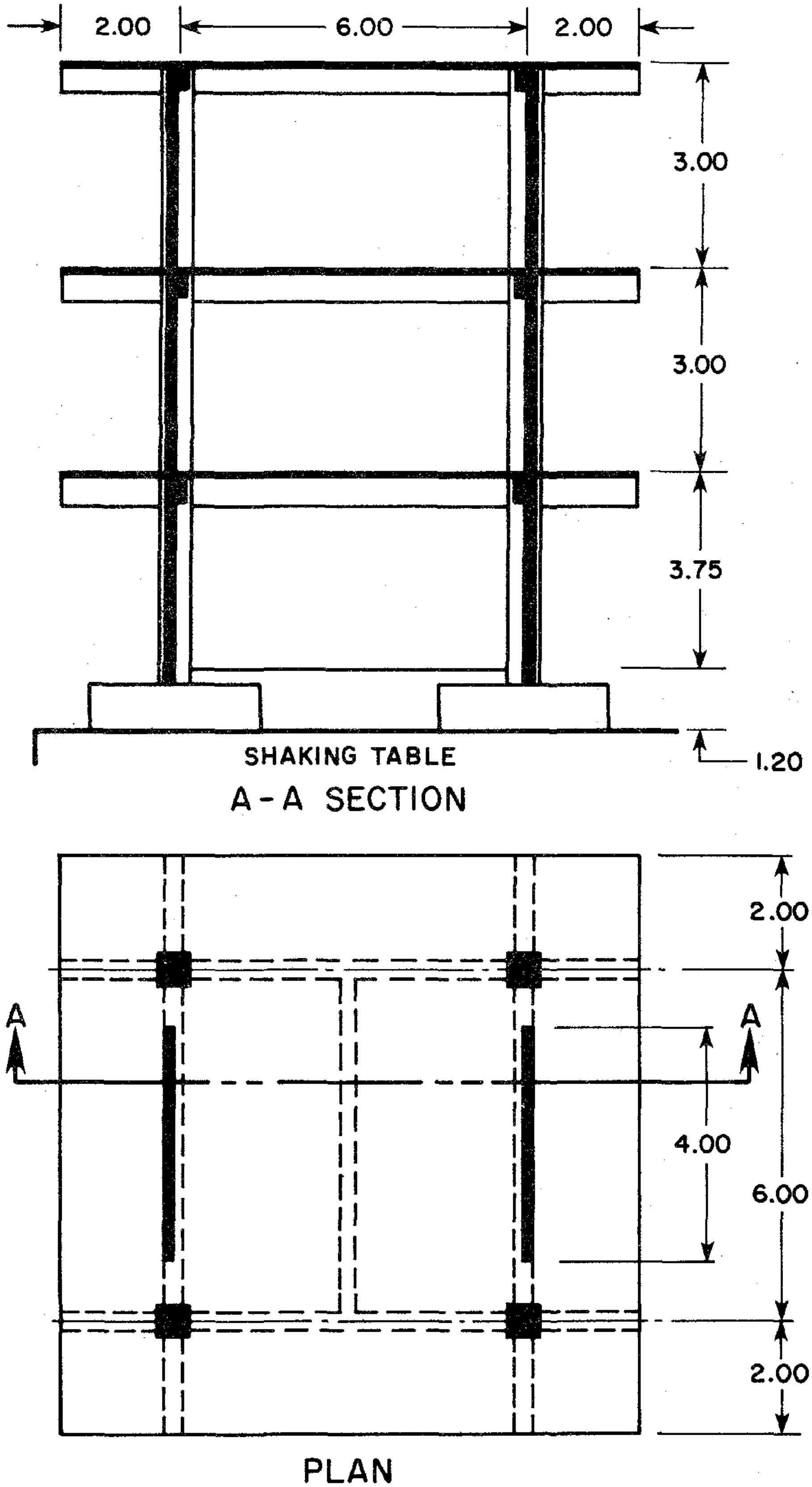


FIG. 16: Shaking Test on Full-Scale Three-Story Model

VI. RECOMMENDED RESEARCH ON STEEL BUILDING STRUCTURES

A. Summary

As previously pointed out for the case of reinforced concrete buildings, there is a recognized need to establish the relationship among full-scale tests, reduced-scale and component tests, and analytical studies of steel building structures designed to resist earthquake ground motions. It is impractical to build prototype structures and wait for actual ground motions to determine the response characteristics and safety levels of such buildings. Utilization of damaging earthquake motions has been and continues to be an important source of information, however, in many of these cases the buildings are not subjected to the design level ground motion or larger. The most efficient method of developing an understanding of damage level building behavior is through carefully planned tests. Design and analytical procedures can be established by using the test results and through computer simulation. Unfortunately, no tests into the cyclic nonlinear range have ever been performed on full-scale steel buildings designed according to the current practice. In recognition of the need for test results on prototype steel building structures, it is recommended that a full-scale seven-story building designed by the latest U.S. and Japanese codes be tested in the Large-Size Structures Laboratory of the Japanese Building Research Institute in Tsukuba New Town. The test structure should be a representative office building with a perimeter moment-resisting frame and a braced interior core. It should be tested in several stages using a loading procedure simulating realistic seismic conditions. The pseudo-dynamic procedure should be considered for this application. At the final stage of testing, nonstructural elements such as curtain walls and partitions should be added to the structural system and the entire structure should be loaded to failure.

In support of the full-scale test, it is recommended that a series of complementary quasi-static tests be conducted in the U.S. and Japan on girder-to-column connections, column-to-footing connections, bracing members, composite floor systems, planar composite beam-and-column assemblages, three-dimensional beam-and-column sub-assemblages, and braced and unbraced frame bents, that one-tenth scale models of the prototype structure be tested under simulated earthquake ground motions on a shaking table in Japan, and that a one-third scale model of the same structure be tested on a large shaking table in the U.S. Results of the one-third scale model tests should be used to establish correlations between the full-scale test and the shaking table test methods.

The recommended associated tests in the two countries should be carefully planned so that they are fully complementary; thus, the results of these tests can greatly assist in predicting the response of the prototype test structure at all levels of load application. The results of the various quasi-static tests and shaking table tests performed in both countries should be correlated with each other and with the results of the prototype structure. It is anticipated that the recommended quasi-static tests and one-tenth scale shaking table tests in Japan will be carried out at the Building Research Institute and the University of Tokyo with participation of the National Disaster Prevention Center, Science and Technology Agency.

The entire program should be well coordinated and researchers from both the U.S. and Japan should cooperate fully during the course of the investigation. It is recommended that researchers from both countries be provided the opportunity of working in each others' laboratories, and that the U.S. investigators take part in the testing of the full-scale building.

B. Tests On A Full-Scale Seven-Story Building In Japan

A seven-story steel framed office building has been recommended for purposes of comparing actual full-scale building behavior with model behavior and computer simulation and for assessing the damage and safety levels of buildings designed using current design practices. Figure 17 shows the floor plan of the test building and Fig. 18 gives the elevation views of the exterior and interior frames. The exterior frames are unbraced moment-resisting frames, whereas the interior frames are braced by K braces in the center bay. The floor system suggested for this building consists of metal decking and cast-in-place lightweight structural concrete. To develop composite action, it should be connected to the girders and floor beams by means of headed shear connectors. All structural members should be made of ASTM A36 steel (or the Japanese equivalent). Two types of K bracing systems, the concentric K and the eccentric K, should be used in different stages of testing. The test buildings should be essentially of welded construction which is the most common construction method for highrise buildings in both countries.

The prototype structure should be designed to satisfy the requirements of both the 1976 Uniform Building Code (U.S.A.) and the draft National Building Code (Japan, 1979). In some respects, the design requirements in the two codes are significantly different. However, it is possible to achieve a compromise design which inherently incorporates the basic design philosophies in these codes. The primary difference is the magnitude of equivalent seismic forces used in the static design procedure. In order to arrive at a structural steel building that will satisfy the code requirements of each country, gravity loads as summarized in Table 2 should be considered in the basic design. Some of these loads may not be precisely the current practice in either country, but they are very similar to the values used at the present time.

Equivalent earthquake lateral forces required by the two codes are also different, but it is again possible to reach a suitable compromise. Lateral forces which may be adopted for design are:

Total base shear coefficient = 0.17

Based shear coefficients for each exterior frame = 0.025

Based shear coefficients for each interior frame = 0.06

It is reasonable to assume that the two exterior frames resist 30 percent of the total base shear and that the two interior frames resist 70 percent. Combining the compromise of the gravity loads and of the earthquake lateral loads as discussed above, two trial designs should be carried out; one design using the available American shapes and the other design using the available Japanese shapes. It should be noted that the Japanese steel mills can roll American shapes of their close equivalents without any difficulty.

Another difference in design procedures arises in the detailing of girder-to-column connections for interior braced frames. Current U.S. practice uses simple shear connections, but Japanese practice adopts moment connections. For this reason, it is recommended that initial testing be conducted on the test structure with shear connections at these locations. The shear connections should then be replaced by moment connections for subsequent testing. This approach is also recommended for some of the support tests carried out in both countries.

It is recommended that the test program for the full-scale steel building include free vibration tests and floor slab repairs as judged necessary and appropriate. Three levels of loading should be considered in the pseudo-dynamic testing: (a) working stress level, (b) post-buckling of braces level, and (c) post moment-frame yielding level. In order to maximize the amount of knowledge that may be gained from the program, the following test sequence is recommended:

1. Bare steel frames with composite slabs. No braces in the core.
2. Concentric braces in the core with simple shear connections on the column lines.
3. Replacing the braces and the associated girders and installing moment connections on the column lines.
4. Replacing concentric braces by eccentric braces and also the girders in the braced bay.
5. Installing nonstructural elements to the structure as in 4 with appropriate member replacement and repair.
6. Test to ultimate displacement near collapse of structural frames, breaking of nonstructural elements, etc,

In 1 through 5, the structure should be loaded by a procedure simulating realistic seismic conditions. If fully developed at the time of testing, the pseudo-dynamic test method is recommended. The load levels in 4 and 5 may be higher than those in 1, 2 and 3. In 5, nonstructural elements commonly used in both countries should be added to the structural frame. Thus, opportunities will be provided to examine not only the modelling of the structural system, but also that of the nonstructural elements. Details of the nonstructural elements should be developed early in the program. Quasi-static cyclic load should be applied in 6.

This test sequence will provide important data on the behavior of full-scale moment frames as well as braced frames coupled with back-up moment frames. Analytical procedures for moment frames are well established. Similar analytical procedures for braced frames are being developed, but cannot be fully confirmed because only a small amount of test data on the behavior of bracing members and on braced frames are available. This full-scale test can provide much-needed data. Also, test results of braced frames which utilize eccentric bracing are needed. In many situations in order to accommodate doorways and/or windows in the frames, it is not practical to use concentric bracing.

As previously stated, a loading procedure simulating realistic seismic conditions is recommended for the full-scale seven-story building test. Hopefully, the pseudo-dynamic test method can be used for this purpose. The types and levels of ground motion input adopted depend upon the desired response stress levels as indicated above. Extensive studies as described in Sec. VIII should be carried out prior to the full-scale test for the purpose of defining appropriate ground motion inputs.

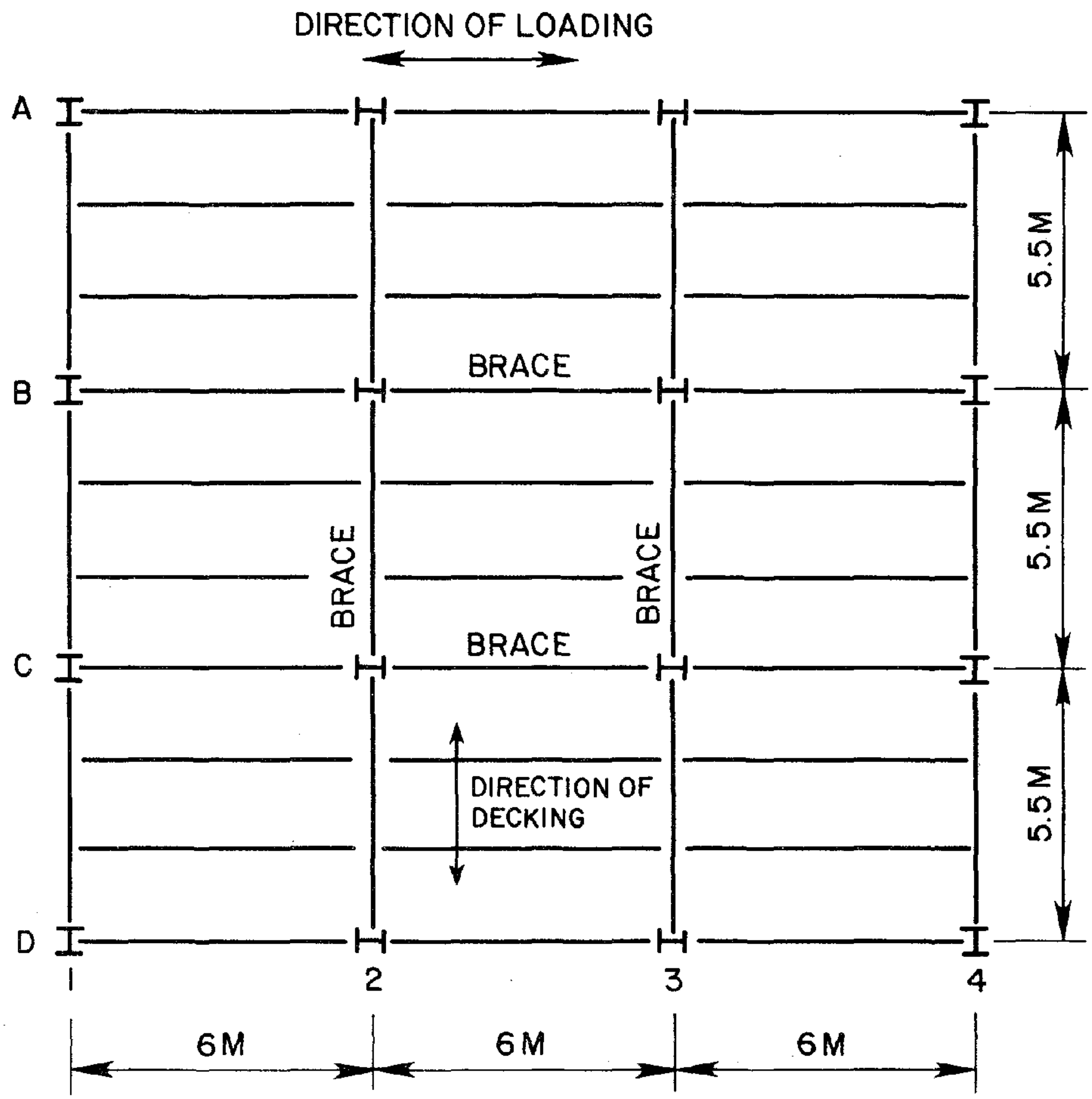
TABLE 2

GRAVITY LOADS ASSUMED FOR DESIGN

(1 psf = 4.88 kg/m^2)

DEAD LOADS	US (psf)	Japan (kg/m^2)
Floor		
Metal Deck	6	18
3-1/2" Lightweight Concrete	39	221
Ceiling and Floor Finishes	10	60
Partitions, etc.	20	50
	75 (366 kg/m^2)	349 (72 psf)
Structural Steel and Fireproofing	15	90
	90 (439 kg/m^2)	439 (90 psf)
Roof		
Metal Deck	6	18
Lightweight Concrete	39	221
Ceiling and Roofing	20	100
	65 (317 kg/m^2)	339 (69 psf)
Structural Steel and Fireproofing	10	70
	75 (366 kg/m^2)	409 (84 psf)
Exterior Wall Weight	15 psf of wall surface	70 kg/m^2

LIVE LOADS (Reduced equivalents from Japanese practice)		
Slab and Beams	60	300
Girders	37	180
Roof	16	80
For Earthquake Combination	16	80



7-Story Office Building

18 M x 16.5 M x 22.5 M

Design Criteria

1. Design by 1976 UBC and the draft new Japanese code.
2. ASTM A36 steel (or Japanese equivalent) F_y = 248 MPa.
3. Metal deck and lightweight concrete floor system acting compositely with girders and floor beams.
4. K braces in central core.

FIG. 17: Plan of Steel Test Structure

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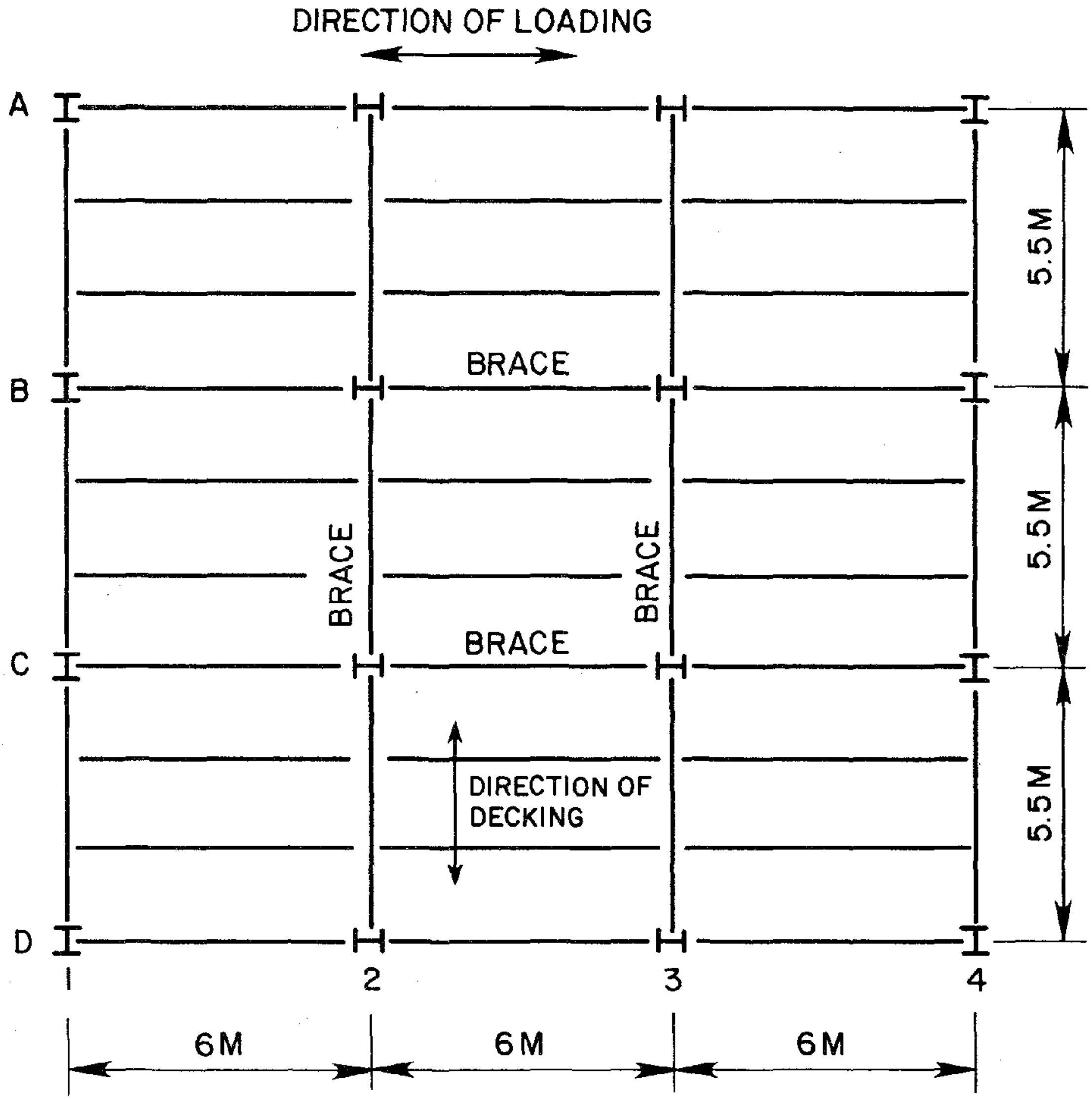

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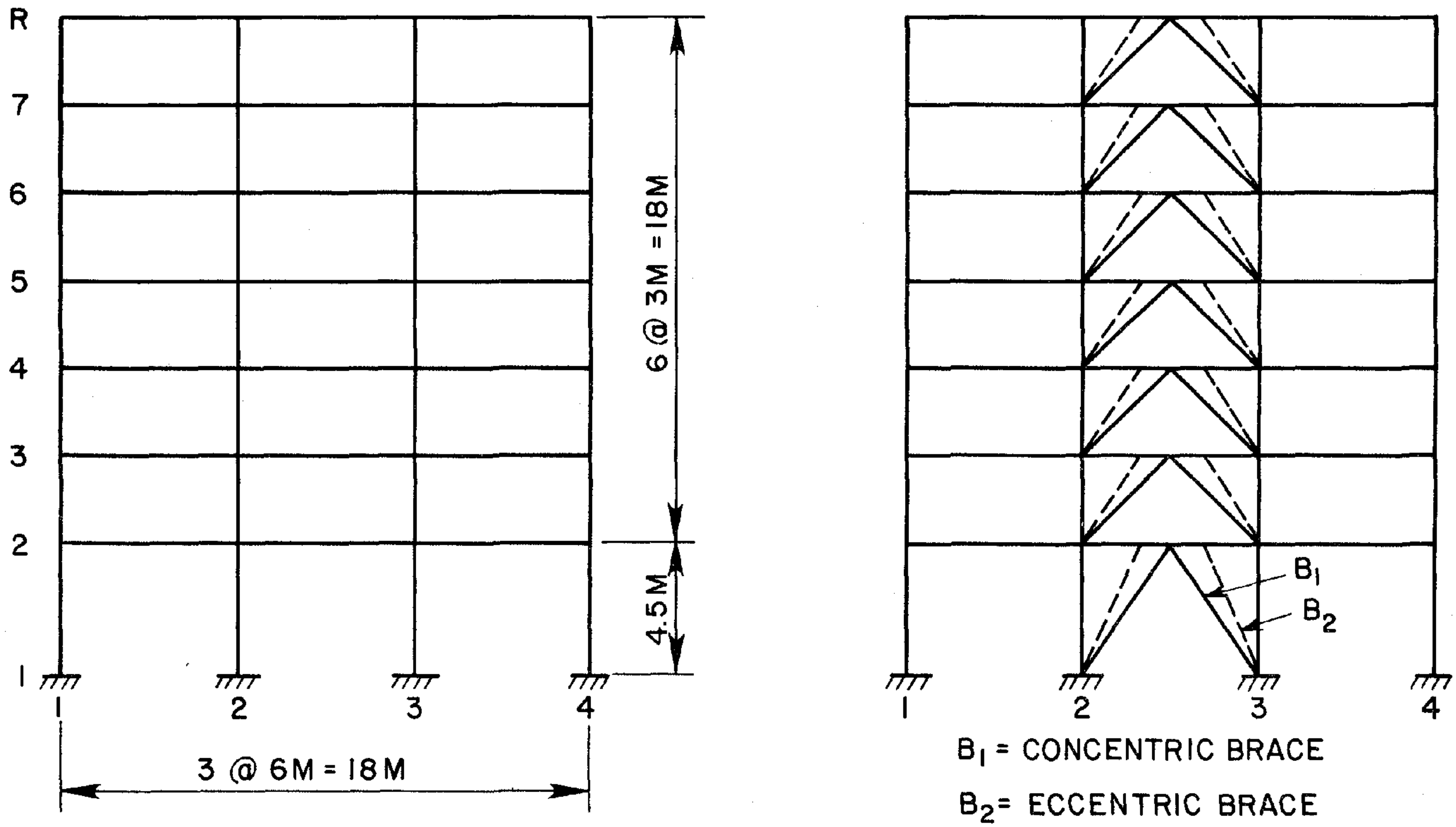


MOMENT-RESISTING EXTERIOR FRAME
(FRAMES A AND D)

BRACED INTERIOR FRAME
(FRAMES B AND C)

FIG. 18: Elevation Views of Exterior and Interior Frames

C. Associated Tests In The United States

In support of the full-scale seven-story building test in Japan, it is recommended that a series of quasi-static tests on components and frames and a shaking table test on a one-third scale model be carried out in the United States. Most of these tests should be conducted before the start of the main test since they are intended to serve the following purposes: (a) To develop basic information on the stiffness characteristics of the various structural components and planar frame bents in the prototype test building. This information is necessary for the development of analytical predictions of the response of the test structure at low and moderate levels of applied loads. Based on these stiffness properties, checks can be made on some of the assumptions made in the design of the test building, especially the one with regard to the distribution of total seismic forces to the moment-resisting frames and to the braced frames. (b) To study the inelastic behavior and ultimate strength of structural components. The results obtained should be used in assessing the ultimate strength and energy absorption capacity of the full-scale test structure. Since the applicable design codes in both countries are based heavily on the inelastic response and ductility of structural elements, the component test results can provide the necessary data for checking the test building to meet these design requirements. (c) To obtain data on the dynamic response characteristics of the complete steel structural system in the elastic and inelastic ranges. Although considerable useful information can be obtained from the quasi-static component and frame tests as well as from the pseudo-dynamic full-scale prototype tests, results of dynamic simulator tests are needed to correlate these tests and analytical procedures with expected earthquake behavior. (d) To provide results which can be useful in developing an appropriate loading program for the main test. The loading program for the main test should be based, in part, on the stiffness and strength characteristics of the test structure which can be investigated in these quasi-static and dynamic associated tests.

Previous experimental and analytical research results should be extensively used in this investigation. The tests recommended in support of the full-scale building tests should involve structures which have heretofore not been studied in the U.S. or in Japan. Behavior of welded steel structures should be of primary concern in these tests. Some of the test specimens may be full size; others may be half- or third-scale. All specimens should be fabricated by commercial fabricators in the United States.

1. Quasi-Static Tests On Structural Components

   a. Girder-to-column connections - Three types of girder-to-column connections with girders framing into the column in the perpendicular directions are recommended as shown in Fig. 19. They represent some of the connections in the exterior moment-resisting frames and in the interior braced core. For each type of connection, two specimens should be tested. One may be taken from the second floor (level 2 in Fig. 18) and the other may be taken from the fourth floor of the test building. Thus, a total of six specimens would be tested. All the girders should be composite with concrete slab cast on formed metal deck and the connections between the slab and the girders should be through headed shear studs.

   b. Bracing members - The cyclic tension-compression behavior of the bracing members in the interior core of the test building needs careful investigation. It is recommended to test four bracing members together with their connections in alternate axial tension and compression. Two of these are braces should be of the concentric K design, and the other two of the eccentric K design. A special setup similar to that shown in Fig. 20 could be used for testing the large size braces under cyclic load.

c. Composite floor systems - The in-plane shear stiffness and strength of the composite floor system used in the test building should be determined experimentally. Two diaphragm-type tests are recommended: one with the floor slab subjected to constant dead load and cyclic shear and the other with constant dead and live loads and cyclic shear. The metal deck should be connected compositely to the girders and floor beams, simulating the situation in the prototype test building. The specimens may be tested using a special test setup as shown in Fig. 21.

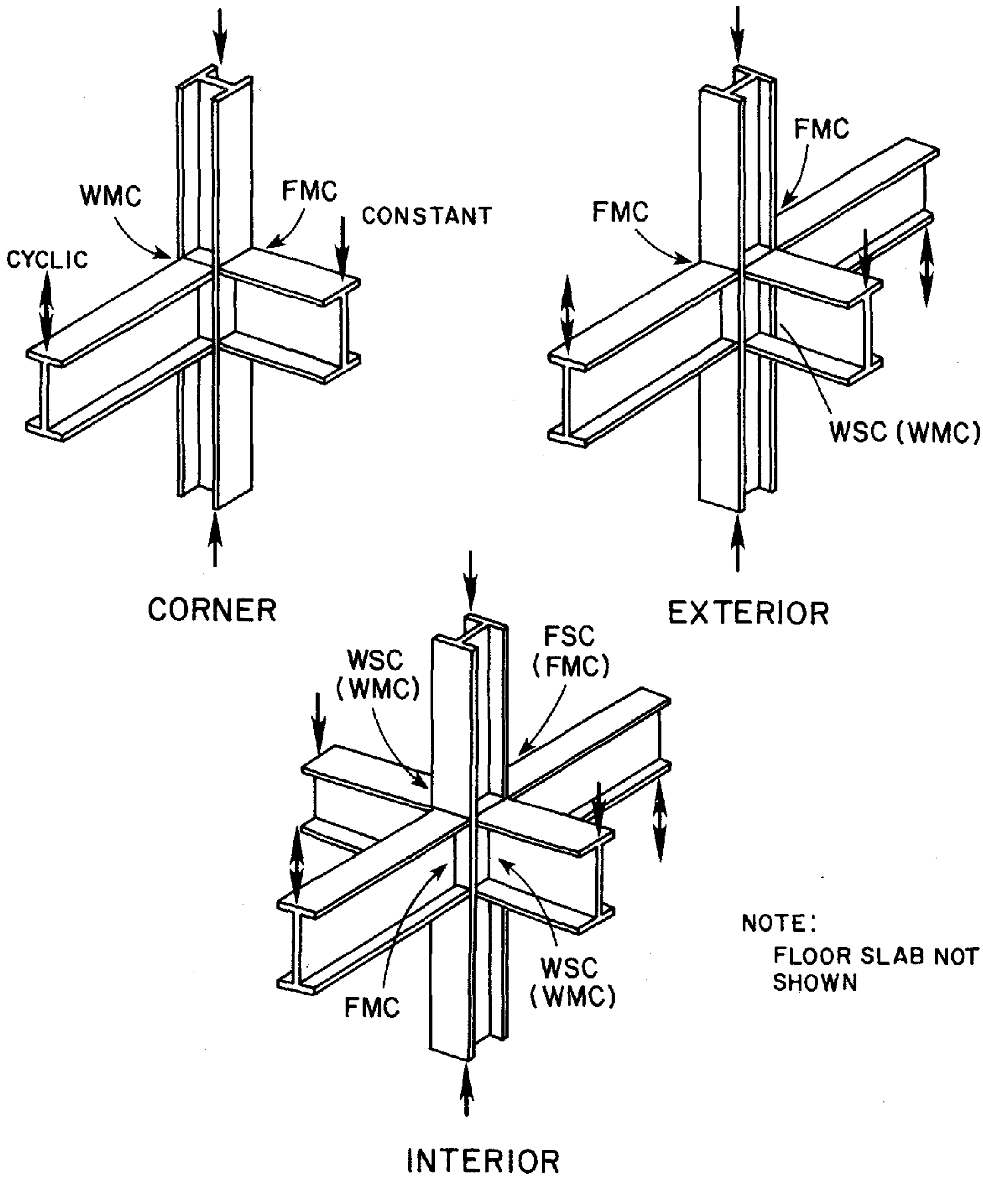
2. Quasi-Static Tests On Planar Frames

a. Moment-resisting exterior frame model - The behavior of moment-resisting frames with slabs acting compositely with the girders are not fully understood, even though some exploratory studies have been carried out in the U.S. and Japan. This is especially true for frames having columns oriented for weak-axis bending (such as the exterior frames of the test building) and with slabs made of light-weight concrete. To study the behavior, it is recommended that tests be conducted on a seven-story half-scale model of the full-scale exterior moment-resisting frame; see Fig. 22. All girder-to-column connections in this model should be moment connections. The structure should be subjected to constant gravity loads and then a program of controlled lateral loads or displacements should be applied at the floor levels, as shown in Fig. 23. The test should be continued until ultimate load or displacement of the structure is reached. To obtain information on the contribution of nonstructural elements to overall behavior, light cladding representing the curtain walls of the full-scale building should be added to the test frame. Then, the structure should again be tested to ultimate condition. Additional tests may also be conducted to study the strength and ductility of selected one-story assemblages of this frame. In this case, the cladding material should be removed and each assemblage should be tested individually to a maximum displacement substantially greater than that corresponding to ultimate load. These assemblage tests should be conducted as shown in Fig. 23 B using a similar setup to the overall frame test.

b. Braced interior frame model - The lateral load-deformation behavior of the seven-story, three-bay interior frame of the test building is likely to be very complex and will be difficult to predict with presently available information. It is therefore recommended that a thorough study of this behavior be conducted by testing a half-scale model of the prototype frame, using a similar setup to that used in testing the exterior moment-resisting frame. The test structure and some of its important structural features could be as shown in Fig. 24. Like the recommended tests on the model exterior frame, this structure should be tested first in its entirety and without any nonstructural elements. As stated in Section VI B, the test program for the prototype building includes both concentric and eccentric braces in the braced bay and both shear and moment connections on the column lines. These variations in design details should also be examined in this study. The test sequence should include (1) concentric braces in the braced bay and simple shear connections on the column lines, (2) concentric braces and moment connections on the column lines, and (3) eccentric braces and moment connections.

At the conclusion of (3), interior partitions should be installed in all of the stories and bays. The frame should then be tested to ultimate load or displacement. Further tests could then be conducted on selected one-story assemblages removed from the test frame to study their inelastic and post buckling behavior.

c. Combined exterior and interior frame test - After completing tests a and b, and before starting the one-story assemblage tests, the two seven-story frame models should be interconnected through the composite floors. Tests should then be conducted with lateral loads applied simultaneously to both frames.



FMC = FLANGE MOMENT CONN. WMC = WEB MOMENT CONN.
FSC = FLANGE SHEAR CONN. WSC = WEB SHEAR CONN.
FSC (FMC) = FSC INITIALLY, FMC SUBSEQUENTLY

FIG. 19: GIRDER-TO-COLUMN CONNECTION TESTS

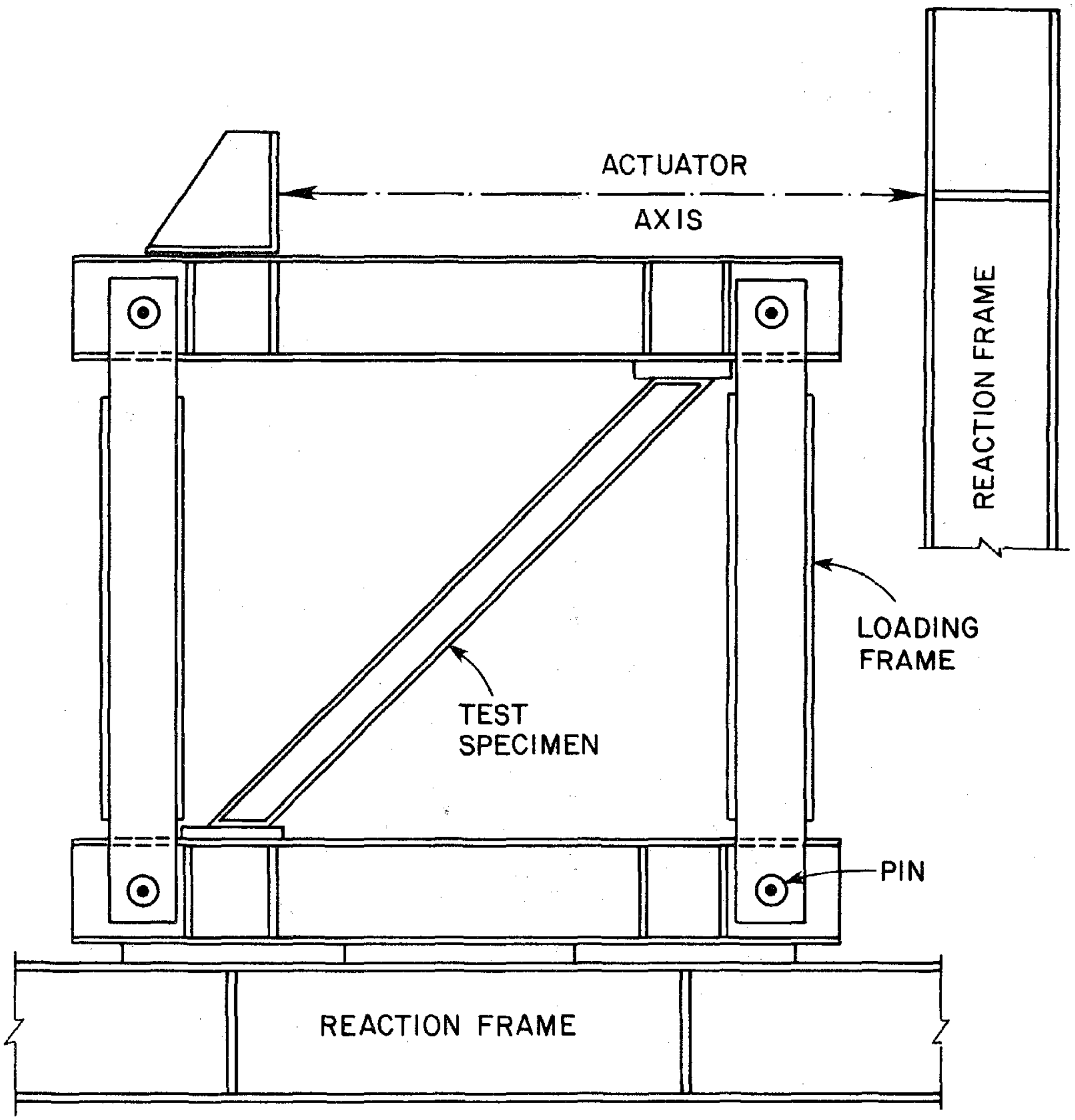


FIG. 20: INDIVIDUAL BRACING TEST

SLAB-TO-GIRDER : FULL COMPOSITE CONNECTION

SLAB-TO-FLOOR BEAM : PARTIAL COMPOSITE CONNECTION

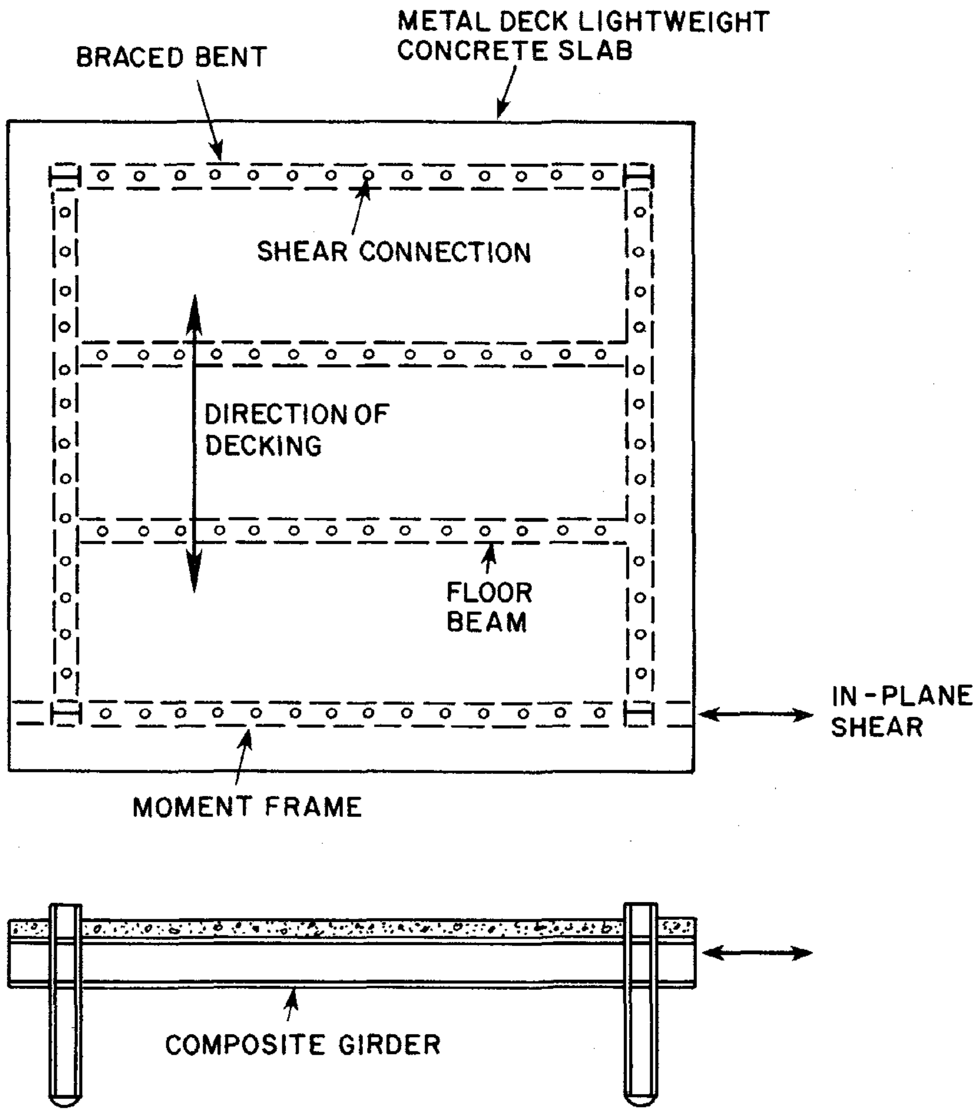
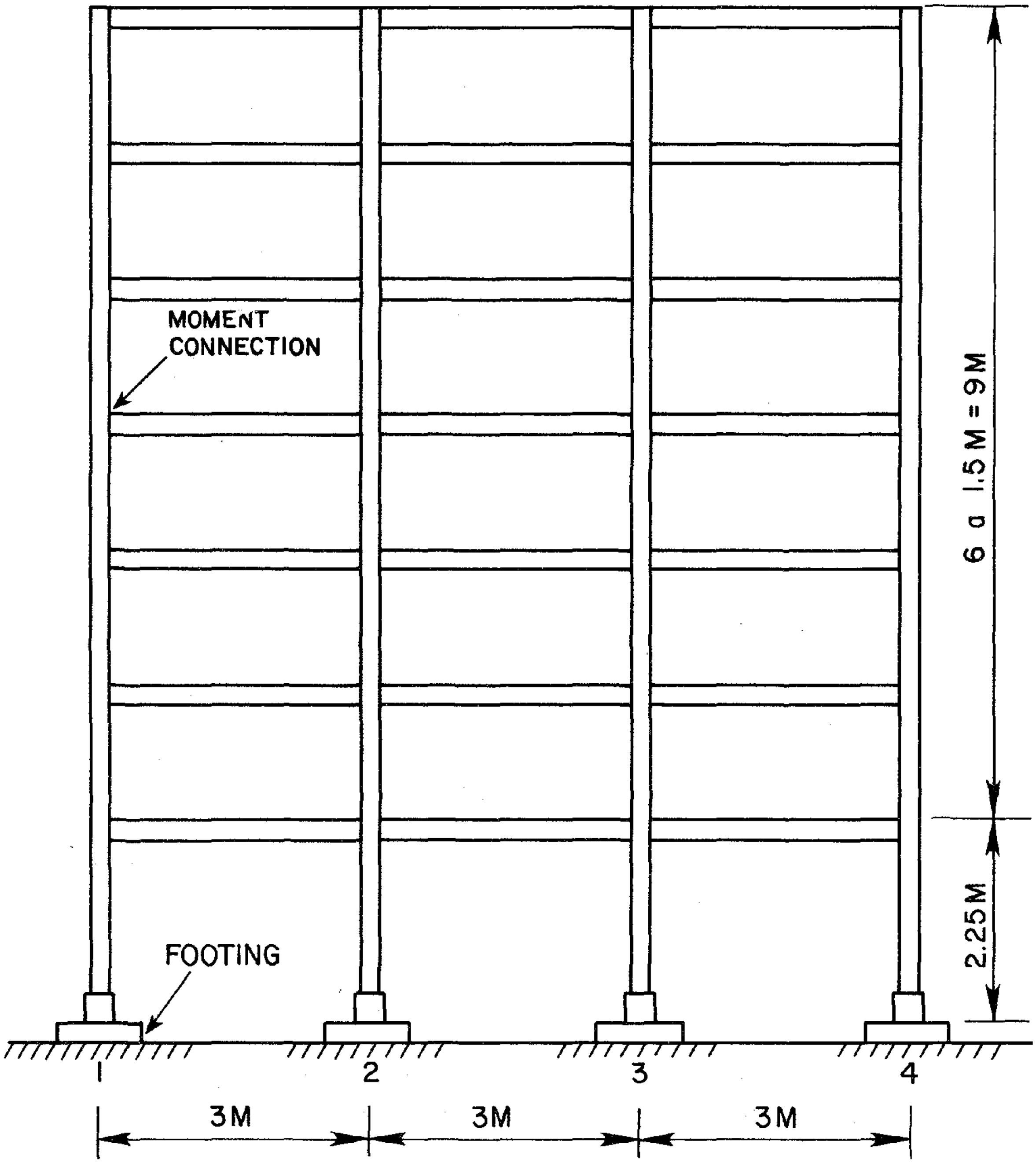


FIG. 21: COMPOSITE FLOOR SYSTEM TEST

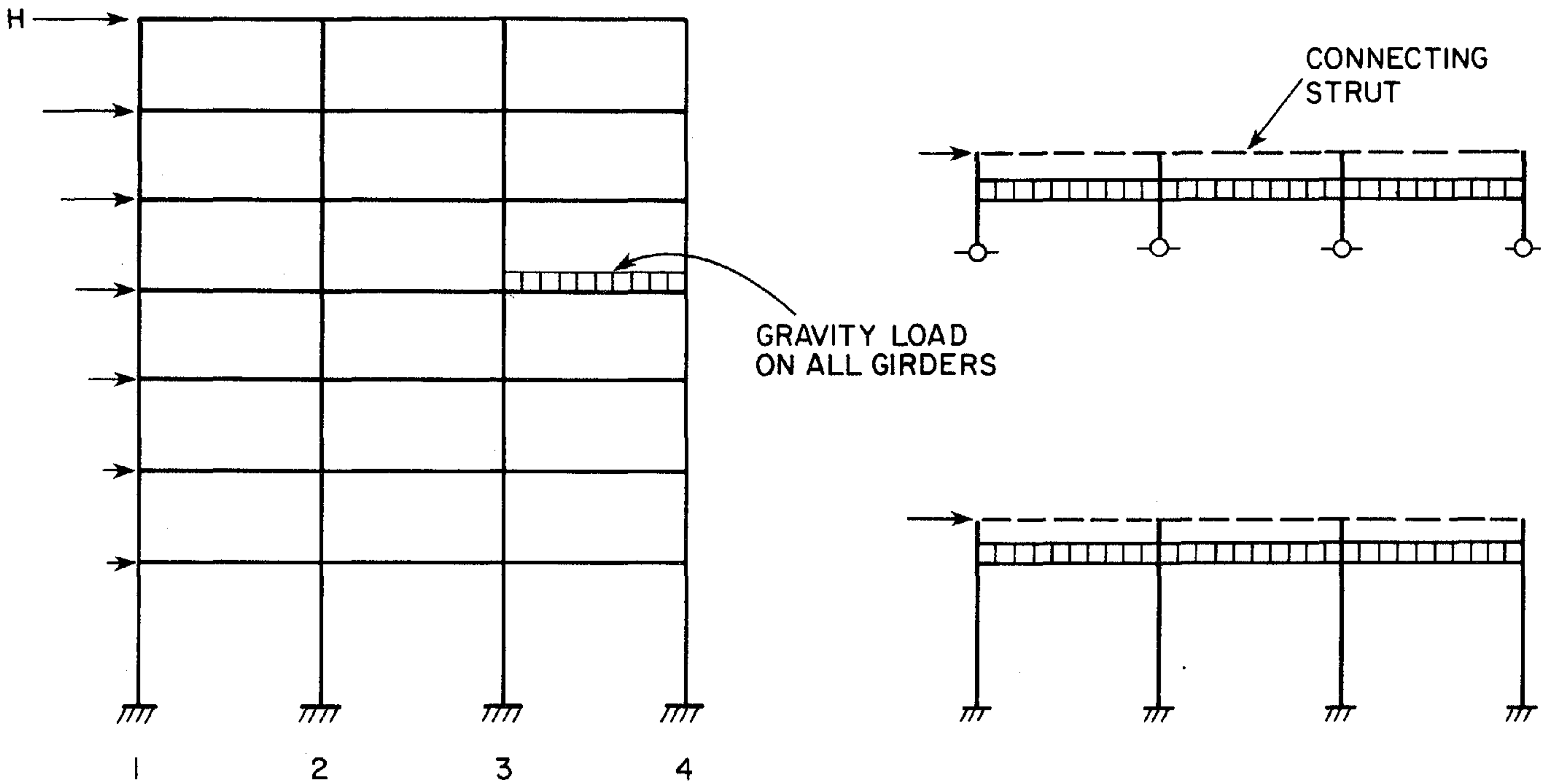


Note: A. Composite floor slab on all girders.

B. Weak-axis orientation for columns on lines 1 & 4.

Strong-axis orientation for columns on lines 2 & 3.

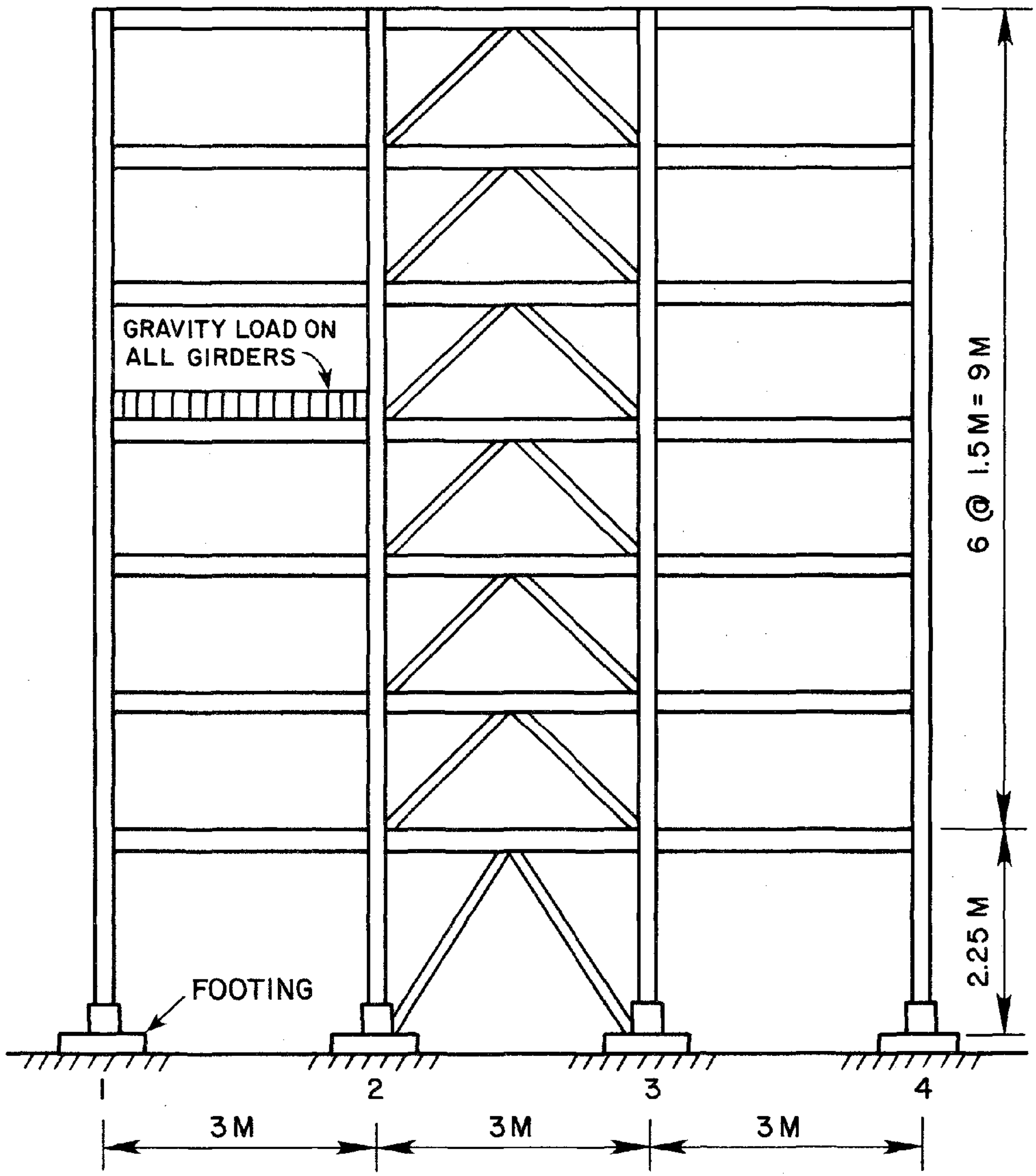
FIG. 22: EXTERIOR MOMENT-RESISTING FRAME MODEL



(A) OVERALL FRAME TEST

(B) ONE-STORY ASSEMBLAGE TEST

FIG. 23: TESTS ON EXTERIOR FRAME MODEL



Note: A. Composite floor system not shown.

B. Weak-axis orientation for columns on lines 1 & 4.

Strong-axis orientation for columns on lines 2 & 3.

C. Test program including both concentric and eccentric K braces.

FIG. 24: INTERIOR BRACED FRAME MODEL

3. Shaking Table Tests On A One-Third Scale Model

Shaking table tests on an approximately one-third scale model of the full-scale seven-story steel building to be tested in Japan are recommended. The specific objective of these tests and of the associated analytical studies is to obtain data on the dynamic behavior of this type of structural system in the elastic and inelastic ranges which can be used to: (a) assess the reliability of moderate scale models for predicting seismic response; (b) develop relationship between quasi-static associated tests, full-scale pseudo-dynamic tests and reduced-scale and pseudo-dynamic tests; (c) to evaluate current analytical methods; and (d) assess the design and loading histories to be used for the full-scale structural tests.

The test model should be designed on the basis of the final designs selected for the full-scale prototype tests (Figs. 17 and 18) and for the associated tests. It should be constructed to the largest scale that will permit significant inelastic deformations to be developed in critical structural components using a shaking table, preferably one providing two-components of motion. A scale factor of about one-third would be suitable for this purpose. Instrumentation should be developed to monitor the distribution of internal forces as well as other key response parameters.

The test program for the recommended shaking table investigations should parallel, as much as possible, the full-scale building tests proposed in Section VI. B. Thus, information would be obtained on the dynamic response of concentrically and eccentrically braced structural systems using free vibration tests and shaking table tests in the elastic and inelastic ranges. It is suggested that the basic sequence of tests (including appropriate structural modifications and repairs) as recommended for the full-scale structure be followed for the one-third scale tests to the extent possible. Certain features may however be added or deleted on the basis of the results of other associated tests. After producing significant, but not excessive, damage to the medium-scale model on the shaking table, the structure should be repaired and retested using loading conditions representing high intensity ground motions. This test could be used to determine the model's large deformation and failure characteristics.

D. Associated Tests In Japan

1. Quasi-Static Tests On Continuous Composite Beam-And-Column Assemblages

The objective of these tests would be (a) to estimate effective width of the slab in inelastic region under seismic loading conditions; (b) to evaluate the effects of bearing force at column face on the load carrying capacity and deformations of the beam and the column; and (c) to observe and investigate overall cyclic behavior of the composite beam including the effect of restraint against lateral buckling of beams. Four two-third scale models are being considered for this investigation. Specimen No. 1 is an assemblage with a continuous composite beam as shown in Fig. 25 and the second is a bare steel assemblage which can be used for comparison purposes with Specimen No. 1. The other two are assemblages with weak-bending columns and beams connected to the columns by shear connections. Specimen No. 3 has the concrete slab like Specimen No. 1. In testing this specimen, the stress distribution and failure mechanism around the shear connections including the concrete slab should be examined. Specimen No. 4 is a bare steel assemblage corresponding to Specimen No. 3 which is intended to be tested for comparison purposes. It is anticipated that these tests would be carried out at the University of Tokyo.

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2. Quasi-Static Tests On Braced And Unbraced Three-Story Frames

The objectives of these tests should be (a) to estimate effects of closed K- and open K-bracing systems; (b) to evaluate post-buckling behavior of closed K- braces (restoring force characteristics); (c) to estimate the bending and shear deformations of the frame models; (d) to examine the differences in failure mode due to moment connections and shear connections in the closed K- braced frames; and (e) to examine the differences in contributions of composite beams to the behavior of frames by two bracing systems. Six two-third scale models are recommended for testing. Specimen No. 1 should be a bare frame without bracing which can serve as the basis for comparison (Fig. 26). Specimen No. 2 should be a bare frame with closed K- braces designed to satisfy objectives (a), (b) and (c), Specimen No. 3 should be a bare frame with open K- braces designed to satisfy objectives (a) and (c), Specimen No. 4 should be a bare frame with closed K-braces and shear connections designed to satisfy objectives (d), Specimen No. 5 should be a closed K- braced frame with composite beam designed to satisfy objective (e), and Specimen No. 6 should be an open K- braced frame with composite beam designed to satisfy objective (e). Figure 27 shows the anticipated details of connections at the ends of the closed K- braces. This series of tests are being planned by the Building Research Institute.

3. Quasi-Static Tests On Three-Dimensional Column-And-Beam Subassemblages

The objectives of these tests should be (a) to study the response behavior of the subassemblage subjected to combined gravity and seismic loads, and (b) to examine the elastic-plastic behavior of the subassemblage due to the cyclic load in a fixed oblique direction. Two identical two-third scale specimens of the type shown in Fig. 28 are recommended for testing to satisfy objectives (a) and (b), respectively.

4. Quasi-Static Tests On Column-To-Footing Connections

The objectives of these tests should be (a) to evaluate the ultimate strength and rotational capacity of such connections and (b) to study the mechanism of their shear transfer. Several two-third scale models of the type shown in Fig. 29 are recommended for testing. Each specimen should have the same steel column section, but the reinforced concrete footing detailing should be different from one specimen to another. It is intended that these tests will be carried out at the Institute of Industrial Science, University of Tokyo.

5. Shaking Table Tests On One-Tenth Scale Models

Recognizing the difficulty in constructing the one-tenth models which fully satisfy the similitude to the prototype, reduced simple models which can demonstrate the most important dynamic characteristics of response behavior are recommended herein. The characteristics to be learned are (a) the effect of strength distribution along the height of building on inelastic response behavior, especially in input-energy accumulation into a particular weak story, and (b) the difference of dynamic behavior of shear deformation model (moment frame) and of flexural deformation model (diagonal bracing system).

The following six one-tenth models are recommended:

UNBRACED FRAMES (Fig. 30)

No. 1 - This model has the same strength distribution along its height as that of the prototype structure, and it should be designed on the weak-column concept.

No. 2 - The strength distribution of this model is the same as that of Specimen No. 1, but it should be designed on the weak-beam concept.

No. 3 - This model should be designed on the weak-column concept, but its strength distribution should be different from Specimen No. 1.

BRACED FRAMES (Fig. 31)

No. 4 - This model has the same strength distribution along its height as that of the prototype structure, and its load carrying ratio of moment frames to the entire structure is also the same as that of the prototype structure. Diagonal bracings should be the closed-K type.

No. 5 - All dimensions of this model are the same as those of Specimen No. 4, but the beam-to-column moment connections should be replaced by shear connections.

No. 6 - This model is the same as Specimen No. 4, but its diagonal bracings should be the open-K type. Plastic hinges can be expected to form at mid-span of the beams; thus, influencing the deflection mode.

These model tests are being planned by the Building Research Institute in Tsukuba New Town.

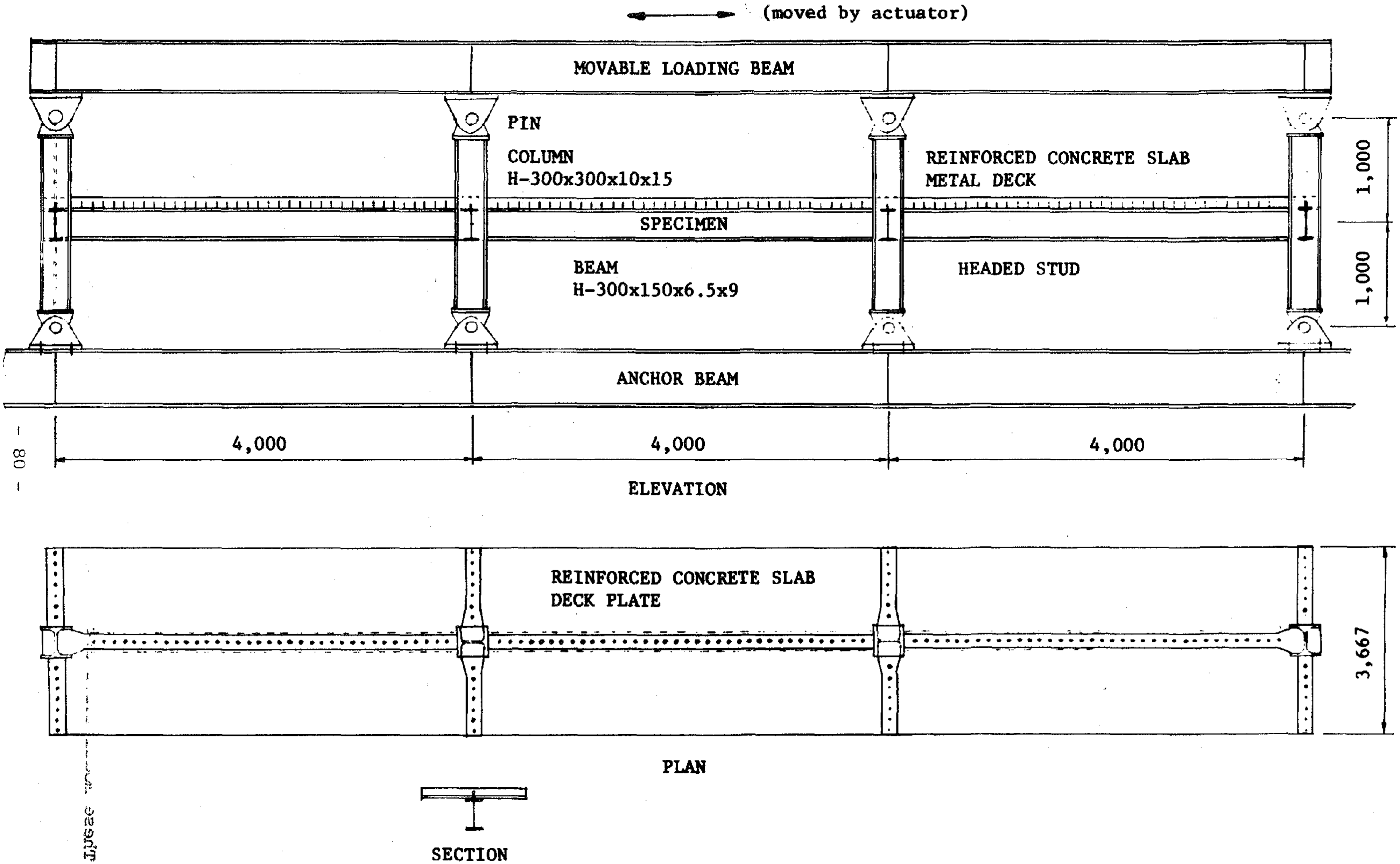


Fig. 25: SCHEMATIC SKETCH OF TEST SETUP FOR A COMPOSITE BEAM-COLUMN SUBASSEMBLAGE

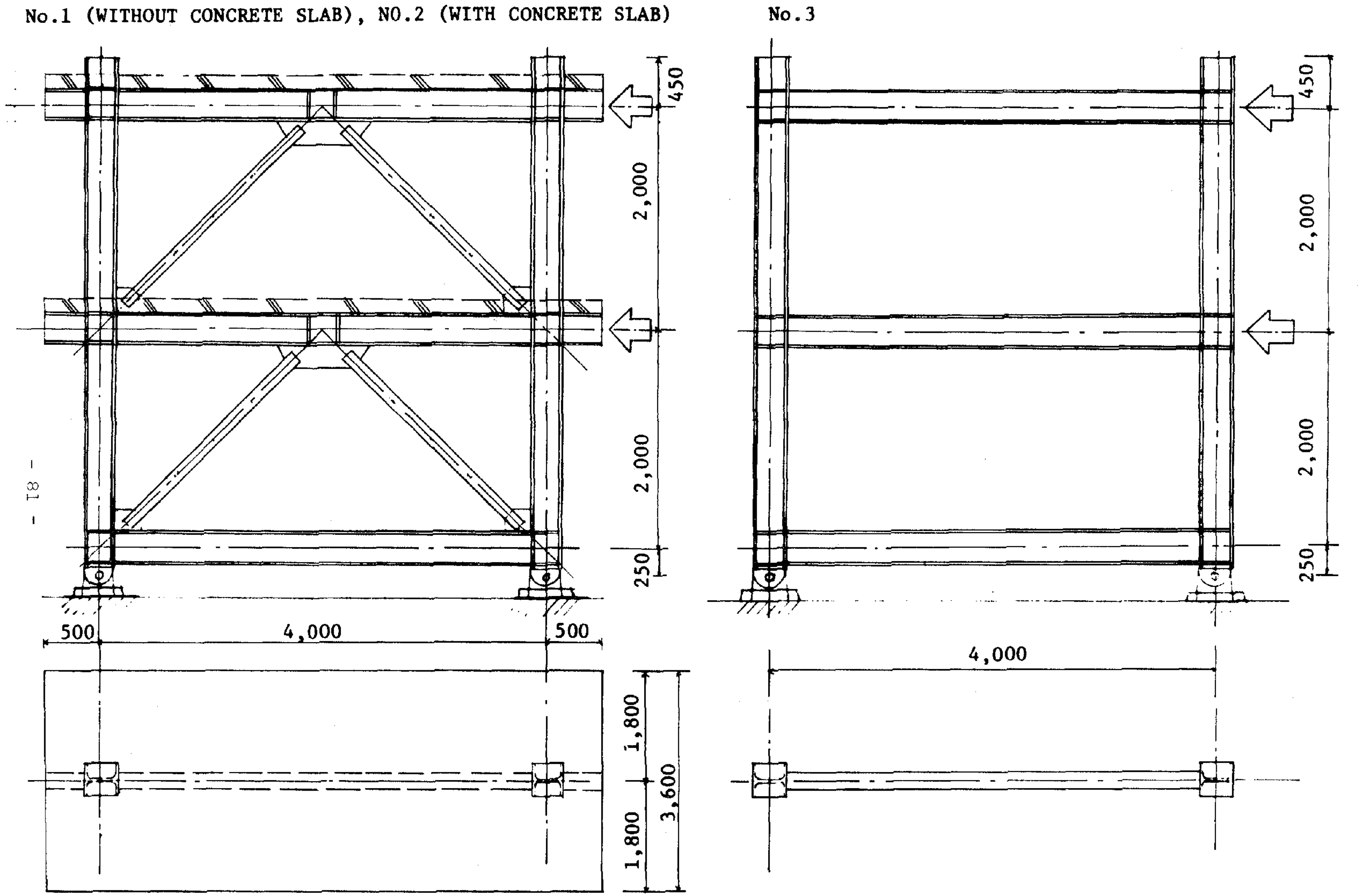


Fig. 26: TEST SPECIMENS OF BRACED AND UNBRACED FRAMES S = 1/50

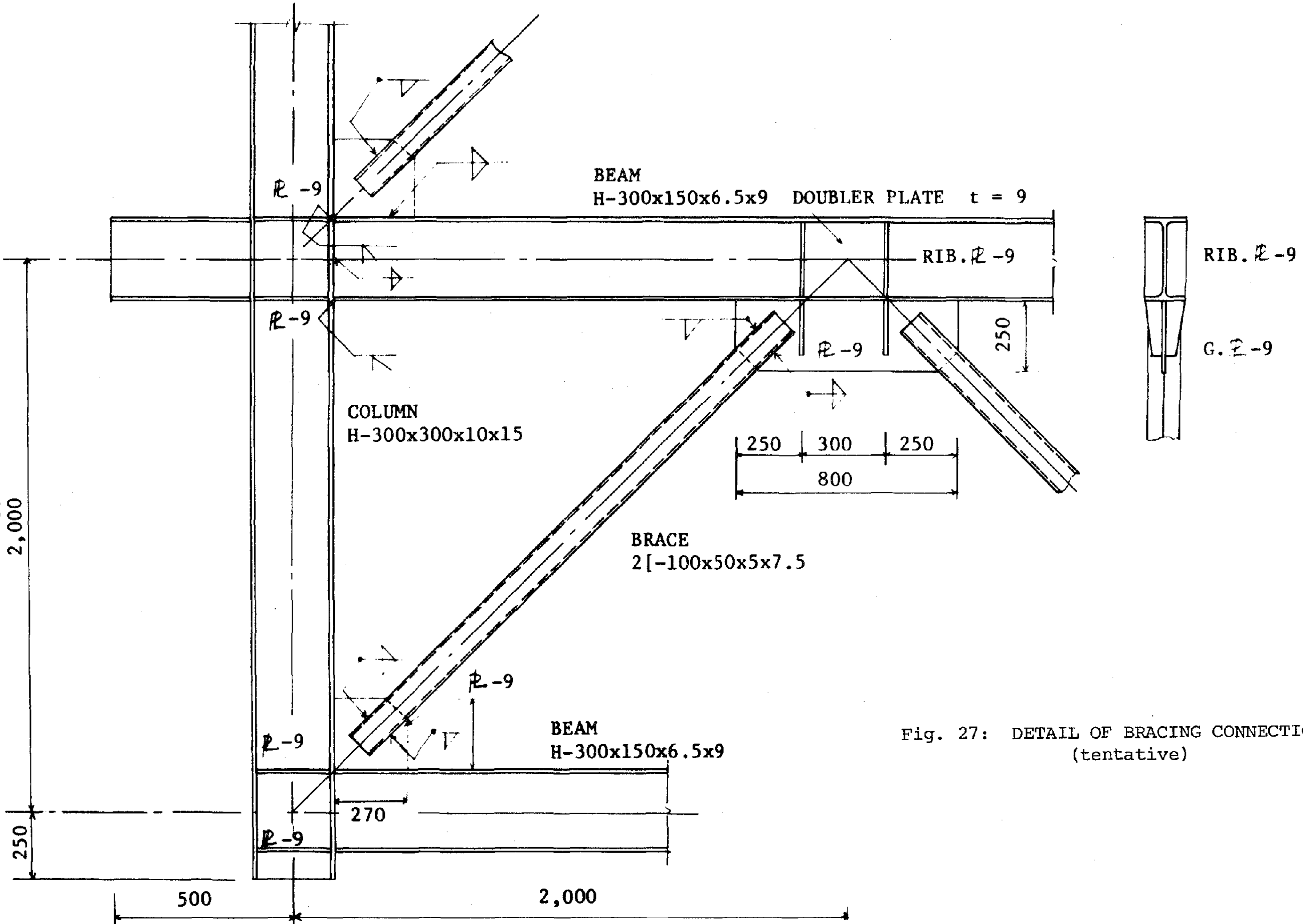


Fig. 27: DETAIL OF BRACING CONNECTIONS (tentative)

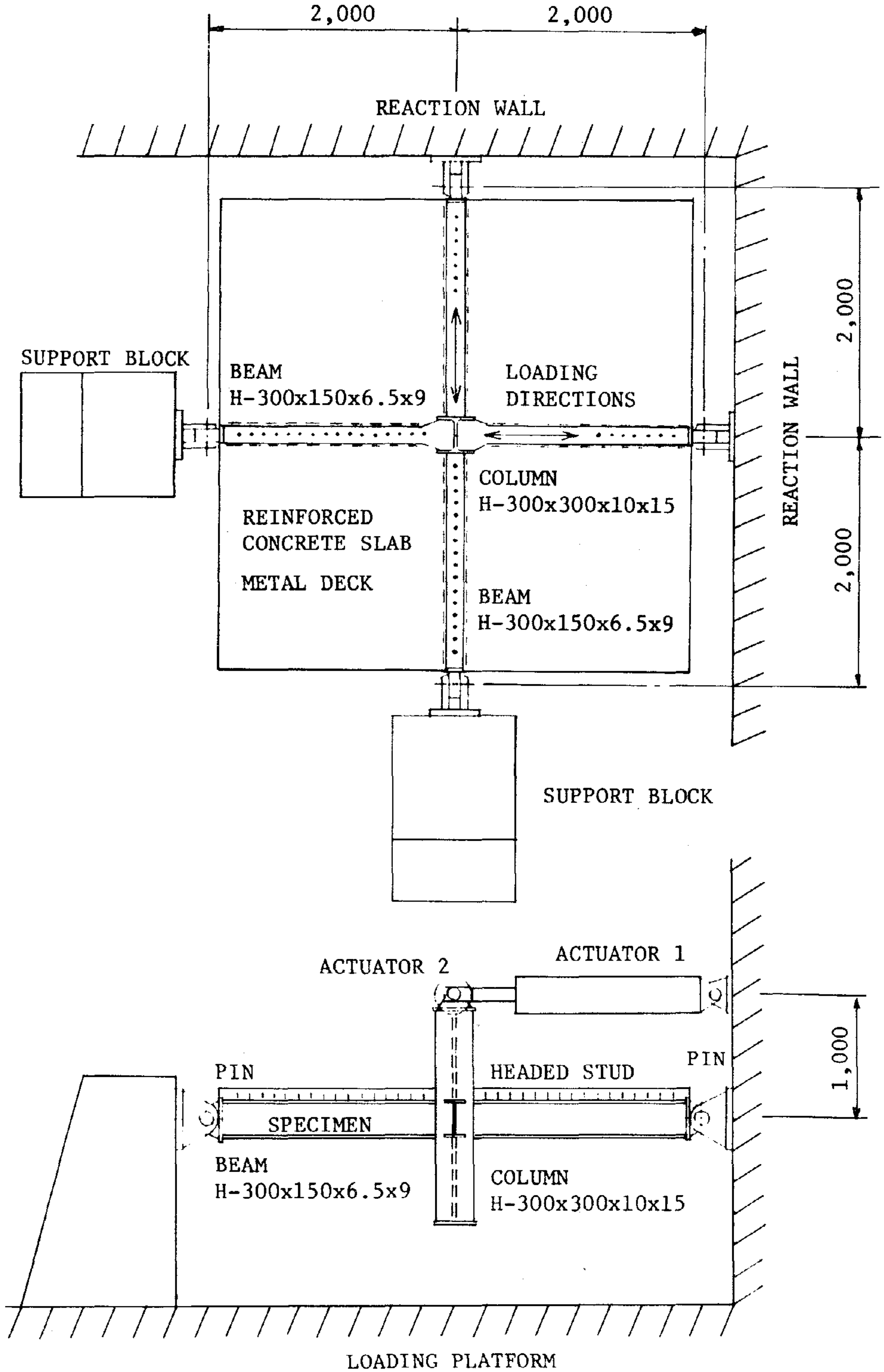
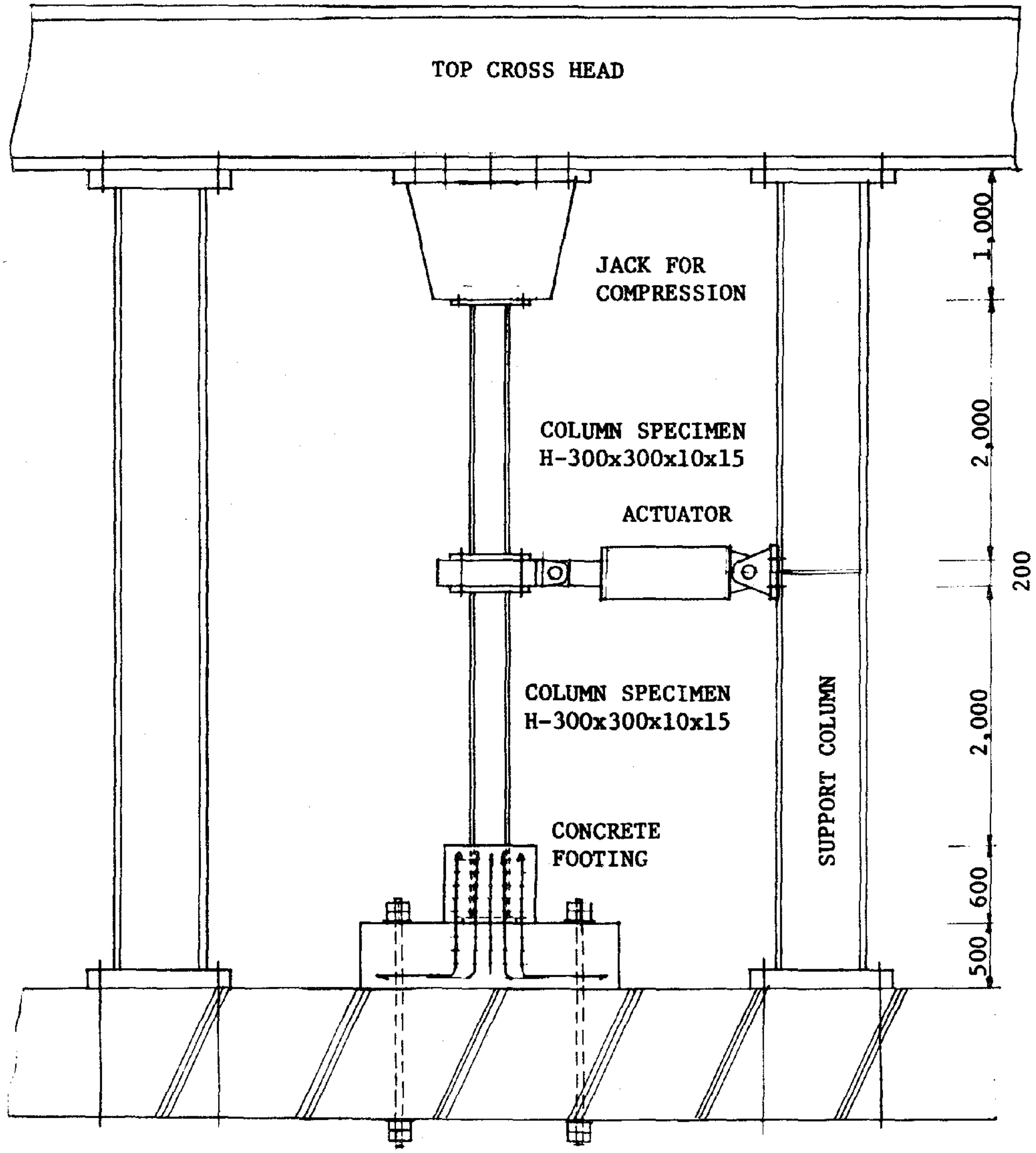


Fig. 28: SCHEMATIC SKETCH OF TEST SETUP FOR THREE DIMENSIONAL SUBASSEMBLAGES SUBJECTED TO HORIZONTAL FORCES IN OBLIQUE DIRECTIONS



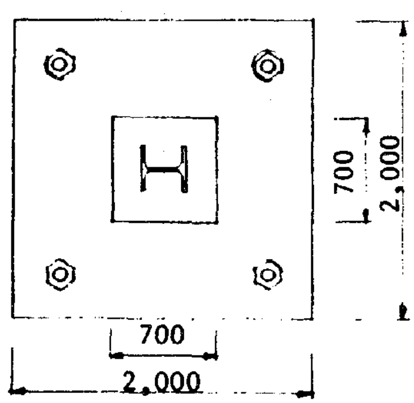


Fig. 29:

SCHEMATIC SKETCH OF TEST SETUP FOR COLUMN BASE (column-to-footing connection details are subject to further study)

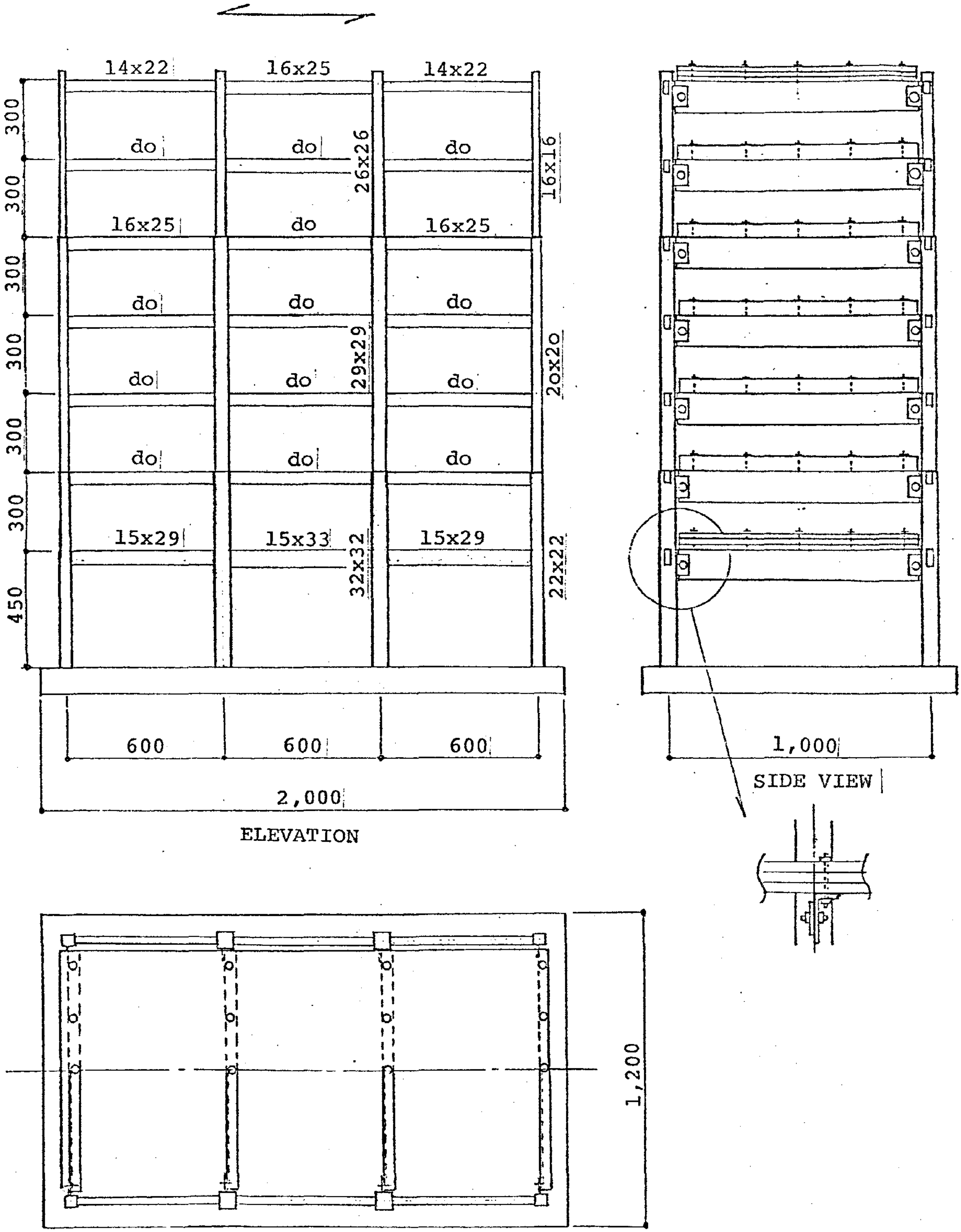


Fig. 30: ONE TENTH SCALE MODEL OF UNBRACED FRAME FOR SHAKING TABLE TEST

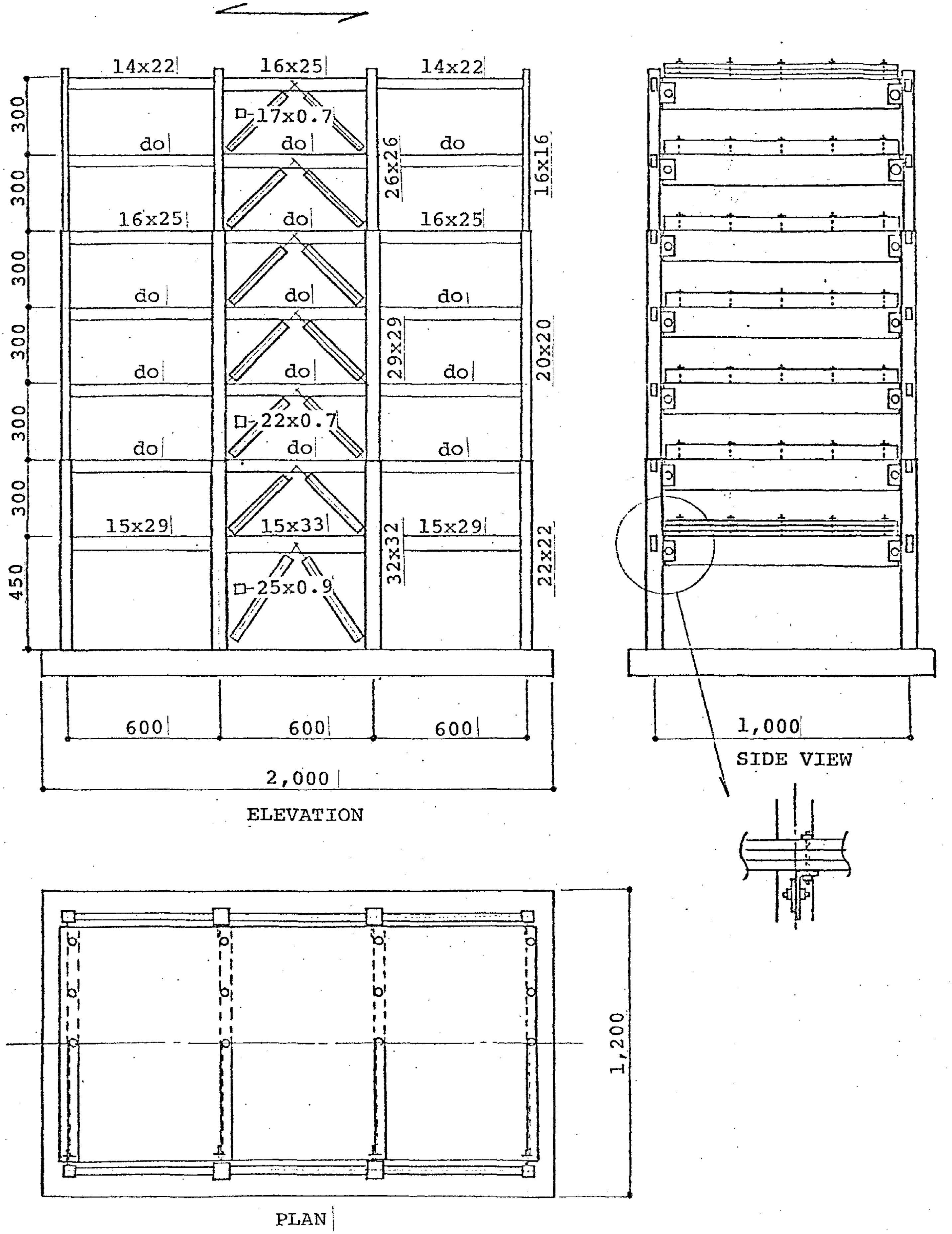


Fig. 31: ONE TENTH SCALE MODEL OF BRACED FRAME OR SHAKING TABLE TESTS

VII. RECOMMENDED RESEARCH ON THE PSEUDO-DYNAMIC TEST METHOD

A. Introduction

The most realistic method for assessing the seismic behavior of structures is to test them using earthquake simulators. However, many structures of interest are either too large, strong or massive to be tested on available shaking tables. Two approaches have been suggested for seismic performance testing of such structures using quasi-static methods. One approach assumes a first mode shape, such as an inverted triangle, and lateral displacements are applied in a cyclic manner. A variation of this approach has been used with the forces at each floor level being proportional to their first mode contribution and the roof displacement controlled in a cyclic manner. A second, more sophisticated approach assumes the force-deformation characteristics of the structure and a non-linear dynamic analysis is performed for a given input earthquake accelerogram to determine the response history of the structure. These computed response histories are used as input data to control the displacements imposed on the test specimen. Similar tests on components, such as beams and columns, can also be performed using displacement sequences determined in this manner. The major shortcoming of these two types of quasi-static methods is that the nonlinear force-deformation characteristics of the structure must be known or assumed prior to starting the test.

The computer-actuator on-line (pseudo-dynamic) test procedure has been suggested as the most realistic method for simulating the dynamic earthquake responses of test specimens which are too large for existing shaking tables. In the on-line test procedure, a computer is used to monitor and control a test specimen so that the quasi-statically imposed displacement sequences closely resemble those that would be developed if the specimen were tested dynamically. Experimental data regarding the nonlinear mechanical characteristics of the test specimen at a particular time are used by the computer, along with numerically prescribed information regarding the system's inertial and damping characteristics, to determine deformations that should be imposed on the specimen for a numerically specified ground motion. Thus, test data are used on-line in controlling the progression of the test in much the same way that current building damage predicates the response of the building during the remaining portion of the earthquake. An additional advantage of the on-line test procedure is that it is possible to pause at any time during a test in order to record visual observations, as well as to recalibrate or relocate instrumentation. Such pauses should be kept to a minimum however as time delays during testing allow for relaxation and redistribution of stresses which would not occur under actual seismic conditions.

There has been considerable interest in the on-line test procedures for several years. Since 1972, various investigators at the University of Tokyo, in particular from the Institute of Industrial Science (IIS), have been developing and evaluating algorithms for on-line test procedures. Similar efforts were initiated in the early 1970's at both the University of Michigan and the University of California, Berkeley, but they have not maintained the continuity of effort that has occurred at the University of Tokyo. Recent efforts have been made to impliment the on-line test procedure at the BRI Large-Scale Test Facility in Tsukuba.

At the Third Planning Group Meeting of the U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities which was held December 18-23, 1978, in Tokyo, one of the major discussions at the loading procedure session centered on the feasibility of the pseudo-dynamic test procedure when eight or more electro-hydraulic jacks are used. Michigan had verified that the pseudo-dynamic test procedure was valid for a one-degree-of-freedom system and the University of Tokyo has verified the procedure for one- or two-degrees-of-freedom systems. The concern expressed at the Third Planning Group Meeting was on the capability of controlling up to eight degrees-of-freedom simultaneously and also was on the required accuracy of the prescribed displacements and measured force outputs necessary to maintain accurate nonlinear dynamic responses of the building.

At this point in the development of the on-line procedure there are three basic areas which need additional research and/or verification efforts before it can be used with full confidence in achieving the expected results. The first of these three areas is verification and sensitivity studies of the numerical algorithm used to connect the dynamic equations of motion and the test specimen for the computer control. Whether the central difference method proposed by IIS, University of Tokyo, is the most accurate and most efficient algorithm for this procedure should be explored and verified. Other possible integration techniques should be considered. The second major aspect is verification that the hydraulic actuator control system can operate accurately in multiple displacement control operation. It is expected that displacement-time control of the actuator movement during incremental simultaneous motion at each of the load points will be necessary to eliminate inaccurate specimen feedback to the measured forces. This verification will require a physical test in which a specimen with force-deformation characteristics similar to those expected in the full-size test structure are used. The third aspect which needs verification is that the basic differential equation of motion is an adequate representation of the actual dynamic response of the building system. This can be verified only by comparing on-line static test results with shaking table test results.

In addition, extensive experimental verification and correlation studies of the on-line loading system at the BRI Large-Scale Test Facility in Tsukuba, Japan, are required before it can be used for the full-scale tests. Studies are required to verify that this system performs as expected for the quasi-static application of predetermined force and/or displacement sequences as well as for pseudo-dynamic tests.

It is recommended that the following experimental verification tests and corresponding analytical studies be performed in Japan and in the U.S. in a coordinated effort to develop the pseudo-dynamic test method to a level suitable for full-scale testing.

B. Verification And Correlation Studies Of The Pseudo-Dynamic Test Method In The United States

1. Verification And Sensitivity Studies Of Algorithm

The algorithm reported by Takanashi, et al. is clearly described in the following quotation from their paper:

"2.2 Description of Method 2

The response values of the k-th story can be known by integrating the equation of motion;

$$M_k \ddot{X} + F_k = M_k \ddot{X}_o \qquad (2)$$

in the computer for the given acceleration of a ground motion $\ddot{X}_o$, where M_k, X_k, and F_k are the mass, the story displacement and the restoring force of the k-th story, respectively. In general, the restoring force is a non-linear function of the story displacement X_k and time t. Then, the direct use of the measured restoring forces at the simultaneously running test can provide the real response of non-linear structures.

An incremental calculation for integration of Eq. (2) is adopted. The simplest central difference gives the following expression for the acceleration of the k-th story, $\ddot{X}_k$:

$$\ddot{X}_k^i = (X_k^{i+1} - 2X_k^i + X_k^{i-1}) / (\Delta t)^2 \quad (3)$$

where Δt denotes the time interval and the superscript i means the variables at the time, $t = i\Delta t$. As an example, to solve Eq. (2) at the time, $t = i\Delta t$, is now considered. Eq. (2) can be solved approximately and X_k^{i+1} can be calculated by the use of Eq. (3) since F_k^i, X_k^{i-1} and X_k^i are already known. The response value at $t = (i+1)\Delta t$, X_k^{i+1}, is the input to the controller of the testing machine. The test frame will be deformed by this response displacement X_k^{i+1} at the k-th floor level. The reaction forces for these displacements are sensed by the load cells and converted into restoring force F_k^{i+1}. Then, all jobs at $t = i\Delta t$ are completed. This procedure is continued successively."

This algorithm can be verified using digital computer simulation without necessity of going to physical testing. The method recommended to verify this algorithm or alternative algorithms suggested as an improvement is as follows:

(a) Establish F(t,x) function analytically or select one from test data which has been obtained by the Japanese. Use a good standard numerical integrator to determine the response of the nonlinear structure to the selected ground motion and define that response as $X^*(t)$.

(b) With the same ground motion input and the same F(t,x) function, use the Japanese algorithm or any competing algorithm to generate X_k^{i+1}. Perform analyses of these systems following classical numerical analysis procedures for appropriate Δt's and compare these responses to $X^*(t)$.

(c) Perform simulations on the algorithms used in Item (b) to determine the effect of errors in executing the displacements and in measuring the force for given displacement, and to determine the sensitivity of the algorithm and the structural model in maintaining the accuracy of the solution. It is suggested that the error functions used in this computation would be a normal distribution of error based upon a percentage of maximum force and displacement expected in the test.

2. Verification Of Computer Control System

It is necessary that the computer control system be adequate to handle simultaneously up to eight degrees of freedom. A recent site visit by an Earthquake Engineering Research Institute Panel to the NASA Huntsville Test Facility provided considerable information regarding this phase of the verification. NASA Huntsville has static and dynamic control systems capable of accomplishing simultaneous actuator movement. Their system has been in operation since January 1977 for structural testing of space vehicles prior to final design. The primary difference between seismic full-scale testing needs and their experience is that these vehicles have been loaded in the small-amplitude linear-elastic range with force control whereas seismic testing of full-scale buildings must be capable of displacement control in the large nonlinear range of structural response.

It is recommended that a simulated physical structure with force deformation characteristics similar to those to be encountered during the full-scale test program be tested. This structure need not necessarily be full-size since relative sensitivity, errors and non-linearity output characteristics are of primary interest. Therefore, small actuators and displacement devices together with a small test structure may be used to simulate the larger structure with equal relative accuracies.

3. Verification Of Discrete Form Of Mathematical Modelling

The third phase of the verification process is to establish that the response of multistory structures obtained using the on-line computer controlled testing procedure resembles that which the structure would achieve if they were subjected to earthquake ground motions. To do this, it is recommended that a thorough study be made comparing results of dynamic shaking tests with corresponding results obtained using the on-line test procedure and nonlinear dynamic analyses. Such comparisons can be used to verify the overall accuracy, reliability and practicability of the test method. Specific investigations carried out in this phase should focus primarily on problems related to representing the nonlinear dynamic response of multistory structures by lumped-mass differential equations of motion of the type suggested by the IIS Group in Eq. 2. The assumptions inherent in these simplified equations may lead to errors in the on-line tests, even if the numerical and control problems previously described are completely resolved.

For the basic equations of motion used, the deformations of a structure should be characterized by as few degrees of freedom as possible and its mass must be lumped at these points. While this is a common analytical idealization, many structures of interest, especially reinforced concrete shear wall buildings and masonry bearing wall buildings, may have considerable portions of their mass distributed along structural elements located between degrees of freedom. The accuracy of lumped mass models and the consequences of distributed masses have not been studied in any great detail. Methods for accounting for distributed masses should be examined and verified using dynamic shaking table results.

The equations of motion used by the IIS Group also disregard the effects of viscous damping. While it is expected that inelastic deformation might be the primary source of energy dissipation, viscous damping may also have an appreciable effect. If shaking table test results indicate the need for including the effects of viscous damping, methods for including these effects in the on-line test procedure should be examined. Coulomb (friction) damping effects are directly accounted for in the restoring force term in Eq. 2. However, this type of damping may be sensitive to rate of loading or high frequency vibrations occuring in the specimens. This possibility should be investigated, if results indicate that such effects are significant.

The restoring forces used in the equations of motion are subject to a number of non-instrumentation errors that may affect the computed response. For example, many materials are rate sensitive so that dynamic forces may differ from those developed in pseudo-dynamic on-line tests. The effects of creep or stress relaxation can also have a significant effect on the measured restoring force. Moreover, in the on-line test procedure restoring forces are applied as concentrated external loads which may result in different distributions of internal forces than would be produced by inertial loading. The consequences of these problems, and methods for mitigating them, should be investigated.

The first step in this study should utilize relatively simple steel and reinforced concrete structures with at least three degrees of freedom for which the masses can adequately be assumed to be lumped at floor levels. In this manner, the basic methods and assumptions can be verified and refined where required. It is considered desirable to use structural test specimens for this stage of testing which are designed to concentrate inelastic deformations in members that can easily be replaced. Thus, on-line tests can be easily and economically repeated using different analytical assumptions regarding mass, damping, etc.

It is also recommended that the behavior of more complex structures with distributed mass be investigated since many structures to be tested with the on-line method will be of this type. Possibly, suitable test specimens for part of this investigation can be identified from those that are recommended for the testing on shaking tables. In this event, it may be possible to build a single specimen which can be tested on-line with the results suitable for comparison with those obtained on the shaking tables. This could save the cost of constructing relatively expensive duplicate specimens.

The results obtained in this phase of the investigation should be carefully evaluated in terms of the ability of the on-line computer controlled pseudo-dynamic test method to provide a meaningful assessment of the seismic behavior of structures. Guidelines and suggestions for potential applications or extensions of the method should be developed.

4. Pseudo-dynamic Testing Using Steel And Reinforced Concrete Frames

It is suggested that more sophisticated on-line tests be conducted where feasible, using steel and reinforced concrete frames constructed for the associated tests. The advantages of coupling these verification tests with preliminary building tests are twofold. First, the results are directly applicable to the expected utilization and second the experimental expense is reduced by multiple use of the test specimens. Steps should be taken to compare and correlate the results obtained from the on-line (pseudo-dynamic) tests with the results obtained from the one-third scale shaking table tests described earlier, eventhough the proposed one-third scale shaking table tests may be carried out after the primary effort of this verification program.

C. Verification And Correlation Studies Of Pseudo-Dynamic Test Method In Japan

1. Verification Studies Of BRI Pseudo-Dynamic Test Systems

A large scale two-story R/C model and a two story steel model is planned for testing in Japan to verify the loading set-up to be used in testing the full-scale seven-story buildings, and the displacement control procedures for predetermined displacement control tests and pseudo-dynamic tests. The planned test arrangement for R/C structure is shown in Fig. 32 and the structural details are shown in Figs. 33 and 34.

2. Correlation Studies Between Pseudo-Dynamic Test And Shaking Test

Two identical R/C two-story medium scale models are planned for testing to investigate the correlation between the pseudo-dynamic and the shaking table test methods. It is intended that the two-story model shown in Fig. 35 be tested on the shaking table and that another identical model be tested by the pseudo-dynamic testing procedure. The table acceleration measured during the shaking table test is to be used for the input ground motion of the pseudo-dynamic loading test.

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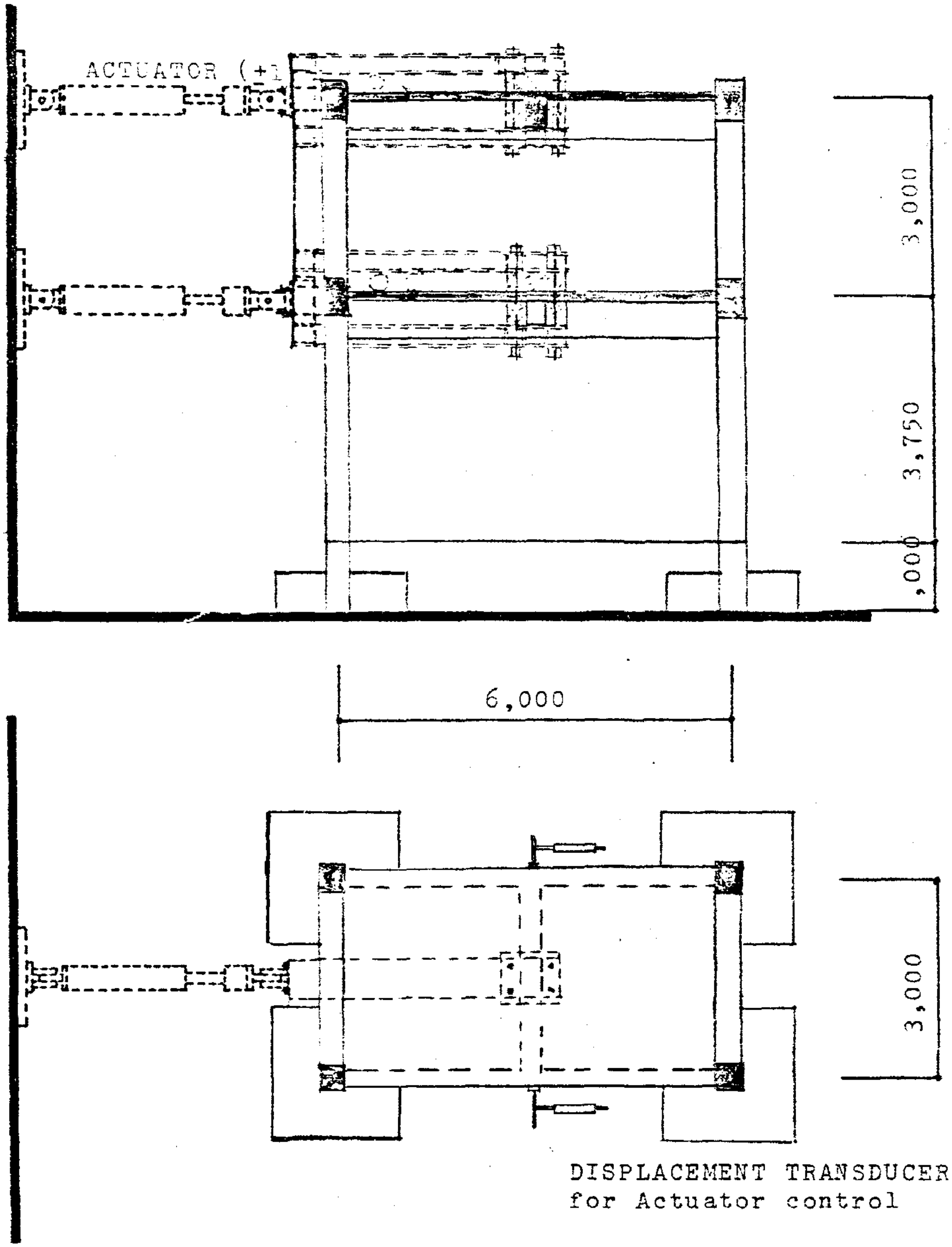

Fig. 32; LARGE SCALE TEST SPECIMEN AND LOADING APPARATUS

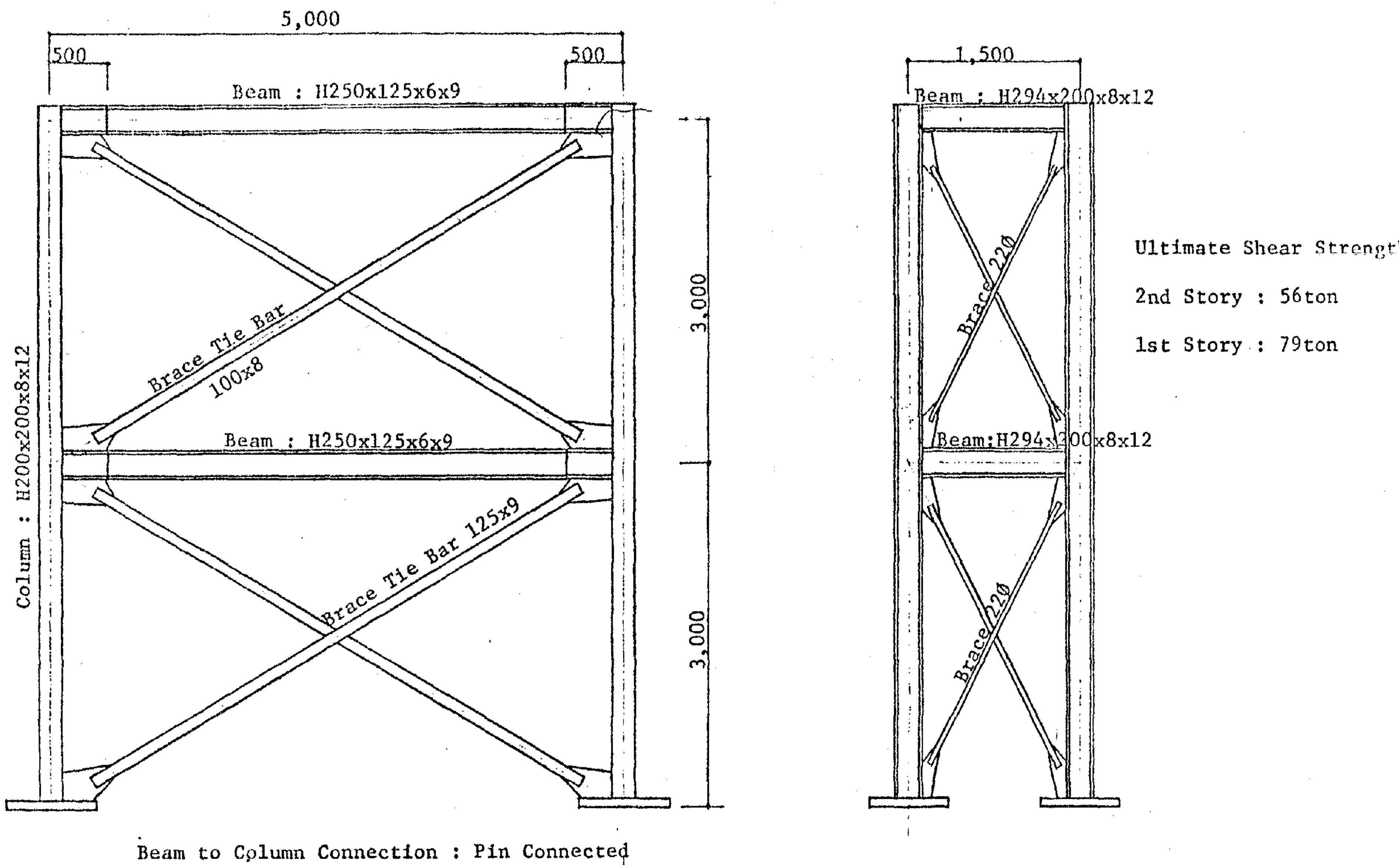

Fig. 33: STEEL FRAME FOR PSEUDO-DYNAMIC TESTING METHOD

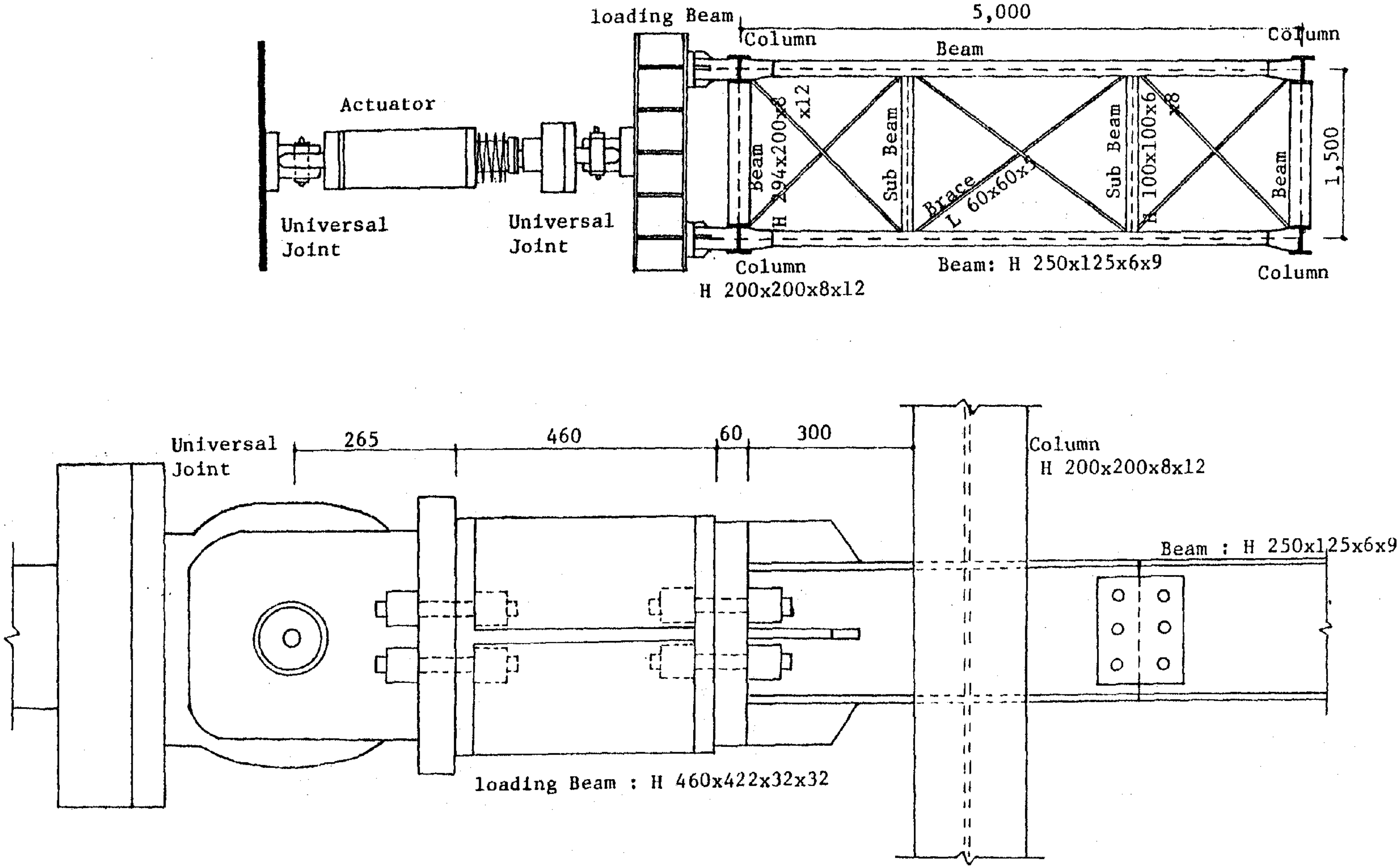

Fig. 34: TEST SET-UP FOR STEEL TEST

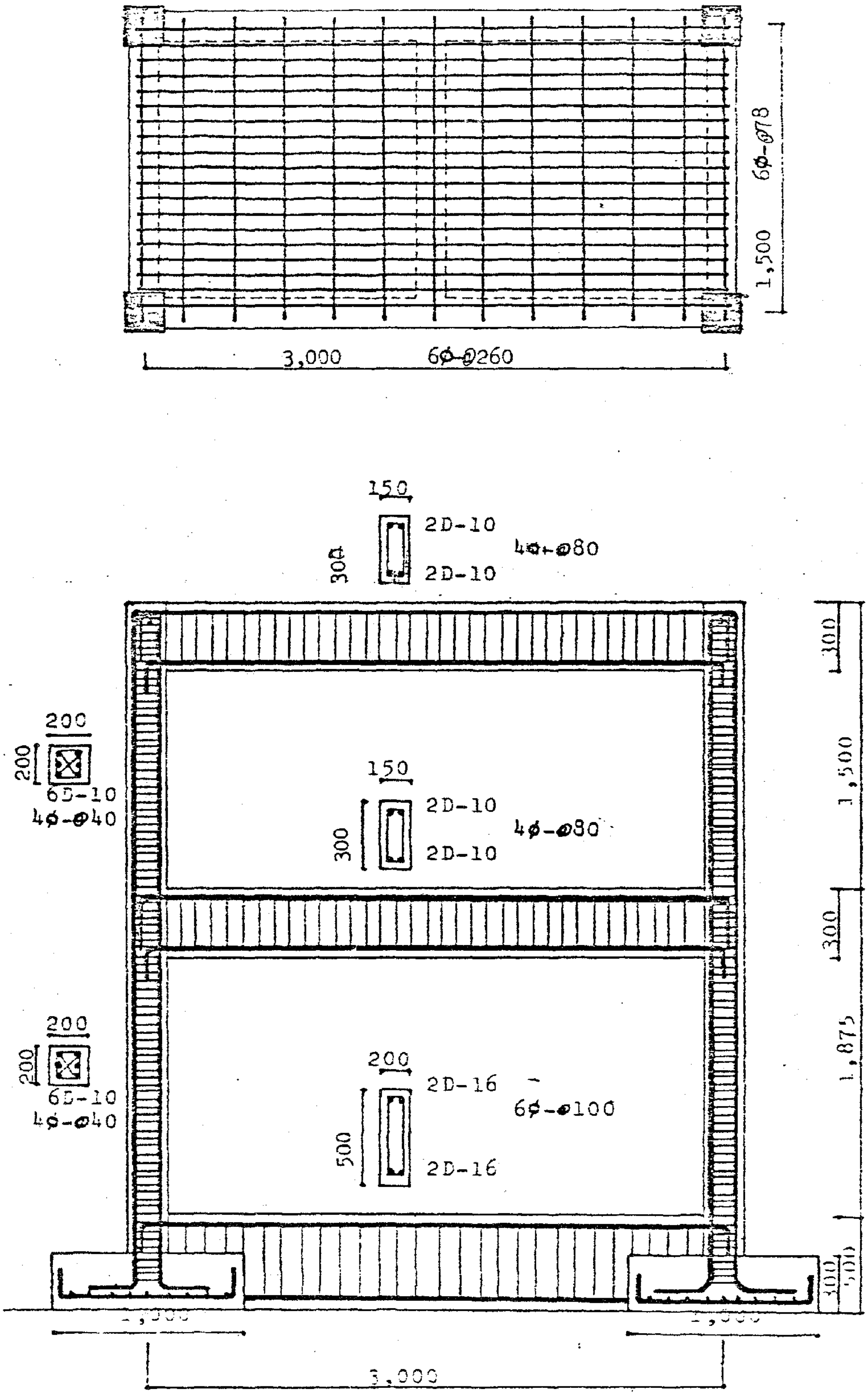

Fig. 35: SECTION OF MEDIUM SCALE TEST SPECIMEN

VIII. RECOMMENDED ANALYTICAL STUDIES

It is recommended that a program of analytical studies be performed to assist in the design of the test specimens, to identify appropriate seismic excitations, and to correlate and evaluate the experimental results. These studies should be undertaken on a cooperative basis at various institutions in Japan and the United States. They should also be carefully coordinated with the experimental portions of the overall research program.

Dynamic analyses should be performed prior to conducting the full-scale tests using the best available computer programs based on linear elastic and inelastic modeling idealizations. Results obtained for various types of seismic excitations should aid in the final design of the test specimen and loading apparatus, and in the selection of the critical seismic actions to be used in the experimental investigations.

Analytical studies should also be made following each phase of the experimental investigations to correlate data obtained with existing research information as well as with experimental and analytical data obtained in other phases of the overall investigation. In particular, relationships among results obtained from quasi-static component, subassemblage and frame tests, small- and medium-scale shaking table tests, and full-scale pseudo-dynamic tests should be determined. Current analytical methods should be evaluated in terms of their ability to predict observed member and structure behavior in the elastic and inelastic ranges. The advantages and disadvantages of each type of experimental and analytical procedure considered should be identified.

IX. CONCLUDING REMARKS

The recommended cooperative research program described herein containing four major components namely (1) research on reinforced concrete building structures, (2) research on steel building structures, (3) research on the pseudo-dynamic test method, and (4) analytical studies, can be effectively carried out over a period of five years provided adequate funds are allocated to the program. With regard to scheduling, it is recommended that the tests on the full-scale reinforced concrete structure be carried out ahead of the tests on the full-scale steel structure and that the associated tests for each structural type be phased with their respective full-scale tests so as to be most effective in the overall program. The pseudo-dynamic test method investigations should be initiated at the beginning of the program as verification of the suitability of this method for multiple actuator applications is needed prior to the start of testing of the full-scale structures. Analytical studies should be conducted throughout the entire program.

In view of their importance to the long-range success of the recommended U.S.-JAPAN COOPERATIVE RESEARCH PROGRAM UTILIZING LARGE-SCALE TESTING FACILITIES, it is appropriate that the pertinent resolutions adopted at the conclusion of the Fourth Planning Group Meeting, Berkeley, California, July 9 - 14, 1979, be stated once again as follows:

(3) The level of funding provided to the cooperative research program should permit the fulfillment of goals and objectives as defined in the Planning Group final report.

(4) To ensure successful execution of the recommended cooperative research program, full coordination of all research activities carried out in both countries is essential; therefore, the following committees are recommended:

(a) Joint Technical Coordination Committee to provide scientific and technical advice to participating institutions in the program. This committee should meet at least once a year during the program.

(b) Joint subcommittees to provide advice on the execution of research related to reinforced concrete buildings, steel buildings, pseudo-dynamic loading techniques, and other major areas of activity. These committees should meet as frequently as needed.

(5) To assure and enhance the cooperative effort in this joint research program, adequate exchange of research personnel from both countries is needed. It would be desirable for one exchange researcher to be associated with each participating research organization in each country.

(6) Following successful completion of the recommended cooperative research programs related to reinforced concrete and steel buildings, similar investigations should be carried out on other structural types as suggested in previous resolutions taking full advantage of the experience gained in the use of the pseudo-dynamic testing procedure. Appropriate planning for this activity should be initiated at an early date.

(7) Long-range plans should include the possibility of testing large-scale structures and systems, other than buildings, in this cooperative program.

(8) The planning group encourages support of the recommended cooperative large-scale test program by the U.J.N.R. Panel on Wind and Seismic Effects.

The members of the U.S.-Japan planning group consider the recommendations set forth herein to be technically sound with high potential of yielding valuable results of mutual value to both Japan and the United States.

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EERC 67-1 "Feasibility Study Large-Scale Earthquake Simulator Facility," by J. Penzien, J.G. Bouwkamp, R.W. Clough and D. Rea - 1967 (PB 187 905)A07

EERC 68-1 Unassigned

EERC 68-2 "Inelastic Behavior of Beam-to-Column Subassemblages Under Repeated Loading," by V.V. Bertero - 1968 (PB 184 888)A05

EERC 68-3 "A Graphical Method for Solving the Wave Reflection-Refraction Problem," by H.D. McNiven and Y. Mengi - 1968 (PB 187 943)A03

EERC 68-4 "Dynamic Properties of McKinley School Buildings," by D. Rea, J.G. Bouwkamp and R.W. Clough - 1968 (PB 187 902)A07

EERC 68-5 "Characteristics of Rock Motions During Earthquakes," by H.B. Seed, I.M. Idriss and F.W. Kiefer - 1968 (PB 188 338)A03

EERC 69-1 "Earthquake Engineering Research at Berkeley," - 1969 (PB 187 906)A11

EERC 69-2 "Nonlinear Seismic Response of Earth Structures," by M. Dibaj and J. Penzien - 1969 (PB 187 904)A08

EERC 69-3 "Probabilistic Study of the Behavior of Structures During Earthquakes," by R. Ruiz and J. Penzien - 1969 (PB 187 886)A06

EERC 69-4 "Numerical Solution of Boundary Value Problems in Structural Mechanics by Reduction to an Initial Value Formulation," by N. Distefano and J. Schujman - 1969 (PB 187 942)A02

EERC 69-5 "Dynamic Programming and the Solution of the Biharmonic Equation," by N. Distefano - 1969 (PB 187 941)A03

EERC 69-6 "Stochastic Analysis of Offshore Tower Structures," by A.K. Malhotra and J. Penzien - 1969 (PB 187 903)A09

EERC 69-7 "Rock Motion Accelerograms for High Magnitude Earthquakes," by H.B. Seed and I.M. Idriss - 1969 (PB 187 940)A02

EERC 69-8 "Structural Dynamics Testing Facilities at the University of California, Berkeley," by R.M. Stephen, J.G. Bouwkamp, R.W. Clough and J. Penzien - 1969 (PB 189 111)A04

EERC 69-9 "Seismic Response of Soil Deposits Underlain by Sloping Rock Boundaries," by H. Dezfulian and H.B. Seed 1969 (PB 189 114)A03

EERC 69-10 "Dynamic Stress Analysis of Axisymmetric Structures Under Arbitrary Loading," by S. Ghosh and E.L. Wilson 1969 (PB 189 026)A10

EERC 69-11 "Seismic Behavior of Multistory Frames Designed by Different Philosophies," by J.C. Anderson and V. V. Bertero - 1969 (PB 190 662)A10

EERC 69-12 "Stiffness Degradation of Reinforcing Concrete Members Subjected to Cyclic Flexural Moments," by V.V. Bertero, B. Bresler and H. Ming Liao - 1969 (PB 202 942)A07

EERC 69-13 "Response of Non-Uniform Soil Deposits to Travelling Seismic Waves," by H. Dezfulian and H.B. Seed - 1969 (PB 191 023)A03

EERC 69-14 "Damping Capacity of a Model Steel Structure," by D. Rea, R.W. Clough and J.G. Bouwkamp - 1969 (PB 190 663)A06

EERC 69-15 "Influence of Local Soil Conditions on Building Damage Potential during Earthquakes," by H.B. Seed and I.M. Idriss - 1969 (PB 191 036)A03

EERC 69-16 "The Behavior of Sands Under Seismic Loading Conditions," by M.L. Silver and H.B. Seed - 1969 (AD 714 982)A07

EERC 70-1 "Earthquake Response of Gravity Dams," by A.K. Chopra - 1970 (AD 709 640)A03

EERC 70-2 "Relationships between Soil Conditions and Building Damage in the Caracas Earthquake of July 29, 1967," by H.B. Seed, I.M. Idriss and H. Dezfulian - 1970 (PB 195 762)A05

EERC 70-3 "Cyclic Loading of Full Size Steel Connections," by E.P. Popov and R.M. Stephen - 1970 (PB 213 545)A04

EERC 70-4 "Seismic Analysis of the Charaima Building, Caraballeda, Venezuela," by Subcommittee of the SEAONC Research Committee: V.V. Bertero, P.F. Fratessa, S.A. Mahin, J.H. Sexton, A.C. Scordelis, E.L. Wilson, L.A. Wyllie, H.B. Seed and J. Penzien, Chairman - 1970 (PB 201 455)A06

EERC 70-5 "A Computer Program for Earthquake Analysis of Dams," by A.K. Chopra and P. Chakrabarti - 1970 (AD 723 994)A05

EERC 70-6 "The Propagation of Love Waves Across Non-Horizontally Layered Structures," by J. Lysmer and L.A. Drake 1970 (PB 197 896)A03

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