

Overview of PRESSSS Research Program



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Presents an overview of a coordinated research program between the United States and Japan on the seismic design and performance of precast concrete structural systems. The objectives of this program are to develop effective seismic structural systems for precast buildings and to prepare seismic design recommendations for incorporation into the model building codes. The program, which has been in operation for about a year, is scheduled to be active for another six years. This paper presents the background to the program and briefly describes the component projects.

The Precast Seismic Structural Systems (PRESSSS) Research Program was initiated as part of the United States-Japan protocol on large scale testing for seismic response of precast concrete buildings, under the auspices of the UJNR Panel on Wind and Seismic Effects. The program follows three earlier coordinated programs on reinforced concrete, structural steel and masonry. It is intended that two additional programs, covering composite steel/concrete and wood structures will follow.

The purpose of these coordinated research programs is to develop recommendations for the seismic design of buildings constructed of a particular material, in this case precast concrete, based on sound analytical and experimental research. Each program consists of separate American and Japanese research efforts coordinated by regular meetings, and by interchange of ideas between researchers.

There are several reasons why precast concrete is particularly suitable for an intensive coordinated research effort:

- Precast construction is a building process ideally suited for the future. Materials are inexpensive and the method of construction, involving factory manufacture of components and rapid site erection, lends itself to innovation in design and construction. Advanced technology, including robotics and the use of computer-aided manufacture, will lead to more efficient erection procedures. The potential for significant reductions in building costs is apparent. The high technology/low labor content aspect makes it suitable for American conditions and technological strengths, without necessarily losing the flexibility of construction form that has resulted from mass produced "system building" developed in countries that are

technologically less advanced.

- Despite the clear and acknowledged potential of precast construction, it has not been developed as extensively in the United States as might be expected and, in fact, some countries are today technologically more advanced in this area than this country. This situation could pose a potential future impediment to the competitiveness of American construction firms both in North America and internationally.
- To a considerable extent, the reason for the lack of advancement of precast structural systems in the United States can be attributed to uncertainty about their seismic performance. The regions of North America where concrete is most competitive as a building material (compared with steel, for example) and where commercial property development is greatest tend to be regions subject to moderate or high seismicity. Although most designers of precast structural systems have confidence in the seismic performance of such systems, a lack of experience in response of major multistory construction to strong earthquake attack, coupled with a paucity of relevant experimental data, has resulted in precast construction being less common in seismic regions.
- This situation is aggravated by design codes which, in the absence of test data, cannot include prescriptive seismic design requirements. The codes require confirmation of the suitability of new designs by satisfaction of performance criteria provided by expensive and time-consuming structural testing. This requirement inhibits innovation and has forced research and design practice into a narrow focus of reinforced concrete emulation instead of expanding the scope to take advantage of the strengths and differences of precast construction. Consequently, precast concrete construction is penalized and the true potential of these structural systems has yet to be realized.
- There is a growing awareness in the United States of the need for developing design methodologies for pre-

cast seismic resistant structural systems based on a sound research background. In recent years, a number of workshops and seminars¹⁻³ have examined the needs and problems of precast construction. However, research funding for development work has not been available at an adequate level to make any significant impact on the major problems. The lack of an integrated approach coordinating the various research activities has also had a negative effect on the impact of research.

- The poor performance of precast structures in the 1988 Armenian earthquake indicates that the seismic design philosophy developed overseas for precast structural systems may be inadequate. It is clear, however, that much of the appalling performance of precast structures in that earthquake resulted from substandard materials and construction practices. It should be noted that several East European countries have put considerable design and research effort into precast "system" building during the past 20 years. Apparently, this effort has not provided solutions that can be translated to American design practice. On the other hand, recent research in the United States, New Zealand and Japan has proven that safe seismic resistant structural systems in precast concrete are possible.

OBJECTIVES AND SCOPE

The rationale presented here led to the adoption of precast concrete construction for the fourth program of the UJNR seismic study, over composite steel/concrete and wood construction, which will be considered subsequently. The objectives, scope and philosophy of the U.S.-PRESSS program are summarized in this section.

Objectives

The fundamental objectives of the U.S.-PRESSS program are two-fold:

- To develop comprehensive and rational design recommendations based on fundamental and basic

research data which will emphasize the viability of precast construction in the various seismic zones.

- To develop new materials, concepts and technologies for precast construction in the various seismic zones.

The PRESSS program sets out to achieve these objectives by a process of examination and assimilation of existing research and design information, by development and evaluation of new PRESSS concepts in close cooperation with industry, by carefully planned analytical and experimental research, and by formulation of the results within a framework of design recommendations based on state-of-the-art design philosophy.

Scope

The program considers only the seismic behavior of building structures where precast construction forms the essence of the structural system. Current precast seismic structural systems can be divided into two categories: precast frame buildings and precast wall panel construction. Both are included in the U.S.-PRESSS program. Innovative structural solutions based on precast elements that do not readily fall into the frame or panel categories are also being investigated. Examples include mixed panel/frame systems and ductile bracing systems. Innovation in the development of new PRESSS concepts is particularly emphasized in the early stages of the program.

Design Philosophy

Precast seismic structural systems can be separated into two basic categories dependent on the design philosophy adopted for the design of the connections between the precast elements.

Strong Connections — The connections are detailed to be effectively rigid and to be stronger than designated locations of inelastic action (plastic hinges). In this case, the design philosophy is to make the structural system behave under seismic loading as though it were an equivalent monolithically constructed structure. If the con-

nection detail is successful, the structural elements could presumably be designed in accordance with existing materials codes. This is the current design philosophy, and it has formed the basis of most recent experimental research on precast seismic structural systems.

Required research is thus limited to establishing the viability of selected strong connection details, or providing basic research data that is not available for equivalent monolithic systems. In this context, it should be noted that seismic design recommendations for ductile monolithic prestressed structural systems do not exist in the United States.

Ductile Connections — The connections are detailed to be weaker than the precast elements, and are intended as locations of ductile inelastic deformation. If the precast elements are designed to have an adequate margin of strength over that of the ductile connection, they will remain elastic under seismic response. As a consequence, the precast elements would not need to be detailed for ductility, resulting in economies. In some cases, it is apparent that ductile connections could be designed to be replaceable after a major earthquake at a much lower cost than repair of damage to a ductile reinforced concrete frame.

Despite the apparent attractions of the "ductile connection" philosophy, it has received comparatively little research and design attention. A considerable amount of research is needed to prove different ductile connection details, to establish the capacity of precast elements to sustain limited ductility resulting from unexpected seismic actions, and to define the margin of strength required between precast element and connections. This latter aspect depends on variability of material properties, hysteretic characteristics of the ductile connections, and the influence of higher mode response (e.g., dynamic shear amplification), and could be significantly different from values appropriate for monolithic construction.

Because of the apparent promise of the ductile connection approach, and the relative absence of relevant research information in comparison

with the strong connection philosophy, more emphasis is being given to the ductile connection philosophy in the early stages of the U.S.-PRESSS program.

STRUCTURE OF THE U.S.-PRESSS PROGRAM

The U.S.-PRESSS program was conceived in three phases. Phase I, which is funded for a three-year period ending in 1993, is focused on identifying and evaluating the most promising structural concepts for precast concrete building systems in seismically active regions. Analytical tools for precast structures will be improved, and a framework for seismic design recommendations will be developed. Both frame and panel precast structures are considered.

Phase II will involve detailed experimental studies of components and subassemblages of precast systems selected during Phase I for more detailed investigation. The experiments will be paralleled by analytical studies to determine expected response to seismicity representative of the various seismic zones of the United States. A request for proposals for Phase II was issued by the National Science Foundation in June of this year, for funding in fiscal year 1992. Thus, as intended in the original research plan for PRESSS,⁴ Phases I and II will overlap.

The third phase of PRESSS is expected to involve one or more multi-story full-size "superassemblage" experiments and the finalization of the seismic design recommendations for incorporation into the model building codes.

The framework for the U.S.-PRESSS research program is outlined in Fig. 1. The research is divided into four interactive categories: concept development, experimental program, analytical studies and design recommendations. The research proceeds from consideration of material characteristics, through behavior of connections and intersections, to subassemblage studies where the interactions between precast elements and connections are investigated in-depth, and finally, to proof by large-scale super-

assemblage experiments.

The experimental and analytical research is driven by recommendations of appropriate PRESSS concepts developed in concept development studies, and by an assessment of required information determined from preliminary stages of the design recommendations study. The final outcome of the study will be a selection of suitable structural concepts for PRESSS, together with detailed design recommendations based on the experimental and analytical research.

DETAILS OF THE PHASE I PROGRAM

The Phase I program, now underway for about a year, consists of five projects:

Concept Development (Research: Englekirk, Hart & Sabol Consulting Engineers, Inc., Los Angeles and Irvine, CA) — The project is focused on the development and evaluation of new concepts for precast concrete construction in Seismic Zones 2, 3 and 4, particularly for low and mid-rise buildings. As mentioned under Design Philosophy, more emphasis is being placed on "ductile connection" concepts than the more traditional "strong connection" concepts. The study has been aided by exposing potential concepts to critical review in a series of workshops and seminars across the United States, attended by designers, precast producers and contractors. An Industry Advisory Panel (as indicated in Fig. 2) reviews the work of this study and reports to the PRESSS Executive Panel. Further details on this project, including initial results, will be provided in a paper by Suzanne D. Nakaki and Robert E. Englekirk in a forthcoming issue of the PCI JOURNAL.

Connection Classification and Modeling (Research: University of Washington, Seattle, WA) — This project involves a comprehensive review of existing test data from this country and overseas, and the development of a classification system for PRESSS connections based on type and function. Again, further details of this research program and results of the workshops will be summarized by

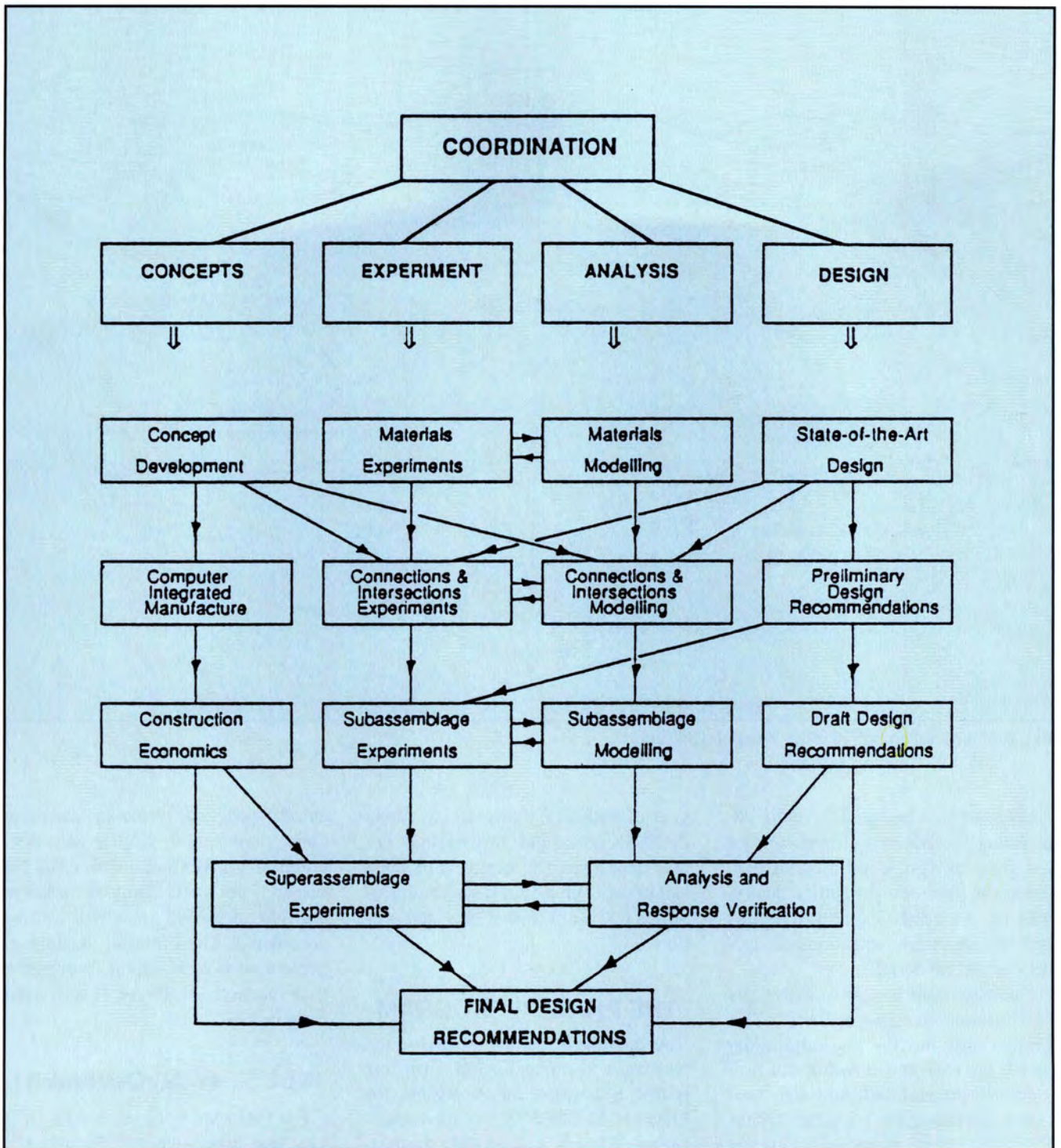


Fig. 1. Component task interaction for systems approach to PRESSS research program.

John F. Stanton in a forthcoming issue of the PCI JOURNAL.

PRESSS Analytical Platform Development (Research: University of California, Berkeley, CA) — The widely used DRAIN-2D inelastic time-history analysis program for seismic response is being expanded to three dimensions. In addition, new elements are being developed to model the special characteristics of precast

members, including joint deformations resulting from slip and ductility. The program will be used extensively in Phases II and III for analytical parameter studies, to determine appropriate levels of lateral design force, and to ascertain necessary strength margins for capacity design of precast buildings in different U.S. seismic zones.

Preliminary Design Recommendations (Research: University of Cali-

fornia, Los Angeles, CA) — Current seismic design codes for precast concrete structures are being reviewed and preliminary prescriptive design requirements for "strong connection" precast construction are being developed. The intent here is to utilize existing information in a form where it could be used by designers as the basis for building designs satisfying the current monolithic reinforced equivalence

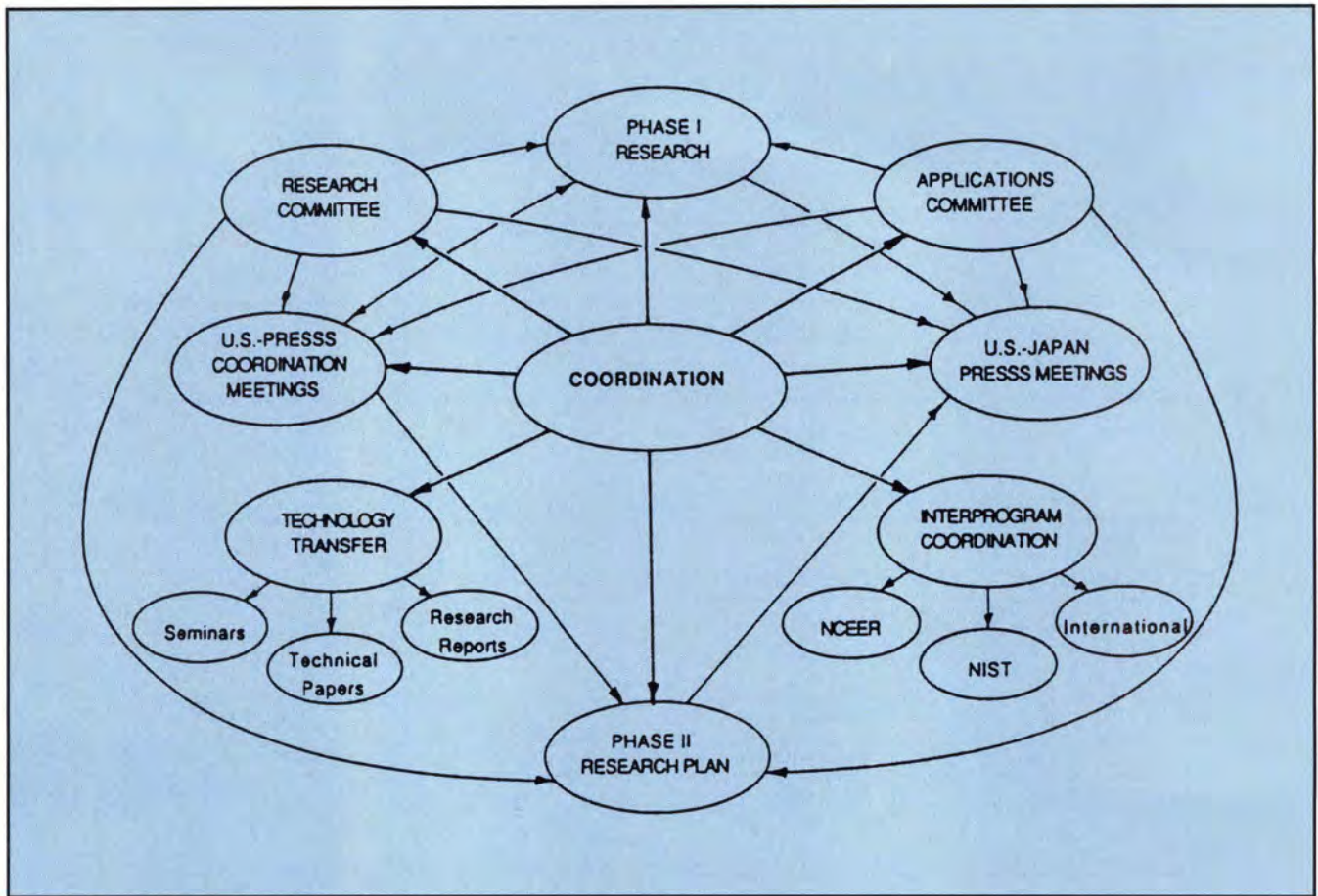


Fig. 2. Coordination of PRESSS Phase I activities.

criteria, without the need for individual testing. In addition, a framework for the final design recommendations, based on structural reliability theory, will be provided. These provisions will include recommendations for ductile connection design.

Coordination (Research: University of California, San Diego, CA) — This project provides the umbrella under which the four above-mentioned projects are interrelated, and also provides coordination with the Japan-PRESSS research team and the current precast concrete experimental program at the National Institute of Standards and Technology (NIST). Fig. 2 indicates some of the functions of coordination within the context of the Phase I program. Formal meetings of the U.S.-PRESSS research team are held twice a year. As the need arises, further meetings are held to solve specific problems and set new directives. The contact between the Concept Development and Connection Classification programs has been particularly close and productive during the first

year of PRESSS. Formal U.S.-Japan PRESSS coordination meetings are held once a year, alternatively in Japan and in the United States. This cooperation is discussed further in a later section.

THE PHASE II PROGRAM

At the time of writing this paper, the National Science Foundation has issued a "Request for Proposals" for Phase II of PRESSS. As mentioned earlier, Phase II will provide much of the detailed experimental and analytical data needed to form the basis for detailed design recommendations. Projects have specifically been solicited in four areas: precast frame systems, precast panel systems, mixed systems including frame/panel interaction and/or ductile bracing, and small-scale shake table experiments on precast superassemblages.

The first three areas will involve both analytical and experimental studies, and the RFP suggests that teams, consisting of an experimental facility,

an analytical facility and a precast producer, cooperate to provide wide coverage of a given area. Proposals for research not specifically included in the four identified areas will also be considered. The proposal deadline is September 1, 1991, and it is expected that research on Phase II will start early in 1992.

INDUSTRY INVOLVEMENT

For PRESSS to be successful, it is vital that it be supported by industry, both financially and with advice. The budget for the three-year Phase I PRESSS program is \$1,040,000. Although the bulk of financial support for the research program comes from the National Science Foundation (NSF), it is a prerequisite of continued NSF funding that the precast concrete industry, which will be a major beneficiary of the research, should pay its share. In fact, to date, industry has been generous in its support of Phase I, particularly through contributions from the Precast/Prestressed Concrete

Institute (PCI) and the Precast Concrete Manufacturers Association of California (PCMAC). Phase II will involve a significant experimental component, and it is hoped that producers will further provide direct support in the form of donated materials and test specimens.

Even more important than industry's financial contributions is its involvement in the research process in an advisory role. There is little point in the PRESSS researchers developing and testing concepts which are uneconomical or unbuildable. To this end, the seismic workshops and seminars organized by PCI under the auspices of the Phase I Concept Development and Connection Classification programs have sought to involve producers, designers and contractors in the process, obtaining their review of new construction and design concepts.

Further, an Industry Advisory Panel (see Fig. 2) reviews the work of the Concept Development Program and reports to the PRESSS Executive Panel. PCI has established a special ad hoc committee to closely monitor and provide liaison with PRESSS to maximize industry input into selection and execution of the research projects.

U.S.-JAPAN COOPERATION

An important and integral part of the UJNR program is coordination between American and Japanese research teams. Both sides develop independent programs which meet the needs of the individual countries. These are then examined to determine the areas where cooperative research between the programs can be developed to the maximum degree possible. An essential aspect of this is a clear understanding of the differences in design philosophy between Japanese and American practice.

Typically, as a result of Japan's higher seismicity, serviceability criteria are given greater emphasis there than in the United States. As a consequence, Japanese designs are typically stronger and stiffer than American designs, but place less emphasis on ductility or capacity design principles. However, recent reinforced concrete

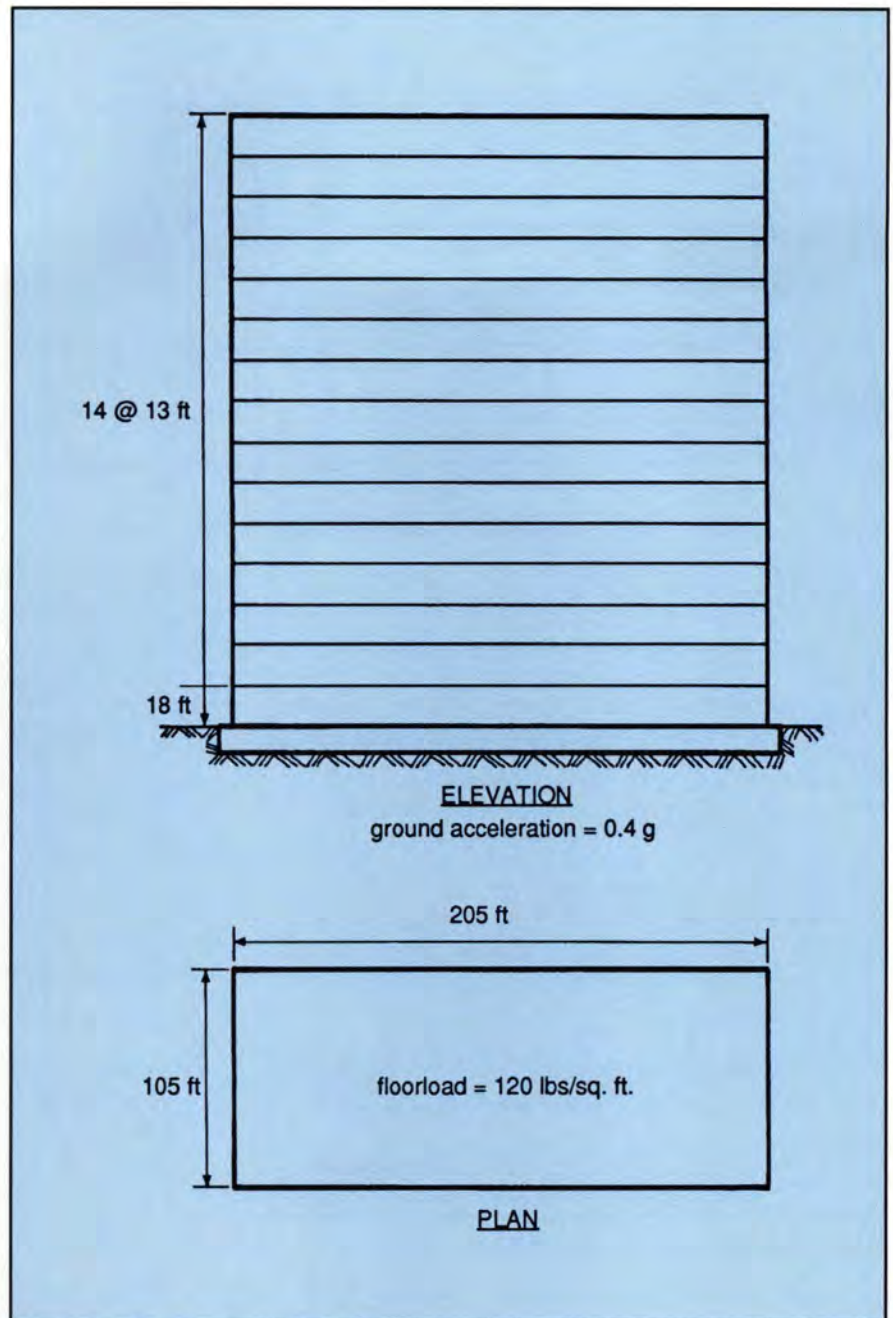


Fig. 3. 15-story test-bed structure.

design recommendations of the Architectural Institute of Japan⁵ indicate that ductility considerations are likely to be more important in future designs.

As a means for comparing seismic design philosophy of the two countries for precast concrete, a test bed structure was agreed upon between the United States and Japan sides at a preliminary coordination meeting held in Tokyo in October 1989. Fig. 3 shows a schematic of the structure, which is a 15-story building of plan dimensions 105 ft x 205 ft (32 m x 62.5 m), with a first story height of 18 ft (5.5 m) and upper story heights of 13 ft (4.0 m).

Structural weight for the seismic evaluation was taken as 120 lbs/sq ft (5.74 kN/m²), inclusive of flooring, structural systems and finishings.

The structure was to be located on a firm soil site, with design peak ground acceleration of 0.4g. It is emphasized that the building size and floor weights were chosen only as a means for comparing structural concepts and current design recommendations, and are not considered to be typical of either country. American practice would be more related to lower structures of lighter floor weight.

In a preliminary comparison, frame

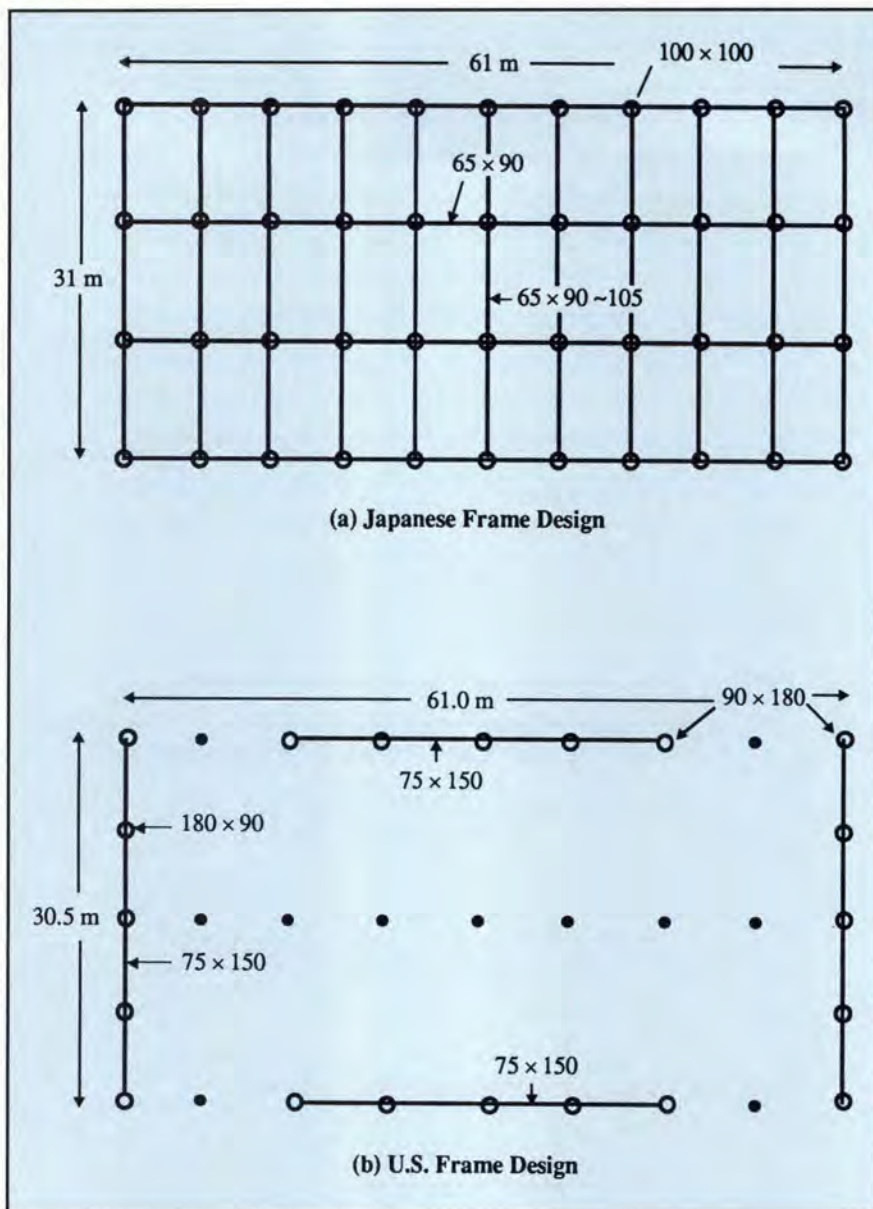


Fig. 4. Floor plans for test-bed structure.

structures were designed according to current practice. The structural systems adopted for the American and Japanese precast buildings were very different.

The Japanese solution relied on a precast two-way frame with precast beams and columns on a 20 x 33 ft (6 x 10 m) grid with a floor system consisting of sub-beams at mid-length of the 33 ft (10 m) beams, and a two-way half-finished reinforced concrete slab. Joints and slab topping were to be cast in place. Fig. 4(a) shows a typical floor plan for the Japanese two-way frame system.

The American design was based on precast peripheral moment-resisting one-way frames with a 25 ft (7.6 m)

bay length. Each transverse and longitudinal moment-resisting frame included five columns, despite the rectangular plan dimensions. This was done to provide uniformity of member sizes and equal response characteristics in both longitudinal and transverse directions.

The floor system consisted of 24 in. (0.6 m) deep double-tee flooring supported by beams and columns on a 25 x 25 ft (7.6 x 7.6 m) module. These internal columns were not designed to contribute to the lateral seismic resistance. The floor plan is shown in Fig. 4(b). It is emphasized that this is only one of many designs that could have been chosen for the U.S. building.

As designed, the American building

had a natural period of 1.55 seconds, compared with 0.97 seconds longitudinally and 1.13 seconds transversely for the Japanese building. Thus, the U.S. building was approximately twice as flexible as the Japanese building. More significant, the ultimate lateral strength of the Japanese building was 3.9 times that of the U.S. building. A detailed description of this building is provided in Reference 6.

Use of the test-bed building concept as a means for information interchange between the United States and Japan has been very successful, providing an understanding of differences in detailing requirements as well as design loads and concepts. It will continue to be a vehicle for information interchange.

CONCLUSIONS

The U.S.-PRESSS program is at too early a stage to have developed research-based conclusions. Nevertheless, the directions of PRESSS are clear: innovation in concept development, carefully planned experimental and analytical research, leading to advanced seismic design recommendations.

Current emphasis of the U.S.-PRESSS program is on the development of ductile connection designs with precast elements protected against inelastic deformations by a capacity design process. The Japanese program is concentrating on the strong-connection approach.

The end product from PRESSS will be a greatly expanded database for design and research of structural performance of precast concrete structures and design recommendations for incorporation into the model building codes. This would lead to increased competitiveness of precast construction in different seismic regions, free from the current constraints of extremely conservative code provisions.

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