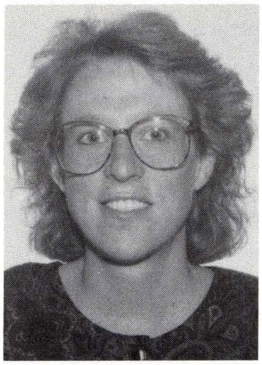
PRESSS Industry Seismic Workshops: Concept Development

In April 1991, a series of industry seismic workshops were conducted by the Precast/Prestressed Concrete Institute (PCI). The primary objective of these workshops was to seek industry input into the Concept Development and Connection Classification Projects of PRESSS (Precast Seismic Structural Systems) Phase 1. The participants in these workshops consisted of precast concrete producers, design engineers and contractors. Several conceptual designs were presented by the PRESSS researchers and critiqued by the workshop participants. This paper describes the results of the workshops as well as the review by the PRESSS Applications Advisory Committee, which recommends concepts worthy of future development by the PRESSS research teams.



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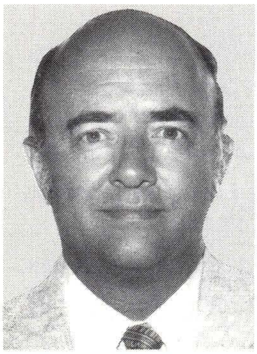

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Phase 1 of the PRESSS Research Program is in the second year of a planned three-year program. PRESSS is the fourth phase of a coordinated United States-Japan Research Program intended to improve the behavior of buildings during earthquakes. More information about PRESSS, the precast concrete portion of this coordinated research program, is found in a PCI JOURNAL article by Priestley.[1]

The conceptual development of economical and constructible precast concrete systems appropriate for use in regions of moderate and high seismicity is the PRESSS task assigned to Englekirk, Hart & Sabol, Inc. (EHS). It is the intent of PRESSS and its sponsors: the National Science Foundation (NSF), PCI and the Prestressed Concrete Manufacturers Association of California (PCMAC), to develop design guidelines, supported by experimental work, that will promote the use of precast concrete systems for various seismic zones which will be widely used both now and in the future.

Four regional workshops were convened by PCI in April 1991. These workshops were conducted by researchers from EHS (for PRESSS Project 1.1: Concept Development)

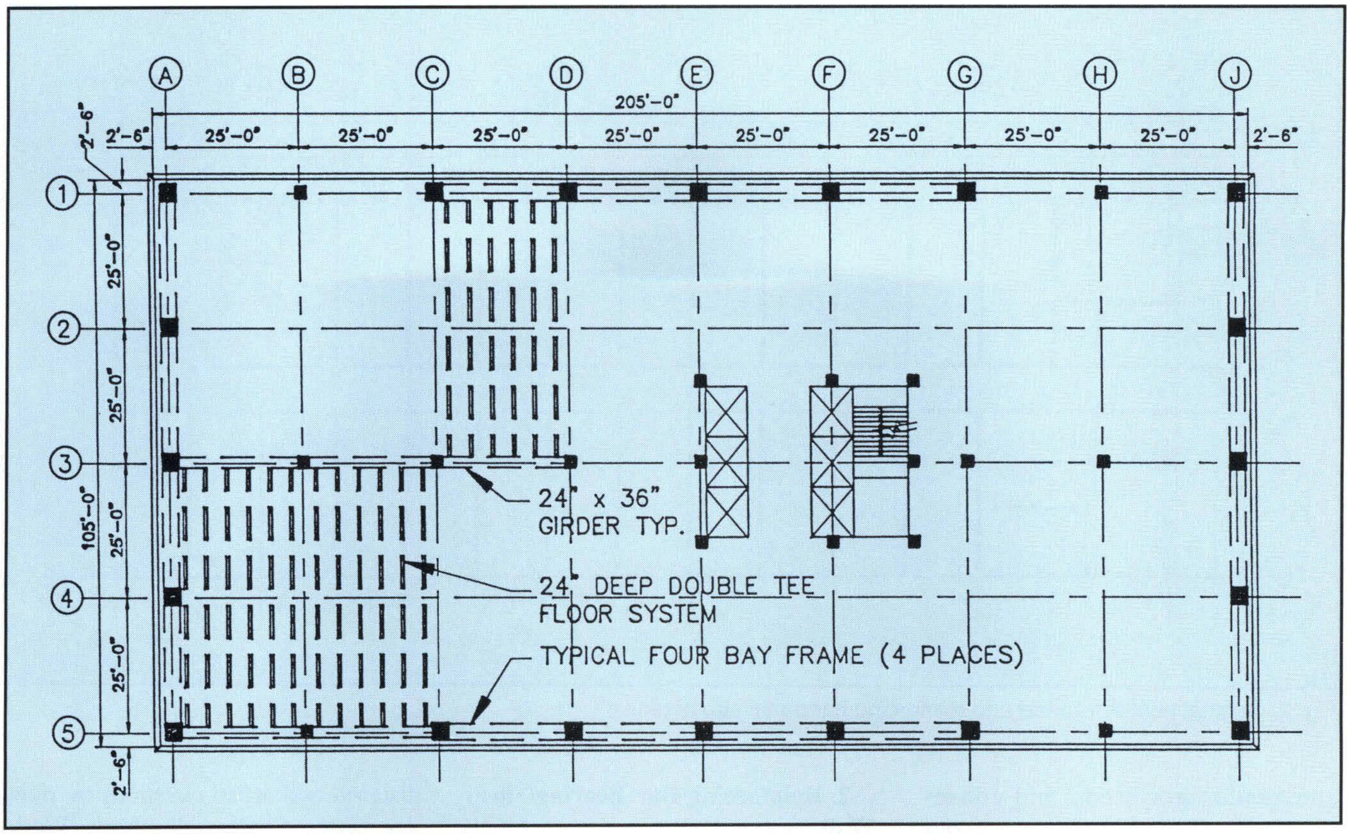

Fig. 1. Original post-tensioned frame.

and from the University of Washington (for PRESSS Project 1.3: Connection Classification and Evaluation). These workshops had as their objectives to:

- Obtain an industry review of the activities of PRESSS Projects 1.1 and 1.3, incorporating regional differences.
- Solicit system concepts which merit consideration, and obtain critical comments on the systems studied to date.
- Establish communications between the PRESSS researchers and the precast concrete design and construction industry.

Workshops were held in Seattle, Chicago, Atlanta and Los Angeles. Participants were selected so as to insure a balanced input from the design community, precast producers and constructors.

PRESSS SYSTEM CONCEPTS

The PRESSS research team decided early to develop system concepts and connection ideas that would apply to real buildings, rather than being just theoretical ideas. In this way, the economics of a system concept can be compared to other building systems during the initial phases of the research. In order to achieve this, two building functions were chosen for study:

1. A four-story office building with the typical floor plan shown in Fig. 1.
2. A six-story hotel with the typical floor plan shown in Fig. 2.

The office building was, in general, used as a vehicle to study seismic frame concepts and their associated connections. Shear wall systems were designed for the hotel building. This choice was made for the sake of example only, since many of the wall concepts could be used very effectively in an office building. Combination systems were not discussed at this stage.

Requirements for two different seismic zones were considered in the conceptual designs. Uniform Building Code (UBC)[2] Seismic Zones 2b and 4 were used to develop seismic load levels as well as to quantify degrees of required ductile behavior. The relationship between connection type, system behavior (i.e., good inelastic behavior and/or energy dissipation) and load is critical to the development of design criteria for precast seismic structural systems. These relationships were discussed extensively in the workshops.

Frame Systems

Three different frame system concepts were developed by the PRESSS team for the office building and presented to workshop participants:

1. Post-tensioned Frame – This bracing system consists of a multi-bay frame with conventionally reinforced concrete columns and post-tensioned beams. The beam-to-column connection occurs at the column face and is accomplished by post-tensioning across the interface. Shear is transferred by friction across a fiber reinforced grouted joint. The friction force is activated by the post-tensioning and the compression component of the beam moment. This connection has been tested at the National Institute of Standards and Technology (NIST).[3,4] A typical floor plan of the post-tensioned frame system is shown in Fig. 1.

2. Cladding System – All seismic loads are resisted solely by the perim-

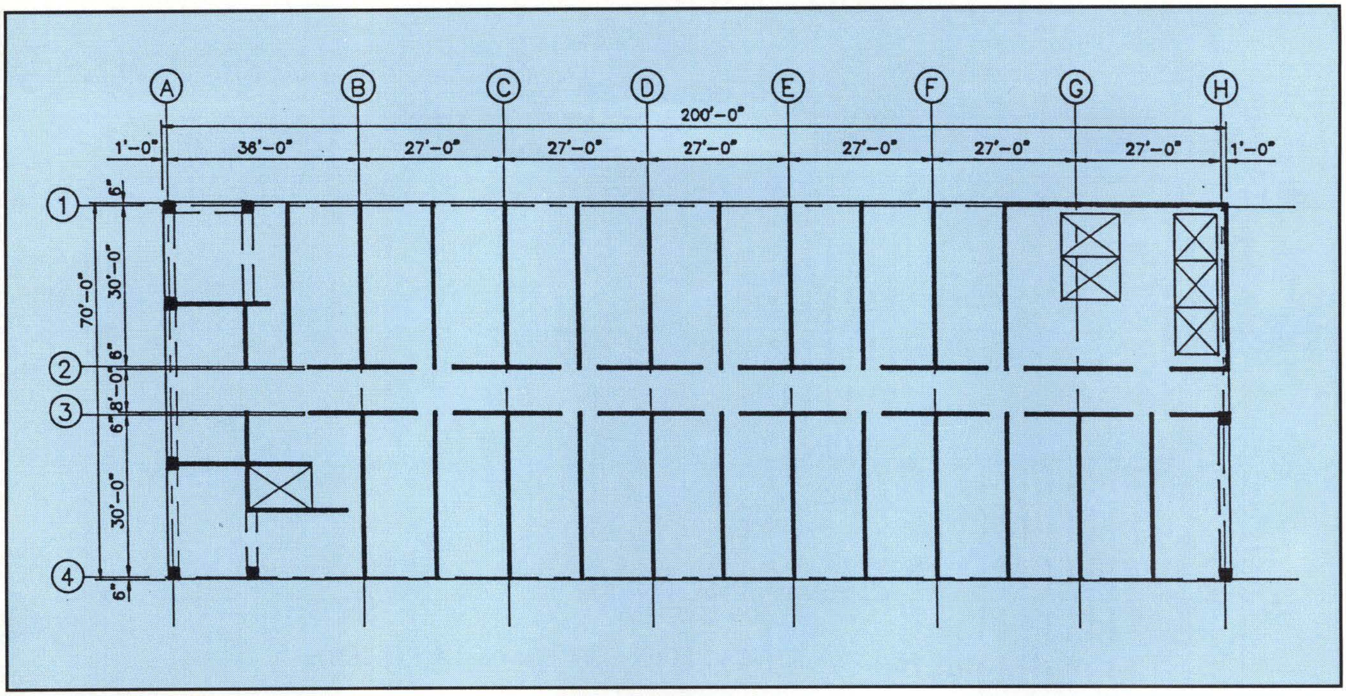

Fig. 2. Original post-tensioned and reinforcing bar panel structures.

eter cladding system, and consequently may be used with any interior gravity load carrying system. Both loadbearing and non-loadbearing panels were considered.

3. Distributed Frame System – This bracing system is modeled after a typical Japanese system in which each beam and column in the system is used to resist seismic loads. This type of system has more seismic connections, but each connection is less complicated, thus less expensive, than those required for a concentrated lateral system. Fig. 3 shows a plan view of the distributed frame system.

Wall Systems

The hotel building configuration, shown in Fig. 2, was used to study two different shear wall systems. In both systems, all of the partition walls were used as shear walls. Although the wall distribution was the same for both systems, the connection methods differed as follows:

1. Post-tensioned Bearing/Shear Wall System – One-story panels are stacked on top of each other and post-tensioned vertically to create a sufficient friction force between the panels to resist shear loads. The vertical post-tensioning also resists overturning loads.

2. Reinforcing Bar Bearing/Shear Wall System – The one-story panels used for this system are connected with welded or sleeved reinforcing bar connections at each floor line which resist both overturning and, given sufficient height-to-depth ratios, panel-to-panel shear forces.

The discussions were not limited to these systems; however, these systems gave the participants a common problem to study and critique. This allowed the researchers an opportunity to understand the reasons behind the opinions that were expressed.

WORKSHOP RESULTS – GENERAL

The two-day workshops started with an introduction to the PRESSS project as well as details of the goals of the two research projects represented (Projects 1.1 and 1.3). There was minimal interaction in the first morning session as information mostly flowed from the researchers to the participants. However, in the afternoon session and the next morning session, the participants worked in small groups of three or four people, critiquing conceptual drawings.

Each small group had at least one producer, design engineer and contractor wherever possible. The researchers listened and asked questions by moving between the small groups. Working in these small groups was one of the most successful and productive features of the workshops since the discussions that took place brought out the differences between the participants' viewpoints and revealed the reasons underlying their preferences in construction sequences, connection details and other structural features.

At the end of each small group session, the workshop conclusions were developed by interaction between all groups, with the researchers keeping notes on an overhead projector. In this way, conclusions for each workshop location were developed with input from all participants. Although each small group was able to reach conclusions on its own fairly easily, the interactive conclusions were less of a total consensus due to the size of the large group (approximately 20 people at each location).

At the completion of all workshops, the two research teams drew conclusions for the entire workshop series based on what had been discussed at the different locations. These conclusions were then used to form the basis of the proposed concepts worthy of further development.

Of primary consideration in developing the systems, both in preparation

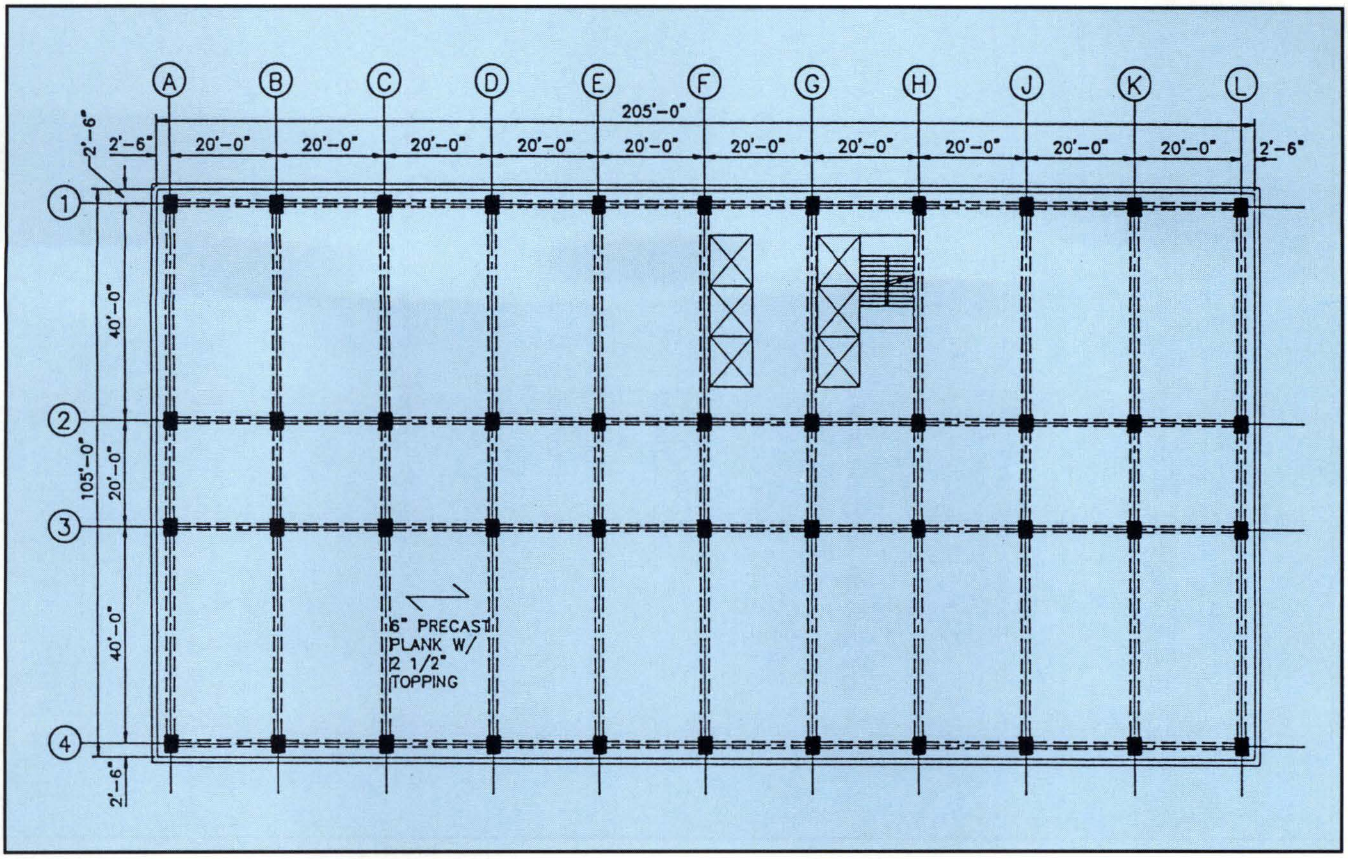

Fig. 3. Original distributed frame system.

for and at the workshops, was the interaction between connection type and system performance. As the researchers initially developed the systems, there was extensive interaction between the concept development and connection research teams to develop systems and connections that were compatible and would achieve the intended system behavior. This interaction continued with the workshop participants as they developed more economical connection details which then influenced the choice of feasible systems concepts, and the anticipated seismic design loads.

One universal conclusion of the workshops was that any design recommendations developed by PRESSS must allow this flexibility to continue. Connector ductility must be considered as a variable in the design process which then influences the available system ductility and required seismic design loads. This is conceptually the same as the current UBC seismic design practice for both cast-in-place concrete and steel in the use of R_w factors and the prescriptive detailing requirements for each of the systems listed in Table 23-O.[2] In order to keep precast concrete as flexible a construction material as it has been, the PRESSS design recommendations should include methods for verifying acceptable connector and system behavior for different design load levels, in addition to any prescriptive detailing requirements that may be provided for systems with specified R_w factors.

The other conclusion supported by all of the participants was the need for design recommendations for untopped diaphragms. This has been strongly recommended to the PRESSS Executive Committee for inclusion in the scope of the Phase 2 Research Program.

WORKSHOP RESULTS – SPECIFIC

The details of the discussions that took place at the four workshops are contained in the Workshop Report.[5] The Building Concepts Research, taken from the Workshop Report,[5] describes the conclusions of the workshops as they relate to the Concept Development research. Further on in this paper, other conclusions are presented which represent the workshop results as interpreted and modified by the PRESSS Applications Advisory Committee.

Building Concepts Research

At the conclusion of the workshop series, the tasks to be addressed in the near future by the concept development team were defined as follows:

1. Revise and detail the systems as outlined below, incorporating the Project 1.3 Connection Classification and Evaluation.

2. Arrange for cost estimates to be provided by producers and contractors.

3. Prepare documentation of economically validated systems for Phase 2 of PRESSS.

The buildings selected for development are versions of those presented at the workshops, modified in light of the information gathered there. Four frame structures and two variants on a basic panel structure are proposed, and are outlined separately here. The first three frame systems are conceived as relatively low rise structures in which

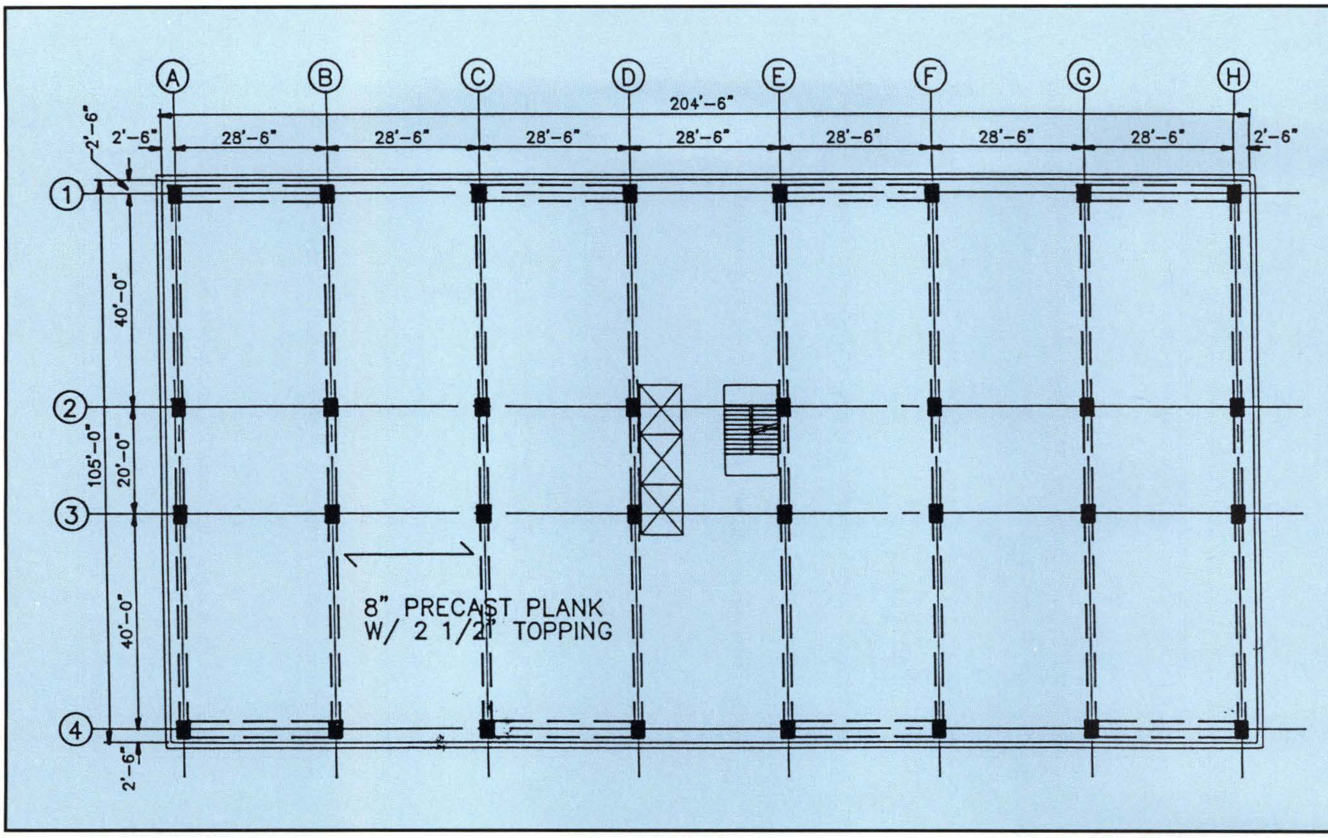

Fig. 4a. Modified frame system.

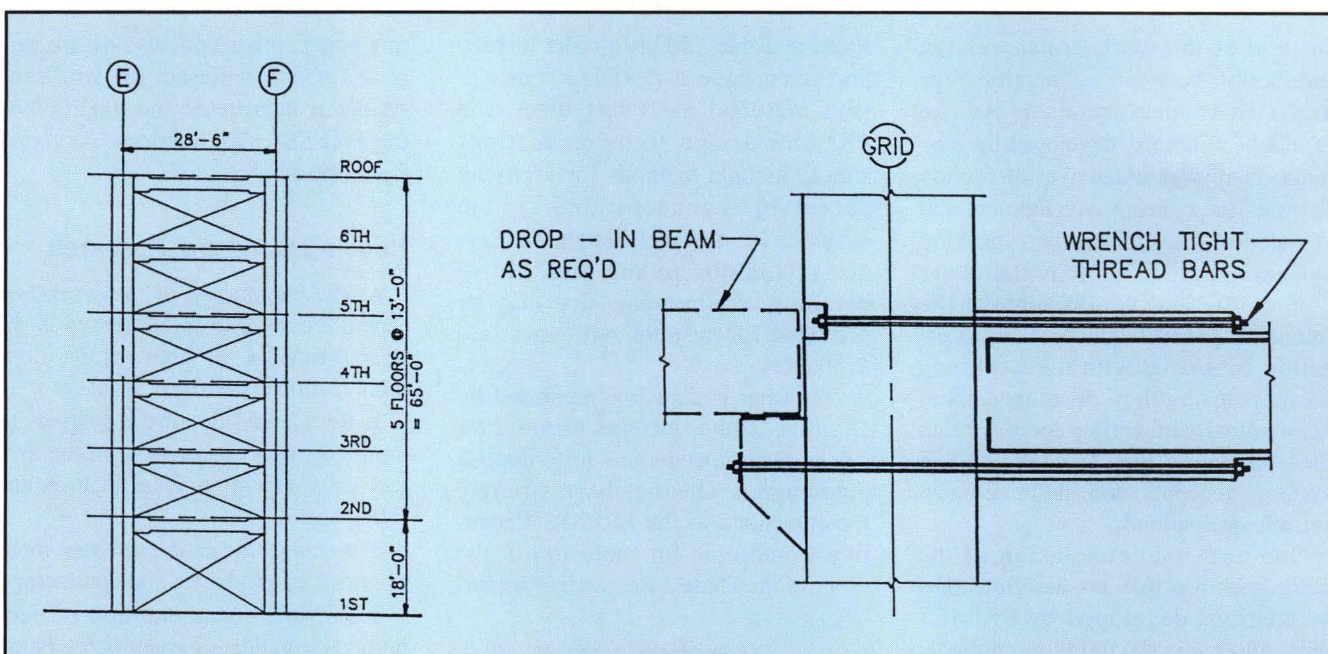

Fig. 4b. Spaced-out threadbar frame.

the columns are made in one piece and in which "up-and-out" construction is possible. In up-and-out construction, the building is built full height at one end, and erection proceeds toward the other end of the structure, with each bay erected full height as the mobile crane backs away. These three low rise systems are relevant to the immediate needs of the precast concrete industry.

The fourth system will be a post-tensioned frame, which is probably better suited to construction floor-by-floor, and which is applicable to higher structures. This is a longer term goal and coordinates well with the Japanese part of the PRESSS program, in which one of the subject building types contains 15 stories. The following building systems were presented

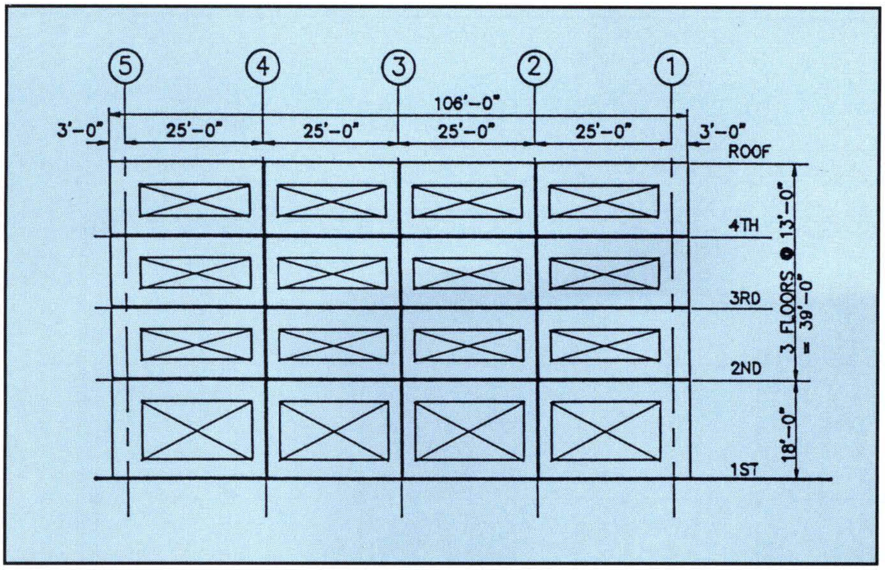

Fig. 5. Window wall panel system.

by the PRESSS Projects 1.1 and 1.3 researchers to the PRESSS Applications Advisory Committee as worthy of future research effort, based on workshop results:

(a) Spaced-out Threadbar Frames – In a spaced-out frame system, longitudinal strength is obtained by making a series of separate one-bay moment frames in which the connections are formed by wrench-tight threaded rods. Drop-in beams using simple connections span between the frames. This framing system has the advantage that each pair of frames can be regarded as a strength nucleus so that many building configurations can be made up by different arrangements of the same basic nuclei. This system is shown as the longitudinal frame system in Fig. 4a. An elevation of each one-bay frame is shown in Fig. 4b, with the detail indicating the wrench-tight threaded rods.

(b) Conventional Reinforcing Bar Frames – In this system, all the transverse frames resist lateral load. They have simple connections at the edge columns and moment-resisting ones at the interior columns. Different joint concepts will be investigated for the transverse frames but they will focus on solutions that are not post-tensioned. This system is shown as the transverse frame system in Fig. 4a.

(c) Window Wall Cladding Panel – This system is essentially the one presented at the workshops, and is shown in Fig. 5. The panels will be non-loadbearing, and different shear connectors between panels will be investigated as the yielding element that limits the forces in the structure. All other connections will be standard architectural precast concrete connectors (i.e., bearing, lateral and in/out connections). The choice of non-loadbearing panels was made to maximize the feasibility of this system with various panel configurations that may be chosen by an architect.

(d) Post-tensioned Frame – This frame will build on the concept presented in Fig. 6. It is expected that the connections will make use of both mild steel reinforcement and post-tensioning to achieve a balance between tying the structure together and dissipating energy.

(e) Panel Structures – These will be studied using post-tensioning and mild steel reinforcement as variants on the same basic scheme, the details being selected in accordance with the requirements of each individual application. The possibility of using steel tubes as energy dissipating coupling beams across the corridors will be investigated. Different means of achieving energy dissipation at the bottom story, and the possibility of making that connection extensible, will be studied. The framing scheme used for these studies is shown in Fig. 7.

For both the frame and the panel structures, diaphragm behavior and design requirements will be addressed.

Connection Research

The results of the workshops were also used to help define the future direction of the connection research. This research is described in a paper entitled "Connection Classification and Evaluation," by Stanton et al.[6] in this issue of the PCI JOURNAL (pages 62-71).

THE NEXT PHASE

The future direction of PRESSS must take into account the interests of both NSF and industry. NSF is primarily interested in long term innovative solutions, whereas the industry support from PCI and PCMAC tends to focus more on short term results. These two needs are balanced by the PRESSS Executive Committee in its recommendations to NSF for Phase 2 funding.

Applications Advisory Committee Recommendations

Keeping this balance in mind, the PRESSS Applications Advisory Committee reviewed the Workshop Report and recommended to the PRESSS Executive Committee that the following concepts be included in the PRESSS Phase 2 Research Program:

1. Some ductility should be provided in every structural system for all seismic zones to provide life safety in the event of a catastrophic event which may have a very long recurrence interval.

2. Both six and 15-story buildings will be studied in response to both short and long term needs.

3. Required system/component relationships will have to be identified for precast seismic structural systems in terms of analytical and/or experimental procedures which relate component, subassembly, or story deformability to system ductility and required load demand.

4. Untopped diaphragms which have no welded joints but are confined by boundary elements will be investigated to assess their ability to transfer shear.

5. Reliable friction transfer mechanisms for use particularly in shear wall designs must be evaluated.

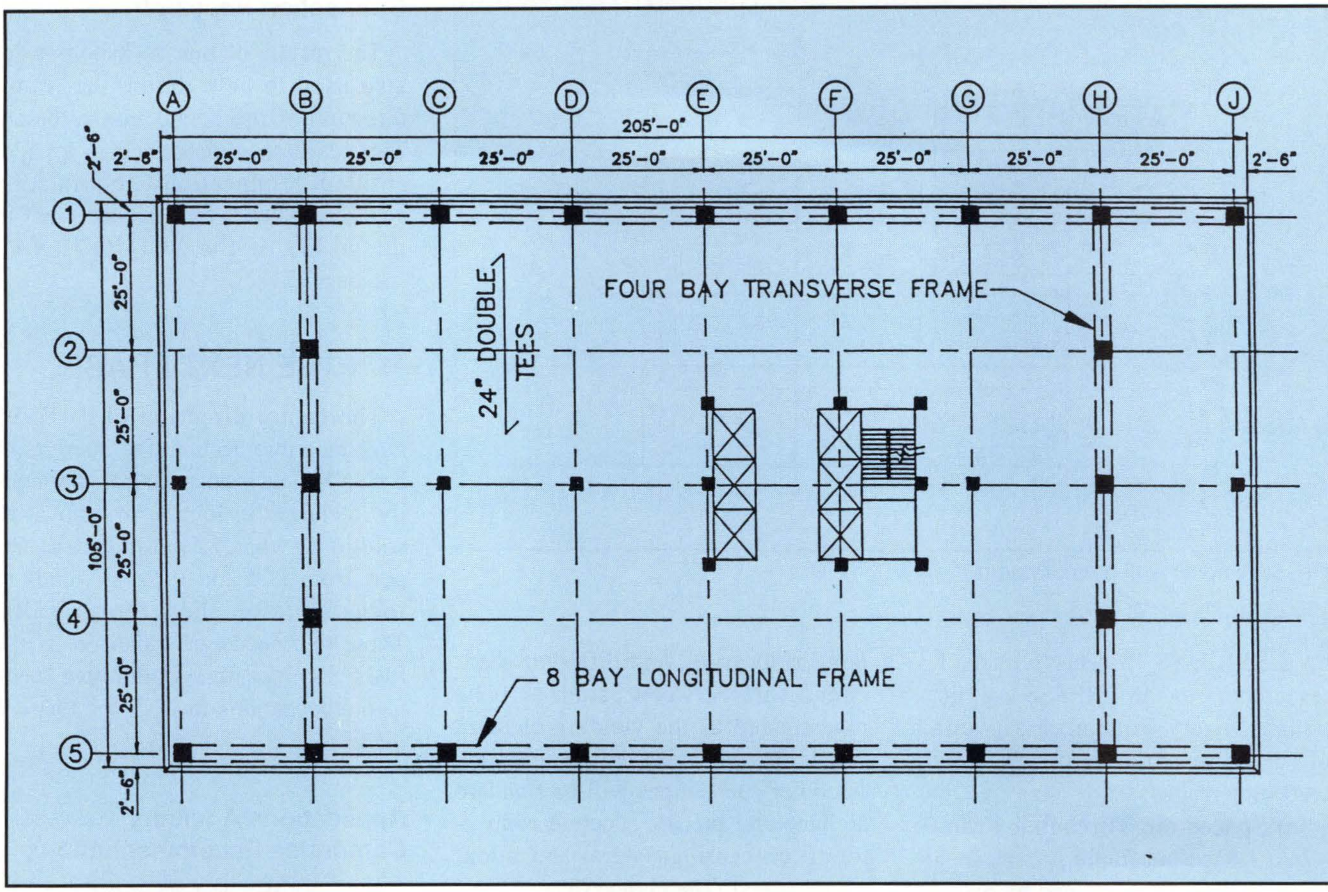

Fig. 6. Modified post-tensioned frame.

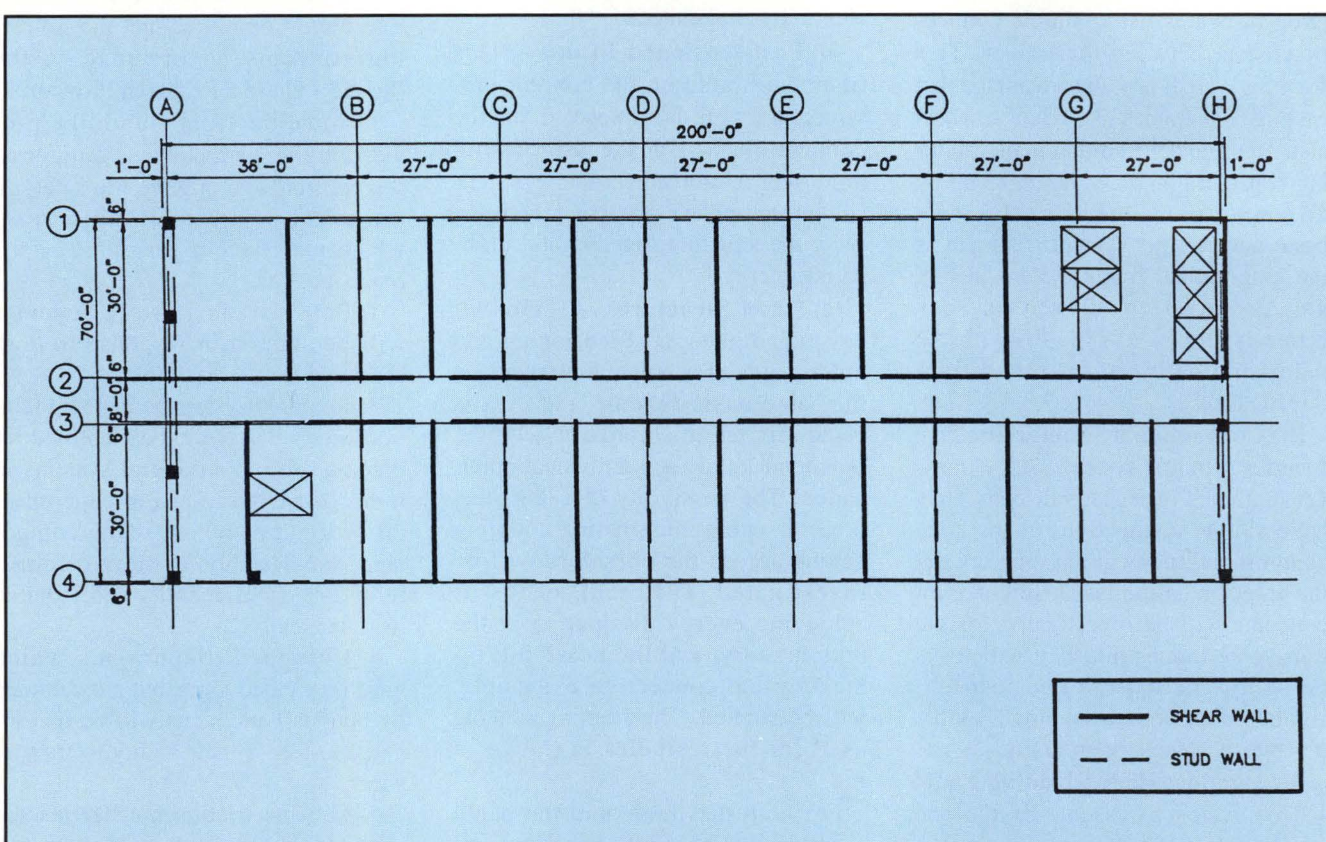

Fig. 7. Modified panel structure.

To provide a basis for economic evaluation of proposed systems, several conceptual designs will be prepared to a stage where preliminary construction costs can be evaluated. The concepts which seem to be the most promising for development are:

(a) Ductile Frame Systems – The floor plan to be used for development of this system is shown in Fig. 4a. A six-story building with single bay frames will be designed with two different concepts.

First, a ductile steel corbel will be developed which resists both the shear load at the end of the beam and the tension at the bottom of the beam caused by the seismic moment. Second, a stressed bar system using a "dog-bone" type beam will be designed. A dog-bone type beam has a deeper section at each end to simplify the connection through the column and is shown in Fig. 4b. Systems similar to this have been studied by Jayashankar and French.[7] Both systems will be designed with the beam-to-column connection as the ductile element (i.e., no strong joints). Two sets of details will be developed: one for a building in UBC Zone 2b using an R_w of 6, and the other for Zone 4 with an R_w of 12.

In addition to the six-story structures, a 15-story building will be designed in part to discourage arbitrary height limits being placed on precast seismic systems, and to facilitate interaction with the Japanese PRESSS Program. This building will be designed for Zone 4 with an R_w of 12. Instead of the single-bay frames, continuous frames will be used with stressed bars or post-tensioning strands provided for the full length of the building.

(b) Shear Wall/Bearing Wall Systems – The floor plan used for these buildings is shown in Fig. 7. A hollow-core floor system, without topping, resists both vertical and diaphragm shear loads. A six-story building (for Zone 4 with an R_w of 6) will have lightly stressed walls in the transverse direction which will be used to develop less ductile details. The corridor walls will be minimized to study details which require higher levels of ductility. Two 15-story buildings (Zones 2b and 4, each with an R_w of 6) will provide still higher system ductility demands and allow the researchers to address high axial load and overturning problems. Both friction and welded horizontal shear transfer mechanisms will be considered. Flexural loads will be resisted by stressed bars, coupled walls and welded connections (for the six-story building only). Both flexural and shear mechanisms will be considered for energy dissipation. Confinement requirements will also be investigated with a strain based criterion to eliminate traditional boundary element requirements.

(c) Cladding Systems – A seismic load resisting system consisting of only the perimeter non-loadbearing cladding system will be developed. This can be used with any interior gravity load carrying system. The panels will be detailed to behave elastically, with all of the energy dissipation provided by panel-to-panel connectors.

Both a six and a 15-story building will be considered for Zones 2b and 4. Detailing requirements for a system with high levels of inelastic displacement capability and/or energy dissipation will be developed using an R_w of 12. In addition, a system more applicable to lower seismic zones, with less extreme inelastic requirements, will be developed using an R_w of 8.

SUMMARY AND CONCLUSIONS

The systems outlined here will be developed in sufficient detail to obtain an economic analysis of the system concept from the construction industry. In addition, these systems have been recommended to the PRESSS Executive Committee, and in turn to NSF, to help provide direction for Phase 2 of PRESSS. The actual choice of proposals to be funded, however, rests with NSF and may or may not include any of these systems.

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Any opinions, findings, conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation, PCI or PCMAC.

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