The PRESSS Five-Story Precast Concrete Test Building

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The five-story PRESSS (Precast Seismic Structural Systems) test building, a large scale structure that includes four structural precast concrete frame systems and a post-tensioned jointed precast concrete shear wall system, underwent severe seismic testing in late 1999 at the structural laboratory of the University of California at San Diego. The results of the five-story building test have verified the design and analysis procedures developed in the earlier phases of the PRESSS research program, and have demonstrated that properly designed precast concrete structural systems can perform extremely well when subjected to high seismic loading. This article presents an overview of the PRESSS research program, a description of the precast structural systems used in the five-story test building, and the principal conclusions drawn from the testing program.

The PRESSS research program is part of a joint U.S.-Japan effort whose aim has been to demonstrate the viability of precast concrete design for various seismic zones.[1] The program has been sponsored primarily by the National Science Foundation (NSF) with industry support provided by the Precast/Prestressed Concrete Institute (PCI) and the Precast/Prestressed Concrete Manufacturers Association of California, Inc. (PCMAC).

An ongoing project since 1991, the PRESSS research program has two primary objectives:

- To develop comprehensive and rational design recommendations needed for a broader acceptance of precast concrete construction in different seismic zones.
- To develop new materials, concepts, and technologies for precast concrete construction in different seismic zones.

A further objective of the program is that the design and construction recommendations resulting from this comprehensive program be incorporated into the appropriate building codes.

The details of the PRESSS research program are described by Priestley,[1] and a more thorough overview of the five-story test building used in the program is presented by Nakaki, Stanton, and Sritharan.[2]

The test building is a five-story structure that combines five different seismic load resisting systems appropriate for use in different seismic zones. It was intended to examine the suitability of design concepts developed in the earlier phases of the PRESSS research program and in related research. One criterion used in determining which systems would be included in the test building was that the concept should have been experimentally validated through component tests. The testing of the complete building (see Fig. 1) addressed many design and constructibility issues that could not be accomplished by individual component testing.

The specific objectives for the five-story building test program were to:

- Validate a rational design procedure for precast seismic structural systems.
- Provide acceptance of prestressing/post-tensioning of precast seismic systems.
- Furnish experimental proof of overall building performance under severe seismic excitation.
- Establish a consistent set of design recommendations for precast seismic structural systems.

The test building was designed using a direct displacement based design (DBD) procedure, rather than a force based design method.[2] With the DBD approach, the resulting design base shear is significantly lower than what would be calculated by force based design. Moreover, it gives the engineer better control of the struc-

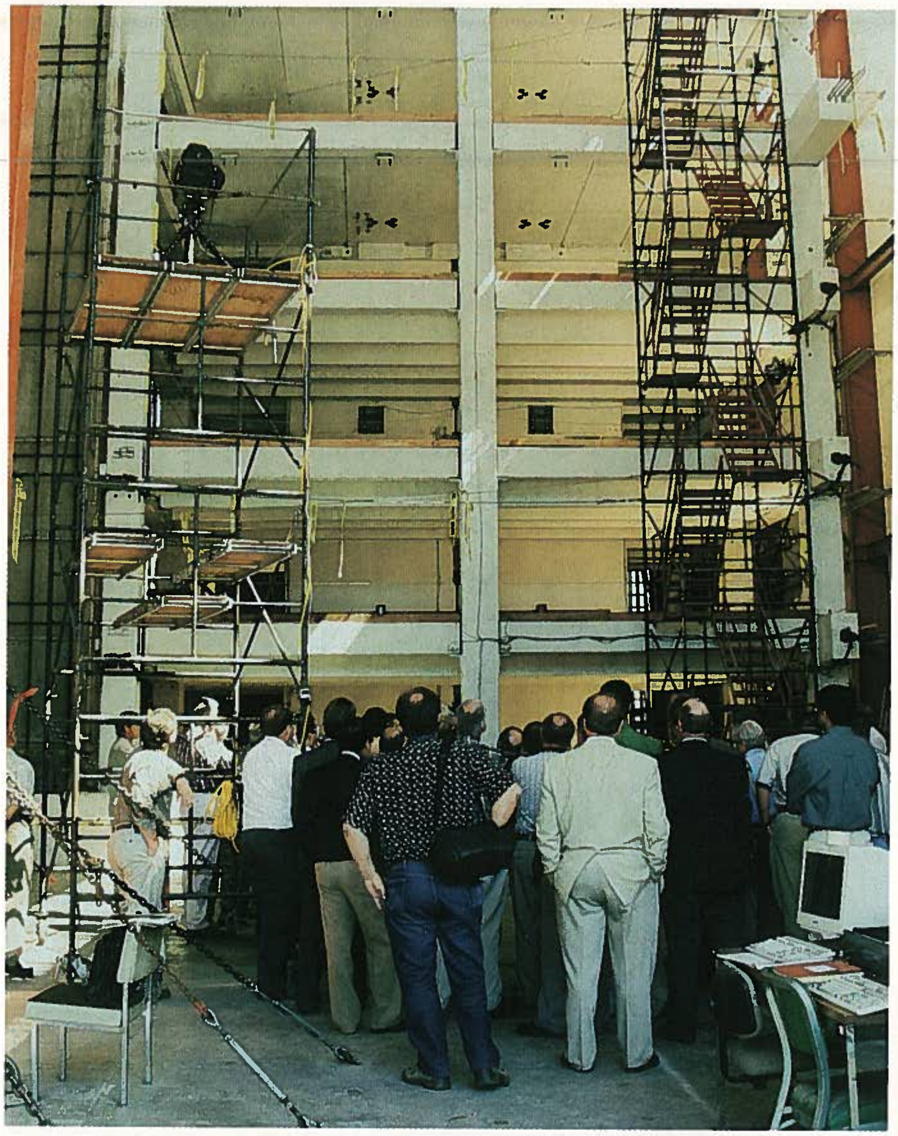

Fig. 1. The seismic testing of the five-story building, which was carried out in the structural laboratory of the University of California at San Diego, verified the design and analysis procedures developed in the earlier phases of the research program.

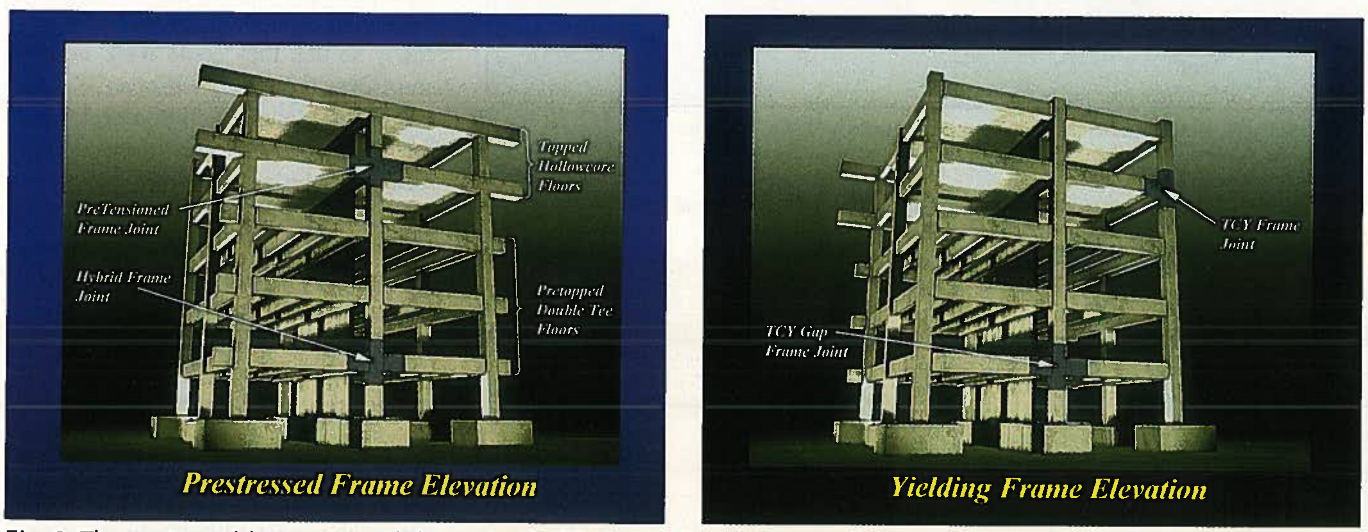

Fig. 2. The prestressed frame system (left) consisted of the hybrid frame connection and pretensioned frame connection. The yielding frame system (right) comprised the TCY gap frame connection and the TCY frame connection. The flooring systems on the first three floors were pretopped double tees while the upper two floors comprised topped hollow-core slabs.

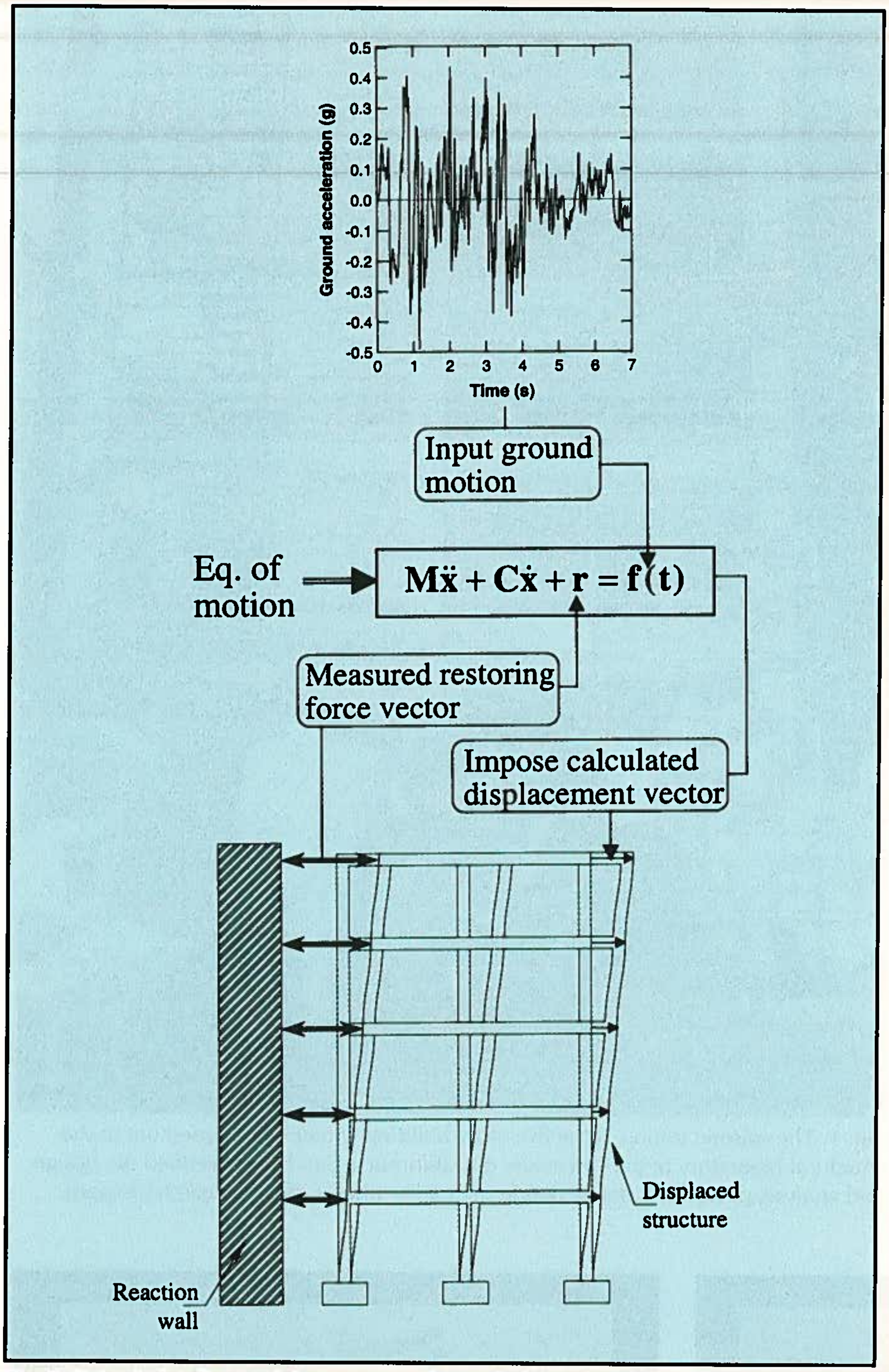

Fig. 3. Seismic loading and the concept of pseudodynamic testing.

Table 1. Structural components for the five-story PRESSS test building (2 bays x 2 bays).

Item		Quantity	Dimensions
Pretopped double tees		12	8.0 x 30.0 ft
6 in. thick hollow-core floor slabs		8	40 in. x 15.0 ft
6 in. thick solid actuator connection floor slabs		12	Variable width x 15.0 ft
Gravity beams		20	8.5 x 16 in. x 15.0 ft
Gravity columns		2	18 x 18 in. x 37.5 ft
Frame systems	Hybrid frame	6	Most are 14 x 23 in. x 15.0 ft
	Pretensioned frame	2	
	TCY gap frame	6	
	TCY frame	4	
Frame columns		9	18 x 18 in. x variable length
8 in. thick shear wall panels		4	9.0 x 18.75 ft

Note: 1 ft = 0.3048 m; 1 in. = 25.4 mm.

tural design by incorporating both strength and stiffness requirements.

The test building consisted of four different ductile structural frame systems in one direction of loading and a jointed structural shear wall system in the orthogonal direction. Table 1 provides information on the components used in the test building.

The structure was tested in two orthogonal directions – one in which only the frames would resist the simulated seismic loading, and the other in which only the shear wall would resist the loading. The loads represented earthquakes of seismic input levels up to 50 percent greater than those required by the Uniform Building Code for Seismic Zone 4. Two independently controlled actuators were used at each floor level to prevent torsion from occurring during the test loadings.

Fig. 2 shows two sides of the test building. The "Prestresssed Frame Elevation" comprises the hybrid frame and pretensioned frame systems, whereas the "Yielding Frame Elevation" incorporates the tension-compression yielding (TCY) gap frame and TCY frame systems. These four frame systems will be elaborated upon in the next section.

The structure was tested under a series of simulated earthquake levels. The principal method of testing was pseudodynamic testing, using spectrum-compatible earthquake segments (see Fig. 3). Because the test building was designed using the DBD approach, displacements at each level of the structure had to be applied delicately so that they could work in unison. Also, because of differential thermal displacements between night and day temperatures, much of the testing took place during the night.

Fig. 4 is a plan view of the test building showing the framing systems of the lower three floors. The flooring system was selected based on the predominance of their use in today's precast concrete construction. On the lower three levels, the system consists of pretopped double tees that span between the seismic-resistant frames. On the upper two floors, topped hollow-core slabs spanned between the gravity frames and the precast concrete shear wall system.

FRAME CONNECTION SYSTEMS

The four different types of ductile connection systems built into the test building were:

- Hybrid frame connection
- Pretensioned frame connection
- TCY (tension-compression yielding) gap frame connection
- TCY frame connection

Even though in practice these four different frame system types are not intended to be used in a single building, the PRESSS research team and advisors felt that these all should be included in the test structure. Testing all four frame systems would provide useful data on the fundamentally different types of behavior that might be appropriate for various situations and demonstrate the versatility of precast concrete that other systems do not possess.

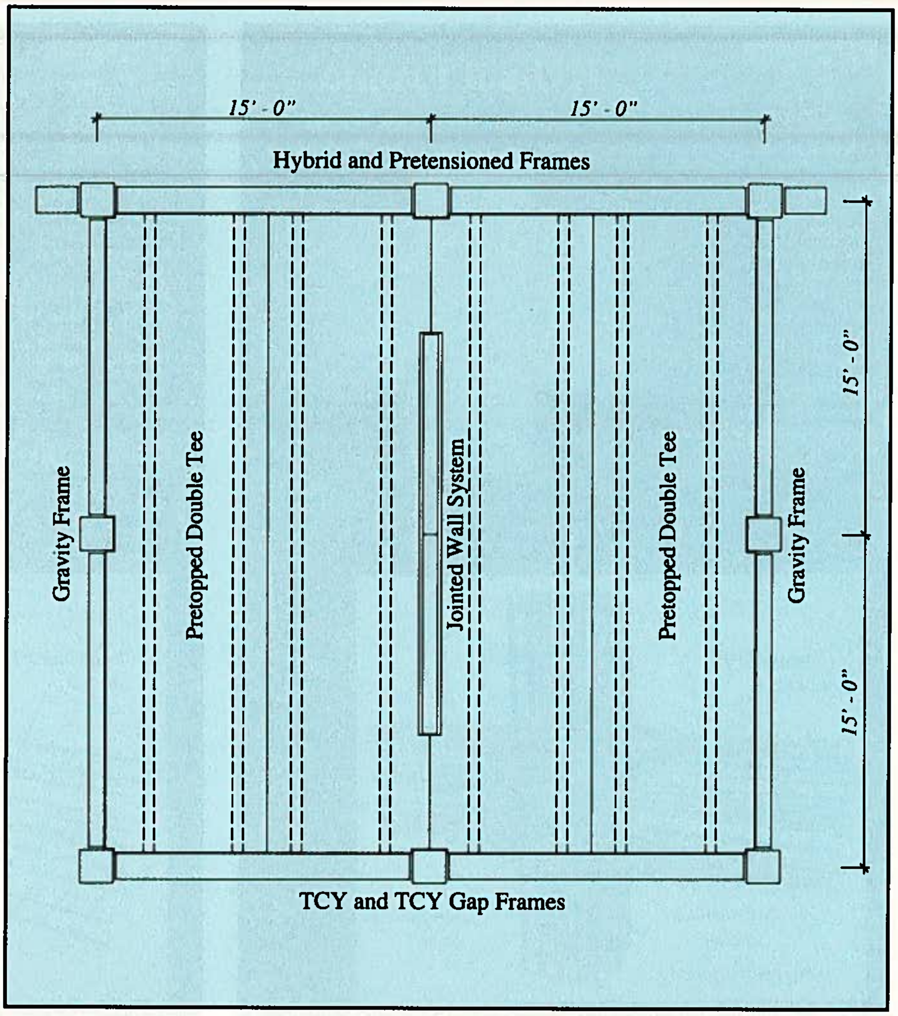

Fig. 4. Plan view of test building showing lower three floors.

Hybrid Frame Connection

The hybrid beam-to-column connection is a system of post-tensioning strands that run through a duct in the center of the beam and through the column. Mild steel reinforcement is placed in ducts on the top and bottom

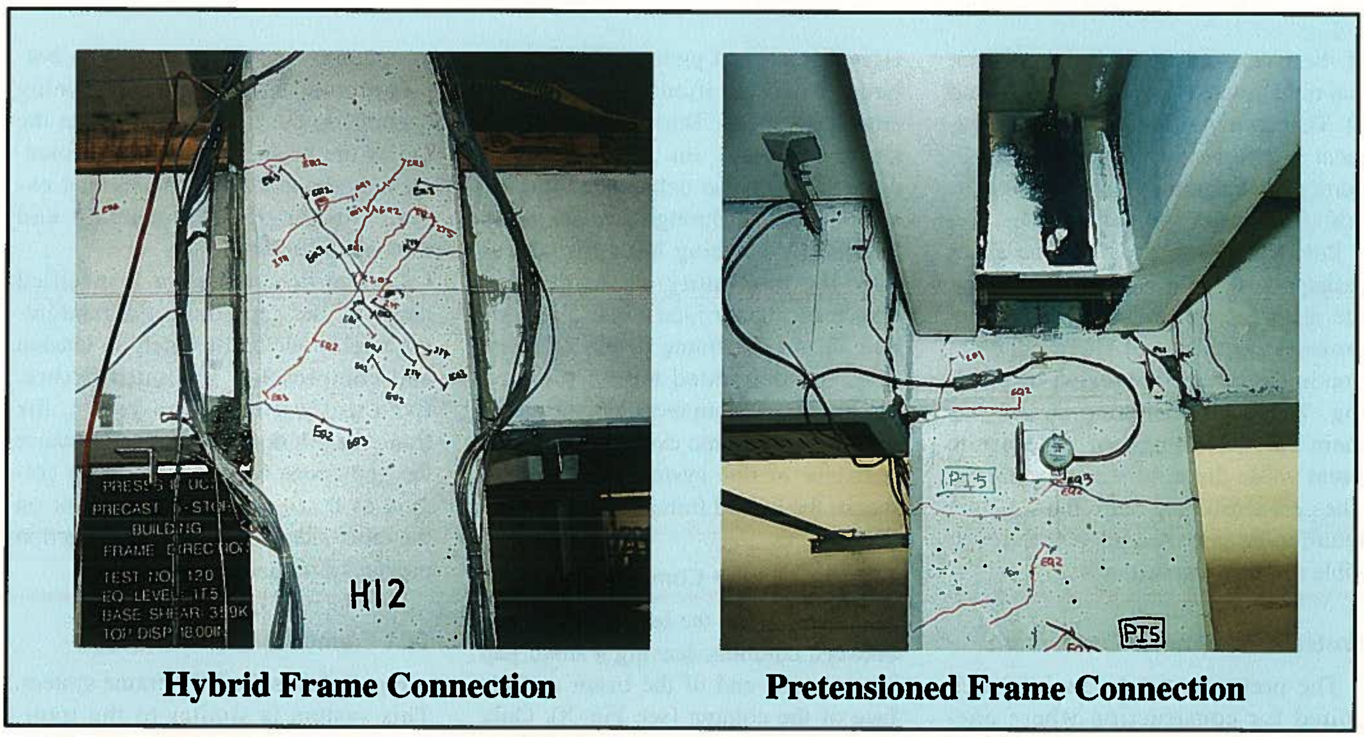

Fig. 5. Condition of the hybrid frame connection (left) and pretensioned frame connection (right) after structure was subjected to drift levels more than twice the design level.[4]

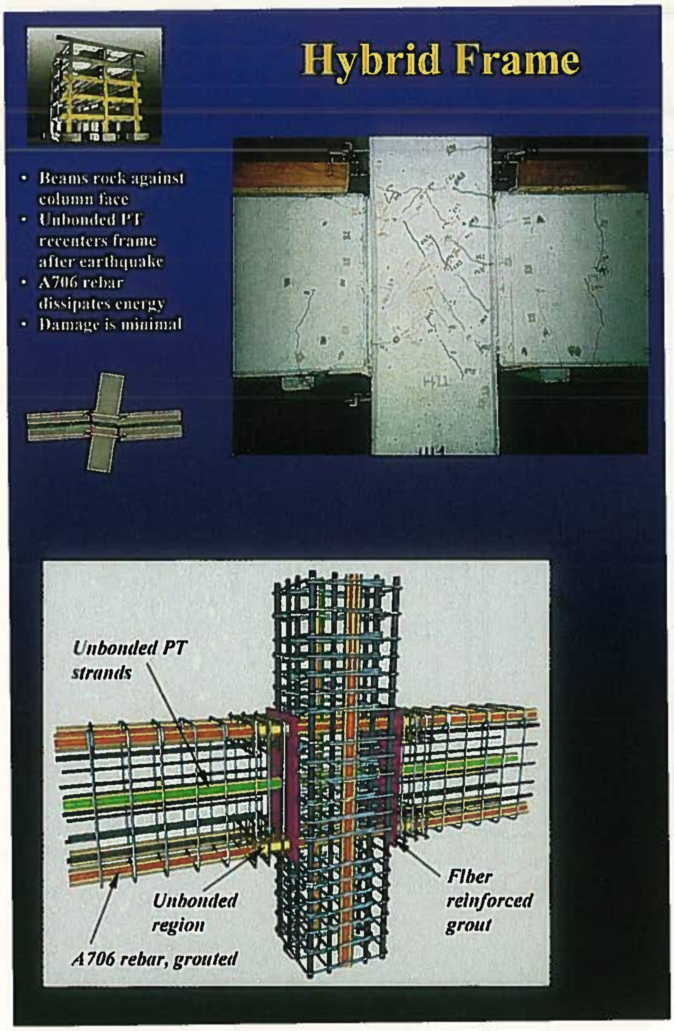

Fig. 6. Details of the hybrid frame connection.

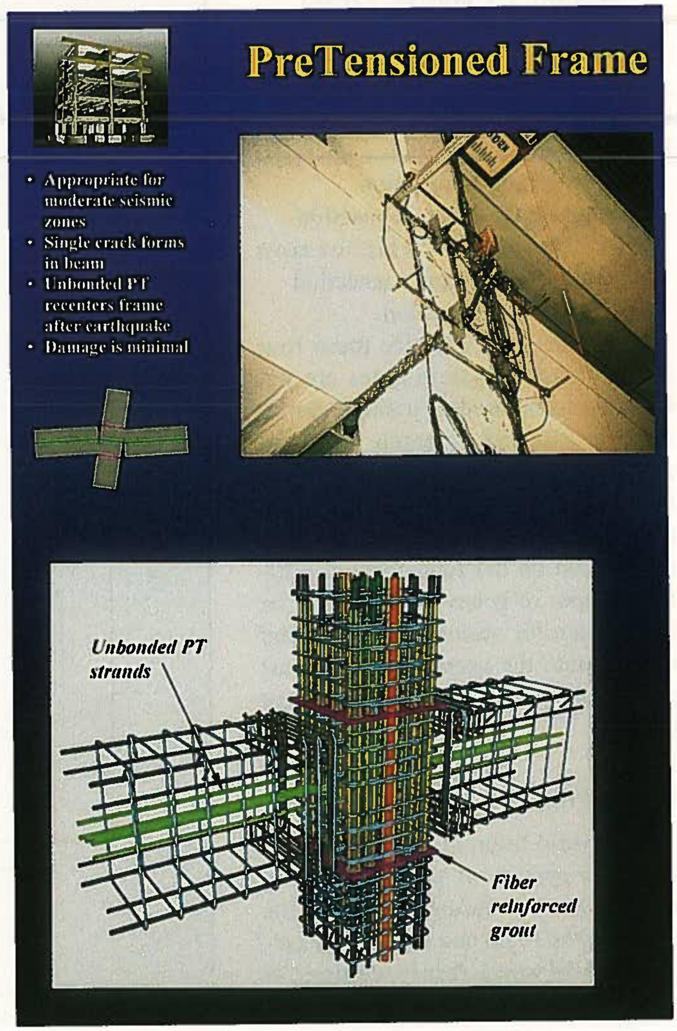

Fig. 7. Details of the pretensioned frame connection.

of the beam and through the column, and then grouted [see Figs. 5 (left) and 6]. The amount of mild steel reinforcement and post-tensioning steel are proportioned so that the frame recenters itself after a major seismic event.

Post-tensioning provides the shear resistance for the beam (eliminating the need for corbels), and mild steel provides ductility and energy dissipation in the connection region by yielding. The post-tensioning strands remain elastic throughout the seismic event while the mild steel is yielding. The post-tensioning helps the structure return to its initial position with negligible residual displacement.

Pretensioned Frame Connection

The pretensioned frame is ideally suited for construction where one-story columns are combined with multi-span beams. The beams are fabricated in normal pretensioned casting beds, with specified lengths of the strand debonded. During erection, the beams are set on the one-story columns, with the column reinforcing steel extending through sleeves in the beams. Reinforcing bar splices provide the continuity of the column above the beam [see Figs. 5 (right) and 7]. As the frame displaces laterally, the debonded strand remains elastic. The system recenters the structure after a seismic event. The overall behavior of this system is similar to that of the hybrid frame system.

TCY Gap Frame Connection

In this system, the beams are erected between columns, leaving a small gap between the end of the beam and the face of the column (see Fig. 8). Only the bottom portion of the gap is grouted to provide contact from beam to column. At the center of this bottom-grouted region, post-tensioning bars clamp the frame together. At the top of the beam, mild steel reinforcement is grouted into sleeves that extend the length of the beam and through the column.

Careful debonding for a specified length at the gap allows the reinforcing steel to yield alternately in tension and compression without fracture. Even as the connection yields, the frame length does not change because the gap opens on one side of the column as it closes an equal amount on the other side. The sleeved connection prevents a premature failure.

TCY Frame Connection

Fig. 9 shows the TCY frame system. This system is similar to the traditional tension-compression yielding connection used in cast-in-place con-

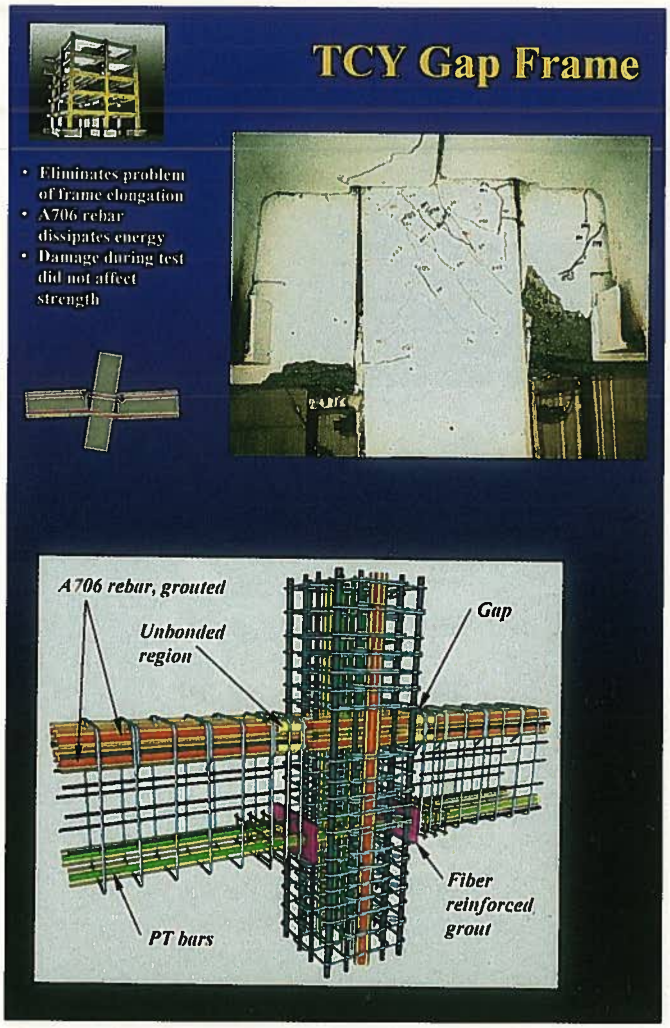

Fig. 8. Details of the TCY gap frame connection.

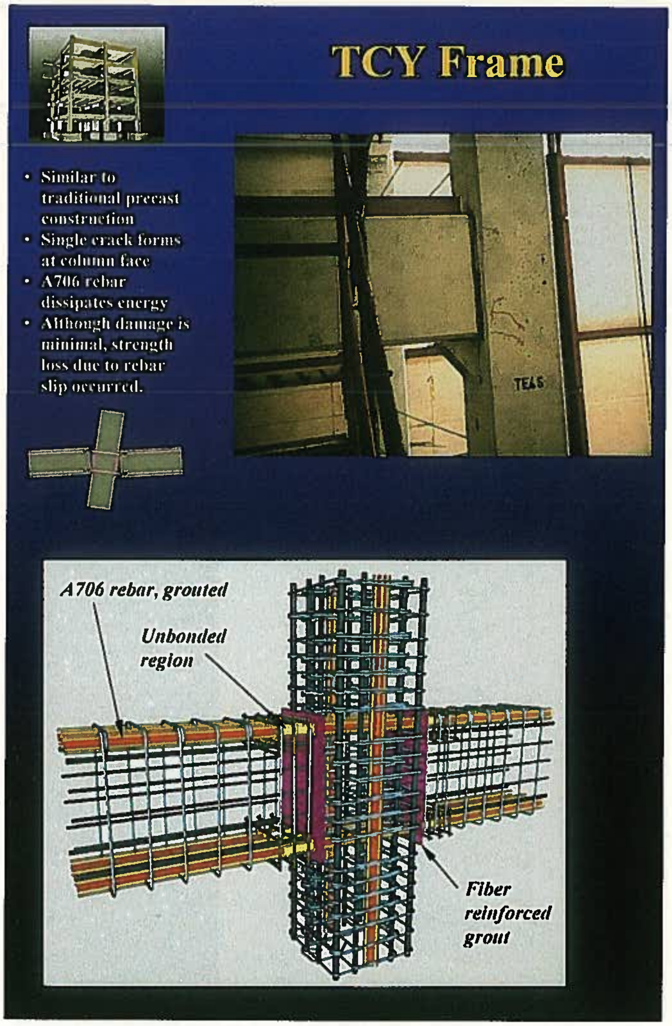

Fig. 9. Details of the TCY frame connection.

struction except that, rather than the yielding being distributed over a finite plastic hinge length, the yielding is concentrated at the connection. The beam reinforcement that provides moment strength and energy dissipation is debonded over a short length at the beam-to-column interface so that the reinforcement will not fracture prematurely at this yielding location.

PRECAST POST-TENSIONED SHEAR WALL SYSTEM

Fig. 10 illustrates a jointed precast post-tensioned shear wall system in the test building. Vertical unbonded post-tensioning is used to resist the lateral loads that could not be resisted by the inherent gravity load of the system. The special feature of this system is the U-shaped flexure plate (UFP). These plates serve as vertical joint connection devices where damping is achieved by means of flexural yielding of the plates (see Fig. 11).

The unbonded post-tensioning is designed to recenter the wall system after the seismic event has occurred. As a result, there will be negligible residual drift. Recentering is ensured by relating the elastic capacity of the post-tensioning system to the yield strength of the panel-to-panel connections.

TEST RESULTS

The major results of the testing program are as follows:

• The test results were very satisfactory, with the structural response exceeding the building code requirements.

• The PRESSS structural systems provide a level of seismic performance equal to or greater than that of other structural systems.

• These systems are suitable for low, moderate, and high seismic regions.

• The systems typically sustain less seismic damage than those of conventional cast-in-place systems.

• The design of these systems is simple and straightforward.

• Response to seismic loading, particularly drift, can be predicted accurately.

• All hardware (precast concrete products, prestressing steel, mild reinforcing steel, steel plates, and other materials) used in the various structural systems is conventional and widely available.

The highlights of the testing event at the University of California, San Diego, are presented in Reference 3, and a comprehensive discussion of the results and conclusions drawn from the

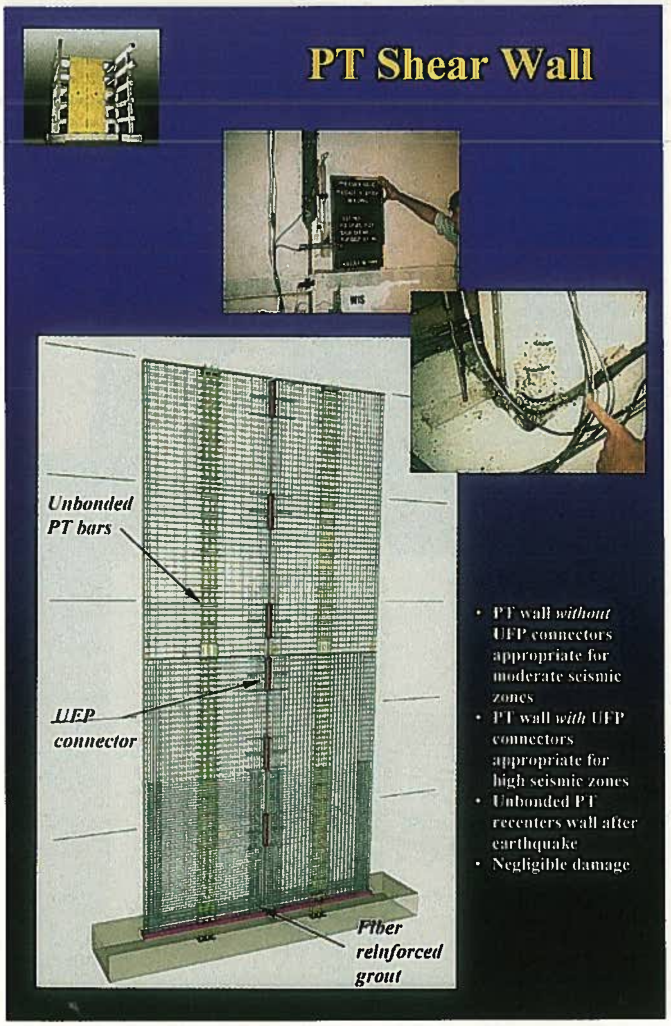

Fig. 10. Details of the post-tensioned shear wall system.

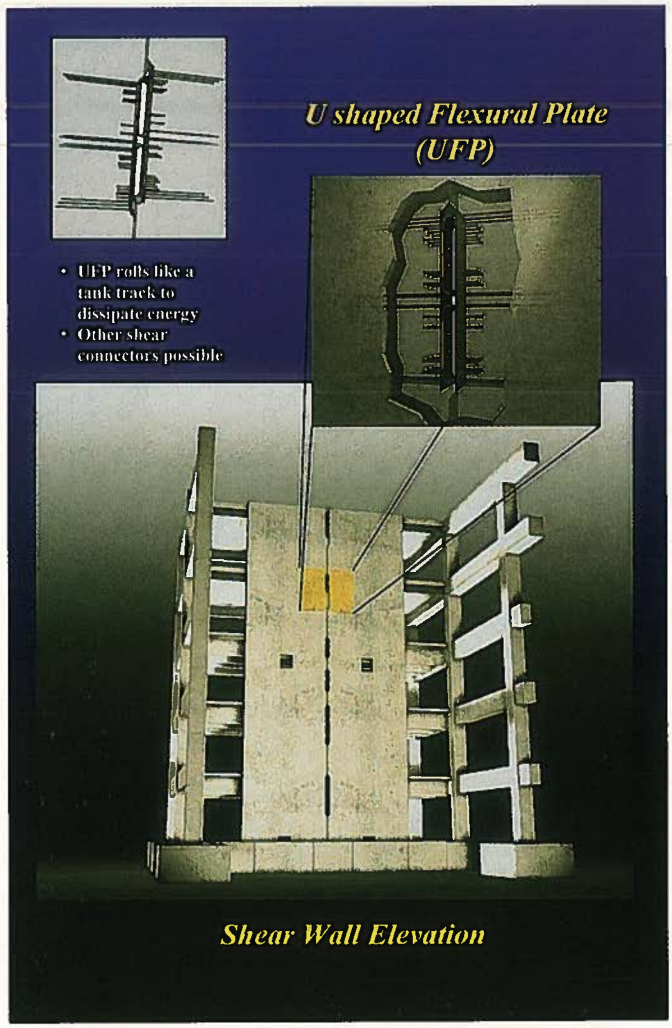

Fig. 11. Details of the U-shaped flexure plate (UFP) for the shear wall system.

program is presented in Reference 4.

Among the five systems examined, results from the hybrid frame, pretensioned frame, and the post-tensioned shear wall were particularly good. Not only did these three systems experience minimal damage, but they also exhibited a self-centering characteristic that does not exist in other seismic systems. This self-centering characteristic allows immediate re-occupancy of the building after a major seismic event and makes precast concrete an attractive choice in seismic areas where previously precast construction would not have been an option.

The PRESSS research program has proved that all-precast concrete systems can provide the highest quality solution for major commercial, institutional, and industrial buildings in all seismic zones. The research under this program is now entering the code-approval process. The PCI JOURNAL will present further test analysis, design and construction details, design implications of the testing, and the direct displacement based design procedure in future issues.

JURY COMMENTS

"This work will advance the precast, prestressed concrete industry by opening new markets in moderate and high seismic areas. A key point is that the performance standards not only met but also exceeded all expectations. The benefits of this successful test are only beginning to be seen, with more undoubtedly to come. Showing the world that precast concrete behaves well in a high seismic area will create more widespread use of the product and better, more cost-effective structures overall."

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CREDITS

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