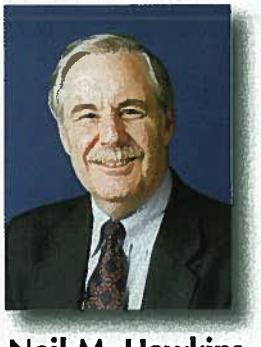
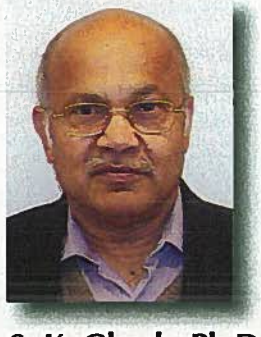
Codification of Precast Seismic Structural Systems: An Update



Neil M. Hawkins, Ph.D., FPCI
Professor Emeritus of Civil Engineering
University of Illinois
at Urbana-Champaign
Urbana, Ill.



S. K. Ghosh, Ph.D., FPCI
President
S. K. Ghosh Associates Inc.
Palatine, Ill.

This article updates the readership on progress made with the codification of structural systems tested as part of the precast seismic structural systems (PRESSS) program. It is expected that the effort will reach a significant milestone with the inclusion of non-emulative design provisions for unbonded, post-tensioned precast structural walls in ACI 318-08.

As part of the precast seismic structural systems (PRESSS) research program, a five-story concrete building was tested at the University of California at San Diego.[1,2] Precast shear walls were used in one direction of the building and, in the orthogonal direction, non-emulative special moment frames were used. On one face of the building, frames with hybrid and pretensioned connections were utilized, while for the other, parallel face, tension-compression yielding (TCY) frames were chosen.

At a meeting of the PRESSS Advisory Group in May 2001, it was decided to pursue the codification process for two structural systems out of the five mentioned previously: the pretensioned precast frame system and the precast shear wall system. It was felt that another one of the five structural systems, the hybrid post-tensioned precast frame, had essentially already been codified. In the July–August 2003 issue of *PCI Journal*, the authors of "Codification of PRESSS Structural Systems" discussed PCI's strategy for codification of two of the structural systems.[3] This article updates *Journal* readers on progress made with the codification of structural systems tested as part of the PRESSS program.

HYBRID POST-TENSIONED PRECAST FRAME

The inclusion of non-emulative special moment frames in ACI 318-02 began with the formation of Innovation Task Group 1 (ITG-1), which developed the provisional standard ACI ITG/T1.1-99 that later became ACI T1.1-01.[4] The preamble to ACI T1.1-01 notes, "This document defines the minimum experimental

evidence that can be deemed adequate to attempt to validate the use of ... weak beam/strong column frames not satisfying fully the prescriptive requirements of Chapter 21 of ACI 318-99." Because ACI 318-02 has now referenced ACI T1.1-01 in Section 21.6.3, it can be said that ACI T1.1-01 unequivocally defines the minimum experimental evidence that must be available in order to construct jointed precast special moment frames.

Section 21.6.3 of ACI 318-02 also contains two requirements beyond those defined in ACI T1.1-01: "(a) Details and materials used in the test specimens shall be representative of those used in the structure; and (b) The design procedure used to proportion the test specimens shall define the mechanism by which the frame resists gravity and earthquake effects, and shall establish acceptance values for sustaining that mechanism. Portions of the mechanism that deviate from code requirements shall be contained in the test specimens and shall be tested to determine upper bounds for acceptance values."

A second standard, ACI T1.2-03,[5] was also developed by ACI ITG-1. This standard defines the requirements, in addition to those in (a) and (b) of ACI 318 Section 21.6.3, for the design of one specific type of moment frame, which consists of precast concrete beams post-tensioned to precast or cast-in-place columns. In this frame type, the columns are continuous through the joints and each beam spans a single bay. Key requirements for this hybrid frame are:

- Equal moment strength for the top and bottom energy-dissipating bars that are grouted in place across the interface between the precast concrete beam and the column; and
- Post-tensioning tendons that are unbonded from anchor to anchor and concentrically located within the cross section of the beam.

Provided the foregoing conditions are met, the University of Washington test results for the Third and Mission Building in San Francisco, Calif., and the results from the PRESSS building frame direction tests can be used as the basis for special precast concrete hybrid moment frame designs in accordance with ACI T1.2-03. The results of the University of Washington tests are on file at ACI Headquarters in conjunction with ACI T1.2-03. The results of the PRESSS building frame direction tests are available in a series of reports from PCI and the Precast Concrete Manufacturers Association of California.

Hybrid frames can be designed using the same values for the response modification factor R, deflection amplification factor C_d, and system overstrength factor Ω_0, as those specified for monolithic special reinforced concrete moment frames in the governing building code if two requirements are met: The provisions of ACI T1.2-03 must be used to determine hybrid frame properties, and the requirements of ACI 318 Section 21.6.3 must be met.

To alert designers to the existence of ACI T1.2-03, the following has been proposed as an addition to the end of ACI 318 Commentary Section R21.6.3 in the 2008 edition: "ACI T1.2 defines design requirements for one type of special precast concrete moment frame that has been validated for use in accordance with 21.6.3." The proposal awaits approval by both the ACI 318 main committee and its subcommittee H.

PRETENSIONED PRECAST FRAME

Use of the pretensioned precast moment-resisting frame has been the subject of a recent article.[6] While these frames performed satisfactorily in the most severe test applied to the PRESSS building, these frames would not be permitted under Section 21.6.3 of ACI 318 to act as the sole seismic-force-resisting system in regions of high seismic risk or for structures assigned to high seismic performance or design categories.[6] Such frames, however, can be designed to satisfy all the requirements of Section 21.12 of ACI 318-02 for intermediate moment frames. Further, the results reported in References 7 and 8 suggest that frames constructed using such pretensioned connections should be acceptable for intermediate moment frames when designed using the same R and C_d factors as those specified in the governing building code for cast-in-place concrete construction. Analyses need to be made to verify that conclusion and acceptance criteria proposed for intermediate moment frames based on structural testing.

Pretensioned precast moment-resisting frames could probably utilize the same acceptance criteria as those for special moment frames except with the relative energy dissipation ratio requirement of Section 9.1.3 of ACI T1.1-01 deleted. Reference to those criteria can then be inserted in ACI 318, and the definition for intermediate moment frames in Section 21.1 of ACI 318 could be amended to a definition similar to that for special moment frames, where both cast-in-place and precast concrete construction are recognized.

In the interim, the results of References 7 and 8, the satisfactory performance of the pretensioned frame in the PRESSS test building, and the provisions of Section 1.4 of ACI 318-02 can be used to seek building department approval of a pretensioned frame system for moderate seismic risk zones or for structures assigned to intermediate seismic performance or design categories.

PRECAST CONCRETE SHEAR WALLS

A proposed provisional standard and commentary titled "Acceptance Criteria for Special Precast Concrete Structural Walls Based on Validation Testing" was developed by Neil M. Hawkins and S. K. Ghosh in early 2003. This document proposed the minimum experimental evidence that can be deemed adequate to attempt to validate the use of structural walls (shear walls) in regions of high seismic risk or in structures assigned to high seismic performance or design categories. This includes coupled walls, for bearing wall and building frame systems (Section 9 of ASCE 7-02), not fully satisfying the prescriptive requirements of Chapter 21 of ACI 318-02.

The provisional standard and commentary were written in such a form that their various parts could be adopted directly into Sections 21.0, 21.1, and 21.2.1 of ACI 318-02 and the corresponding sections of ACI 318R-02. Among the subjects covered were design procedures for test modules, configurations for these modules, test methods, test reports, and determination of satisfactory performance.

Input on the provisional standard and commentary was re-

ceived from a PCI review group. A modified version, which accommodated the review group input, was presented at a meeting of Building Seismic Safety Council (BSSC) Technical Subcommittee 4 on Concrete (TS4) in February 2003, in Portland, Ore. A letter ballot of the technical subcommittee was subsequently conducted. Further modifications were made in response to several comments received on the ballot.

The modified document was then balloted by the BSSC Provisions Update Committee (PUC) prior to its meeting in San Diego in June 2003; the proposal drew a large number of negative votes. Considerable effort was spent to respond to every negative comment that was submitted. Further significant adjustments were made to the proposal at the PUC meeting.

With the modifications incorporated, the PCI-initiated proposal to permit non-emulative design of special precast concrete shear walls using a modified version of "Acceptance Criteria for Special Precast Concrete Structural Walls Based on Validation Testing" was approved by the PUC for inclusion in the 2003 edition of National Earthquake Hazard Reduction Program (NEHRP) Provisions.[9] Some relatively minor additional adjustments were made as a result of comments received from a letter ballot of the member organizations of BSSC (including PCI).

The adjusted version of "Acceptance Criteria for Special Structural Walls Based on Validation Testing" now appears in the 2003 NEHRP Provisions. The extensive commentary that was originally developed is now part of the 2003 NEHRP Provisions Commentary. One result of all the input was that the scope of the "Acceptance Criteria for Special Structural Walls Based on Validation Testing" became limited to special precast concrete wall systems to the exclusion of special cast-in-place walls. The 2003 NEHRP versions of the "Acceptance Criteria for Special Precast Concrete Structural Walls Based on Validation Testing" were published in the September–October 2004 issue of *PCI Journal*.[10]

A proposal was made to have the 2003 NEHRP requirements concerning non-emulative design of special precast concrete structural walls included in Section 14.2 of ASCE 7-05 in the form of an amendment to Chapter 21 of ACI 318-05. If the proposal was accepted, such designs would have been permitted by the 2006 International Building Code (IBC) because ASCE 7-05 is adopted by reference in that code. The proposal did not succeed because a majority on the Seismic Task Committee on ASCE 7 felt that new requirements such as this should be left up to ACI Committee 318.

To follow the path that led to the inclusion of non-emulative special moment frames in ACI 318-02, the formation of an ACI ITG was requested by PCI to develop a provisional standard similar to ACI T1.1 for precast concrete shear wall systems. The request was approved and led to the formation of ACI ITG 5, which used the "Acceptance Criteria for Special Precast Concrete Structural Walls Based on Validation Testing" published in Reference 10 as the starting point or Draft No. 1. During several rounds of ballots, comments were received that resulted in several modified drafts. Draft No. 6 was finally approved by the Technical Activities Committee (TAC) at its 2005 summer meeting, subject to satisfactory responses to TAC comments. ACI ITG 5 responses to the TAC comments were finalized at the fall 2005 ACI Convention in Kansas City, Mo. The only matter remaining is the redrafting of several of the figures to satisfy some TAC concerns. That action is now in progress and should be completed soon, resulting in the publication of ACI T5.1. The scope of the approved document is limited to unbonded post-tensioned precast concrete structural walls for bearing wall and building frame systems (ASCE 7-05 Section 12.2.1).

PROPOSED ACI 318-05 CHANGE

In anticipation of the availability of ACI T5.1, the following change has been proposed to ACI 318-05 and is now being balloted by ACI 318 Subcommittee H: "Add new Section 21.8.2 to ACI 318-05 as follows:

21.8.2—Special shear walls constructed using precast concrete and unbonded post-tensioning tendons and not satisfying the requirements of 21.8.1 shall satisfy the requirements of ACI T5.1 'Acceptance Criteria for Special Unbonded Post-Tensioned Precast Concrete Structural Walls Based on Validation Testing.'"

For special precast concrete moment frames, ACI 318 Section 21.6.3 contains two additional requirements that are not part of ACI T1.1-01 and are related to (a) the details and materials used in test specimens, and (b) the design procedure used to proportion test specimens. For walls, similar requirements are not needed because they are specifically included in ACI T5.1.

The following change to ACI 318 Commentary has also been proposed and is also being balloted by ACI 318 Subcommittee H:

Add new R21.8.2 as follows:

R21.8.2—Unbonded post-tensioned precast concrete shear walls not satisfying fully the prescriptive requirements of Chapter 21 have been demonstrated in experimental and analytical studies to provide satisfactory seismic performance characteristics.[a–d] ACI T5.1 defines a protocol for establishing a design procedure, validated by analysis and laboratory tests, for such walls, coupled or uncoupled. The design procedure should identify the load path and mechanisms by which the walls resist gravity and earthquake effects and establish procedures to ensure that undesirable modes of behavior do not occur. The required tests are configured to test critical behavior and establish upper bounds for the engineering design values for the walls of the structure and any of their critical components. The design procedure used for the structure should not deviate from that used to design the test specimens, and factored engineering design values should not exceed the nominal engineering design values demonstrated by the tests as acceptable. Deviations are acceptable only if the engineer can demonstrate that those deviations do not adversely affect the behavior of the walls.

a. Priestley, M.J.N., Sritharan, S., Conley, J., and Pampanin, S., "Preliminary Results and Conclusions from the PRESSS Five-Story Precast Concrete Test Building," *PCI Journal*, V.44, No.6, Nov.–Dec. 1999, pp. 42–67.

b. Perez, F.J., Pessiki, S., Sause, R., and Lu, L.-W., "Lateral Load Tests of Unbonded Post-Tensioned Precast Concrete Walls," SP-211, *Large Scale Structural Testing,* American Concrete Institute, Farmington Hills, MI, 2003, pp. 161–182.
c. Rahman, A.M., and Restrepo, J.I., "Earthquake Resistant Precast Concrete Buildings: Seismic Performance of Cantilever Walls Prestressed Using Unbonded Tendons," Research Report 2000-5, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, August 2000, 109 p.
d. Thomas, D.J. and Sritharan, S., "An Evaluation of Seismic Design Guidelines Proposed for Precast Jointed Wall Systems," ISU-ERI-Ames Report ERI-04643, Iowa State University, Ames, IA , June 2004.

REMAINDER OF PROCESS

If the proposed code and commentary changes are approved by ACI 318 Subcommittee H, as submitted or as modified, they will be forwarded on to the full ACI 318 committee. If the full committee approves of the changes following one or more letter ballots, again with or without modifications, the changes will then become part of ACI 318-08, subject to ACI TAC and Standards Board approval. TAC comments can sometimes result in further modifications.

Assuming that the above transpires, non-emulative design of unbonded, post-tensioned, special precast structural walls will be permitted by the 2009 IBC because ACI 318-08 will be adopted by reference in that code.

CONCLUSIONS

A course is being vigorously pursued to have requirements for non-emulative design of unbonded, post-tensioned, special precast structural walls included in ACI 318-08, the reference document for the 2009 IBC. The PRESSS testing program was concluded in 1999. IBC 2009 will represent a 10-year period required for codification of the precast concrete shear wall system that was tested as part of that program.

REFERENCES

1. Nakaki, S. D., J. F. Stanton, and S. Sritharan. 1999. An Overview of the PRESSS Five-Story Precast Test Building. *PCI Journal*, V. 44, No. 2 (March–April): pp. 26–39.
2. Nakaki, S. D., J. F. Stanton, and S. Sritharan. 2001. The PRESSS Five-Story Precast Concrete Test Building, University of California at San Diego, La Jolla, California. *PCI Journal*, V. 46, No. 5 (September–October): pp. 20–26.
3. Ghosh, S. K., and N. M. Hawkins. 2003. Codification of PRESSS Structural Systems. *PCI Journal*, V. 48, No. 4 (July–August): pp. 140–143.
4. American Concrete Institute (ACI) Innovation Task Group 1 and Collaborators. 2001. *Acceptance Criteria for Moment Frames Based on Structural Testing (ACI T1.1-01) and Commentary (ACI T1.1R-01).* Farmington Hills, MI: ACI.
5. ACI Innovation Task Group 1 and Collaborators. 2003. *Special Hybrid Moment Frames Composed of Discretely Jointed Precast and Post-Tensioned Concrete Members (T1.2-03) and Commentary (T1.2R-03).* Farmington Hills, MI: ACI.
6. Hawkins, N. M., and S. K. Ghosh. 2004. Requirements for the Use of PRESSS Moment-Resisting Frame Systems. *PCI Journal*, V. 49, No. 2 (March–April): pp. 98–103.
7. Priestley, M. J. N., and R. G. Macrae. 1996. Seismic Tests of Precast Beam-to-Column Joint Subassemblages with Unbonded Tendons. *PCI Journal*, V. 41, No. 1 (January–February): pp. 64–81.
8. El-Sheikh, M. T., R. Sause, S. Pessiki, and L. W. Lu. 1999. Seismic Behavior of Unbonded Post-Tensioned Precast Concrete Frames. *PCI Journal*, V. 44, No. 3 (May–June): pp. 54–71.
9. Building Seismic Safety Council, National Earthquake Hazards Reduction Program (NEHRP). 2003. *Recommended Provisions for the Development of Seismic Regulations for New Buildings and Other Structures.* Washington DC: NEHRP.
10. Hawkins, N. M., and S. K. Ghosh. 2004. Acceptance Criteria for Special Precast Concrete Structural Walls Based on Validation Testing. *PCI Journal*, V. 49,No. 5 (September–October): pp. 78–92.