IN-LB Inch-Pound Units

An ACI Standard

Requirements for Design of a Special Unbonded Post-Tensioned Precast Shear Wall Satisfying ACI 550.6 (ACI 550.7) and Commentary

Reported by Innovation Task Group 5

ACI 550.7-19

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This standard defines procedures that may be used to design special precast concrete shear walls, coupled or uncoupled, composed of discretely jointed precast panels that are vertically post-tensioned to the foundation with unbonded tendons. Such walls are suitable for use in regions of high seismicity and for structures assigned to high seismic design categories. After a major seismic event, these walls can be expected to exhibit minimal damage in the flexural hinging region at the base of the wall as well as negligible permanent displacements. Such walls do not satisfy the prescriptive requirements of Chapter 18 of ACI 318-14 for shear walls of monolithic construction. According to 18.2.1.7 of ACI 318-14, their acceptance requires demonstration by experimental evidence and analysis that the walls have strength and toughness equal to or exceeding those provided by comparable monolithic reinforced concrete walls that satisfy the prescriptive requirements of Chapter 18. This standard describes the procedures that the designer may use to demonstrate, through analysis, that one type of unbonded post-tensioned precast wall has strength and toughness at least equal to that of comparable special reinforced concrete monolithic walls. The standard consists of Design Requirements and a Commentary.

Among the subjects covered in these Design Requirements are requirements for:

1. Materials, including considerations for the coupling or connection devices, that provide the primary source of energy dissipation for the wall system;

2. Individual walls, including considerations to ensure ductility, energy dissipation, integrity, stiffness, and strength; and

3. Coupled walls, including considerations of the roles of the post-tensioning tendons and coupling devices in providing energy dissipation, and strength and stiffness for coupled walls greater than the sum of those provided by the coupled walls acting as separate units.

The Commentary references documentary evidence, additional to the references of ACI 550.6 and Chapter 18 of ACI 318R-14, that supports these Design Requirements. In this standard, however, no comparison is made between the performance of precast test modules satisfying the prescriptive requirements of ACI 318 and modules satisfying these Design Requirements but not satisfying ACI 318. Such comparisons, both experimental and analytical, are available in the cited references.

All references to ACI 318 and ACI 318R in these Design Requirements and Commentary refer to ACI 318-14 unless another edition of ACI 318 is specifically designated. All references to ASCE/SEI 7 in these Design Requirements and Commentary are to ASCE/SEI 7-10, including third printing updates.

In this standard, consistent with the format of ACI 318-14, the word "Section" is not included before a reference to a section of ACI 318-14. To more clearly designate a section in this standard, however, the word "Section" is used before any reference to a section of this standard. Consistent with the format of ASCE/SEI 7-10, the word "Section" is included before a reference to a section of ASCE/SEI 7-10.

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Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

Keywords: coupling devices; drift angle; energy dissipation; lateral resistance; post-tensioning; precast concrete; prestressed concrete; seismic design; special shear wall; test module; toughness.

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CHAPTER 1—GENERAL

1.1—Introduction

For regions of high seismic risk, where structures assigned to Seismic Design Category (SDC) D, E, or F shall be used, 18.2.1.7 of ACI 318 permits the use of structural systems that do not meet the prescriptive requirements of Chapter 18 if certain experimental evidence and analysis are provided (all references to ACI 318 and ACI 318R in this standard refer to ACI 318-14 unless another edition of ACI 318 is specifically designated). The intent of ACI 550.6 is to define the minimum experimental evidence that is deemed sufficient to permit the use of unbonded post-tensioned precast structural wall systems, in accordance with 18.2.1.7 of ACI 318, when those systems do not satisfy fully the prescriptive requirements for wall systems in Chapter 18 of ACI 318.

Before validation testing can be undertaken, ACI 550.6 requires that a design procedure be developed for prototype wall systems having the generic form for which acceptance is sought, and that design procedure is used to proportion the test modules. This standard defines the design procedure for a specific type of wall system that does not satisfy the prescriptive requirements of Chapter 18 of ACI 318, but is validated for use in regions of high seismicity under ACI 550.6. The wall system uses precast concrete panels that are post-tensioned to the foundation and intended to rock on that foundation under seismic actions.

For coupled walls, coupling devices located along the vertical boundaries of adjacent walls provide the required energy dissipation and energy-dissipating reinforcement that crosses the wall-foundation interface is unnecessary. During an earthquake, the coupled walls displace as rigid bodies that are tied together. Wall deformations occur primarily at the interface between each individual wall and the foundation, with each wall rocking separately at that interface.

The unbonded post-tensioning has two purposes. First, the post-tensioning steel is deliberately designed to remain essentially elastic during the design basis earthquake (DBE), defined in ASCE/SEI 7, so that it forces the walls to return to their undeformed positions following the event. Second, the friction induced by the post-tensioning and gravity loading on the wall transfers the horizontal shears due to lateral loadings at the interfaces between the wall and the foundation and between the precast panels of the wall.

The detailing procedures described in this standard are for one specific type of unbonded post-tensioned precast shear wall system, coupled or uncoupled. Four statements define key characteristics of uncoupled and coupled unbonded post-tensioned precast concrete cantilever shear walls that satisfy this standard:

(a) Post-tensioning tendons unbonded from an anchor in the foundation to an anchor at the top of the wall and located in a single duct on the vertical centerline of the wall or, if needed, in two or more ducts positioned symmetrically on either side of that vertical centerline and within 10% of the wall length from that centerline;

(b) Precast panels one story or more in height; and

(c) For uncoupled walls, two sets of energy-dissipating reinforcing bars crossing the interface between the lower-

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most precast panel of the wall and the foundation and with the sets located symmetrically about the vertical centerline of the wall; or

(d) For coupled walls, energy-dissipating coupling devices for a given vertical joint between coupled walls, of equal strength, at least two in number for each coupled edge of a panel in the wall, and positioned so that the width of the vertical joint between panels remains approximately constant in width as the walls rock on their bases.

R1.1

Large-scale laboratory experiments (Bora et al. 2007; Perez et al. 2003; Priestley et al. 1999; Rahman and Restrepo 2000; Santana 2005) have shown that unbonded post-tensioned precast concrete cantilever shear walls can provide safety and serviceability levels, during and after an earthquake, that meet or exceed performance levels required by 18.2.1.7 of ACI 318 and ACI 550.6. Analytical studies (Kurama 2002; Perez et al. 2004a,b; Rahman and Restrepo 2000; Stanton and Nakaki 2002; Thomas and Sritharan 2004; Sritharan et al. 2007) have shown that to achieve such performance levels, the shear walls should be proportioned and detailed in accordance with specific considerations. This standard is developed from the aforementioned studies and related references. This standard contains the minimum requirements for ensuring that one type of unbonded post-tensioned precast concrete cantilever shear wall system, uncoupled or coupled, can sustain a series of oscillations into the inelastic range of response without critical decay in strength or excessive story drifts. Further, that shear wall should show only minimal or no damage to the wall, and minimal or no permanent displacements after the oscillations cease.

In this specific type of coupled or uncoupled wall system, the post-tensioning tendons are unbonded and designed to remain elastic during the DBE. Except at the foundation, the horizontal joints between the precast panels that make up a cantilever wall are designed to remain closed during an earthquake.

For uncoupled walls, vertical reinforcing bars grouted into ducts located in the wall panels abutting the foundation and in the foundation, and described in this standard as energy-dissipating reinforcement, provide energy dissipation as they yield alternately in tension and compression during an earthquake. These bars also provide continuity additional to the post-tensioning between the cantilever wall and the foundation, and additional moment strength for the wall. The grouted bars are deliberately debonded for a specific distance in the panel adjacent to the wall-foundation interface to reduce the high cyclic strains that would otherwise occur at that location. Consequently, during an earthquake, the cantilever wall can displace essentially as a rigid body. Vertical deformations occur primarily at the wall-foundation interface as the wall rocks against the foundation.

Under seismic loading, the special shear walls described in this standard are intended to behave differently than monolithic shear walls. Most of the deformations of the walls occur from the opening and closing of the joint at the interface between the precast walls and the foundation. Consequently, with the detailing procedures described in this standard, damage during a DBE event is limited in extent, confined essentially to the wall to foundation joint filler material or to the concrete cover over the boundary element reinforcement at the wall toes, and can be readily repaired after the earthquake. By contrast, monolithic walls, coupled and uncoupled, designed to Chapter 18 of ACI 318, can suffer significant cracking, crushing, and spalling in the plastic hinging regions at the base of the walls, in the coupling beams, or both, and repair can be costly. Further, monolithic special shear walls designed to Chapter 18 of ACI 318 may show permanent lateral deformations following a DBE event whereas the special shear walls described in this standard should not.

Precast shear walls with the following can be proportioned to have performance characteristics similar to the walls described in this standard:

1. Unbonded tendons that cross the wall-foundation interface at locations along the length of the wall that are more than 10% of the wall length from its vertical centerline; or

2. Uncoupled walls with energy dissipation devices having characteristics differing from those for the energy-dissipating reinforcement described in Section 1.1(c) and positioned differently along the length of the wall; or

3. Coupled walls with coupling elements connecting vertical boundaries of adjacent walls and having characteristics for the coupling elements differing from those for the coupling devices described in Section 1.1(d).

Research investigations additional to those completed to date, and modifications of the procedures described in this standard, however, are needed before prescriptive provisions for the design of such precast shear walls can be formulated.

1.2—Scope

1.2.1 This standard defines design requirements for a certain class of unbonded post-tensioned precast concrete shear walls that can be used as special reinforced concrete shear walls for Bearing Wall and Building Frame Special Reinforced Concrete Shear Wall Systems, as defined in ASCE/SEI 7.

1.2.2 The requirements described in this standard are for special unbonded post-tensioned precast shear walls with:

1. Essentially planar proportions in the vertical direction, no significant discontinuities in plan, in vertical configuration, or in their lateral-force-resisting system, and designed to have a single critical section for flexure and axial loads at the base of the shear wall;

2. Post-tensioning tendons unbonded from anchor to anchor and located in a single duct at the centroid of the transverse cross section of the wall, or in an additional two or more ducts positioned symmetrically on either side of that centroid and within 10% of the shear wall length from that centroid; and

3. Energy dissipation provided: a) for uncoupled walls by energy-dissipating reinforcement that crosses the interface between the base of the wall and the foundation; and b) for coupled walls by coupling devices that connect adjacent vertical boundaries of shear walls, number at least two for

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