White Paper WP004

When to Specify Intermediate Precast Concrete Shear Walls

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Introduction

In regard to precast concrete systems, the addition of two new categories of Seismic Force-Resisting Systems (SFRS) in IBC 2006 has created some confusion about whether to specify intermediate precast concrete structural walls or ordinary precast concrete structural walls in seismic design category (SDC) B. In addition, it has been questioned how intermediate precast concrete structural walls that include openings should be reinforced. This document provides an overview on the history of precast concrete systems used to resist earthquake induced lateral forces and their applicability and requirements throughout the different editions of NEHRP. Also, the following paper summarizes the different requirements of ACI and IBC when intermediate precast walls are specified as part of the SFRS, and provides guidelines on when to specify intermediate precast walls in SDC B.

History

Provisions concerning precast/prestressed concrete Seismic Force-Resisting Systems (SFRS) were first introduced in the provisions of NEHRP 1994 edition. The scope of these provisions was limited to precast concrete frames and walls. The design of precast frames was based on an emulative approach by using ductile connections or strong connections. It wasn't until the 1997 edition of the NEHRP provisions that precast/prestressed construction was allowed to be used as part of the SFRS. However, penalties were imposed when these systems were used (S.K. Ghosh, 2000) [1]. In this edition of NEHRP along with the editions of ASCE 7-98 and IBC 2000, a distinction in the classification of concrete shear walls was introduced. Prior to these editions, concrete shear walls were defined only as reinforced concrete shear walls. The provisions of NEHRP 1997, ASCE 7-98, and IBC 2000 distinguished between ordinary reinforced concrete shear walls and special reinforced shear walls. These also included appropriate requirements for precast concrete shear walls that are based soley on amendments to ACI 318.

ACI 318 Provisions

ACI 318-02 was the first code to recognize three categories of structural walls (shear walls), (1) Ordinary Structural Walls (Cast-in-Place or Precast), (2) Intermediate Structural Walls (Precast only), and (3) Special Structural Walls (Cast-in-Place or Precast). However, the seismic design coefficients (R, Ω and C_d) for intermediate precast concrete shear walls did not exist in the editions of IBC 2003, ASCE 7-02, or NEHRP 2000. IBC 2006 was the first code to assign seismic design coefficients to structural precast wall systems, including systems with intermediate shear walls (S. K. Ghosh, 2004) [2].

In IBC 2003, the seismic design coefficients depend only on whether or not ordinary or special shear walls are used. It doesn't matter if the ordinary or special shear wall is cast-in-place or precast. However, ordinary shear walls constructed using precast concrete elements that are to be used in SDC "C" shall conform with the additional requirement of ACI 318-02, Section 21.13 for intermediate precast concrete structural wall (ductile connections).

NEHRP 2003, ASCE 7-05, IBC 2006 provisions

NEHRP 2003, ASCE 7-05, and IBC 2006 provisions have created additional rows in the table of seismic design coefficients, under bearing wall systems and building frame systems, for ordinary precast shear walls and intermediate precast shear walls. It is assumed that an intermediate precast concrete shear wall would have the same ductility and energy dissipations as an ordinary cast in place shear wall. Therefore, the same seismic response coefficient, R, given to an ordinary cast in place shear wall will be assigned to an intermediate precast concrete shear wall. Although, in the case of special precast shear walls, precast and cast in place structural walls are grouped together. Special precast shear walls must meet the detailing requirements for cast-in-place walls, in addition to the ductile detailing requirements applied to Intermediate Precast Concrete Shear Walls. This may include boundary elements with special confinement reinforcement at close spacing that prevents the buckling of the main flexural reinforcing after yielding under cyclic loading. For special structural walls, only those that meet the ACI 318 Chapter 21 and ACI ATG-5.1 requirements have R coefficients.

IBC 2006 amendments to ACI 318-05 for intermediate precast shear walls with openings (shear reinforcement)

Precast structural walls (shear walls) that are assigned a seismic response coefficient, (R), to that of an intermediate precast concrete structural wall, shall be reinforced according to chapters 1 through 18 of ACI 318 in addition to Section 21.13, and the amendments in IBC 2006, section 1908.1.13. Reinforcement detailing for intermediate structural walls with openings is not addressed in ACI 318. However, IBC 2006 amends ACI 318-05 Section 21.13 by adding new Sections 21.13.5 and 21.13.6. To summarize, wall piers that are not considered part of a moment frame, that is, a wall segment that has a clear height of at least two times its horizontal height and a horizontal length (l_{ws}) to thickness (t) ratio of at least 2.5 but no more than 6, shall have transverse reinforcement designed in accordance with Section 21.12.3. The transverse reinforcement spacing (S_{max}) shall not exceed 8 in. and must extend 12 in. above and below the opening (refer to the Figure 1). On the other hand, if the wall segments lws/t is less than 2.5, it must meet the requirements for columns of intermediate frames (Section 21.12.5). If the wall segments lws/t is more than 6, it is then designed as a wall (chapters 1-18).

The provisions described above are not required for wall piers that are designed in accordance with the provisions of Section 21.11 (Members not designed as part of the SFRS).

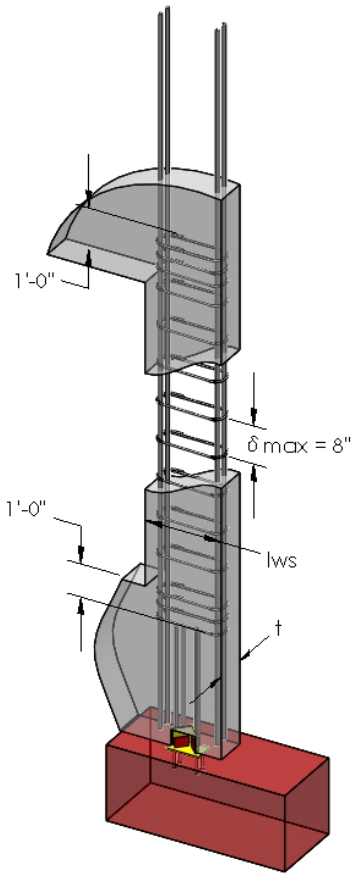


Figure 1

Connections for intermediate and special precast concrete lateral resisting systems

Emulative detailing is defined as the design of connection systems in a precast concrete structure so that its structural performance is equivalent to that of a conventionally designed, cast-in-place, monolithic concrete structure (Ericson and Warnes 1990) [8].

Emulative detailing is distinct from jointed detailing, where precast elements are connected with special jointing details, such as welded or bolted plates, in that the bending stiffness of the connections differs from that of the members, ACI 550.1R-09 (Guide to Emulating Cast in Place Detailing for Seismic Design of Precast Concrete Structures). The purpose of this guide is to provide an overview of emulation and emulative detailing to meet the requirements in current codes. In addition, ACI 550 provides a variety of emulative details and their use.

Connections between precast shear walls, and between precast shear walls and the foundation, must meet the criteria specified in ACI 318-05 section 21.13. Most ductile connections are designed to use some form of reinforcement splicing (Figure 2). According to ACI 318, Type 2 mechanical splices need to develop the specified tensile strength of the reinforcing bar. This translates to 150% of the specified yield strength. Most mechanical splicing devices are recognized by a model code through an evaluation service, and may have formal conditions for acceptance in a structure. *ACI 439.3R (Types of Mechanical Splices for Reinforcing Bars)* provides a guide to the types of mechanical splices available, their applications, and whether they are suitable as type 1 or 2 connections as defined in ACI 318.

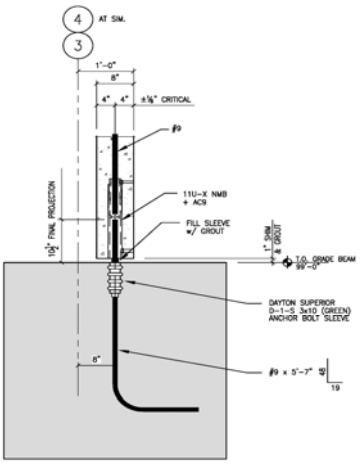
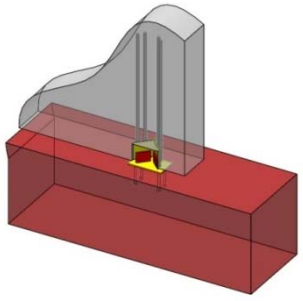


Figure 2

For connections that incorporate loose plates and concrete embeds with headed concrete anchors (HCA), Figure 3, all parts of the connection that are not designed to yield (i.e. weld between plates and anchoring to concrete), must be designed for 150% of the specified yield strength of the reinforcing bar. In addition, the design strength of anchors must meet the requirements of ACI 318, section D.3.3 for SDC C-F



According to ASCE 7-05, Connections that are designed to yield, shall be capable of maintaining 80% of their design strength at the deformation induced by design displacement, or shall use type 2 mechanical splices.

ACI 318-08, Seismic Provisions for Precast Structural Walls

The seismic provisions for concrete Earthquake-Resistant Structures, ACI 318, Chapter 21, were completely restructured and renumbered to the required seismic provisions in order of increasing SDC. Requirements for intermediate precast concrete structural walls are defined now in section 21.4 and section 21.10 for special precast concrete structural walls. According to ACI 318, intermediate precast concrete structural walls need to meet the requirements of sections 1 through 18 of ACI 318-08, in addition to section 21.4, while special precast shear walls need to meet the requirement of section 21.9, in addition to sections 21.4.2 and 21.4.3.

New in NEHRP 2009

NEHRP 2009 adopts ASCE 7-05 by reference. There are only modifications to ASCE 7-05 sections in the main body of NEHRP 2009. With regard to intermediate precast structural walls, the provisions from NEHRP 2003, ASCE 7-05, and IBC 2006, remained the same with the exception that "*where intermediate precast structural walls are used in SDCs D, E, and F, wall piers should satisfy the requirements of ASCE/SEI 7-05 Section 14.2.2.9 rather than 14.2.2.14." (Commentary to Chapter 14, section C14.2.2.14).*

Wall Piers and Wall Segments

A wall pier is recognized as a separate category of structural element in this document but not in ACI 318 (NEHRP 2009) [9].

Wall piers are typically segments between openings in walls that are slender in the direction normal to the horizontal length of the wall. In current practice, these elements are often not regarded as columns or as part of the structural walls. Wall segments with a horizontal length-to-thickness ratio of less than 2.5 are required to be designed as columns in compliance with Section 21.3 or 21.6 if they are utilized as part of the lateral-force-resisting system, even though the shortest cross-sectional dimension may be less than 12 in., in violation of Section 21.6.1.1. Such wall segments may be designed to comply with Section 21.13 if they are not utilized as part of the lateral-force-resisting system. Wall segments with a horizontal length-to-thickness ratio larger than or equal to 6, must be designed as structural walls in full compliance with Section 21.4, 21.9 and 21.10.

Summary:

Detailing of Precast Concrete Shear Walls (i.e. walls that are part of the seismic-force-resisting system) regardless of the Seismic Design Category.

System	Wall Segment	NEHRP 2009	IBC 2009	ASCE 7-05	ACI 318-08
Ordinary Precast Shear Walls	Wall (L/t >6)	**Section 14.2.2.1 (ACI 318, 1-18)**	**Section 1908.1.1 (ACI 318, 1-18)**	**Section 14.2.2.4 (ACI 318, 1-18)**	**CH. 1-18**
	Pier (6 ≤ L/t ≤ 2.5)	**N/A**	**N/A**	**N/A**	**CH. 1-18**
	Column (L/t < 2.5)	**N/A**	**N/A**	**N/A**	**CH. 1-18**
Intermediate Precast Shear Walls	Wall (L/t >6)	**Section 14.2.2.1 (ACI 318, 21.4)**	**Section 1908.1.2 (ACI 318, 21.4)**	**Section 14.2.2.14 (ACI 318, 21.4)**	**CH. 1-18 & 21.4**
	Pier (6 ≤ L/t ≤ 2.5)	**Section 14.2.2.4 (Transverse Reinf.) For SDC D, E and F use Section 14.2.2.5**	**Section 1908.1.3 (Transverse Reinf.)**	**Section 14.2.2.14 (Transverse Reinf.)**	**N/A**
	Column (L/t < 2.5)	**Section 14.2.2.4 (ACI 318, 21.3) For SDC D, E and F use Section 14.2.2.5**	**Section 1908.1.3 (ACI 318, 21.3)**	**Section 14.2.2.14 (ACI 318, 21.3)**	**N/A**
Special Precast Shear Walls	Wall (L/t >6)	**Section 14.2.2.1 (ACI 318, 21.10)**	**Section 1908.1.2 (ACI 318, 21.10)**	**Section 14.2.2.9 (ACI 318, 21.10)**	**CH. 21.10**
	Pier (6 ≤ L/t ≤ 2.5)	**Section 14.2.2.5 (Transverse Reinf.)**	**Section1908.1.4 (Transverse Reinf.)**	**Section 14.2.2.9 (Transverse Reinf.)**	**N/A**
	Column (L/t < 2.5)	**Section 14.2.2.5 (ACI 318, 21.6)**	**Section1908.1.4 (ACI 318, 21.6)**	**Section14.2.2.9 (ACI 318, 21.6)**	**N/A**

Conclusions

Ordinary and intermediate precast structural walls are permitted to be used in SDC B without height limits. By specifying an intermediate precast structural wall in SDC B, the base shear is reduced compared to the base shear calculated using an ordinary precast structural wall. This is due to the inherent ductility and energy dissipation that are characteristic of intermediate shear walls, and are reflected by the value of the seismic response coefficient, R. The seismic response modification coefficient R, for ordinary precast walls, is 3 for bearing wall systems and 4 for building frame systems, compared to 4 and 5 for intermediate precast panels used in bearing wall systems and building wall systems respectively. This difference in *R*-values, when detailing an ordinary precast shear wall versus an intermediate shear wall, may substantially impact the cost of shear reinforcement (i.e. if $V_u > \phi V_c$, due to a larger base shear, shear reinforcement needs to be designed in accordance with section 11.10.09 "*Design of shear reinforcement for walls*") and the cost of connections between panels and the foundation for structures assigned to SDC B. However, if the building is low rise with a large number and size of openings, the reinforcement around the openings, as required by IBC, may offset the savings. Therefore, a cost analysis is required while deciding when to use intermediate precast shear walls in SDC B. Please note, that for structures assigned to SDC A, the base shear is calculated using section 11.7.2 of ASCE 7-05 in which the R coefficient is not relevant. However, for structures assigned to SDC C through F, ordinary precast shear walls are not permitted.

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