

ACI 550.4M-18

An ACI Standard

Qualification of Precast Concrete Diaphragm Connections and Reinforcement at Joints for Earthquake Loading (ACI 550.4M-18) and Commentary (ACI 550.4RM-18)

Reported by Joint ACI-ASCE Committee 550



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Special thanks to S. K. Ghosh and S. Nakaki for their contributions to this standard.

ACI 550.4M prescribes testing and evaluation requirements for mechanical connections and reinforcement at joints intended for use under the design provisions of [ASCE/SEI 7](#) and [ACI 318M](#) for precast concrete diaphragms subject to earthquake loading. These mechanical connections and reinforcement at joints transfer the vertical and in-plane forces between the precast concrete members that comprise the diaphragm, and between the diaphragm and vertical elements of the seismic-force-resisting system of the structure. The response of precast concrete diaphragms under earthquake loading depends not only on the strength of the connections and the reinforcement at joints, but also on their stiffness and

deformation capacities. The seismic forces specified in [ASCE/SEI 7](#) for the design of precast concrete diaphragms, including chords and collectors, in structures assigned to Seismic Design Category (SDC) C, D, E, or F are tied to the shear overstrength provided by the connections and the reinforcement at joints. This overstrength depends, in turn, on the design methodology, elastic or ductile, used for the diaphragm. ACI 550.4M prescribes the experimental procedures needed to assess the stiffness, strength, and deformation capacity of mechanical connections and reinforcement at joints for diaphragm flange-to-flange connections, including chord connections, of double-tee (DT) beams for earthquake loadings and evaluation procedures to categorize connection performance for use with the design procedures specified for precast concrete diaphragms in [ASCE/SEI 7](#) and [ACI 550.5M](#). ACI 550.4M does not prescribe experimental procedures for assessing the same information for connections for hollow-core members used in the untopped condition.

Keywords: connection category; diaphragm connections; precast concrete; qualification criteria; seismic design; test method..

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CHAPTER 1—GENERAL

1.1—Introduction

ACI 550.4M specifies the minimum experimental evidence that shall be provided by tests on individual connections and defines the minimum information required for the design of double-tee (DT) precast concrete diaphragms satisfying the lateral load performance requirements of Chapter 18 of ACI 318M-14.

Consistent with ACI 318M requirements for analysis, ACI 550.4M specifies that prior to the testing of individual connectors, a design procedure shall have been developed for precast concrete DT diaphragms having the generic form for which acceptance is sought, and that design procedure used to proportion the connections used in the testing required by ACI 550.4M. One such design procedure has evolved from research and is specified in ACI 550.5M-18. These procedures supplement the provisions of Chapter 18 of ACI 318M-14 and do not supplant them. The procedure is applicable only to the lateral load design of precast concrete DT diaphragms using connection performance characteristics determined using ACI 550.4M.

COMMENTARY

R1—GENERAL

R1.1—Introduction

For structures assigned to high Seismic Design Categories (SDCs), Chapter 18 of ACI 318M-14 permits the use of structural systems that do not meet the prescriptive requirements of the chapter if certain experimental evidence and analytical results are provided. Precast concrete double-tee (DT) members are extensively used in the construction of floor and roof diaphragms. Gravity load design requirements for diaphragms of precast concrete construction are covered by the general provisions of ACI 318M. However, unless a diaphragm of precast concrete construction is provided with a topping that meets all the prescriptive requirements for diaphragms in that chapter, the precast concrete diaphragm cannot be designed directly using Chapter 18 of ACI 318M-14. In precast concrete DT diaphragms without a topping, structural integrity and force transfer within the diaphragm are provided by the discrete web and chord connections or reinforcement that join the individual precast concrete members. If a precast concrete DT diaphragm without a topping is to provide a structural system with a lateral load performance equal to or exceeding that of a comparable cast-in-place diaphragm, accurate knowledge of the strength, stiffness, and deformability of the individual connections used in the diaphragm needs to be available.

Precast concrete floor diaphragms are extensively used for parking structures and residential and commercial buildings. Those diaphragms frequently consist of precast concrete members connected to one another through discrete embedded mechanical connectors or reinforcement at joints. Industry practice has been to use those diaphragms in an untopped condition in buildings assigned to SDC C or lower SDCs and with topping in buildings assigned to SDC D or higher SDCs. Where topped diaphragms with a topping thickness of 75 mm or less are subjected to significant earthquake loading, the topping is likely to crack along the edges of the precast member. Once cracking occurs, unless large amounts of reinforcement are continuous across the member edges, the topped diaphragm behaves similarly to a diaphragm composed of untopped precast concrete members.

Where mechanical connections are used to join the precast concrete members forming a diaphragm, the effects of all vertical and in-plane shear forces acting between members on these connections should be considered. Under earthquake loadings, the connections are subject to combinations of in-plane shear and tensile or compressive forces, the values of which depend on the magnitude of the earthquake motions and the response of the structure to those motions.

Post-earthquake reconnaissance following the 1994 Northridge earthquake (Iverson and Hawkins 1994) revealed that precast concrete diaphragms with toppings having thickness less than 75 mm or limited amounts of reinforcement were susceptible to damage, and that the degree of susceptibility increased as the aspect ratio for the diaphragm increased as the span length of the diaphragm between lateral force-

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COMMENTARY

resisting vertical elements increased. In Fig. R4.1a(a), the span length of the diaphragm is the distance between the structural walls. Those observations resulted in a comprehensive research study to develop better design models for precast concrete diaphragms and comprehensive studies of the strength and deformation capacity of diaphragm connections. In the improved design methodology ([Fleischman 2014](#)) and the [ASCE/SEI 7-16](#) provisions resulting from that research, the choice of connection type is tied to the tension deformation and shear overstrength needed in the diaphragm to achieve the required design performance. Where connections with limited deformation capacity are used, the earthquake design forces need to be higher than for ductile connections. The choice of the appropriate factors that should be used in diaphragm design requires detailed knowledge of the strength and deformation capacities of the diaphragm connections for the differing combinations of forces and deformations acting on the connections.

To ensure that requirements of the performance-based diaphragm design methodology are satisfied, a consistent experimental procedure is needed to define the strength and deformation capacities of connections and reinforcement at joints. ACI 550.4M defines a consensus experimental approach for assessing the stiffness, strength, and deformation capacity of an embedded connector or reinforcement at joints. ACI 550.4M also defines the procedures that should be followed to categorize the deformation performance and strength factors that can be associated with a given connection or reinforcement at joints where this reinforcement resists seismic forces and where the reinforcement does not conform to [ASTM A615/A615M](#) or [ASTM A706/A706M](#) or deformed wires or welded wire reinforcement that do not conform to [ASTM A1064/A1064M](#).

Hollow-core (HC) members are frequently used for diaphragms. However, the research completed to date is inadequate to fully define a design methodology, such as [ACI 550.5M](#) for DT members, for the use of HC diaphragms, as now constructed, in untopped conditions in structures assigned to SDC C, D, E, or F. However, if in the future, HC members are manufactured using a method that permits the embedment of discrete connectors, such diaphragms may use this protocol for any SDC.

1.2—Scope

1.2.1 ACI 550.4M defines the minimum testing requirements and the acceptance criteria for different performance levels for connections or reinforcement at joints where used to connect precast concrete DT members subject to earthquake loading. Extrapolation of qualification results for connections and reinforcement at joints obtained using ACI 550.4M is not permitted. Project details shall match details qualified using ACI 550.4M.

1.2.2 Test modules containing discrete connections or reinforcement at joints, tested in accordance with ACI 550.4M, establish dependable and predictable load-defor-

R1.2—Scope

For the connections described in ACI 550.4M, the detailing of the connectors or reinforcement at joints, any confining reinforcement specified for the proper performance of the connectors, and the manner in which the connection between members is completed, should be the same as that specified on structural drawings.

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mation responses for those connections or that reinforcement at joints, and can be used to determine the relative deformability category of the connection or reinforcement at joints detailed in accordance with the classification criteria of **Chapter 7**.

1.3—Structural drawings

Structural drawings for the test modules shall show all features of the members into which the connectors or reinforcement at joints are cast and all details of the connectors or reinforcement at joints essential for accurate representation of the likely performance of the connectors, the reinforcement at joints, and the connection.

Essential details include:

- a) The anchorage of the connector or reinforcement at joints into the test panel
- b) The procedures and materials by which the connection between connectors, or reinforcement at joints, in adjacent panels of the module shall be made
- c) Confining reinforcement specified as necessary for the proper performance of the connectors or reinforcement at joints
- d) Supplemental reinforcement that shall be included in the test panels to ensure that the performance of the member during the testing does not materially affect the measured response of the connections or reinforcement at joints

1.4—Units

The official version of this standard is in the English language using inch-pound units published by the American Concrete Institute.

COMMENTARY**R1.3—Structural drawings**

Reinforcement details in the vicinity of the connectors or reinforcement at joints and the means and procedures by which the connection between the precast concrete members is completed affect the performance of the connection. Details for connectors should be specified completely, including specified tolerances, alignment requirements, and any confining reinforcement requirements, and should be fully documented on the structural drawings for the test modules. Details for reinforcement at joints should include reinforcement requirements, minimum and maximum yield and strength values, and ultimate strain values. The material specifications for the concrete should also be shown.

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COMMENTARY

CHAPTER 2—NOTATION AND DEFINITIONS

R2—NOTATION AND DEFINITIONS

2.1—Notation

K_e	= initial elastic stiffness from multi-segment backbone qualification curve, kN/mm
P_1, P_1', P_2	= forces corresponding to Points 1, 1', and 2, respectively
T_{max}	= maximum tension force from tension force transfer test, kN
V_{max}	= maximum shear force measured in shear force transfer test, kN
Δ_{sy}	= yield displacement from shear force transfer test, mm
Δ_{ty}	= yield displacement from tension force transfer test, mm
$\Delta_1, \Delta_2, \Delta_3$	= displacements corresponding to Points 1, 2, and 3, respectively

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, ACI Concrete Terminology. Definitions provided herein complement that resource.

connection—region where two adjacent precast concrete members are joined mechanically, including the bars, weld metal, or mechanical device that joins the connectors or reinforcement embedded in the precast concrete members.

connector—fabricated part embedded in concrete for anchorage and intended to complete a load path across a precast concrete joint.

maximum considered earthquake (MCE_R)—most severe earthquake considered by ASCE/SEI 7-16 Standard; procedures for determining MCE_R ground motion values are provided in Section 11.4.3 of ASCE/SEI 7-16.

R2.2—Definitions

connection—in precast concrete members, an assembly of connectors or reinforcement at joints with linking parts, welds, and anchorage to concrete.

connector—a mechanical device, including any attached reinforcement, embedded in the precast concrete member and used to connect adjacent precast concrete members.