ACI 421.2R-10

Guide to Seismic Design of Punching Shear Reinforcement in Flat Plates

Reported by Joint ACI-ASCE Committee 421

American Concrete Institute®

First Printing
April 2010

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The committee would like to thank Frieder Seible for his contribution to this guide.

During an earthquake, the unbalanced moments transferred at flat plate-column connections can produce significant shear stresses that increase the vulnerability of these connections to brittle punching shear failure. This guide provides recommendations for designing flat plate-column connections with sufficient ductility to withstand lateral drift without punching shear failure or loss of moment transfer capacity. This guide treats reinforced concrete flat plates with or without post-tensioning.

Keywords: ductility; flat plate; post-tensioning; punching shear; seismic design; shear reinforcement; stud shear reinforcement.

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ACI 421.2R-10 supersedes ACI 421.2R-07 and was adopted and published April 2010.

CHAPTER 1—INTRODUCTION

1.1—General

Brittle punching failure can occur due to the transfer of shear forces combined with unbalanced moments between slabs and columns. During an earthquake, significant horizontal displacement of a flat plate-column connection may occur, resulting in unbalanced moments that induce additional slab shear stresses. As a result, some flat plate structures have collapsed by punching shear in past earthquakes (Berg and Stratta 1964; Yanev et al. 1991; Mitchell et al. 1990, 1995). During the 1985 Mexico earthquake (Yanev et al. 1991), 91 waffle-slab and solid-slab buildings collapsed, and another 44 buildings suffered severe damage. Hueste and Wight (1999) studied a building with a post-tensioned flat plate that experienced punching shear failures during the 1994 Northridge, CA, earthquake. Their study provided a relationship between the level of gravity load and the maximum story drift ratio that a flat plate-column connection can undergo without punching shear failure. The displacement-induced unbalanced moments and resulting shear forces at flat plate-column connections, although unintended, should be designed to prevent brittle punching shear failure. Even when an independent lateral-force-resisting system is provided, flat plate-column connections should be designed to accommodate the moments and shear forces associated with the displacements during earthquakes.

1.2—Scope

In seismic design, the displacement-induced unbalanced moment and the accompanying shear forces at flat plate-column connections should be accounted for. This demand may be effectively addressed by changes in dimensions of certain members, or their material strengths (for example, shear walls and column sizes), or provision of shear reinforcement or a combination thereof. This guide does not address changes in dimensions and materials of such members, but focuses solely on the punching shear design of flat plates with or without shear reinforcement.

This guide, supplemental to ACI 421.1R, focuses on the design of flat plate-column connections with or without shear reinforcement that are subject to earthquake-induced displacement; reinforced concrete flat plates with or without post-tensioning are treated in the guide. Slab shear reinforcement can be structural steel sections, known as shearheads, or vertical rods. Although permitted in ACI 318, shearheads are not commonly used in flat plates. Stirrups and shear stud reinforcement (SSR), satisfying ASTM A1044/A1044M, are the most common types of shear reinforcement for flat plates. Shear stud reinforcement is composed of vertical rods anchored mechanically near the bottom and top surfaces of the slab. Forged heads or welded plates can be used as the anchorage of SSR; the area of the head or the plate is sufficient to develop the yield strength of the stud, with negligible slip at the anchorage. The design procedure recommended in this guide was developed based on numerical studies (finite element method) and experimental research on reinforced concrete slabs subjected to cyclic drift reversals that simulate seismic effects. The finite element analyses, supplemental to