IN-LB	Inch-Pound Units
SI	International System of Units

Seismic Design of Punching Shear Reinforcement in Flat Plates—Guide

Reported by Joint ACI-ASCE Committee 421

ACI PRC-421.2-21

American Concrete Institute
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First Printing
August 2021
ISBN: 978-1-64195-152-4

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

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

CONTENTS

ACI PRC-421.2-21 supersedes ACI 421.2R-07 and was adopted and published August 2021.

CHAPTER 1—INTRODUCTION AND SCOPE

1.1—General

Brittle punching failure can occur due to the transfer of shear forces combined with moments between slabs and columns. During an earthquake, significant horizontal displacement of a flat plate-column connection may occur, resulting in moments inducing shear stresses, as evidenced by the collapse of flat plate structures due to punching shear failures 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. 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

Seismic design should account for the displacement-induced moment and the accompanying shear forces at flat plate-column connections. This demand may be effectively addressed by changes in dimensions of certain members (for example, shear walls and column sizes), their material strengths, 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 is supplemental to ACI 421.1R and 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 also discussed in this guide. Stirrups and headed shear stud reinforcement (HSSR) satisfying ASTM A1044/A1044M are the common types of shear reinforcement for flat plates. Shear stud reinforcement is composed of vertical or inclined rods anchored mechanically near the bottom and top surfaces of the slab. Forged heads or welded plates can be used as the anchorage of HSSR; 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 (Megally 1998). The finite element analyses, supplemental to the experimental research, used software, constitutive relations, and models that were subject to extensive verifications by comparing the results of the analyses with the behavior observed in tests (Megally and Ghali 2000b).

ACI 318 requires that structural integrity reinforcement be provided near the bottom of the slab extending through the columns. The code requirements in ACI 318-14 are addressed (refer to Eq. (4b)). This guide supplements ACI 352.1R and ACI 421.1R, which, respectively, include recommendations such as extending a minimum amount of integrity reinforcement through the column core and providing details of design for shear reinforcement in flat plates. For post-tensioned slabs, the integrity tendons can be in the top of the slab as they approach the column, in which