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Effect of openings and shear bolt pattern in seismic retrofit of reinforced concrete slab–column connections

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ABSTRACT

This study addresses seismic retrofit of reinforced concrete flat slab–column connections against punching shear failure. The tested slabs are retrofitted using shear bolts. These bolts were developed for installation in existing slabs by drilling holes around columns or concentrated load application points and then tightening against the slab surfaces. Slabs with and without openings are investigated. The effect of the pattern of shear reinforcing elements around the column area, namely orthogonal and radial is also investigated. This paper describes tests on six flat slab–column specimens; three with two openings at the column and three without openings. Among each of the three specimens in a group, one has no shear reinforcement; one is retrofitted in the orthogonal pattern; and one in the radial pattern. The test results, comparisons of the behavior of the specimens, and comparisons with the current code formulas are presented and discussed. The results indicate that shear bolts increase lateral drift capacity and ductility of the slab–column connections.

1. Introduction

Reinforced concrete flat slab–column structural systems are economical and easy to construct. However, especially when used in seismic zones, they can be susceptible to a brittle punching shear failure. Flat slabs supported on columns are usually constructed together with additional lateral load supporting system, but they still need to be able to sustain seismic lateral movements without abrupt, local failures.

Many of the flat reinforced concrete slabs, especially the older ones, were constructed without any shear reinforcement. Their punching shear capacity depends on concrete strength only. Although concrete might be able to provide adequate shear strength, it will not provide ductility at large deformations. Under seismic loads slabs are subject to large imposed deformations, which cause cracking, and thus weaken the concrete shear strength, and therefore can result in punching failure. One way to avoid such failure is to retrofit the original unreinforced slabs using externally inserted shear bolts.

Shear bolts, a punching shear strengthening method for concrete flat slabs were developed at the University of Waterloo [1–3] (Fig. 1), where they were proven effective under both static and reversed cyclic lateral loads. They increase punching shear capacity and ductility of existing slab–column connections in a similar way as normal, properly anchored shear reinforcement does in newly constructed slabs. Shear bolts are installed in existing slabs in the column area. Small holes are drilled through the slab thickness first. Then the bolts are inserted through the holes and tightened against the slab surfaces. The process is straightforward and no prestressing is needed.

In practical situations, it is often necessary to create openings in slabs to allow electrical, water or air conditioning ducts to go through floors. These openings, located next to columns for practical and aesthetic reasons, reduce the punching shear capacity of the connection. Strengthening a slab with openings with shear bolts is one way of preventing punching failure. This has been shown in previous research on slabs with openings under static loads, [2,3].

The focus of research presented herein is the understanding of the behavior of retrofitted flat concrete slabs with and without openings next to columns, under gravity and reversed cyclic horizontal loads. Current codes of practice, e.g., [4–7], consider different shear reinforcement patterns. The two most popular patterns, orthogonal and radial, are investigated in this work. This study is part of the larger testing research program, which examines the behavior of slabs with and without openings and with and without shear bolts [8,1]. Six tests described in this paper address the following parameters: openings next to the column,

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