Strengthening and Retrofitting of RC Flat Slabs to Mitigate Progressive Collapse by Externally Bonded CFRP Laminates

Kai Qian, A.M.ASCE¹; and Bing Li²

Abstract: Previous studies indicated that RC flat slabs, especially without drop panels, are of high vulnerability to progressive collapse because no beams could assist in redistributing the axial force previously carried by the lost columns. In order to reduce the likelihood of progressive collapse, necessary strengthening schemes should be applied. Six specimens of similar dimensions and reinforcement details were prepared, two of which were un strengthened and served as control specimens, while the remaining four were strengthened with two different schemes: orthogonally (Scheme 1) or diagonally (Scheme 2) bonded carbon-fiber-reinforced polymer (CFRP) laminates on the top surface of the slab. The progressive collapse performance of the strengthened specimens was studied in terms of their load-displacement relationships, first peak strength, initial stiffness, and energy dissipation capacities. The dynamic ultimate strength and corresponding dynamic effects of flat slabs after the sudden removal of a corner column was also discussed due to the dynamic nature of progressive collapse. Test results indicated that both schemes were effective in improving the performance of RC flat slabs in resisting progressive collapse. DOI: 10.1061/(ASCE)CC.1943-5614.0000352. © 2013 American Society of Civil Engineers.

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Introduction and Background

Progressive collapse is a situation in which a local failure causes a chain reaction spreading throughout the entire structure culminating in a catastrophic collapse. In general, progressive collapse is characterized by a disproportion in size between the triggering event and the resulting collapse (Ellingwood 2006; Bao and Li 2010; Li et al. 2011). Examples of such structural collapses in the last decades include the Ronan Point apartment building in London, which partially collapsed in 1968 due to a gas explosion, and the Murrah Federal Building in Oklahoma City, which was destroyed in 1995 following an explosion of a bomb truck. Due to the catastrophic consequences, progressive collapse has gained increasing interest in the civil engineering research community, especially in terms of the development of design guidelines. Recently, several design guidelines [U.S. General Service Administration (GSA) 2003; U.S. Department of Defense (DoD) 2009] have proposed step-by-step procedures to evaluate the vulnerability of structures to progressive collapse. However, the current design guidelines require refinements through further experimental and analytical studies. For this purpose, a number of experimental tests (Yi et al. 2008; Orton et al. 2009; Su et al. 2009; Yap and Li 2011; Qian and Li 2012a, b, 2013b) were conducted recently. Although the experimental tests significantly improved the understanding of the performance of RC frames in resisting progressive collapse, only beam-column subassemblages or beam-column-slab structures were tested. Flat slabs have a higher likelihood of progressive collapse compared to the beam-column-slab structures because there are no beams that could assist in redistributing the load previously carried by the lost columns. Thus, Qian and Li (2013a) tested six one-third-scaled flat slab substructures at Nanyang Technological University (NTU), Singapore, to investigate the drop panel effects on the performance of RC flat slabs in resisting progressive collapse. The test results indicated that flat slabs, especially those without drop panels (flat plate structures), were highly vulnerable to progressive collapse. Thus, in order to reduce the likelihood of progressive collapse for such specimens, necessary strengthening schemes had to be applied.

In recent years, repairs and strengthening of existing structures have been among the most important challenges in civil engineering. Steel plates have been used in many countries for flexural strengthening of concrete beams for several years (MacDonald and Calder 1982; Zhang et al. 2001). The main disadvantage of using steel plates is corrosion, which adversely affects the bond at the steel-concrete interface. Fiber-reinforced polymers (FRPs) have been frequently used in recent decades because FRPs are not prone to electrochemical corrosion like steel. Moreover, they can be formed, fabricated, and bonded easier than steel plates. The mechanical properties of FRPs vary with the type and orientation of the reinforcing fibers. Thus, the fibers can be placed in any orientation to maximize the strength in a desired direction. In this study, unidirectional carbon-fiber-reinforced polymer (CFRP) is used to strengthen the flat slabs in resisting progressive collapse due to the previous advantages.

In order to investigate the performance of the strengthened flat slabs in resisting progressive collapse and study the effectiveness of...