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

# Integrity and Collapse Resistance of Structural Concrete Floor Systems—Report

Reported by ACI Committee 377

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*This report provides a summary of the present understanding of collapse-resisting mechanisms of reinforced concrete and post-tensioned flat plates, flat slabs, slabs with beams, joist floor systems, and precast floor systems following initial local failures.*

**Keywords:** beam growth; catenary action; collapse resistance; collapse-resisting mechanisms; column removal; compressive membrane action; emulative connection; flat plate; flat slab; floor systems; joist floor; post-punching capacity; post-tensioned; precast; punching; structural integrity.

## CONTENTS

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# CHAPTER 1—INTRODUCTION AND SCOPE

## 1.1—Introduction

Progressive or disproportionate collapse of structures happens with low probability but may cause large-scale—relative to the extent of the initial damage—structural failure. The following are some notable collapse examples that occurred previously in different types of reinforced concrete (RC) buildings during different abnormal events:

*Ronan Point building in the United Kingdom in 1968*—This 22-story precast concrete wall panel building suffered collapse when the partial collapse of one floor due to an accidental explosion propagated down to the rest of the floors.

*Alfred P. Murrah Building in Oklahoma City, OK, in 1995*—The explosion of a truck bomb destroyed an exterior column supporting a transfer girder and the blast may have also destroyed two adjacent exterior columns (Corley 2004). The loss of these columns led to the collapse of nearly half the RC frame building and 168 deaths.

*A flat-plate office building in Jackson, MI, in 1956*—The collapse occurred when concrete placement on the fourth floor resulted in punching failures at the second floor (Feld 1964).

*A flat-plate structure in Boston, MA, in 1971*—The punching failure of a slab-column connection at the roof level propagated all the way to the ground level, resulting in the collapse of two-thirds of the building. Construction overload, poor material properties in cold weather, and inappropriate positioning of slab top reinforcement precipitated this failure (King and Delatte 2004).

*L'Ambiance Plaza in Bridgeport, CT, in 1987*—The 16-story building collapsed during construction. The lift-slab method was used for construction with the floors supported by steel columns. Several potential causes of the collapse were identified, but the triggering collapse mechanism was never established (Martin and Delatte 2000). However, the anomalous design details of the slab unbonded post-tensioning tendons was considered a major factor in the propagation of the collapse after it had begun (Poston et al. 1991).

The aforementioned incidents indicate that, even though collapse takes place with low frequency, disproportionate structural collapse may cause severe consequences. Given that collapse is defined as loss of vertical-load-carrying capacity of structure, floor systems are critically important in providing structural integrity and redistributing gravity loads away from failing components. Once collapse is initiated, often due to column loss, the remaining structural system should be capable of resisting the progression of the collapse. The way in which the floor system redistributes the loads varies with the type of collapse initiation and the type of floor system. Current integrity provisions are intended to aid in redistributing gravity load after an initial failure.

This report is meant to assist engineers and practitioners in addressing an increasing desire by clients demanding designs beyond the integrity requirements in ACI 318.

## 1.2—Scope

The report seeks to summarize our present understanding of collapse initiations, collapse-resisting mechanisms, collapse-resisting strengths of floor systems, and to discuss the role of current integrity provisions in providing resistance to collapse.

This report is designed to be used by engineers, practitioners, and researchers. It will be used to improve understanding of how concrete floor systems redistribute gravity loads following the onset of initial failure. This report can also be used by educators to describe the mechanics of collapse resistance and direct them to the applicable code provisions currently in place.

Each chapter details possible causes of collapse initiation, collapse-resisting mechanisms, collapse-resisting strengths of floor systems, and discussion of relevant code requirements. Chapters 3 and 4 mainly correspond to cast-in-place concrete structures without and with beams, respectively. The focus of Chapter 5 is on precast concrete structures. The report also presents relevant integrity provisions in ACI 318, and CSA A23.3, and the New York City Building Code (2014).

If an engineer is required to perform a comprehensive progressive collapse analysis, including the determination of collapse initiation scenarios, the design guidelines provided by the General Services Administration (GSA) or the Department of Defense (DoD) should be used. Furthermore, this report can be used to supplement current material-specific GSA and DoD guidelines with the approval of the authority having the jurisdiction over the project.

This report is developed based on analytical and experimental studies conducted on RC elements and structures with uniaxial concrete compressive design strength of approximately 3 to 8 ksi (21 to 55 MPa). Application of the collapse-resisting mechanisms discussed herein to high-strength concrete or high-strength reinforcement requires further study.

# CHAPTER 2—NOTATION AND DEFINITIONS

## 2.1—Notation

$A_{sb}$ = area of bottom slab and beam reinforcement passing through each face of column
$A_{sm}$ = area of integrity reinforcement required in each principle direction
$F$ = beam vertical load-carrying capacity
$f_y$ = specified yield strength of reinforcement
$L$ = span length of beam or one-way slab
$L_1$ = governing bay length
$L_n$ = length of clear span measured face-to-face of supports
$\ell_1$ = center-to-center span length
$\ell_2$ = center-to-center span width (perpendicular to $\ell_1$)
$\ell_x$ = clear span length in the short direction
$\ell_y$ = clear span length in the long direction
$M$ = moment at right end of beam
$M'$ = moment at left end of beam
$P$ = beam axial force