View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by University of Queensland eSpace

CURRENT TRENDS AND DEVELOPMENTS IN PROGRESSIVE COLLAPSE RESEARCH ON REINFORCED CONCRETE FLAT PLATE STRUCTURES

Huizhong Xue[1,*], Hong Guan[1], Benoit Gilbert[1], Xinzheng Lu[2], and Yi Li[3]
[1] Griffith School of Engineering, Griffith University Gold Coast Campus, QLD, 4222, Australia.
*Email:huizhong.xue@griffithuni.edu.au
[2] Department of Civil Engineering, Tsinghua University, Beijing, 100084, China
[3] College of Architecture and Civil Engineering, Beijing University of Technology, Beijing 100124, China

ABSTRACT

Progressive collapse of structures caused by extreme or accidental loads may lead to significant loss of life and property. Considerable research efforts have been made to date to mitigate the probability of progressive collapse and its consequences. This study summarises the fundamentals of progressive collapse in relation to the existing theoretical concepts and understanding. Specifically the existing theories pertinent to progressive collapse of building structures, in particular reinforced concrete (RC) flat plates, are examined from the following four key aspects: (1) definition of progressive collapse from deformation and/or strength perspectives with respect to the failure criteria of structural members and the entire structural system; (2) failure mechanisms of load-bearing systems undergoing progressive collapse with respect to the structural ultimate capacity, which has not been considered in the design process; (3) research methodologies for investigating collapse mechanisms, with emphases on experimental and numerical approaches; and (4) collapse-resistant design principles as covered in several international design standards in which a number of robustness requirements have been recognised. Based on the schematic review of the current trends and developments, gaps and limitations in progressive collapse research are identified and a new research direction is established to advance the progressive collapse study of RC flat plate structures.

KEYWORDS

Progressive collapse, flat plate structures, collapse mechanism, collapse-resistant design and evaluation.

INTRODUCTION

Progressive collapse is initiated as a consequence of local damage resulting in a chain effect throughout the structure and its elements, thereby leading to a disproportionately large extent of failure (Ellingwood 2006; Keyvani *et al*. 2014). The failure growth is due to the stable load transfer paths being disturbed within the structure. The study on the progressive collapse resistance was initiated due to the gas explosion of Ronan Point Tower in 1968. Further justification and development of the principles was promoted by the truck bombing attack of Alfred P. Murrah Federal Building in 1995 and the 9/11 tragedy of the World Trade Center in 2001. For flat plate systems in particular, the Sampoogn Department Store collapse in 1995 (Figure 1a) claimed the life of more than 500 people with 937 injures. The Pipers Row car park collapse in 1997 (Figure 1b), although with no casualties, still caused considerable economic loss and social concerns. These two collapse cases highlighted the significance of understanding the triggering punching shear failure of RC flat plate structures as well as the resulting load transfer patterns when a progressive collapse occurs (Park 2012; Wood 2003).

(a) Sampoong Department Store collapse (Park 2012)

(b) Pipers Row car park collapse (Wood 2003)

Figure 1 RC flat plate structures collapses

To date a significant achievement relevant to progressive collapse studies has been made. Accordingly, several countries including the USA, UK, and China, have compiled the required standards and guidelines attempting to mitigate the progressive collapses in their building designs. However, the majority of the existing knowledge is pertinent to frame structures whilst the understanding of progressive collapse in RC flat plate structures is limited. Given that RC flat plates are a popular construction type in Australia and worldwide, extra efforts towards progressive collapse research on such systems are timely required.

Four key aspects associated with the progressive collapse research can be identified: (1) failure criteria of progressive collapse, (2) failure mechanisms of load-bearing systems undergoing progressive collapse, (3) methodologies for investigating collapse problems, and (4) collapse-resistant design principles. This study aims to investigate these key aspects with an emphasis on RC flat plate structures. Through a schematic review of the current trends and developments, latest achievements in the progressive collapse research field are presented. Additionally, gaps and limitations are identified and a new research direction is established for advanced progressive collapse study of RC flat plates.

FAILURE CRITERIA DEFINING PROGRESSIVE COLLAPSE

The failure criteria considered in structural analysis are typically investigated from three levels: material, elemental, and structural. In particular, the progressive collapse analysis mostly focuses on the elemental and structural levels. This is principally due to the element-based damage propagation and ultimately the global structural failure due to the loss of vertical load-bearing element(s) at the local regions.

To assess whether an element fails or otherwise, appropriate collapse-related failure criteria must be established, i.e. elemental failure criteria. Based on their failure types, the elements can be categorised as deformation controlled or strength controlled. For deformation controlled element types, a certain number of elements which exhibit ductile properties, e.g. forming a plastic hinge after yielding, are still capable of bearing loads and accommodating deformation. Under this situation, the elemental deformation criterion should be applied. For strength controlled element types, on the other hand, when the elements exhibit brittle behaviour by losing load-bearing capacity rapidly after yielding, the elemental strength criterion should be applied. Given that the residual strength of elements exists in most element failure cases, it would be more appropriate to employ the deformation criterion. Nevertheless, the new ASCE 41 (2013) distinguishes the forces (e.g. axial load, shear, and moment) acting on the elements as deformation controlled or force controlled actions. This requires that the elemental deformation and strength must be assessed individually under each action.

Elemental Deformation Criterion

The elemental deformation criterion refers to the failure of elements if their deformations (displacements and rotations) exceed the corresponding allowable limits. An application of the deformation criterion is given in the General Services Administration (GSA) (2003) standard where ductility ratios and plastic hinge angles are used as performance indicators in the nonlinear analysis. The ductility ratios refer to as the ratios of the maximum deflections to the corresponding yield deflections at strategic points. While the plastic hinge angles refer to as the ratios of the maximum deflections to the corresponding span lengths. In order to align with the specifications in ASCE 41 (2013) and DoD (The Department of Defense) (2013), the new GSA (2013) standard adopts the same analysis procedures using the plastic rotation (hinge) angles as the acceptance criteria with minor modification in the nonlinear analysis. For RC structures, plastic hinges in general can be efficiently formed at element interconnections.

Elemental Strength Criterion

The elemental strength criterion denotes that the elements have failed if their maximum internal forces exceed the corresponding allowable limits. The GSA standard (2003) applies the strength criterion in the form of the Demand-Capacity Ratios (*DCR*) method for linear analysis. The *DCR* can be calculated using Eq. 1.

$$DCR = \frac{Q_{UD}}{Q_{CE}} \tag{1}$$

where, Q_{UD} is the acting force (demand) determined in component or connection/joint (moment, axial force, shear, and possible combined forces), Q_{CE} is the expected ultimate, un-factored capacity of the component or connection/joint (moment, axial force, shear, and possible combined forces).

In the latest version of DoD and GSA guidelines against progressive collapse, the *DCR* is considered as a prerequisite for employing linear analysis of buildings with irregularity features (DoD 2013; GSA 2013). Alternatively, simplified force controlled criteria for both linear and nonlinear analysis procedures are recommended as shown in Eq. 2, following the load and resistance factor design principles.

$$\phi Q_{CL} \geq Q_{UF} \tag{2}$$

where, Q_{UF} is the force-controlled action, Q_{CL} is the lower-bound strength of an element, and ϕ is the strength reduction factor.

Elemental Failure Criteria Used in Numerical Analyses

Lu *et al*. (2011) proposed a set of elemental failure criteria that can be used in numerical analyses of RC building structures, which is also applicable to flat plates. In the analyses, fibre beam and multi-layer shell elements were often used. The elemental failure criteria were introduced based on the predefined material failure criteria:

(1) For column or shear wall elements, the tension reinforcement is considered to have failed when the ultimate tensile strain of steel is reached. The compression reinforcement is considered to have failed when its compressive strain exceeds the maximum attainable strain in compression (concrete crushing). Consequently, if all of the reinforcement fibre or layer elements fail, then the column or shear wall is considered to have failed.

(2) Beam or slab elements are considered to be in compressive state at the small deformation stage and in tensile state at the large deformation stage. In addition to the tension reinforcement, the compression reinforcement is also able to provide tensile load-bearing capacity at the large deformation stage. Therefore, only if all of the reinforcement fibres or layers fail in tension, can the beam or slab elements be considered failed.

Structural Failure Criteria

The structural failure criteria determine if the progressive collapse is likely to occur from a structural level point of view. Mitchell and Cook (1984) utilised 0.15 times of the shorter span in slab structures as the allowable mid-span deflection, i.e. the threshold for progressive collapse. The DoD (2005) indicates that after the loss (removal) of elements due to the initial local damage, the extent of subsequent damage propagation can be used as an indicator to assess the severity of structural collapse. The DoD also stipulates that subsequent to the removal of an exterior column, the failure region of its upper structure shall not exceed the lesser value of 15% of the total floor area or 70m^2. When an interior column is removed, the failure region of its upper structure shall not exceed the lesser value of 30% of the total floor area or 140m^2. However, in the later version published in 2013, the DoD no longer requires the failure assessment at the structural level. Instead, the damage propagation limits are restricted to the following: the plastic deformation of the remaining structure shall not exceed the elemental failure criteria as aforementioned.

FAILURE MECHANISMS PERTINENT TO RC FLAT PLATES

An RC flat plate structure is a typical load-bearing system with compromised structural continuity and ductility (Ellingwood 2006). It is inherently more vulnerable to progressive collapse when compared with other ductile structural systems, such as moment resisting frame structures (Ellingwood 2006; Hawkins and Mitchell 1979; Qian and Li 2013a). This is largely because the system has no beams to facilitate redistribution of loads if local damage occurs.

Failure of an RC flat plate can generally be attributed to flexural or shear. Flexural failure arises in the spans of slab where significant deflection and cracking of concrete occurs. Moreover, this type of failure only occurs when the flexural reinforcement in the mid-span is inadequate and the shear reinforcement at the restrained ends of the slab is relatively heavily arranged. Shear failure, conversely, is distinguished by two possible modes: (1) a wide beam-shear failure or (2) a punching shear failure (Hawkins and Mitchell 1979). The wide beam-shear failure mostly occurs in corner column areas with the slab exhibiting flexural failure characteristics and a diagonal crack line cutting through the slab corner. Preventing this type of failure is commonly achieved through increased slab depth while decreasing the slab width to depth ratio within allowable ranges. Majority of current design standards deliver a conservative design of slab-column connections so that beam-shear failures can be prevented. It is an area where future research can be conducted to facilitate the design to be more cost effective. The punching shear failure, being the most critical type of shear failure, is discussed below.

Punching Shear Failure in RC Flat Plates

Hawkins and Mitchell (1979) and Keyvani *et al*. (2014) suggested that the area most likely to trigger progressive collapse of a flat plate structure is the interior slab-column joint, primarily due to punching shear failure. If such a failure brings the inability of the interior column to bear load (i.e., column loss), the gravity loading previously taken by this column will be redistributed. Such will cause load concentrations as well as large deformations at the region of the slab-column joint. Extra bending moment and shear are also generated in this region. Moreover, the adjoining slab will experience a torsional action. Combination of these induced forces results in severe stress concentration at the slab-column joint region, likely leading to a punching shear failure (Liu *et al*. 2015).

The punching shear failure begins when flexural cracks appear around the columns. These cracks propagate in an inclined direction to form a critical shear surface. Aggregate interlocking and dowel action work together to transfer shear before the critical shear surface is allowed to go through the entire slab thickness (Keyvani *et al*. 2014), upon which, a punching shear cone forms above the column. Meanwhile, the strength of concrete is reduced and the load is gradually transferred to the continuous reinforcement. Subsequently, the punching shear failure propagates from the current joint to the other regions of the structure (mainly the slab), due to moments not being able to be effectively distributed to the remaining structure.

Membrane Action in Progressive Collapse

The development of a membrane action within the plane of a slab consists of compressive and tensile membrane phases during a typical progressive collapse process. In the compressive phase, along with the downward deformation, the slab attempts to expand in-plane; oppositely, the lateral restraints, provided by columns, produce compressive stresses within the slab. The result of this compressive membrane stress is the considerable enhancement in punching shear strength although the damage continues to expand (Keyvani et al. 2014). Cracks and crushing appear on both slab faces leading to an increase in tensile stresses in the reinforcement, ultimately forming tensile membrane action in the slab. The tensile membrane acts as an alternate load path after the initial column damages, providing an effective load-carrying mechanism to prevent progressive collapse.

The existing experimental results showed that the ultimate load bearing capacities of slabs are much larger than those estimated by the plastic yield-line theory due to the abovementioned membrane actions (Dat and Hai 2013; Yi *et al*. 2014). Therefore, the predictions of the current standards underestimate both punching shear and ultimate loading capacities as these membrane actions, not having been fully quantitatively studied, are neglected. Influences of critical parameters such as material strength, reinforcement ratios, and slab thickness on the formation of membrane actions are yet to be investigated.

EXISTING AND PROPOSED RESEARCH METHODOLOGIES

Progressive collapse occurs unexpectedly and within seconds therefore acquiring first hand data in real time is challenging. The common methodology of in-situ monitoring consequently proves unreliable due to the difficulties associated with dynamic and large deformations. This has led to researchers attempting to simulate the progressive collapse through the use of physical and numerical models for a better understanding of the collapse mechanism and behaviour of the structures. This section presents the existing research methodologies with a focus on the experimental study and numerical simulation of the progressive collapse.

Experimental Investigations of Flat Plate and Slab-Column Structures

To better understand the collapse mechanism of flat plates, several experiments have been conducted on a variety of structure types. Although most experiments are often scaled down due to cost and capacity (e.g. the testing equipment size) restraints, there are exceptional cases. For example, Tian *et al*. (2008) investigated five large-scale isolated RC slab-column connections designed based on the old standards requiring no continuous bottom bars through columns, each tested under a different loading condition. While the experiment was not targeted at identifying the structural behaviours associated with progressive collapse, it revealed that high reinforcement ratios and continuous bottom steel bars increase the strength and stiffness of the connections. A similar conclusion was found by Mirzaei and Sasani (2011) who investigated 26 slab specimens to identify the effects of tensile and integrity reinforcement in post punching shear failure. Ultimately, the strength and stiffness of the connections have been found to rely on the formation of compressive and tensile membrane actions. Yi *et al*. (2014) confirmed these actions by recording concrete and reinforcement strains in the simulation of interior, exterior, and corner column losses.

Qian and Li (2012; 2013a; 2013b) performed a series of experimental tests on RC substructures investigating the progressive collapse resistance. The slab contribution on the ultimate resistance capacity of RC frame structures (Qian and Li 2012) and the influence of drop-panels on the response of RC flat plates (Qian and Li 2013a) were studied. Strengthening of the slab using carbon-fibre-reinforced polymer (CFRP) laminates were also investigated (Qian and Li 2013b). The laminates, being attached either orthogonally or diagonally on the slab surfaces, significantly improved the performance of the RC flat plate structure when compared to the control slab experiments.

The most recent development in RC flat slab research is reported by Russell *et al*. (2015) in investigating the dynamic response on six 2×1 bay slab specimens and one 4×1 bay specimen. It was found that punching shear failure is likely to trigger failure propagation, ultimately leading to a progressive collapse. It was also identified that the load path, after initial damage is sustained, does not necessarily go through the failed column. This interaction was discovered for the first time when an edge column was removed from rectangular specimens, consequently creating an unexpected load path due to the unequal stiffness of the surrounding slab regions.

Numerical Simulations of RC Flat Plates

The use of physical models requires considerable time and cost associated with the manufacturing process and monitoring equipment needed for the test setup. To reduce the constraints on these resources, numerical model are often employed. Moreover, significant safety issues are apparent due to the large deformations that are involved in physical progressive collapse testing, further increasing the desire for numerical modelling.

Kang *et al*. (2009) implemented a set of modelling techniques for simulating the nonlinear behaviour of RC flat plate systems in shake table tests. In their numerical model, the nonlinear behaviour of the slab-column connection was defined and controlled using zero-length link elements including springs and hinges. The adoption of these link elements implied that the slab and columns could be disconnected for the purpose of modelling the separate structural behaviours such as shear and bending. These structural behaviours were further defined by assigning nonlinear mechanical properties to the linking elements. This enabled the exploration of complex structural behaviours including the slab flexural yielding due to unbalanced moment transfer and the loss of slab-to-column moment transfer capacity due to punching shear failure. It is noted that this flat plate model was in a form of a simplified 2D frame where the slabs were modelled by equivalent beams. Therefore, the model was incapable of incorporating the spatial membrane actions. Moreover, the model was only loaded to a limited deformation state and the post punching shear behaviour of RC flat plates in progressive collapse was unable to be evaluated.

Keyvani *et al*. (2014) proposed an alternate modelling method to simulate the behaviour of a slab-column joint with emphasis on the post punching behaviour. The slab was modelled using shell elements whilst the reinforcement was explicitly modelled by beam elements. By means of deactivating the concrete elements through decreasing their stiffness after punching shear failure, the post punching response of the continuous reinforcement could be studied.

Liu *et al*. (2013; 2015) proposed a macro numerical model for progressive collapse analysis of RC flat plate structures. In their model, the region of the slab-column joint was isolated from the remaining slab and the two were linked through connector beam elements. This is because the shell elements alone cannot truly reflect the complex structural behaviour at the slab-column regions. The use of shell elements for modelling the steel bars into smeared reinforcement layers in addition to the definition of the nonlinear responses of the connector beam elements allowed membrane actions and punching shear failure to be investigated.

Xue *et al*. (2014) proposed a spring connection model based on the modelling techniques discussed above. The spring connection unit included five springs representing different structural behaviours at the slab-column region (Figure 2). These springs allowed the bending, axial and shear behaviours of the concrete to be independent of one another while the flexural and integrity reinforcement springs only allowed for axial deformation. By comparing against the experimental result, this connection unit was found to be able to exhibit the initial slab-column joint stiffness after loading and capture the trend of the force-displacement curve. Additional work was required to improve the modelling accuracy of the structural behaviours of the concrete and the reinforcement using such springs as discrepancies appeared at the large deformation stage.

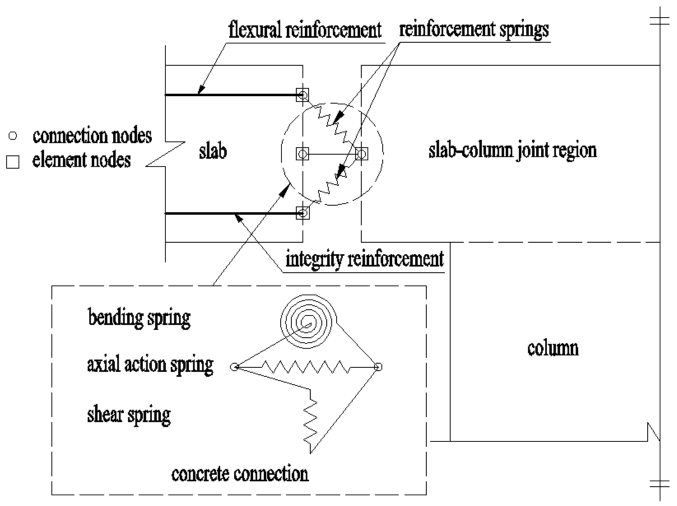

Figure 2 Spring Connection Unit (Xue *et al*. 2014)

DESIGN CONSIDERATIONS AGAINST PROGRESSIVE COLLAPSE

Design guidelines are included in several standards aiming at mitigating progressive collapse which are based on three primary considerations: event control, direct design, and indirect design (Stevens *et al*. 2011; Qian and Li 2013a). The event control method is commonly followed in the engineering management discipline; whereas the direct and indirect design are widely adopted in structural design and implemented through several detailed building strengthening methods discussed below.

Collapse mechanism analyses indicate that structures with higher integrity and redundancy are preferred to resist the progressive collapse. In addition, secondary load-bearing mechanisms are also demanded to confine the damage propagation. Following these two rules, researchers and engineers mitigate the consequences due to progressive collapse by using the following methods: (1) design the elements with higher redundancy and ductility, (2) design the joints with adequate continuity, (3) add alternate load paths, (4) strengthen critical elements, and (5) consider resisting load reversals. Amongst these methods, methods (1) and (2) are able to increase the resistance to progressive collapse by improving the local strength and integrity of the structure, representing the indirect design. In comparison, methods (3), (4), and (5) offer specific threat dependent considerations to mitigate progressive collapse consequences, exemplifying the direct design.

Redundancy, Ductility, and Continuity

Redundancy and ductility facilitate the structures with the capability of resisting collapse (robustness) by providing extra restraints and deformation capacity to the structural elements. They are generally achieved by strengthening the connections and providing structural elements with extra strength. Specifically, load amplification factors and material strength reduction factors are employed in the design process (DoD 2013; GSA 2013). To increase the overall integrity of the structures and effectively redistribute the loads after initial damages, continuity conditions must be satisfied, in particular, in the regions where the horizontal elements (beams and slabs) and the vertical elements (columns and walls) meet. The tie forces check calculation in the guidelines confirms such integrity requirement (DoD 2013, GSA 2013). Additionally, allowing the bottom reinforcement to continuously go through the columns at the joint regions is a typical construction measure to enhance continuity.

Alternate Load Paths

The alternate load paths are the secondary load-bearing mechanism to efficiently redistribute the extra loads to assist the structure to hold positon after the original load path is broken. As the standards (DoD 2013; GSA 2013) specify a rigorous design routine to apply the alternate load path method to structures against progressive collapse, the evaluation of the capability of resisting progressive collapse is able to be simplified as examining the remaining structure losing a critical load-bearing element according to the specified failure criteria (Stevens *et al*. 2011; Valipour and Foster 2010). In addition to the building design, the procedure of “notional removal of elements in a structure” is reasonably practicable in both experimental and numerical research approaches.

Critical Element Strengthening and Load Reversals

Enhancing local resistance approach is put forward to minimise the initial damage which potentially exists according to the occupancy situation (DoD 2013; GSA 2013). In addition to providing elements with standard redundancy and ductility, the capacities of two types of critical elements are required to be distinctively enhanced. Firstly, the elements at special locations (i.e., corner and penultimate edge columns), near openings (i.e., slabs close to elevators), and with special functions (i.e., beams supporting equipment floors) are more likely to experience external impacts or usually bearing extra loads. Secondly, the elements located on the expected alternate load path (i.e., beams above corner and penultimate columns) will undertake extra redistributed loading after the initial damage.

The load reversal typically occurs after the removal of a vertical support element which leads to a change of the load-bearing characteristics (Dat and Hai, 2011). Considering the case of an interior column removal in a RC frame structure, part of the beams and slabs at the removed column location, originally designed to bear negative (hogging) moment, have to carry positive (sagging) moment instead. To worsen the situation, the doubled span length significantly increases this sagging moment, which makes it difficult for the slab to maintain even a small deformation. As such, potential weaknesses are introduced by the absence of the top reinforcement at mid-span and the bottom reinforcement at beam and slab ends due to the compressive actions given by the gravity loads. Accordingly, the continuous steel bars are recommended for both top and bottom reinforcement arrangements.

DISCUSSIONS AND FUTURE WORK

The current trends in the progressive collapse research of RC flat plates are reflected by the increasing efforts of experimental and numerical investigations. Especially, given the execution, cost, and safety considerations, numerical simulation is truly promising. It is also noted that defining the complex punching shear behaviours in slab-column joint regions is rather challenging (Kang *et al*. 2009; Keyvani *et al*. 2014). Specifically, for the spring connection modelling, a set of spring stiffness properties fitted from the existing experimental data would likely to increase the reliability of the numerical model. However, the existing experiments are limited and they vary in load and boundary conditions as well as material properties. In order to make use of these experimental data, new parameters and normalization of variables must be introduced to remove such variations. Alternatively, the spring stiffness could be obtained through analysing an adequately refined numerical 3D slab-column joint models which are capable of capturing the punching shear behaviour. Ultimately, the spring connection modelling would be optimized with enough accuracy to compete the inefficient refined 3D modelling. In addition to the challenge of defining the spring stiffness, the torsional effect, which critically interacts with other structural behaviours in punching shear, must also be considered.

CONCLUSIONS

This work presents a schematic review of the developments of progressive collapse research with an emphasis on RC flat plate structures. Their failure criteria and failure mechanisms are described in some detail. The most recent achievements including both experimental work and numerical simulation, are presented. Several key considerations against progressive collapse as included in the design process are interpreted. Specifically for numerical simulation, a spring connection modelling is discussed yet further improvement is needed. This requires a more precise spring stiffness properties conforming to the experimental data. Furthermore, an additional spring element defining the torsional behaviour at the slab-column joint regions is also expected to be developed.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support received from the Australian Research Council through an ARC Discovery Project (DP150100606).

REFERENCES

ASCE 41-13, "*Seismic rehabilitation of existing buildings*", American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191-4400.

Dat, P. X., & Hai, T. K. (2013). "Membrane actions of RC slabs in mitigating progressive collapse of building structures". *Engineering Structures*, 55(2013), 107-115.

DoD. (2013). "*Design of building to resist progressive collapse*." Unified Facility Criteria, UFC 4-023-03, Washington, DC.

Ellingwood, B. R. (2006). “Mitigating risk from abnormal loads and progressive collapse”. *Journal of Performance of Constructed Facilities*, 20(4), 315-323.
GSA. (2013). “*Alternate path analysis and design guidelines for progressive collapse resistance*.” Washington, DC.
Hawkins, N. M., & Mitchell, D. (1979). “Progressive collapse of flat plate structures”. *ACI Journal*, 76(7), 775-808.
Kang, T. H., Wallace, J. W., & Elwood, K. J. (2009). “Nonlinear modeling of flat-plate systems”. *Journal of Structural Engineering*, 135(2009), 147-158.
Keyvani, L., Sasani, M., & Mirzaei, Y. (2014). “Compressive membrane action in progressive collapse resistance of RC flat plates”. *Engineering Structures*, 59(2014), 554-564.
Liu, J., Tian, Y., & Orton, S. L. (2013). “Vulnerability of Disproportionate Collapse in Older Flat Plate Buildings Subjected to Sudden Removal of a Bearing Column”. *Structures Congress 2013*.
Liu, J., Tian, Y., Orton, S. L. & Said, A. M. (2015). Resistance of flat-plate buildings against progressive collapse. I: modeling of slab-column connections. *Journal of Structural Engineering*, 04015053.
Lu, X., Li, Y., & Ye, L. (2011). “*Theory and design method for progressive collapse prevention of concrete structures*”. Beijing, China: China Architectures & Building Press.
Mirzaei, Y. & Sasani, M. (2011). “Punching shear failure in progressive collapse analysis”. *Proceeding of Structural Congress*, 2011, ASCE, 2941-2950.
Mitchell, D. & Cook, W, D. (1984). “Preventing progressive collapse of slab structures”. *Journal of Structural Engineering*, 110(7), 1513-1532.
Park, T. W. (2012). “Inspection of collapse cause of Sampoong department store”. *Forensic Science International*, 217(2012), 119–126.
Qian, K., & Li, B. (2012). “Slab effects on response of reinforced concrete substructures after loss of corner column”. *ACI Structural Journal*, 109(6), 845-855.
Qian, K., & Li, B. (2013a). “Experimental study of drop-panel effects on response of reinforced concrete flat slabs after loss of corner column”. A*CI Structural Journal*, March-April, 2013, 319-329.
Qian, K., & Li, B. (2013b). “Strengthening and retrofitting of RC flat slabs to mitigate progressive collapse by externally bonded CFRP laminates”. *Journal of Composites for Construction*, 17(2013), 554-565.
Russell, J. M., Owen, J. S., & Hajirasouliha, I. (2015). “Experimental investigation on the dynamic response of RC flat slabs after a sudden column loss”. *Engineering Structures*, 99(2015), 28-41.
Stevens, D., Crowder, B., Sunshine, D., Marchand, K., Smilowitz, R., Williamson, E., and Waggoner, M. (2011). “DoD research and criteria for the design of buildings to resist progressive collapse”. *Journal of Structural Engineering*, September, 2011, 870-880.
Tian, Y., Jirsa, J. O., Bayrak, O., Widianto, & Argudo, J. F. (2008). “Behavior of slab-column connections of existing flat-plate structures”. *ACI Structural Journal*, 105(5), 561-569.
Valipour, H, R., & Foster, S. J. (2010). “Progressive collapse analysis of planar reinforced concrete frames using a 1D element with distributed non-linearity”. *Australia Journal of Structural Engineering*, 10(3), 263-275.
Wood, J. G. M. (2003). “Pipers row car park collapse: identifying risk”. *Concrete*, 37(9), 29-31.
Xue, H., Guan, H., & Li, Y. (2014). “Preliminary collapse simulation of a reinforced concrete flat plate substructure using spring connection modelling”. *Applied Mechanics and Materials*, 638-640(2014), 1445-1448.
Yi, W., Zhang, F., & Kunnath, S. K. (2014). “Progressive collapse performance of RC flat plate frame structures”. *Journal of Structural Engineering*, 2014.