F4-K: Fundamental Science of Progressive Collapse Resistance of RC Structures

Post-Punching Behavior of RC Flat Slabs: Local Failure and System level Progressive Collapse Analysis of Structures

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Abstract

The column failure due to an explosion can propagate in the structure through punching shear failure at the location of the neighboring columns, leading to progressive collapse. An analytical model is developed to be used in a finite element model of flat plate/slab structures to estimate the initiation of punching shear failure as well as post-punching shear response using ABAQUS. The mechanical model is used to determine the mechanical properties of the analytical model of the connection zone, which is between a rigid zone of slab directly above the column and the rest of the slab, which simulates the contribution of the reinforcing bars to the shear transfer after a punching shear failure. The analytical model and the results of system level study can be of interest in assessing progressive collapse resistance of existing structures and in design of new structures.

Relevance

Following the Alfered P. Murrah Federal Building attack in 1995 and the establishment of the Interagency Security Committee (ISC) for development of construction standards for federal buildings subject to terrorist attack, the General Services Administration (GSA) published guidelines for progressive collapse analysis of structures. The outcomes of this research are aligned with an urgent need to enhance such guidelines for punching shear in flat slab structures, which can be used to mitigate the likelihood of progressive collapse.

Technical Approach

Column Explosion: Field Experiment

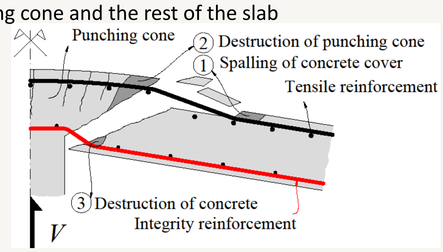
Response of an actual two-story parking garage with flat slab following column explosion is experimentally evaluated.

Shear Transfer Mechanism of Punching

Radial compressive strain at the bottom of the slab at the face of the punched column starts to decrease at about 80% of the ultimate load and even turns into tension, which is related to a stage of redistribution of internal forces. Hence, in the proposed model, shear stiffness of the cracked zone is significantly reduced at 80% of the punching strength.

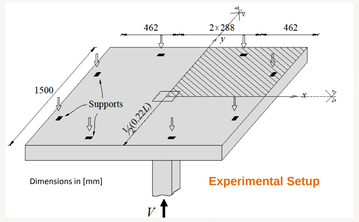
Shear Transfer After Punching

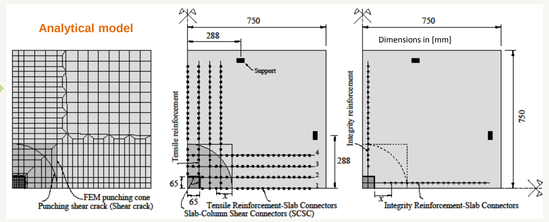
Longitudinal reinforcement are the only link between the punching cone and the rest of the slab

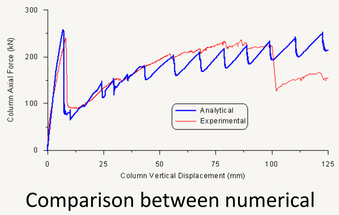


Local Punching Failure

Experimental results of a half-scale simply supported slab specimen is used to verify the numerical simulation method.



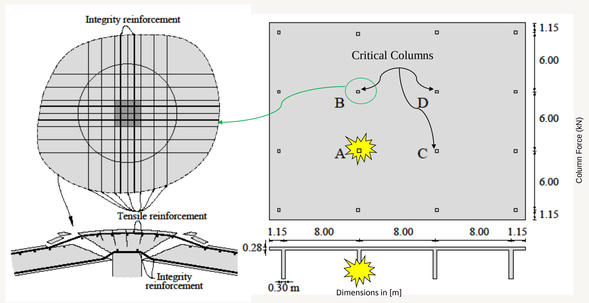


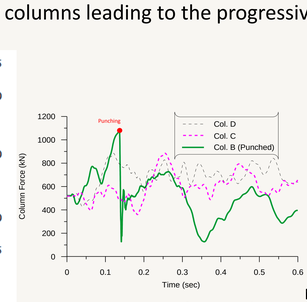


Comparison between numerical and experimental results

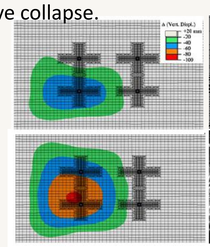
Progressive Collapse Resistance of Flat Slabs

Following a column explosion, the force in column B exceeds the punching strength leading to slab shear failure and a significant drop in the column force. The presence of the integrity reinforcement and to some extent that of tensile reinforcement and their proper modeling provides an alternative load path for the load redistribution and prevents the structure from collapse. If the post-punching strength was not considered, punching shear would have occurred in other columns leading to the progressive collapse.

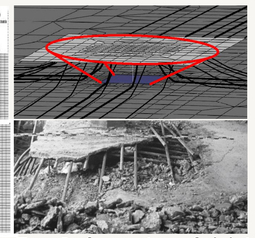




History of critical column axial forces



Slab deformations right before punching failure (Top) and at end of analysis (Bot.)



Top: Deformation of slab in vicinity of punched column
Bot.: Typical actual punching shear failure

Accomplishments Through Current Year

- Response of an actual two-story parking garage with flat slab following column explosion was experimentally evaluated.
- A new mechanical-based modeling technique was developed to account for post-punching response of flat slabs, which was verified against experimental data.
- The new modeling technique was used to evaluate progressive collapse resistance of a flat-slab structure following the explosion of a column, in which the collapse was arrested in part due to the proper modeling of the slab post punching response.

Future Work

- Account for in-plane action of the slab in punching shear strength as progressive collapse of critical structures is significantly controlled by strength of the structure rather than deformation capacity which is important in seismic analysis, and simulate the development of in-plane action in progressive collapse analysis of structure following an explosion.
- Development of a predictive method for coupled flexural-axial response of beams and slabs accounting for membrane, catenary and Vierendeel frame actions for the entire range of deformation up to collapse to be used in an early warning systems for progressive collapse evaluation.

Opportunities for Transition to Customer

The Unique and pioneering experimental program on response of actual structures following an explosion and the complementing numerical simulation in this project is a direct response to an urgent need identified by the Multihazard Mitigation Council of the NIBS (2003): "General structural integrity needs to be founded on **substantiated data**." Developing a reliable understanding of progressive collapse resisting mechanisms is a required step in establishing a method and the corresponding technology for early warning systems for progressive collapse evaluation, which would be an asset for the **first responders** as well as for **effective evacuation of damaged structures**.

Patent Submissions

Publications Acknowledging DHS Support

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- Mirzaei, Y., and Sasani, M., (2011). "Punching Shear Failure in Progressive Collapse Analysis," Structures Congress, April 14-16, 2011, Las Vegas, NV.
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