Casino Parking Garage Collapse Forensic Investigation

Matthew SHEEHAN
Senior Engineer
CTLGroup
Skokie, IL, USA
MSheehan@ctlgroup.com

Matthew Sheehan received his civil engineering degrees from the University of Minnesota. He has approximately 15 years of experience in forensic evaluation and assessment of concrete structures and construction materials.

Eric VANDUYNE
Structural Engineer
The Consulting Engineers Group, Inc.
Mt. Prospect, IL, USA
EricVanDuyne@cegengineers.com

Eric VanDuyne received his civil engineering degrees from the University of Illinois. He has approximately 15 years of experience in structural analysis, design, evaluation and assessment of reinforced concrete structures.

W. Gene CORLEY
Senior Vice President
CTLGroup
Skokie, IL, USA
GCorley@ctlgroup.com

Dr. Corley received his civil engineering degrees from the University of Illinois. He has over 40 years of experience related to the development and advancement of reinforced concrete design and construction technology and assessing behavior and performance of structural systems.

Summary

The expansion of a casino entertainment complex in the eastern United States was progressing in 2003, when a collapse of an approximate 15 by 60 m area of the parking garage occurred during placement of cast-in-place concrete at an upper garage level. Garage construction generally consisted of stay-in-place, precast, prestressed concrete formwork and cast-in-place composite slab system connected with mild steel reinforcing to cast-in-place concrete columns and shearwalls. Collapse of multiple levels of the composite floor system occurred, but nearly all perimeter columns and shearwalls in the area remained standing. The authors were retained to investigate and determine the cause of the failure and study the progressive collapse. The investigation results were used to successfully assess failure cause and make recommendations on how to avoid such accidents in the future.

Keywords: Collapse investigation, reinforced concrete garage, stay-in-place precast pre-stressed formwork, forensic engineering.

1. Introduction

The expansion of a casino entertainment complex in the eastern United States was progressing in 2003, when a portion of the multi-story parking garage under construction collapsed during an 8th level concrete floor placement. Numerous construction worker fatalities and injuries occurred. Several investigations were initiated to determine the cause of collapse. The authors were retained to investigate and evaluate the cause of the failure and study the progressive collapse of the reinforced concrete parking garage.

2. Background

The expansion project area was generally located within a city block in an existing entertainment district. The primary components of the design-build expansion project included a hotel tower, parking garage areas, and areas for retail, dining and entertainment. The 13-story garage region directly adjacent to the street and overbuild area is where the 2003 collapse occurred.

Project structural drawings and specifications provide for garage construction using a combination of stay-in-place, precast, prestressed concrete formwork and cast-in-place composite one-way floor system. Individual floor system panels are connected with mild steel reinforcing. Mild steel reinforcing is also used to connect the floor system to cast-in-place concrete columns and shearwalls. The stay-in-place form system was used in slab areas and for beams by incorporating a thickened version of the slab system in what would otherwise be beam locations.

3. Garage Collapse

Collapse of an approximate 15 by 60 m area of the garage occurred during placement of cast-in-place floor system concrete at an upper level of the parking garage. A progressive failure of

https://doi.org/10.2749/222137908796293091

multiple levels of the stay-in-place precast formwork and cast-in-place composite floor system occurred, but nearly all perimeter columns and shearwalls in the area remained standing. The slabs pulled away from the exterior column line but remained hanging from the first interior column line.

4. Collapse Investigation

Following the collapse, a protocol was established for demolition activities that included provisions for preservation of artifacts that might be useful when evaluating the cause of the garage collapse. Observations were made at both the collapse site and a yard where artifacts were stored. A testing plan was established to assist in evaluating retained garage components.

Since the garage slabs fell away from the Line 1 columns and shearwall, the joints along this elevation were a focus of the investigation. Based on review of project design and construction documents, the field-placed mild steel reinforcing required to connect the slab to the columns and shearwall along Line 1 included slab top and bottom reinforcing bars embedded into the columns and shearwall, and integrity steel reinforcing bars passing through column cores. Observations and testing revealed that only the top slab bars had been placed. The amount of embedment into columns often was not sufficient to develop the bars.

As a result of the as-constructed steel reinforcing at Line 1 slab-column and slab-shearwall joints, the ability to resist negative moments and maintain the integrity of the joint upon concrete cracking at the exterior span was reduced to near zero.

5. Structural Evaluation

During the investigation concerns were raised regarding adequacy of the design, so the authors were tasked to evaluate whether the design met Building Code requirements and whether it had sufficient strength to prevent collapse if constructed in accordance with the design intent.

Analyses suggest that the punching shear strength of the slab-column joints did not meet Building Code requirements. Once the effects of cracking and steel reinforcing deformation and yielding were considered, calculations support that the structural design had the strength to prevent collapse if steel had been installed according to design intent. However, slab defections and crack widths would have exceeded those permitted by the code.

6. Findings and Conclusions

Investigation and evaluation of the cause of the progressive collapse revealed the following findings and conclusions:

Improper as-constructed steel reinforcing placement at numerous slab-column and slab-shear wall connections resulted in minimal to marginal ability to resist negative moments at the exterior span perimeter and maintain the structural integrity of the joints upon concrete cracking.

Even with the as-constructed joint reinforcing deficiencies, the structure was temporarily able to redistribute loads to other areas, this redistribution made up for the joint deficiencies at the perimeter column line. Collapse occurred when the cumulative effects of multiple levels of improperly reinforced joints were finally overcome by the self-weight and construction loads while concrete for the 8^{th} level was being placed.

Analyses suggest that as-designed strength of the slab-column joints did not meet Building Code requirements. Once the effects of cracking, steel reinforcing deformation and yielding were considered, calculations support that the structural design had the strength to prevent collapse if steel were installed according to design intent, but slab deflections and crack widths would still exceed those permitted by the code.

Review of project documents, witness accounts, and investigation results suggest that the collapse of this garage was preventable. Improved communication and organization of project documents among all members of the design-build project team were needed to prevent the collapse.