A Numerical Investigation on the Collapse of the Champlain Towers South in Florida

Daigoro Isobe, University of Tsukuba, Tsukuba-shi, Ibaraki, Japan Email: isobe@kz.tsukuba.ac.jp

Junnan Zhu, Graduate School, University of Tsukuba, Tsukuba-shi, Ibaraki, Japan Email: zhu.junnan.su@alumni.tsukuba.ac.jp

Janine Pardee, Orbit City Engineering LLC, Florida, USA Email: janinepardee@yahoo.com

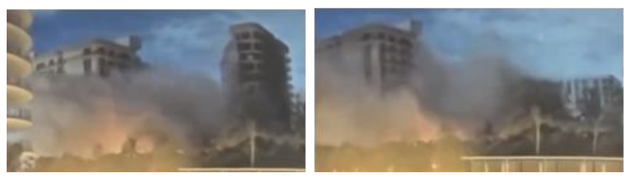
***Abstract*— In this study, the Champlain Towers South building collapse in Florida allegedly caused by a deck collapse was examined through the finite element analysis based on the existing hypotheses and investigation. The Adaptively Shifted Integration (ASI) – Gauss code was applied for the numerical analysis. In addition, the member strength failure algorithm of RC components was modified, and the flat-plate structure was introduced into the numerical model of the building. According to the analyses, the building did not collapse when the pool deck beams connecting to the columns of the 1st-floor interior, so-called key columns, were removed by the collapse of the pool deck. When the model was revised to include deterioration of concrete slab and corrosion of rebars, and then triggered by the removal of columns in the underground parking garage, the middle section of the buildings reached a total collapse. This supports the latest collapse theories, which cite punching shear failure at pool deck columns as the initiating event.**

Index Terms—**collapse analysis, flat-plate structure, RC building, deterioration, corrosion, ASI–Gauss code**

Collapse of the Champlain Towers South

Figure 1. Champlain Towers South Condominium.

(a) 1 s from collapse initiation (b) 3 s from collapse initiation



(c) 5 s from collapse initiation (d) 12 s from collapse initiation

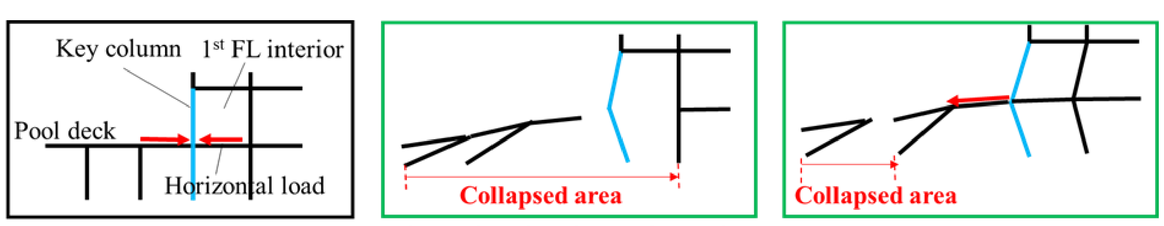
Figure 2. Collapse sequence of the Champlain Towers South.

The middle and eastern sections of Champlain Towers South in Florida (Fig. 1), USA, a 13-story condominium built in 1981, collapsed without warning at approximately 1:25 a.m. on June 24, 2021. According to the surveillance video, the collapses of the middle section and the following eastern section only lasted for 12 seconds (Fig. 2). At least half of the 136 units in the building had collapsed (Fig. 3), and all of them were characterized by the fact that they collapsed instantly after it began to collapse.

Figure 3. Collapsed site of the Champlain Towers South.

It is currently believed by many that the direct cause was the additional concrete, sand, and pavers placed on the surface layer of the pool deck located in the southeast area of the building in 1996. This increased its weight, causing the deck to finally cave in as punching shear gradually progressed between it and the columns in the basement. The collapse of the deck reduced the buckling capacity of the first-floor columns, or the failure of the connection dragged the columns into failure, leading to the progressive collapse of two-thirds of the building. Others believe that the main causes of the collapse were water infiltration and the deterioration of the reinforced concrete of the parking lot beneath the housing units due to corrosion of the rebar. Florida is a regular hurricane zone, and as buildings are exposed to saltwater, deterioration is likely to progress. Also, the possibility that the direct trigger of the collapse was a collision of a vehicle with a column in the basement garage cannot yet be ruled out.

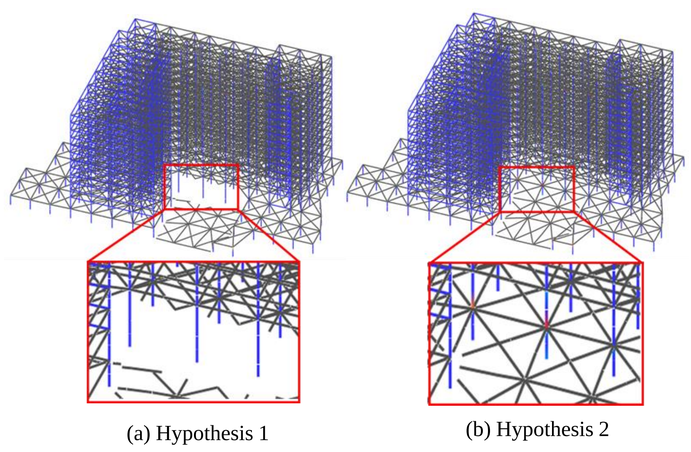
Numerical Simulations Based on the Hypotheses Presented in the Washington Post



(a) State before collapse (b) First hypothesis by Mosalam *et al*. (c) Second hypothesis by Porter *et al*.

Figure 4. Hypotheses of the building collapse.

A 13-story RC building model was analyzed based on the hypotheses published in newspapers (Fig. 4). In the case where the extent of pool deck collapse exceeded the key column (Hypothesis 1), neither the final state nor buckling of the key column was confirmed. In the case where the extent of pool deck failure did not exceed the key column (Hypothesis 2), the key column was in the final state, but the entire building did not collapse (Fig. 5).



(a) Hypothesis 1 (b) Hypothesis 2

Figure 5. Numerical results based on the hypotheses with pool deck collapse as the main cause.

Numerical Simulations Based on the Hypothesis with Deterioration of Concrete Slabs, Corrosion of Rebars, and Loss of Key Columns as the Main Cause

Figure 6. Western section remaining after the accident.

Figure 7. Enlarged photo of a collapsed section.

Figure 8. Cross-section of a collapsed floor.

Figure 9. Wind-resistant wall of western section left at accident site.

Figure 10. South end of the uncollapsed western section. This photo is looking west. It can be inferred that the entire pool deck plus two bays of the first level parking slab collapsed in punching shear. The columns of the building did not collapse despite the increased unbraced length. The column labeled for parking space 75 is K-13.1 and the one in front of it is L-13.1. The pool deck collapse is attributed to these two slab-column failures.

Figure 11. Slabs of the eastern section. This photo is looking north from the pool deck across the debris pile. The roof is at the left, the tan tile is on the 13th story balcony slab, the red tiles on 12th, and so on, with the pink tile at far right the 9th floor balcony. This indicates the eastern section toppled south and then west.

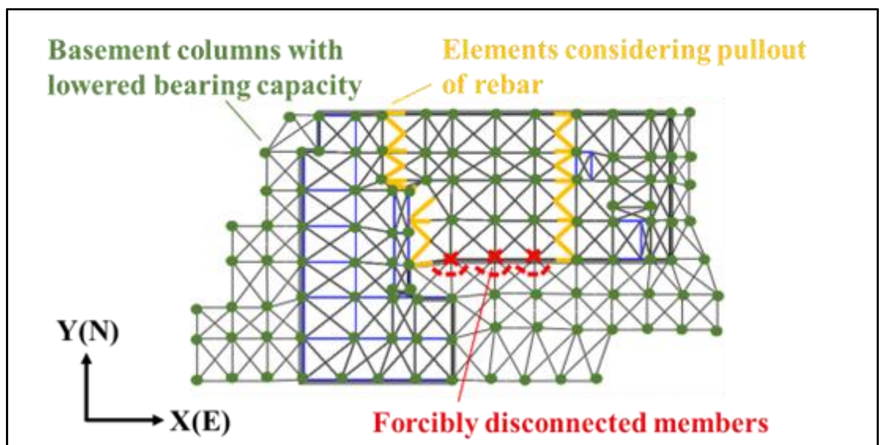
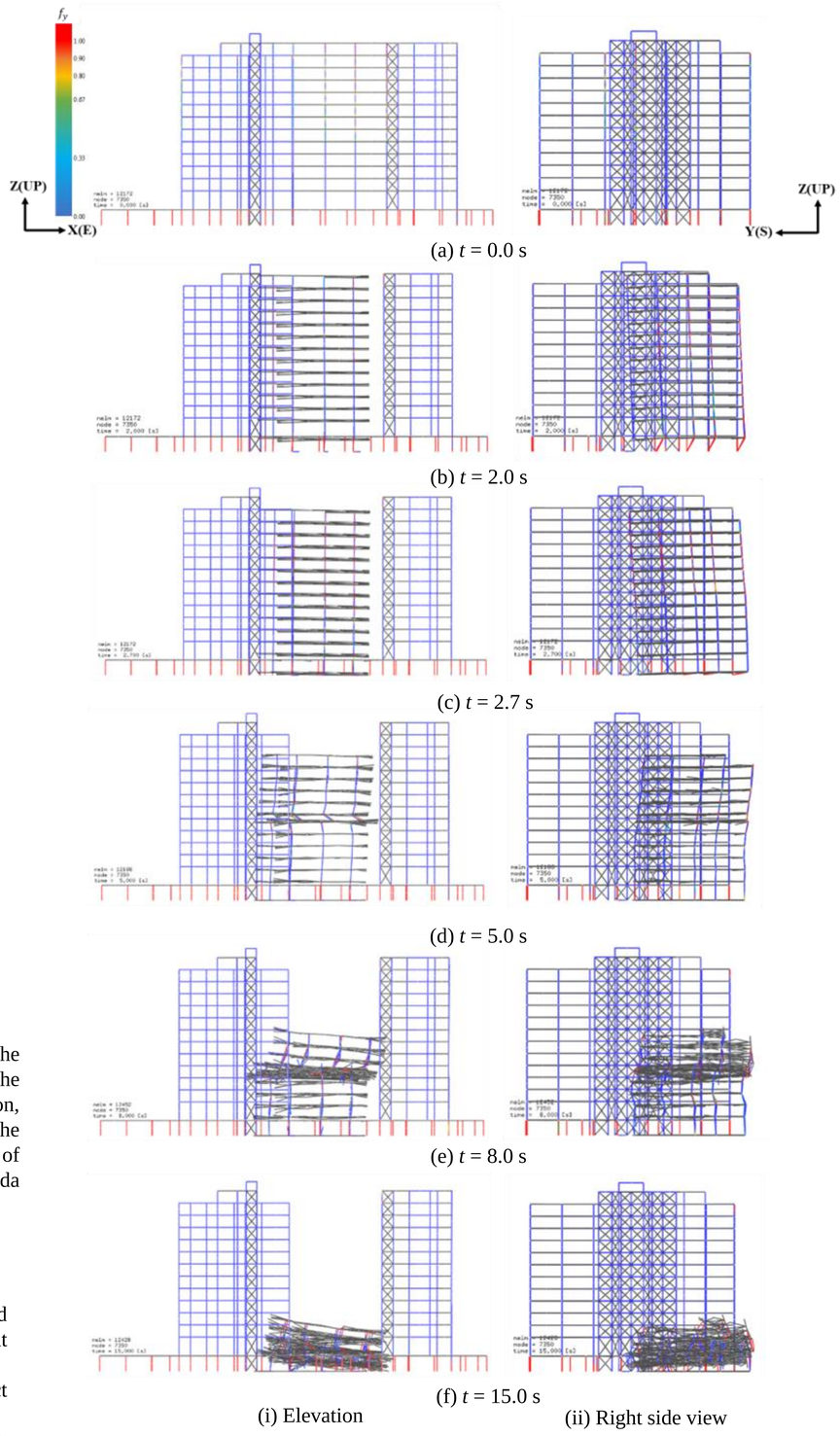


Figure 12. Numerical conditions based on the hypothesis with deterioration of concrete slabs, corrosion of rebars, and loss of key columns as the main cause.

A collapse analysis was conducted based on the hypothesis that removal of key columns was the main cause of the collapse, by constructing a model that considered the pullout of the rebar and the reduction in the bearing capacity of the reinforced concrete based on the investigation (Fig. 6 – Fig. 12). The model confirmed the collapse of the middle section, but no collapse was observed in the eastern section of the building (Fig. 13).. These results suggest that the pullout of the rebar at the connection joint between the wind-resistant wall and the flat-plate floor, the reduction in bearing capacity of the basement columns, and the removal of key columns were some of the main mechanisms of the collapse of the Florida Condominiums.



(a) t = 0.0 s (b) t = 2.0 s (c) t = 2.7 s (d) t = 5.0 s (e) t = 8.0 s (f) t = 15.0 s

(i) Elevation (ii) Right side view

Figure 13. Numerical results based on the hypothesis with deterioration of concrete slabs, corrosion of rebars, and loss of key columns as the main cause.

Conclusions and Future Works

In recent years, the progressive collapse of buildings due to the deterioration of structural members has been occurring frequently, posing a significant threat to social assets and human lives. Understanding the collapse mechanism of buildings with deteriorated components or construction defects will enable effective reinforcement of buildings and prevent unexpected collapses.

There is still room for further study of the phenomenon considering the more recent evidence provided by investigating engineers. Revising the numerical model to reflect construction flaws can provide further confirmation of the hypothetical causes and the observed mechanisms.

Since there are thousands of similar condominium developments in the USA alone, the number of such collapses could increase in the future. Engineers must continue to elucidate the collapse mechanisms of buildings with deteriorated or flawed members. In Florida, and other parts of the world, flat-plate structures have been used because they are economical. New codes and standards mean that many existing buildings must now be re-evaluated, and their collapse mechanisms in worst scenarios, if needed, should be investigated.