Progressive Collapse Caused By Extreme Events:

A Parking Garage Case Study

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Abstract

Progressive Collapse is the total or partial failure of a structure due to the spread of local failure from element to element throughout the structure. This research aims to determine whether the removal of a column from a multi-story building will cause total or partial collapse. The OSU North cannon parking garage was used as a case study for this purpose. A 3D model of the building was made using SAP2000. Before the demolition of the building on January 12th, a column was removed from the fifth story of the building, and various data was collected using accelerometers, strain gauges, drones, robots, and cameras. The objective of the research is to understand the reaction of the structure in the case of the extreme event of removing a column. All data collected will be combined and compared to the theoretical model and suggestions to the model will be presented.

Background and Motivation

Progressive Collapse is the total or partial failure of a structure due to the spread of local failure from element to element throughout the structure which can be triggered by manmade or natural events. The level of damage on a structure during an extreme event can be predicted from accurate measurements of stiffness, deformation, and dynamic characteristics of given structure. The main objective of the research is to determine whether the removal of a column from a multi-story building will cause partial or total collapse of the building. The OSU North cannon parking garage was used as a case study for this purpose (Sezen, 2020).

To date, the given tools to predict such damage such as SAP2000 or Ansys have further room for research and improvement especially during extreme events. A full-scale documentation of dynamic scenes during physical damage and demolition activities are yet to be deployable at an adequate level. In addition, there are very limited rules or guidelines toward the prevention of progressive collapse.

A similar previous study was conducted by Brian Song and Halil Sezen to evaluate the differences between 2D and 3D design models. The study was conducted in a similar manner where four columns were physically removed from a four-story building and data were measured for load redistribution (Song, 2013). The study concluded that 3D models are significantly more accurate than 2D models since 3D models consider more variables and more accuracy.

The most important facts about the problem of predicting damage given structure measurements are (i) the method of integration of large data from multiple sources/multiple studies, (ii) determining whether a multiple story structure will collapse or endure extreme damage if one or more vertical columns were suddenly lost, and (iii) the analysis of large geo-localized to develop meaningful models for long-term monitoring of structures.

The goal of assessing whether a structure can withstand the loss of one or multiple columns is ultimately to improve life safety in structures and give accurate predictions whether extreme damage will occur in a given structure during extreme events. Examples of such failures that could be prevented in the future are the Worlds Trade Center (McAllister, 2002), Murrah Federal Building in Oklahoma City (Osteraas, 2006), and Ronan Point Building (Pearson, 2005).

Significance

While progressive collapse events are uncommon, their effects are catastrophic. The research can aid in providing specific design methods and specifications that will prevent large amounts of damage and potential casualties in the future.

Methodology

A 3D model of the building to be tested will be made using the SAP2000 software. A picture of the model can be shown in Figure 1, this model was based on the building as shown in Figure 2. Before the demolition of the building, a column will be removed from the fifth story of the building, and the load redistribution data will be recorded using strain gauges. The events that will occur after the removal of the columns will be recorded using multiple cameras and drones. Deflection will be measured using Deflection gages. Further data including acceleration will be measured using three accelerometers that are installed around the column to be removed. Three accelerometers will be installed in the building around the column to be removed as shown in Figure 3.

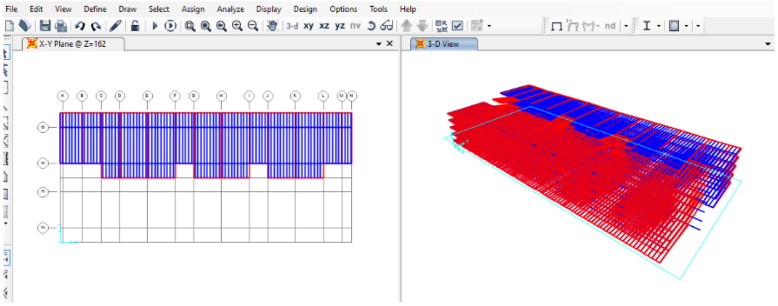

Figure 1: SAP2000 Model of North Cannon Garage

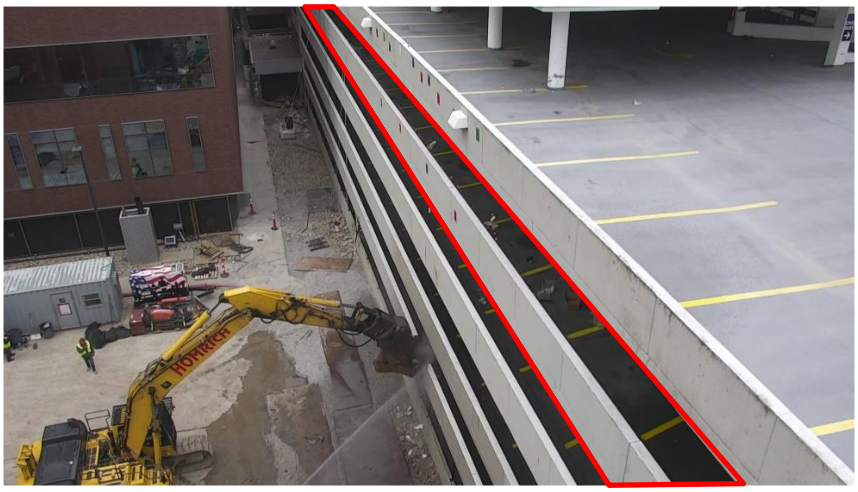

Figure 2: A drone picture of the North Cannon Garage with the 5^{th} floor highlighted

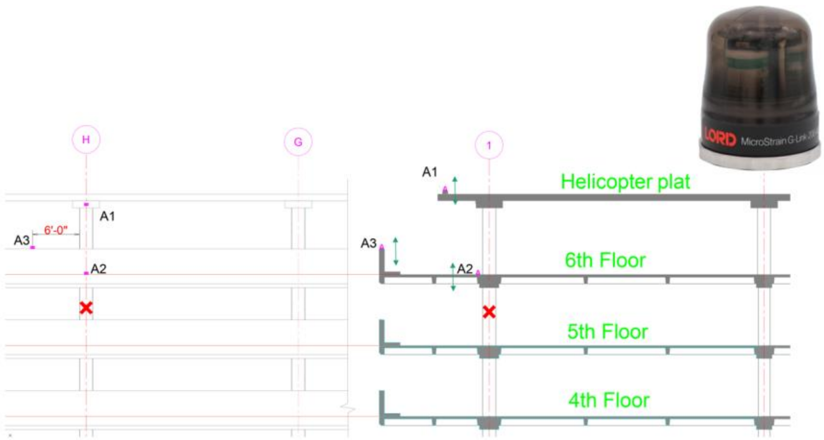

Figure 3: Accelerometers placement on the building

The data recorded during the demolition is recorded in a time graph as shown in Figure 4. The data will be divided into smaller portions and connected to camera video recordings to show the specific impact of each action on the structure. This data can be compared to the previously made SAP2000 model by adding forces on the model and comparing the results between the model and the accelerometer data. Furthermore, the accelerometer data can be compared with strain gauge data to gain insight into the different effects of the partial demolition and column removal on the building. This specific data will be combined with the rest of data, including drone videos, inside camera recordings, deflection measurement, and LIDAR scan data, will be synthesized to be compared with the theoretical model and suggestions to the model will be presented.

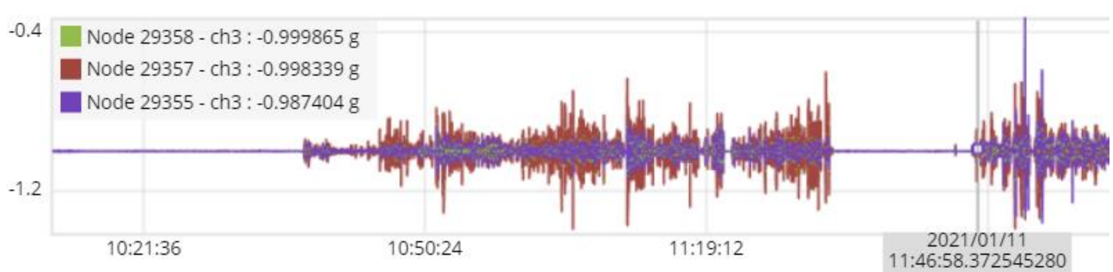

Figure 4: Accelerometer Data of the column during demolition

Challenges

There are three main challenges with the progressive collapse case study. Chief among these is the increase of noise in data collection for the removal of the outside concrete before the demolition of the column. The sensor data can be adapted through MATLAB functions in order to determine whether the noise in data is significant to affect the results. Finally, the sensors may have trouble identifying the accurate horizontal (x,y) directions for the data recorded since the most accurate data is the vertical (z) direction.

Conclusion

Extreme events such as the removal of the column can have detrimental effects on the building and can lead to progressive collapse of the structure. Preliminary data analysis of the acceleration data shows accurate movement with the structure that can be linked to strain gauge and drone data taken at the same time. Further analysis will give a more clear picture of the demolition event which will be compared to the digital models; The given comparison will be used to give feedback for future models and applicable building codes for future structure safety.

Bibliography

Song, Brian I., and Halil Sezen. "Experimental and Analytical Progressive Collapse Assessment of a Steel Frame Building." *Engineering Structures*, vol. 56, 2013, pp. 664–672., doi:10.1016/j.engstruct.2013.05.050.

McAllister, Therese, and Gene Corley, eds. *World Trade Center Building performance study: Data collection, preliminary observations, and recommendations*. Diane Publishing Company, 2002.

Osteraas, John D. "Murrah building bombing revisited: A qualitative assessment of blast damage and collapse patterns." *Journal of performance of Constructed Facilities* 20.4 (2006): 330-335.

Pearson, Cynthia, and Norbert Delatte. "Ronan point apartment tower collapse and its effect on building codes." *Journal of Performance of Constructed Facilities* 19.2 (2005): 172-177.

Sezen, Halil. Structural Engineering. The Ohio State University. Personal Interview. April 20th 2020.