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Failure in concrete and methods to improve the performance

Shiyin Li

City University of Hong Kong,Hong Kong,999077,China

Abstract. This scientific article presents a comparative analysis of two engineering failures caused by concrete deterioration: the collapse of the Champlain Towers South apartment complex in Surfside, Florida, and the failure of the I-35W Mississippi River bridge in Minneapolis. By examining these catastrophic events, this study aims to identify the underlying causes of the concrete failures and draw valuable lessons to prevent similar incidents in the future.

Keywords: concrete; failure; corrosion; comparative analysis; case study..

1. Introduction

In the areas of infrastructure, industrial production, and building, concrete has several uses. In addition to other infrastructure projects, it is essential for developing residential buildings, roadways, airport runways, etc. The structural stability and seismic resistance of structures can be improved by adding concrete to the manufacturing process of building materials like blocks and wall panels. Concrete clinker is produced by industrial manufacturing processes and is used to create concrete mixtures like cement mortar and concrete. Buildings, roads, and bridges are frequently constructed using these combinations. Concrete also plays a crucial role in the construction of infrastructure, acting as a strong foundational material that increases the resilience and stability of highways, bridges, and airport runways. As a result, the project's quality and safety are enhanced. Additionally, waste materials from the production of concrete can be reused to create environmentally friendly goods like fly ash and cement kiln ash. These waste items can be used to make road base materials and construction wall materials, which will conserve resources and lessen environmental damage.

Around 10 million tons of cement were produced globally in 1900; by 1998, the number had increased to 1.6 billion tones. Only 40 million cubic meters of concrete were used in 1900, but 6.4 billion cubic meters of concrete were produced in 1997. This equates to slightly more than 1 cubic meter or more than 2.5 tons of concrete per person per year. According to this data, cement and concrete consumption in infrastructure and building projects throughout the world has dramatically increased, which reflects patterns in global population expansion and urbanization over the past century. Given the exponential rise in cement and concrete use over the past century, it is obvious that these materials are now essential to all construction and infrastructure projects conducted worldwide. Nevertheless, the occurrence of concrete failure has grown significantly more concerning because of the extensive usage of concrete. In this article, we'll examine the exact ways that concrete affected building collapse and consider other possible reasons.

2. An Engineering Failure Case Caused by Concrete

Concrete is a material that is frequently used in buildings and is characterized by its toughness, adaptability, and durability. Concrete is nonetheless susceptible to deterioration over time owing to exposure to environmental and other causes, like other materials. Experts have identified several concrete-related problems that may have led to the collapse of the Champlain Towers South building.

On June 24, 2021, the Champlain Towers South apartment complex in Surfside, Florida, collapsed tragically due to poor engineering, killing at least 98 people. Although the cause of the collapse is still being investigated, structural problems and aging concrete and steel parts of the building are thought to be to blame. The structure, which was built in 1981 and was located on the seaside in the Miami enclave of Surfside, had just recently undergone a recertification procedure for its structural

integrity. The disaster has prompted calls for tougher construction rules and inspection procedures as well as worries about the safety and upkeep of old infrastructure across the United States.

The main factors that led to the collapse of Champlain Towers South Condominium are still not completely understood. According to several specialists, the collapse was the consequence of several damages and a combination of failure mechanisms, which had a tragic conclusion. A preliminary analysis of the building indicated several potential contributory reasons, including differential foundation settlement, corrosion of the reinforcement, concrete cracking, and persistent waterproofing problems. These elements might have combined to cause the building's gradual decline, which ultimately led to its partial collapse.

To give tensile strength and sustain the structure, reinforcement is included in the concrete structures. But over time, as the building is near the ocean, it was exposed to moisture, salt, and other environmental elements that can cause reinforcement to corrode. The expansion of the steel due to corrosion of the reinforcement may result in cracks in the surrounding concrete. The corrosion of the reinforcement may then be accelerated by these gaps allowing moisture to penetrate the concrete, weakening the entire structure. Early structural assessments demonstrated that concrete cracking, long-term waterproofing difficulties, corrosion of the reinforcement, and corrosion of the reinforcement might all be influencing variables. If the concrete of the building had not been adequately maintained, this might have pushed up the corrosion of the reinforcement and added to the structure's gradual decline.

The utilization of lightweight concrete posed an additional challenge in the construction of the building. To reduce its weight, lightweight aggregates like expanded sandstone, ceramics, or scree are incorporated into the production of lightweight concrete. Although lightweight concrete serves certain purposes, its strength and durability may not match those of conventional concrete. The incorporation of lightweight concrete in constructing the balconies of the Champlain Towers South building could have contributed to their collapse. It was found that the balconies, which were constructed using lightweight concrete, were insufficiently inclined to facilitate proper drainage. Consequently, this inadequacy may have resulted in water infiltration and deterioration of the reinforcement steel.

3. Compare with Another Case and Materials characterization

As the date of the accident is relatively recent, there is not enough data to analyze the causes of the accident, so other similar cases are used here as a reference. The failure of the I-35W Mississippi River bridge in Minneapolis due to the failure of concrete supports that had been damaged by corrosion is capable to be a reference here.

Catastrophic engineering errors led to the deaths of many people in the collapses of the I-35W Mississippi River bridge in Minneapolis, Minnesota, USA, in 2007 and the Champlain Towers South apartment building in Surfside, Florida, in 2021. Both cases used concrete as their main building material, and the failure of the concrete is what caused them to collapse. In this section, the concrete failure in these two examples is compared and the testing methods are described.

3.1 Similarities in Concrete Failure:

There are significant similarities between the collapses of the Champlain Towers South apartment complex and the I-35W Mississippi River Bridge in terms of concrete failure. The breakdown of structural concrete components was identified as the cause of the collapse in both instances. The National Transportation Safety Board (NTSB) examination into the I-35W Mississippi River bridge collapse found that the failure of the gusset plates that joined the bridge truss members to the bridge deck was the result of a design flaw. It was discovered that several of the bridge's concrete columns and girders were in an advanced stage of corrosion because of this failure, which led to the bridge collapsing.

Similarly, it is thought that concrete failure contributed to the collapse of the Champlain Towers South residential complex.

Aspect	Champlain Towers South	I-35W Mississippi River Bridge
Type of Structure	Residential apartment complex	Highway bridge
Cause of Failure	Poor engineering	Corrosion of concrete supports
Engineering Oversight	Identified deficiencies	Inadequate inspections
Structural Component Failure	Collapse of building structure	Failure of concrete supports
Pre-existing Issues	Structural damage, settling	Corrosion in steel components
Impact on Infrastructure	Localized to the building	Major disruption to the transportation network
Legal and Regulatory Consequences	Ongoing investigations and lawsuits	Investigations, bridge design and inspection improvements

3.2 Methods for Material Testing:

After the bridge collapsed, tests were conducted on the concrete to ascertain its composition, strength, and density. The tests were conducted utilizing destructive testing techniques, including as petrographic analyses, compressive strength tests, and flexural strength tests. The cylindrical concrete specimens were crushed to evaluate the strength of the concrete using compressive strength testing. The concrete's resistance to bending was evaluated using flexural strength tests, and its composition was investigated using petrographic analysis. These materials testing methods can also be used to examine the concrete used in the Champlain Towers South apartment building.

These materials testing methods can also be used to examine the concrete used in the Champlain Towers South apartment building. The compressive strength tests can be used to determine the concrete's strength, and the flexural strength tests can be used to measure the concrete's ability to resist bending. Petrographic analysis can also be used to examine the concrete's composition and identify any defects or anomalies that may have contributed to the concrete failure.

The Champlain Towers South collapse investigation can apply the core drilling test used in the I-35W Mississippi River bridge collapse to assess the strength class of concrete used in the building's construction. The strength, quality, and compliance with design requirements of the concrete may be evaluated using core samples collected from the building's structure. Testing might not be as simple as it was in the instance of the I-35W Mississippi River bridge collapse, however, because the Champlain Towers South fall's concrete failure is due to a waterproofing problem rather than a defect in the concrete itself. To ascertain the degree of water infiltration and corrosion of the reinforcing steel composition, additional tests may be required.

In conclusion, there are similarities between the collapses of the I-35W Mississippi River bridge and the Champlain Towers South in terms of the concrete failure that resulted in the infrastructure's destruction. The significance of appropriate infrastructure design, building, and maintenance is demonstrated in both instances.

4. Discussion

The collapse of the Champlain Towers South apartment building provides a clear example of how the failure of concrete can lead to catastrophic consequences. The structure in question was built in 1981, and over time, exposure to salt water and air caused the concrete that was used to create it to degrade. This degradation caused the steel reinforcement in the building to corrode, which weakened the structure and eventually caused it to collapse.

The occurrence makes it clear that concrete's construction performance must be improved. Creating new and better concrete mixes that are more resilient and impervious to the variables that contribute to degradation is one method to accomplish this. High-performance concrete, which can tolerate more extreme climatic conditions and resist degradation better than conventional concrete combinations, has undergone considerable developments in recent years.

Utilizing cutting-edge construction methods that can reduce concrete's exposure to factors that contribute to deterioration is another strategy for enhancing its performance. For instance, the use of waterproofing materials and coatings can lessen the danger of corrosion and damage by preventing moisture from entering concrete buildings.

Additionally, it is crucial to regularly inspect and maintain concrete structures to spot any signs of deterioration early on and take the necessary precautions to stop further harm. This involves employing non-destructive testing techniques like ultrasonic testing, which may find interior concrete flaws without endangering the building.

In conclusion, the collapse of the Champlain Towers South apartment building highlights the importance of improvement in concrete performance. It is crucial to develop new and improved concrete mixtures and innovative construction techniques that can withstand harsher environmental conditions and resist deterioration. Regular inspection and maintenance of concrete structures are also essential to detect any signs of deterioration early and prevent catastrophic failures. By addressing these issues, we can ensure that concrete continues to be a safe and reliable building material for years to come.

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