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A Secure Skyline

A comprehensive analysis of the World Trade Center collapse
and
Recommendations for revisions to current fire resistance building codes

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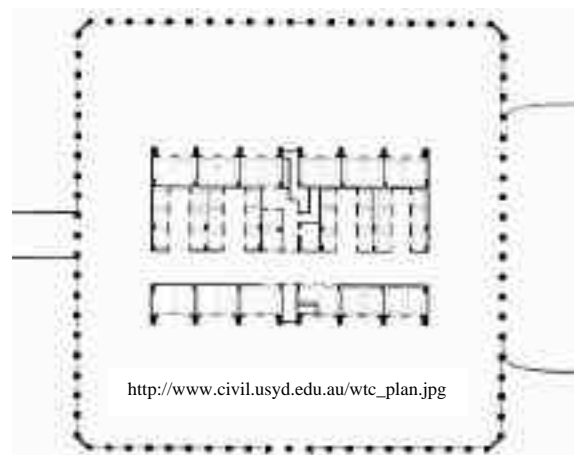
Introduction:

As per our funding proposal, Ceseach has completed thorough and comprehensive research that analyzes the structural layout of the World Trade Center and deciphers the causes of the failure. Continuing to build skyscrapers has to be considered first. It is much more tragic when a fairly large group of people die at one time. As Dr. Sparks explained, a skyscraper's fundamental purpose is to concentrate a large population of people in a relatively small area in order to allow for easy communication. However, with today's technology, communications have been improved so much that it is just as easy to communicate your views from your living room couch than from walking up a couple of floors in a skyscraper. Yet, skyscrapers are more than a place to allow for easy interaction between lots of people; they are forms of art, engineering masterpieces, and they are the American Way. In a sense, it would be unpatriotic to allow this type of disaster to completely stop the design and construction of these magnificent buildings. For these reasons, Ceseach has prepared an overview of the World Trade Center and recommendations of measures that can be taken into account when building future skyscrapers.

A disaster of this type was hard to imagine or design for; however, now that we know it is a reality, Ceseach would like to embrace the challenge of recommending design features that should now be considered. These recommendations are to be considered and implemented on a federal level.

History of the World Trade Center:

When analyzing the failure of a building it is important to understand the design and the purpose of the design. Owned by the New York/New Jersey Port Authority, the World Trade Center buildings were designed by Minoru Yamasaki. John Skilling and Leslie Robertson were the chief engineers in charge of the structural design of the buildings. Built in the late 1960's and early 1970's, the World Trade Center's structural design was fairly new and innovative. Unlike past skyscrapers, the World Trade Center was designed as a "tube" structure, as shown in the figure above. The Empire State Building, for example, was supported by an intricate skeleton of steel. Many believe this structure was redundant and overbuilt. The World Trade Center, on the other hand, boasted the majority of its structural components on the outside walls of the building. Most of the load was supported by several fourteen-inch columns, forty inches on center, surrounding the building; giving it the appearance of a pinstriped suit. The only other main structural component was the core of steel columns that supported



the elevator shafts and stairwells in the center of the building. Because the building “rested” on the exterior columns, the design significantly added floor space and opened up the interior of the building immensely. This innovative and efficient design, although very spacious, was thought to be almost flimsy. The floor trusses added stiffness to the structure. Very lightweight steel trusses spanning sixty feet, connected the exterior columns to the central core, supporting the floors/ceilings. This connection between the floor truss and the exterior column was a very important structural component, resisting wind and buckling forces.

We at Ceseach find it unproductive to try and assign blame to any one person or design feature. With these recommendations, we are not blaming the structural engineers of the World Trade Center. The fact that the buildings stood for well over an hour to allow tens of thousands of people to escape was tremendous. John Mangusson, the chairman and CEO of Skilling’s current engineering firm, said, “Ninety-nine percent of all buildings would collapse immediately when hit by a 767.” For this reason, the structural engineers should be commended on their design; however, now that we know this kind of disaster is possible, revisions to the current building codes are considered necessary.

The World Trade Center collapsed because of two reasons: impact and fire. The impact of the building was very critical in the building’s collapse because several floors were destroyed and internal damage occurred. But, the building probably would not have collapsed if this was the only damage that it suffered. As a result, the World Trade Center is not classified as a complete structural failure; it was more of a fire failure that caused fatal structural damage. This fire failure started with the aviation fuel.

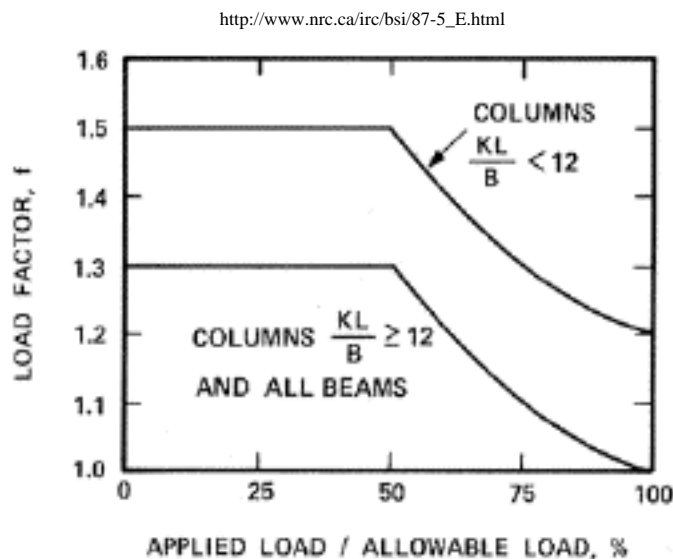
Aviation Fuels:

When designed in the 1960’s, Leslie Robertson said that the buildings were designed to withstand a direct hit from a Boeing 707, which is 20% lighter than a Boeing 767. At the time this plane was the largest and most advanced plane in the sky. Robertson went on to explain that only the forces acting on the building from the impact were considered but, for some reason, the explosion and fire were not considered. Fire protection testing includes experiments that subject different materials (i.e., steel) to gradual rises in temperature, which is the case in any typical fire. These testing procedures do not consider extreme rises in temperature in a very short period of time, which was the case when the planes exploded upon impact at the World Trade Center.

Our recommendation is for the National Institute of Standards and Technology to implement new testing procedures that consider extreme temperature rises in a short period of time. This testing will provide a better understanding of how steel behaves when subjected to these types of temperature rises and will give ideas of how to improve safety measures in order to prevent this type failure in the steel.

Steel Failure Modes and Steel Behavior:

The fact that most of the load was supported by the exterior columns is key to understanding why the buildings fell in the fashion that they did. As explained earlier, the lightweight truss system in the floors was the only structural system that added rigidity to the buildings. Structural mechanics provides us with the simple fact that shorter objects are more difficult to buckle. This knowledge is fundamental to understanding how the World Trade Center collapsed. The intense fire first burned through several floors because the truss system was lightweight and the steel used in the truss system was much thinner. The columns in the core were substantial and capable of bearing huge gravity loads. However, they depended on the floor truss system to provide lateral support. As the flooring system was destroyed by fire, greater lengths of core columns were exposed, which were already overloaded because of the destruction of the exterior columns. Taking away the lateral support of the flooring system caused the core columns to have a larger effective length factor (K), and the columns buckled, causing the floors to crash straight down on one another. The figure above shows that with a larger K-value, the allowable load on a column is significantly less.



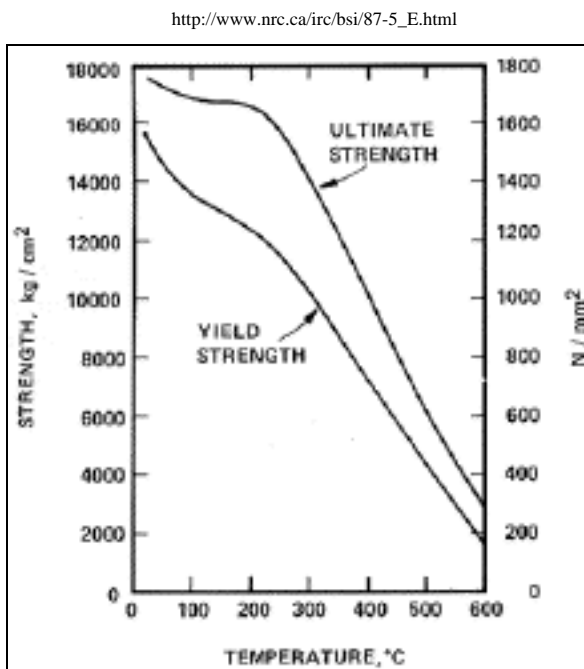
Many New York Fire Fighters pointed out that the same innovations that make these buildings more economical to erect and more pleasant to inhabit also make them more vulnerable to fire. The fact that it was a “tube” structure and the lightweight flooring system contributed to the behavior of the collapse. Perhaps a skeleton structure, although redundant and overbuilt, would provide a safer building for public interaction. It is hard to determine how a skeleton structure would have behaved if exposed to this type of tragedy. Some believe it would have toppled over, causing even more damage to surrounding businesses, and others believe only the sections where the planes hit would have been destroyed.

Fire Protection Materials:

In the early 20th Century, as buildings were beginning to reach “skyscraper levels,” more attention was given to fire regulations. The public obviously feared the collapse of a 50 or more story building. These newer structures had the capacity to destroy more of the surrounding area than the lower buildings of the time. Legal enforcement was needed to keep the structural frame or “shell” from collapsing. After more information was gained

through constructed assemblies, experiments conducted on the intensity and duration of building fires, and actual field data, some of the building codes were somewhat relaxed. More of the building requirements focused on concepts that would protect the fire fighters and people inside. Certain measures were developed that kept the actual floors and the interior living area protected. However, in a recent incident, these types of safety methods did not keep the World Trade Center's floors from failing. At the World Trade Center, a lack of sufficient judgment and analysis resulted in a terrible tragedy as firefighters and rescue workers were sent into the building. People did not know that the building would collapse, but some level of skepticism concerning its wounded strength could have possibly saved the lives of some of the rescue workers.

Current building codes call for fire protection materials to be used in all buildings housing public operations. Typical methods used for columns and beams include steel beams cast in concrete, steel reinforcing bars in concrete, or a fire protection mineral-fiber spray on the outside of steel. Concrete is a non-combustible material; however, steel is sensitive to heat and loses considerable strength when exposed to fire or extreme temperatures as seen by this figure. This figure shows the decrease of ultimate strength when steel is directly exposed to heat. The method of casting steel beams in concrete is very effective. The concrete provides a durable and thick layer of protection around the steel beam, though it can be considerably more expensive and increases the weight of the entire structure. For this reason, a spray on coating is desirable because it is efficient, easy to apply, and lightweight. The current New York City building codes require three layers of half-inch thick spray to surround steel beams to provide two hours of resistance.



This spray has its disadvantages, however. It is known to flake off easily. Because the planes did not pass all the way through the World Trade Center buildings, it is likely that the core structure stopped the planes. The core structure consisted of steel beams with this spray on fire protection material. It is suspected that the material was stripped off the steel, directly exposing the columns to the intense fire.

Our recommendation for this problem would be to use a more durable fire protection material around the columns and beams, which adheres to the steel and will not be knocked off. Perhaps using angled steel bars in the flooring system would hold the spray on material better. Encasing important structural components in concrete could be an additional solution to this problem. An alternative recommendation is to over-design the structural members. This would give the members a larger moment of inertia, allowing

them to withstand the same loads at higher temperatures. More costs would be incurred, but safety of the public is an engineer's first priority.

Conclusion:

This analysis has shown the immediate need for revisions to current building codes in order to insure the safety of the American public. Some say engineers could have never designed for this type of tragedy. It is impossible to ask engineers to design every building safe from every possible event; however, that is what people expect. It is an engineer's duty to meet these expectations. Engineers have an incredible responsibility to design infrastructure that is safe, attractive, and cost efficient. The true problem is balancing these design characteristics while still having the building function as intended. We feel these recommendations will provide balance by focusing much needed attention on safety. Safety is many times overlooked when cutting corners will save money. This is why we are asking you to implement these recommendations for revisions to the building codes on the federal level – to ensure that safety measures are given their proper level of importance in the future.

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