Rebirth – Seven World Trade Center

By Bart Sullivan, P.E.

In 1984, Silverstein Properties began development of the 7 World Trade Center project. The 47 story, 2 million square foot office tower was to be built over the top of an existing electric sub-station operated by Consolidated Edison Company of New York (ConEd). The site was situated just north of World Trade Center Tower 1.

Structurally, the building had a similar design to many other contemporary office towers in New York City: it utilized steel framing with a composite concrete floor slab placed over metal deck; braced frames in the building's core provided the primary lateral stability for the structure; and it was founded on drilled caissons seated in bedrock.

Tenants began occupying the building in 1987.

On September 11, 2001, the building collapsed. The building had sustained damage from the collapse of the twin towers and had several fires burning uncontrolled for nearly 7 hours after the terrorist attacks that morning. The building met its demise at 5:20 PM.

7 WTC July 11, 2005.

Starting Anew

In a matter of weeks, Silverstein Properties assembled a design team to reconstruct the fallen building. WSP Cantor Seinuk (WSP-CS) was selected as the structural engineer. Collaboration on conceptual designs with the architect, Skidmore, Owings, and Merrill (SOM) began immediately.

Several things drove the project early on. First and foremost was the owners' desire to simply rebuild what was unjustly stripped from the City of New York. From the standpoint of practicality, the electric sub-station housed at the base of the building needed to be restored quickly, as it provided power for a large portion of lower Manhattan. In the interim, ConEd provided power by means of a temporary station across the East River in Brooklyn, NY.

The new building shape became a clean parallelogram now bounded by Greenwich St. to the East, Washington St. to the West, Barclay St. to the North and Vesey St. to the South. The new smaller footprint would require a building taller than its predecessor in order to fit the same amount of programmable space. In the end, it was determined that only 1.6 of the original 2.0 million sq. ft. of office space was attainable without the use of an elevator sky lobby, a non-starter for ownership. Silverstein Properties wanted a fast, efficient elevator system that did not force tenants to travel on express elevators and then transfer to local elevators to reach their final destination. A further design challenge was to create sufficient space for the electric sub-station and a ground floor lobby, something the original building lacked. This was achieved.

Peri-form (red) in central core.

The electric sub-station occupies the majority of the ground floor, in addition to three levels above. The building's mechanical systems occupy the next two levels, and the first office floor is located above this – over 100 feet in the air.

SOM designed a closely spaced stainless steel grill to clad the base of the building. The small triangular bars of the grill provide an aesthetic appearance, yet are also quite practical in that they provide the necessary ventilation for the transformer vaults that occupy the majority of the street front. A clear glass curtainwall clads the balance of the structure above.

Structural Concept

Various structural and architectural alternatives were studied early on. In choosing an appropriate structural system, many factors were considered including safety, scheduling, constructability, and of course economy. The final solution was a hybrid of reinforced concrete and structural steel – each used strategically to optimize its strengths.

continued on next page

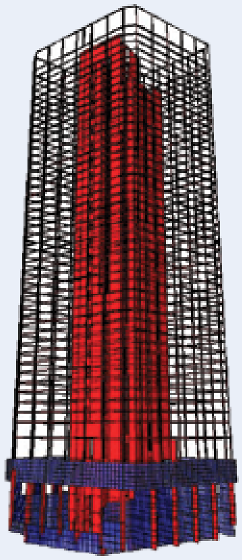

Figure 2: 3D FEA model of structure.

The structure is founded on high capacity drilled caissons which are socketed into bedrock. The building podium is constructed completely of conventional reinforced concrete. The office floors are framed in steel supporting a traditional concrete slab over metal deck. Finally, a concrete core functions as the primary lateral system throughout the building height.

Foundations

Much of the World Trade Center site is built on reclaimed land. Therefore, the upper strata of soil are of relatively poor material with a water table as high as street level in flood conditions.

Quality bedrock in downtown Manhattan is found some 80 feet below street level. Thus, a deep foundation system was the only viable solution for a 750-foot-tall building.

Fortunately, caissons from the original structure survived the building collapse and were determined to be structurally sound. Therefore, the design attempted to utilize these elements wherever possible. Almost all of the existing caissons were employed to some extent. However, because the new building and its structure hardly resembled that of the original, approximately 95 new 2500 ton caissons were required. Caisson caps range in depth from 8 feet to 10 feet thick and use 8000 psi concrete.

Podium Structure

The base of the building was designed as an entirely reinforced concrete structure (*see Figure 2*). One of the main project objectives was to have ConEd's sub-station up and running as soon as possible. By using reinforced concrete, the long lead times of structural steel were avoided and construction could get underway much more quickly.

The schedule was so aggressive that only a portion of the building was built up to the 4th floor while work was still continuing on the foundations for the remainder of the building. Three of the 10 transformers needed to come online as soon as possible to serve the immediate needs of downtown Manhattan. The remainder of the transformers would be used to power future lower Manhattan developments. Obviously, this created further challenges to the engineering design and construction logistics.

Though schedule was a significant factor, there were several other benefits to using concrete in this location as well. First, the transformer vault walls are designed to be blast resistant in case of a transformer explosion – making concrete a simple solution. Second, a perimeter transfer system was required since none of the tower perimeter columns continued straight down to the foundation. A concrete belt wall provided flexibility for mechanical openings and more redundancy than a traditional steel truss. Third, the massive concrete floors, walls, and columns provided added overall robustness to the tower's base.

Office Tower Structure

The building's office space is designed using steel framing with concrete slabs over metal deck. This system is used outside the building's core. It provides a relatively light weight structural system that achieves large column free spaces, typically with 45-foot spans.

The office tower's lateral system, however, is a departure from the traditional approach of steel braced frames. After many conceptual studies, a concrete shearwall system at the core of the building was found to be the most economical. Furthermore, the concrete walls (over 2 feet thick in places) provide added robustness and protection to the vertical circulation of the building.

Within the core, the floor system is a reinforced concrete flat plate system. Concrete floors made sense in terms of erection sequencing. They also provided a shallow structural system that gave increased headroom and space for distribution of building services.

Figure 3: Robust concrete base housing Con Edison Electric substation.

Construction Issues

Due to labor restrictions in New York City, it is not possible to erect the concrete core ahead of the structural steel framing – ruling out an efficient slip forming operation. In the past, contractors in the city relied on "erection framing" which consisted of light weight steel elements designed only to carry the steel framing and a limited number of floor slabs. The concrete operation would follow behind the steel erection and encase the erection framing using traditional formwork. This process was streamlined at Seven WTC.

Here, the steel floor framing was pulled back off of the column lines to create a gap between the beams and the outside face of the core walls. This allowed a proprietary self-jacking form system developed by Peri Formwork Systems to be employed (*see Figure 3*). In this case, the steel erection occurred approximately 8 floors above the concrete operations as the tower rose. The forms were mounted on the surrounding steel framing, and raised floor by floor by a system of pulleys. After casting the walls, the inner concrete floor system was placed. In this way, the concrete operation was able to maintain pace with the fast erection of the steel framing above.

Enhancements

Silverstein Properties has been intent on developing buildings for the World Trade Center site that are safer and more secure than any other public building. To this end, a variety of enhancements were implemented in the building. Certain enhancements were made explicitly to the structure, others were made to indirectly protect the structure, and still others were made as upgrades to current life safety measures.

As the reader may imagine, information regarding the exact measures taken in creating a more robust structural system is particularly sensitive. However, the principles employed have been widely discussed by the engineering community since September 11, 2001.

The vertical circulation is of particular concern when considering the evacuation of tenants in an emergency. As was previously stated, this was one of the reasons for choosing a concrete shearwall system to frame the core of the building. All elevator shafts and stairwells are surrounded by concrete walls for the full height of the building.

Creating alternate load paths to carry the gravity forces to the foundations is another feature of the building. The steel frame of the tower is designed with added redundancy, as is the transfer system at the podium levels. Structural members and connections are designed to mitigate progressive collapse scenarios with the occurrence of a catastrophic event.

Some of the most substantial measures that can be made to prevent a progressive collapse of the structure do not change the structure in any way. For instance, creating stand-off distances at the street levels can provide substantial protection by simply keeping explosive threats at a distance. This was achieved by providing protective bollards throughout the site. Also, proper screening procedures for persons entering the building greatly enhances the security of the structure.

The improvements noted above aim to prevent or mitigate disasters. On the other hand, in the event that a dangerous incident does occur, many upgrades were made to create safer egress from the building. For instance, the exit stairs were placed at opposite corners of the building core so as to reduce the travel distance to them as much as possible. The stairs and landings were made significantly wider than current code requirements.

To further increase the safety of the egress routes, redundancy was added. In scenarios where an exit is blocked, occupants are given the opportunity to take alternate routes.

Mechanical, electrical, and fire protection systems also added to the increased safety of the building. The stairwells are pressurized to prevent smoke infiltration into paths of egress. The air intake for the pressurization is located at the building rooftop where contamination is less likely. Also, the building core at each level will be sealed in the event of fire by smoke stop doors.

Fire protection was also enhanced by providing redundant fire standpipes and redundant communication equipment, and by applying high density spray-on fireproofing.

Conclusion

The 1.6 million square feet of Class A office space of Seven World Trade Center opened officially in the spring of 2006. It is only the beginning of an immense reconstruction process that will see the rebirth of lower Manhattan▪.

Bart Sullivan, P.E. is a Vice President with WSP Cantor Seinuk, and has been with the company in New York City for the past 13 years. Recently, he has relocated to Dubai, UAE to lead the company's high rise division in the Middle East.

Portions of this article were previously published in the October 2006 issue of *Civil Engineering Magazine* (ASCE). Reprinted with permission.

Architect's render of 7 WTC looking north along Greenwich Street.