Christopher McCune
Structural Option
Eight Tower Bridge
Faculty Advisor: Dr. Hanagan
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# Senior Thesis Proposal

## Executive Summary

Eight Tower Bridge is a 16 story steel high-rise office tower located outside of Philadelphia in Conshohocken, Pennsylvania. Completed in April of 2002, Eight Tower Bridge sits on the shore of the Schuylkill River, next to the Fayette Street Bridge, leading to both interstates I-476 and I-76. The building was designed by Skidmore, Owings and Merrill, and is owned by a partnership of Oliver Tyrone Pulver Corporation and Brandywine Reality Trust.

The building is the latest of the Tower Bridge projects to be constructed in the Conshohocken area. As such, the architect has incorporated the signature precast concrete and green-tinted glass façade of the other Tower Bridge buildings into this project. This façade is supported by a steel superstructure resting on pile caps covering groups of auger cast concrete piles. Additional foundation elements include a 4'3" thick MAT slab and concrete grade beams. The W-shape columns and floor beams support a composite concrete slab cast on metal deck. Theses members help support a rooftop mechanical penthouse that sits atop the 16th floor. The lateral force resisting system is a combination of moment resisting frames and a series of braced frames located at the building core.

The main focus of this thesis project will be the transformation of the existing steel superstructure into a concrete structure, employing a flat plate, post-tensioned concrete floor slab. The existing steel columns will be redesigned to be cast-in-place concrete columns, and the existing steel braced lateral resisting system will be replaced with concrete shear walls located around the building core similar to the existing frames. The purpose this concrete redesign is to evaluate and understand fully the impact on the overall building when the structural material is changed, as well as gain an understanding of post-tensioned concrete systems.

Two breadth topics will also be studied during this report. The first will be a construction schedule comparison based on the concrete structural system designed. The second topic will be an analysis of the mechanical system and the affects of increasing the mechanical plenum space, or decreasing the overall building height as a result of a employing a concrete flooring system over the existing steel system.

## Building Introduction and Background

Eight Tower Bridge is a 16 story steel high-rise office tower located outside of Philadelphia in Conshohocken, Pennsylvania. Completed in April of 2002, Eight Tower Bridge sits along the banks of the Schuylkill River, next to the Fayette Street Bridge, which leads to both interstates I-476 and I-76. Being located in the steadily growing Conshohocken area puts Eight Tower Bridge in a prime location for a multi-tenant office building and is less than 15 minutes outside of Centre City Philadelphia.

The building was designed by the high profile architecture firm of Skidmore, Owings and Merrill, who have been responsible for such structures as the Sears Tower in Chicago, and are currently designing the new Freedom Tower in New York City. Eight Tower Bridge is one of the most recent office buildings to be constructed in the Conshohocken area and was lead by the real estate development company Oliver Tyrone Pulver Corporation, in partnership with Brandywine Realty Trust. The signature precast concrete panels and green tinted glazing façade of Eight Tower Bridge was designed in concert with existing Tower Bridge projects in Conshohocken.

The office tower provides nearly 315,000 total square feet of office space on levels 2 through 16, while the ground level houses the entrance lobby, parking for nearly 40 vehicles, and a small space for a retail tenant. The three story entrance lobby is decorated with marble walls and floors, stainless steel doors with glazing, and wood paneled doors for the five passenger elevators and service elevator. The structure has been designed with long spanning bays, so the nearly 21,400 square foot floor plan is free of column obstructions. The typical story height is 12'1" with 8'6" floor to ceiling heights, and total structure height of 214 feet.

Eight Tower Bridge also incorporates the use of a rooftop penthouse to house mechanical equipment and an elevator machine room. The mechanical engineering firm of Jaros, Baum & Bolles was consulted in the design of the VAV rooftop system, while the structural considerations were taken care by Skidmore, Owings and Merrill.

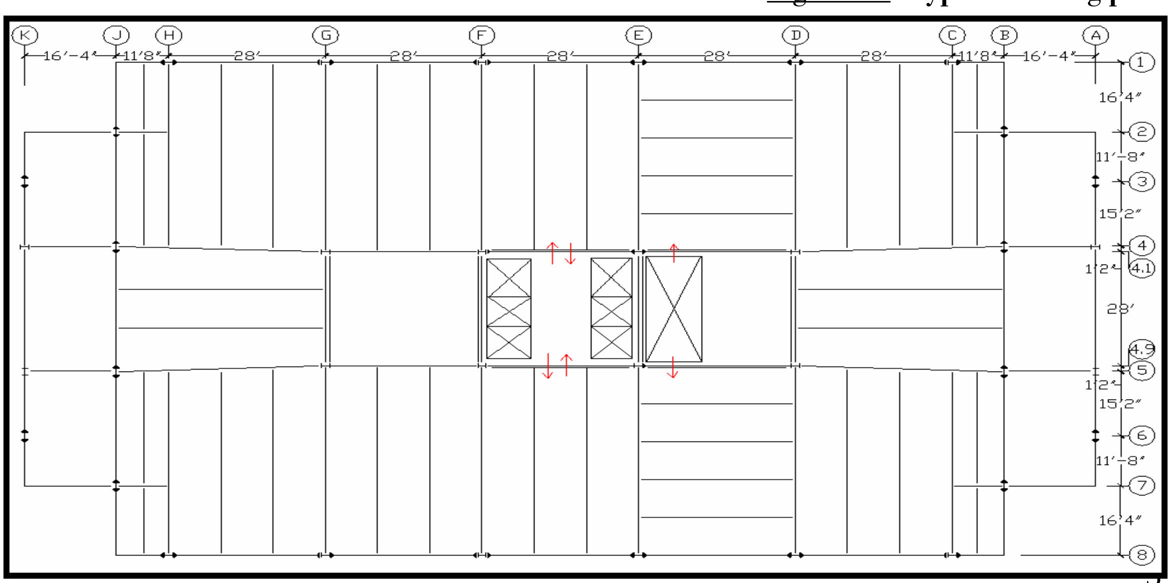
## Building Structure

Eight Tower Bridge is a steel framed high-rise office tower. The foundation system of the building supports 16 stories stretching 192' into the air. The steel frame structure also supports a mechanical penthouse level that rises 22' above the 16th story, topping the building out at 214' above grade. The steel superstructure sits on a foundation system consisting of 16" diameter auger cast, 4000psi concrete piles driven to an average depth of thirteen feet below grade. These piles are topped with pile caps and connecting grade beams. The core of the building employs a 4'3" thick reinforced concrete MAT slab to support additional gravity loads contributed from the rooftop HVAC and elevator equipment.

### Floor System

The steel framed office tower has been designed with repetitive floor structure, allowing for 13 of the 16 stories to have identical framing plans. Column sizes range from W14x550 at the building base to W14x61 at the rooftop level, and span two levels. Beams are sized primarily as W18 shapes, with the most common being W18x40 typically spanning 44'4" and spaced at 9'4". Exterior girders have been sized to W21x44 with spans ranging from 28' to 12'. Interior girders are primarily sized as W18 shapes with weights ranging from 26 to 86 pounds per foot. These beams and girders support a 5-1/4" composite slab poured over 2" metal decking. The layout of a typical framing plan is shown below in Figure 1.1 with arrows indicating egress openings.

**Figure 1.1- Typical framing plan**



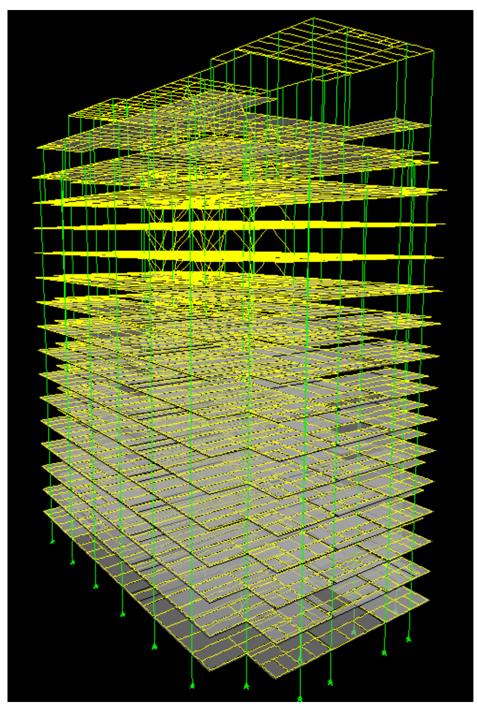
**Lateral Force Resisting System**

The lateral system of Eight Tower Bridge is comprised of both braced frames and moment resisting connections. At the core of the structure is an 18-story tower with a combination of six braced frames in conjunction with moment resisting connections at various points within the frame. The braced frames are located at the core of the building rather than the exterior to avoid conflicting with the building façade and aesthetics. However, eccentric bracing of the frames was necessary in order to provide stair tower doorway openings as well as elevator lobby entrances on each floor. The exterior of the building contains moment resisting frames only.

The lateral force resisting system has been analyzed under both wind and seismic loadings. Wind and seismic forces were developed in both Technical Assignments 1 and 3 through methods set forth in ASCE7-02, chapters 6 and 9 respectively. It was found that the wind forces control design in both the East-West and North-South direction, with the exception of top three floors in the North-South direction, where seismic loading was found to control.

## Problem Development

As previously mentioned, Eight Tower Bridge was designed by Skidmore, Owings and Merrill, a much respected architectural engineering firm. Therefore, it is acknowledged by the author that the structural design of the building was performed by design professionals with the utmost thought and design considerations. Research and understanding of the building's existing superstructure has been conducted through the completion of three Technical Assignments that reviewed the existing structural system, alternate flooring system options, and the lateral force resisting system. The existing structural members were found to be adequately sized to carry loads for the office building with the desired factor of safety. The flooring system was also found to be the most efficient when compared with compatible alternate flooring systems that didn't require changing the material of building. The third technical report analyzed the lateral force resisting system of the building. The building was modeled using the structural software ETABS and results compared to hand calculations refined from Technical Report 1.



In nearly all structural design offices, it is common practice to arrive at a structural system solution for any given building through the comparison of several different structural options for the same building. Some of these options may include large variations such as entirely different structural materials, most commonly concrete versus steel framing. Building options may also have other variations such a steel frame building with composite slab over metal deck, compared with pre-cast hollow core planks as the flooring system. These different options are compared against multiple criteria, including performance under loading, building type, system cost, constructability, site limitations, location factors and ultimately, a design that satisfies the client both functionally and aesthetically. It is probable that the design professionals at Skidmore, Owings and Merrill followed this practice and selected a steel framed structure with composite slab on metal deck.

Although the design professionals in charge of the Eight Tower Bridge project selected a steel frame structure with composite metal deck, there are obviously other systems that could be designed and compared with the existing system. This alternate system could be more advantageous in regards to the construction schedule, appearance, performance under loading, or constructability. Although high-rise office towers located in the Philadelphia region are predominantly designed as steel frame buildings, it is possible that Eight Tower Bridge could be designed as a concrete structure.

An alternate concrete structural system will be developed for Eight Tower Bridge. Of course, the primary consideration when evaluating any structural system is the ability of the system to adequately perform under the loading. Due to the relatively long spanning bays (44'4"x28') found in Eight Tower Bridge, a post tensioned flat plate concrete slab will be designed in place of the current slab on metal deck over steel beam configuration. The implementation of a post-tensioned concrete floor system will allow the column placement to remain relatively unchanged due to the capability of post-tensioned concrete to span longer distances that regular reinforced slabs. The change to a concrete system will require that concrete columns and beams be sized to carry the existing live and dead loads, as well as the self weight of the floor slab. The change to a concrete floor system will also require the elimination of the existing braced frames in the lateral force resisting system. Concrete shear walls will be designed and place "U-shapes" around the two stair towers located in the core of the building. The loadings used to analyze this system will be updated from BOCA 96 to IBC 2000, which references ASCE7-02.

It is expected that the change from a steel system to a concrete system will alter the building cost and construction schedule. It is also expected that either the overall building height will decrease, or the floor to ceiling height on each floor will increase, as post-tensioning allows for an overall thinner flooring system. A third result of the concrete system would be an unchanged overall and floor to ceiling height, and an increase in the mechanical plenum space. The increase of this mechanical plenum space may allow for the use of a squarer duct, thus altering the mechanical system.

Any time there is a change in the scope of work of the building, such as changing the entire structural system, there will be an obvious change in the cost and schedule of the building. A cost and construction schedule comparison will be conducted as part of my breadth work. A second breadth study will be conducted regarding the value of increasing the mechanical plenum space with the possibility of increasing mechanical system efficiency against decreasing the overall building height to save costs on mechanical and electrical system delivery components.

## Problem Solution

The existing composite steel flooring system will be changed to a post-tensioned concrete slab in the 44'4"x28' bays and a two-way reinforced concrete slab in the mechanical spaces. Additionally, columns carrying the building load to the foundation will be redesigned as cast-in-place concrete members or a comparable size to the original W14 sized columns. Once the gravity system and flooring system has been redesigned, concrete shear walls will be designed to resist the lateral wind and seismic loads, replacing the current steel braced frames.

## Solution Method

Altering the building's structural material from steel to entirely concrete will require the redesign of all the structural components, including beams, shear walls, columns and in some cases, column capitals or drop panels. These elements will be designed in accordance with ACI 318-05 *Building Code Requirements for Structural Concrete* and IBC 2000.

Since there has been little study of post-tensioned concrete systems in my coursework, there will undoubtedly be a good deal of research required in order to adequately design and incorporate such a system into the current structure. This will be done with consultation with design professionals, faculty advisors, and fellow classmates. Once a sufficient amount of information regarding post-tensioned systems has been developed, a flooring system will be designed that incorporates both post-tensioned and two-way steel reinforced slabs.

The design of concrete columns will be first be done by hand in accordance with ACI 318-05 and verified with PCACOL. Once the gravity elements have been designed, a concrete shear wall design will be conducted knowing the placement of the existing lateral system, but altering the placement of the walls slightly. The shear wall design will be conducted in accordance with ACI 318-05, Chapter 14. The shear walls will be verified using STAAD or ETABS.

## Tasks and Tools

The following is a general list of tasks to be completed in order to transform the existing steel structure of Eight Tower Bridge to concrete in order to study the effects this change would have.  Additional tasks include the two out of option breadth studies, which will be related to the change of the building from steel to conrete.

Task 1: Development of post-tensioned floor system

a. Research post-tensioned slabs
b. Determine minimum thickness of slabs through 9.5(a)
c. Design post-tensioned slabs for 28'x44'4" bays

Task 2: Additional concrete members

a. Calculate new floor loads with slab self weight
b. Design columns for the structure to carry loads developed in Task 1 and Task 2 (a)
c. Design two way slabs for mechanical floors

Task 3: Design of concrete shear walls

a. Design concrete shear walls using ACI 318-05, Chapter 14 and with loading developed in Technical Report 3
b. Verify shear walls with computer model
c. Compare with original system performance

Task 4: Cost estimate development

a. Through a take off in RS Means, a superstructure cost estimate will be developed for the original and altered structures.

Task 5: Construction schedule

a. A construction schedule for the two separate systems will be developed and compared.

Task 6: Mechanical breadth work

a. The existing efficiency of the mechanical system will be evaluated
b. The efficiency of the mechanical system with altered duct sizes due to a larger mechanical plenum space will be evaluated
c. A financial impact on the mechanical system of lowering the building height will be conducted.  The main cost savings will be in the length of duct and piping used.  This will be compared with the change in mechanical performance.

Task7: Finalization of work

a. Compilation of semester's work
b. Draft final paper with conclusions
c. Write and practice presentation

Below is a time table set for the Spring semester pertaining to when these tasks are to be completed.

| Month | Week Of | Task/Event |
|---|---|---|
| JANUARY | 9 | Classes Start<br>Researching/Consult on Post-tensioning systems |
| | 16 | Researching/Consult on Post-tensioning systems |
| | 23 | Design of post-tensioned floor system |
| | 30 | Additional concrete system element designed (columns, two-way slabs, edge beams, etc) |
| FEBRUARY | 6 | |
| | 13 | Shear Wall Design |
| | 20 | System Modeled in ETABS/Foundation Check |
| | 27 | Development of cost estimate/construction schedule for comparrison |
| MARCH | 6 | ***********SPRING BREAK *********** |
| | 13 | Mechanical Breadth work |
| | 20 | Composition of paper/wrap up of research |
| | 27 | Final paper finishing touches/presentation prepared |
| APRIL | 3 | Final paper due |
| | 5 | Presentation preparation |
| | 12 | Presentation |
| | 28 | Review of thesis experience |
| MAY | 1 | Final review and CPEP site final check |

## Breadth Studies

As eluded to above, two out of option breadth studies will be conducted in concert with the main body of research in this report. The first breadth will be comparison in the construction schedule between the existing structural system and the newly designed concrete one. The second study will be a Mechanical system evaluation also based on the change from a concrete to steel structure.

The construction management breadth will compare the construction schedule of the existing steel superstructure to the new concrete one. Site concerns and logistics related to the change of a material will also be addressed in this breadth, but will not be the emphasis of the breadth.

A second breadth study will be done with the focus of the building mechanical system. The current HVAC units of Eight Tower Bridge are housed within a rooftop penthouse, and the mechanical duct work runs through three feet of mechanical plenum space at each floor. A comparison will be made between two options that become available when a flat plate concrete floor system is involved. The first will be the option to increase the mechanical plenum space to allow for a redesign of ductwork, which may increase mechanical efficiency or allow for the resizing of cooling units. The second option will involve keeping the plenum space the same as the original design, and translating the estimated 6"-8" reduction in floor depth to an overall reduction in building height. This would decrease the length of vertical mechanical runs, translating into an overall reduction in mechanical system material cost. The material savings will be compared to any savings in mechanical efficiency.

## Conclusion

The goal of the AE Senior Thesis is to obtain "real world" design experience while gaining technical competence with respect to design and construction. As previously mentioned, post-tensioned concrete building systems is a topic within the structural discipline that I have not been overly exposed to throughout my course of study. It is my goal to complete a full transformation from a steel building to a concrete structure in order to obtain a firm grasp on post-tensioned concrete, and how multiple design options affect the other disciplines regarding building design.