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Structural Option
Eight Tower Bridge
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December 12th, 2005

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 focus of this thesis design project will be the lateral system. The goal of the project is to perform an in-depth analysis of the current system to develop a better understanding on how the lateral forces are distributed throughout the superstructure of Eight Tower Bridge. With this knowledge, alternate lateral systems will be developed and compared to the existing lateral system. The alternate systems will first be compared with respect to their structural performance, and then evaluated on a cost and constructability scale to determine if there is a more economical lateral system that maintains structural adequacy. A 3D model of the entire structure will be developed through ETABS, and costs compared through R.S. Means.

Two breadth topics will also be studied during this report. The first will be a construction schedule comparison based on the alternate lateral system found to be most viable. The second topic will be an analysis of the rooftop mechanical penthouse, more specifically the noise and vibration effects associated with rooftop HVAC equipment.

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 Reality 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.

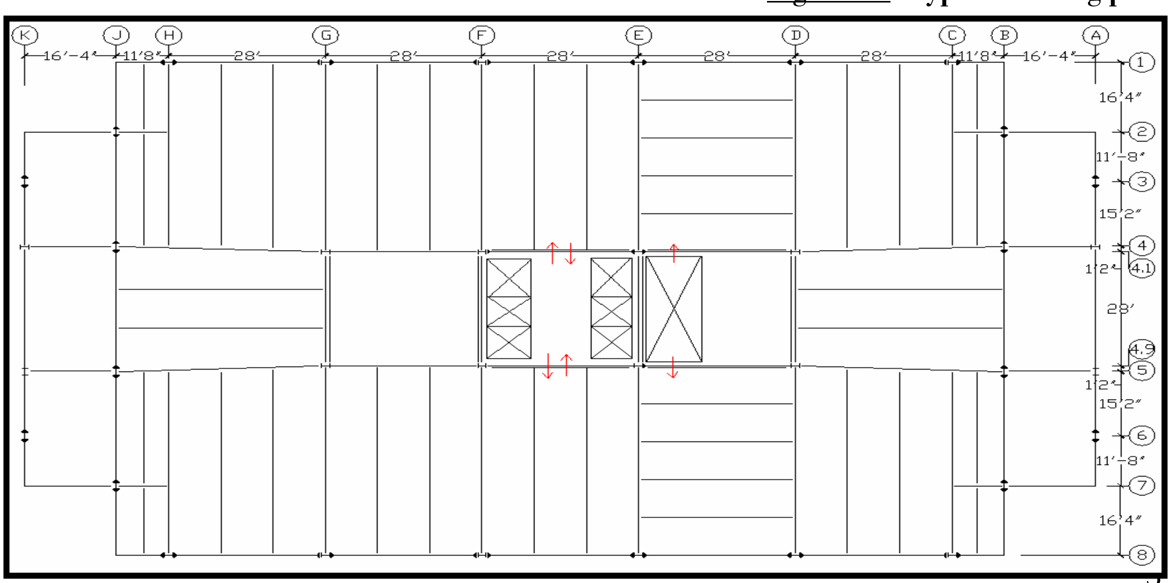
Eight Tower Bridge also incorporates the use of a rooftop penthouse to house mechanical equipment and an elevator machine room. The mechanical engineering firm of Jaros, Baum & Bolles was consulted in the design of the VAV rooftop system, while the structural considerations were taken care by Skidmore,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

Building Structure

Eight Tower Bridge is a steel framed high-rise office tower. The structural 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 superstructure sits on a foundation system consisting of auger cast 16" diameter, 4000psi concrete piles driven to an average bearing depth of thirteen feet below grade, and 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.

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

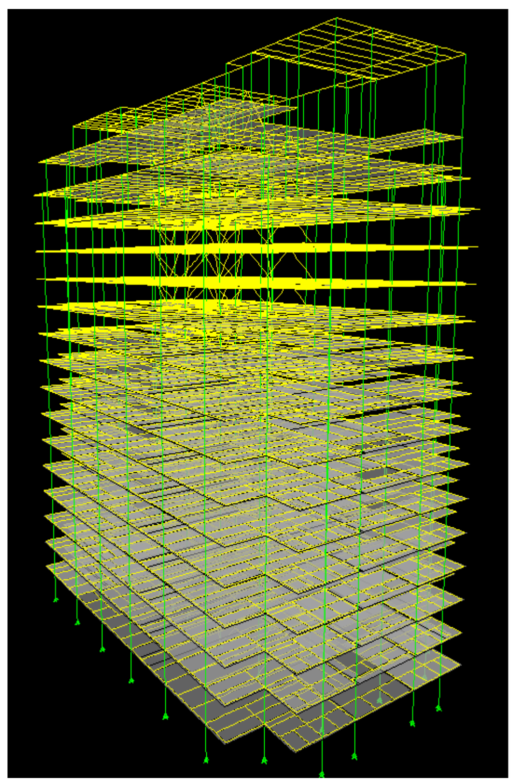


The lateral system of Eight Tower Bridge is comprised of both braced frames and moment resisting connections. At the core of the structure is an 18-story tower with a combination of six braced frames in conjunction with moment resisting connections at various points within the frame. The braced frames 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 Statement

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 practice experience and resources that extend beyond those available for analysis thus far in senior thesis. Through completion of three Technical Assignments that reviewed the existing structural system, alternate flooring system options, and the lateral force resisting system respectively, no glaring structural deficiency could be found. 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. However, it was during the third technical assignment that a chance for a structural depth topic presented itself. As previously mentioned, Technical Report #3 was a review of the lateral force resisting system.



3D Model developed through ETABS

In Technical Assignment #3, the lateral system was analyzed through both methods from ASCE7-02 and through computer analysis with the structural modeling software ETABS. The system was found to perform adequately under the assumptions made to simplify the analysis. However, discrepancies did exist between the results of the computer model and hand calculations. The disagreement of results can be attributed largely to computer modeling errors. Therefore, the lateral force resisting system will be looked at through a more in-depth investigation to develop an accurate behavior model of the existing lateral system, and to see if an alternate system can be developed.

Lateral system design is something that I have not been overly exposed to in my coursework as a structural engineer, so performing an in-depth analysis of an existing system will allow me to develop some familiarity with the subject matter. I feel that this is one of the most important purposes of the Architectural Engineering Senior Thesis experience. In my primary analysis of the lateral force resisting system, it was assumed that the braced frames were the only lateral load resisting elements of the structure. However, when comparing the lateral forces on each frame from hand calculation results to output from the ETABS model, it can be seen that other elements in the structure help to resist these forces. In actuality, lateral forces on the structure would be resisted by the moment resisting frames found on the building perimeter, and the effects of "leaning columns" should be considered. The goal of this lateral system investigation is to develop an accurate, industry standard model and review the performance of the system under wind and seismic loading. I will then develop alternate lateral systems and compare them to the existing system, with a primary goal of eliminating some of the costly and detail-intensive moment connections found in the current lateral system without sacrificing structural stability.

Problem Solution

A study of the existing lateral system is the proposal for my thesis research next semester. The system will be evaluated with respect to its overall strength and resistance to drift, while also being analyzed from a constructability and cost standpoint. The current 3D model setup in ETABS will be refined in its design and modeling assumptions and subjected to wind and seismic loadings in accordance with ASCE7-02. Hand calculations will be used to verify the results, as well as consultation with the structural engineer of record. Other structural programs such as STAAD or RAM may be used to analyze a single frame.

After the existing lateral system has been reviewed and evaluated from a structural standpoint, three other systems will be researched and introduced as alternate lateral system solutions. The three alternate systems to be researched are

- -concrete shear walls
- -eccentrically braced frames at the building core
- -the introduction of braced frames at the building's exterior

Other structural elements, such as columns and foundations will be designed accordingly as the alternate systems require.

These systems will be evaluated in regards to their structural capacity first and secondly, cost and constructability to determine if they are more or less economically efficient.

Solution Method

The repetitive steel floor design Eight Tower Bridge lends the ability to investigate and incorporate multiple types of lateral systems fairly easily. Since a "working" 3D model of the superstructure and existing lateral system was created through ETABS for Technical Assignment #3, the model simply needs refinement and verification. Once this is done, the model can be altered through ETABS to include the different lateral systems of interest. The analysis and design of each of these systems will be in accordance with the Load and Resistance Factor Design methods as set forth in the AISC steel manual, as well as ACI 318-05 for all concrete elements. Wind and seismic loads will be developed through ASCE7-02, chapters 6 and 9 respectively, both through Method 2 in chapter 5. After the alternate systems are determined to be structurally sufficient, they will be evaluated from a monetary standpoint through RS Means to see if they are more or less cost efficient.

Breadth Studies

In addition to the structural depth that serves as the focus of this thesis project, two breadth studies will be performed in out-of-option disciplines. The first breadth study will be under the Construction Management option, which will include the development and comparison of the construction schedule for the original lateral system and the alternative system designed. As previously mentioned, the moment connections found in the existing system are rather costly and detail-intensive, so the removal of them will hopefully reduce the overall construction schedule.

The second breadth study will involve a review of the mechanical penthouse and the rooftop equipment that is housed within it. More specifically, I will analyze the acoustic and vibration affects of locating this equipment on the roof of this high-rise office tower.

Tasks and Tools

The first step in this lateral system redesign is going to be the revision and review the 3D model created in ETABS, as well as the review of the wind and seismic loads developed in Technical Reports 1 and 3. These calculations will be verified with both the design engineer and faculty consultant.

Once the 3D model in ETABS is constructed to industry standards, it will be altered to include the alternate systems of interest. These systems will first be checked for structural adequacy, and further reviewed based on cost and constructability factors. The alternate systems may also have to be reviewed in regards to any impact they may have on the overall architectural design of the building.

Once the alternate systems are subjected to an in-depth cost analysis is carried out on each system, RS Means will be used to develop a partial construction schedule, focusing primarily on the superstructure, and more specifically the lateral system elements. The timetable for the completion of this work can be found below.

Timetable

Month	Week Of	Task/Event
JANUARY	9	Classes Start Review/Verify Seismic and Wind Calculations
	16	ETABS Model Verified
	23	ETABS original model analyzed
	30	Change ETABS model to include alternate lateral systems and output reviewed
FEBRUARY	6	
	13	Hand calculations complied as needed/members spot checked
	20	Cost evaluation performed on alternate systems
	27	Best alternative selected/Construction schedules developed
MARCH	6	***********SPRING BREAK ***********
	13	Mechanical penthouse vibration/noise evaluated
	20	Results compiled/final paper constructed
	27	Final paper finishing touches/presentation prepared
APRIL	3	Final paper due
	5	Presentation preparation
	10	Presentations
	28	Review of thesis experience
MAY	1	Final review and CPEP site final check