510 Glenwood Avenue
Raleigh, North Carolina

The Pennsylvania State University
Architectural Engineering Thesis 2005
By
Nicole Pawolleck – Structural Option

510 Glenwood Avenue
Raleigh, North Carolina

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Thesis website - http://arche.psu.edu/thesis/2005/nip101

Project Overview
- Multi-use building - Restaurant, Retail, Office, and Residential Condominiums
- Seven Stories
- Size - 137,066 ft^2
- Construction dates - July 1999 through Spring 2001
- Approximate Cost - $26 million
- Design-Bid-Build Project

Project Team
- Burcam Capital II, LLC - Owner
- Cline Davis Architects - Architect
- Stewart Engineering - Structural Engineer
- Diversified Consulting Group - Mechanical/Electrical
- Able Fire Protection Design - Sprinkler/Fire Protection
- Choate Construction - General Contractor

Architecture
- Modern living in one of the most sought-after destinations in downtown Raleigh
- Condos are of a graceful and stylish quality and are positioned on the top floors of a building that houses restaurants and clubs below
- Condos include nine-foot ceilings, hardwood floors and gas-log fireplaces
- Brick veneer facade

Structural
- Cast-in-place concrete flat plate and flat slab systems
- Lateral loads are resisted by cast-in-place concrete shear walls
- 12" thick reinforced cast-in-place concrete slab on grade
- 9" thick reinforced cast-in-place concrete floor slab
- 45 mil EPDM fully adhered roofing sytem with 4" minimum Polyisocyan insulation over metal deck and steel joists

Mechanical
- Individual HVAC systems in each condominium
- Gas fired hot water heater in mechanical closet for each condo
- Two cooling Towers, gas fired hot water heater, and 100 Gal. ASME compression tanks

Lighting/Electrical
- Fluorescent strip lighting in restaurant area
- Recessed downlighting in entrance areas and lobbies
- Track, fluorescent, and downlighting in condominiums
- 1200A main circuit breaker, 1200A cross bussing, 125 Ampere, 2 Pole Fusible for each respective unit

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Executive Summary

Located along the highly desirable Glenwood South corridor, 510 Glenwood offers the convenience of modern living in one of the most sought-after destinations in downtown Raleigh.

510 Glenwood Avenue is a seven-story, 150,000 sq. ft. Class A mixed-use building (restaurant, retail, office, residential and parking) consists of a cast-in-place concrete flat plate and flat slab systems. Cast-in-place concrete shear walls resist lateral loads.

My proposed solution is to do a redesign of the buildings structural system by using wide flange steel members as the main material. A steel structure can be efficiently erected and decrease the labor costs created by the formwork needed for all the cast-in-place concrete. A redesign from concrete to steel was done to compare the two construction materials and get a better sense if either of the two would have been more advantageous in the construction of 510 Glenwood Avenue.

For the gravity system of the building a composite beam and girder construction was analyzed by RAM and for the lateral system a system of braced frames placed where the original shear walls existed was chosen. A redesign of the building from concrete to steel was found feasible for this particular building.

In a cost and schedule analysis it was found that the steel structure cost more, but took less time to erect than the concrete structure. As a final conclusion the steel structure would be more economical, since some cost factors, such as the foundation and connections, were not considered in the redesign.

Fireproofing of the steel is another important factor that needed to be considered and designed. A 1 1/8 inch thickness of MK-6 spay-on fireproofing for both columns and floor system was found adequate for a needed 2 hour rating.

INTRODUCTION

Project Team

Owner/Developer	BURCAM CAPITAL II, LLC
Architects	CLINE DAVIS ARCHITECTS PA www.clinedesignassoc.com www.jdavisarchitects.com
Structural Engineer	STEWART ENGINEERING www.stewart-eng.com
Mechanical/Electrical	DIVERSIFIED CONSULTING GROUP
Sprinkler/Fire Protection	ABLE FIRE PROTECTION DESIGN
General Contractor	CHOATE CONSTRUCTION COMPANY www.choateco.com

Building Overview

Located along the highly desirable Glenwood South corridor, 510 Glenwood offers the convenience of modern living in one of the most sought-after destinations in downtown Raleigh. The condos are of a graceful and stylish quality and are positioned on the top floor of a building that houses restaurants and clubs below.

Figure 1: Front View of 510 Glenwood Ave

510 Glenwood offers the convenience of downtown life that is literally only seconds away. Each condo is specially designed to make city living truly relaxing, with nine-foot ceilings, hardwood floors and gas-log fireplaces - to mention just a few of the luxurious amenities that complement the convenience of the 510 Glenwood location.

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Figure 2: Front View Picture taken July 2004

General Existing Conditions

General Project Data

- **Building Name:** 510 Glenwood Avenue
- **Location and Site:** 510 Glenwood Avenue-Downtown Raleigh, North Carolina
- **Building Occupant Name:** Grubb & Ellis, Thomas Linderman
- **Function:** Multi-use Building - Restaurant, Retail, Office, Residential Condominiums
- **Size:** 137,066 SQ FT
- **Number of Stories:** 7 Floors – 6 above and 1 below grade
- **Dates of Construction:** July 1999 through Spring 2001
- **Actual Cost:** Approximately $26 million
- **Project Deliver Method:** Design – Bid – Build

Architecture

The architects decided for a brick veneer façade and aluminum window frames, but what makes this building unique is its atrium corner of the L-shaped building. The atrium is the first thing that will catch your eye, as soon as you come into that part of the town.

Major National Model Codes

The major building codes used for this project is the North Carolina State Building code of 1996, North Carolina Accessibility Codes, and City of Cary

Codes and Ordinances. Other codes such as the AIA Document A201-1997 and ASCE 7-95 were also applied.

Zoning and Historical

510 Glenwood Avenue is located downtown Raleigh in North Carolina. The site itself is located between Johnson Street and Tucker Street, which run perpendicular to Glenwood Avenue. The zoning for this site is specified as I-2 – Downtown Residential Overlay District, which means that the building could be either residential or commercial. In this case the architects went for a combination of both. The ground floor contains restaurants and building services, the first floor includes retail and restaurant space, the second and third floor are designated for offices, and the remaining three floors are residential condominiums.

Building Envelope

The building envelope consist of a 12" concrete slab with welded wire fabric over 6 mil vapor barrier and a 4" granular fill for the slab on grade and 9.5" cast-in-place reinforced concrete floor slab with 4" thick spray on insulation for all the remaining floors. The exterior wall at ground level is made of 4" brick veneer over 8" cmu over 6" metal studs with R19 batt insulation and the remaining exterior wall consists of 4" brick veneer over ½" gypsum sheathing over 6" metal studs with R19 batt insulation. For all window openings, aluminum window frames were used with different types of windows depending on location within the building. The roof of the building is made of 45 mil EPDM fully adhered roofing system with 4" minimum Polyisocyan insulation over metal deck and steel joists and with a suspended gypsum ceiling.

Electrical

480V/3PH switchboard is located in the main electrical room on the ground floor. Each condominium has a 120/240V panel.

Lighting

In the restaurant area fluorescent strip lighting was used and recessed downlighting in entrance areas and lobbies. For the condominiums track, fluorescent, and downlighting was used.

Mechanical

In each condominium there are individual HVAC systems and gas fired hot water heater in the mechanical closet. Two cooling Towers, gas fired hot water heater, and 100 Gal. ASME compression tanks are located on the roof of the building.

Structural

The structural system consists of cast-in-place concrete flat plate and flat slab system. Cast-in-place concrete shear walls resist the lateral loads.

Construction

The construction process was design-bid-build. Construction started in July 1999 and ended around the springtime in 2001.

Fire Protection

A sprinkler system is in place for the entire building. Each floor and the wall surrounding the staircases have a fire resistive rating of 2hours. The roof has a fire resistive rating of 1hour.

Transportation

Two elevators are located in the northwest part of the building. One is used for access to the condominiums only and the other one is used to access the offices on the 2nd and 3rd floor. In addition to the elevators, there are two main staircases that run the whole height of the building. One staircase is located in the northeast part of the building and the other is located in the southwest part.

STRUCTURAL

Original Structural System

510 Glenwood Avenue located in downtown Raleigh, NC is a seven-story, 150,000 sq. ft. Class A mixed-use building (restaurant, retail, office, residential and parking) consists of a cast-in-place concrete flat plate and flat slab systems. Cast-in-place concrete shear walls resist lateral loads.

The foundation of the building consists of caissons, located underneath every concrete column and underneath the shear walls, and a 9" thick cast in place slab on grade. Concrete Grade Beams were chosen for the support of the slab on grade and the exterior wall system around the perimeter of the building.

The first through fourth floor consist of a 9" thick cast in place two-way flat slab with 4" drop panels around each concrete column. The fifth and sixth floor and the roof are made of 10" thick cast in place two-way flat plate. Each floor is supported by 20"x20" TYP columns, which are spaced 25' or 30' on center throughout the building. Above the ground floor, for each floor the perimeter is constructed of concrete beams placed on top of the exterior concrete columns. These concrete beams support the perimeter of each floor slab and give more support for the exterior wall system.

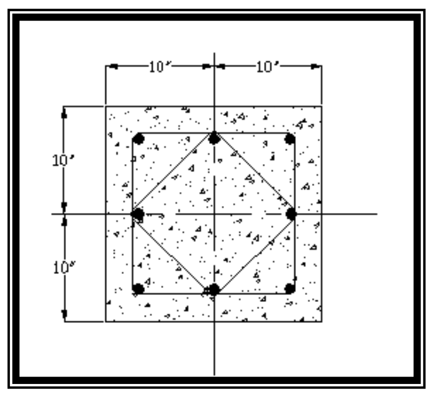

Figure 3: Typical Column

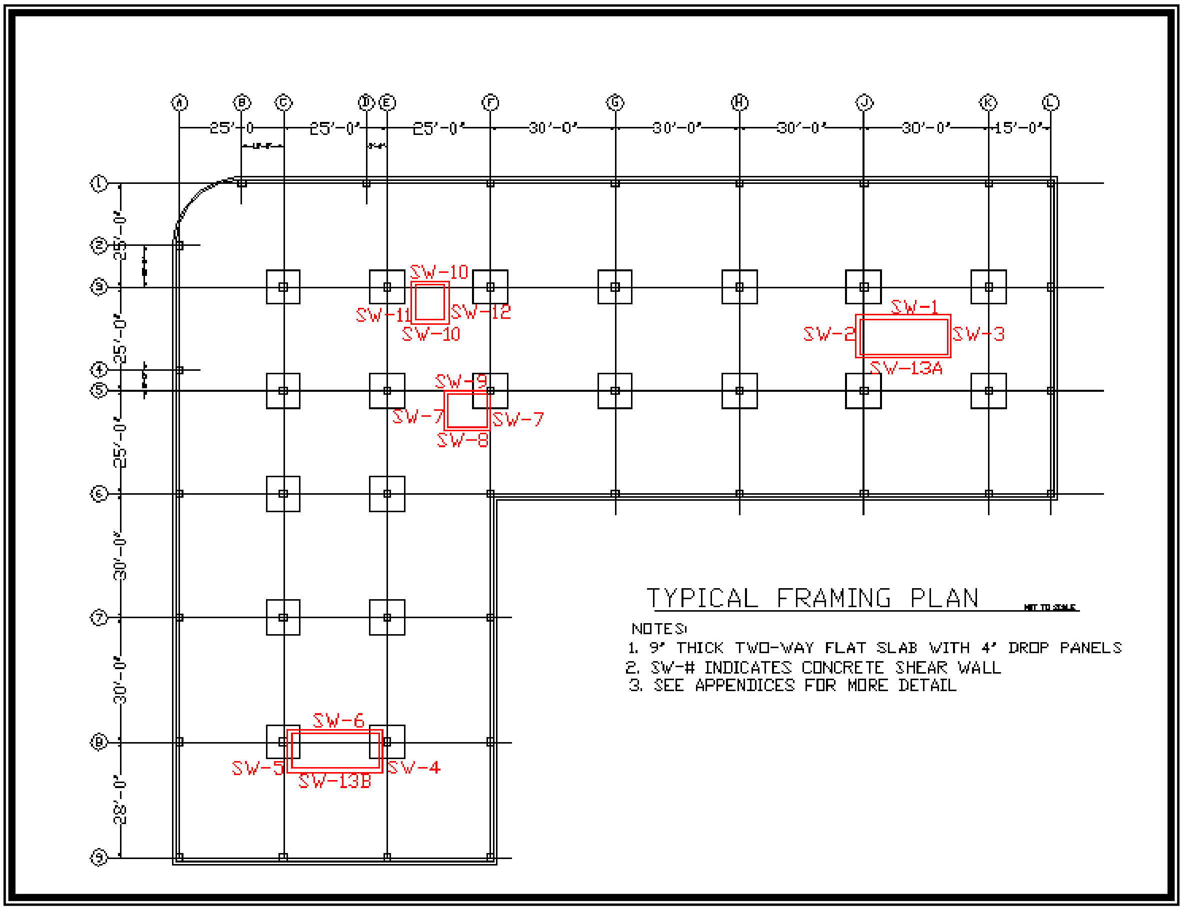

Figure 4: Typical Floor Framing Plan

Concrete shear walls were chosen for the lateral support system. These shear walls are located around each elevator shaft and around the stairs located at the northeast and southwest part of the building. The shear walls are 12" thick cast-in place concrete and the vertical and horizontal reinforcement is #5@12". All shear walls run for the entire length of the building except the one located around the office elevator (north-west corner of building).

Appropriate Building Codes

- North Carolina Standard Building Code 1996
- ASCE 7-96
- American Concrete Institute (ACI) 301, "Specifications for Structural Concrete for Buildings"
- ACI 318, "Building Code Requirements for Reinforced Concrete"
- Concrete Reinforcing Steel Institute (CRSI) "Manual of Standard Practice"
- AISC's "Specification for Structural Steel Buildings – Allowable Stress Design and Plastic Design"
- AISC's "Load and Resistance Factor Design (LRFD) Specification for Structural Steel Buildings

Design Live Loads

- Roof 20 PSF
- Residential 40 PSF
- Parking 50 PSF
- Retail 75 PSF
- Office 80 PSF
- Corridors 2nd to 6th Floor 80 PSF
- Corridors Ground & 1st Floors 100 PSF
- Restaurants 100 PSF
- Stairs 100 PSF

Seismic loads

Seismic loads were calculated according to the North Carolina Building Code of 1996.

- Peak velocity related to acceleration, A_v = 0.075
- Peak acceleration, A_a = 0.050
- Hazard Exposure Group II
- Performance Category B
- Soil profile type, S = 2.0
- Reinforced concrete shear walls:
- Response modification factor, R = 4.5
- Deflection amplification factor, C_d = 4.0

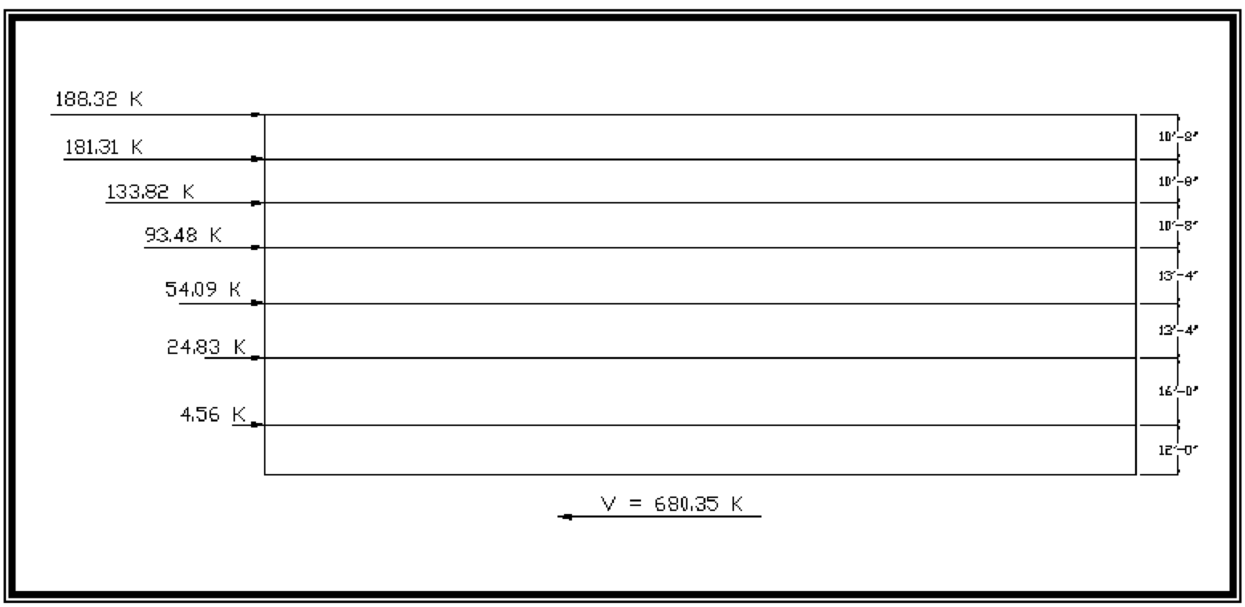

Figure 5: Seismic Story Loads

Wind loads

- Wind Loads were calculated according to ASCE 7-98
- Basic design wind velocity = 80 Mph
- Exposure C
- Importance Factor, I = 1.07

Height	K_z	q_z	P_{wz} (psf)
0-15	0.85	12.67	8.62
20	0.90	13.41	9.12
25	0.94	14.01	9.53
30	0.98	14.60	9.93
40	1.04	15.50	10.54
50	1.09	16.24	11.0
60	1.13	16.84	11.45
70	1.17	17.43	11.85
80	1.21	18.03	12.26
90	1.24	18.48	12.57
100	1.26	18.77	12.76

Figure 6: Calculated Wind Loads

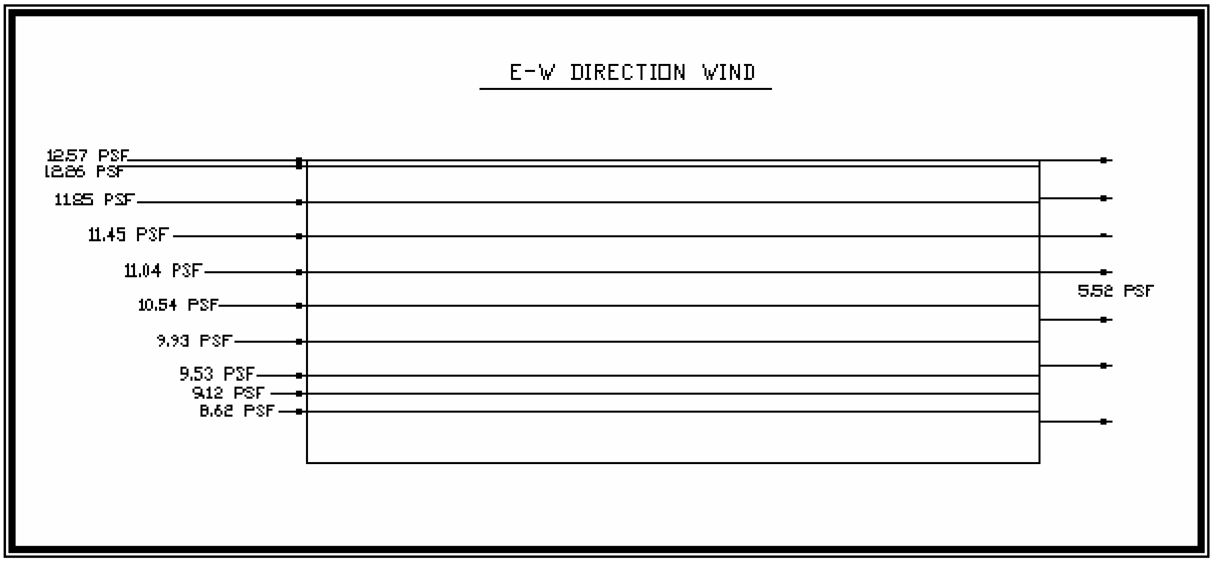

Figure 7: East-West Wind Loading

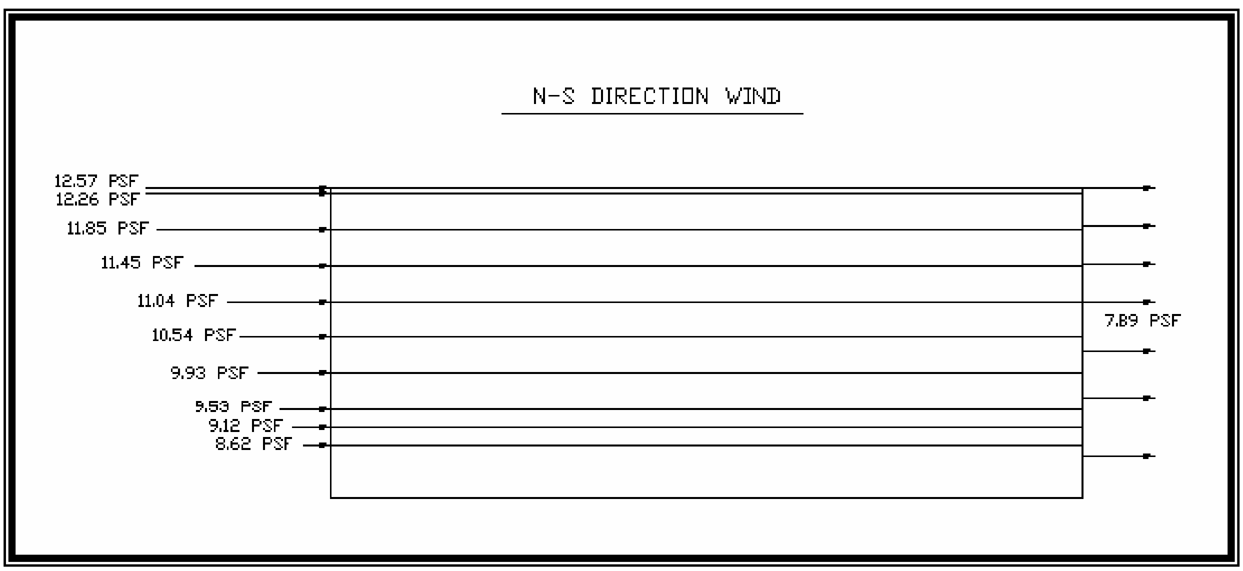

Figure 8: North-South Wind Loading

Problem Statement

510 Glenwood Avenue is located in downtown Raleigh, North Carolina. The main building material chosen for this building was cast-in place concrete. Concrete is a heavy material and therefore the dead loads for this building tend to very high, which ultimately result in bigger columns and slabs. In addition the formwork is very tedious and expensive for an all around cast-in-place building. Cost and time is an inevitable issue in all building projects. It is therefore important to analyze different structural systems and incorporate the most economical in the structure. Unfortunately a lot of times a time restraint does not allow for a complete analysis of multiple structural systems.

Figure 9: Construction Photo

Proposal

My proposed solution is to do a redesign of the buildings structural system by using wide flange steel members as the main material. A steel structure can be efficiently erected and decrease the labor costs created by the formwork needed for all the cast-in-place concrete. Within a new steel design there are number of gravity systems, lateral systems, and combinations of these that can be investigated to determine an optimum steel system. Wide flange steel shapes will be utilized in the columns, the girders and the beams. The existing concrete columns will be replaced by steel columns, which should not change the floorplan much at all. Fireproofing will now need to be taken into account due to the fact that steel is not naturally fire resistant like the previously designed concrete.

For the floor system one option will be explored to see which would be more economical. A metal deck and slab floor system is easy to install and very common in the construction industry.

The options to explore for the lateral system include moment frames and braced frames. Due to construction time and connection cost braced frames are more economical moment frames. However, moment frames allow for an open plan and unobstructed views. The moment connections also inhibit the disassembly of a structure, but the additional members of a braced frame contribute more material to the overall structure. A preliminary check for both systems will be done to see which one would be more feasible in 510 Glenwood Avenue. Whichever lateral system is more economical will be incorporated in the final design.

.The price of the structure should be fairly comparable to the previous design since the labor costs will be decreased as will erection time. Therefore, a comparison estimate and schedule can be produced. The resulting steel system will be compared to the existing concrete structure considering cost, schedule, and fire protection.

Loads will be determined by combining originally specified loads with loads calculated using ASCE7-02. Preliminary typical frame analysis of the floor system will be analyzed using the LRFD method in RAM Structural System. Hand calculations will be performed using the forces determined by RAM and the design procedure prescribed by the AISC LRFD Steel Manual to ensure the economy of members. Layout and geometry of braced frames will be determined integrally with the architectural design. Trial members will be determined using gravity loads only. The resulting frames will be modeled and analyzed in RAM. Individual members of the braced frame will be checked for axial loading and flexure will be checked in the moment frame members.

Design Criteria

One of the most important design criterions in the steel redesign is to not change the architectural layout of the building to keep the architectural intent of the building. In addition to keeping the original architecture, the economical aspects of the redesign need to be investigated to see if the redesign is a feasible alternative to the original. Some of the important factors to consider when designing a steel building are:

- Sizes of members – the lightest section are not always the most economical, repetition of member size is usually the more economical solution
- Connections – bolted or welded, bolted connections are cheaper and less labor intensive
- Lateral system – moment or braced frames
- Floor system – composite or non-composite

Of course the most economical choice is not always a feasible choice.

The design criteria for wind loading stayed the same as in the original building. For the seismic loading, the only thing that changed was the R value, from a 4.5 to a 3. An R value of 3 was chosen, since an R value greater than 3 would invoke the detailing requirements in the AISC Seismic Provisions, which include member requirements and connection requirements. As a result, the lateral framing systems for R > 3 will almost always be heavier than lateral framing systems for R = 3, even though the seismic base shear is smaller. Therefore choosing an R value of 3 is conservative.

DEPTH WORK

Overview

The premise of my structural redesign is concrete versus steel. The existing structural system of 510 Glenwood Avenue is cast-in-place concrete columns with either a flat slab or flat plate. Some of the advantages of a reinforced concrete structure are: durability, fire resistance, speed of construction, cost, and availability of labor and materials. A reinforced concrete structure, with proper concrete protection of the steel reinforcement, will have a long life, even under highly adverse environmental conditions. It also provides maximum fire protection, since concrete does not need any additional fire proofing. In terms of the entire period, from the date of approval of the contract drawings to the date of completion, a concrete building can often be completed in less time than a steel structure. Although the field erection of a steel building is more rapid, this phase must necessarily be preceded by prefabrication of all parts in the shop. In almost every case, maintenance costs of a concrete structure a less. In addition it is always possible to make use of local sources of labor and in many cases a nearby source of good aggregate can be found.

In a flat slab with drop panels system, the slab is directly supported on the columns, where the slab is thickened around the column to increase the shear strength of the floor system in the critical region around the column and provide increased effective depth for the flexural steel in the region of high negative bending moment over the support. In general, flat slab construction is economical for live loads of 100 psf or more and for spans up to about 30 feet.

In a flat plate construction the drop panels are omitted, so that the floor of uniform thickness is directly supported by the columns. This system has been found economical for apartment buildings, where the spans are moderate and loads are relatively light. The construction depth for each floor is minimal, which results in a less overall height of the building. Very simple formwork reduces construction time and labor costs.

There are several different types of steel construction: bearing wall construction, skeleton construction, long-span construction, and a combination of steel and concrete framing. The skeleton steel construction was used for the redesign, where the loads are transmitted to the foundation by the framework of beams and columns. In this type of construction the frame usually consists of columns spaced 20, 25, or 30 feet apart, which works with the original layout of the building.

In comparison to concrete, steel offers a maximum of flexibility and adaptability, increased useful life, high earthquake security, rapid construction times and elegance. In addition, steel constructions can be reinforced, expanded, raised, dismantled and moved to a new location more easily than designs made of concrete. Some of the other advantages of steel construction are: high strength, uniformity, permanence, ductility, and toughness. Steel has a very high strength per unit weight, which means that the weight of the overall structure will be small. The properties of steel do not change appreciably with time as with reinforced concrete. In addition, if steel frames are maintained properly, they will last indefinitely. One of the major advantages of steel is that a steel frame structure has a fast erection time compared to concrete.

A redesign from concrete to steel was done to compare the two construction materials and get a better sense if either of the two would have been more advantageous in the construction of 510 Glenwood Avenue.

Gravity System

Design Loads

100 psf maximum live load

20 psf superimposed dead load

20 psf construction dead load

Design

When designing steel floor framing, the major considerations are the level of composite action, whether or not to camber, the bay dimensions, the beam spacing, and the depth of the floor framing. Composite floors have steel beams bonded together with concrete slabs so that they act together as one unit resisting the total loads that the beam sections would otherwise have to resist alone. When composite floors are used the steel beams can be smaller, because the slab acts as part of the beams and therefore utilizes the concrete's high compressive strength. Composite floor systems have a lesser floor thickness compared to non-composite floor systems. For the redesign of the 510 Glenwood, a typical composite floor system, where the steel beam is bonded to the concrete with shear connectors, was picked out of the Vulcraft Steel Roof and Floor Deck Manual. A Vulcraft 1.5VL with 2.5 inch slab above the metal deck and ¾ inch diameter studs was chosen out of the manual and modeled with the skeleton steel frame in the Ram Structural System Program. Steel columns were placed where the original concrete columns existed to not interfere with the original layout of the building. Since all of the bays in the building were either 25ft by 25ft or 25ft by 30ft, all beams were designed 5ft on center in the Ram program. A typical beam size of W12X14 or W12X19 was calculated and checked by hand calculations (see Appendix A) using the Manual of Steel

Construction LRFD Third Edition. Two typical floor layouts including beam and girder sizes are shown, not including the number of shear studs.

Figure 10: Typical Floorplan for the 1st through 4th Floor

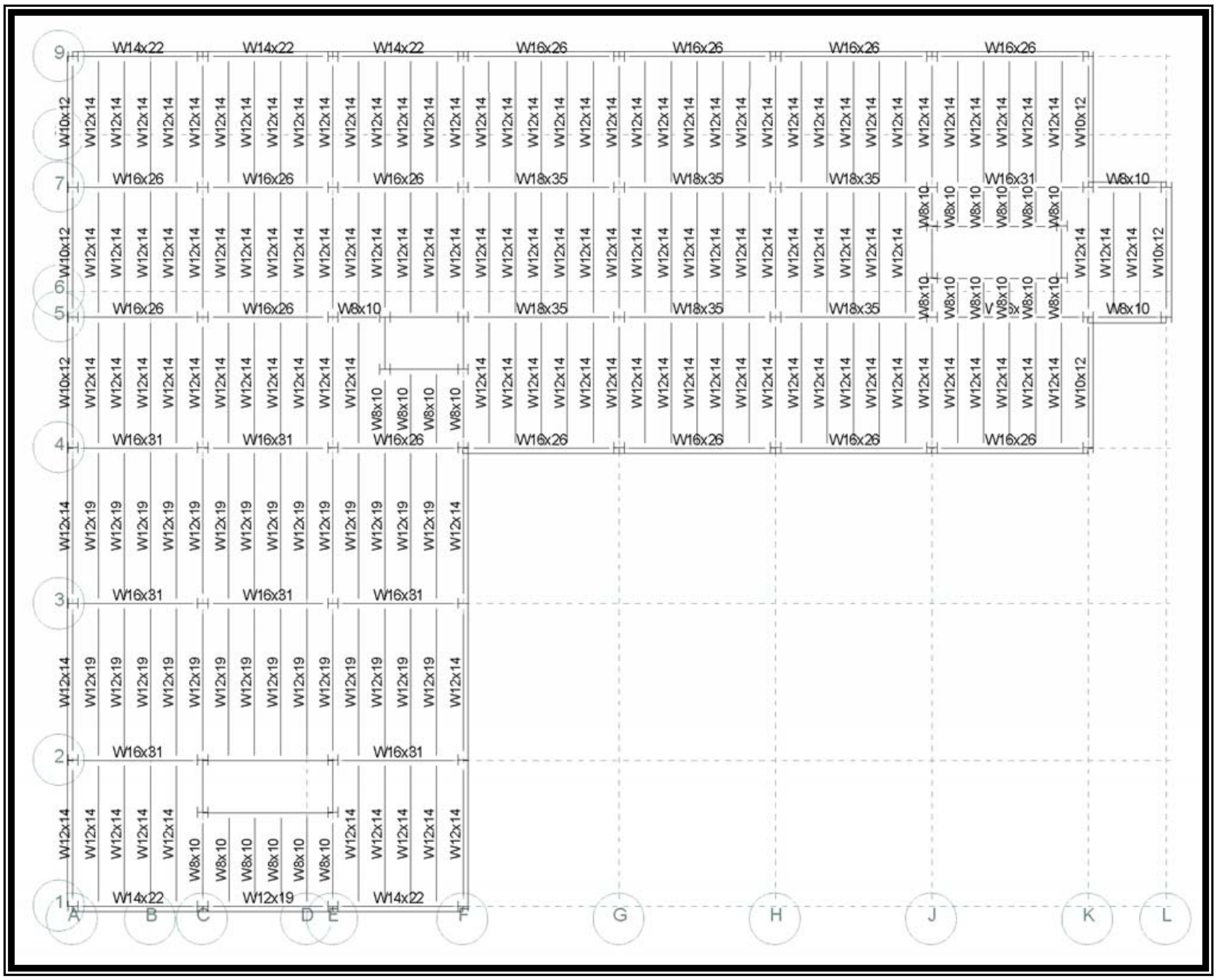

Figure 11: Typical Flooplan for 5th & 6th Floor & Roof

W12 shapes were chosen for the gravity column design. Splicing of these columns was input into Ram at the top of second and fourth level to reduce the length of the columns. A typical W12X40 column was found to be adequate almost everywhere in the building with a few exceptions. Hand calculations to check the adequacy can be found in Appendix A and a complete list of column sizes can be found in Appendix B.

Lateral System

Design Loads

Wind loads were calculated in Ram according to ASCE 7-98 and Seismic loads were calculated according to SBC 1994. The following load combinations were used in the lateral redesign of the building:

1.4D
$1.2D+1.6L+0.5(L_r$ or S or R)
$1.2D+1.6(L_r$ or S or R)+(0.5L or 0.8W)
$1.2D+1.6W+0.5L+0.5(L_r$ or S or R)
1.2D+/-1.0E+0.5L+0.2S
0.9D+/-(1.6W or 1.0E)

where:

D – dead load
L – live load
L_r – roof live load
S – snow load
W – wind load
E – earthquake load
R – nominal load due to rainwater or ice

Design

In the original structure, one foot thick concrete shear walls resisted the lateral loads of the building. These shear wall were located around the elevator shafts and around the two main staircases of the building. The existing lateral system of the building would most likely work the steel gravity system redesign since the overall structure would be lighter than the flat plate/slab construction. Two other choices for lateral systems would be moment frames or braced frames. Due to construction time and connection cost braced frames are more economical than moment frames. However, moment frames allow for an open plan and unobstructed views. The moment connections also inhibit the disassembly of a structure, but the additional members of a braced frame contribute more material to the overall structure. In addition, bolting of steel structures is a very rapid field erection process that requires less skilled labor than welding or riveting does. Since moment connections are more expensive than regular bolted connection, braced frames were chosen for the new lateral system and modeled in Ram. These braced frames were placed where the original shear wall existed to not interfere with the layout of the building. Figure 12 shows the layout of the braced frames. The most common brace used in the frames is the X brace. The X brace is only convenient around elevator shafts, staircases, and walls with few or no openings. The other type of brace used is the knee brace. This particular brace was used in parts of the lateral frame to allow for door openings in the stairwells and elevator shafts. Another layout of the braced lateral frame would almost be impossible since building façade has many windows and the interior layout of the building does not allow for braced frames anywhere else, unless more columns would be added to place the braces in wall partitions.

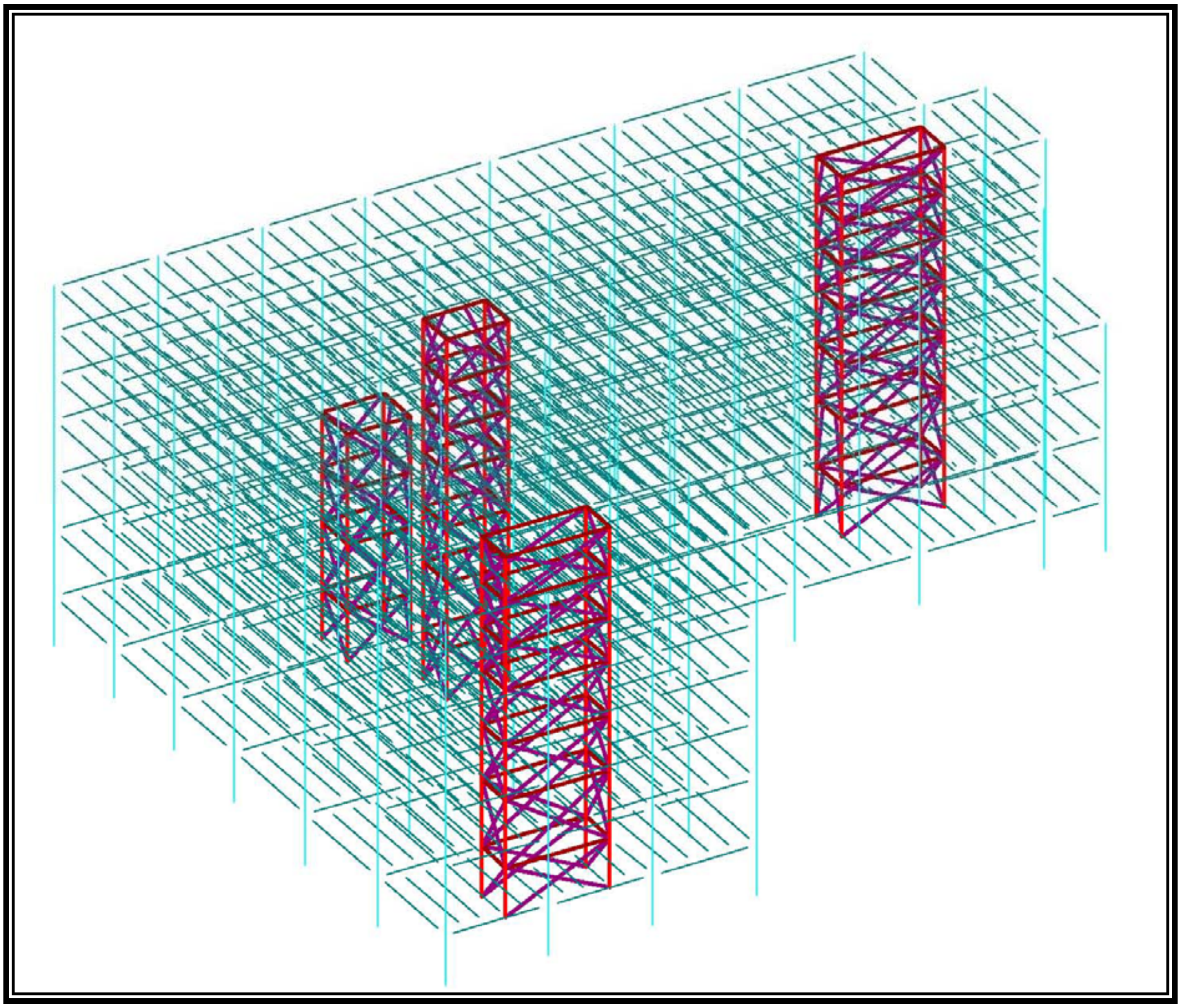

Figure 12: Framing of Entire Building Including Braced Frames

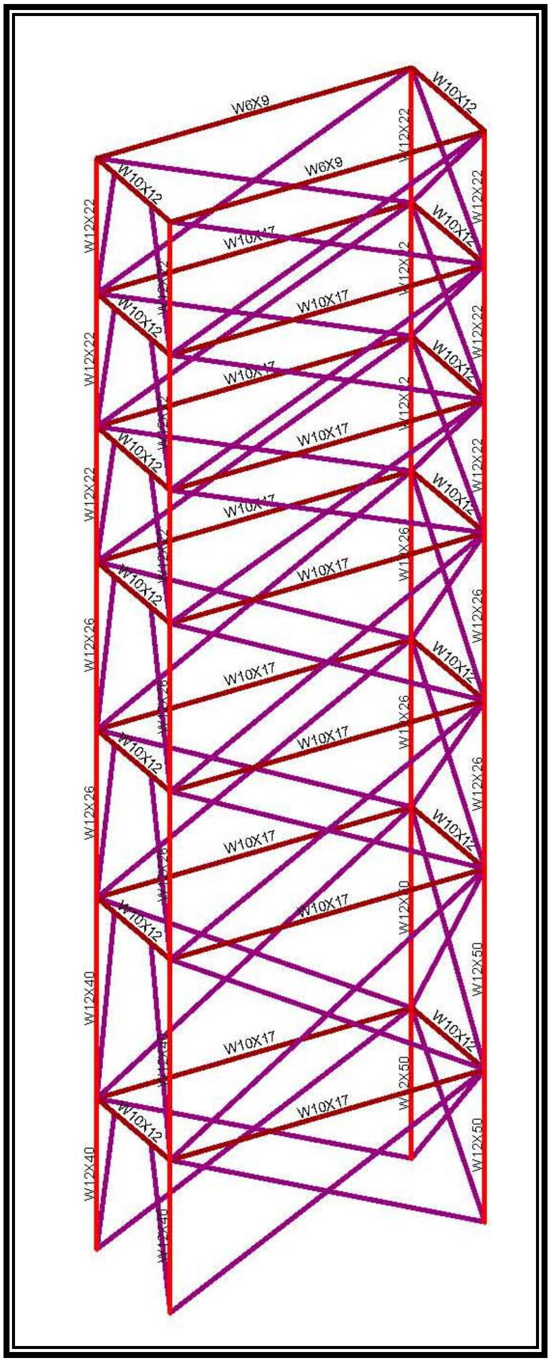

Figure 13: Typical Lateral Frame

A typical lateral frame is shown to the right. All lateral frames were modeled in Ram Structural System program and designed according to the loads and load combinations mentioned earlier. Due to the heavy bracing of the lateral frames most members turned out relatively small. The biggest member in a frame is a W12X65 column. After the design of all members in the lateral system was completed, the story displacements were checked and compared to H/400. All displacements turned out to be more than adequate. For a detailed output of all displacements see Appendix C. A closer view of a typical lateral frame is shown in figure 14 to display the beam, column, and brace sizes.

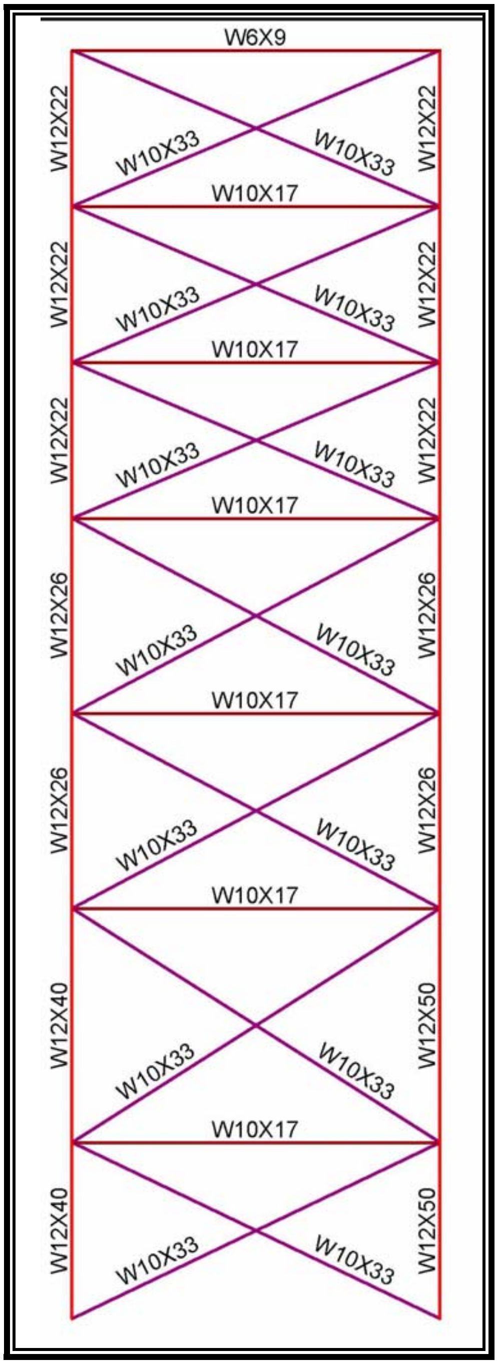

Figure 14: Elevation View of a Typical Lateral Frame including Member Sizes

Conclusion

A redesign of the building from concrete to steel is definitely feasible for this particular building. Since the layout of the building allows for repetitive bays of either 25'x30' or 25'x25' most of the steel member are repetitive and a reasonable size. Although a composite floor system is more labor intensive, it reduces the sizes of the beams and girders. In addition, the lighter frame contributes to smaller columns. As for the lateral system, since the frames were braced heavily, the sizes for the beams, columns, and braces also stayed within reasonable sizes. Unfortunately the steel frame would increase the floor to floor height by about 6 inches for each floor. This would not make much of a difference for the first four floors, since they are for retail and offices and have a high floor to floor height to begin with. The last three floors, the condo floors, are required to have a nine foot floor to ceiling height, therefore the floor to floor height would have to be increased by approximately by 1 ½ foot. Otherwise the redesign would not create a significant change.

BREADTH WORK

Overview

Cost and time are two thriving factors in construction. When choosing a structural system for a building structural engineers look for the most economical solution, which means the system that takes the least amount of time and money. Time restraints usually do not allow a full investigation of several structural systems. Therefore a cost and schedule analysis was done to compare the steel redesign to the original system.

Fireproofing was not needed for the existing structural system, since concrete has a natural fire resistance. Unfortunately steel strength is tremendously reduced at temperatures normally reached in fires when the other materials of a building burn. The fire resistance of structural steel members can be greatly increased by coating them with fire-protective covers such as concrete, gypsum, mineral fiber sprays, special paints, and other materials. The thickness and type of fireproofing depends on the building use, degree of fire hazards, and economics. The most common types of fireproofing today are spray-on fireproofing materials.

Construction Management

Cost Analysis

The existing structure cost was calculated using prices out of R.S. Means 2005 for floor assemblies. The 1st through 4th floor consisted of a 9" cast-in-place flat slab with 4" drop panels. The total cost for a typical 25'x30' bay, minimum column size of 22", and 9 ½ " to 8" slab is estimated to be $14.50 per square foot. For the flat slab system used for the 5th, 6th floor & roof the total cost is estimated at $13.20 per square foot. These prices are multiplied by the square footage to give a total cost of $2,245,000.

EXISTING STRUCTURE COST

CAST-IN-PLACE FLAT SLAB WITH DROP PANELS (FIRST THROUGH FOURTH FLOOR)	
MATERIAL COST	$6.50 PER SQ. FT.
INSTALLATION COST	$8.00 PER SQ. FT.
TOTAL COST	$14.50 PER SQ. FT.

CAST-IN-PLACE FLAT PLATE (FIFTH & SIXTH FLOOR & ROOF)	
MATERIAL COST	$5.85 PER SQ. FT.
INSTALLATION COST	$7.35 PER SQ. FT.
TOTAL COST	$13.20 PER SQ. FT.

SQUARE FOOTAGE PER FLOOR	23000 SQ. FT.
TOTAL COST	$2,244,800.00

Figure 15: Existing Structure Cost

The cost for the redesign was calculated using an estimator program for Ram downloaded from the AISC website which calculated all the pieces of steel and their weight and multiplies those by the unit cost input by the user. The price for steel is currently at $570 per ton. This base price was added to the other costs involving steel construction found in R.S. Means, such as drafting, shop fabrication, trucking, erection, etc.

Steel Quantity Totals by Group

Structure Total			Fy (ksi)	Weight	Pieces	Unit Cost	Cost
	Gravity Beams						
		Wide Flange	50	305.2	1537	2495	$761,474
	Lateral Beams						
		Wide Flange	50	13	100	2495	$32,435
	Gravity Columns						
		Wide Flange	50	78.1	131	2495	$194,859
	Lateral Columns						
		Wide Flange	50	23.7	46	2495	$59,132
	Lateral Braces						
		Wide Flange	50	62	193	2495	$154,690
	Totals			482	2007		$1,202,590

All			Fy (ksi)	Weight	Pieces	Unit Cost	Cost
	Gravity Beams						
		Wide Flange	50	305.2	1537	2495	$761,474
	Lateral Beams						
		Wide Flange	50	13	100	2495	$32,435
	Gravity Columns						
		Wide Flange	50	78.1	131	2495	$194,859
	Lateral Columns						
		Wide Flange	50	23.7	46	2495	$59,132
	Lateral Braces						
		Wide Flange	50	62	193	2495	$154,690
	Totals			482	2007		$1,202,590

Figure 16: Steel Column, Beam, and Girder Cost

Structure Total		Fy (ksi)	Quantity	Units	Unit Cost	Cost
Gravity Beams						
	Wide Flange	50	305.2	1537	2495	$761,474
Lateral Beams						
	Wide Flange	50	13	100	2495	$32,435
Gravity Columns						
	Wide Flange	50	78.1	131	2495	$194,860
Lateral Columns						
	Wide Flange	50	23.7	46	2495	$59,132
Lateral Braces						
	Wide Flange	50	62	193	2495	$154,690
Concrete Topping			159450	sq ft	3.05	$486,323
Metal Deck			159450	sq ft	2.4	$382,680
Totals						$2,071,593

All		Fy (ksi)	Quantity	Units	Unit Cost	Cost
Gravity Beams						
	Wide Flange	50	305.2	1537	2495	$761,474
Lateral Beams						
	Wide Flange	50	13	100	2495	$32,435
Gravity Columns						
	Wide Flange	50	78.1	131	2495	$194,860
Lateral Columns						
	Wide Flange	50	23.7	46	2495	$59,132
Lateral Braces						
	Wide Flange	50	62	193	2495	$154,690
Concrete Topping			159450	sq ft	3.05	$486,323
Metal Deck			159450	sq ft	2.4	$382,680
Totals						$2,071,593

Figure 17: Total Structural Steel Cost

The total cost of the steel structure, including fireproofing cost calculated Appendix D came to approximately $2,380,000, which is about $150,000 more than the original structure cost calculated. The added fireproofing cost of the steel structure made it more expensive than the original concrete structure. Also since a detailed cost estimate of the structural system of 510 Glenwood Avenue was not provided, a simplified method was used to calculate the cost. It is my understanding that if a more detailed estimate of cost would be done, including the price of rebar and shear walls, the cost would be higher than that of the steel structure. In addition, the steel structure is a lighter system and therefore the buildings foundation could most likely be redesigned to be a cheaper system.

Schedule Analysis

A schedule analysis comparing both structural systems was done taking information from R.S. Means, which says that a crane can typically erect 45 normal size members in a day. There are 2007 structural members in the entire building, therefore the entire structure could be erected in 45 days. The 45 days do not include the steel lead and fabrication time, which is usually about 6 months. If incorporated into the entire project schedule correctly the time it takes the steel to get to the job site should not affect the erection time.

For the concrete structure it takes about 7 days to form, rebar, and pour the slab and columns. So for a 7 story building it takes about 11 weeks to construct the structure, 7 week to pour everything and another 28 days for the entire structure to be cured.

Fire Protection

The selection of building materials and the design of the details of construction play an important role in building fire safety. Two of the important structural fire considerations are the ability of the structural frame to avoid collapse and the ability of the barriers to prevent ignition and resulting flame spread into adjacent spaces.

Exposed structural steel is vulnerable to fire damage. In order to have fire resistance, it must be protected from high temperatures encountered in fires. Protection for steel beam, girders, and columns, such as encasements of concrete, clay, tile, or gypsum blocks, have been generally superseded by plastered or spayed-on applications.

Monokote® Fireproofing is the world's most widely specified spray applied cementitious fireproofing. Recognized worldwide for their in-place performance and superior durability, Monokote products can be found in all types of buildings including high-rise construction, manufacturing facilities, schools, hospitals and sports facilities. Monokote® MK-6® is a gypsum based cementitious spray-applied fire resistive material for structural steel framed buildings. One of Monokote®'s best benefits is its reliable bond strength. This is an important consideration because it stays in place, not just during application, but over the total life cycle of the building including construction, renovation and demolition. The following chart details the most common UL designs utilizing Monokote MK-6 fireproofing.

Construction[1]	Restrained Assembly Rating (Hr.) 1	1 1/2	2	3	4	UL Design No.
Protected Floor/Ceiling Systems						
Fluted Deck	•	•	•	•	•	D779
Electrified Floor Options	•	•	•	•	•	D739
Unclassified Painted Decking	•	•	•			D744
Form Deck	•	•	•	•		D780
Fluted Deck/3-1/4" LW Concrete	•	•	•	•	•	D782
Beams/Joists[2]						
Beam Only — Floor Systems	•	•	•	•	•	N706
	•	•	•	•	•	N708, N782
Joist Only — Floor Systems	•	•	•	•	•	N736
	•	•	•	•		N777
Beam Only — Roof Systems	•	•	•	•	•	S735
	•	•	•	•	•	S734
Joist Only — Roof Systems	•	•	•	•		S728
	•	•	•	•		S736
Columns[3]						
(Size) (Metric Equivalent)						
W6 x 9 To (W150 x 13)						
W14 x 730 (W360 x 1086)						
W-shaped Steel Column[4] Formula	•	•	•	•	•	X772, Y715
Tube and Pipe Columns	•	•	•	•	•	X771, Y710
Concrete Filled Pipe Column	•	•	•	•	•	X791

Figure 18: UL designs utilizing Monokote MK-6 fireproofing

From the Table above the appropriate UL design was chosen to be D780 for the beam and steel deck assembly and X772 for the columns. From the appropriate thickness tables for the floor assembly and columns, the thickness of the cementitious fireproofing was chosen according to the biggest member, which is a W12X65 for columns and a W18X35 for the beam/girder floor system. A 1 1/8 inch thick spray-on fire proofing is needed for the floor and 1 1/8 inch for the columns for a 2 hour rating. The added cost of the fireproofing was calculated in Appendix C and came to approximately $307,000. Appendix D shows the thickness tables used to determine the thickness of spray-on fireproofing.

Conclusion

In comparison to the original structural system the steel redesign turned out to be more expensive once the fireproofing cost of the steel was included in the total price. Although in my analysis the steel construction cost more, a steel structure would be more economical. The structure is lighter and could reduce the foundation needed and the cost associated with the foundation. In addition, a steel structure would take less time to construct and therefore cost less money.

Fireproofing of a steel structure is necessary, whereas concrete is naturally fire resistant. Spray-on fireproofing for steel is the most common fireproofing used in today's construction. The thickness of fireproofing needed was determined from Grace Construction Website and found to be 1 1/8 inch for both columns and floor system for a 2 hour fire resistive rating.

Final Conclusion and Recommendations

When designing a buildings structural system, many options can be considered and explored. Unfortunately the structural engineer most likely does not have the time to analyze several different systems to see which one would be more economical. In addition, the choices of the engineer are limited to what the owner and/or architect specifies. A structural frame system for 510 Glenwood would have been feasible to design, reducing the overall dead load of the structure, column sizes, overall cost, and possibly the foundation system. One disadvantage of a steel structure would have been an increase in floor to floor height, increasing the height of the overall building. Another disadvantage of a steel structure is the added cost of fireproofing the steel. A more detailed analysis of the overall structure of the building is needed to compare the two systems more accurately, though it was found that 510 Glenwood Avenue could have been constructed using steel as a main material of construction.

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