THE ODYSSEY
ARLINGTON, VA

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Structural Option
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Executive Summary:

The Odyssey is a 475,650 SF luxury residential complex located in Arlington, Virginia. The main structure are two adjoined 16 story towers with residential units and are clad with glass curtain walls and brick facade. The Odyssey is a perfect example of the latest designs for the rising market of luxury apartment and condominium construction with a concrete structural system. The typical floor system throughout the residential levels is a 2-way post-tensioned flat plate and the lateral systems are shear walls located throughout the plan of the Odyssey and concrete slab frames.

The building was structurally designed to minimize floor-to-floor heights thereby maximizing residential units which increase the profit return on the building. A post-tensioned 2-way flat plate system was chosen for the minimal design slab depth which effectively fits 16 residential levels under the zoning height limitation. Maintaining a comparable floor-to-floor height and preserving the architectural layout of residential units will be one of the objectives in redesigning the structural system of the Odyssey.

A 2-way reinforced flat plate system will be designed and investigated as an alternative to the current system. The similarity of systems will enable the design to have slight modifications in floor-to-floor heights while maintaining the integrity of the architecture and column layout. The lateral system will be redesigned to accommodate the alterations in the floor system and lateral loading in combination with the slab frame of the Odyssey. The proposed designs will be carried out using design references and computer analysis throughout the semester. This structural redesign will provide a better understanding of alternative concrete designs of similar mid-rise building structures as the Odyssey.

The structural redesign of the Odyssey will be evaluated further through breadth studies focusing in topics pertaining to non-structural option areas. First, a construction management breadth study will investigate the implications of the alternative design with respect to the construction schedule and cost compared to the current system. Second, a study of the existing building envelope will explore the thermal and moisture efficiency of the curtain walls compared to the typical brick façade with aluminum punch windows. Additionally, construction schedule and cost implications will be investigated to evaluate the value engineering practicality of the glass curtain walls.

Building Introduction:

The Odyssey is located in Arlington, Virginia adjacent to the Court district and several blocks from the commercial center of downtown Arlington. The complex is 475,650 SF with a total project cost of $65 million financed by Monument Realty, LCC. The primary use of the building is residential apartments and luxury condominiums located throughout the 1st-15th levels of the tower structure. A mechanical penthouse and an adjacent residential amenity space are located on the 16th level. Retail spaces are designed into the upper garage levels which extend 3 levels below grade. The tower structure of the Odyssey makes up the majority of the 1st-16th levels and is clad with glass curtain walls and brick facade with aluminum punch windows. The overall tower height from the 1st floor is 167' and 175' from the average grade.

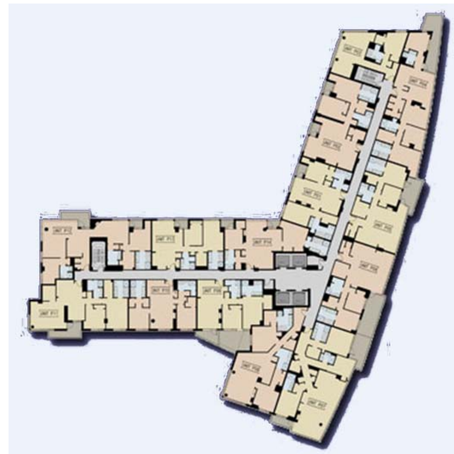
The site for the Odyssey was chosen for its ideal location within Arlington and proximity to the metro train with access into Washington D.C. within minutes. It is zoned under the "Special Affordable Housing Protection District" ("SAHPD") designation and requires the replacement of existing affordable residential units demolished on site during construction of the Odyssey. A row of multistory townhouses is incorporated into the design of the overall structure of the building due to this zoning ordinance.

Townhouses are built adjacent to the 3 sub-grade garage levels with a one-way flat slab concrete structural system. The lower garage level is composed of 4" concrete slab (f'c=5ksi) on grade and reinforced with 6x6 – w1.4 x w1.4 wire mesh. Foundation structures include two 54" mat foundations; however the typical foundations are concrete footings of various rectangular sizes, depths, and reinforcement.

The remaining lower garage levels through the first floor are primarily 8.5" conventionally reinforced 2-way concrete flat plates with bottom reinforcement of #4 bars @ 13"o.c. Additional top and bottom reinforcement is specified as needed throughout the floor with varying bar sizes at specified spacing. Drop panels are located at specified columns and typically extend 4-1/2" below slab with several panels up to 6-1/4" to 8" below the slab.

The floor system of the towers is primarily an 8" 2-way post tensioned flat concrete plate (f'c=5ksi) with continuous bottom reinforcement of #4 bars @ 24" o.c in each direction. Negative moment reinforcement of the plate at columns is typically #4 bars expanding $(.33)l_n$ in both span directions. Post tensioning tendons are 7 wire strands spanning columns and mid spans on a typical frame. Floor bays vary in size with 25'x 22' and 25'x 28' and columns typically sized at 18"x 26" with #11 bar reinforcement.
(See Appendix-A for the typical floor plan)

The lateral systems of the Odyssey are reinforced concrete shear walls with groupings throughout the building and integrated concrete slab frames. A set of walls surround elevator shafts at the central core of the Odyssey with another set located at a stair well in the west wing of the building. The final shear wall is located in the east wing oriented at the askew angle of the adjoined towers. The shear walls are typically 10” and 14” thick with #5 & #6 bar reinforcement at 12” o.c.
(See Appendix-B for shear wall details)



Problem Statement:

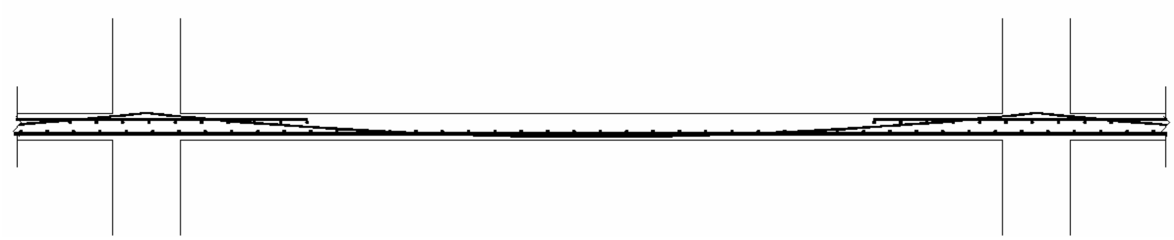
The Odyssey was built primarily as a residential building with a range of apartment sizes and upper level Platinum condominiums. The intention of these luxury residential buildings is to maximize the number of units, thereby increasing the profit return after completion and occupation of the building. These profit returns can be achieved by maximizing the amount of residential levels of the building built within the zoning height limitation, considering a fixed gross floor area.

The Odyssey was designed through consideration of a minimum floor-to-floor height and an overall height limitation of 180’ by the Code of Virginia zoning ordinances. The floor system must be designed per IBC 2003 International Building Code for the residential floors to resist all subjected dead loads and a live load of 40psf for residential space and 100psf for corridors. A list of relevant gravity loads follow:

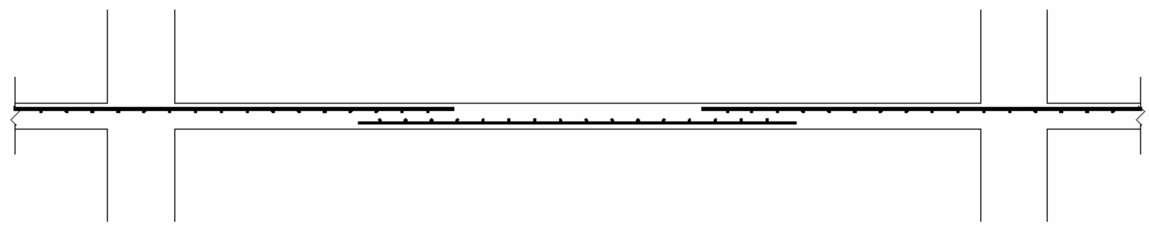
Gravity Loads: (psf)

Floor Live:		Floor Dead:	
Residential Units	40	Concrete Slab	120 (9.5” slab)
Public Areas/Corridors	100	Partitions	8
Mech. Room	150	Flooring	4
Pool Terrace	100	Ceiling	5
Parking Garage	50	Mechanical	10
Stairs and Exits	100	Beams/Columns	(* varies)
Roof Live:		Roof Snow:	
Min. Roof Live Load	30	Roof Snow Load	21

A 2-way post tensioned flat plate floor system was chosen to limit the design depth of the structural system to 8”. The floor-to-floor height of residential units was kept to 9’-4” with a ceiling height of 8’-8” and a mechanical drop soffit around the perimeter of the spaces at 7’-10”. Although the design decreases overall floor-to-floor height, the construction schedule and costs are increased by implementing the post-tensioning into the system.



The Odyssey was designed with consideration of the zoning height restriction and a minimum floor-to-floor height to maximize the quantity of residential units within the building. A 2-way post-tensioned flat plate floor was therefore chosen as the ideal floor system for these restraints with a minimum structural slab depth. An alternative floor system will be implemented into the Odyssey's design considering the zoning height limitation. The proposed system will accommodate the existing ceiling heights and mechanical spaces without exceeding the building height limitation of 187'. The focus of implementing an alternative system is to compare the proposed structural design to the ideal post-tensioned floor system. The comparison will investigate the construction cost, labor cost, and construction schedule of the floor systems.



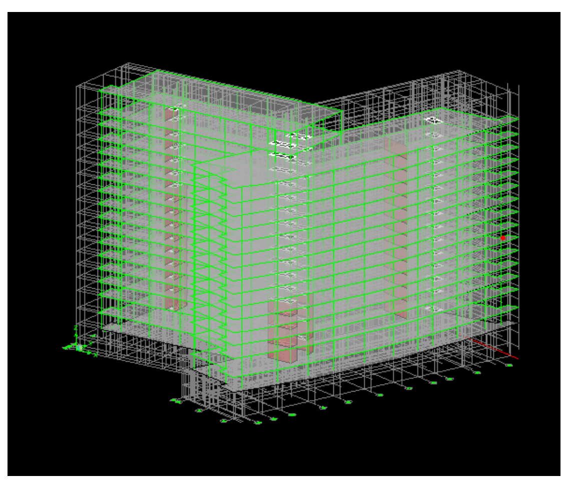
The proposed alternative system will be designed as a 2-way reinforced flat plate. Adjusted floor-to-floor heights from the increase in the design plate depth will not effect the existing ceiling height conditions. The flat plate will also allow the existing mechanical/electrical soffit designs to remain in residential units so there are no induced costs for changes in duct work design. The overall architectural design of the Odyssey will, for the most part, remain similar to details found under the existing system. The same number of levels and identical residential unit layouts will result in similar column locations and typical bay sizes throughout the floor plan. Columns will be designed to the existing column sizes to effectively maintain architectural dimensions of the residential units with the concrete strengths adjusted for the increase in slab dead load. The exclusion of post-tensioning from the floor system will effectively increase the constructability of the flat plate and reduce related project costs.

The lateral load resisting system will be designed with reinforced concrete shear walls. The walls are located at the central elevator core, a stairwell in the west wing, and within a residential unit wall in the north wing. The induced dead load of the alternative floor design will need to be taken into consideration when analyzing lateral effects caused by seismic loads. The shear walls will effectively assist in seismic shear distribution throughout the structure in combination with the floor slab frame. An increase in slab frame stiffness will reduce the shear distributed into the shear walls. As a result, a reduction in the shear wall design for size and reinforcement will be investigated. Torsional effects will also be considered when designing exterior shear walls located in the wings of the Odyssey towers. These effects will control the final design of these shear walls over the core shear walls around the elevator shafts which only extend to the 4th level of the condominium.

Solution Method:

The design of a 2-way reinforced flat plate will result in an acceptable slab depth to resist gravity loads and limit floor-to-floor height enough to comply with the zoning ordinance amendment. The concrete floor system will be designed in accordance with ACI318-05 *Building Code Requirements for Reinforced Concrete*. The minimum slab thickness will be based on the effective spans of the residential floors and by the provision of ACI 318-05 Table 9(c) for flat plate construction. The reinforcement will be designed using the Equivalent Frame Method based on ACI 318-05 Chapter 13. Dead loads will be calculated for the self-weight of the slab with superimposed dead loads and live loads from IBC 2003 1996 Table 1606. The resolved dead loads and live loads will be patterned over the frame and analyzed in the SAP2000 or ETABS analysis computer programs for the resulting worse moments distributed to the column and middle strips according to ACI 318-05 Section 13.6. Live load patterns to be investigated include full live load on all spans, full and half live load on adjacent spans, and 75% full load and no load on adjacent spans. Shear will be checked in accordance with ACI 318-05 chapter 11, and slab deflection will be checked for adequacy in accordance with limitations set by ACI 318-05 Table 9(b). The flat plate floor system will be designed and reinforced to accommodate the design loads and moments resolved from the equivalent frame analysis. Lateral loading will be taken by the shear walls and column design will accommodate gravity loads with an adjustment for lateral loading upon the frame. The column design will be in accordance with ACI 318-05.

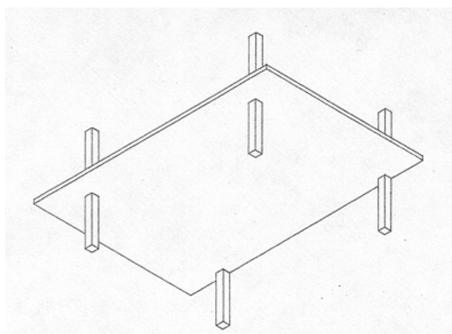
The design of the shear walls will be analyzed by a 3-D model of the lateral systems in the ETABs analysis computer program. Wind and seismic loads will be computed for the building through provisions of ASCE7-02 section 6 & 9. The ETABs model will distribute lateral loading through the shear walls by an analysis of alternative loading combinations in accordance with loading provisions of IBC 2003. Wind loading at 45° to the primary lateral directions and 75% of both directions will be considered for a worse case shear distribution. Seismic loading will take into account the increase in dead load by the floor slab, and will distribute shear by stiffness through the frame and shear wall structural elements. The shear walls will be designed to resist the lateral loading in combination with the slab frame of the floor system. ETABs will output individual shear wall forces from the worse case of distributed loads that will be checked for sufficient reinforcement by ACI318-05 Section 11.10, special provisions for walls. The lateral force resisting systems will be checked for inter-story drift which is limited to .015hsx by provisions of ASCE7-02 .



Breadth Study:

Construction Management

Redesigning the post-tensioned floor system will have construction implications regarding the project schedule and cost. A breadth study will investigate these implications associated with changing the floor system to a 2-way concrete flat plate. A construction schedule of the proposed system will be constructed and compared to information obtained through the construction manager regarding the current post-tensioned system. Also, a cost estimate of the proposed 2-way flat plate floor system will be created by referencing R.S. Means data and construction professionals. The data will include factors such as labor and material costs of the alternative design which will be compared to the post-tensioned design for any project cost alterations. This breadth study will show the efficiency of the flat plate design through the expedited work schedule and cost savings of removing the post-tensioning element from the floor structure.



Building Envelope

The initial envelope design of the Odyssey did not incorporate a series of glass curtain wall systems into sections of the eastern façade. Donohoe Construction, the construction managers of The Odyssey, suggested the alternative design with curtain walls replacing the standard brick façade with aluminum punch windows. A breadth study of the thermal and moisture efficiency of the curtain walls will be compared to the brick façade. Additionally, construction schedule and cost implications will be investigated to evaluate the value engineering of the building envelope redesign with glass curtain walls. The investigations will reveal that the curtain wall is a more efficient cladding system with a better aesthetic appeal for the luxury condominium.

Tasks:

1. Floor System Alternative: 2-way reinforced flat plate

Task 1. Determine Floor Loads

a) Determine minimum slab thickness for bay size and punching shear

b) Find self-weight of the plate (f'c = 5ksi)

c) Find superimposed dead loads

d) Find live loads

Task 2. Design Floor System

a) Use SAP2000 or ETABs to perform Equivalent Frame Analysis

b) Determine worse case moment distribution for pattern loading

c) Design the plate reinforcement based on resulting moments

d) Check shear and short / long term deflection

2. Column Design

Task 1. Design Columns

a) Find loads and moments on columns from floor design

b) Design columns with architectural design considerations

3. Shear Wall Analysis/Design

Task 1. Determine Lateral Loads

a) Calculate the wind loading

b) Calculate the seismic loading

Task 2. Design Shear Walls

a) Construct ETABs model and input lateral load combinations

b) Design Reinforcement from member load output

c) Determine building drift and compare with seismic limit

d) Check story drift with allowable limit $.015h_{sx}$

4. Construction Management

Task 1. Schedule/Cost Comparison

a) Obtain schedule/cost information of post-tensioned floor system

b) Create project schedule for alternative floor system

c) Develop a cost estimate for alternative floor system through R.S. Means

d) Compare schedule/cost of floor systems

5. Building Envelope

Task 1. Thermal / Moisture Investigation

a) Obtain design information of the curtain wall system

b) Research thermal/moisture effects of curtain wall system/brick facade

c) Compare building envelopes

Task 2. Constructability

a) Obtain schedule/cost information of curtain wall system/brick façade

b) Compare building envelopes

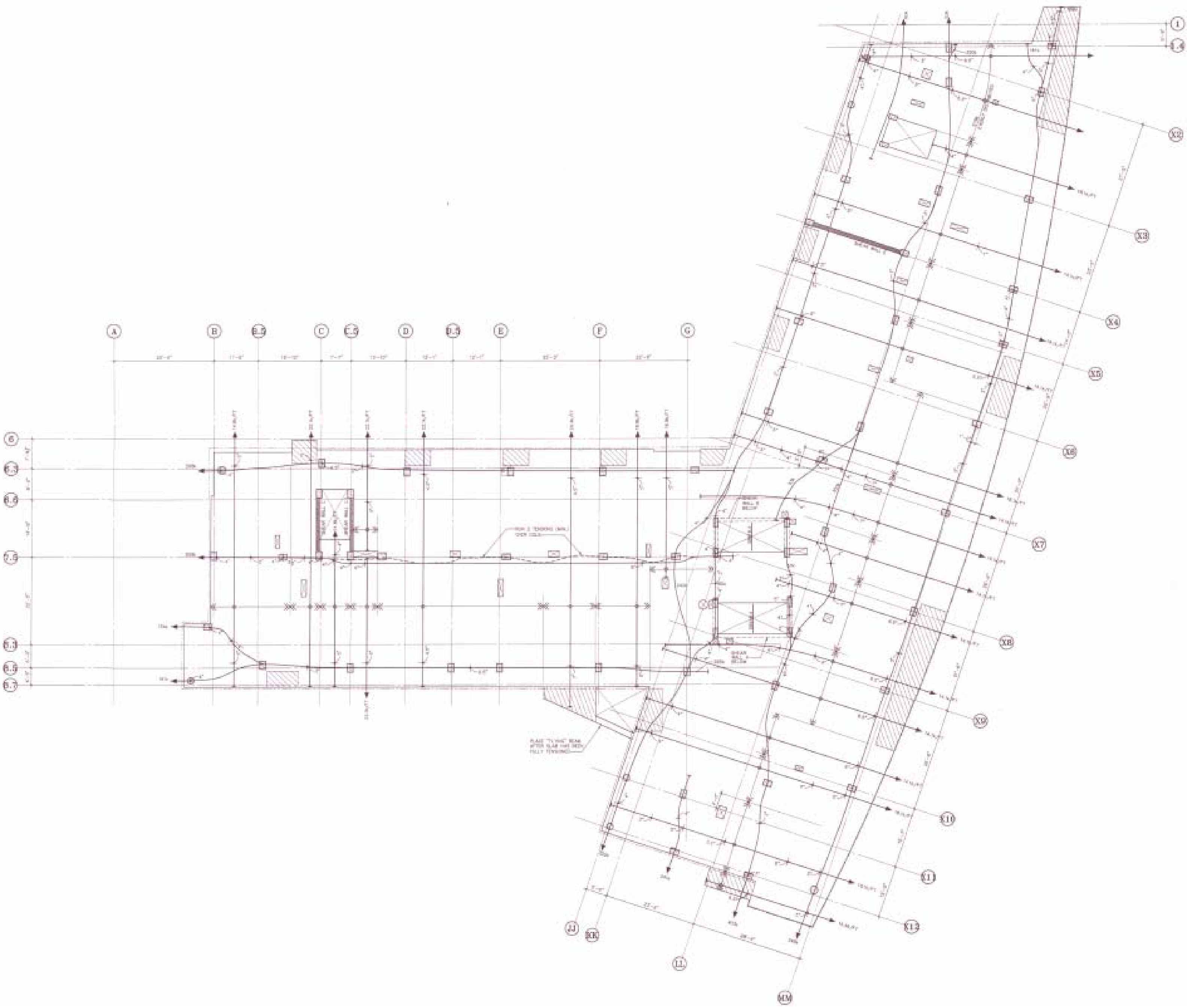
Task 3. Architectural Aesthetics

a) Research aesthetics of curtain wall system

Timetable:

WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TASK	1/9	1/16	1/23	1/30	2/6	2/13	2/20	2/27	3/6	3/13	3/20	3/21	4/3	4/10	4/17	4/24
Revise Proposal/Schedule	■								S							
Determine Gravity/Lateral Loads		■							P							
Equivalent Frame Analysis		■	■						R							
Design Floor System: 2-way flat slab				■	■				I							
Design Columns					■	■			N							
Adjust ETABs Model						■	■		G							
Shear wall Analysis/Design							■	■								
Breadth 1: Construction Management								■	B	■						
Breadth 2: Building Envolope									R	■	■					
Written Report/ Presentation Prep									E		■	■	■			
Present Thesis									A					■		
Review / Reflect									K						■	■

Appendix – A FLOOR PLAN



Appendix B – Shear Wall Plan Summary

Shear wall A:

Resists both lateral load directions: North-South & East-West.
Location: Surrounds north-core elevator shafts
Range: B3 - 4th level
Size: North-South walls - 1’-2” x 10’
Integrated columns - 14”x 28”
Column Reinforcement – 6 #9 bars
East-West wall – 10”x17’-10”
Wall Reinforcement: #5 & #6 bars @ 12”

Shear wall B:

Resists both lateral load directions: North-South & East-West.
Location: Surrounding south-core elevator shafts
Range: B3 - 4th level
Size: North-South walls - 1’-2” x 10’-0”
Integrated into columns - 14”x 28”
Column Reinforcement – 6 #9 bars
East-West wall – 10”x17’-0”
Wall Reinforcement: #5 & #6 bars @ 12”

Shear wall C , C1:

Resists lateral load directions: North-South
Location: Surrounding West stair tower.
Range: 1st - 16th level
C1 terminates at 10th level
Size: North-South walls - 10”x 13’-10.5”
Ends attached to columns – 18”x 26” and 24”x 24”
Column Reinforcement – (varies) #11 bars
Wall Reinforcement: #5 & #6 bars @ 12”

Shear wall E:

Resists lateral load directions: North West-South East
Location: Column line X4 - North side of East tower
Range: 1st - 14th level
Size: North-South walls - 10”x 29’-5”
Ends attached to columns – 18”x 26”
Column Reinforcement – (varies) #11 bars
Wall Reinforcement: #5 & #6 bars @ 12”