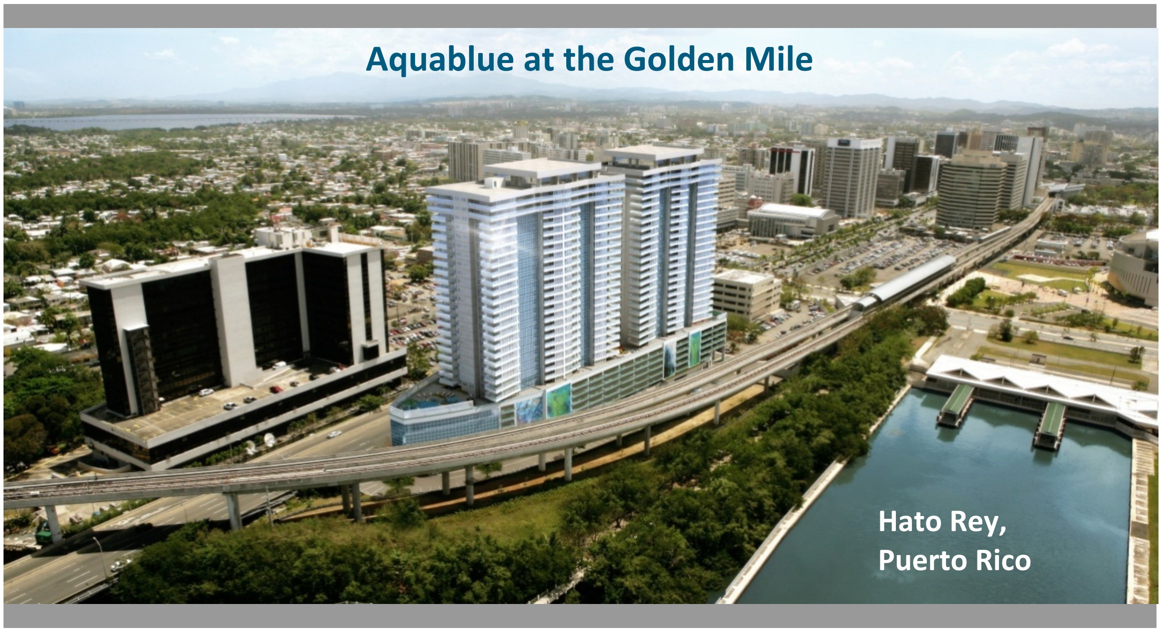
Thesis Proposal



Lindsay Lynch

Structural Option

Dr. Andres Lepage

20 January 2009

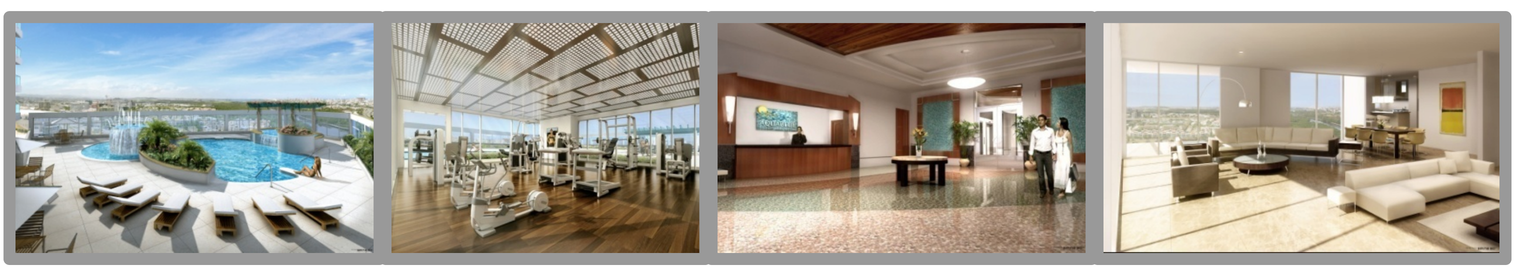


Table of Contents

Executive Summary

Aquablue at the Golden Mile is a 31-story apartment building in Hato Rey, Puerto Rico. There is a parking garage from the ground up to level 7, and above this level, the luxury apartments are divided into two towers. The primary building material for the structure is concrete, and the existing gravity system consists of two-way, flat plate, post-tensioned slabs of varying thicknesses. The lateral system is a series of shear wall located in two groups near the core of the building.

The purpose of this report is to propose an in-depth study of the structural system and two breadth studies of other aspects of the building. Because of the difficulties of designing the lateral force resisting system for this building (primarily the lack of an open floor plan), a re-design of the shear walls will be completed for this thesis project. An optimization of the design will allow for a more efficient and cost effective system, and the proposed solution will likely have a limited impact on the architecture of the building. (However, a few walls may need to be moved slightly or increased in thickness.) The existing gravity system will not be changed because it is already optimized. The flat plate, post-tensioned slabs are efficient because they have minimal depth compared to other structural systems, and they allow for a small floor-to-floor height.

Both hand calculations and computer programs will be used in the re-design of the shear walls. In particular, ETABS will be used for the three-dimensional model, and PCA Column will be used to optimize the reinforcement design. The use of computer programs will fulfill the need for the integration of a graduate level course (AE 597A) into the AE senior thesis project.

The breadth studies will be in two of the following three areas: lighting design, electrical design, or an acoustics study. The area of focus will be an individual apartment unit, and the design will be based on optimizing the comfort of the tenants (because this is an expensive, luxury apartment building). Although primarily based on the needs of the tenants, the design will also have to incorporate efficiency to ensure that it is feasible.

General Building Information

Aquablue at the Golden Mile is a high-rise apartment building in Hato Rey, Puerto Rico. It is located in an urban area, about two miles away from the San Juan Bay (fig. 1). The building size is about 900,000 total square feet, and there are 31 stories above grade. (Up to level 7, the typical floor area is about 51,900 ft^2. For the apartment towers, which are above level 7, the typical floor areas are 11600 and 14500 ft^2.) The ground level will be developed as a commercial area, and the rest of the floors up to level 7 will be used for both parking and office space. Level 7 is an indoor/outdoor public area for the apartment residents, and the floors above are private apartments. There is a sky lobby above the penthouse apartments.

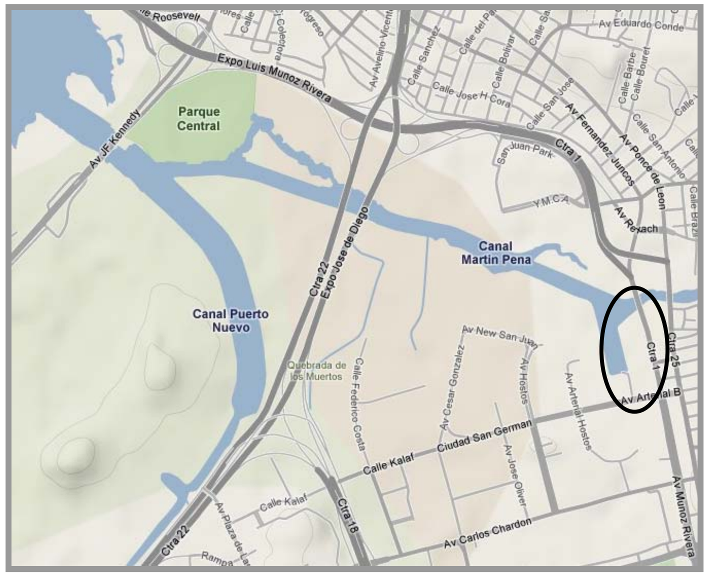


Figure 1 – Building Site (maps.google.com – Hato Rey Central, PR)

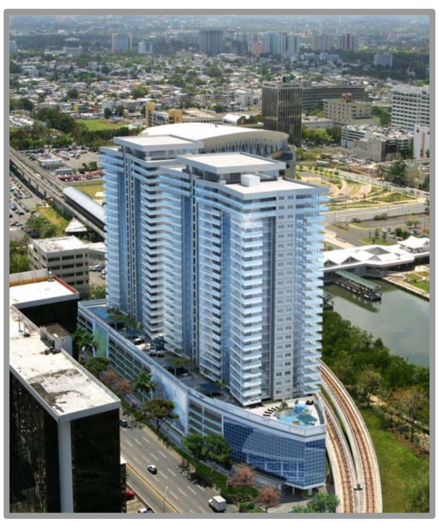


Figure 2 – Rendering of Aquablue

The parking structure (levels 2-6) is open, with concrete parapets along the exterior. As an architectural feature, there are two sections of an 8" masonry wall that extend from the ground up to level 7. The office areas of these floors are enclosed with a glass curtain wall system, as can be seen toward the bottom of figure 2. Above level 7, the façade materials are glass and concrete precast panels.

The primary building material is reinforced concrete, and the structure consists of a building frame system with shear walls. Each floor has a post-tensioned slab supported by concrete columns.

Description of Existing Structure

The **foundation** consists of drilled piles that are aligned with the columns. They are the primary foundation system, although there are some grade beams as well. (The grade beams are only used occasionally; they do not span all of the piles.) At the foundation level, there is a 10" reinforced concrete slab.

Each floor consists of a two-way, post-tensioned **structural slab** supported by reinforced columns, which span between 25'-0" and 34'-0". It is a flat plate system, so beams are not a part of the general floor framing. The slabs are 9" thick for the first six stories. At level 7, parts of the slab are 12" thick because the loads are heavier on this partially outdoor level (due to the pool and landscaping). For the apartment levels, the post-tensioned slabs are 8" thick.

The **lateral force resisting system** is a series of shear walls near the core of the building. They are 18" thick, and they require integrated boundary elements. The system of shear walls is grouped into two sections, and each one extends into one of the apartment towers.

There is one **expansion joint**, which breaks the building into two similar sections. It is a 5" seismic joint, and it runs parallel to the short dimension of the building. Because the joint falls between the two towers, it only extends from the ground to level 7. For the purpose of the structural analysis, this allows for the separation of Aquablue into two 'buildings.'

The **material strengths** of the concrete for the various structural elements are listed in table 1. The concrete strength of the slabs and columns changes around level 12. The highlighted material strengths are relevant to the analysis of the shear walls.

Concrete Material Strengths

Structural Component		Strength, f'_c (ksi)
pile cap		4
retaining wall / basement wall		4
grade beam		4
slab on grade		5
formed slab	foundation - level 12	6
	above level 12	5
beams		5
parapet / vehicle barrier wall		5
columns / shear walls	foundation - level 13	8
	above level 13	6

Table 1 – Concrete Strengths for Various Structural Elements

Typical Floor Framing Plans

There are two typical floor plans in this building: one for the parking garage levels and one for the apartment levels. As seen below on one of the parking level plans (fig. 3), there are not a whole lot of elements in the gravity-based structural system. The columns are supporting a two-way, flat plate, post-tensioned slab. Also shown in the figure below is the lateral force resisting system of reinforced concrete shear walls concentrated toward the center of the floor plan. The most extensive shear wall system is at the base of the building, and the number and length of the walls decreases as the height above grade increases.

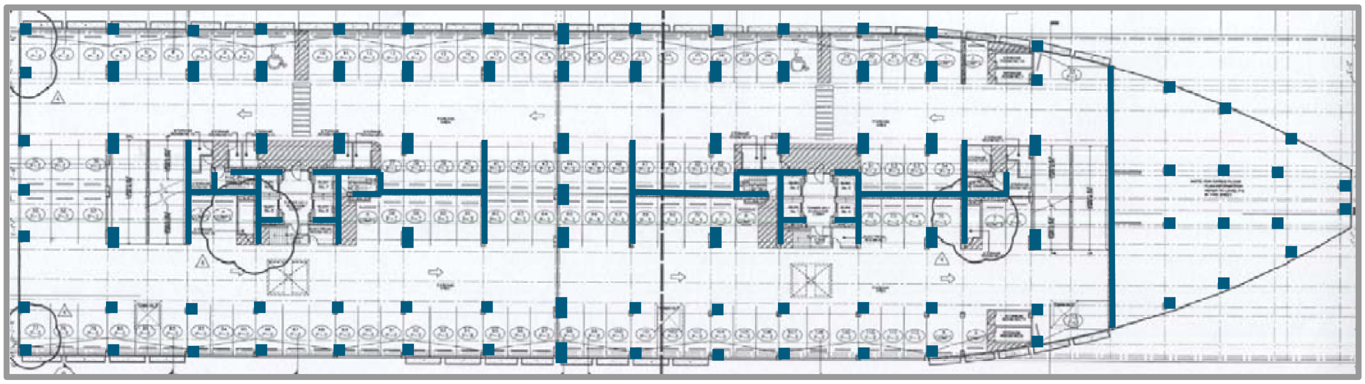


Figure 3 – Column and Shear Wall Layout for Typical Parking Garage Level

The plan below (fig. 4) is a typical apartment level floor plan. Both the columns and shear walls are shown, and the extension /simplification of the shear wall system can be seen by comparing this figure with the one above.

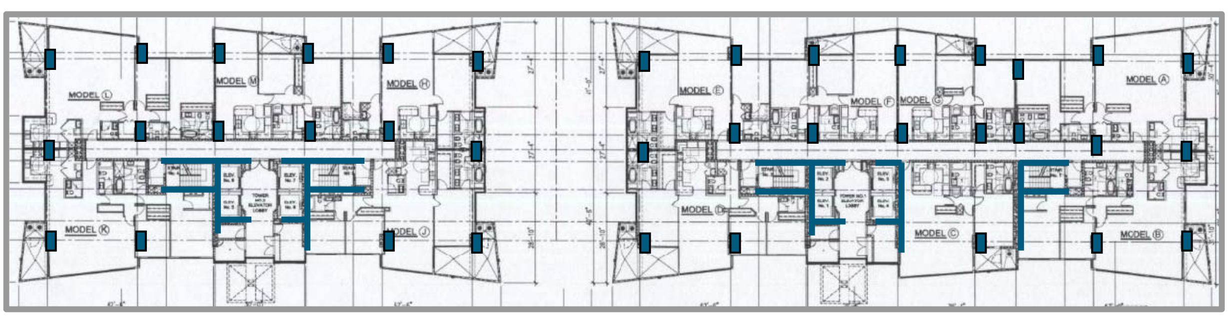


Figure 4 – Column and Shear Wall Layout for Typical Apartment Level

Description of Lateral System

The existing lateral system is composed of reinforced concrete shear walls that are concentrated toward the center of the building. As can be seen in figure 5 to the right, the walls in both the north-south and east-west directions are integrated into one multi-branch system. This detail is just one example of the general type of shear wall design. In the case of figure 5, the wall lengths and reinforcing layout represent one shear wall system between levels 7 and 9.

The concrete strength of the shear walls changes once over the height of the building. Below level 13, f'_c = 8 ksi, and above level 13, f'_c = 6 ksi. Similarly, the reinforcement becomes less dense over the height of the building.

Also, the boundary elements of the shear walls are relatively complex due to their intersection at the wall joints.

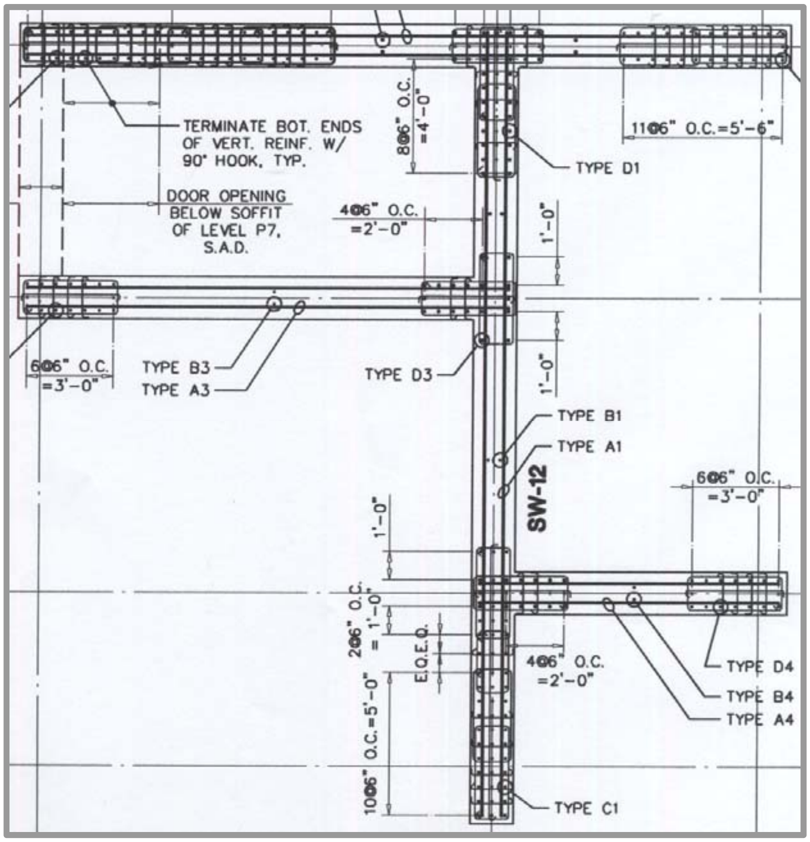


Figure 5 – Example of Shear Wall System (Levels 7-9)

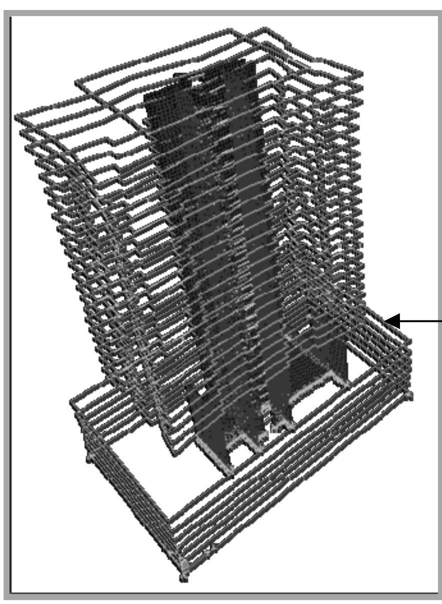


Figure 6 – 3-Dimensional Model of Existing Shear Walls

The figure to the left shows a representation of the lateral force resisting system for one of the two building towers (from an ETABS computer model). The image gives the general idea of the location and density of the shear wall system in this tower. In order to visualize its relation to the rest of the building, the seismic joint is labeled in the figure.

Problem Statement

One of the difficulties in designing the structure of Aquablue occurs in the lateral force resisting system. In particular, the layout of the shear walls poses numerous problems. First of all, the walls cannot be placed along the exterior of the building for architectural reasons. The tenants of this luxury apartment building need to have great views of the outside, and the shear walls would limit the amount of glass on the façade. Also, shear walls that are located at the exterior of the apartment buildings would run right through the middle of the parking garage, which would potentially complicate its design. Therefore, the shear walls need to be located at the core of building, specifically in two separate groups that can be continuous through each of the two towers.

Because of the specific architectural layout of apartments in the two towers of Aquablue, there is an additional challenge in the detailed layout of the shear walls. They cannot be placed just anywhere in the core of the building, so this limitation on the wall placement can result in some odd and inefficient shapes. These shear wall difficulties provide an opportunity for research and re-design for the Spring 2009 thesis project.

Proposed Solution

For this thesis project, the shear walls will be completely re-designed to be more efficient and more cost effective. The location of the walls will remain at the core of the building (one group in each of the two towers), but the layout will be modified to be two I-shapes that are connected by coupling beams at the 'flanges'. These symmetric shapes would be much more efficient, and after a preliminary look at the existing layout, it seems like they could be incorporated into the building without too much of an impact on the architecture. The figure below gives a preliminary sketch of the potential solution for one of the towers. The dimensions are approximate, and the I-shape might have to be modified in other areas of the building.

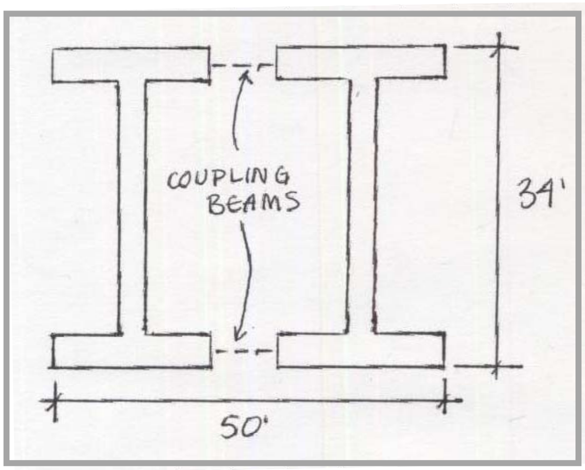


Figure 7 – Sketch of Proposed Shear Wall System

In order to achieve this goal, the use of both preliminary hand calculations as well as computer programs will be used. Once the wall layout is determined, a simple analysis based on the factored shear forces and wall lengths will give a likely solution to the wall thicknesses. Further analysis will be done with the use of computer programs, and if there are any problems with the design, the wall layout or thicknesses could be modified to reflect a better solution.

The building will be modeled 3-dimensionally in ETABS, with the primary elements being the shear walls, coupling beams, and floor diaphragms. The beams will have to be designed with minimal depth, because the existing gravity system is a flat plate, post-tensioned slab that is only 8" deep in the residential towers. This efficient floor system limits the floor-to-floor height of the building, so the coupling beams will have to be designed (if possible) to fit within a limited depth of about 18". If this design does not work, there might be some implications for the floor height and overall height of th e building.

The program input will include user-defined loads based on previously calculated wind and seismic shear forces. Inherent torsion will be included, as well as accidental torsion by applying 5% eccentricity of the loads to each floor (with potential amplification). The relevant output will include the shear/axial forces and moments in each particular wall and beam, as well as the floor displacements and story drifts. Again, if there are any problems with excessive displacements, the wall layout or thickness could be modified to ensure the design meets the code requirements.

Although the structural engineers designed this building based primarily on the Puerto Rico Building Code 1999 and the UBC 1997, the following codes will be used for this design project:

- IBC 2006 (International Building Code)
- ASCE 7-05 (American Society of Civil Engineers)
- ACI 318-08 (American Concrete Institute)

Once the shear wall layout is determined, the reinforcement will be designed using the computer program PCA Column. Based on the output from the model in ETABS, the overturning moment at each level for each I-shaped section of shear walls could be determined by assigning pier labels to each group. These moments, in addition to the axial forces in each wall based on gravity loads, would provide enough information to determine a reasonable layout of the reinforcement in PCA Column. The arrangement of the reinforcement for the boundary elements and for the wall in general will give the program the information needed to create an interaction diagram. A comparison of the interaction diagram with the actual loads will determine if the reinforcement is adequate. It will also illustrate if the reinforcement is over-designed by giving the location of the data point(s) relative to the edge of the diagram.

Breadth Topics

Two non-structural aspects of the building will be studied as a part of the thesis research. These topics will include two out of the following three issues (finalized topics to be determined by the beginning of the Spring 2009 semester):

- Lighting Design
- Electrical Design
- Acoustics Design

The breadth topics will include a study of acoustics, a new lighting design, or a new electrical design of a typical apartment unit. Because the available construction documents are limited to the architectural and structural drawing sets, the localized design of a typical apartment unit is unknown. Therefore, the thesis research will include a new design of a typical unit. The design will be based primarily on comfort because these are expensive, luxury apartments, but they will also be designed as efficiently as possible.

Tasks and Tools

DEPTH

- Determination of Wall Layout
  - Study of existing lateral force resisting system and the purpose of each shear wall (i.e. – one long wall in the first seven stories is only located on one side of the building)
  - Development of preliminary sketches based on optimization of shear wall design and limited architectural impact
- 3-Dimensional Computer Modeling
  - Further development of existing ETABS model with new shear walls and coupling beams
  - Input of factored seismic and wind shear forces
  - Study of model output, including shear forces and moments in the lateral members, displacements and drifts, and overall moments in each integrated group of shear walls
- Determination of Reinforcement
  - Development of PCA Column models to represent each group of shear walls
  - Calculation of axial forces in the walls based on gravity loads and the walls' tributary areas
  - Determination of appropriate reinforcement layout for the entire wall and for the boundary elements (multiple consecutive floors will have the same reinforcement design)
  - Optimization of design by ensuring that the data points are not too far inside the interaction diagram
- Impact on Foundation
  - Addition of columns to the computer model
  - Calculation of gravity loads to be defined in the model
  - Verification to see if current foundation design is sufficient or if the piles (location or design) need to be modified

BREADTH

- Lighting Design
  - Determination of appropriate lighting levels for each area of the apartment using the IESNA Handbook
  - Modeling of the design in AGi32 (v. 2.0) to create interior renderings of the critical spaces
- Electrical Design
  - Determination of electrical layout, including switches, outlets, luminaires, and panelboards
  - Development of layout in AutoCAD 2009
- Acoustics Design
  - Study of typical residential partitions, and determination of most efficient wall sections for sound isolation between apartment units

Schedule

WEEK OF: / TASK	1/12/2009	1/19/2009	1/26/2009	2/2/2009	2/9/2009	2/16/2009	2/23/2009	3/2/2009	3/9/2009	3/16/2009	3/23/2009	3/30/2009	4/6/2009	4/13/2009
Finalize Design Loads	■	■												
Develop Preliminary Shear Wall Layout	■	■												
Update ETABS Model and Check Feasibility of Design		■												
Refine Original Model and Model the Second Tower			■	■										
Model Shear Wall Sections in PCA Column				■	■	■								
Optimize Reinforcement for Each Typical Section						■								
Add Gravity System to ETABS Model							■	■						
Study Foundation Impact								■						
Spring Break									■					
Determine Appropriate Lighting Levels		■	■											
Model the Apartment Unit in AGi32 and Create Renderings				■	■	■								
Develop Preliminary Electrical Layout		■	■											
Create AutoCAD Model of Electrical Layout			■	■										
Research Wall Sections Based on Acoustics						■	■	■						
Compile Final Report										■	■	■		
Submit Final Report													■	
Present Thesis Project														■

Note: The final breadth topics will be determined after the preliminary structural analysis is complete. For example, the shear wall locations might have an impact on the interior wall and partition locations, which would call for an architectural breadth study.

Overall Progress Schedule

MILESTONE	DEADLINE
Determine if shear wall and coupling beam configuration is feasible	1/26/2009
Finalize the detailed ETABS model for the two individual towers	2/9/2009
Design the shear and flexural reinforcement for the shear walls	2/23/2009
Complete the structural analysis and study of breadth topics (after 3/16/09, just work on compiling report)	3/16/2009

Conclusions

For the Aquablue thesis project, an in-depth analysis of the structural system will be completed. There will be no re-design of the gravity system because it is already optimized by the existing two-way, flat plate, post tensioned slabs (8" or 9"). This shallow floor system saves money by limiting the floor-to-floor height, and any other system would have a significant impact on the floor height and overall building height. However, the shear walls will be optimized by making them more efficient and cost effective (primarily by taking advantage of symmetry). The use of various computer programs will be used during the process of re-designing the walls.

Also, two breadth topics will be studied to give a more well-rounded report at the end of the semester. The potential topics are lighting design, electrical design, and acoustics. The breadth issues will be applied to a typical apartment unit.