Thesis Proposal

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Structural Option
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Inova Fairfax Hospital | South Patient Tower

Falls Church, VA

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Executive Summary:

The main purpose of this proposal is to identify a challenge, and then propose a solution to that challenge while outlining the tasks, tools and schedule which will be used to resolve the challenge for the South Patient Tower (SPT). The SPT located in Falls Church, VA is the latest addition to the Inova Fairfax Hospital Development Plan to further expand upon its current facilities with additional medical/surgical rooms as well as patient rooms. The original structure consists of a two-way concrete flat slab system with drop panels to take the gravity loads. The lateral system is a dual system consisting of reinforced concrete shear walls located around the main elevator shaft and staircase and concrete moment frames situated at the North and South ends of the building. Also, because of the thickness associated with the two-way flat slab system, the floor system is also capable of receiving some of the lateral loads when applied to the structure.

As it currently stands, the SPT has very few structural challenges with the exception of torsional issues. Due to the location of the shear walls and moment frames, when loads are applied in the East-West direction, the structure undergoes significant torsion with displacements at the South end of the building having deflections tenfold when compared to the North end (connection to the existing hospital). Therefore, a scenario has been created where the University of California, Berkeley (UC Berkeley) has requested the design of a similar hospital patient tower. Seismic forces are expected to increase and stricter codes in regards to seismic performance will be accounted for in the redesign. The proposed solution will consist of two similar concrete structures with different base restrictions located in Berkeley, CA. The first redesign will consist of converting the current structure to a one-way slab system to increase the number of moment frames within the building and ultimately increase the lateral stiffness of the structure. The second structure will consist of the one-way slab system utilizing base isolators. Due to the occupancy type of the hospital patient tower, it is of the upmost important that the facility be able to maintain operation directly after a moderate to strong earthquake. Therefore, the structure will be designed to meet the ASCE 41-06 “S-1 Immediate Occupancy” seismic drift and damage criteria.

In addition to the structural depth, two breadths will be integrated into the design. Because of the increase in the floor depth associated with the one-way slab, an architectural breadth will be conducted comparing the changes accompanying the one-way slab system. Also, due to the relocation of the structure, an alternate façade system that complements the surrounding campus architecture will be chosen and compared to the original precast concrete panel system. The second breadth will consist of evaluating the thermal properties of the building envelope with respect to the original panel system and the new system. Energy models created will help compare the thermal performance of a typical exterior hospital patient room.

The MAE coursework incorporated into the proposed design consist of Computer Modeling, Earthquake Design and Steel Connections. These courses will be heavily relied on throughout the project. The MAE coursework, the methods and the tasks/tools to carry out the proposed redesign are discussed in this proposal. A schedule is also included to ensure work will be completed by the deadline with the depth and breadths both depicted.

Building Introduction:

As an early phase in the Inova Fairfax Hospital Campus Development Plan, the South Patient Tower will be connected to the existing patient tower (see Figure 1) at all levels above grade including the penthouse. Construction started in the Summer of 2010 and is expected to be completed by Fall 2012 with an overall project cost of around \$76 million. Standing at 175 ft, the 236,000 ft^2 concrete structure consists of 12 stories above grade (excluding the penthouse) with an additional story below grade. A system of auger-cast piles and pile caps are used to support the structure with a soil bearing pressure of 3000 psf.

Figure 1:
Aerial map from Bing.com showing the location of the building site

Along with the physical connection, the architecture of the South Patient Tower shares some similarities with the surrounding campus/hospital buildings. Wilmot/Sanz Architects designed the South Patient Tower as a continuation of the main architectural features of the existing patient tower building while at the same time displaying Inova's commitment to sustainable and functional buildings. Consisting of 174 all-private intensive-care and medical/surgical patient rooms, the floor plans are situated so that the various intensive-care unit specialties correspond to the same level as that of the existing main hospital. In order to meet the patient's specialized needs, workstations will be placed outside of the patient's rooms to maintain privacy while being able to monitor the patients at the same time.

The façade is largely composed of a smooth finished precast concrete panel as well as a precast concrete panel with a thin brick face (see Figure 2). To add more architectural detail, thin brick soldier courses are used at every story level, starting with the 4th floor and continuing up the building to the 11th floor. The only tangent from the typical architectural pattern occurs on the 5th floor (main mechanical floor) where architectural louvers are used to allow air to exit the building. The first two levels are composed entirely of an aluminum curtain wall system which is also used for the majority of the building's windows. The two main architectural features that stand out along the

Figure 2:
Exterior rendering showing the circular entrance and precast concrete façade (Provided by Turner Construction)

ground floor of the building are the large two-story rotunda and the canopy covering the main entrance which is constructed from 4 custom steel columns.

The South Patient Tower is attempting to achieve LEED Silver Certification by including numerous sustainable design features (see Figure 3). Inside the patient rooms, the use of low-VOC paints, building materials and furniture will lead to higher indoor air quality. Also, the use of low flow plumbing fixtures and sensors will reduce water consumption by up to 30%. Outside of the building, native drought resistant plants will surround the building. From the patient rooms, guests will be able to see the green roof and the water cisterns used to capture rain water.

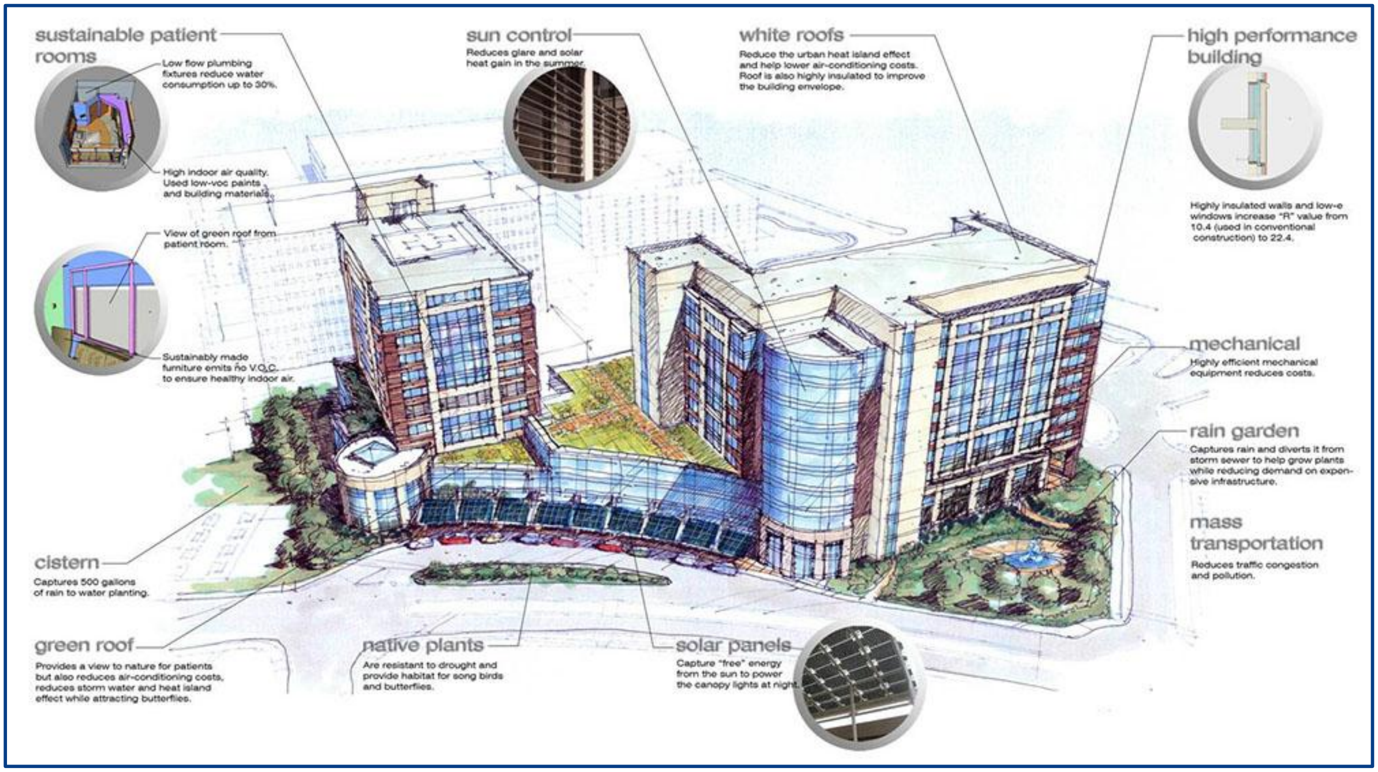


Figure 3:
Sustainability features (rendering provided by Wilmot/Sanz Architects)

Structural Overview:

Foundation:

Schnabel Engineering North performed the geotechnical studies for the South Patient Tower (SPT) and provided the report in which they explain the site and below-grade conditions. The structural engineers of Cagley & Associates designed the foundation for an undisturbed soil net allowable bearing pressure of 3000 psf. Also given in the geotechnical report are lateral equivalent fluid pressures which are 60 psf/ft of depth for both the braced walls and cantilevered retaining walls. The sliding resistance (friction factor) was found to be 0.30.

In light of the soil conditions, the SPT utilizes a foundation with a system of 16 in. diameter auger-cast piles and pile caps on top of a slab on grade (see Figure 4). Due to higher stresses around the staircase and elevator pit, a large pile cap is situated around each of these areas to help alleviate the stresses on the slab (see Figure 5). The number of piles per pile cap varies throughout the foundation with the most common being 9 and 11.

Along with the 5 in. slab on grade, grade beams connect the piles within the foundation footprint. Along the perimeter of the foundation, the SPT makes use of spread and strip footings (see Figure 6). Since the foundation does not cover the entire area of the ground floor, some areas consist of piles and pile caps directly underneath the ground floor slab to support the main entrance and lobby space.

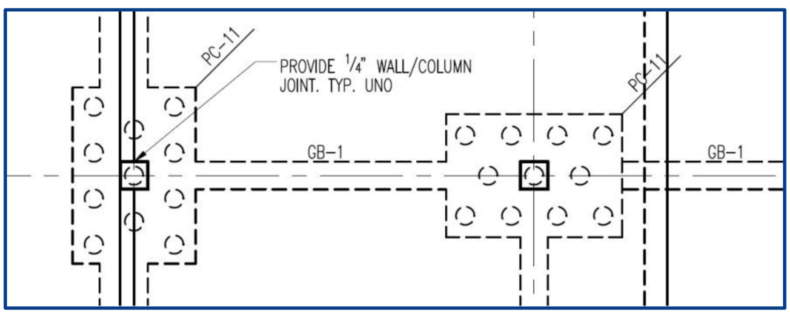


Figure 4:
Typical pile and pile cap (Provided by Turner Construction)

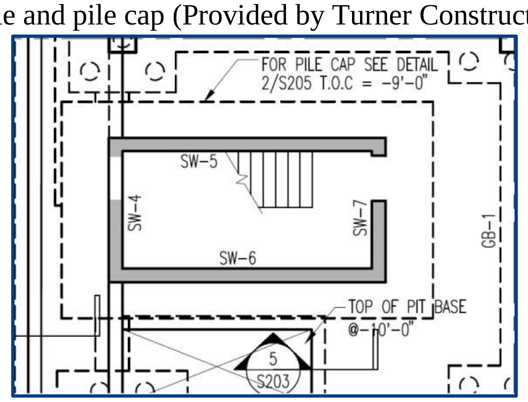


Figure 5:
Pile cap constructed around staircase
(Provided by Turner Construction)

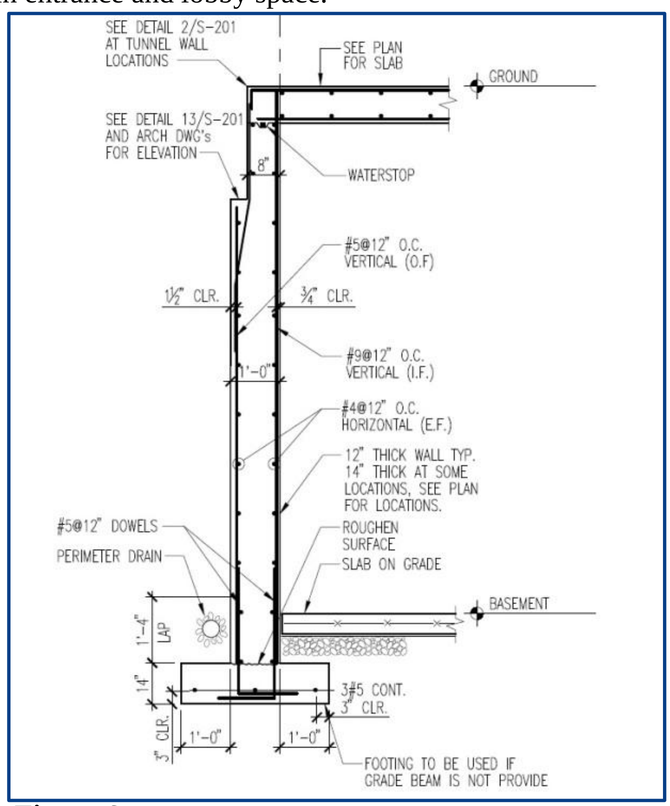


Figure 6:
Spread footing with basement wall (Provided by Turner Construction)

Floor System:

The elevated floors of the South Patient Tower are comprised of a 9 ½ in. two-way flat concrete slab. A drop panel is located at every column location in order to prevent punching shear as well as to increase the thickness of the slab to help with the moment carrying capacity of the slab near the columns. The typical size for the drop panel is 10 ft x10 ft x 6 in.

For the ground floor through the 4th floor, 5000 psi concrete is used for construction of the two-way slab while the upper floors use a 4000 psi concrete. The one exception to the 9 ½ in. slab is the mechanical floor (5th floor). Because of the higher load imposed by the mechanical equipment over the entire floor, the slab was designed accordingly and increased to a 10 ½ in. depth.

Reinforcement for the two-way slab system is comprised of both top and bottom steel. The typical bottom reinforcement consists of #5@12 in. o.c. each way (see Figures 7 and 8 for reinforcement details). Additional bottom reinforcement is listed on the drawings wherever needed as well as top reinforcement, which is located in areas of negative moments (mainly around the columns and between column lines depending on which direction the frame of interest is going). With a fairly simple column layout, the two-way slab system has a span of 29 ft in both directions for the most part.

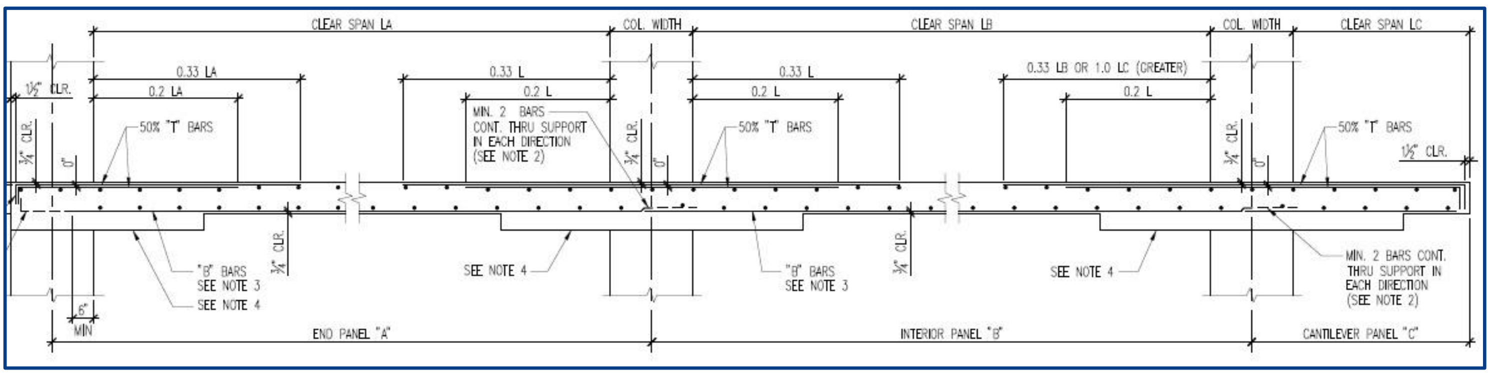


Figure 7:
Typical column strip reinforcement and placement (Provided by Turner Construction)

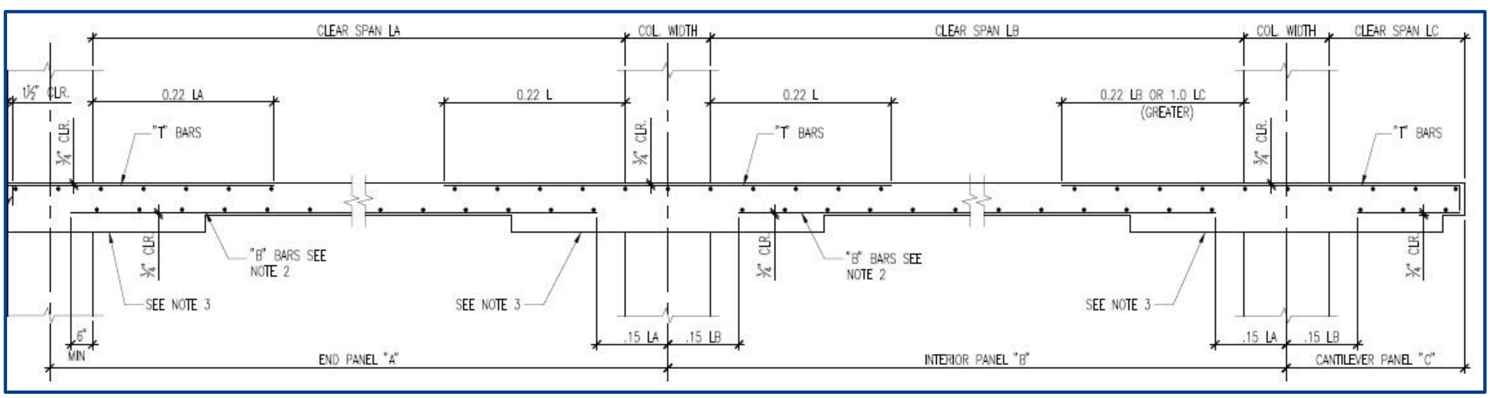


Figure 8:
Typical middle strip reinforcement and placement (Provided by Turner Construction)

Framing System:

As mentioned in the previous section, the columns follow a pretty regular pattern with a few exceptions. Typically the bay sizes are 29 ft x 29 ft with drop panels at every location. There are no interior beams, but there are a few beams along the perimeter of the building towards the south end of the structure and near the connection to the existing hospital.

The columns are all cast-in-place concrete with the largest column being 30 in. x 30 in. in the basement level. The typical column size is 24 in. x 24 in. and 12 in. x 18 in. (rotated as required to fit the wall thickness). Because of the higher loads located in the columns towards the lower portions of the building, 7000 psi concrete is utilized up to the 5th floor level with the rest of the upper floor columns being 5000 psi concrete. Consisting of mainly #11 reinforcement bars with #4 stirrups, the maximum number of longitudinal reinforcement bars within a column is 20, with the typical number being 4.

Lateral Systems:

Shear walls and ordinary moment resisting frames make up the main lateral force resisting system in the South Patient Tower and are situated throughout the building to best resist the lateral forces in the building. Seven different walls make up the shear wall system which surrounds both the main staircase and the main elevator while the moment frames are situated near the connection to the existing portion of the hospital and at the far end of the structure (see Figure 9 located on the next page). The shear walls are 12 in. thick and are composed of 5000 psi cast-in-place concrete. Most span from the basement level to the main roof line, but the northern core around the elevator shaft extends up the entire 175 ft height to the top of the penthouse level.

All of the shear walls are connected to the foundation with dowels to properly allow the loads to travel through the walls down to the foundation. The moment frames are mainly situated in the Y-Direction. After performing the analysis using ETABS, the displacements found in the Y-Direction were significantly smaller than the X-Direction. Due to the connection with the existing structure, the displacements in the Y-Direction are limited. This explains the need for most of the moment frames in that direction as well as the larger shear walls located near the connection point. Because most of the rigidity falls near the existing structure, the far end located furthest from the connection point could be of concern when dealing with displacements due to the lack of a lateral system in the X-Direction. Detailed elevations of the shear wall can be seen in Figure 10 depicting the various openings located in shear walls in both the X and Y direction.

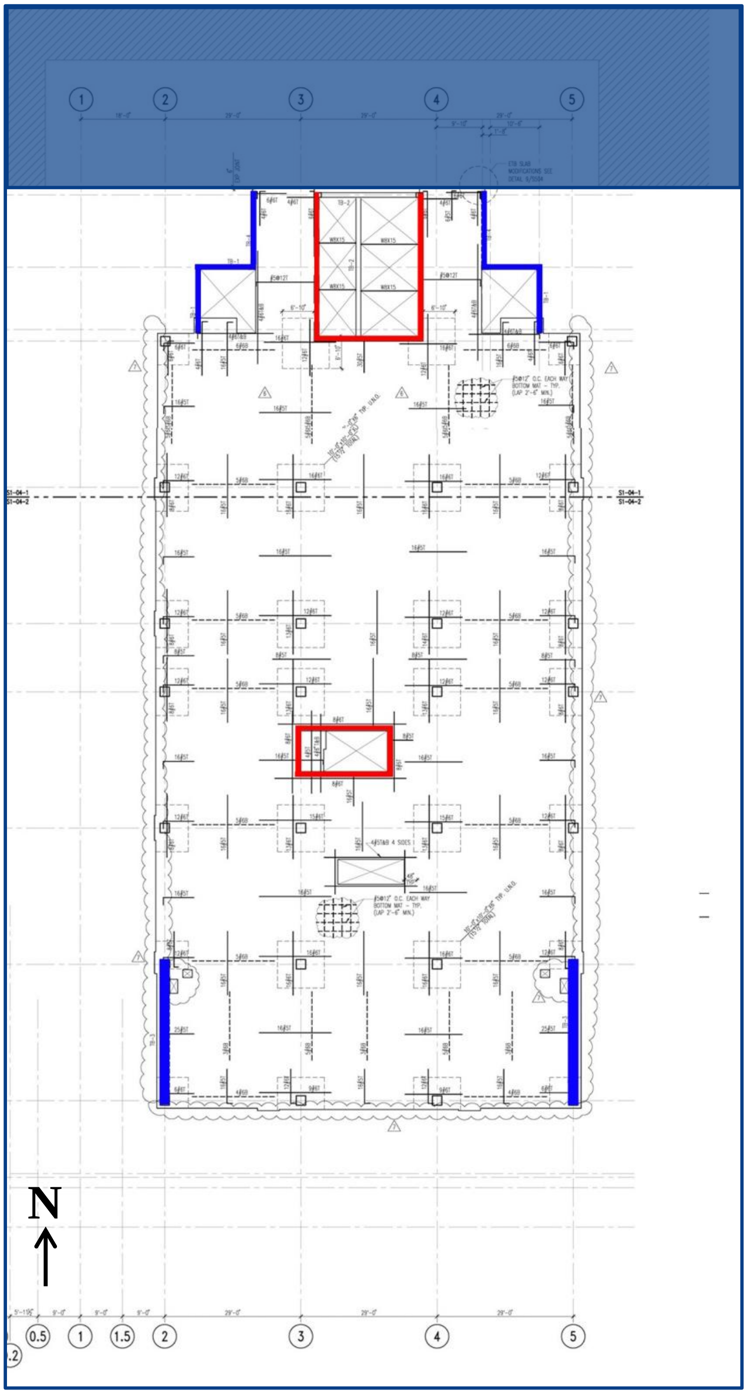


Figure 9:
Typical floor plan depicting the shear walls (shaded in red) and the moment frames (shaded in blue)
Adapted from drawing S1-04-1 and S1-04-2 (Provided by Turner Construction)

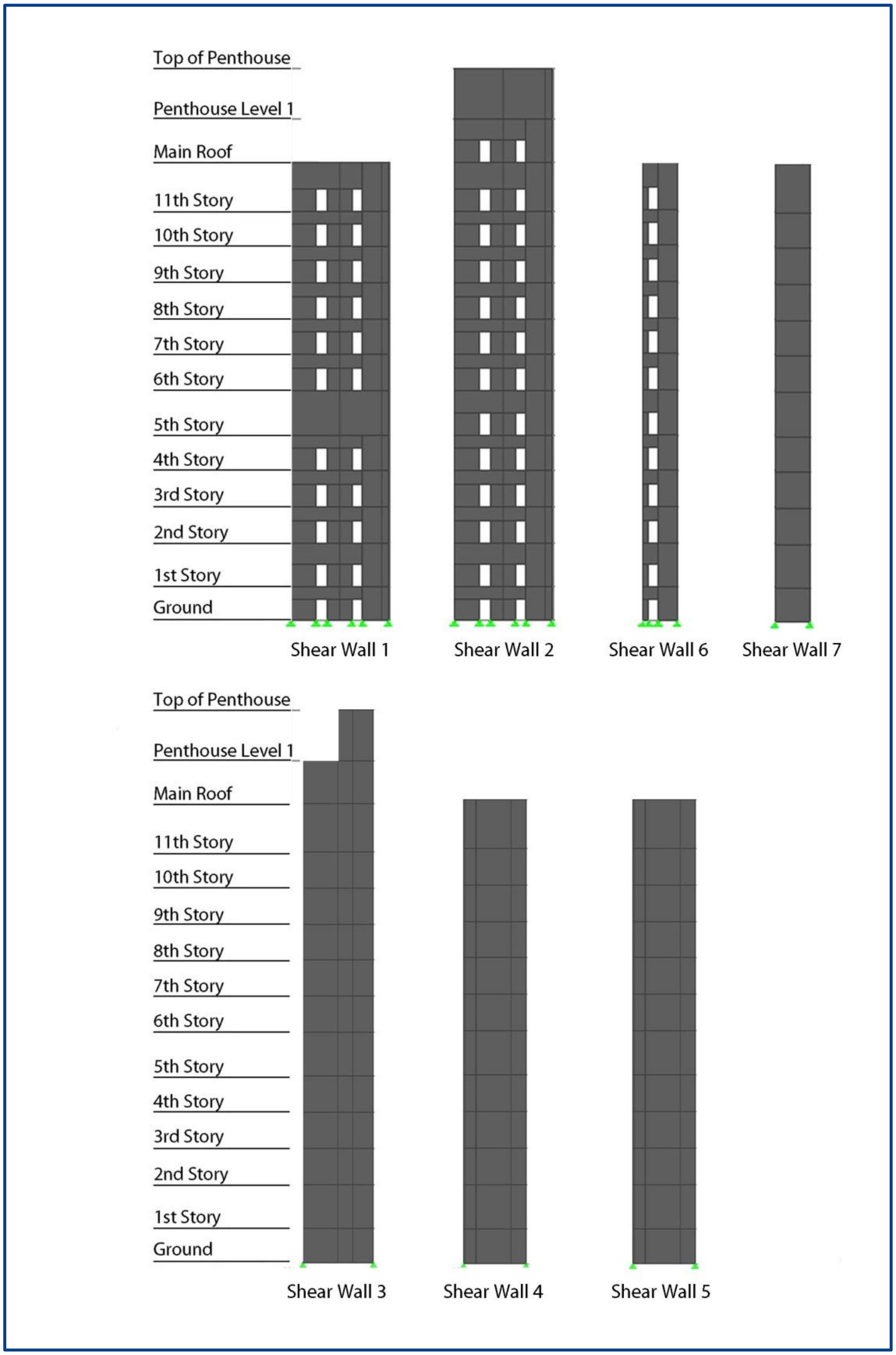


Figure 10:
Shear wall elevations with the upper half being the walls located in the Y-Direction and the lower half in the X-Direction

Roof System:

In general, there are three different main roof levels (see Figure 11). The roofing system on the 11th floor is comprised mainly of Polyvinyl-Chloride (PVC) roofing situated on top of composite polyisocyanurate board insulation. This system rests on top of a concrete slab with varying thickness.

Highlighting the 11th floor roof is the pre-engineered aluminum helicopter landing system. Supporting the landing platform is a system of structural steel columns with vibration isolators.

The main design features of the lower roof level (2nd floor) consist of a vegetated roof system, accent vegetation and concrete roof pavers. Also, on the lower roof a hexagonal skylight covers the circular rotunda (see Figure 12). The slab thickness for the lower roofs (excluding the green roof) varies but is mainly 9 ½ in., while the main roof, which supports higher loads from the mechanical penthouse, is 12 in. thick.

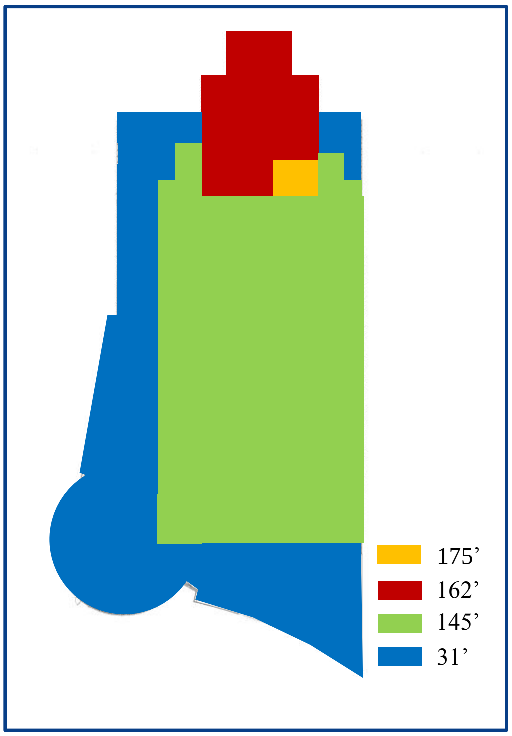


Figure 11:
Showing different roof heights in relation to 0’-0”

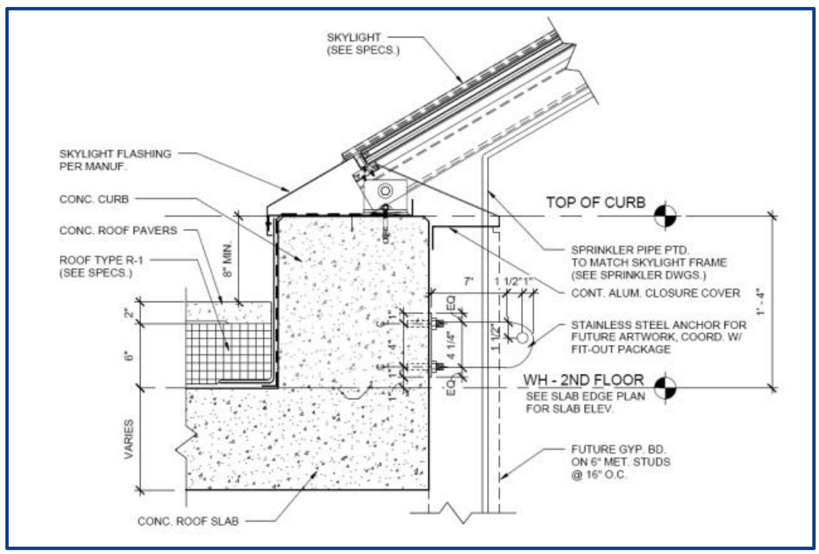


Figure 12:
Roof and skylight detail (Provided by Turner Construction)

Design Codes:

According to Sheet S0-01, the original building was designed to comply with the following codes/standards:

- 2006 International Building Code (IBC 2006)
- 2006 Virginia Uniform Statewide Building Code (Supplement to 2006 IBC)
- Minimum Design Loads for Building and Other Structures (ASCE7-05)
- Building Code Requirements for Structural Concrete (ACI 318-05)
- American Concrete Institute Manual of Concrete Practice – Parts 1 through 5 (ACI)
- Manual of Standard Practice (Concrete Reinforcing Steel Institute)
- Manual of Steel Construction – Allowable Stress Design 9th Edition (American Institute of Steel Construction - AISC)
- Manual of Steel Construction, Volume II, Connections (ASD 9th Edition/LRFD 1st Edition – AISC)
- Detailing for Steel Construction (AISC)
- Structural Welding Code ANSI/DWS D1.1 (American Welding Society – AWS)
- Design Manual for Floor Decks and Roof Decks (Steel Deck Institute – SDI)
- Standard Specifications for Structural Concrete (ACI 301)

Thesis Codes and References:

- 2009 International Building Code
- ASCE 7-05
- ACI 318-08
- AISC Steel Manual - 14th Edition (2010)

Materials Used:

The various kinds of materials and standards used for the construction of the South Patient Tower are listed in Figures 13a and 13b on the following page. All information was derived from Sheet S0-01.

Concrete		
Usage	**Strength (psi)**	**Weight**
Piles	4000	Normal
Pile Caps	5000	Normal
Footings	3000	Normal
Grade Beams	3000	Normal
Foundation Walls	3000	Normal
Shear Walls	5000	Normal
Columns	5000/7000	Normal
Slabs-on-Grade	3500	Normal
Reinforced Slabs LG-L4	5000	Normal
Reinforced Beams LG-L4	5000	Normal
Reinforced Slabs L5-Roof	4000	Normal
Reinforced Beams L5-Roof	4000	Normal
Topping Slabs	3000	Lightweight
Concrete on Steel Deck	3000	Lightweight

Steel		
Type	**Standard**	**Grade**
Wide Flange Shapes and Tees	ASTM A992	50
Round Hollow Structural Shapes	ASTM A992 ASTM 501	B (F_y = 35 ksi) F_y = 36 ksi
Square or Rectangular Hollow Structural Shapes	ASTM A500	B (F_y = 46 ksi)
Other Structural Shapes and Plates	ASTM A36	N/A
High Strength Bolts	ASTM A325 N	N/A
Smooth and Threaded Rods	ASTM A572	N/A
Headed Shear Studs	ASTM A108	N/A
Welding Electrodes	AWS A5.1 or A5.5	E70xx
Galvanized Steel Floor Deck	ASTM A653 SS	33

Figure 13a:
Summary of materials used on the SPT project with design standards and strengths

Reinforcement	
Type	**Standard**
Deformed Reinforcing Bars	ASTM A615 (Grade 50)
Weldable Deformed Reinforcing Bars	ASTM A706
Welded Wire Fabric (WWF)	ASTM A185
Epoxy Coated Reinforcing Bars	ASTM A6775
Mechanical Connection Splices	DYIDAG, Lenton, or ACI 318 §12.14.3
Adhesive Reinforcing Bar Doweling Systems	ASTM A621

Miscellaneous	
Type	**Standard/Value**
Cement	ASTM C150 (Type I or II)
Blended Hydraulic Cement	ASTM C595
Aggregates	ASTM C33 (NW) ASTM C330 (LW)
Air Entraining Admixture	ASTM C260
Chemical Admixture	ASTM C494
Grout	ASTM C1107 (F'_c = 5000 psi)

Concrete Water Cementitious Ratio	
F'c @ 28 Days (psi)	**W/C (Max)**
$F'_c \leq 3500$	0.55
$3500 < F'_c < 5000$	0.50
$5000 \leq F'_c$	0.45

Figure 13b:
Summary of materials used on the SPT project with design standards and strengths

Gravity Loads:

As part of this technical report, the dead, live and snow loads have all been calculated and compared to the loads listed on the structural drawings.

Dead and Live Loads:

The structural drawings list the superimposed dead loads used by the structural engineers for the design of the gravity members which are summarized in Figure 14.

Superimposed Dead Loads	
Description	**Load**
Floors	20 psf
Standard Roof	20 psf
Main Roof	20 psf

Figure 14:
Summary of superimposed dead loads

Following the confirmation of the superimposed dead loads, these loads along with the weights of the slabs, columns, shear walls, roofs, façade and the drop panels were used to calculate the overall weight of the entire structure. The exterior walls are made up of 5 ½ in. concrete with a ½ in. thin brick face. To simplify calculating the weight of this system, a 6 in. concrete panel was assumed to account for both elements. Figure 15 on the following page shows the overall weight of each floor as well as the complete weight of the entire structure which was found to be approximately 39,000 K.

A comparison of the live loads used in the SPT and Table 4-1 in ASCE 7-05 resulted in very little differences except when it came to the loads used for the offices as well as the patient floors (see Figure 16). The offices were all designed for 60 + 20 psf partition loading, which is 10 psf over the value given in Table 4-1. This could be due to the fact that offices are located on floors with patient rooms and corridors which both have a total live load of 80 psf. To be conservative, the project engineer probably just used 80 psf to be on the safe side. One other difference in live load occurred with the patient floor levels. According to ASCE, the minimum live load for hospital patient floors is 40 psf + partitions. However, the engineers for the SPT used 60 psf + partitions. A possible explanation for the increased load could be attributed to the future needs of individualized patients. Because certain patients may need different equipment, the exact load is uncertain. Therefore, the more conservative value of 60 psf was chosen. Calculations involving the patient floors will use 60 psf + 20 psf for partitions for this report and future reports.

Live loads for both the café and the roof were not given, but a live load of 80 psf was assumed for the café. Since the main roof utilizes a helicopter landing system, the specification for the system indicated a minimum live load of 100 psf and therefore will be used. Because the green roof will be accessible, a live load of 100 psf will be used for the lower vegetated roofs.

Weight Per Level		
Level	**Area (ft^2)**	**Weight (kips)**
Ground	25513	N/A
1st	25513	4393
2nd	11649	2418
3rd	17958	3902
4th	16571	3011
5th	16571	3285
6th	16571	3078
7th	16571	3011
8th	16571	3011
9th	16571	3011
10th	16571	3011
11th	16571	3066
Penthouse/Roof	16571	3831
		39026

Figure 15:
Distribution of weight per floor level

Live Loads			
Space	**Design Live Load (psf)**	**ASCE 7-05 Live Load (psf)**	**Notes**
Assembly Areas	100 (U)	100	N/A
Corridors	100	100 (first floor) ; 80 psf above	Based on both "Corridors" and "Hospitals" Section
Patient Floors	60 + 20	60 + 20	Based on "Hospitals - Operating Rooms, Laboratories"
Lobbies	100	100	N/A
Marquess and Canopie	75	75	N/A
Mechanical Rooms	150 (U)	N/A	N/A
Offices	60 + 20	50 + 20	Office Load + Partition Load
Stairs and Exitways	100 (U)	100	N/A
Café	N/A	80	N/A
Roof	N/A	100	Based on Future Helicopter Landing System

Figure 16:
Comparison of live loads

Snow Loads:

Following the procedure outlined in Chapter 7 of ASCE 7-05 and using the snow load maps, the roof snow load and drift values were obtained. The factors used to calculate the flat roof snow load are summarized in Figure 17. A flat roof snow load of 21 psf was calculated which matched the structural drawings. Due to the different roof heights, drift was considered at multiple locations. A summary of the snow and drift calculations and results can be found in Figure 18.

Flat Roof Snow Load Calculations	
Variable	**Value**
Ground Snow Load - p_g (psf)	25
Exposure Factor - C_e	1
Temperature Factor - C_t	1
Importance Factor - I	1.2
Flat Roof Snow Load - p_f (psf)	21

Figure 17:
Summary of roof snow load values

Snow Drift Load Calculations								
Roof Levels	**Windward**				**Leeward**			
	L_u (ft)	**h_d (ft)**	**p_d (psf)**	**w_d (ft)**	**L_u (ft)**	**h_d (ft)**	**p_d (psf)**	**w_d (ft)**
1 and 2	39.83	1.55	26.80	6.22	175.33	4.35	75.10	17.42
2 and 3	159.5	3.13	53.98	12.52	46.33	2.26	38.92	9.03
2 and 4	159.5	3.13	53.98	12.52	31.33	1.80	31.00	7.19
1 and 3	37.33	1.50	25.82	5.99	50.17	2.36	40.67	9.43
3 and 4	19.33	0.98	16.91	3.92	30.83	1.78	30.70	7.12

Figure 18:
Summary of roof snow drift calculations

Problem Statement:

The current structural system for the South Patient Tower is sufficient for both strength and serviceability requirements as determined in Technical Reports 1 and 3. However, as mentioned in the Lateral System section above, the one area of concern for the structure pertains to the lateral system in the East-West direction. The majority of the lateral system is situated along the North-South direction to prevent the structure from damaging the existing hospital. The structure as it stands currently undergoes significant torsional issues when the loads are applied in the East-West direction. In the current location, the controlling load case depends on the direction of interest as well as the height of the floor level. The majority of the upper levels are controlled by seismic loads whereas the lower levels see wind as the controlling factor. Due to the author's interest in seismic design, the structure being controlled by wind forces on certain levels was an undesirable condition.

Therefore, a scenario has been created in which the University of California, Berkeley (UC Berkeley) has decided to design and construct a similar hospital patient tower on campus. Because it is believed that the structure will be classified into a higher seismic design category, the structure will be subjected to more severe strength and serviceability checks. Since the structure encompasses intensive care units and medical/surgical rooms, the building should be designed for an ASCE 41-06 Structural Performance Level of "S-1 Immediate Occupancy" to allow immediate access to the facilities directly after an earthquake with only minor damage to the structure. A table explaining the structural requirements for the various S levels can be found in Figure 19 on the following page (taken from FEME 356).

Therefore, a structural system must be designed to provide the adequate strength and serviceability to obtain an S-1 structural performance level as defined in ASCE 41-06. This must be achieved with as little impact to the architecture, cost and schedule of the current structure.

Table C1-3 Structural Performance Levels and Damage[1, 2, 3]—Vertical Elements

		Structural Performance Levels		
Elements	**Type**	**Collapse Prevention S-5**	**Life Safety S-3**	**Immediate Occupancy S-1**
Concrete Frames	Primary	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.	Extensive damage to beams. Spalling of cover and shear cracking (<1/8" width) for ductile columns. Minor spalling in nonductile columns. Joint cracks <1/8" wide.	Minor hairline cracking. Limited yielding possible at a few locations. No crushing (strains below 0.003).
	Secondary	Extensive spalling in columns (limited shortening) and beams. Severe joint damage. Some reinforcing buckled.	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.	Minor spalling in a few places in ductile columns and beams. Flexural cracking in beams and columns. Shear cracking in joints <1/16" width.
	Drift	4% transient or permanent	2% transient; 1% permanent	1% transient; negligible permanent
Steel Moment Frames	Primary	Extensive distortion of beams and column panels. Many fractures at moment connections, but shear connections remain intact.	Hinges form. Local buckling of some beam elements. Severe joint distortion; isolated moment connection fractures, but shear connections remain intact. A few elements may experience partial fracture.	Minor local yielding at a few places. No fractures. Minor buckling or observable permanent distortion of members.
	Secondary	Same as primary.	Extensive distortion of beams and column panels. Many fractures at moment connections, but shear connections remain intact.	Same as primary.
	Drift	5% transient or permanent	2.5% transient; 1% permanent	0.7% transient; negligible permanent

Table C1-3 Structural Performance Levels and Damage[1, 2, 3]—Vertical Elements (continued)

		Structural Performance Levels		
Elements	**Type**	**Collapse Prevention S-5**	**Life Safety S-3**	**Immediate Occupancy S-1**
Concrete Walls	Primary	Major flexural and shear cracks and voids. Sliding at joints. Extensive crushing and buckling of reinforcement. Failure around openings. Severe boundary element damage. Coupling beams shattered and virtually disintegrated.	Some boundary element stress, including limited buckling of reinforcement. Some sliding at joints. Damage around openings. Some crushing and flexural cracking. Coupling beams: extensive shear and flexural cracks; some crushing, but concrete generally remains in place.	Minor hairline cracking of walls, <1/16" wide. Coupling beams experience cracking <1/8" width.
	Secondary	Panels shattered and virtually disintegrated.	Major flexural and shear cracks. Sliding at joints. Extensive crushing. Failure around openings. Severe boundary element damage. Coupling beams shattered and virtually disintegrated.	Minor hairline cracking of walls. Some evidence of sliding at construction joints. Coupling beams experience cracks <1/8" width. Minor spalling.

Figure 19:
Performance requirements for Concrete Frames and Walls taken from FEMA 356 (similar to ASCE 41)

Problem Solution:

The existing lateral system found in the South Patient Tower will be redesigned using a one-way floor slab system that was investigated in Technical Report 2. The one-way slab will increase the lateral stiffness of the structure in the East-West direction and help correct the torsional irregularity problem. Although this system was deemed not to be a viable option in Technical Report 2, the architectural changes will be investigated in an Architectural Breadth. Upon completion of a suitable lateral system, the building will be moved to Berkeley, California. Next, new seismic loads will be calculated to determine the controlling load combination. Two separate structures will then be created using ETABS to compare the effectiveness of these structures for higher seismic loads and the S-1 performance requirements:

- One-way slab system with a traditional fixed base
- One-way slab system utilizing base isolators

For comparison purposes, a one-way slab system model will be constructed using the loads for the current location.

Because the interstory drifts were found to be excessive in Technical Report 3, the redesign of the lateral system should help improve the serviceability criteria for the present location. Once the structure is moved to California, the higher seismic loads could potentially produce an interstory drift issue with the newly designed one-way slab system. One solution is the use of base isolators. These include a range of different devices to provide flexibility into the building and creating a point of energy dissipation in the structure. The base isolator increases the flexibility/period of the building, which in turn reduces the forces seen by the structure. However, with this increase in period, there also is an increase in overall displacement of the structure. On the other hand, the general ideal behind using base isolators is that most of the ground movement produced from the earthquake will not be transmitted to the building and therefore, the structure as a whole will experience much smaller floor accelerations and interstory drifts. The key to preventing/eliminating structural and non-structural damage (façade panels and various architectural details) is to minimize interstory drifts.

Various types of base isolators will be researched and investigated in order to utilize the one that is both cost efficient and readily available. An example of a friction pendulum can be seen to the right in Figure 20. This device along with lead-rubber bearings and high-damping rubber bearings are the most popular devices in the United States for seismic isolation. The friction pendulum allows the structure to displace both vertically and horizontally as the ball bearing travels in the bowl.

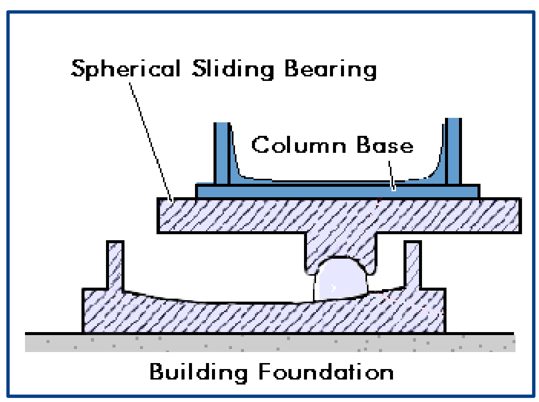


Figure 20:
Friction pendulum, taken from MCEER's website

Breadth Topics:

Architectural Breadth:

Using a different lateral system will have a direct impact on the façade of the South Patient Tower. The current façade consists of precast concrete panels with a glass curtain wall system. Because of the addition of the beams from the moment frames, a glass curtain wall system may not be the best façade since the beams will be visible from the outside. This may impact the window placement and size. Also, because of the relocation to California, it may not be best to use the same precast concrete panel façade and an alternative system may be best for the building when comparing both costs and architectural aspects. Since the patient tower is located on a campus, the surrounding architecture will play a significant role in deciding the best alternate façade system. This breadth will mainly focus on how changing the structural system will influence the architectural appearance of the patient tower.

Mechanical Breadth:

Due to architectural changes to the façade, the alternate system that is chosen in the Architectural Breadth will be compared to the original precast concrete panel with glass curtain walls on the basis of thermal performance. Once obtaining the properties of the two systems, a model of a typical patient room will be created using Trace and the two different façade systems will be analyzed and compared.

MAE Coursework:

As a requirement for completing the MAE degree, graduate level coursework much be incorporated into the proposal. Much of the calculation of the proposed redesign will draw upon material learned in the MAE courses. Computer modeling will be an integral tool utilized in the completion of the redesign as well as the modeling of the base isolators. Concepts such as insertion points, rigid diaphragm constraints and modal analysis results will be used for the redesign of the South Patient Tower and were taught in AE 597A – Advanced Computer Modeling

AE 538 – Earthquake Resistant Design will also be heavily relied on for this proposal. The design of concrete structures for seismic locations was first taught in this class. Also, an introduction to base isolation techniques and theories were discussed and will be applied to the proposal and redesign.

Finally, coursework from AE 534 – Steel Connections will be integrated into the design of the column-to-base isolator connection.

Tasks and Tools:

Depth – One-way slab with fixed base vs. One-way slab with base isolation

Task 1: Design one-way slab system

- Determine slab thickness based on loading established in the original structural drawings for a typical floor, 5th floor, and the roof (5th floor chosen due to higher mechanical loads)
- Size beams/girders/columns in typical bays by hand for required loading, serviceability concerns and structural depth limitations using ACI318-08
- Using ETABS, compare the lateral deflections and interstory drifts of the current structure and the one-way slab model to compare the lateral stiffness

Task 2: Optimize the one-way slab system with fixed base for Berkeley, CA

- Recalculate Equivalent Lateral Force seismic loads according to ASCE 7-05 and compare to Main Wind Force Resisting System wind loads
- Modify beam sizes and locations to minimize torsion, irregularities and architectural impacts
- Size beam/girders by hand for controlling lateral loads and serviceability criteria
- Compare results to the design in the current location

Task 3: Design the one-way slab system utilizing base isolation for Berkeley, CA

- Become familiar with provisions for the design of structures incorporating base isolators and select the appropriate design method
- Calculate seismic loads as required for selected design method using Ch. 18 of ASCE 7-05
- Size base isolator as required using ASCE 7-05 and ASCE 41-06
- Model the system using ETABS to verify adequacy of the system and optimize the design to meet the S-1 rating as given in ASCE 41-06

Task 4: Non-linear Analysis

- Locate a time history record for an appropriate earthquake and define the non-linear properties to damper elements
- Define special parameters necessary for the procedure
- Apply time history loading to the model located in Berkeley, CA using ETABS and perform the non-linear analysis
- Compare the results to the linear models

Breadth 1– Architectural Impacts

Task 1: Exterior Adjustments

- Include placement and sizes of beams into a model to determine the effect on the existing façade

Task 2: Alternate Façade

- Chose an alternate façade material that is more representative of the campus architecture and compare to the existing façade

Task 3: Models

- Create two models, one with the existing façade and another to accommodate the proposed façade
- Compare the two façades based on visual appearance

Breadth 2– Mechanical Impacts

Task 1: Thermal Properties

- Determine the thermal properties associated with the two different façades

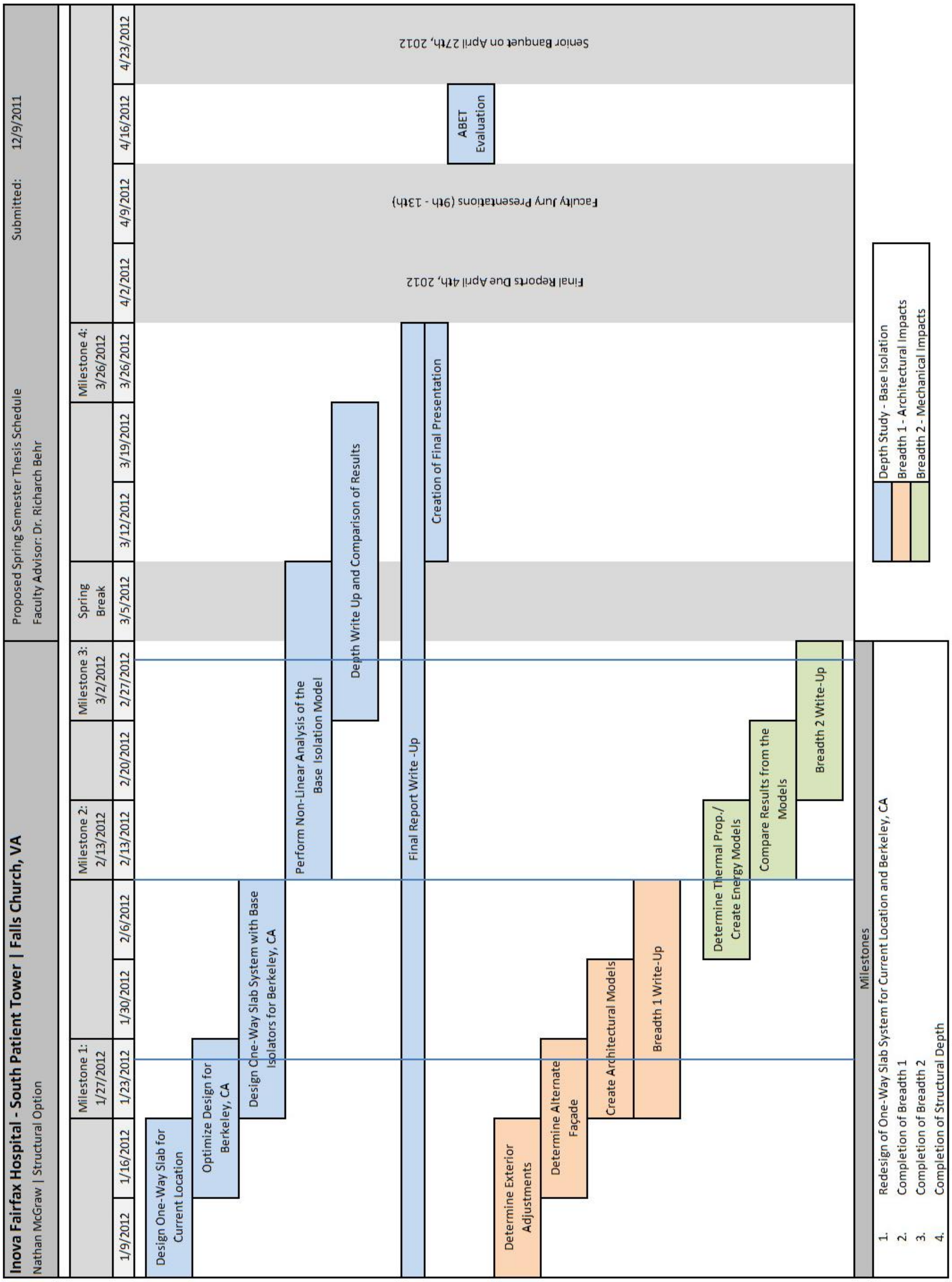
Task 2: Energy Model

- Create two models using Trace to depict a typical exterior patient room, one with the existing façade and another to accommodate the proposed façade

Task 3: Comparison

- Compare the two separate panel systems based on thermal performance

Thesis Schedule:



Conclusion:

The proposed redesign of the SPT focuses on relocating the structure to Berkeley, California to explore higher seismic loads as opposed to the current mixed loading that controls the building in Falls Church, Virginia. To address these new seismic loads, the current structural system will be redesigned as a one-way slab system to help increase the lateral stiffness of the building while also decreasing the extreme torsional irregularities associated with the current design. Once the California loads have been applied to the new structure, the building will be optimized to satisfy the requirements as specified by ASCE 41-06 category “S-1 Immediate Occupancy.” Once these requirements have been met, the structure will then undergo a transition to incorporate base isolators located within the basement level. The structure including the base isolators will then be optimized once again to meet S-1 requirements and then compared to both the original structure and the one-way slab redesign with traditional base restrictions to determine the feasibility.

Because of the changes to the slab system, an architectural breadth will be conducted to compare the changes need to incorporate the new system. Due to the relocation of the structure, an alternate façade system will be selected. The Architectural Breadth will encompass a comparison of the original façade system to the newly proposed system in terms of aesthetic appearances, window layout and cost/scheduling. Additionally, a Mechanical Breadth will be completed and will include two separate energy models two compare the façade systems. The thermal performance of each façade system will be conducted on a typical exterior patient room to determine the feasibility of the proposed system.