Thesis
Final Report

Nemours Children's Hospital as a part of The Nemours Foundation

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Structural Option

Advisor: Dr. Boothby

04.02.12

General Information

Building Type: Hospital
Building Size: 600,000 SF
Height: 135 ft
Construction: July 2009-July2012
Cost: $400 million
Delivery: Design-Bid-Build

Architecture

- 85-bed tower and outpatient center
- Glass curtain walls dominate the majority of the façade.
- Other materials include metal and terracotta panels.
- Main features of the building: curved curtain wall, deep canopies, and green roofs

Structure

- Concrete spread footings placed on improved soils
- Framing system consists of concrete columns and beams
- 12-14" elevated two-way flat slab with drop panels
- Lateral system comprises of shear walls located in elevator core and stairways

MEP

Nemours Children's Hospital as a part of The Nemours Foundation gains power from the Central Energy Plant (CEP) attached to the hospital. The CEP contains the main electrical and mechanical distribution systems, except for the AHUs.

CEP

- Three 1300 ton dual cell cooling towers
- Three 1300 ton centrifugal chillers
- Three water tube boilers
- Main and 15kV chiller source transfer switching
- Four 2250 kW generators

Hospital

- Thirty-two AHUs located on the 1st floor mezzanine or 7th floor mechanical room.
- Mix use of VAV and CV boxes

Project Team

Owner: The Nemours Foundation
CM/GC: Skanska USA Building
Architects: Stanley Beaman & Sears
Perkins + Will
Engineers: (Civil) Harris Civil Engineers
(Structural) Simpson, Gumpertz & Heger
(Landscape Architect) AECOM
(MEP&T) TLC Engineering for Architecture




CPEP Website: http://www.engr.psu.edu/ae/thesis/portfolios/2012/CYB5027/index.html

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Acknowledgements:

I would like to thank The Nemours Foundation for allowing me to use The Nemours Children's Hospital as a part of The Nemours Foundation in Orlando, Florida for my senior thesis study.

Additionally, I would like to thank Simpson Gumpertz & Heger, especially Michael Bolduc and Cynthia Staats, for providing me with all the documents and reports needed to complete this project along with their invaluable advice and direction.

I would also like to thank the following professors at The Pennsylvania State University Architectural Engineering Department:

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Dr. Andres Lepage
Dr. Kevin Houser
Professor Parfitt
Professor Holland
The entire AE faculty and staff

A special thanks to my family and friends who have provided me with endless help and support these past five years.

Executive Summary:

Nemours Children's Hospital as a part of The Nemours Foundation (NCHTNF) is a 7-story building located in Orlando, Florida. The entire complex consists of a hospital, clinic, loading dock data center, central energy plant (CEP), and parking facility. The 600,000 square foot hospital consists of two components: a bed tower and outpatient center. The combined components will provide 85 beds, emergency department, diagnostics and ambulatory programs, educational and research centers, and an outpatient clinic. Stanley Beaman & Sears and Perkins + Will are the architects of the project. Harris Civil Engineers, Simpson Gumpertz & Heger, AECOM, and TLC Engineering for Architecture are responsible for the engineering design of NCHTNF. Skanska USA Building is acting as the construction manager and general contractor of the design-bid-build project, which is scheduled to be completed July 2012 after ground was broken July 2009.

This thesis focuses on redesigning the lateral system using concrete moment frames instead of the current concrete shear walls. The existing structure uses 157 mph design wind speed, far surpassing the minimum code level. This lateral analysis studies if concrete moment frames are feasible for 110 mph, the minimum design wind speed for Orlando, in addition to the 157mph case. Pending a practical design, concrete moment frames create an open floor plan by eliminating shear walls. These changes alter the weight of the building, so the foundation needs to be reevaluated.

Additionally, a flat plate system is considered rather than the current flat slab. Flat plate designs eliminate drop panels and column capitals, thus producing a more cost effective slab system with a reduction of formwork. The slab-column connections require detailed analyses to determine if the connection can withstand the moment transfer and applied shear. If the slab-column connections cannot carry the load, solutions are presented and studied to mitigate the moment transfer.

In addition to the lateral and floor system redesign, two breadth topics are explored. One topic is a daylighting study of the sun management of a south facing façade. This determines if the current louvers can adequately control the sun. Additionally, an alternative interior sun control system is presented. The second breath topic examines the structural system of the façade, for both constructability and maintainability. An aluminum mullion design is presented as an alternate to the current silicone structural sealant; comparisons of advantages and disadvantages of each drive the final decision.

Building Introduction:

NCHTNF is a 7-story building located in Orlando, Florida, shown in Figure 1. The entire complex consists of a hospital, clinic, loading dock data center, central energy plant (CEP), and parking facility. The 600,000 square foot hospital consists of two components: a bed tower and outpatient center. The combined components will provide 85 beds, emergency department, diagnostics and ambulatory programs, educational and research centers, and an outpatient clinic. Stanly Beaman & Sears and Perkins + Will are the architects of the project. Harris Civil Engineers, Simpson Gumpertz & Heger, AECOM, and TLC Engineering for Architecture are responsible for the engineering design of NCHTNF. Skanska USA Building is acting as the construction manager and general contractor of the design-bid-build project, which is scheduled to be completed July 2012 after ground was broken July 2009.

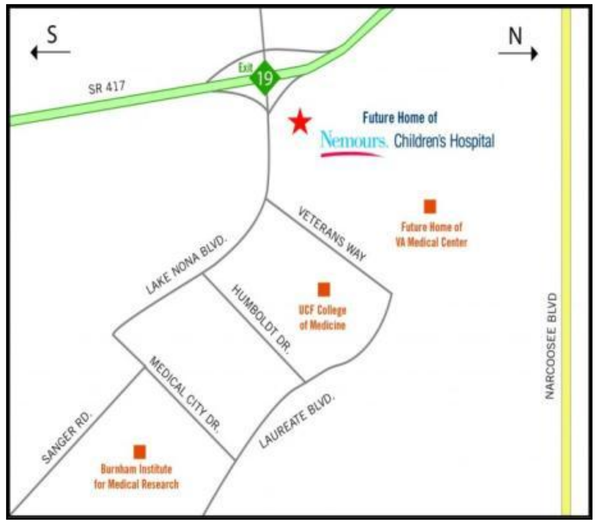

Figure 1 - Location of NCHTNF. Courtesy The Nemours Foundation.

The design of this $400 million building uses 2007 Florida Building Code with 2009 updates. The Florida Building Code is based on the International Building Code and subsidiary related codes. The building is classified as I-2 while the clinic can be considered business class, the hospital is industrial because of overnight patients, thus making the entire project industrial. The site is an undeveloped parcel of land that underwent clearing and mass grading to reach its current topography. The site location does not have any restrictions presiding over the NCHTNF's design.

Figure 2 – Nemours Children's Hospital as a part of The Nemours Foundation. Courtesy The Nemours Foundation.

The primary structure is concrete with curtain walls dominating the majority of the façade. The glass curtain walls vary between metal sunscreen systems, fritt patterns, and insulated spandrels. Other building materials include ribbed metal panel system, terracotta tile wall system, terrazzo wall panels, and composite metal panels to complement the glass systems in the curtain walls. A curved curtain wall, deep canopies, and two green roof gardens provide additional architectural features to the building design.

NCHTNF is designed to withstand the effects of a category 3 hurricane using 157 mph design wind speed. The National Oceanic and Atmospheric Administration, NOAA, describes a category 3 hurricane as an event where devastating damage will occur, resulting in injury and death. The Nemours Foundation wants NCHTNF to be listed as a place of refuge, more technically known as an Enhanced Hurricane Protection Area, during a category 3 hurricane. This requires the building's design to at least meet NOAA's classification of a category 3 hurricane, having sustained winds of 110-130 mph. To qualify as an Enhanced Hurricane Protection Area, the hospital is designed to these standards with a factor of safety.

Figure 3 - Installation of Sun shading Device. Courtesy SGH.

The building envelope's design is more complex than most to meet the Enhanced Hurricane Protection Area standards. The modular curtain wall, constructed by Trainor, is designed with 30,000 feet of dual sealant joints to allow weeping between the two joints. A probe test is specified to be conducted after the sealant has cured to ensure the joint is working properly. The north side of the building features a curved curtain wall supported by slanted structural columns. The deep canopies and fritt pattern glass, acting as sun shading devices to provide adequate shading from the Florida sun, are prevalent throughout the building. An example of the one of the sun shading devices is shown in Figure 3. NCHTNF incorporates several different roofing systems to accommodate different functions of the roof. A fluid-applied membrane acts as the roofing system for the patient accessible roof gardens. Thermoplastic membrane roofing and SBS-modified bituminous membrane roofing comprise the other roofs on the building. A lab in Florida tested a mock-up of NCHTNF against conditions generated by a category 3 hurricane. A 2-story 10-bay mock-up is required to pass various tests to ensure the building envelope will be able to sustain the effects of a category 3 hurricane. Laminated glass and extensive use of roof fasteners help the building envelope meet the standards of the hurricane test.

The design of NCHTNF follows the USGBC's LEED prerequisites and credits needed for certification based on LEED for New Construction 2.2. The building has two green roof gardens on the second and fourth floor roofs as mentioned in the paragraph above. The green roofs double as outdoor gardens for patients as well as sustainability features for the building. NCHTNF has numerous sunshades to block the sun from the vast glass façades. Deep canopies provide shade for large spaces on the south façade of the building. The building's design implements Fritt pattern and insulated spandrel glass systems. These devices block some of the intense Florida sun to lessen the load on the HVAC system of the building.

Structural Overview:

NCHTNF bears on spread footings on either improved or natural soils, shown in Figure 4. The hospital and clinic portion of the building predominately consist of reinforced concrete, with the exception of steel framed mechanical penthouses. The loading dock data center and central energy plant are primarily steel framed structures. The lateral system is comprised of shear walls, most of which continue through the entire building height. NCHTNF uses unusual framing techniques for the wave and sloped curtain wall backup.

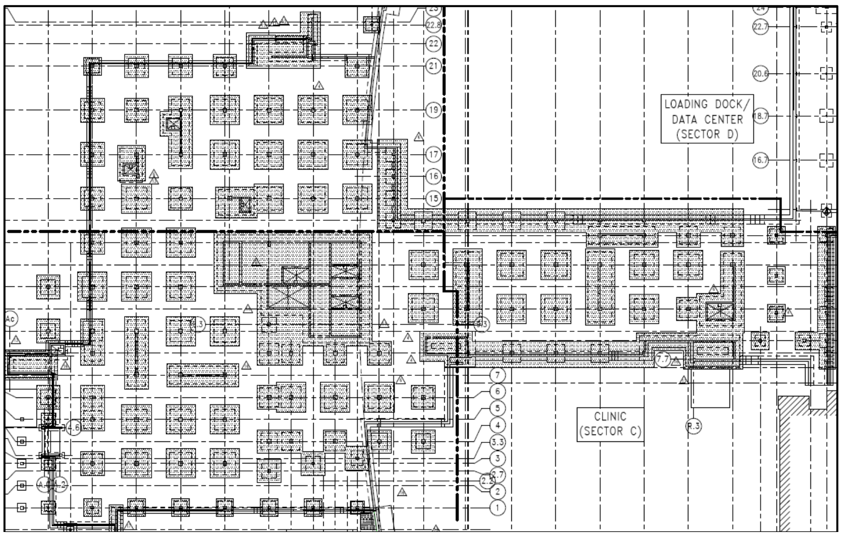

Figure 4 - Foundation Plan of NCHTNF. Courtesy SGH.

Foundation:

PSI, the geotechnical firm, performed nineteen borings across the site in January 2009. The soils generally consist of varying types of fine sands graded relatively clean to slightly silty in composition. The boring blow counts record the upper layers of sand to be of medium dense condition, while the lower layers of sand are generally loose to medium dense condition.

PSI recommends utilizing shallow foundations only if the foundation design implements soil improvement to increase the allowable bearing capacity used in the design. PSI proposes another foundation solution, if soil improvement is not desirable implement a pile foundation system. These reinforced augercast piles withstand considerably higher foundation loads than the shallow foundation system. The downside of augercast piles are they can bulge or neck where very loose soils are encountered, requiring stringent monitoring and quality control. Due to the specialized nature of the augercast piles for this project, spread footings with soil improvement is chosen as the foundation system for the NCHTNF.

Additionally, the water table is measured only 4 feet below the surface raises concerns about excavations. The sump system dewaters shallow excavations while deeper excavations require well-pointing or horizontal sock drains for proper dewatering.

Floor System:

NCHTNF has numerous types of floor construction due to different design requirements in different sections of the building. The building contains 5"-6" normal weight concrete as the slab on grade. A few sections of the foundation system utilize mat foundations, varying from 2' to 4'-3" normal weight concrete. The hospital and clinic are built with normal weight elevated two-way flat slabs, with and without drop panels, varying in depth from 9"-14". A typical structural floor plan detailing a typical 30'x30' bay is shown in Figures 5 and 6. The loading dock data center and central energy plant are constructed with a 4-1/2" 1-way slab on 3"-20 GA. composite metal deck, which is supported by a steel frame system. Some specialty areas, such as the green roof and the slab over the lecture hall, vary slightly from the typical slab in the remainder of the building.

There are 29 different concrete beam sizes in the NCHTNF. The beams range from 16" x20" to 89" x 48". The hospital and clinic predominately consist of 15' x 30' bays with a few 15' x 15' and 30' x 30' bays to accommodate for the elevator and stair core. The bays in the loading dock data center are irregular. They vary from the smallest being 21' x 30'-3" to the largest being 30' x 45' – 2". The central energy plant also has a variety of bay sizes, ranging from 22' x 11'-2" to 22' x 26'-7".

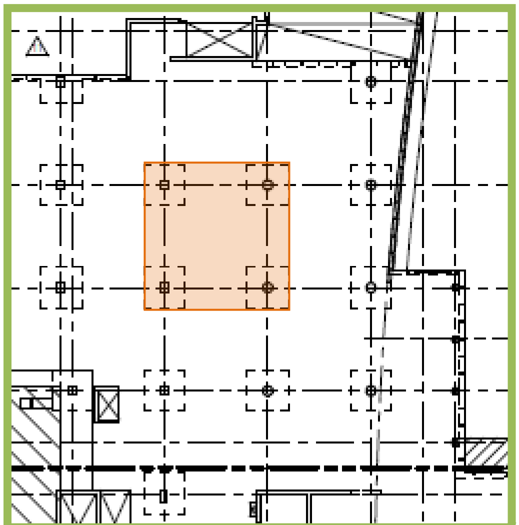

Figure 5 - Level 1 Typical Structural Bay (30'x30') Key Plan. Courtesy SGH.

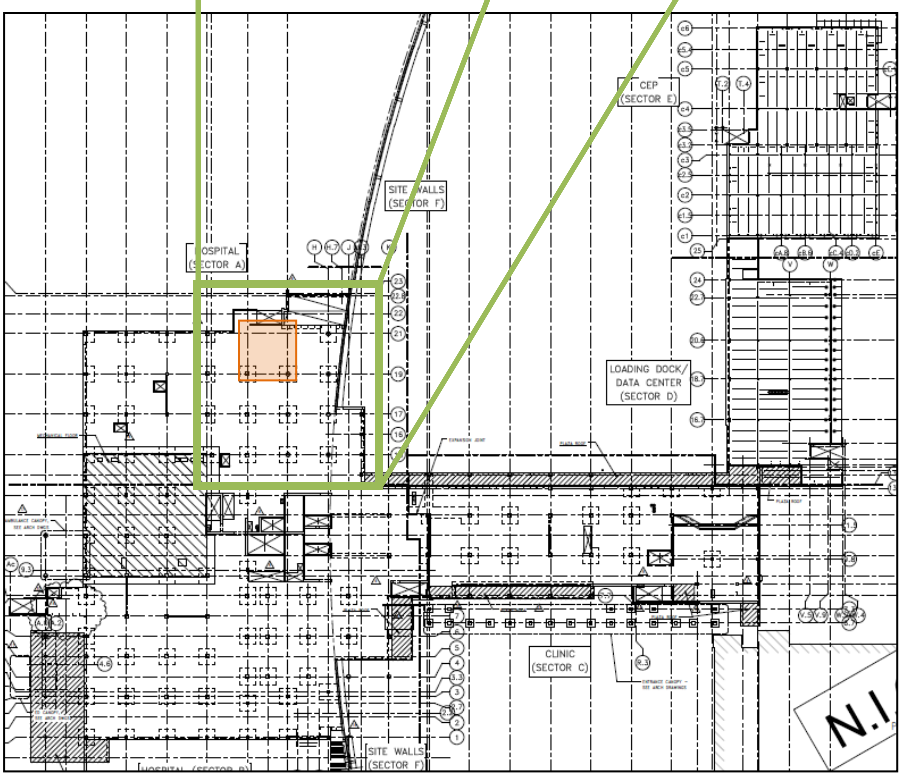

Figure 6 - Level 1 Typical Structural Bay (30'x30'). Courtesy SGH.

Framing System:

The columns supporting the NCHTNF are mostly reinforced concrete columns. Steel columns support the mechanical penthouse on the 7th floor. The concrete columns supporting the hospital and clinic typically start at a dimension of 30" x 30" and taper to 22" x 22" by Level 6. The mechanical penthouse is constructed with W12x53 columns on both the hospital and clinic. W14x109, W10x49, W10x60, and W14x68 mainly support the loading dock data center. HSS8x8 and HSS12x8 dominate the central energy plant's supporting structure along with a few W12x65 and W12x79 columns.

Lateral System:

Shear walls resist lateral loads in the hospital and clinic of the NCHTNF. These walls are 12-14" thick and tie into mat foundations with dowels matching the typical wall reinforcement, mostly #8 bars. The shear walls are located in the elevator/stair core in the hospital and in the elevator bays and lecture hall in the clinic, which are highlighted below in green in Figure 7. Also, the central energy plant has one shear wall, the rest of the lateral system of the CEP being braced framing which, discussed in the next paragraph. A few shear walls include knockout panels to plan for future openings.

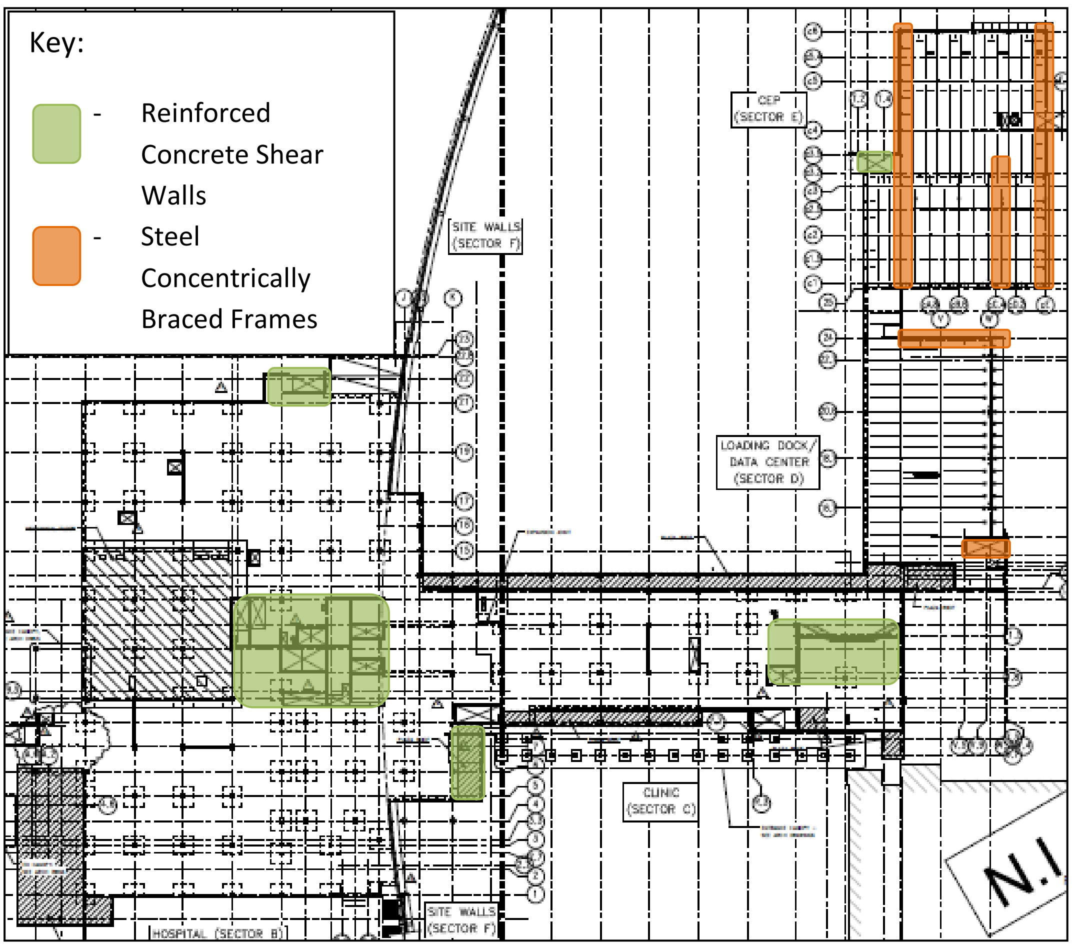

Figure 7 - Level 1 Structural Floor Plan Highlighting the Lateral System. Courtesy SGH.

Steel concentrically braced frames resist lateral loads in the loading dock data center and central energy plant, highlighted above in orange in Figure 7. Diagonal members, HSS6x6 and HSS5x5, brace into W14, W16, and W21 beams in the loading dock data center. Diagonal members, HSS8x8 and HSS8x8, brace into W18 and W21 beams respectively in the central energy plant. As mentioned above, the central energy plant has one shear wall along with the steel concentrically braced frame system. The loading dock data center and CEP will not be analyzed in this report.

The load path in NCHTNF starts with the wind load against the façade of the building. Once the load is applied to the façade it is transferred to the diaphragms on each floor. The diaphragms then transfer the load to the lateral elements, being reinforced concrete shear walls in the hospital and clinic and steel concentrically braced frames in the loading dock data center and CEP. These lateral elements transfer the load to the foundation system, the final step of the load path of NCHTNF.

Roof System:

NCHTNF has several different roofing systems to accommodate different functions of the roof. A fluid-applied membrane acts as the roofing system for the roof garden that is accessible to patients and also doubles as a green roof. The fluid-applied membrane utilizes type IV extruded polystyrene board insulation. The other roofs on the building are constructed with thermoplastic membrane roofing and SBS-modified bituminous membrane roofing. Each of these roofs use polyisocyanurate board insulation, which is type II glass fiber mat facer. The other roofing system is 1-1/2" – 18 GA. metal roof deck, located on the loading deck data center, central energy plant, and mechanical penthouses on the 7th floor.

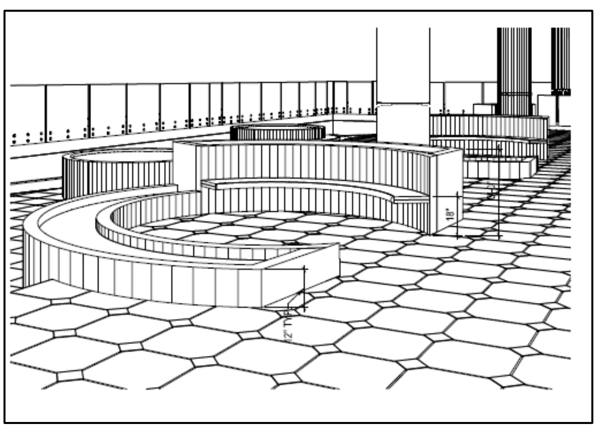

Figure 8 - Green Roof Rendering. Courtesy SGH.

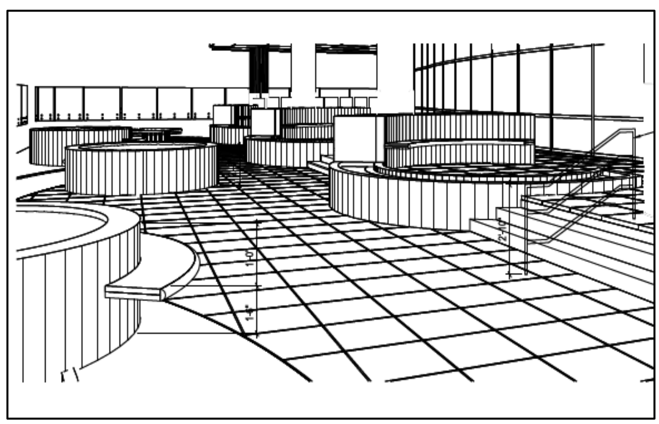

Figure 9 - Green Roof Rendering. Courtesy SGH.

Thesis Objective:

Structural Analysis and Design:

Problem Statement:

A primary design principle of NCHTNF is remembering the structure is first and foremost a children's hospital. The importance of an open floor plan is paramount, seeing as the goal is to not make the patients feel confined in the hospital. NCHTNF current design uses 39 shear walls for the lateral force resisting system. The central core in the hospital, where the majority of shear walls are located, has limited floor space due to the placement of shear walls, highlighted in figures 11 & 13. Similarly, floor space is limited in a portion of the clinic due to shear walls shown in figures 10 & 12. Additionally, the shear walls require coordination with MEP systems to provide penetrations for ducts and conduit passing through the walls without losing structural integrity of the wall.

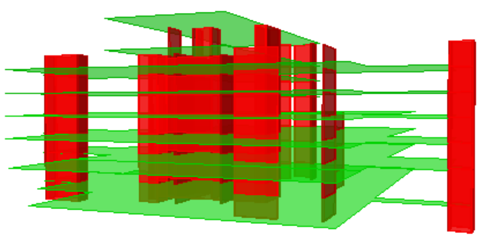

Figure 10 - 3D Hospital ETABS Model

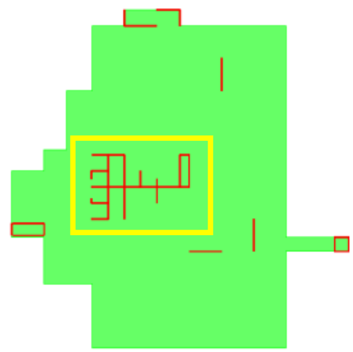

Figure 11 - First Floor Hospital ETABS Model

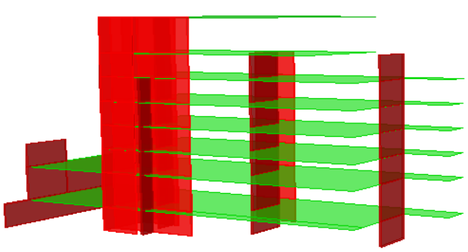

Figure 12 - 3D Clinic ETABS Model

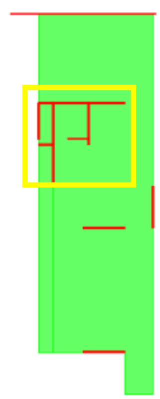

Figure 13 - First Floor Clinic ETABS Model

The design of typical hospitals strives to have large floor to ceiling heights. The more vertical space provided allows for a less complicated coordination in the ceiling plenum. NCHTNF currently uses a flat slab floor system. This allows the slab to be supported without beams or girders, which results in higher floor to ceiling heights. These higher clearances provide more space for MEP equipment, which eases the coordination process. On the contrary, drop panels require additional time to construct because the construction process requires more formwork than with a two-way flat plate system.

Problem Solution:

The lateral system of NCHTNF will be redesigned using concrete moment frames. This reduces the number of shear walls in the building, which creates a more open floor plan. A study to determine whether the moment frames can be integrated within the slab depth, which might require changing the slab thickness, will be performed. The floor system is analyzed as a flat plate system in efforts to keep the high floor to ceiling heights and remove the need for drop panels. Removing the drop panels from the floor design may reduce construction time and cost because the formwork for the drop panels will not be required.

In addition to analyzing the proposed lateral system redesign using the existing 157 mph design wind speed, the minimum required code wind speed of 110 mph is studied too. These analyses focus on the feasibility of implementing concrete moment frames as the lateral system. Also, using the 110 mph can be justified as an adequate design wind speed for an Enhanced Hurricane Protected Area based on historical max wind speed data.

The lateral and floor systems changes result in a reduction in the overall weight of the building. The foundation of the building needs to be analyzed to determine if either the bearing force or overturning moment have been exceeded with the change in weight. Gravity members require evaluation to determine if they need a redesign with the combination of lateral and gravity loads. Additionally, a model of the building needs to be constructed to check drift limitations and torsion with the adjusted lateral system.

Design Goals:

The overall design goal of this project is to design a lateral system producing a more flexible architectural layout. An additional underlying theme is reducing the current design wind load on the building, while still meeting the Enhanced Hurricane Protection Area standards mentioned in the introduction of this report. Other goals to be met throughout this project include:

- Do not decrease the amount of useable space per floor
- Eliminate the need for drop panels, which require supplementary formwork
- Analyze the feasibility of concrete moments by hand, Structure Point, SAP, and ETABS
- Evaluate non-structural systems affected by designing the building to withstand a hurricane, such as the façade louvers and structural sealant.

Breadth Studies:

The façade of the building is predominately glass, as per the owner's request. An analysis of the sun shading system, consisting of specifically calculated size louvers, studies the existing control of the sun's exposure into the building. The analysis centers on studying the year-round daylighting of the building in an effort to maximize the performance of the glass wall system. An alternative sun controlling device is presented regardless of the outcome of the analysis of the current system.

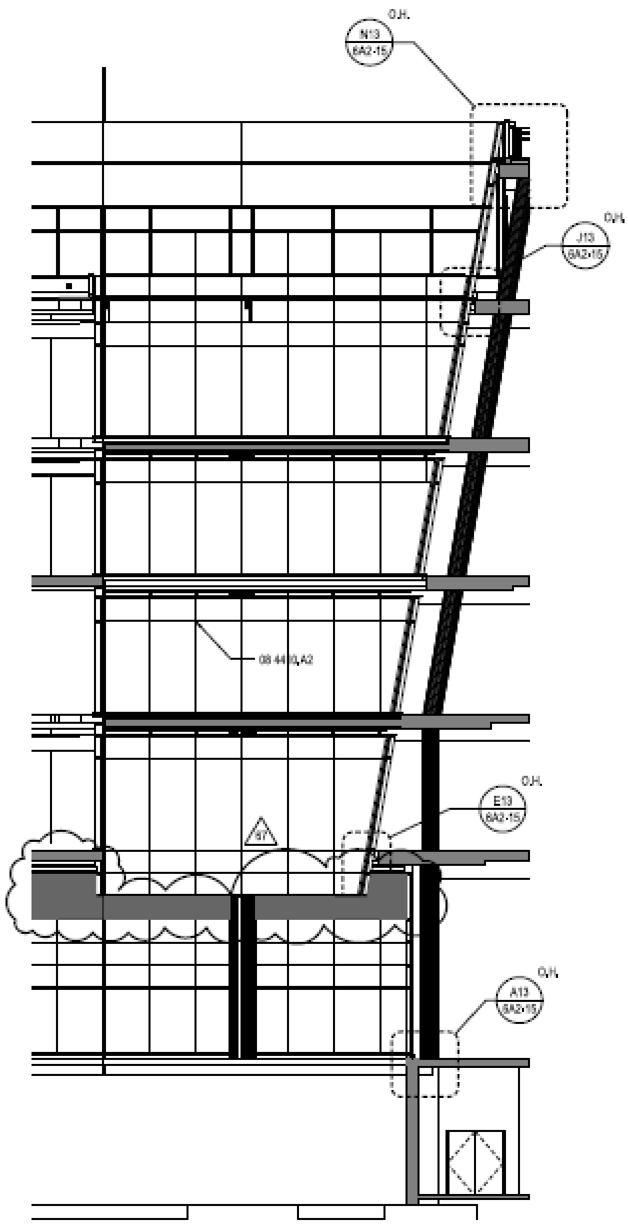

Figure 14 – NCHTNF East Façade. Courtesy SGH.

The other study examines the efficiency of the sealant of the current façade, a section view of the façade is shown in Figure 14. An alternate façade structural system is investigated to compare efficiency of each system. The focus on waterproofing the building, seeing as one of the design focuses is making the building hurricane proof, determines the final choice of design. The new system considers the effects of thermal, air, and moisture infiltration along with the life cycle cost of the wall system.

MAE Requirements:

The MAE requirement for this report is met by modeling NCHTNF in ETABS. Generating computer models in various structural analysis programs is the curriculum of AE 597A – Computer Modeling of Buildings. This class explains how to manipulate building models, within structural analysis computer programs, and study the given results. Additionally, the MAE requirement is met with incorporating course material from AE 542 – Building Enclosure Science and Design. This course studies design and analysis of building façades, which applies to NCHTNF.

Structural Analysis and Design:

Introduction:

Concrete Moment Frames:

Concrete moment frames with a flat plate slab are analyzed as an alternative to the current shear wall system in NCHTNF. Moment frames are feasible when the building is below 8-10 stories, which NCHTNF's 8 story height falls within the requirement[1]. The moment frames give the floor plan flexibility for layout and ease MEP coordination by eliminating cumbersome shear walls. Designing and modeling moment frames with the proposed slab-column connections is a subject that has not been completely developed. Much of this design process combines of a variety of ideas from different research papers and textbooks.

Gravity and lateral loads need to be simultaneously analyzed when designing a slab-column moment frame. Since, flat plate system designs primarily focus on solely resisting gravity loads, many researchers study if a flat plate can withstand combined lateral and gravity loads. The main issue is overestimating the lateral stiffness of the slab-column frame during the design process, which underestimates the lateral deflections[2]. β, the cracked stiffness modifier, is a point of disagreement between researchers because this modifier has been assigned a range of values. The modifier helps negate the overestimation of lateral stiffness, giving reason to why it has not received an exact value. Figure 15 shows the given range of β values. In regards to slab-column connections, many researchers have decided on their own specific value of β. For example, Wight and MacGregor suggest using β=0.33 for both interior and exterior connections as well as positive and negative sections. Other designers might disagree and suggest applying β=0.5 for positive bending regions and β=0.33 for negative bending regions. For this analysis, β=0.33 is used throughout, which is described in more detail in the modeling section[3].

TABLE 13-7 Recommended α and β values for the flexural stiffness of slab-beam elements

Region of the slab	α-value (for effective width $\alpha \ell_2$)	β-value (for $I_e = \beta I_g$)
Positive bending regions	0.5	0.5
Negative bending regions (interior columns)	0.5	0.5, for gravity analysis only 0.33, for lateral-load analysis
Negative bending regions (exterior columns)	0.2 to 0.5 (function of edge beam stiffness)	0.33

Figure 15 - Alpha and Beta Values for Slab-Column Connections. Courtesy Wight & MacGregor

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[1] Wight, James and James MacGregor, Reinforced Concrete Mechanics & Design, (Upper Saddle, NJ: Pearson Prentice Hall, 2008), 641-731.

[2] Kim, Hyun-Su, and Dong-Guen Lee. "Efficient Seismic Analysis of Flat Plate System Structures." *13th World Conference on Earthquake Engineering*. (2004). http://www.iitk.ac.in/nicee/wcee/article/13_680.pdf (accessed February 15, 2012).

[3] Wight et al. 2008.

A slab-column connection experiences combined shear and moment transfer, so the capacity of the slab needs to be evaluated accordingly. The moment transfer is partially transferred by flexure with the remainder by shear; this is explained during the lateral system design section. The shear capacity must exceed that of the amount being transferred and if not, there are feasible solutions[4]. Examples being, the slab can be made deeper or expanding the cross section of a column increases the shear capacity of the slab-beam and decrease the shear and moment transfer. Also, stud rails, interior beams, and edge beams can be employed to mitigate the shear and moment transfer problem.

Equivalent Frame Method is commonly used for analysis of a flat plate structure subject to lateral loads. Of course finite element analysis is preferred, but this method gives a good base reference to compare a design to[5]. One drawback to equivalent frame method is the difficulty of applying it to buildings with openings in the slab. Slab openings are ignored in this analysis to simplify calculations. Additionally, some researchers believe the Effective Beam Width Method is more accurate than the Equivalent Frame Method when analyzing lateral loads on a flat plate system. According to research, Equivalent Frame Method may not produce accurate slab moments and lateral deflections while Equivalent Beam Width Method produces satisfactory results[6].

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[4] Wight et al. 2008.

[5] Choi, Jung-Wook, Chul-Soo Kim, Jin-Gyu Song, and Soo-Gon Lee. "Effective Beam Width Coefficients for Lateral Stiffness in Flat-Plate Structures." *KCI Concrete Journal*, July 2001. http://www.ceric.net/wonmun2/kci/KCI_3_2001_13_2_49(C).pdf (accessed January 20, 2012).

[6] Han, S. Whan, Y.-M. Park, and J. Oak Cho. "Effective beam width for flat plate frames having edge beams." *Magazine of Concrete Research*, November 2010. http://earthquake.hanyang.ac.kr/submenu/pdf/journal/[2010]_Han_Effective beam width for flat plate frames having edge beams.pdf (accessed March 17, 2012).

Hurricane Design:

As mentioned earlier in this report, NCHTNF is designed using 157mph wind speed. This wind speed represents a category 3 hurricane, which has the possibility of creating catastrophic building failure, with a factor of safety. ASCE 7-05 requires NCHTNF to be built using a minimum of 110 mph design wind speed, so the chosen design wind speed far exceeds the code[7]. Appendix A shows the wind load calculations used for the 110 mph design speed. The orange star represents Orlando, which is within the green line, representing 110 mph design wind speed, shown in Figure 16. The reasoning of designing NCHTNF for 157 mph is The Nemours Foundation wants the building to be an area of refuge for the event of a hurricane crossing over Orlando. Besides the increased wind speed, no other considerations are taken into account to make NCHTNF an area of refuge.

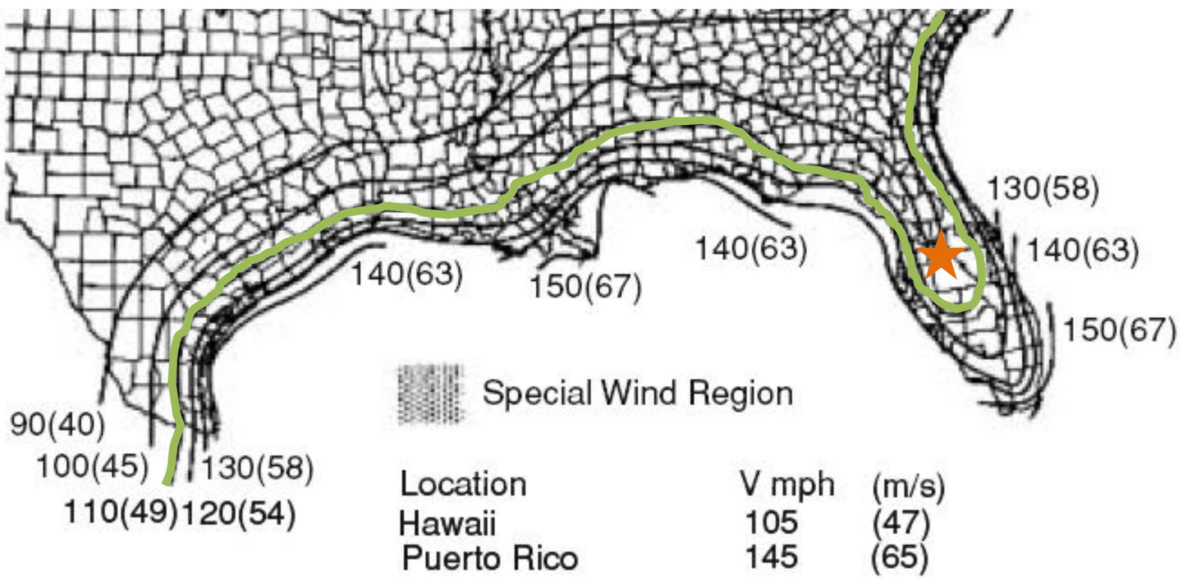


Figure 16 - Design Wind Speeds. Courtesy ASCE 7-05.

[7] *ASCE 7-05*. Reston, VA: American Society of Civil Engineers, 2006.

Research has shown in a 56 year data gathering time period, 79 mph is the highest recorded wind speed in Orlando, reference Figure 17[8]. Even though hurricanes make landfall in Florida, their winds dissipate once they reach inland Orlando. Seeing as the probability of experiencing 157 mph is extremely low, this thesis focuses using the 110 mph design wind speed instead of 157 mph. Additionally, calculations determine whether concrete moment frames can be designed using 157 mph design wind speed.

	YRS	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		ANN	
Florida		DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP
APALACHICOLA, FL	48	E	48	E	42	E	54	SE	51	SE	47	E	55	N	63	NE	59	E	67	NW	56	SE	47	SE	42	E	67
DAYTONA BEACH, FL	57	26	43	20	44	24	58	18	46	22	48	33	40	34	43	15	69	11	58	5	53	50	39	34	40	15	69
FORT MYERS, FL	54	25	40	25	39	35	46	20	39	32	44	31	48	18	45	14	50	5	92	35	62	30	32	33	35	5	92
JACKSONVILLE, FL	25	30	38	30	39	22	44	32	46	29	34	28	39	26	57	11	38	80	46	21	31	33	38	31	40	26	57
KEY WEST, FL	29	27	41	12	57	22	54	1	58	13	46	18	40	12	61	18	61	12	62	15	71	12	47	26	39	15	71
MIAMI, FL	48	24	46	19	55	4	46	24	35	32	52	13	37	25	43	12	86	6	69	15	69	7	38	32	38	12	86
ORLANDO, FL	56	25	42	25	46	24	46	2	50	35	51	32	64	14	46	12	79	60	61	5	48	26	46	20	35	12	79
PENSACOLA, FL	33	31	40	13	40	16	39	33	43	12	39	29	46	27	76	14	56	12	77	22	39	21	35	20	36	12	77
TALLAHASSEE, FL	46	23	46	9	40	27	48	19	35	29	40	3	44	22	39	2	58	8	46	20	32	16	40	28	37	2	58
TAMPA, FL	53	32	44	32	50	29	43	28	44	36	46	31	67	32	58	11	38	34	56	21	40	25	40	36	45	31	67
WEST PALM BEACH, FL	56	29	48	11	48	27	51	32	55	27	45	9	71	34	46	13	86	26	64	13	83	10	39	36	38	13	86

Figure 17 - Florida Max Wind Speeds. Courtesy SERCC.

[8] The Southeast Regional Climate Center, "Maximum Wind Speed (mph) for Selected Cities in the Southeast." Accessed March 20, 2012. http://www.sercc.com/climateinfo/historial/maxwind.html .

Design Codes:

The standards and codes of this structural analysis and design are the same used with the original design of NCHTNF:

Design Codes	
Code	*Description*
Florida Building Code 2007*	With 2009 Updates
Florida Statutes 471 & 553	Main Hospital/Clinic, CEP, & Loading Dock Data Center are all considered "Threshold Buildings"**
ASCE/SEI 7-05	Minimum Design Loads for Buildings and Other Structures
AISC 360-05	Specifications for Structural Steel Buildings
AISC	Code of Standard Practice
AWS D1.1	Structural Welding Code – Steel
ACI	301 – Specification for Structural Concrete
ACI	302 – Concrete Floor and Slab Construction
	318 – General Design of Reinforced Concrete Not Otherwise Specified

Figure 18 - Standards and Codes used in Design

**Note: The 2007 Florida Building Code is based off of the International Building Code and subsidiary related codes.*
***Note: "Threshold Buildings" is defined as any building which is greater than 3 stories or 50 feet in height, or which has an assembly classification that exceeds 5,000 square feet in area and an occupant content of 500 people or greater.*

Materials Used:

The chart below lists the structural materials used in the design for NCHTNF:

Material Properties		
Material		*Strength*
Steel	Grade	fy = ksi
Wide Flange Shapes	A992	50
Hollow Structural Shapes	A500, GR. B	45
Plates	A36	36
Angles	A36	36
Reinforcing Steel	A615	60
Welded Wire Reinforcement	A497	N/A
Welding Electrodes	E70XX	70
Concrete	Weight (pcf)	f'c = psi
Footings/Mat Foundation	145	4,000
Foundation Piers	145	4,000
Foundation Walls ≤ 5' Tall	145	4,000
Foundation Walls > 5' Tall	145	5,000
Slab-On-Grade	145	4,000
Elevated Slabs	145	5,000
Columns	145	6,000
Shear Walls	145	5,000
Beams	145	5,000
Concrete On Metal Deck	145	4,000
Masonry	Grade	Strength = ksi
Concrete Masonry Units	C90	$f_y = 2.8$
Mortar	C270, Type S	$f'_m = 1.8$

Figure 19 - Material Properties Used in Design

Lateral Design:

Portal Method:

The portal method estimates forces in members of laterally loaded multistory frames. The design process is based on a few assumptions[9]:

- Shears in the interior columns are twice as large as the shears in the exterior columns
- A point of inflection occurs at mid-height of each column
- A point of inflection occurs at mid-span of each girder

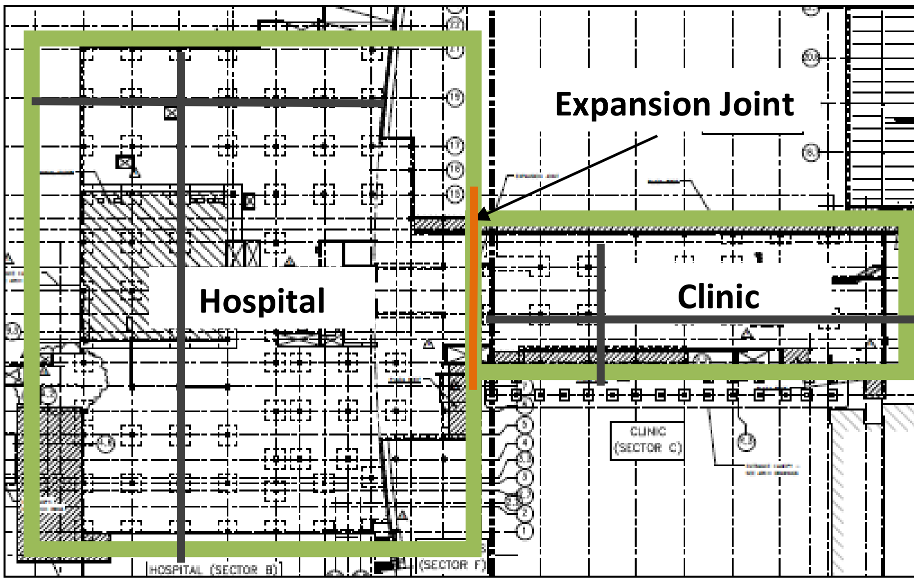


Figure 20 - Level 1 Structural Floor Plan Highlighting the Expansion Joint and Frames Analyzed. Courtesy SGH.

As mentioned before, NCHTNF is split into two different buildings for analysis purposes at the expansion joint, reference Figure 20. A "worst case scenario" frame is analyzed in each direction for both the hospital and clinic, shown in Figure 20 highlighted in dark grey. These frames are not standardized in height, so further assumptions are taken when performing the portal method. These assumptions modify the given assumptions to fit NCHTNF's irregular frames. The distribution factors applied to each column reflect an estimate of the stiffness of the individual assembly. These rough estimates are solely based on the geometry of the frames. Lateral forces resulting from 157 mph determined in Technical Report III are used for this lateral analysis. Lateral forces due to 110 mph design wind speed are determined using the same techniques used in Technical Report III, sample calculations found in Appendix A. The columns experience small axial loads due to the irregularity in height, but this is assumed as 0 kips because the axial load values are negligible. The portal frame analysis encompasses studying the frames with the loading for both 157 mph and 110 mph, sample calculations located in Appendix B. Even though this analysis is purely a lateral study, it provides an approximation to give a base point to start designing the columns and slab.

[9] Leet, Kenneth, Chia-Ming Uang, and Anne Gilbert. *Fundamentals of Structural Analysis*, (New York: McGraw Hill, 2008), 638-643.

Moment Transfer:

The transfer of moment from the column to the slab governs the design of slab-column connection. This ultimately determines if a slab has the capacity to withstand the transfer or if other solutions, such as stud rails or edge beams, are necessary.

$$\gamma_f = \frac{1}{1 + \left(\frac{2}{3}\right)\sqrt{b_1/b_2}}$$

Figure 21 - Flexure Transfer Fraction Equation. Courtesy Wight & MacGregor.

ACI 318-08 section 13.5.3 states when a gravity load and lateral forces cause transfer of moment between slab and column, a fraction of the unbalanced moment shall be transferred by flexure[10]. A fraction of the unbalanced moment, which this moment is calculated using the portal method, is considered to transfer by flexure within the effective beam width. The fraction transferred by flexure is calculated using the equation in Figure 21. Then, multiplying the fraction by the unbalanced moment determines the moment transferred by flexure, the rest being transferred by shear. Sample calculations can be found in Appendix C.

From this point, all the shear acting on the slab is calculated to determine if it exceeds the shear capacity of the effective slab beam. Appendix D shows the complete steps determining the total shear. Cells highlighted in red have exceeded 4√f'c, meaning the slab-column connection cannot carry the moment transfer. This calculation determines the concrete moment frames with flat plate system is only applicable in certain areas of the building. The failed connections will need additional resistance for the applied shear.

Additionally, the 157 mph wind load case analysis stops at this point. Three out of four of the frames have the first three floors completely failing when the total shear is compared to the shear capacity. In conclusion, concrete moment frames are not a feasible choice for 157 mph wind load with NCHTNF.

[10] *ACI 318-08*. Farmington Hills, MI: American Concrete Institute, 2009.

Shear Solutions:

There are many solutions to increase the shear capacity of the connection or decrease the transfer of moments. One simple solution is increase the size of columns, but the NCHTNF columns are already sufficiently large. Increasing the slab depth increases the shear capacity, but the slab is already 12" and a deeper slab is not feasible. Drop panels and column capitals help the moment transfer without requiring interior beams. This solution is not practical because the existing slab system already employs drop panels, which one of the goals of this thesis is removing these. Another solution is using stud rails at the slab-column connection. This adds shear capacity without adding additional concrete to the system. One last system is designing edge beams. The edge beams directly address the issue of inefficient shear capacity at the exterior slab-column connections without completely disrupting the open floor to ceiling heights. This thesis studies both stud rails and edge beams, which are both feasible solutions.

Specifically for slab-column connections, stud rails consist of rows of vertical studs attached to a plate on the top end, as shown in Figure 22. The shear studs rails are placed at the corner of columns and protrude out perpendicularly into the slab from this point[11]. ACI Chapter 11 states shear studs are capable of resisting shear and some moment[12]. Stud rails are only effective if their shear capacity is less than the shear being mitigated, which is the case for NCHTNF. The shear studs will require less formwork than the edge beams while still providing enough shear capacity for the slab-column connections. Sample calculations can be found in Appendix G.

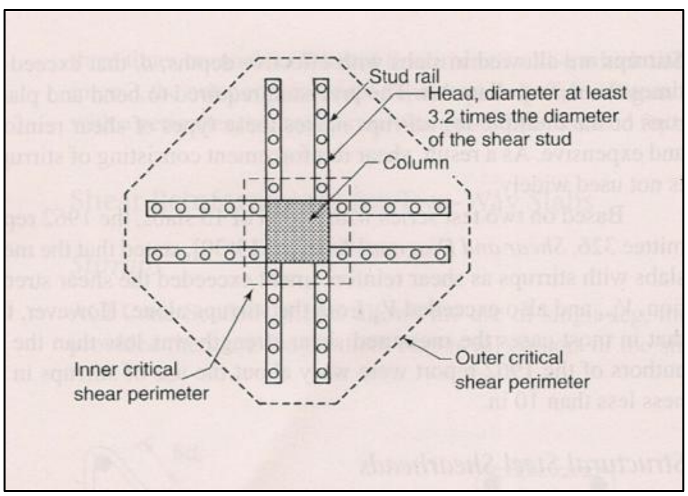


Figure 22 - Example of Stud Rail Layout. Courtesy Wight & MacGregor.

[11] Wight et al. 2008
[12] "ACI 318-08" 2009

Edge beams help diminish the shear transfer between the slab-column connection, see Appendix H for an edge beam design. These concrete beams increase the stiffness at the perimeter of the building, which in turn alleviates a lot of the shear stress from the interior connections. Stiffening of the structure helps the deflection, which is needed because the calculated deflections surpass the code limits; discussed in detail in the ETABS Models section. This method also solves the shear capacity issue, but potentially creates another issue at the same time. Making the outer columns stiffer also makes the inner columns more obsolete. The shear is mitigated, but the outer frames need to be reanalyzed with the new stiffness to determine if they can carry the load. This would make an interesting study to determine if NCHTNF could be designed with edge beams and perimeter concrete moment frames, but time did not permit this study.

Structure Point Models:

Structure Point is a program analyzing column and slab designs for individual stories of a building under the assumption that the columns are fixed-fixed, as shown in Figure 23. The fixed condition forces the program to only analyze gravity loads, not a combination of lateral and gravity loads. Similar to the portal frame analysis, the Structure Point models provide a benchmark design for the concrete moment frames. Additionally, Structure Point takes into account changes in moment of inertia throughout the length of the slab. This is an advantage because programs like SAP and ETABS do not automatically compute calculations with the changed moment of inertia values. In conclusion, column dimensions, slab depth, and rebar sizing are determined using Structure Point. These results are used in SAP and ETABS models, which are discussed in the upcoming sections.

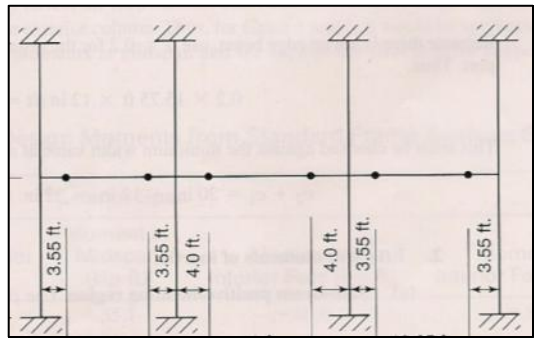


Figure 23 - Example of end conditions in Structure Point Models. Courtesy Wight & MacGregor.

SAP Models:

Unlike Structure Point, SAP allows models to be studied under combined lateral and gravity loads. Also, SAP is beneficial for studying two dimensional frames instead of studying the entire building. It is advantageous to create a frame of reference to check the complete building model with. Additionally, SAP provides the means to manually inserting changes in the moment of inertia in the slab. Three elements are drawn and connected by two link elements to model the change in moment of inertia, shown in Figures 24 and 25.

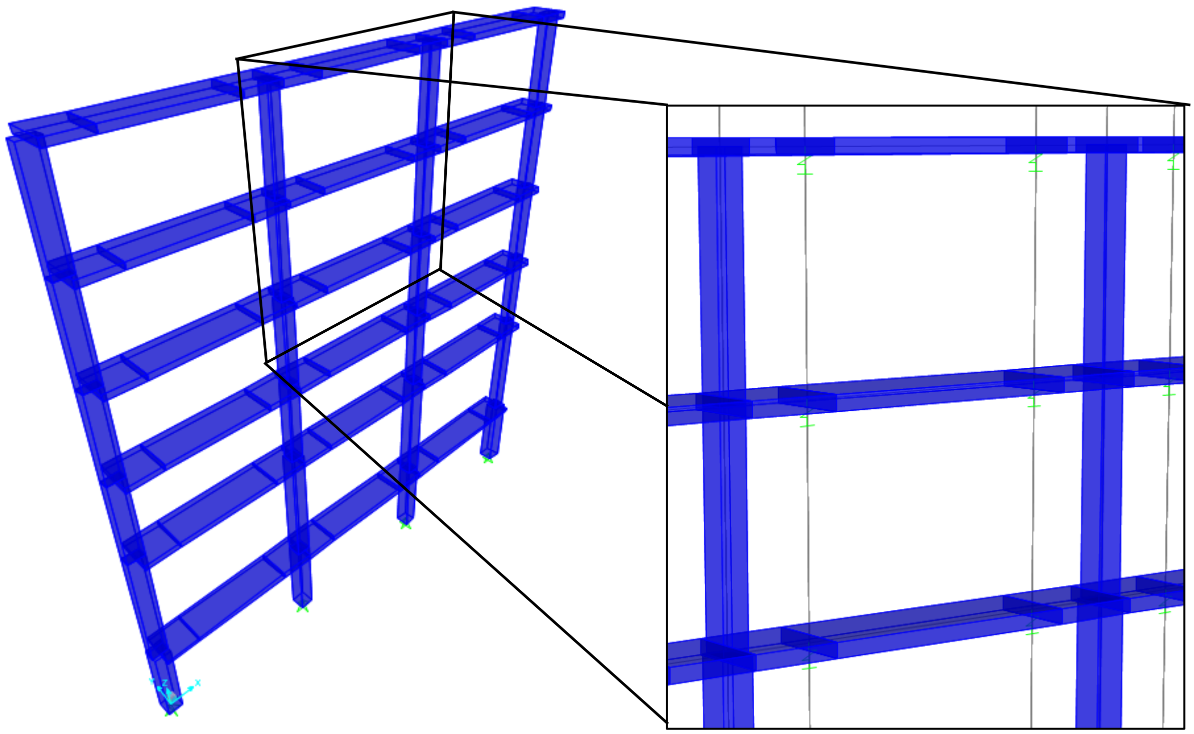


Figure 24 - SAP Model of Frame

Figure 25 - SAP Model Detail of Link Elements

The two outer pieces represent the effective moment of inertia, which is determined from Figure 15. The inner piece represents the typical modified moment of inertia of the slab[13]. The link elements show the computer program the three line elements need to act as one while exhibiting different properties. The slab is modeled as the effective beam width to represent the portion of the slab that exhibits beam-like tendencies. A further explanation of the effective beam width theory can be found in the structural analysis and design introduction. Also, the lateral loads applied to the frame are determined based on an assumption. Due to symmetry, it is assumed the lateral loads distribute evenly to each frame. So a fraction of the total lateral load is applied to this frame. This assumption can be verified in ETABS with a complete building analysis, which is discussed in the next section.

[13] "CSI Analysis Reference Manual For SAP2000, ETABS, and SAFE." Computers & Structures Inc., June 2008. http://www.comp-engineering.com/downloads/manuals/SAFE/SafeManuals/CSI Analysis Reference.pdf (accessed March 17, 2012).

	Int. Column		Ext. Column	
	Moment (ft-k)	*Shear (k)*	*Moment (ft-k)*	*Shear (k)*
Excel	1013	135	506	68
SAP	1643	110	290	20

Figure 26 - Comparison of Calculated Versus Computer Generated Values

The SAP moment and shear outputs, as shown in Figure 26, are comparable to those from the Excel calculations. These numbers further verify the need for additional shear capacity, as was discussed earlier in this report. The moment outputs for the columns are within the interactions diagrams, diagrams located in Appendix E. Additionally, a slab capacity check can be found in Appendix F. Also, the SAP story displacements are within the code limits, see Figure 27. The ETABS deflections are not within the code limits; this will be discussed in the EATBS section. This analysis verifies the Excel calculations and also provides a check for the ETABS model.

	Deflections	
	SAP (in)	*ETABS (in)*
Story 6	2.92	3.38
Story 5	2.50	3.21
Story 4	1.99	2.93
Story 3	1.46	2.52
Story 2	0.93	1.98
Story 1	0.41	0.87
	Code Limit	*2.93*

Figure 27 - Frame and Building Deflections

ETABS Models:

The clinic portion of NCHTNF is modeled as a three dimensional structure in ETABS. This model includes all lateral resisting structural elements in the building as designed. Analysis assumptions included in the ETABS model include, but are not limited to:

- Rigid diaphragms modeled at each floor
- Structural members modeled with specific material property
- Wind loads are applied at the center of pressure
- Columns and the slab effective beam width are modeled as line elements
- Slab is also modeled as a shell element
- All restraints at the ground level are pinned

As an initial study, two ETABS models are created to compare the outputs of modeling the slab as a shell element with line elements representing the effective beam width of the slab (non-shell) and modeling the slab only as a shell element (shell), Figures 28 and 29 respectively. Additionally, each floor system is assigned a rigid diaphragm to provide adequate story displacement data. After applying gravity and lateral loads, the analyses significantly differed. The displacements significantly contrasted along with the moment and shear outputs. In conclusion, the non-shell model provides a more accurate representation of how NCHNF reacts to lateral and gravity loads.

Figure 28 - ETABS "Non-Shell" Model

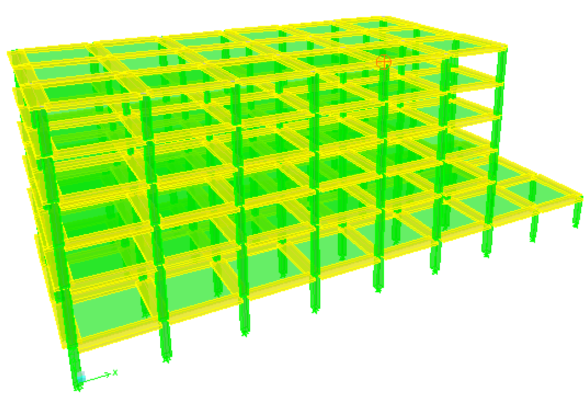
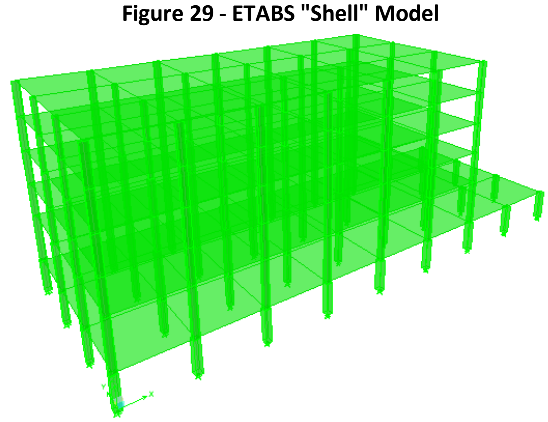


Figure 29 - ETABS "Shell" Model



The non-shell element's deflections exceed the code limitations, as shown in Figure 27, so the building needs additional stiffness. One solution is using edge beams, as was mentioned earlier in this report. The edge beams mitigate the shear capacity issues as well as make the building stiffer, resisting the lateral forces. The only issue with edge beams is the beams take the majority of the load to the perimeter of the building with the increase in stiffness, so the building needs to be reanalyzed to study placing the lateral system on the perimeter of the building.

As mentioned in the SAP section, the lateral loads are equally divided between each frame, assuming equal stiffness. To verify this assumption, take a section cut at each story and divide the story shear by the total base shear. Continue this method for each floor to determine the stiffness of the concrete moment frame. This analysis is not performed in this report due to time constraints. In conclusion, the ETABS model provides shear and moment outputs due to the gravity and lateral loads. Also, this model determines edge beams need to be installed to control the excessive deflections.

Torsion:

Lateral loads applied to a building induce torsion when the center of pressure and the center of mass are not located at the same point. If the center of pressure is not equal with the center of mass then a moment equal to the force multiplied by the eccentricity is produced. A formal torsion calculation is not necessary due to the building and lateral system's complete symmetry.

Foundation Check:

The critical overturning moment results in the direction with least depth, which is 90' for NCHTNF. Wind loads control the design of the building, so the overturning moment is calculated using the wind forces per floor and individual heights. The resisting moment must exceed the overturning moment and is calculated by multiplying the weight of the building by the moment arm of half the width of the building. In summary, the resisting moment is much larger than the overturning moment. Figure 30 shows the calculation of both the overturning and resting moments.

The weight of the building decreases only slightly with the change from concrete moment frames to shear walls. This weight difference marginally changes the axial load on the column, which is still below the soil capacity given by the geotechnical engineer. Sample calculations can be found in Appendix I. So, the foundation does not require any redesigning due to the changes with the lateral system.

Overturning Moments			
Story	*Wind Force (k)*	*Elevation (ft)*	*Moment (k-ft)*
6	102	97.5	9,945
5	100	82.5	8,250
4	97	67.5	6,548
3	93	52.5	4,883
2	112	37.5	4,200
1	100	15	1,500
		∑	35,326
		M_r=15,700 k x 45'=	706,500

Figure 30 - Overturning and Resisting Moment Calculation

Conclusion:

This structural analysis and design has determined concrete moment frames are not beneficial for a design wind speed of 157 mph, but can be implemented for 110 mph. A two-way flat plate system can work if the extra shear capacity is addressed by using edge beams or stud rails. The models verify the hand calculations as well as providing data on story deflections. Edge beams will have to be used to stiffen the building to prevent the current excessive deflections. An additional analysis will have to be performed to study if perimeter concrete moment frames will be able to support NCHTNF with the addition of edge beams. In conclusion, the concrete moment frames are a feasible lateral system to implement in NCHTNF.

Daylighting Analysis:

A majority of the façades on NCHTNF are predominately glass systems. These exterior glass walls promote unfavorable heating conditions, which escalates the strain on the mechanical equipment. To solve this problem, the façade design incorporates louvers to control the sun's exposure to the building. This breadth focuses on analyzing the efficiency of the louvers for different times of day and specific days of the year on the south façade of the clinic. Additionally, a discussion about the use of sun shades instead of louvers is presented.

Daylighting a building has been a topic of discussion in the recent years with the emergence of green building. Natural light is the most sustainable source of light for interiors, promoting green building and high performance design. Another advantage is daylighting is a free source of light for a building. On the contrary, daylighting is not a reliable light source. The source of light is dependent on the time of day, season, and weather conditions. Even though this form of lighting is cheap, it is hard to control the quantity and direction. This is why many buildings use daylighting to supplement the electric lighting in an effort to balance the benefits and drawbacks of each system. An additional advantage to daylighting a building, unrelated to costs and energy savings, is positive psychological effects on the building occupants. Studies have shown providing an exterior view from a patient's recovery room increase their recovery time[14]. The Nemours Foundation wants a predominately glass façade building, so controlling the daylight of the building is implemented, hence the louvers.

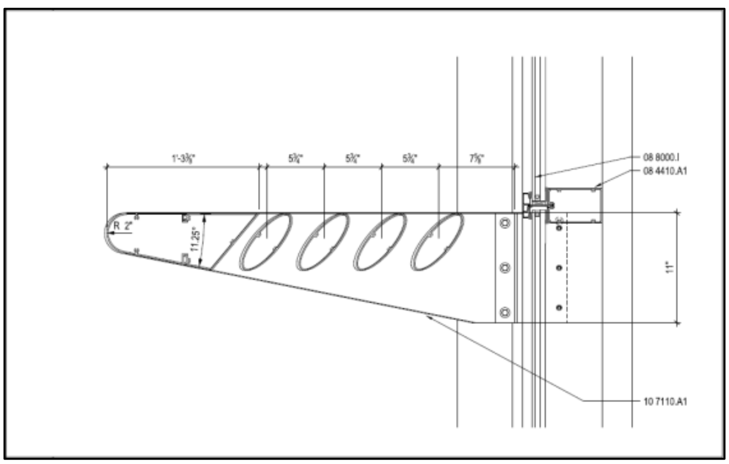


Figure 31 - Louver Detail. Courtesy SGH.

Initially, the sun's path across NCHTNF is analytically studied using an Excel spreadsheet, found in Appendix J. The summer and winter solstices are studied because they represent the most extreme conditions of the sun's angles the building experiences. The Excel spreadsheet calculates angles showing where the sun's light passes over the building[15]. These sun angles are applied to the louver, louver design shown in Figure 31, to determine if it blocks the sun's light from entering the building's window. Additionally, the Excel calculations are verified with a Google SketchUp model. The model, reference Figure 32, shows the louvers adequately block the sun from the windows for only the summer solstice. Even though heat gain might not be problematic in the winter due to solar energy, the issue of glare requires attentions.

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[14] DiLaura, David L., Kevin W. Houser, Richard G. Mistrick, and Gary R. Steffy. *The Lighting Handbook Tenth Edition: Reference and Application*. New York: Illuminating Engineering Society of North America, 2011.

[15] Houser, Kevin. "AE 497D Daylighting Analysis." Rome. June 15, 2011.

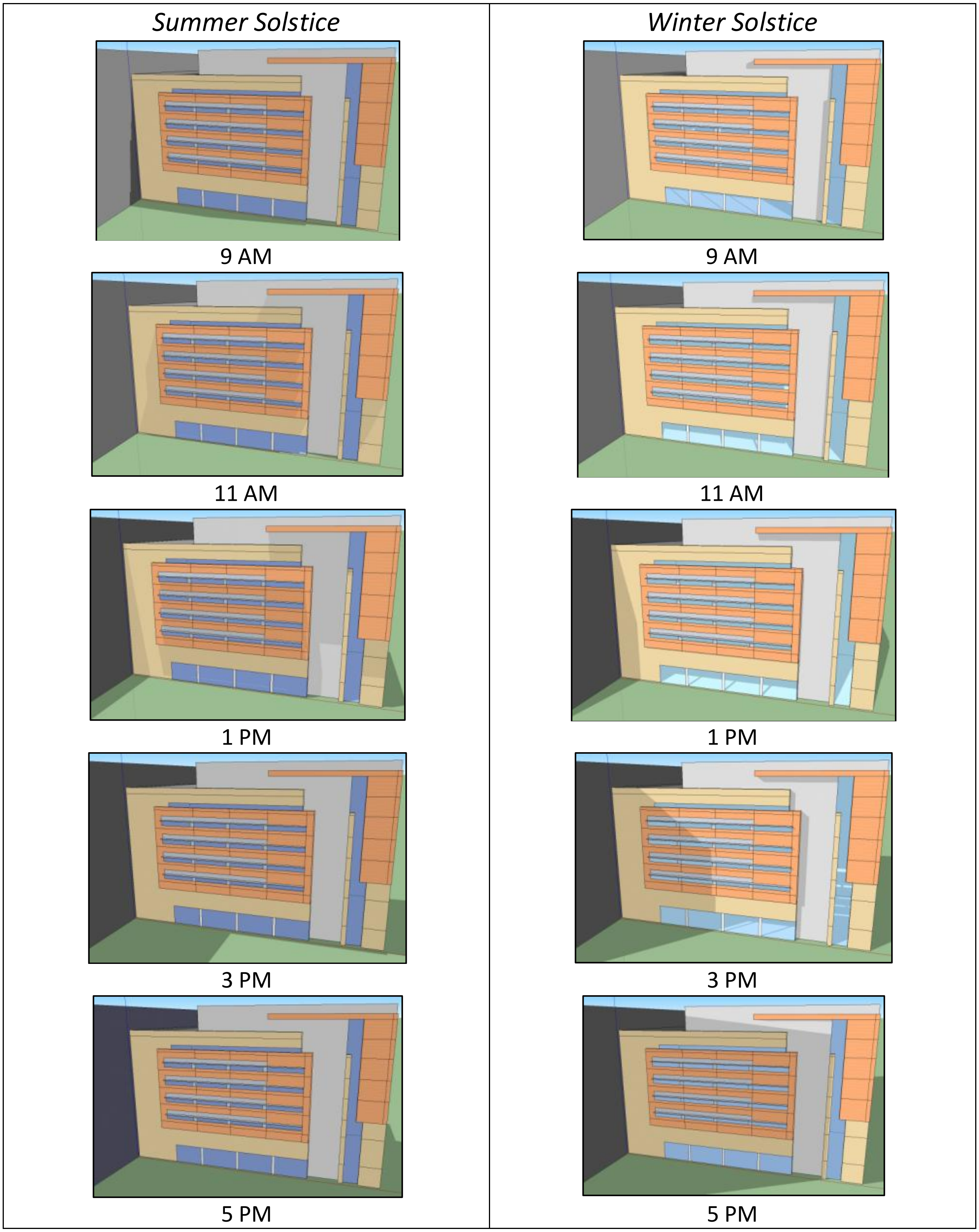

Figure 32 – Analysis of louvers during summer and winter solstices

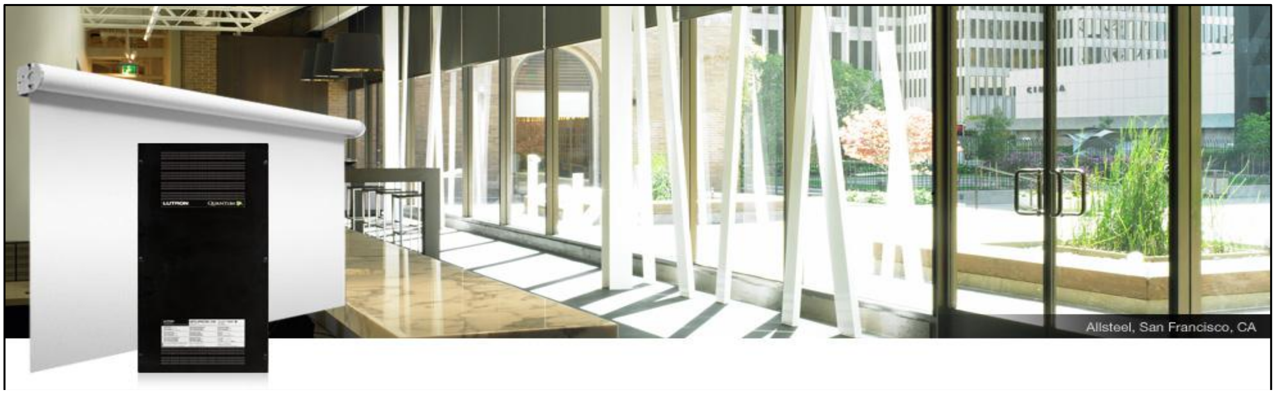

Figure 33 - Sun Shade Example. Courtesy lutron.com

Keeping with the theme of hurricane resistant design, the exterior louvers have the potential to become windborne debris in the event of a hurricane. Instead of using this form of passive solar shading, sun shades can be installed on the interior of the glass wall systems to block the sun's direct light. This eliminates any chance of the shading device becoming a windborne element because it is completely inside the building. An added benefit to this solution is it is more versatile with the integration of technology. Lutron promotes an automated shading system that adjusts its position in regards to the position of the sun and the intensity of the sun light, an example is shown in Figure 33. 43% of a building's electricity is spent on lighting fixtures in a health care facility, see Figure 34, which is a figure that should be strived to be reduced. The automated shades can be linked to the lighting system in the building, so the light fixtures react to the actions of the shades. If the shades rise to allow indirect sun light into the building, the lights automatically turn off[16]. This technologically intensive system is much more expensive than the louvers, but the versatility of the sun shading system has its advantages over louvers. Additionally, the automated sun shades are the most expensive sun shade system, so cheaper solutions are available.

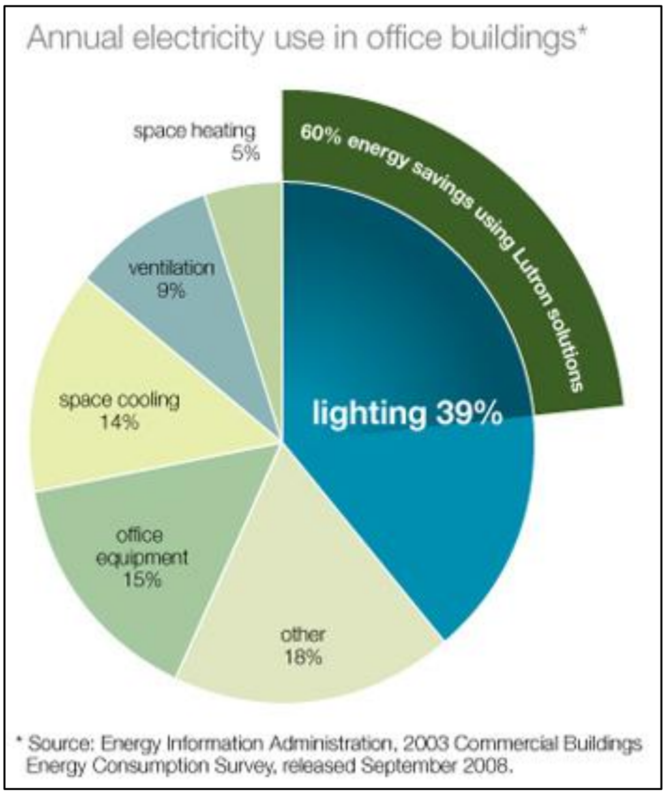

Figure 34 - Electricity Use in Office Buildings. Courtesy lutron.com.

[16] Lutron Electronics, Inc., "Lutron." Last modified 2012. Accessed March 14, 2012. http://www.lutron.com/Pages/Default.aspx.

Building Envelope Performance Analysis:

NCHTNF predominately uses silicone structural sealant with minimal aluminum mullions as the structural system for the glass façade. Ultimately this sealant is chosen because the architect does not want the distinct lines aluminum mullions create in the design of the exterior of the building. This analysis studies the multiple advantages and disadvantages of using a silicone structural sealant versus a urethane sealant or aluminum mullions. Additionally an underlying theme of constructing a façade is quality control, involving various forms of testing procedures. The testing procedures of silicone structural sealant used in the field and warehouse are outlined and compared to those of aluminum mullions. Finally, an aluminum mullion design is presented as a substitution to the existing silicone structural sealant.

Comparison of Sealants and Mullions:

Figure 35 - Performing Probing Sealant Test. Courtesy SGH

Structural sealant typically lasts longer than urethane sealants in high UV exposure settings, which are the conditions NCHTNF experiences. Also, this sealant tends to make better bonds with metal and glass than urethane sealants. NCHTNF's façades are predominately metal and glass, making the silicone sealant much more beneficial. Furthermore, the silicone sealants are typically more watertight on day one, but of course deteriorate with time. Ultimately, SGH decided to use the silicone structural sealant for the façade design.

A disadvantage of any type of structural sealant is the detailed testing procedure. Structural sealant requires a probe test, specifically ASTM C1521 Standard Practice for Evaluating Adhesion of Installed Weatherproofing Sealant Joints. The sealant needs to be fully cured before it is tested, details concerning the testing process will be further discussed. Also, the substrate has to be completely clean and free of any debris and construction dust to ensure a proper bond between the sealant and façade material. In addition, this sealant naturally collects more dirt than aluminum mullions and looks dirtier over time. Also, sealants typically have a lifespan of 10-20 years. Tremco, the sealant manufacturer, does not provide any warranties for the sealant installed on NCHTNF. Aluminum mullions last longer than 10-20 years and do not require nearly as much maintenance. Finally, structural sealant systems tend to be more expensive than aluminum mullions designs.

Figure 36 - Sealant Curing on Paper. Courtesy SGH.

Figure 37 - Example of a Cup Test. Courtesy SGH.

Structural sealant requires a sealant probe test, ASTM C1521 Standard Practice for Evaluating Adhesion of Installed Weatherproofing Sealant Joints. This test requires testing every inch of the sealant. Before the test is performed, the sealant needs to be completely cured, which effects the installation schedule. Figure 35 shows a worker probing the sealant joint between the precast panels. It is extremely important for the substrate to be clean and free of any debris and construction dust because otherwise the sealant will fail.

As another method of quality control, Trainor, the facade manufacturer, implements simple sealant tests in the warehouse. The first test is placing a swatch of sealant on a piece of paper and allowing it to cure, see Figure 36. If the oils bleed out or the sealant never cures, the sealant has failed and a new batch needs to be made. An additional test to ensure quality control is the cup test, example shown in Figure 37. A popsicle stick is pushed into a cup full of sealant. After the sealant has cured, the popsicle stick is pulled out of the sealant. If the popsicle stick pulls out of the sealant, the sealant fails. The point of these two tests is simplicity in performance and the results are easily understood, so the factory workers can readily determine if the sealant is to a standard of installation.

NCHTNF Current Façade:

The current façade of NCHTNF uses a dual sealant waterproofing system with silicone structural sealant. Simpson Gumpertz & Heger perform the sealant probe test of the building, which is comprised of testing both interior and exterior sealant joints throughout every inch of the building façade. This system is chosen largely due to aesthetic reasons, but this structural sealant is just as capable of waterproofing a building as aluminum mullions.

Seeing as how waterproofing is not an issue between using structural sealant versus aluminum mullions, the aluminum mullions are being designed to be compared for cost differences in this analysis. As mentioned before, the silicone structural sealant is more expensive and requires detailed testing to assure quality control. Aluminum mullions do not require a complicated installation and are cheaper, thus aluminum mullions should be implemented instead of structural sealant. The wind loading on the building results in an 8mm thick aluminum mullion, calculations can be found in Appendix K.

Graduate Course Integration:

The thesis topic chosen directly uses knowledge gained in two graduate level courses. NCHTNF is modeled and analyzed in ETABS, which reflects the course theme from AE 597A, Computer Modeling of Buildings. This model is used to evaluate the building under lateral and gravity loads. The Building Enclosure Study includes material learned from AE 542, Building Enclosure Science and Design. Specifically, designing aluminum mullions and learning about façade products is covered in this class, which is applied to the façade study.

Final Summary:

The overall design goal of this thesis is met by designing a lateral system that creates a more flexible floor plan layout. A complicated design process filled with smaller studies leads to this overall conclusion. Summaries of each smaller study are presented below:

First, this report studies the feasibility of concrete moment frames for the current 157 mph design wind speed and the code minimum 110 mph design speed. The transfer of moment between the column and slab fails for the first three floors of NCHTNF using the 157 mph. Thus, it is determined the existing lateral system consisting of shear walls is much more sufficient than concrete moment frames. The 110 mph design yields a few places that fail with the moment transfer at the slab-column connection. It is determined that edge beams need to be employed to mitigate the shear failures at the slab-column connections and stiffen the building to control the excessive deflections. The deflections are determined to be an issue using the ETABS model.

Additionally, wind data is studied to determine if the 157 mph wind speed is necessary to design to for the building to be an area of refuge in the event of a large scale hurricane in Orlando. The maximum wind speeds in Orland for the past 56 years have only peaked at 79 mph, so it is fair to say the code minimum value of 110 mph is a valid design value. NCHTNF should never see 157 mph because the hurricane's wind speeds have usually diminished significantly once they are that far inland.

Also, the façade's sun controlling system and structural system are studied. The existing louvers adequately shade the building in the summer, but not in the winter. This creates issues for glare and unwanted extreme heating conditions. Automatic sun shades are presented as a solution to the louvers. This new design will also remove the need for the louvers, which can become windborne debris in a hurricane event. In addition to this lighting study, the structural design of the façade is studied. The main focus is determining which system will perform better during a hurricane. It is determined that although both the sealant and mullion systems are both equivalent in waterproofing, the aluminum mullions are a cheaper design option.

In summary, the concrete moment frames are a feasible lateral design for NCHTNF if edge beams are implemented to mitigate the excessive shear transfer and building deflection. The thesis design can be classified as successful because the initial design goals were met:

- The amount of useable space per floor is not decreased
- Drop panels are eliminated from the slab design
- Concrete moment frames are found feasible by hand, Structure Point, SAP, and ETABS
- Façade is analyzed and suggestions are presented to give it the ability to withstand a hurricane better.

References:

***ACI 318-08*. Farmington Hills, MI: American Concrete Institute, 2009. ("ACI 318-08" 2009)**

- American Concrete Institute publishes this code to provide requirements for structural concrete design. Discussions on torsional compatibility, stud rails, and combined lateral and gravity loads were followed for this thesis analysis

***ASCE 7-05*. Reston, VA: American Society of Civil Engineers, 2006. ("ASCE7-05" 2006)**

- American Society of Civil Engineers writes these standards to provide information on a variety of structural loading cases. Seeing as seismic does not control for NCHTNF, wind is the only load case ASCE7-05 is able to provide information for.

Choi, Jung-Wook, Chul-Soo Kim, Jin-Gyu Song, and Soo-Gon Lee. "Effective Beam Width Coefficients for Lateral Stiffness in Flat-Plate Structures." *KCI Concrete Journal*, July 2001. http://www.ceric.net/wonmun2/kci/KCI_3_2001_13_2_49(C).pdf (accessed January 20, 2012). (Choi et al. 2001)

- An article providing an opinion on using effective beam width coefficients for flat-plate system design and analysis. Details on modeling and analysis are presented with minimal theory.

"CSI Analysis Reference Manual For SAP2000, ETABS, and SAFE." *Computers & Structures Inc.*, June 2008. http://www.comp-engineering.com/downloads/manuals/SAFE/SafeManuals/CSI Analysis Reference.pdf (accessed March 17, 2012). ("CSI Analysis Reference Manual For SAP2000, ETABS, and SAFE" 2008)

- Computers & Structures Inc. provides a detailed guide explaining all the nuances to modeling buildings in analysis programs. For this thesis report, the sections concerning joints and link elements were studied.

DiLaura, David L., Kevin W. Houser, Richard G. Mistrick, and Gary R. Steffy. *The Lighting Handbook Tenth Edition: Reference and Application*. New York: Illuminating Engineering Society of North America, 2011. (DiLaura et al. 2011)

- IES Lighting Handbook provides design, analysis, and reference data for many different lighting situations. This thesis report focused on Chapter 14, Designing Daylighting, to understand evaluating a daylit building.

Han, S. Whan, Y.-M. Park, and J. Oak Cho. "Effective beam width for flat plate frames having edge beams." *Magazine of Concrete Research*, November 2010. http://earthquake.hanyang.ac.kr/submenu/pdf/journal/[2010]_Han_Effective beam width for flat plate frames having edge beams.pdf (accessed March 17, 2012). (Han et al. 2010)

- The academic article explained how the equivalent frame method is not accurate when analyzing a flat plate system with edge beams. The authors then propose the equivalent beam width method to use when analyzing this situation.

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- This lecture was given by Dr. Kevin Houser, Architectural Engineering Professor at Penn State, during a study abroad class in Rome, Italy. His lecture detailed how to calculate sun angles geometrically along with the Excel spreadsheet developed throughout the class.

Leet, Kenneth, Chia-Ming Uang, and Anne Gilbert. *Fundamentals of Structural Analysis*, (New York: McGraw Hill, 2008), 638-643. (Leet et al. 2008)

- The textbook gives a description of the theory behind the portal frame method. A complete example is provided, which was followed for the portal method analysis in this thesis analysis.

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- Lutron's website provided valuable information concerning "smart" sun shading devices. They also presented information concerning energy savings when utilizing their products effectively.

The Southeast Regional Climate Center, "Maximum Wind Speed (mph) for Selected Cities in the Southeast." Accessed March 20, 2012. http://www.sercc.com/climateinfo/historial/maxwind.html . ("Maximum Wind Speed (mph) for Selected Cities in the Southeast"

- SERCC provides the maximum wind speeds for selected cities in the Southeast United States. Most of their data has been gathered for at least 20 years.

Wight, James and James MacGregor, Reinforced Concrete Mechanics & Design, (Upper Saddle, NJ: Pearson Prentice Hall, 2008), 641-731. (Wight et al. 2008)

- This book explains the theory behind design and analysis of two-way slabs. The structural depth of this thesis followed the Equivalent Frame Method along with combined lateral and gravity design methods outlined in the textbook

Appendix A: 110 mph Wind Load Calculation

A.1 Wind Pressures

Table A.1-1 Hospital North-South Wind Calculations

North - South Hospital (MWFRS)									
Floor	Elevation	z	k_z	q_z	q_h	Windward(psf)	Leeward (psf)	Trib. Area (ft^2)	Force (k)
Ground	89.1	0	0.85	25.74	40.88	12.35	-9.50	2137.5	47
1	104.1	15	0.85	25.74	40.88	12.35	-9.50	5343.75	117
2	126.6	37.5	1.025	31.04	40.88	14.90	-9.50	5343.75	130
3	141.6	52.5	1.1	33.31	40.88	15.99	-9.50	4275	109
4	156.6	67.5	1.16	35.12	40.88	16.86	-9.50	4275	113
5	171.6	82.5	1.22	36.94	40.88	17.73	-9.50	4275	116
6	186.6	97.5	1.26	38.15	40.88	18.31	-9.50	4275	119
Penthouse	201.6	112.5	1.29	39.06	40.88	18.75	-9.50	5343.75	151
Roof	224.1	135	1.35	40.88	40.88	19.62	-9.50	3206.25	93
								∑F	995
								Overturning Moment (k*ft)	134000

Table A.1-2 Hospital East-West Wind Calculations

East - West Hospital (MWFRS)									
Floor	Elevation	z	k_z	q_z	q_h	Windward(psf)	Leeward (psf)	Trib. Area (ft^2)	Force (k)
Ground	89.1	0	0.85	25.74	40.88	12.64	-9.79	1125	25
1	104.1	15	0.85	25.74	40.88	12.64	-9.79	2812.5	63
2	126.6	37.5	1.025	31.04	40.88	15.24	-9.79	2812.5	70
3	141.6	52.5	1.1	33.31	40.88	16.36	-9.79	2250	59
4	156.6	67.5	1.16	35.12	40.88	17.25	-9.79	2250	61
5	171.6	82.5	1.22	36.94	40.88	18.15	-9.79	2250	63
6	186.6	97.5	1.26	38.15	40.88	18.74	-9.79	2250	64
Penthouse	201.6	112.5	1.29	39.06	40.88	19.19	-9.79	2812.5	82
Roof	224.1	135	1.35	40.88	40.88	20.08	-9.79	1687.5	50
								∑F	537
								Overturning Moment (k*ft)	72500

Table A.1-3 Clinic North-South Wind Calculations

North - South Clinic (MWFRS)									
Floor	Elevation	z	k_z	q_z	q_h	Windward(psf)	Leeward (psf)	Trib. Area (ft^2)	Force (k)
Ground	89.1	0	0.85	25.74	40.88	12.35	-9.50	1830	40
1	104.1	15	0.85	25.74	40.88	12.35	-9.50	4575	100
2	126.6	37.5	1.025	31.04	40.88	14.90	-9.50	4575	112
3	141.6	52.5	1.1	33.31	40.88	15.99	-9.50	3660	93
4	156.6	67.5	1.16	35.12	40.88	16.86	-9.50	3660	97
5	171.6	82.5	1.22	36.94	40.88	17.73	-9.50	3660	100
6	186.6	97.5	1.26	38.15	40.88	18.31	-9.50	3660	102
Penthouse	201.6	112.5	1.29	39.06	40.88	18.75	-9.50	4575	129
Roof	224.1	135	1.35	40.88	40.88	19.62	-9.50	2745	80
								∑F	852
								Overturning Moment (k*ft)	115000

Table A.1-4 Clinic East-West Wind Calculations

East - West Clinic (MWFRS)									
Floor	Elevation	z	k_z	q_z	q_h	Windward(psf)	Leeward (psf)	Trib. Area (ft^2)	Force (k)
Ground	89.1	0	0.85	25.74	40.88	12.64	-9.79	675	15
1	104.1	15	0.85	25.74	40.88	12.64	-9.79	1687.5	38
2	126.6	37.5	1.025	31.04	40.88	15.24	-9.79	1687.5	42
3	141.6	52.5	1.1	33.31	40.88	16.36	-9.79	1350	35
4	156.6	67.5	1.16	35.12	40.88	17.25	-9.79	1350	37
5	171.6	82.5	1.22	36.94	40.88	18.15	-9.79	1350	38
6	186.6	97.5	1.26	38.15	40.88	18.74	-9.79	1350	39
Penthouse	201.6	112.5	1.29	39.06	40.88	19.19	-9.79	1687.5	49
Roof	224.1	135	1.35	40.88	40.88	20.08	-9.79	1012.5	30
								∑F	322
								Overturning Moment (k*ft)	43500

Appendix B: Portal Method Analysis

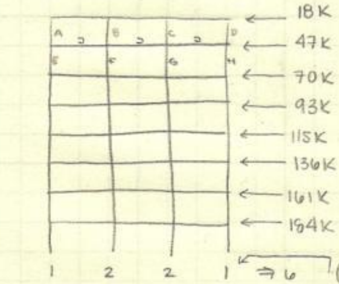
B.1 Hand Calculation

Caitlin Behm | AE Senior Thesis | Portal Method | 1/1

Sample Calculation

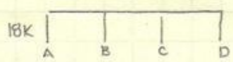
Grid N (N-S Clinic)

Stiffness assumed to be equal between to determine division of forces per frame



h = story height
w = story width

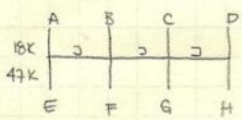
(distribution of forces between columns)



moment A = (shear A) x h/2
axial A = (moment A) / (w/2)
shear A = (dist. of forces, cols A)(story force / sum dist. of forces, col)

moment B = (shear B) x h/2
axial B = 0
shear B = (dist of forces, cols B)(story force / sum dist. of forces, col)

C is similar to B
D is similar to A



moment E = (shear E) x h/2
axial E = (moment E + moment A + moment J) / w/2
shear E = (dist. of forces E x ((story force + story force(s) previous)/(sum dist forces))

moment F = (shear F) x h/2
axial F = 0
shear F = (dist. of forces F)x((story force + story force(s) previous)/(sum dist forces))

G is similar to F
H is similar to E

moment J = moment A + moment E

* progressing down the frame, the story forces are cumulative

See Excel spreadsheets for complete calculations

TOPS 35502

B.2 Hospital (N-S) 157mph

story force (k)											height (ft)
24											22.5
62											15
93											15
122											15
151											15
179											15
212											22.5
242											15
	30	30	30	30	30	30	30	30	30	30	width (ft)
											sum
dist. of forces	1	2	2	2	2	2	2	1.8	1	0.1	15.9

Grid E (N-S Hospital)

24										
	A	B	C	D	E	F	G	H		

moment (A)	16.8	ft-k	moment (B)	33.6	ft-k	moment (C)	33.6	ft-k	moment (D)	33.6	ft-k	moment (E)	33.6	ft-k	moment (F)	33.6	ft-k	moment (G)	33.6	ft-k	moment (H)	30.2	ft-k
axial (A)	1.1	k	axial (B)	0.0	k	axial (C)	0.0	k	axial (D)	0.0	k	axial (E)	0.0	k	axial (F)	0.0	k	axial (G)	0.0	k	axial (H)	2.0	k
shear (A)	1.5	k	shear (B)	3.0	k	shear (C)	3.0	k	shear (D)	3.0	k	shear (E)	3.0	k	shear (F)	3.0	k	shear (G)	3.0	k	shear (H)	2.7	k

	A	B	C	D	E	F	G	H		
24	U	U	U	U	U	U	U			
62										
	J	K	L	M	N	P	Q	R	S	T

moment (J)	40.6	ft-k	moment (K)	81.1	ft-k	moment (L)	81.1	ft-k	moment (M)	81.1	ft-k	moment (N)	81.1	ft-k	moment (P)	81.1	ft-k	moment (Q)	81.1	ft-k	moment (R)	73.0	ft-k	moment (S)	40.6	ft-k	moment (T)	4.1	ft-k	moment (U)	57.4	ft-k
axial (J)	7.6	k	axial (K)	0.0	k	axial (L)	0.0	k	axial (M)	0.0	k	axial (N)	0.0	k	axial (P)	0.0	k	axial (Q)	0.0	k	axial (R)	0.0	k	axial (S)	0.0	k	axial (T)	0.3	k			
shear (J)	5.4	k	shear (K)	10.8	k	shear (L)	10.8	k	shear (M)	10.8	k	shear (N)	10.8	k	shear (P)	10.8	k	shear (Q)	10.8	k	shear (R)	9.7	k	shear (S)	5.4	k	shear (T)	0.5	k			

	J	K	L	M	N	P	Q	R	S	T
62	AF	AF	AF	AF	AF	AF	AF	AF	AF	
93										
	V	W	X	Y	Z	AA	AB	AC	AD	AE

moment (V)	84.2	ft-k	moment (W)	168.4	ft-k	moment (X)	168.4	ft-k	moment (Y)	168.4	ft-k	moment (Z)	168.4	ft-k	moment (AA)	168.4	ft-k	moment (AB)	168.4	ft-k	moment (AC)	151.6	ft-k	moment (AD)	84.2	ft-k	moment (AE)	8.4	ft-k	moment (AF)	91.8	ft-k
axial (V)	14.4	k	axial (W)	0.0	k	axial (X)	0.0	k	axial (Y)	0.0	k	axial (Z)	0.0	k	axial (AA)	0.0	k	axial (AB)	0.0	k	axial (AC)	0.0	k	axial (AD)	0.0	k	axial (AE)	7.0	k			
shear (V)	11.2	k	shear (W)	22.5	k	shear (X)	22.5	k	shear (Y)	22.5	k	shear (Z)	22.5	k	shear (AA)	22.5	k	shear (AB)	22.5	k	shear (AC)	20.2	k	shear (AD)	11.2	k	shear (AE)	1.1	k			

	V	W	X	Y	Z	AA	AB	AC	AD	AE
93	AQ	AQ	AQ	AQ	AQ	AQ	AQ	AQ	AQ	
122										
	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP

moment (AG)	141.8	ft-k	moment (AH)	283.6	ft-k	moment (AI)	283.6	ft-k	moment (AJ)	283.6	ft-k	moment (AK)	283.6	ft-k	moment (AL)	283.6	ft-k	moment (AM)	283.6	ft-k	moment (AN)	255.2	ft-k	moment (AO)	141.8	ft-k	moment (AP)	14.2	ft-k	moment (AQ)	156.2	ft-k
axial (AG)	25.5	k	axial (AH)	0.0	k	axial (AI)	0.0	k	axial (AJ)	0.0	k	axial (AK)	0.0	k	axial (AL)	0.0	k	axial (AM)	0.0	k	axial (AN)	0.0	k	axial (AO)	0.0	k	axial (AP)	11.9	k			
shear (AG)	18.9	k	shear (AH)	37.8	k	shear (AI)	37.8	k	shear (AJ)	37.8	k	shear (AK)	37.8	k	shear (AL)	37.8	k	shear (AM)	37.8	k	shear (AN)	34.0	k	shear (AO)	18.9	k	shear (AP)	1.9	k			

	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP
122	BB	BB	BB	BB	BB	BB	BB	BB	BB	
151										
	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA

moment (AR)	213.0	ft-k	moment (AS)	425.9	ft-k	moment (AT)	425.9	ft-k	moment (AU)	425.9	ft-k	moment (AV)	425.9	ft-k	moment (AW)	425.9	ft-k	moment (AX)	425.9	ft-k	moment (AY)	383.3	ft-k	moment (AZ)	213.0	ft-k	moment (BA)	21.3	ft-k	moment (BB)	238.5	ft-k
axial (AR)	39.5	k	axial (AS)	0.0	k	axial (AT)	0.0	k	axial (AU)	0.0	k	axial (AV)	0.0	k	axial (AW)	0.0	k	axial (AX)	0.0	k	axial (AY)	0.0	k	axial (AZ)	0.0	k	axial (BA)	18.3	k			
shear (AR)	28.4	k	shear (AS)	56.8	k	shear (AT)	56.8	k	shear (AU)	56.8	k	shear (AV)	56.8	k	shear (AW)	56.8	k	shear (AX)	56.8	k	shear (AY)	51.1	k	shear (AZ)	28.4	k	shear (BA)	2.8	k			

	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA
151	BM	BM	BM	BM	BM	BM	BM	BM	BM	
179										
	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL

moment (BC)	297.2	ft-k	moment (BD)	594.5	ft-k	moment (BE)	594.5	ft-k	moment (BF)	594.5	ft-k	moment (BG)	594.5	ft-k	moment (BH)	594.5	ft-k	moment (BI)	594.5	ft-k	moment (BJ)	535.0	ft-k	moment (BK)	297.2	ft-k	moment (BL)	29.7	ft-k	moment (BM)	336.8	ft-k
axial (BC)	56.5	k	axial (BD)	0.0	k	axial (BE)	0.0	k	axial (BF)	0.0	k	axial (BG)	0.0	k	axial (BH)	0.0	k	axial (BI)	0.0	k	axial (BJ)	0.0	k	axial (BK)	0.0	k	axial (BL)	25.9	k			
shear (BC)	39.6	k	shear (BD)	79.3	k	shear (BE)	79.3	k	shear (BF)	79.3	k	shear (BG)	79.3	k	shear (BH)	79.3	k	shear (BI)	79.3	k	shear (BJ)	71.3	k	shear (BK)	39.6	k	shear (BL)	4.0	k			

	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL
179	BX	BX	BX	BX	BX	BX	BX	BX	BX	
212										
	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW

moment (BN)	595.8	ft-k	moment (BO)	1191.5	ft-k	moment (BP)	1191.5	ft-k	moment (BQ)	1191.5	ft-k	moment (BR)	1191.5	ft-k	moment (BS)	1191.5	ft-k	moment (BT)	1191.5	ft-k	moment (BU)	1072.4	ft-k	moment (BV)	595.8	ft-k	moment (BW)	59.6	ft-k	moment (BX)	652.2	ft-k
axial (BN)	103.0	k	axial (BO)	0.0	k	axial (BP)	0.0	k	axial (BQ)	0.0	k	axial (BR)	0.0	k	axial (BS)	0.0	k	axial (BT)	0.0	k	axial (BU)	0.0	k	axial (BV)	0.0	k	axial (BW)	49.4	k			
shear (BN)	53.0	k	shear (BO)	105.9	k	shear (BP)	105.9	k	shear (BQ)	105.9	k	shear (BR)	105.9	k	shear (BS)	105.9	k	shear (BT)	105.9	k	shear (BU)	95.3	k	shear (BV)	53.0	k	shear (BW)	5.3	k			

	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	
212	CJ	CJ	CJ	CJ	CJ	CJ	CJ	CJ	CJ		
242											
	BY	BZ	CA	CB	CC	CD	CE	CF	CG	CH	CI

moment (BY)	511.1	ft-k	moment (BZ)	1022.3	ft-k	moment (CA)	1022.3	ft-k	moment (CB)	1022.3	ft-k	moment (CC)	1022.3	ft-k	moment (CD)	1022.3	ft-k	moment (CE)	1022.3	ft-k	moment (CF)	920.1	ft-k	moment (CG)	511.1	ft-k	moment (CH)	51.1	ft-k	moment (CI)	51.1	ft-k	moment (CJ)	1106.9	ft-k
axial (BY)	77.2	k	axial (BZ)	0.0	k	axial (CA)	0.0	k	axial (CB)	0.0	k	axial (CC)	0.0	k	axial (CD)	0.0	k	axial (CE)	0.0	k	axial (CF)	0.0	k	axial (CG)	0.0	k	axial (CH)	0.0	k	axial (CI)	3.4	k			
shear (BY)	68.2	k	shear (BZ)	136.3	k	shear (CA)	136.3	k	shear (CB)	136.3	k	shear (CC)	136.3	k	shear (CD)	136.3	k	shear (CE)	136.3	k	shear (CF)	122.7	k	shear (CG)	68.2	k	shear (CH)	6.8	k	shear (CI)	6.8	k			

B.3 Hospital (E-W) 157mph

story force (k)							height (ft)
17							22.5
45							15
67							15
89							15
110							15
130							15
154							22.5
176							15
	30	30	30	30	30	30	width (ft)
							sum
dist. of forces	0.2	0.4	0.4	0.8	1	2	4.8

Grid 19 (E-W Hospital)

17							
				A	B	C	D

moment (A)	32.4	ft-k	moment (B)	40.5	ft-k	moment (C)	81.0	ft-k	moment (D)	81.0	ft-k
axial (A)	2.2	k	axial (B)	0.0	k	axial (C)	0.0	k	axial (D)	5.4	k
shear (A)	2.9	k	shear (B)	3.6	k	shear (C)	7.2	k	shear (D)	7.2	k

				A	B	C	D
17				J	J	J	
45							
				E	F	G	H

moment (E)	78.2	ft-k	moment (F)	97.7	ft-k	moment (G)	195.5	ft-k	moment (H)	195.5	ft-k	moment (J)	110.6	ft-k
axial (E)	14.7	k	axial (F)	0.0	k	axial (G)	0.0	k	axial (H)	25.8	k			
shear (E)	10.4	k	shear (F)	13.0	k	shear (G)	26.1	k	shear (H)	26.1	k			

				E	F	G	H
45				P	P	P	
67							
				K	L	M	N

moment (K)	162.3	ft-k	moment (L)	202.8	ft-k	moment (M)	405.7	ft-k	moment (N)	405.7	ft-k	moment (P)	240.5	ft-k
axial (K)	32.1	k	axial (L)	0.0	k	axial (M)	0.0	k	axial (N)	56.1	k			
shear (K)	21.6	k	shear (L)	27.0	k	shear (M)	54.1	k	shear (N)	54.1	k			

				K	L	M	N
67				U	U	U	
89							
				Q	R	S	T

moment (Q)	273.3	ft-k	moment (R)	341.6	ft-k	moment (S)	683.2	ft-k	moment (T)	683.2	ft-k	moment (U)	435.6	ft-k
axial (Q)	58.1	k	axial (R)	0.0	k	axial (S)	0.0	k	axial (T)	101.6	k			
shear (Q)	36.4	k	shear (R)	45.5	k	shear (S)	91.1	k	shear (T)	91.1	k			

				Q	R	S	T
89				Z	Z	Z	
110							
				V	W	X	Y

moment (V)	410.5	ft-k	moment (W)	513.1	ft-k	moment (X)	1026.1	ft-k	moment (Y)	1026.1	ft-k	moment (Z)	683.8	ft-k
axial (V)	91.2	k	axial (W)	0.0	k	axial (X)	0.0	k	axial (Y)	159.5	k			
shear (V)	54.7	k	shear (W)	68.4	k	shear (X)	136.8	k	shear (Y)	136.8	k			

				V	W	X	Y
110				AH	AH	AH	
130							
	AA	AB	AC	AD	AE	AF	AG

moment (AA)	2.5	ft-k	moment (AB)	5.1	ft-k	moment (AC)	5.1	ft-k	moment (AD)	572.8	ft-k	moment (AE)	716.1	ft-k	moment (AF)	1432.1	ft-k	moment (AG)	1432.1	ft-k	moment (AH)	983.3	ft-k
axial (AA)	0.2	k	axial (AB)	0.0	k	axial (AC)	0.0	k	axial (AD)	0.0	k	axial (AE)	0.0	k	axial (AF)	0.0	k	axial (AG)	229.4	k			
shear (AA)	19.1	k	shear (AB)	38.2	k	shear (AC)	38.2	k	shear (AD)	76.4	k	shear (AE)	95.5	k	shear (AF)	190.9	k	shear (AG)	190.9	k			

	AA	AB	AC	AD	AE	AF	AG
130	AP	AP	AP	AP	AP	AP	
154							
	AI	AJ	AK	AL	AM	AN	AO

moment (AI)	2.3	ft-k	moment (AJ)	4.5	ft-k	moment (AK)	4.5	ft-k	moment (AL)	1148.2	ft-k	moment (AM)	1435.2	ft-k	moment (AN)	2870.5	ft-k	moment (AO)	2870.5	ft-k	moment (AP)	1721.0	ft-k
axial (AI)	115.1	k	axial (AJ)	0.0	k	axial (AK)	0.0	k	axial (AL)	0.0	k	axial (AM)	0.0	k	axial (AN)	0.0	k	axial (AO)	401.6	k			
shear (AI)	25.5	k	shear (AJ)	51.0	k	shear (AK)	51.0	k	shear (AL)	102.1	k	shear (AM)	127.6	k	shear (AN)	255.2	k	shear (AO)	255.2	k			

	AI	AJ	AK	AL	AM	AN	AO
154	AX	AX	AX	AX	AX	AX	
176							
	AQ	AR	AS	AT	AU	AV	AW

moment (AQ)	4.4	ft-k	moment (AR)	8.8	ft-k	moment (AS)	8.8	ft-k	moment (AT)	985.1	ft-k	moment (AU)	1231.4	ft-k	moment (AV)	2462.8	ft-k	moment (AW)	2462.8	ft-k	moment (AX)	2133.3	ft-k
axial (AQ)	142.7	k	axial (AR)	0.0	k	axial (AS)	0.0	k	axial (AT)	0.0	k	axial (AU)	0.0	k	axial (AV)	0.0	k	axial (AW)	497.8	k			
shear (AQ)	32.8	k	shear (AR)	65.7	k	shear (AS)	65.7	k	shear (AT)	131.3	k	shear (AU)	164.2	k	shear (AV)	328.4	k	shear (AW)	328.4	k			

B.4 Clinic (N-S) 157mph

story force (k)				height (ft)	
18				22.5	
47				15	
70				15	
93				15	
115				15	
136				15	
161				22.5	
184				15	
	30	30	30	width (ft)	
					sum
dist. of forces	1	2	2	1	6

Grid N (N-S Clinic)

18					moment (A)	34.0	ft-k	moment (B)	67.9	ft-k	moment (C)	67.9	ft-k	moment (D)	34.0	ft-k			
	A	B	C	D	axial (A)	2.3	k	axial (B)	0.0	k	axial (C)	0.0	k	axial (D)	2.3	k			
					shear (A)	3.0	k	shear (B)	6.0	k	shear (C)	6.0	k	shear (D)	3.0	k			

	A	B	C	D															
18	J	J	J		moment (E)	81.8	ft-k	moment (F)	163.6	ft-k	moment (G)	163.6	ft-k	moment (H)	81.8	ft-k	moment (J)	115.8	ft-k
47					axial (E)	7.7	k	axial (F)	0.0	k	axial (G)	0.0	k	axial (H)	7.7	k			
	E	F	G	H	shear (E)	10.9	k	shear (F)	21.8	k	shear (G)	21.8	k	shear (H)	10.9	k			

	E	F	G	H															
47	P	P	P		moment (K)	169.7	ft-k	moment (L)	339.4	ft-k	moment (M)	339.4	ft-k	moment (N)	169.7	ft-k	moment (P)	251.5	ft-k
70					axial (K)	16.8	k	axial (L)	0.0	k	axial (M)	0	k	axial (N)	16.8	k			
	K	L	M	N	shear (K)	22.6	k	shear (L)	45.3	k	shear (M)	45.3	k	shear (N)	22.6	k			

	K	L	M	N															
70	U	U	U		moment (Q)	285.8	ft-k	moment (R)	571.7	ft-k	moment (S)	571.7	ft-k	moment (T)	285.8	ft-k	moment (U)	455.56	ft-k
93					axial (Q)	30.4	k	axial (R)	0.0	k	axial (S)	0	k	axial (T)	30.4	k			
	Q	R	S	T	shear (Q)	38.1	k	shear (R)	76.2	k	shear (S)	76.2	k	shear (T)	38.1	k			

	Q	R	S	T															
93	Z	Z	Z		moment (V)	429.3	ft-k	moment (W)	858.6	ft-k	moment (X)	858.6	ft-k	moment (Y)	429.3	ft-k	moment (Z)	715.14	ft-k
115					axial (V)	47.7	k	axial (W)	0.0	k	axial (X)	0	k	axial (Y)	47.7	k			
	V	W	X	Y	shear (V)	57.2	k	shear (W)	114.5	k	shear (X)	114.5	k	shear (Y)	57.2	k			

	V	W	X	Y															
115	AE	AE	AE		moment (AA)	599.2	ft-k	moment (AB)	1198.3	ft-k	moment (AC)	1198.3	ft-k	moment (AD)	599.2	ft-k	moment (AE)	1028.5	ft-k
136					axial (AA)	68.6	k	axial (AB)	0.0	k	axial (AC)	0	k	axial (AD)	68.6	k			
	AA	AB	AC	AD	shear (AA)	79.9	k	shear (AB)	159.8	k	shear (AC)	159.8	k	shear (AD)	79.9	k			

	AA	AB	AC	AD															
136	AJ	AJ	AJ		moment (AF)	1200.8	ft-k	moment (AG)	2401.7	ft-k	moment (AH)	2401.7	ft-k	moment (AI)	1200.8	ft-k	moment (AJ)	1800	ft-k
161					axial (AF)	120.0	k	axial (AG)	0.0	k	axial (AH)	0	k	axial (AI)	120.0	k			
	AF	AG	AH	AI	shear (AF)	106.7	k	shear (AG)	213.5	k	shear (AH)	213.5	k	shear (AI)	106.7	k			

	AF	AG	AH	AI															
161	AO	AO	AO		moment (AK)	1030.3	ft-k	moment (AL)	2060.6	ft-k	moment (AM)	2060.6	ft-k	moment (AN)	1030.3	ft-k	moment (AO)	2231.1	ft-k
184					axial (AK)	148.7	k	axial (AL)	0.0	k	axial (AM)	0	k	axial (AN)	148.7	k			
	AK	AL	AM	AN	shear (AK)	137.4	k	shear (AL)	274.7	k	shear (AM)	274.7	k	shear (AN)	137.4	k			

B.5 Clinic (E-W) 157mph

story force (k)									height (ft)
41									22.5
107									15
158									15
209									15
258									15
306									15
363									22.5
414									15
	30	30	30	30	30	30	30	30	width (ft)
									sum
dist. of forces	0.8	2	2	2	2	1	0.2	0.1	10.1

Grid 10 (E-W Clinic)

41								
	A	B	C	D	E	F		

moment (A)	90.8	ft-k	moment (B)	90.8	ft-k	moment (C)	90.8	ft-k	moment (D)	90.8	ft-k	moment (E)	45.4	ft-k	moment (F)	45.4	ft-k
axial (A)	6.1	k	axial (B)	0.0	k	axial (C)	0.0	k	axial (D)	0.0	k	axial (E)	0.0	k	axial (F)	3.0	k
shear (A)	8.1	k	shear (B)	8.1	k	shear (C)	8.1	k	shear (D)	8.1	k	shear (E)	4.0	k	shear (F)	4.0	k

	A	B	C	D	E	F	
41	N	N	N	N	N		
107							
	G	H	J	K	L	M	

moment (G)	218.7	ft-k	moment (H)	218.7	ft-k	moment (J)	218.7	ft-k	moment (K)	218.7	ft-k	moment (L)	109.3	ft-k	moment (M)	109.3	ft-k	moment (N)	309.5	ft-k
axial (G)	41.3	k	axial (H)	0.0	k	axial (J)	0.0	k	axial (K)	0.0	k	axial (L)	0.0	k	axial (M)	30.9	k			
shear (G)	29.2	k	shear (H)	29.2	k	shear (J)	29.2	k	shear (K)	29.2	k	shear (L)	14.6	k	shear (M)	14.6	k			

	P	G	H	J	K	L	M
107	X	X	X	X	X	X	
158							
	Q	R	S	T	U	V	W

moment (P)	181.5	ft-k	moment (Q)	181.5	ft-k	moment (R)	453.7	ft-k	moment (S)	453.7	ft-k	moment (T)	453.7	ft-k	moment (U)	453.7	ft-k	moment (V)	226.9	ft-k	moment (W)	226.9	ft-k	moment (X)	363.0	ft-k
axial (P)	12.1	k	axial (Q)	48.4	k	axial (R)	0.0	k	axial (S)	0.0	k	axial (T)	0.0	k	axial (U)	0.0	k	axial (V)	0.0	k	axial (W)	46.6	k			
shear (P)	24.2	k	shear (Q)	24.2	k	shear (R)	60.5	k	shear (S)	60.5	k	shear (T)	60.5	k	shear (U)	60.5	k	shear (V)	30.2	k	shear (W)	30.2	k			

	Q	R	S	T	U	V	W
158	AF	AF	AF	AF	AF	AF	
209							
	Y	Z	AA	AB	AC	AD	AE

moment (Y)	305.6	ft-k	moment (Z)	764.1	ft-k	moment (AA)	764.1	ft-k	moment (AB)	764.1	ft-k	moment (AC)	764.1	ft-k	moment (AD)	382.1	ft-k	moment (AE)	382.1	ft-k	moment (AF)	487.1	ft-k
axial (Y)	65.0	k	axial (Z)	0.0	k	axial (AA)	0.0	k	axial (AB)	0.0	k	axial (AC)	0.0	k	axial (AD)	0.0	k	axial (AE)	73.1	k			
shear (Y)	40.8	k	shear (Z)	101.9	k	shear (AA)	101.9	k	shear (AB)	101.9	k	shear (AC)	101.9	k	shear (AD)	50.9	k	shear (AE)	50.9	k			

	Y	Z	AA	AB	AC	AD	AE
209	AN	AN	AN	AN	AN	AN	
258							
	AG	AH	AI	AJ	AK	AL	AM

moment (AG)	459.1	ft-k	moment (AH)	1147.6	ft-k	moment (AI)	1147.6	ft-k	moment (AJ)	1147.6	ft-k	moment (AK)	1147.6	ft-k	moment (AL)	573.8	ft-k	moment (AM)	573.8	ft-k	moment (AN)	764.7	ft-k
axial (AG)	102.0	k	axial (AH)	0.0	k	axial (AI)	0.0	k	axial (AJ)	0.0	k	axial (AK)	0.0	k	axial (AL)	0.0	k	axial (AM)	114.7	k			
shear (AG)	61.2	k	shear (AH)	153.0	k	shear (AI)	153.0	k	shear (AJ)	153.0	k	shear (AK)	153.0	k	shear (AL)	76.5	k	shear (AM)	76.5	k			

	AG	AH	AI	AJ	AK	AL	AM
258	AV	AV	AV	AV	AV	AV	
306							
	AO	AP	AQ	AR	AS	AT	AU

moment (AO)	640.7	ft-k	moment (AP)	1601.7	ft-k	moment (AQ)	1601.7	ft-k	moment (AR)	1601.7	ft-k	moment (AS)	1601.7	ft-k	moment (AT)	800.9	ft-k	moment (AU)	800.9	ft-k	moment (AV)	1099.8	ft-k
axial (AO)	146.6	k	axial (AP)	0.0	k	axial (AQ)	0.0	k	axial (AR)	0.0	k	axial (AS)	0.0	k	axial (AT)	0.0	k	axial (AU)	165.0	k			
shear (AO)	85.4	k	shear (AP)	213.6	k	shear (AQ)	213.6	k	shear (AR)	213.6	k	shear (AS)	213.6	k	shear (AT)	106.8	k	shear (AU)	106.8	k			

	AO	AP	AQ	AR	AS	AT	AU
306	BD	BD	BD	BD	BD	BD	
363							
	AW	AX	AY	AZ	BA	BB	BC

moment (AW)	1284.1	ft-k	moment (AX)	3210.1	ft-k	moment (AY)	3210.1	ft-k	moment (AZ)	3210.1	ft-k	moment (BA)	3210.1	ft-k	moment (BB)	1605.1	ft-k	moment (BC)	1605.1	ft-k	moment (BD)	1924.8	ft-k
axial (AW)	256.6	k	axial (AX)	0.0	k	axial (AY)	0.0	k	axial (AZ)	0.0	k	axial (BA)	0.0	k	axial (BB)	0.0	k	axial (BC)	288.7	k			
shear (AW)	114.1	k	shear (AX)	285.3	k	shear (AY)	285.3	k	shear (AZ)	285.3	k	shear (BA)	285.3	k	shear (BB)	142.7	k	shear (BC)	142.7	k			

	AW	AX	AY	AZ	BA	BB	BC		
363	BP	BP	BP	BP	BP	BP			
414									
	BG	BH	BI	BJ	BK	BL	BM	BN	BO

moment (BG)	1101.7	ft-k	moment (BH)	2754.2	ft-k	moment (BI)	2754.2	ft-k	moment (BJ)	2754.2	ft-k	moment (BK)	2754.2	ft-k	moment (BL)	1377.1	ft-k	moment (BM)	1377.1	ft-k	moment (BN)	137.7	ft-k	moment (BO)	137.7	ft-k	moment (BP)	2385.7	ft-k
axial (BG)	318.1	k	axial (BH)	0.0	k	axial (BI)	0.0	k	axial (BJ)	0.0	k	axial (BK)	0.0	k	axial (BL)	0.0	k	axial (BM)	0.0	k	axial (BN)	0.0	k	axial (BO)	168.2	k			
shear (BG)	146.9	k	shear (BH)	367.2	k	shear (BI)	367.2	k	shear (BJ)	367.2	k	shear (BK)	367.2	k	shear (BL)	183.6	k	shear (BM)	183.6	k	shear (BN)	18.4	k	shear (BO)	18.4	k			

B.6 Hospital (N-S) 110mph

story force (k)											height (ft)
12											22.5
31											15
45											15
60											15
74											15
88											15
104											22.5
119											15
	30	30	30	30	30	30	30	30	30	30	width (ft)
											sum
dist. of forces	1	2	2	2	2	2	2	1.8	1	0.1	15.9

Grid E (N-S Hospital)

12											
	A	B	C	D	E	F	G	H			
	A	B	C	D	E	F	G	H			
12	U	U	U	U	U	U	U				
31											
	J	K	L	M	N	P	Q	R	S	T	
	J	K	L	M	N	P	Q	R	S	T	
31	AF	AF	AF	AF	AF	AF	AF	AF	AF		
45											
	V	W	X	Y	Z	AA	AB	AC	AD	AE	
	V	W	X	Y	Z	AA	AB	AC	AD	AE	
45	AQ	AQ	AQ	AQ	AQ	AQ	AQ	AQ	AQ		
60											
	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	
	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	
60	BB	BB	BB	BB	BB	BB	BB	BB	BB		
74											
	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	
	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	
74	BM	BM	BM	BM	BM	BM	BM	BM	BM		
88											
	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	
	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	
88	BX	BX	BX	BX	BX	BX	BX	BX	BX		
104											
	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	
	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	
104	CJ	CJ	CJ	CJ	CJ	CJ	CJ	CJ	CJ		
119											
	BY	BZ	CA	CB	CC	CD	CE	CF	CG	CH	CI

moment (A)	8.2	ft-k	moment (B)	16.5	ft-k	moment (C)	16.5	ft-k	moment (D)	16.5	ft-k	moment (E)	16.5	ft-k	moment (F)	16.5	ft-k	moment (G)	16.5	ft-k	moment (H)	14.8	ft-k
axial (A)	0.5	k	axial (B)	0.0	k	axial (C)	0.0	k	axial (D)	0.0	k	axial (E)	0.0	k	axial (F)	0.0	k	axial (G)	0.0	k	axial (H)	1.0	k
shear (A)	0.7	k	shear (B)	1.5	k	shear (C)	1.5	k	shear (D)	1.5	k	shear (E)	1.5	k	shear (F)	1.5	k	shear (G)	1.5	k	shear (H)	1.3	k

moment (J)	19.9	ft-k	moment (K)	39.7	ft-k	moment (L)	39.7	ft-k	moment (M)	39.7	ft-k	moment (N)	39.7	ft-k	moment (P)	39.7	ft-k	moment (Q)	39.7	ft-k	moment (R)	35.8	ft-k	moment (S)	19.9	ft-k	moment (T)	2.0	ft-k	moment (U)	28.1	ft-k
axial (J)	3.7	k	axial (K)	0.0	k	axial (L)	0.0	k	axial (M)	0.0	k	axial (N)	0.0	k	axial (P)	0.0	k	axial (Q)	0.0	k	axial (R)	0.0	k	axial (S)	0.0	k	axial (T)	0.1	k			
shear (J)	2.6	k	shear (K)	5.3	k	shear (L)	5.3	k	shear (M)	5.3	k	shear (N)	5.3	k	shear (P)	5.3	k	shear (Q)	5.3	k	shear (R)	4.8	k	shear (S)	2.6	k	shear (T)	0.3	k			

moment (V)	41.3	ft-k	moment (W)	82.5	ft-k	moment (X)	82.5	ft-k	moment (Y)	82.5	ft-k	moment (Z)	82.5	ft-k	moment (AA)	82.5	ft-k	moment (AB)	82.5	ft-k	moment (AC)	74.3	ft-k	moment (AD)	41.3	ft-k	moment (AE)	4.1	ft-k	moment (AF)	45.0	ft-k
axial (V)	7.1	k	axial (W)	0.0	k	axial (X)	0.0	k	axial (Y)	0.0	k	axial (Z)	0.0	k	axial (AA)	0.0	k	axial (AB)	0.0	k	axial (AC)	0.0	k	axial (AD)	0.0	k	axial (AE)	3.4	k			
shear (V)	5.5	k	shear (W)	11.0	k	shear (X)	11.0	k	shear (Y)	11.0	k	shear (Z)	11.0	k	shear (AA)	11.0	k	shear (AB)	11.0	k	shear (AC)	9.9	k	shear (AD)	5.5	k	shear (AE)	0.6	k			

moment (AG)	69.5	ft-k	moment (AH)	139.0	ft-k	moment (AI)	139.0	ft-k	moment (AJ)	139.0	ft-k	moment (AK)	139.0	ft-k	moment (AL)	139.0	ft-k	moment (AM)	139.0	ft-k	moment (AN)	125.1	ft-k	moment (AO)	69.5	ft-k	moment (AP)	7.0	ft-k	moment (AQ)	76.6	ft-k
axial (AG)	12.5	k	axial (AH)	0.0	k	axial (AI)	0.0	k	axial (AJ)	0.0	k	axial (AK)	0.0	k	axial (AL)	0.0	k	axial (AM)	0.0	k	axial (AN)	0.0	k	axial (AO)	0.0	k	axial (AP)	5.8	k			
shear (AG)	9.3	k	shear (AH)	18.5	k	shear (AI)	18.5	k	shear (AJ)	18.5	k	shear (AK)	18.5	k	shear (AL)	18.5	k	shear (AM)	18.5	k	shear (AN)	16.7	k	shear (AO)	9.3	k	shear (AP)	0.9	k			

moment (AR)	104.4	ft-k	moment (AS)	208.8	ft-k	moment (AT)	208.8	ft-k	moment (AU)	208.8	ft-k	moment (AV)	208.8	ft-k	moment (AW)	208.8	ft-k	moment (AX)	208.8	ft-k	moment (AY)	188.0	ft-k	moment (AZ)	104.4	ft-k	moment (BA)	10.4	ft-k	moment (BB)	116.9	ft-k
axial (AR)	19.4	k	axial (AS)	0.0	k	axial (AT)	0.0	k	axial (AU)	0.0	k	axial (AV)	0.0	k	axial (AW)	0.0	k	axial (AX)	0.0	k	axial (AY)	0.0	k	axial (AZ)	0.0	k	axial (BA)	9.0	k			
shear (AR)	13.9	k	shear (AS)	27.8	k	shear (AT)	27.8	k	shear (AU)	27.8	k	shear (AV)	27.8	k	shear (AW)	27.8	k	shear (AX)	27.8	k	shear (AY)	25.1	k	shear (AZ)	13.9	k	shear (BA)	1.4	k			

moment (BC)	145.8	ft-k	moment (BD)	291.5	ft-k	moment (BE)	291.5	ft-k	moment (BF)	291.5	ft-k	moment (BG)	291.5	ft-k	moment (BH)	291.5	ft-k	moment (BI)	291.5	ft-k	moment (BJ)	262.4	ft-k	moment (BK)	145.8	ft-k	moment (BL)	14.6	ft-k	moment (BM)	165.1	ft-k
axial (BC)	27.7	k	axial (BD)	0.0	k	axial (BE)	0.0	k	axial (BF)	0.0	k	axial (BG)	0.0	k	axial (BH)	0.0	k	axial (BI)	0.0	k	axial (BJ)	0.0	k	axial (BK)	0.0	k	axial (BL)	12.7	k			
shear (BC)	19.4	k	shear (BD)	38.9	k	shear (BE)	38.9	k	shear (BF)	38.9	k	shear (BG)	38.9	k	shear (BH)	38.9	k	shear (BI)	38.9	k	shear (BJ)	35.0	k	shear (BK)	19.4	k	shear (BL)	1.9	k			

moment (BN)	292.1	ft-k	moment (BO)	584.3	ft-k	moment (BP)	584.3	ft-k	moment (BQ)	584.3	ft-k	moment (BR)	584.3	ft-k	moment (BS)	584.3	ft-k	moment (BT)	584.3	ft-k	moment (BU)	525.8	ft-k	moment (BV)	292.1	ft-k	moment (BW)	29.2	ft-k	moment (BX)	319.8	ft-k
axial (BN)	50.5	k	axial (BO)	0.0	k	axial (BP)	0.0	k	axial (BQ)	0.0	k	axial (BR)	0.0	k	axial (BS)	0.0	k	axial (BT)	0.0	k	axial (BU)	0.0	k	axial (BV)	0.0	k	axial (BW)	24.2	k			
shear (BN)	26.0	k	shear (BO)	51.9	k	shear (BP)	51.9	k	shear (BQ)	51.9	k	shear (BR)	51.9	k	shear (BS)	51.9	k	shear (BT)	51.9	k	shear (BU)	46.7	k	shear (BV)	26.0	k	shear (BW)	2.6	k			

moment (BY)	250.6	ft-k	moment (BZ)	501.3	ft-k	moment (CA)	501.3	ft-k	moment (CB)	501.3	ft-k	moment (CC)	501.3	ft-k	moment (CD)	501.3	ft-k	moment (CE)	501.3	ft-k	moment (CF)	451.2	ft-k	moment (CG)	250.6	ft-k	moment (CH)	25.1	ft-k	moment (CI)	25.1	ft-k	moment (CJ)	542.8	ft-k
axial (BY)	37.9	k	axial (BZ)	0.0	k	axial (CA)	0.0	k	axial (CB)	0.0	k	axial (CC)	0.0	k	axial (CD)	0.0	k	axial (CE)	0.0	k	axial (CF)	0.0	k	axial (CG)	0.0	k	axial (CH)	0.0	k	axial (CI)	1.7	k			
shear (BY)	33.4	k	shear (BZ)	66.8	k	shear (CA)	66.8	k	shear (CB)	66.8	k	shear (CC)	66.8	k	shear (CD)	66.8	k	shear (CE)	66.8	k	shear (CF)	60.2	k	shear (CG)	33.4	k	shear (CH)	3.3	k	shear (CI)	3.3	k			

B.7 Hospital (E-W) 110mph

story force (k)							height (ft)
8							22.5
22							15
33							15
44							15
54							15
64							15
76							22.5
86							15
	30	30	30	30	30	30	width (ft)
							sum
dist. of forces	0.2	0.4	0.4	0.8	1	2	4.8

Grid 19 (E-W Hospital)

story force (k)				
8				
	A	B	C	D

moment (A) 15.9 ft-k	moment (B) 19.8 ft-k	moment (C) 39.6 ft-k	moment (D) 39.6 ft-k	
axial (A) 1.1 k	axial (B) 0.0 k	axial (C) 0.0 k	axial (D) 2.6 k	
shear (A) 1.4 k	shear (B) 1.8 k	shear (C) 3.5 k	shear (D) 3.5 k	

story force (k)				
	A	B	C	D
8	J	J	J	
22				
	E	F	G	H

moment (E) 38.3 ft-k	moment (F) 47.9 ft-k	moment (G) 95.7 ft-k	moment (H) 95.7 ft-k	moment (J) 54.1 ft-k
axial (E) 7.2 k	axial (F) 0.0 k	axial (G) 0.0 k	axial (H) 12.6 k	
shear (E) 5.1 k	shear (F) 6.4 k	shear (G) 12.8 k	shear (H) 12.8 k	

story force (k)				
	E	F	G	H
22	P	P	P	
33				
	K	L	M	N

moment (K) 79.5 ft-k	moment (L) 99.4 ft-k	moment (M) 198.9 ft-k	moment (N) 198.9 ft-k	moment (P) 117.8 ft-k
axial (K) 15.7 k	axial (L) 0.0 k	axial (M) 0.0 k	axial (N) 27.5 k	
shear (K) 10.6 k	shear (L) 13.3 k	shear (M) 26.5 k	shear (N) 26.5 k	

story force (k)				
	K	L	M	N
33	U	U	U	
44				
	Q	R	S	T

moment (Q) 134.0 ft-k	moment (R) 167.5 ft-k	moment (S) 334.9 ft-k	moment (T) 334.9 ft-k	moment (U) 213.5 ft-k
axial (Q) 28.5 k	axial (R) 0.0 k	axial (S) 0.0 k	axial (T) 49.8 k	
shear (Q) 17.9 k	shear (R) 22.3 k	shear (S) 44.7 k	shear (T) 44.7 k	

story force (k)				
	Q	R	S	T
44	Z	Z	Z	
54				
	V	W	X	Y

moment (V) 201.3 ft-k	moment (W) 251.6 ft-k	moment (X) 503.1 ft-k	moment (Y) 503.1 ft-k	moment (Z) 335.2 ft-k
axial (V) 44.7 k	axial (W) 0.0 k	axial (X) 0.0 k	axial (Y) 78.2 k	
shear (V) 26.8 k	shear (W) 33.5 k	shear (X) 67.1 k	shear (Y) 67.1 k	

story force (k)							
				V	W	X	Y
54				AH	AH	AH	
64							
	AA	AB	AC	AD	AE	AF	AG

moment (AA) 1.2 ft-k	moment (AB) 2.5 ft-k	moment (AC) 2.5 ft-k	moment (AD) 280.9 ft-k	moment (AE) 351.1 ft-k	moment (AF) 702.3 ft-k	moment (AG) 702.3 ft-k	moment (AH) 482.2 ft-k
axial (AA) 0.1 k	axial (AB) 0.0 k	axial (AC) 0.0 k	axial (AD) 0.0 k	axial (AE) 0.0 k	axial (AF) 0.0 k	axial (AG) 112.5 k	
shear (AA) 9.4 k	shear (AB) 18.7 k	shear (AC) 18.7 k	shear (AD) 37.5 k	shear (AE) 46.8 k	shear (AF) 93.6 k	shear (AG) 93.6 k	

story force (k)							
	AA	AB	AC	AD	AE	AF	AG
64	AP	AP	AP	AP	AP	AP	
76							
	AI	AJ	AK	AL	AM	AN	AO

moment (AI) 1.1 ft-k	moment (AJ) 2.2 ft-k	moment (AK) 2.2 ft-k	moment (AL) 563.0 ft-k	moment (AM) 703.8 ft-k	moment (AN) 1407.5 ft-k	moment (AO) 1407.5 ft-k	moment (AP) 843.9 ft-k
axial (AI) 56.4 k	axial (AJ) 0.0 k	axial (AK) 0.0 k	axial (AL) 0.0 k	axial (AM) 0.0 k	axial (AN) 0.0 k	axial (AO) 196.9 k	
shear (AI) 12.5 k	shear (AJ) 25.0 k	shear (AK) 25.0 k	shear (AL) 50.0 k	shear (AM) 62.6 k	shear (AN) 125.1 k	shear (AO) 125.1 k	

story force (k)							
	AI	AJ	AK	AL	AM	AN	AO
76	AX	AX	AX	AX	AX	AX	
86							
	AQ	AR	AS	AT	AU	AV	AW

moment (AQ) 2.1 ft-k	moment (AR) 4.3 ft-k	moment (AS) 4.3 ft-k	moment (AT) 483.1 ft-k	moment (AU) 603.8 ft-k	moment (AV) 1207.7 ft-k	moment (AW) 1207.7 ft-k	moment (AX) 1046.1 ft-k
axial (AQ) 70.0 k	axial (AR) 0.0 k	axial (AS) 0.0 k	axial (AT) 0.0 k	axial (AU) 0.0 k	axial (AV) 0.0 k	axial (AW) 244.1 k	
shear (AQ) 16.1 k	shear (AR) 32.2 k	shear (AS) 32.2 k	shear (AT) 64.4 k	shear (AU) 80.5 k	shear (AV) 161.0 k	shear (AW) 161.0 k	

B.8 Clinic (N-S) 110mph

story force (k)				height (ft)	
9				22.5	
23				15	
35				15	
46				15	
56				15	
67				15	
79				22.5	
90				15	
	30	30	30	width (ft)	
					sum
dist. of forces	1	2	2	1	6

Grid N (N-S Clinic)

9				
	A	B	C	D

moment (A)	16.7	ft-k	moment (B)	33.3	ft-k	moment (C)	33.3	ft-k	moment (D)	16.7	ft-k
axial (A)	1.1	k	axial (B)	0.0	k	axial (C)	0.0	k	axial (D)	1.1	k
shear (A)	1.5	k	shear (B)	3.0	k	shear (C)	3.0	k	shear (D)	1.5	k

	A	B	C	D
9	J	J	J	
23				
	E	F	G	H

moment (E)	40.1	ft-k	moment (F)	80.3	ft-k	moment (G)	80.3	ft-k	moment (H)	40.1	ft-k	moment (J)	56.8	ft-k
axial (E)	3.8	k	axial (F)	0.0	k	axial (G)	0.0	k	axial (H)	3.8	k			
shear (E)	5.4	k	shear (F)	10.7	k	shear (G)	10.7	k	shear (H)	5.4	k			

	E	F	G	H
23	P	P	P	
35				
	K	L	M	N

moment (K)	83.3	ft-k	moment (L)	166.7	ft-k	moment (M)	166.7	ft-k	moment (N)	83.3	ft-k	moment (P)	123.5	ft-k
axial (K)	8.2	k	axial (L)	0.0	k	axial (M)	0	k	axial (N)	8.2	k			
shear (K)	11.1	k	shear (L)	22.2	k	shear (M)	22.2	k	shear (N)	11.1	k			

	K	L	M	N
35	U	U	U	
46				
	Q	R	S	T

moment (Q)	140.4	ft-k	moment (R)	280.8	ft-k	moment (S)	280.8	ft-k	moment (T)	140.4	ft-k	moment (U)	223.75	ft-k
axial (Q)	14.9	k	axial (R)	0.0	k	axial (S)	0	k	axial (T)	14.9	k			
shear (Q)	18.7	k	shear (R)	37.4	k	shear (S)	37.4	k	shear (T)	18.7	k			

	Q	R	S	T
46	Z	Z	Z	
56				
	V	W	X	Y

moment (V)	211.0	ft-k	moment (W)	421.9	ft-k	moment (X)	421.9	ft-k	moment (Y)	211.0	ft-k	moment (Z)	351.39	ft-k
axial (V)	23.4	k	axial (W)	0.0	k	axial (X)	0	k	axial (Y)	23.4	k			
shear (V)	28.1	k	shear (W)	56.3	k	shear (X)	56.3	k	shear (Y)	28.1	k			

	V	W	X	Y
56	AE	AE	AE	
67				
	AA	AB	AC	AD

moment (AA)	294.4	ft-k	moment (AB)	588.9	ft-k	moment (AC)	588.9	ft-k	moment (AD)	294.4	ft-k	moment (AE)	505.42	ft-k
axial (AA)	33.7	k	axial (AB)	0.0	k	axial (AC)	0	k	axial (AD)	33.7	k			
shear (AA)	39.3	k	shear (AB)	78.5	k	shear (AC)	78.5	k	shear (AD)	39.3	k			

	AA	AB	AC	AD
67	AJ	AJ	AJ	
79				
	AF	AG	AH	AI

moment (AF)	590.2	ft-k	moment (AG)	1180.4	ft-k	moment (AH)	1180.4	ft-k	moment (AI)	590.2	ft-k	moment (AJ)	884.65	ft-k
axial (AF)	59.0	k	axial (AG)	0.0	k	axial (AH)	0	k	axial (AI)	59.0	k			
shear (AF)	52.5	k	shear (AG)	104.9	k	shear (AH)	104.9	k	shear (AI)	52.5	k			

	AF	AG	AH	AI
79	AO	AO	AO	
90				
	AK	AL	AM	AN

moment (AK)	506.4	ft-k	moment (AL)	1012.8	ft-k	moment (AM)	1012.8	ft-k	moment (AN)	506.4	ft-k	moment (AO)	1096.6	ft-k
axial (AK)	73.1	k	axial (AL)	0.0	k	axial (AM)	0	k	axial (AN)	73.1	k			
shear (AK)	67.5	k	shear (AL)	135.0	k	shear (AM)	135.0	k	shear (AN)	67.5	k			

B.9 Clinic (E-W) 110mph

story force (k)									height (ft)
20									22.5
52									15
78									15
103									15
127									15
150									15
178									22.5
203									15
	30	30	30	30	30	30	30	30	width (ft)

										sum
dist. of forces	0.8	2	2	2	2	1	0.2	0.1		10.1

Grid 10 (E-W Clinic)

20									
		A	B	C	D	E	F		
		A	B	C	D	E	F		
20		N	N	N	N	N			
52									
		G	H	J	K	L	M		
	P	G	H	J	K	L	M		
52	X	X	X	X	X	X			
78									
	Q	R	S	T	U	V	W		
	Q	R	S	T	U	V	W		
78	AF	AF	AF	AF	AF	AF			
103									
	Y	Z	AA	AB	AC	AD	AE		
	Y	Z	AA	AB	AC	AD	AE		
103	AN	AN	AN	AN	AN	AN			
127									
	AG	AH	AI	AJ	AK	AL	AM		
	AG	AH	AI	AJ	AK	AL	AM		
127	AV	AV	AV	AV	AV	AV			
150									
	AO	AP	AQ	AR	AS	AT	AU		
	AO	AP	AQ	AR	AS	AT	AU		
150	BD	BD	BD	BD	BD	BD			
178									
	AW	AX	AY	AZ	BA	BB	BC		
	AW	AX	AY	AZ	BA	BB	BC		
178	BP	BP	BP	BP	BP	BP			
203									
	BG	BH	BI	BJ	BK	BL	BM	BN	BO

moment (A)	44.6	ft-k	moment (B)	44.6	ft-k	moment (C)	44.6	ft-k	moment (D)	44.6	ft-k	moment (E)	22.3	ft-k	moment (F)	22.3	ft-k
axial (A)	3.0	k	axial (B)	0.0	k	axial (C)	0.0	k	axial (D)	0.0	k	axial (E)	0.0	k	axial (F)	1.5	k
shear (A)	4.0	k	shear (B)	4.0	k	shear (C)	4.0	k	shear (D)	4.0	k	shear (E)	2.0	k	shear (F)	2.0	k

moment (G)	107.3	ft-k	moment (H)	107.3	ft-k	moment (J)	107.3	ft-k	moment (K)	107.3	ft-k	moment (L)	53.7	ft-k	moment (M)	53.7	ft-k	moment (N)	151.9 ft-k
axial (G)	20.2	k	axial (H)	0.0	k	axial (J)	0.0	k	axial (K)	0.0	k	axial (L)	0.0	k	axial (M)	15.2	k		
shear (G)	14.3	k	shear (H)	14.3	k	shear (J)	14.3	k	shear (K)	14.3	k	shear (L)	7.2	k	shear (M)	7.2	k		

moment (P)	89.1	ft-k	moment (Q)	89.1	ft-k	moment (R)	222.8	ft-k	moment (S)	222.8	ft-k	moment (T)	222.8	ft-k	moment (U)	222.8	ft-k	moment (V)	111.4	ft-k	moment (W)	111.4	ft-k	moment (X)	178.2 ft-k
axial (P)	5.9	k	axial (Q)	23.8	k	axial (R)	0.0	k	axial (S)	0.0	k	axial (T)	0.0	k	axial (U)	0.0	k	axial (V)	0.0	k	axial (W)	22.9	k		
shear (P)	11.9	k	shear (Q)	11.9	k	shear (R)	29.7	k	shear (S)	29.7	k	shear (T)	29.7	k	shear (U)	29.7	k	shear (V)	14.9	k	shear (W)	14.9	k		

moment (Y)	150.1	ft-k	moment (Z)	375.4	ft-k	moment (AA)	375.4	ft-k	moment (AB)	375.4	ft-k	moment (AC)	375.4	ft-k	moment (AD)	187.7	ft-k	moment (AE)	187.7	ft-k	moment (AF)	239.3	ft-k
axial (Y)	31.9	k	axial (Z)	0.0	k	axial (AA)	0.0	k	axial (AB)	0.0	k	axial (AC)	0.0	k	axial (AD)	0.0	k	axial (AE)	35.9	k			
shear (Y)	20.0	k	shear (Z)	50.0	k	shear (AA)	50.0	k	shear (AB)	50.0	k	shear (AC)	50.0	k	shear (AD)	25.0	k	shear (AE)	25.0	k			

moment (AG)	225.6	ft-k	moment (AH)	564.0	ft-k	moment (AI)	564.0	ft-k	moment (AJ)	564.0	ft-k	moment (AK)	564.0	ft-k	moment (AL)	282.0	ft-k	moment (AM)	282.0	ft-k	moment (AN)	375.7	ft-k
axial (AG)	50.1	k	axial (AH)	0.0	k	axial (AI)	0.0	k	axial (AJ)	0.0	k	axial (AK)	0.0	k	axial (AL)	0.0	k	axial (AM)	56.4	k			
shear (AG)	30.1	k	shear (AH)	75.2	k	shear (AI)	75.2	k	shear (AJ)	75.2	k	shear (AK)	75.2	k	shear (AL)	37.6	k	shear (AM)	37.6	k			

moment (AO)	314.9	ft-k	moment (AP)	787.1	ft-k	moment (AQ)	787.1	ft-k	moment (AR)	787.1	ft-k	moment (AS)	787.1	ft-k	moment (AT)	393.6	ft-k	moment (AU)	393.6	ft-k	moment (AV)	540.4	ft-k
axial (AO)	72.1	k	axial (AP)	0.0	k	axial (AQ)	0.0	k	axial (AR)	0.0	k	axial (AS)	0.0	k	axial (AT)	0.0	k	axial (AU)	81.1	k			
shear (AO)	42.0	k	shear (AP)	105.0	k	shear (AQ)	105.0	k	shear (AR)	105.0	k	shear (AS)	105.0	k	shear (AT)	52.5	k	shear (AU)	52.5	k			

moment (AW)	631.1	ft-k	moment (AX)	1577.8	ft-k	moment (AY)	1577.8	ft-k	moment (AZ)	1577.8	ft-k	moment (BA)	1577.8	ft-k	moment (BB)	788.9	ft-k	moment (BC)	788.9	ft-k	moment (BD)	946.0	ft-k
axial (AW)	126.1	k	axial (AX)	0.0	k	axial (AY)	0.0	k	axial (AZ)	0.0	k	axial (BA)	0.0	k	axial (BB)	0.0	k	axial (BC)	141.9	k			
shear (AW)	56.1	k	shear (AX)	140.2	k	shear (AY)	140.2	k	shear (AZ)	140.2	k	shear (BA)	140.2	k	shear (BB)	70.1	k	shear (BC)	70.1	k			

moment (BG)	541.5	ft-k	moment (BH)	1353.7	ft-k	moment (BI)	1353.7	ft-k	moment (BJ)	1353.7	ft-k	moment (BK)	1353.7	ft-k	moment (BL)	676.9	ft-k	moment (BM)	676.9	ft-k	moment (BN)	67.7	ft-k	moment (BO)	67.7	ft-k	moment (BP)	1172.6	ft-k
axial (BG)	156.3	k	axial (BH)	0.0	k	axial (BI)	0.0	k	axial (BJ)	0.0	k	axial (BK)	0.0	k	axial (BL)	0.0	k	axial (BM)	0.0	k	axial (BN)	0.0	k	axial (BO)	82.7	k			
shear (BG)	72.2	k	shear (BH)	180.5	k	shear (BI)	180.5	k	shear (BJ)	180.5	k	shear (BK)	180.5	k	shear (BL)	90.2	k	shear (BM)	90.2	k	shear (BN)	9.0	k	shear (BO)	9.0	k			

Appendix C: Moment Transfer Analysis

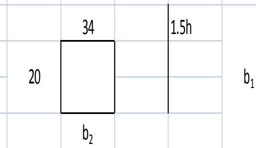
C.1 Hospital (N-S) 157mph

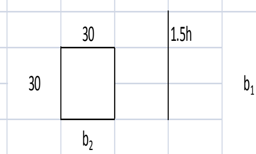
Grid E Hospital

ext. col

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor				
Floor 6	b_1	38 in		
	b_2	34 in		
	γ_f	0.59		
	$\gamma_f M$	53.88	ft-k	transferred by flexure
		37.97	ft-k	transferred by shear
Floor 5	b_1	38 in		
	b_2	34 in		
	γ_f	0.59		
	$\gamma_f M$	91.65	ft-k	transferred by flexure
		64.59	ft-k	transferred by shear
Floor 4	b_1	38 in		
	b_2	34 in		
	γ_f	0.59		
	$\gamma_f M$	139.87	ft-k	transferred by flexure
		98.58	ft-k	transferred by shear
Floor 3	b_1	38 in		
	b_2	34 in		
	γ_f	0.59		
	$\gamma_f M$	197.55	ft-k	transferred by flexure
		139.23	ft-k	transferred by shear
Floor 2	b_1	48 in		
	b_2	30 in		
	γ_f	0.54		
	$\gamma_f M$	353.84	ft-k	transferred by flexure
		298.38	ft-k	transferred by shear
Floor 1	b_1	48 in		
	b_2	30 in		
	γ_f	0.54		
	$\gamma_f M$	600.51	ft-k	transferred by flexure
		506.39	ft-k	transferred by shear

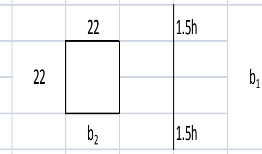


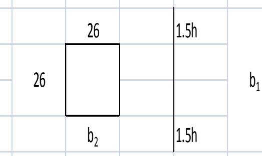


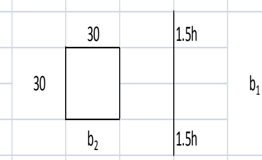
int. col

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor				
Floor 6	b_1	58 in		
	b_2	22 in		
	γ_f	0.48		
	$\gamma_f M$	44.11	ft-k	transferred by flexure
		47.74	ft-k	transferred by shear
Floor 5	b_1	58 in		
	b_2	22 in		
	γ_f	0.48		
	$\gamma_f M$	75.03	ft-k	transferred by flexure
		81.22	ft-k	transferred by shear
Floor 4	b_1	62 in		
	b_2	26 in		
	γ_f	0.49		
	$\gamma_f M$	117.50	ft-k	transferred by flexure
		120.96	ft-k	transferred by shear
Floor 3	b_1	62 in		
	b_2	26 in		
	γ_f	0.49		
	$\gamma_f M$	165.94	ft-k	transferred by flexure
		170.83	ft-k	transferred by shear
Floor 2	b_1	66 in		
	b_2	30 in		
	γ_f	0.50		
	$\gamma_f M$	327.94	ft-k	transferred by flexure
		324.28	ft-k	transferred by shear
Floor 1	b_1	66 in		
	b_2	30 in		
	γ_f	0.50		
	$\gamma_f M$	556.56	ft-k	transferred by flexure
		550.34	ft-k	transferred by shear



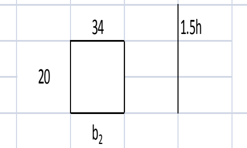


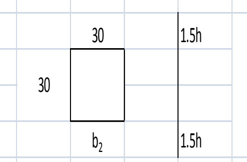


int. col

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor				
Floor 6	b_1	38 in		
	b_2	34 in		
	γ_f	0.59		
	$\gamma_f M$	53.88	ft-k	transferred by flexure
		37.97	ft-k	transferred by shear
Floor 5	b_1	38 in		
	b_2	34 in		
	γ_f	0.59		
	$\gamma_f M$	91.65	ft-k	transferred by flexure
		64.59	ft-k	transferred by shear
Floor 4	b_1	38 in		
	b_2	34 in		
	γ_f	0.59		
	$\gamma_f M$	139.87	ft-k	transferred by flexure
		98.58	ft-k	transferred by shear
Floor 3	b_1	38 in		
	b_2	34 in		
	γ_f	0.59		
	$\gamma_f M$	197.55	ft-k	transferred by flexure
		139.23	ft-k	transferred by shear
Floor 2	b_1	38 in		
	b_2	34 in		
	γ_f	0.59		
	$\gamma_f M$	382.58	ft-k	transferred by flexure
		269.64	ft-k	transferred by shear
Floor 1	b_1	66 in		
	b_2	30 in		
	γ_f	0.50		
	$\gamma_f M$	556.56	ft-k	transferred by flexure
		550.34	ft-k	transferred by shear

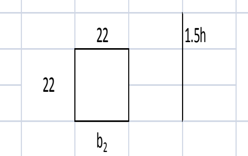




ext. col

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor				
Floor 1	b_1	40 in		
	b_2	22 in		
	γ_f	0.53		
	$\gamma_f M$	582.91	ft-k	transferred by flexure
		523.99	ft-k	transferred by shear



C.2 Hospital (E-W) 157mph

Grid 19 Hospital

ext. col — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 3	42 in	20 in	0.51	500.13 ft-k	483.17 ft-k
Floor 2	44 in	26 in	0.54	921.68 ft-k	799.34 ft-k
Floor 1	44 in	26 in	0.54	1142.47 ft-k	990.82 ft-k

int. col — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 3	58 in	22 in	0.48	472.18 ft-k	511.12 ft-k
Floor 2	62 in	26 in	0.49	848.01 ft-k	873.01 ft-k
Floor 1	62 in	26 in	0.49	1051.15 ft-k	1082.14 ft-k

int. col — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 3	58 in	22 in	0.48	472.18 ft-k	511.12 ft-k
Floor 2	58 in	22 in	0.48	826.44 ft-k	894.58 ft-k
Floor 1	62 in	26 in	0.49	1051.15 ft-k	1082.14 ft-k

int. col — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 6	40 in	22 in	0.53	126.63 ft-k	113.83 ft-k
Floor 5	40 in	22 in	0.53	229.38 ft-k	206.19 ft-k
Floor 4	44 in	26 in	0.54	366.18 ft-k	317.57 ft-k
Floor 3	62 in	26 in	0.49	484.51 ft-k	498.79 ft-k
Floor 2	66 in	30 in	0.50	865.35 ft-k	855.68 ft-k
Floor 1	66 in	30 in	0.50	1072.64 ft-k	1060.66 ft-k

int. col — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 6	58 in	22 in	0.48	115.47 ft-k	124.99 ft-k
Floor 5	58 in	22 in	0.48	209.16 ft-k	226.41 ft-k
Floor 4	62 in	26 in	0.49	336.91 ft-k	346.84 ft-k
Floor 3	62 in	26 in	0.49	484.51 ft-k	498.79 ft-k
Floor 2	62 in	26 in	0.49	848.01 ft-k	873.01 ft-k
Floor 1	62 in	26 in	0.49	1051.15 ft-k	1082.14 ft-k

ext. col — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 6	44 in	26 in	0.54	128.77 ft-k	111.68 ft-k
Floor 5	44 in	26 in	0.54	233.27 ft-k	202.30 ft-k
Floor 4	48 in	30 in	0.54	370.94 ft-k	312.81 ft-k
Floor 3	48 in	30 in	0.54	533.45 ft-k	449.84 ft-k
Floor 2	52 in	34 in	0.55	943.30 ft-k	777.72 ft-k
Floor 1	52 in	34 in	0.55	1169.27 ft-k	964.02 ft-k

C.3 Clinic (N-S) 157mph

Grid N Clinic

	int. cols.							
$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)})$								
Floor 6	b_1	58	in			22	1.5h	
	b_2	22	in		22			b_1
	γ_f	0.48						
						b_2	1.5h	
	$\gamma_f M$	120.78	ft-k	transferred by flexure				
		130.74	ft-k	transferred by shear				
Floor 5	b_1	58	in					
	b_2	22	in					
	γ_f	0.48						
	$\gamma_f M$	218.76	ft-k	transferred by flexure				
		236.80	ft-k	transferred by shear				
Floor 4	b_1	62	in			26	1.5h	
	b_2	26	in		26			b_1
	γ_f	0.49						
						b_2	1.5h	
	$\gamma_f M$	352.38	ft-k	transferred by flexure				
		362.76	ft-k	transferred by shear				
Floor 3	b_1	62	in					
	b_2	26	in					
	γ_f	0.49						
	$\gamma_f M$	506.77	ft-k	transferred by flexure				
		521.71	ft-k	transferred by shear				
Floor 2	b_1	66	in			30	1.5h	
	b_2	30	in		30			b_1
	γ_f	0.50						
						b_2	1.5h	
	$\gamma_f M$	905.06	ft-k	transferred by flexure				
		894.94	ft-k	transferred by shear				
Floor 1	b_1	66	in					
	b_2	30	in					
	γ_f	0.50						
	$\gamma_f M$	1121.82	ft-k	transferred by flexure				
		1109.29	ft-k	transferred by shear				

	ext. cols.							
$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)})$								
Floor 6	b_1	38	in			24	1.5h	
	b_2	24	in		20			b_1
	γ_f	0.54						
						b_2		
	$\gamma_f M$	136.78	ft-k	transferred by flexure				
		114.74	ft-k	transferred by shear				
Floor 5	b_1	38	in					
	b_2	24	in					
	γ_f	0.54						
	$\gamma_f M$	247.74	ft-k	transferred by flexure				
		207.82	ft-k	transferred by shear				
Floor 4	b_1	38	in			34	1.5h	
	b_2	34	in		20			b_1
	γ_f	0.59						
						b_2		
	$\gamma_f M$	419.49	ft-k	transferred by flexure				
		295.65	ft-k	transferred by shear				
Floor 3	b_1	38	in					
	b_2	34	in					
	γ_f	0.59						
	$\gamma_f M$	603.28	ft-k	transferred by flexure				
		425.19	ft-k	transferred by shear				
Floor 2	b_1	38	in					
	b_2	34	in					
	γ_f	0.59						
	$\gamma_f M$	1055.85	ft-k	transferred by flexure				
		744.15	ft-k	transferred by shear				
Floor 1	b_1	38	in					
	b_2	34	in					
	γ_f	0.59						
	$\gamma_f M$	1308.73	ft-k	transferred by flexure				
		922.38	ft-k	transferred by shear				

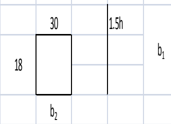
C.4 Clinic (E-W) 157mph

Grid 10 Clinic

ext. col

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

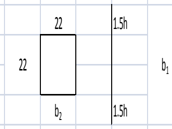
Floor 6	b_1	36	in	
	b_2	30	in	
	γ_f	0.58		
	$\gamma_f M$	209.77	ft-k	transferred by flexure
		153.20	ft-k	transferred by shear
Floor 5	b_1	36	in	
	b_2	30	in	
	γ_f	0.58		
	$\gamma_f M$	281.53	ft-k	transferred by flexure
		205.60	ft-k	transferred by shear
Floor 4	b_1	36	in	
	b_2	30	in	
	γ_f	0.58		
	$\gamma_f M$	441.95	ft-k	transferred by flexure
		322.75	ft-k	transferred by shear
Floor 3	b_1	36	in	
	b_2	30	in	
	γ_f	0.58		
	$\gamma_f M$	635.59	ft-k	transferred by flexure
		464.17	ft-k	transferred by shear
Floor 2	b_1	36	in	
	b_2	30	in	
	γ_f	0.58		
	$\gamma_f M$	1112.38	ft-k	transferred by flexure
		812.37	ft-k	transferred by shear
Floor 1	b_1	36	in	
	b_2	30	in	
	γ_f	0.58		
	$\gamma_f M$	1378.81	ft-k	transferred by flexure
		1006.94	ft-k	transferred by shear

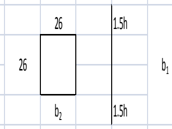


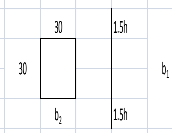
int. col

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor 6	b_1	58	in	
	b_2	22	in	
	γ_f	0.48		
	$\gamma_f M$	174.30	ft-k	transferred by flexure
		188.67	ft-k	transferred by shear
Floor 5	b_1	58	in	
	b_2	22	in	
	γ_f	0.48		
	$\gamma_f M$	233.92	ft-k	transferred by flexure
		253.21	ft-k	transferred by shear
Floor 4	b_1	62	in	
	b_2	26	in	
	γ_f	0.49		
	$\gamma_f M$	376.80	ft-k	transferred by flexure
		387.91	ft-k	transferred by shear
Floor 3	b_1	62	in	
	b_2	26	in	
	γ_f	0.49		
	$\gamma_f M$	541.89	ft-k	transferred by flexure
		557.86	ft-k	transferred by shear
Floor 2	b_1	66	in	
	b_2	30	in	
	γ_f	0.50		
	$\gamma_f M$	967.78	ft-k	transferred by flexure
		956.97	ft-k	transferred by shear
Floor 1	b_1	66	in	
	b_2	30	in	
	γ_f	0.50		
	$\gamma_f M$	1199.57	ft-k	transferred by flexure
		1186.17	ft-k	transferred by shear



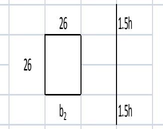


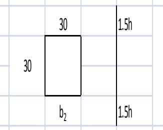


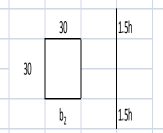
int. col.

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor 6	b_1	62	in	
	b_2	26	in	
	γ_f	0.49		
	$\gamma_f M$	178.85	ft-k	transferred by flexure
		184.12	ft-k	transferred by shear
Floor 5	b_1	62	in	
	b_2	26	in	
	γ_f	0.49		
	$\gamma_f M$	240.03	ft-k	transferred by flexure
		247.10	ft-k	transferred by shear
Floor 4	b_1	62	in	
	b_2	26	in	
	γ_f	0.49		
	$\gamma_f M$	376.80	ft-k	transferred by flexure
		387.91	ft-k	transferred by shear
Floor 3	b_1	66	in	
	b_2	30	in	
	γ_f	0.50		
	$\gamma_f M$	552.97	ft-k	transferred by flexure
		546.79	ft-k	transferred by shear
Floor 2	b_1	66	in	
	b_2	30	in	
	γ_f	0.50		
	$\gamma_f M$	967.78	ft-k	transferred by flexure
		956.97	ft-k	transferred by shear
Floor 1	b_1	66	in	
	b_2	30	in	
	γ_f	0.50		
	$\gamma_f M$	1199.57	ft-k	transferred by flexure
		1186.17	ft-k	transferred by shear



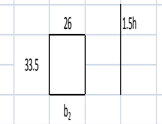


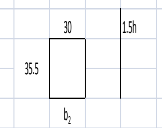


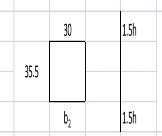
int. col.

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor 6	b_1	51.5	in	
	b_2	26	in	
	γ_f	0.52		
	$\gamma_f M$	187.27	ft-k	transferred by flexure
		175.70	ft-k	transferred by shear
Floor 5	b_1	51.5	in	
	b_2	26	in	
	γ_f	0.52		
	$\gamma_f M$	251.32	ft-k	transferred by flexure
		235.81	ft-k	transferred by shear
Floor 4	b_1	51.5	in	
	b_2	26	in	
	γ_f	0.52		
	$\gamma_f M$	394.53	ft-k	transferred by flexure
		370.17	ft-k	transferred by shear
Floor 3	b_1	51.5	in	
	b_2	26	in	
	γ_f	0.52		
	$\gamma_f M$	567.39	ft-k	transferred by flexure
		532.36	ft-k	transferred by shear
Floor 2	b_1	53.5	in	
	b_2	30	in	
	γ_f	0.53		
	$\gamma_f M$	1018.24	ft-k	transferred by flexure
		906.51	ft-k	transferred by shear
Floor 1	b_1	71.5	in	
	b_2	30	in	
	γ_f	0.49		
	$\gamma_f M$	1175.70	ft-k	transferred by flexure
		1210.04	ft-k	transferred by shear



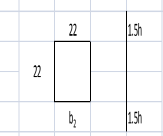




int. col.

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

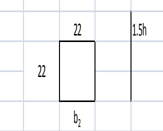
Floor 1	b_1	58	in	
	b_2	22	in	
	γ_f	0.48		
	$\gamma_f M$	1145.64	ft-k	transferred by flexure
		1240.11	ft-k	transferred by shear



ext. col.

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor 1	b_1	40	in	
	b_2	22	in	
	γ_f	0.53		
	$\gamma_f M$	1256.36	ft-k	transferred by flexure
		1129.38	ft-k	transferred by shear



C.5 Hospital (N-S) 110 mph

Grid E Hospital

ext. col

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor 6	b_1	38	in	
	b_2	34	in	
	γ_f	0.59		
	$\gamma_f M$	26.41	ft-k	transferred by flexure
		18.61	ft-k	transferred by shear
Floor 5	b_1	38	in	
	b_2	34	in	
	γ_f	0.59		
	$\gamma_f M$	44.93	ft-k	transferred by flexure
		31.67	ft-k	transferred by shear
Floor 4	b_1	38	in	
	b_2	34	in	
	γ_f	0.59		
	$\gamma_f M$	68.58	ft-k	transferred by flexure
		48.33	ft-k	transferred by shear
Floor 3	b_1	38	in	
	b_2	34	in	
	γ_f	0.59		
	$\gamma_f M$	96.87	ft-k	transferred by flexure
		68.27	ft-k	transferred by shear
Floor 2	b_1	48	in	
	b_2	30	in	
	γ_f	0.54		
	$\gamma_f M$	173.50	ft-k	transferred by flexure
		146.31	ft-k	transferred by shear
Floor 1	b_1	48	in	
	b_2	30	in	
	γ_f	0.54		
	$\gamma_f M$	294.46	ft-k	transferred by flexure
		248.31	ft-k	transferred by shear

int. col

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor 6	b_1	58	in	
	b_2	22	in	
	γ_f	0.48		
	$\gamma_f M$	21.62	ft-k	transferred by flexure
		23.40	ft-k	transferred by shear
Floor 5	b_1	58	in	
	b_2	22	in	
	γ_f	0.48		
	$\gamma_f M$	36.78	ft-k	transferred by flexure
		39.81	ft-k	transferred by shear
Floor 4	b_1	62	in	
	b_2	26	in	
	γ_f	0.49		
	$\gamma_f M$	57.61	ft-k	transferred by flexure
		59.31	ft-k	transferred by shear
Floor 3	b_1	62	in	
	b_2	26	in	
	γ_f	0.49		
	$\gamma_f M$	81.37	ft-k	transferred by flexure
		83.77	ft-k	transferred by shear
Floor 2	b_1	66	in	
	b_2	30	in	
	γ_f	0.50		
	$\gamma_f M$	160.81	ft-k	transferred by flexure
		159.01	ft-k	transferred by shear
Floor 1	b_1	66	in	
	b_2	30	in	
	γ_f	0.50		
	$\gamma_f M$	272.91	ft-k	transferred by flexure
		269.86	ft-k	transferred by shear

int. col

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor 6	b_1	38	in	
	b_2	34	in	
	γ_f	0.59		
	$\gamma_f M$	26.41	ft-k	transferred by flexure
		18.61	ft-k	transferred by shear
Floor 5	b_1	38	in	
	b_2	34	in	
	γ_f	0.59		
	$\gamma_f M$	44.93	ft-k	transferred by flexure
		31.67	ft-k	transferred by shear
Floor 4	b_1	38	in	
	b_2	34	in	
	γ_f	0.59		
	$\gamma_f M$	68.58	ft-k	transferred by flexure
		48.33	ft-k	transferred by shear
Floor 3	b_1	38	in	
	b_2	34	in	
	γ_f	0.59		
	$\gamma_f M$	96.87	ft-k	transferred by flexure
		68.27	ft-k	transferred by shear
Floor 2	b_1	38	in	
	b_2	34	in	
	γ_f	0.59		
	$\gamma_f M$	187.60	ft-k	transferred by flexure
		132.22	ft-k	transferred by shear
Floor 1	b_1	66	in	
	b_2	30	in	
	γ_f	0.50		
	$\gamma_f M$	272.91	ft-k	transferred by flexure
		269.86	ft-k	transferred by shear

ext. col

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor 1	b_1	40	in	
	b_2	22	in	
	γ_f	0.53		
	$\gamma_f M$	285.83	ft-k	transferred by flexure
		256.94	ft-k	transferred by shear

C.6 Hospital (E-W) 110 mph

Grid 19 Hospital

$\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor		ext. col	int. col	int. col	int. col	int. col	ext. col
Floor 6	b_1				40 in	58 in	44 in
	b_2				22 in	22 in	26 in
	γ_f				0.53	0.48	0.54
	$\gamma_f M$ transferred by flexure				62.06 ft-k	56.59 ft-k	63.11 ft-k
	transferred by shear				55.78 ft-k	61.25 ft-k	54.73 ft-k
Floor 5	b_1				40 in	58 in	44 in
	b_2				22 in	22 in	26 in
	γ_f				0.53	0.48	0.54
	$\gamma_f M$ transferred by flexure				112.44 ft-k	102.53 ft-k	114.35 ft-k
	transferred by shear				101.08 ft-k	110.99 ft-k	99.17 ft-k
Floor 4	b_1				44 in	62 in	48 in
	b_2				26 in	26 in	30 in
	γ_f				0.54	0.49	0.54
	$\gamma_f M$ transferred by flexure				179.53 ft-k	165.18 ft-k	181.87 ft-k
	transferred by shear				155.70 ft-k	170.05 ft-k	153.36 ft-k
Floor 3	b_1	42 in	58 in	58 in	62 in	62 in	48 in
	b_2	20 in	22 in	22 in	26 in	26 in	30 in
	γ_f	0.51	0.48	0.48	0.49	0.49	0.54
	$\gamma_f M$ transferred by flexure	245.24 ft-k	231.53 ft-k	231.53 ft-k	237.58 ft-k	237.58 ft-k	261.58 ft-k
	transferred by shear	236.92 ft-k	250.63 ft-k	250.63 ft-k	244.58 ft-k	244.58 ft-k	220.58 ft-k
Floor 2	b_1	44 in	62 in	58 in	66 in	62 in	52 in
	b_2	26 in	26 in	22 in	30 in	26 in	34 in
	γ_f	0.54	0.49	0.48	0.50	0.49	0.55
	$\gamma_f M$ transferred by flexure	451.96 ft-k	415.83 ft-k	405.25 ft-k	424.33 ft-k	415.83 ft-k	462.56 ft-k
	transferred by shear	391.96 ft-k	428.09 ft-k	438.67 ft-k	419.59 ft-k	428.09 ft-k	381.36 ft-k
Floor 1	b_1	44 in	62 in	62 in	66 in	62 in	52 in
	b_2	26 in	26 in	26 in	30 in	26 in	34 in
	γ_f	0.54	0.49	0.49	0.50	0.49	0.55
	$\gamma_f M$ transferred by flexure	560.22 ft-k	515.44 ft-k	515.44 ft-k	525.98 ft-k	1051.15 ft-k	573.36 ft-k
	transferred by shear	485.86 ft-k	530.64 ft-k	530.64 ft-k	520.10 ft-k	1082.14 ft-k	472.72 ft-k

C.7 Clinic (N-S) 110 mph

Grid N Clinic

int. cols.

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor 6	b_1	58	in			22	1.5h	
	b_2	22	in		22			b_1
	γ_f	0.48						
						b_2	1.5h	
	$\gamma_f M$	59.29	ft-k	transferred by flexure				
		64.18	ft-k	transferred by shear		l1		
Floor 5	b_1	58	in					
	b_2	22	in					
	γ_f	0.48						
	$\gamma_f M$	107.45	ft-k	transferred by flexure				
		116.30	ft-k	transferred by shear				
Floor 4	b_1	62	in			26	1.5h	
	b_2	26	in		26			b_1
	γ_f	0.49						
						b_2	1.5h	
	$\gamma_f M$	173.14	ft-k	transferred by flexure				
		178.25	ft-k	transferred by shear				
Floor 3	b_1	62	in					
	b_2	26	in					
	γ_f	0.49						
	$\gamma_f M$	249.04	ft-k	transferred by flexure				
		256.38	ft-k	transferred by shear				
Floor 2	b_1	66	in			30	1.5h	
	b_2	30	in		30			b_1
	γ_f	0.50						
						b_2	1.5h	
	$\gamma_f M$	444.81	ft-k	transferred by flexure				
		439.84	ft-k	transferred by shear				
Floor 1	b_1	66	in					
	b_2	30	in					
	γ_f	0.50						
	$\gamma_f M$	551.38	ft-k	transferred by flexure				
		545.22	ft-k	transferred by shear				

ext. cols.

$\gamma_f=1/(1+(2/3)(\sqrt{(b_1/b_2)}))$

Floor 6	b_1	38	in			24	1.5h	
	b_2	24	in		20			b_1
	γ_f	0.54						
						b_2		
	$\gamma_f M$	67.15	ft-k	transferred by flexure				
		56.33	ft-k	transferred by shear				
Floor 5	b_1	38	in					
	b_2	24	in					
	γ_f	0.54						
	$\gamma_f M$	121.68	ft-k	transferred by flexure				
		102.07	ft-k	transferred by shear				
Floor 4	b_1	38	in			34	1.5h	
	b_2	34	in		20			b_1
	γ_f	0.59						
						b_2		
	$\gamma_f M$	206.12	ft-k	transferred by flexure				
		145.27	ft-k	transferred by shear				
Floor 3	b_1	38	in					
	b_2	34	in					
	γ_f	0.59						
	$\gamma_f M$	296.47	ft-k	transferred by flexure				
		208.95	ft-k	transferred by shear				
Floor 2	b_1	38	in					
	b_2	34	in					
	γ_f	0.59						
	$\gamma_f M$	518.92	ft-k	transferred by flexure				
		365.73	ft-k	transferred by shear				
Floor 1	b_1	38	in					
	b_2	34	in					
	γ_f	0.59						
	$\gamma_f M$	643.24	ft-k	transferred by flexure				
		453.35	ft-k	transferred by shear				

C.8 Clinic (E-W) 110mph

Grid 10 Clinic

ext. col — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 6	36 in	30 in	0.58	103.00 ft-k	75.22 ft-k
Floor 5	36 in	30 in	0.58	138.28 ft-k	100.98 ft-k
Floor 4	36 in	30 in	0.58	217.15 ft-k	158.59 ft-k
Floor 3	36 in	30 in	0.58	312.34 ft-k	228.10 ft-k
Floor 2	36 in	30 in	0.58	546.71 ft-k	399.26 ft-k
Floor 1	36 in	30 in	0.58	677.69 ft-k	494.91 ft-k

int. col — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 6	58 in	22 in	0.48	85.58 ft-k	92.64 ft-k
Floor 5	58 in	22 in	0.48	114.89 ft-k	124.37 ft-k
Floor 4	62 in	26 in	0.49	185.14 ft-k	190.60 ft-k
Floor 3	62 in	26 in	0.49	266.30 ft-k	274.15 ft-k
Floor 2	66 in	30 in	0.50	475.64 ft-k	470.33 ft-k
Floor 1	66 in	30 in	0.50	589.59 ft-k	583.01 ft-k

int. col. — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 6	62 in	26 in	0.49	87.81 ft-k	90.40 ft-k
Floor 5	62 in	26 in	0.49	117.89 ft-k	121.37 ft-k
Floor 4	62 in	26 in	0.49	185.14 ft-k	190.60 ft-k
Floor 3	62 in	26 in	0.49	266.30 ft-k	274.15 ft-k
Floor 2	66 in	30 in	0.50	475.64 ft-k	470.33 ft-k
Floor 1	66 in	30 in	0.50	589.59 ft-k	583.01 ft-k

int. col. — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 6	51.5 in	26 in	0.52	91.95 ft-k	86.27 ft-k
Floor 5	51.5 in	26 in	0.52	123.44 ft-k	115.82 ft-k
Floor 4	51.5 in	26 in	0.52	193.86 ft-k	181.89 ft-k
Floor 3	51.5 in	26 in	0.52	278.83 ft-k	261.62 ft-k
Floor 2	53.5 in	30 in	0.53	500.44 ft-k	445.53 ft-k
Floor 1	71.5 in	30 in	0.49	577.86 ft-k	594.74 ft-k

int. col. — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 1	58 in	22 in	0.48	563.08 ft-k	609.52 ft-k

ext. col. — $\gamma_f=1/(1+(2/3)(\sqrt{b_1/b_2}))$

Floor	b_1	b_2	γ_f	$\gamma_f M$ (transferred by flexure)	transferred by shear
Floor 1	40 in	22 in	0.53	617.50 ft-k	555.09 ft-k

Appendix D: Combined Shear & Moment Transfer (Slab-Column Connection Shear Check)

D.1 Hand Calculation

Caitlin Behm	AE Senior Thesis	Combined Shear & Moment Transfer	1/1

combined shear & moment transfer in two-way slabs

$v = \frac{\gamma_v (M_{u_1} - M_{u_2})c}{J_c}$ ⇒ shear due to unbalanced moment

$v = \frac{V_u}{b_o d}$ ⇒ shear stresses due to V_u

Traditional ACI commentary Design Method

$$v_u = \frac{V_u}{b_o d} \pm \frac{\gamma_v (M_{u_1} - M_{u_2})c}{J_c}$$

b_o → length of critical shear perimeter
d → effective slab depth
J_c → effective polar moment of inertia for critical shear section
V_u → factored shear being transferred from slab to column
c → measurement from the centroid of the critical shear perimeter to the edge of the perimeter where the stress, v_u, is being calculated.
γ_v → $1 - \gamma_F$
γ_f → $1 / [1 + 2/3\sqrt{b_1/b_2}]$
M_u → factored moment being transferred at the connection.

$$J_c = 2\left[\frac{b_1 d^3}{12} + \frac{d b_1^3}{12}\right] + 2(b_2 d)\left[\frac{b_1}{2}\right]^2$$

$b_1 = c_1 + 2(d/2)$ (⊥ to axis of bending)
$b_2 = c_2 + 2(d/2)$ (∥ to axis of bending)
c_1 = width of column ⊥ to axis of bending
c_2 = width of column ∥ to axis of bending

} Int. columns

$$J_c = 2\left[\frac{b_1 d^3}{12} + \frac{d b_1^3}{12} + (b_1 d)\left[\frac{b_1}{2} - C_{AB}^2\right]\right] + b_2 d\, C_{AB}^2$$

$$C_{AB} = \frac{2(b_1 d)(b_1/2)}{2(b_1 d) + (b_2 d)}$$

} edge columns

$V_u \leq \phi 4\sqrt{f'_c}$
↳ Concrete capacity

See Excel spreadsheet for complete calculations

TOPS 35502

D.2 Hospital 157mph

Hospital (N-S)		Column BY	Column BZ	Column CA	Column CB	Column CC	Column CD	Column CE	Column CF	Column CG	Column CH	Column CI
Level 6	b_o	144	160	160	160	160	160	160	160	160	144	
	d	12	12	12	12	12	12	12	12	12	12	
	c	32	17	17	17	17	17	17	17	17	32	
	γ_v	0.41	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.41	
	M_u	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	77733.11243	324224	324224	324224	324224	324224	324224	324224	324224	77733.11243	
	b_1	32	34	34	34	34	34	34	34	34	32	
	b_2	46	34	34	34	34	34	34	34	34	46	
	c_1	20	22	22	22	22	22	22	22	22	20	
	c_2	34	22	22	22	22	22	22	22	22	34	
	V_u	0.221131009	0.085507872	0.085507872	0.085507872	0.085507872	0.085507872	0.085507872	0.085507872	0.085507872	0.221131009	
Level 5	b_o	144	160	160	160	160	160	160	160	176	144	
	d	12	12	12	12	12	12	12	12	12	12	
	c	32	17	17	17	17	17	17	17	17	32	
	γ_v	0.41	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.41	
	M_u	1875	1875	1875	1875	1875	1875	1875	1875	1875	1875	
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	77733.11243	324224	324224	324224	324224	324224	324224	324224	324224	77733.11243	
	b_1	32	34	34	34	34	34	34	34	34	32	
	b_2	46	34	34	34	34	34	34	34	34	46	
	c_1	20	22	22	22	22	22	22	22	22	20	
	c_2	34	22	22	22	22	22	22	22	22	34	
	V_u	0.354535188	0.106569369	0.106569369	0.106569369	0.106569369	0.106569369	0.106569369	0.106569369	0.101526756	0.354535188	
Level 4	b_o	144	176	176	176	176	176	176	176	176	144	
	d	12	12	12	12	12	12	12	12	12	12	
	c	32	19	19	19	19	19	19	19	19	32	
	γ_v	0.41	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.41	
	M_u	2861	2861	2861	2861	2861	2861	2861	2861	2861	2861	
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	77733.11243	449920	449920	449920	449920	449920	449920	449920	449920	77733.11243	
	b_1	32	38	38	38	38	38	38	38	38	32	
	b_2	46	38	38	38	38	38	38	38	38	46	
	c_1	20	26	26	26	26	26	26	26	26	20	
	c_2	34	26	26	26	26	26	26	26	26	34	
	V_u	0.524838839	0.111723085	0.111723085	0.111723085	0.111723085	0.111723085	0.111723085	0.111723085	0.111723085	0.524838839	
Level 3	b_o	144	176	176	176	176	176	176	176	176	144	
	d	12	12	12	12	12	12	12	12	12	12	
	c	32	19	19	19	19	19	19	19	19	32	
	γ_v	0.41	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.41	
	M_u	4041	4041	4041	4041	4041	4041	4041	4041	4041	4041	
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	77733.11243	449920	449920	449920	449920	449920	449920	449920	449920	77733.11243	
	b_1	32	38	38	38	38	38	38	38	38	32	
	b_2	46	38	38	38	38	38	38	38	38	46	
	c_1	20	26	26	26	26	26	26	26	26	20	
	c_2	34	26	26	26	26	26	26	26	26	34	
	V_u	0.72852133	0.136997796	0.136997796	0.136997796	0.136997796	0.136997796	0.136997796	0.136997796	0.136997796	0.72852133	
Level 2	b_o	156	192	192	192	192	192	192	192	192	144	
	d	12	12	12	12	12	12	12	12	12	12	
	c	30	21	21	21	21	21	21	21	21	32	
	γ_v	0.46	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.41	
	M_u	7827	7827	7827	7827	7827	7827	7827	7827	7827	7827	
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	125874	604800	604800	604800	604800	604800	604800	604800	604800	77733.11243	
	b_1	42	42	42	42	42	42	42	42	42	32	
	b_2	42	42	42	42	42	42	42	42	42	46	
	c_1	30	30	30	30	30	30	30	30	30	20	
	c_2	30	30	30	30	30	30	30	30	30	34	
	V_u	0.875976794	0.181339717	0.181339717	0.181339717	0.181339717	0.181339717	0.181339717	0.181339717	0.181339717	1.381983237	
Level 1	b_o	156	192	192	192	192	192	192	192	192	192	124
	d	12	12	12	12	12	12	12	12	12	12	12
	c	30	21	21	21	21	21	21	21	21	21	22
	γ_v	0.46	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.47
	M_u	13283	13283	13283	13283	13283	13283	13283	13283	13283	13283	13283
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	125874	604800	604800	604800	604800	604800	604800	604800	604800	604800	72794
	b_1	42	42	42	42	42	42	42	42	42	42	34
	b_2	42	42	42	42	42	42	42	42	42	42	34
	c_1	30	30	30	30	30	30	30	30	30	30	22
	c_2	30	30	30	30	30	30	30	30	30	30	22
	V_u	1.466782068	0.275532262	0.275532262	0.275532262	0.275532262	0.275532262	0.275532262	0.275532262	0.275532262	0.252455005	1.925732996

Hospital (E-W)		Column AQ	Column AR	Column AS	Column AT	Column AU	Column AV	Column AW
Level 6	b_o				124	124	160	140
	d				12	12	12	12
	c				22	17	17	26
	γ_v				0.47	0.47	0.52	0.46
	M_u				2885	2885	2885	2885
	V_u				53.33	106.5	106.5	53.33
	J_c				72794	324224	324224	96862
	b_1				34	34	34	38
	b_2				34	34	34	38
	c_1				22	22	22	26
	c_2				22	22	22	26
	V_u				0.454172192	0.143192812	0.134110463	0.391944326
Level 5	b_o				124	124	160	140
	d				12	12	12	12
	c				22	17	17	26
	γ_v				0.47	0.47	0.52	0.46
	M_u				5227	5227	5227	5227
	V_u				53.33	106.5	106.5	53.33
	J_c				72794	324224	324224	96862
	b_1				34	34	34	38
	b_2				34	34	34	38
	c_1				22	22	22	26
	c_2				22	22	22	26
	V_u				0.793622231	0.201308094	0.197923234	0.684224041
Level 4	b_o				140	140	176	156
	d				12	12	12	12
	c				26	19	19	30
	γ_v				0.46	0.46	0.51	0.46
	M_u				8205	8205	8205	8205
	V_u				53.33	106.5	106.5	53.33
	J_c				96862	449920	449920	125874
	b_1				38	38	38	42
	b_2				38	38	38	42
	c_1				26	26	26	30
	c_2				26	26	26	30
	V_u				1.055999753	0.224324306	0.226190176	0.916946697
Level 3	b_o	124	160	160	176	176	176	156
	d	12	12	12	12	12	12	12
	c	21	17	17	19	19	19	30
	γ_v	0.49	0.52	0.52	0.51	0.51	0.51	0.46
	M_u	11800	11800	11800	11800	11800	11800	11800
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33
	J_c	75643.34948	324224	324224	449920	449920	449920	125874
	b_1	36	34	34	38	38	38	42
	b_2	32	34	34	38	38	38	42
	c_1	24	22	22	26	26	26	30
	c_2	20	22	22	26	26	26	30
	V_u	1.626361964	0.37705984	0.37705984	0.278015818	0.303191008	0.303191008	1.3061733
Level 2	b_o	140	176	160	192	192	176	172
	d	12	12	12	12	12	12	12
	c	26	19	17	21	21	19	34
	γ_v	0.46	0.51	0.52	0.50	0.50	0.51	0.45
	M_u	20652	20652	20652	20652	20652	20652	20652
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33
	J_c	96862	449920	324224	604800	604800	449920	160310
	b_1	38	38	34	42	42	38	46
	b_2	38	38	34	42	42	38	46
	c_1	26	26	22	30	30	26	34
	c_2	26	26	22	30	30	26	34
	V_u	2.609831576	0.492830386	0.618336779	0.402755991	0.402755991	0.492830386	1.979945576
Level 1	b_o	140	176	176	192	192	176	172
	d	12	12	12	12	12	12	12
	c	26	19	19	21	21	23	34
	γ_v	0.46	0.51	0.51	0.50	0.50	0.51	0.45
	M_u	25600	25600	25600	25600	25600	25600	25600
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33
	J_c	96862	449920	449920	604800	604800	791936	160310
	b_1	38	38	38	42	42	46	46
	b_2	38	38	38	42	42	46	46
	c_1	26	26	26	30	30	34	34
	c_2	26	26	26	30	30	34	34
	V_u	3.227415039	0.59880877	0.59880877	0.488163598	0.488163598	0.427566609	2.448053971

D.3 Clinic 157mph

Clinic (N-S)						
		Column A	Column B	Column C	Column D	
Level 6	b_o	124	160	160	124	
	d	12	12	12	12	
	c	24	17	17	24	
	γ_v	0.46	0.52	0.52	0.46	
	M_u	3018	3018	3018	3018	
	V_u	53.33	106.5	106.5	53.33	
	J_c	67991.47405	324224	324224	67991.47405	
	b_1	32	34	34	32	
	b_2	36	34	34	36	
	c_1	20	22	22	20	
	c_2	24	22	22	24	
	V_u	0.518428236	0.137732013	0.137732013	0.518428236	k
Level 5	b_o	124	160	160	124	
	d	12	12	12	12	
	c	24	17	17	24	
	γ_v	0.46	0.52	0.52	0.46	
	M_u	5467	5467	5467	5467	
	V_u	53.33	106.5	106.5	53.33	
	J_c	67991.47405	324224	324224	67991.47405	
	b_1	32	34	34	32	
	b_2	36	34	34	36	
	c_1	20	22	22	20	
	c_2	24	22	22	24	
	V_u	0.909881598	0.204460192	0.204460192	0.909881598	k
Level 4	b_o	144	176	176	144	
	d	12	12	12	12	
	c	32	19	19	32	
	γ_v	0.41	0.51	0.51	0.41	
	M_u	8582	8582	8582	8582	
	V_u	53.33	106.5	106.5	53.33	
	J_c	77733.11243	449920	449920	77733.11243	
	b_1	32	38	38	32	
	b_2	46	38	38	46	
	c_1	20	26	26	20	
	c_2	34	26	26	34	
	V_u	1.512324466	0.23425897	0.23425897	1.512324466	k
Level 3	b_o	144	176	176	144	
	d	12	12	12	12	
	c	32	19	19	32	
	γ_v	0.41	0.51	0.51	0.41	
	M_u	12342	12342	12342	12342	
	V_u	53.33	106.5	106.5	53.33	
	J_c	77733.11243	449920	449920	77733.11243	
	b_1	32	38	38	32	
	b_2	46	38	38	46	
	c_1	20	26	26	20	
	c_2	34	26	26	34	
	V_u	2.161417245	0.314804099	0.314804099	2.161417245	k
Level 2	b_o	144	192	192	144	
	d	12	12	12	12	
	c	32	21	21	32	
	γ_v	0.41	0.50	0.50	0.41	
	M_u	21600	21600	21600	21600	
	V_u	53.33	106.5	106.5	53.33	
	J_c	77733.11243	604800	604800	77733.11243	
	b_1	32	42	42	32	
	b_2	46	42	42	46	
	c_1	20	30	30	20	
	c_2	34	30	30	34	
	V_u	3.759693125	0.41911715	0.41911715	3.759693125	k
Level 1	b_o	144	192	192	144	
	d	12	12	12	12	
	c	32	21	21	32	
	γ_v	0.41	0.50	0.50	0.41	
	M_u	26773	26773	26773	26773	
	V_u	53.33	106.5	106.5	53.33	
	J_c	77733.11243	604800	604800	77733.11243	
	b_1	32	42	42	32	
	b_2	46	42	42	46	
	c_1	20	30	30	20	
	c_2	34	30	30	34	
	V_u	4.652771132	0.508427372	0.508427372	4.652771132	k

Clinic (E-W)										
		Column BG	Column BH	Column BI	Column BJ	Column BK	Column BL	Column BM	Column BN	Column BO
Level 6	b_o	132	160	160	176	160	160	155		
	d	12	12	12	12	12	12	12		
	c	29	17	17	19	17	17	27		
	γ_v	0.42	0.52	0.52	0.51	0.52	0.52	0.48		
	M_u	4356	4356	4356	4356	4356	4356	4356		
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33		
	J_c	65002.5	324224	324224	449920	324224	324224	128600.3294		
	b_1	30	34	34	38	34	34	45.5		
	b_2	42	34	34	38	34	34	38		
	c_1	18	22	22	26	22	22	33.5		
	c_2	30	22	22	26	22	22	26		
	V_u	0.848172516	0.174179777	0.174179777	0.14373089	0.174179777	0.174179777	0.464022923		
Level 5	b_o	132	160	160	176	160	160	155		
	d	12	12	12	12	12	12	12		
	c	29	17	17	19	17	17	27		
	γ_v	0.42	0.52	0.52	0.51	0.52	0.52	0.48		
	M_u	5846	5846	5846	5846	5846	5846	5846		
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33		
	J_c	65002.5	324224	324224	449920	324224	324224	128600.3294		
	b_1	30	34	34	38	34	34	45.5		
	b_2	42	34	34	38	34	34	38		
	c_1	18	22	22	26	22	22	33.5		
	c_2	30	22	22	26	22	22	26		
	V_u	1.126783741	0.214786331	0.214786331	0.175646919	0.214786331	0.214786331	0.61294		
Level 4	b_o	132	176	176	176	176	176	155		
	d	12	12	12	12	12	12	12		
	c	29	19	19	19	19	19	27		
	γ_v	0.42	0.51	0.51	0.51	0.51	0.51	0.48		
	M_u	9176	9176	9176	9176	9176	9176	9176		
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33		
	J_c	65002.5	449920	449920	449920	449920	449920	128600.3294		
	b_1	30	38	38	38	38	38	45.5		
	b_2	42	38	38	38	38	38	38		
	c_1	18	26	26	26	26	26	33.5		
	c_2	30	26	26	26	26	26	26		
	V_u	1.749659794	0.246999859	0.246999859	0.246999859	0.246999859	0.246999859	0.945865858		
Level 3	b_o	132	176	176	192	176	176	155		
	d	12	12	12	12	12	12	12		
	c	29	19	19	19	19	19	27		
	γ_v	0.42	0.51	0.51	0.50	0.51	0.51	0.48		
	M_u	13197	13197	13197	13197	13197	13197	13197		
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33		
	J_c	65002.5	449920	449920	449920	449920	449920	128600.3294		
	b_1	30	38	38	38	38	38	45.5		
	b_2	42	38	38	38	38	38	38		
	c_1	18	26	26	26	26	26	33.5		
	c_2	30	26	26	26	26	26	26		
	V_u	2.501510182	0.333127324	0.333127324	0.323311939	0.333127324	0.333127324	1.347728209		
Level 2	b_o	132	192	192	192	192	192	167		
	d	12	12	12	12	12	12	12		
	c	29	21	21	21	21	21	30		
	γ_v	0.42	0.50	0.50	0.50	0.50	0.50	0.47		
	M_u	23097	23097	23097	23097	23097	23097	23097		
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33		
	J_c	65002.5	604800	604800	604800	604800	604800	154051.2688		
	b_1	30	42	42	42	42	42	47.5		
	b_2	42	42	42	42	42	42	42		
	c_1	18	30	30	30	30	30	35.5		
	c_2	30	30	30	30	30	30	30		
	V_u	4.352808455	0.444961233	0.444961233	0.444961233	0.444961233	0.444961233	2.156481051		
Level 1	b_o	132	192	192	192	192	192	203	160	124
	d	12	12	12	12	12	12	12	12	12
	c	29	21	21	21	21	21	23.75	17	22
	γ_v	0.42	0.50	0.50	0.50	0.50	0.50	0.51	0.52	0.47
	M_u	28629	28629	28629	28629	28629	28629	28629	28629	28629
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33
	J_c	65002.5	604800	604800	604800	604800	604800	796598.75	324224	72794
	b_1	30	42	42	42	42	42	47.5	34	34
	b_2	42	42	42	42	42	42	42	34	34
	c_1	18	30	30	30	30	30	35.5	22	22
	c_2	30	30	30	30	30	30	30	22	22
	V_u	5.387269272	0.540461271	0.540461271	0.540461271	0.540461271	0.540461271	0.45480922	0.83573632	4.186449024

D.4 Hospital 110mph

Hospital (N-S)		Column BY	Column BZ	Column CA	Column CB	Column CC	Column CD	Column CE	Column CF	Column CG	Column CH	Column CI
Level 6	b_o	144	160	160	160	160	160	160	160	160	144	
	d	12	12	12	12	12	12	12	12	12	12	
	c	32	17	17	17	17	17	17	17	17	32	
	γ_v	0.41	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.41	
	M_u	540	540	540	540	540	540	540	540	540	540	
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	77733.11243	324224	324224	324224	324224	324224	324224	324224	324224	77733.11243	
	b_1	32	34	34	34	34	34	34	34	34	32	
	b_2	46	34	34	34	34	34	34	34	34	46	
	c_1	20	22	22	22	22	22	22	22	22	20	
	c_2	34	22	22	22	22	22	22	22	22	34	
	v_u	0.124123755	0.070192625	0.070192625	0.070192625	0.070192625	0.070192625	0.070192625	0.070192625	0.070192625	0.124123755	
Level 5	b_o	144	160	160	160	160	160	160	160	176	144	
	d	12	12	12	12	12	12	12	12	12	12	
	c	32	17	17	17	17	17	17	17	17	32	
	γ_v	0.41	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.41	
	M_u	919	919	919	919	919	919	919	919	919	919	
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	77733.11243	324224	324224	324224	324224	324224	324224	324224	324224	77733.11243	
	b_1	32	34	34	34	34	34	34	34	34	32	
	b_2	46	34	34	34	34	34	34	34	34	46	
	c_1	20	22	22	22	22	22	22	22	22	20	
	c_2	34	22	22	22	22	22	22	22	22	34	
	v_u	0.189532468	0.080519179	0.080519179	0.080519179	0.080519179	0.080519179	0.080519179	0.080519179	0.075476565	0.189532468	
Level 4	b_o	144	176	176	176	176	176	176	176	176	144	
	d	12	12	12	12	12	12	12	12	12	12	
	c	32	19	19	19	19	19	19	19	19	32	
	γ_v	0.41	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.41	
	M_u	1403	1403	1403	1403	1403	1403	1403	1403	1403	1403	
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	77733.11243	449920	449920	449920	449920	449920	449920	449920	449920	77733.11243	
	b_1	32	38	38	38	38	38	38	38	38	32	
	b_2	46	38	38	38	38	38	38	38	38	46	
	c_1	20	26	26	26	26	26	26	26	26	20	
	c_2	34	26	26	26	26	26	26	26	26	34	
	v_u	0.273059047	0.080480039	0.080480039	0.080480039	0.080480039	0.080480039	0.080480039	0.080480039	0.080480039	0.273059047	
Level 3	b_o	144	176	176	176	176	176	176	176	176	144	
	d	12	12	12	12	12	12	12	12	12	12	
	c	32	19	19	19	19	19	19	19	19	32	
	γ_v	0.41	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.41	
	M_u	1982	1982	1982	1982	1982	1982	1982	1982	1982	1982	
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	77733.11243	449920	449920	449920	449920	449920	449920	449920	449920	77733.11243	
	b_1	32	38	38	38	38	38	38	38	38	32	
	b_2	46	38	38	38	38	38	38	38	38	46	
	c_1	20	26	26	26	26	26	26	26	26	20	
	c_2	34	26	26	26	26	26	26	26	26	34	
	v_u	0.372971987	0.092878113	0.092878113	0.092878113	0.092878113	0.092878113	0.092878113	0.092878113	0.092878113	0.372971987	
Level 2	b_o	156	192	192	192	192	192	192	192	192	144	
	d	12	12	12	12	12	12	12	12	12	12	
	c	30	21	21	21	21	21	21	21	21	32	
	γ_v	0.46	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.41	
	M_u	3838	3838	3838	3838	3838	3838	3838	3838	3838	3838	
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33	
	J_c	125874	604800	604800	604800	604800	604800	604800	604800	604800	77733.11243	
	b_1	42	42	42	42	42	42	42	42	42	32	
	b_2	42	42	42	42	42	42	42	42	42	46	
	c_1	30	30	30	30	30	30	30	30	30	20	
	c_2	30	30	30	30	30	30	30	30	30	34	
	v_u	0.444055067	0.1124781	0.1124781	0.1124781	0.1124781	0.1124781	0.1124781	0.1124781	0.1124781	0.693385727	
Level 1	b_o	156	192	192	192	192	192	192	192	192	192	124
	d	12	12	12	12	12	12	12	12	12	12	12
	c	30	21	21	21	21	21	21	21	21	21	22
	γ_v	0.46	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.47
	M_u	6513	6513	6513	6513	6513	6513	6513	6513	6513	6513	6513
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33
	J_c	125874	604800	604800	604800	604800	604800	604800	604800	604800	604800	72794
	b_1	42	42	42	42	42	42	42	42	42	42	34
	b_2	42	42	42	42	42	42	42	42	42	42	34
	c_1	30	30	30	30	30	30	30	30	30	30	22
	c_2	30	30	30	30	30	30	30	30	30	30	22
	v_u	0.733767839	0.158667233	0.158667233	0.158667233	0.158667233	0.158667233	0.158667233	0.158667233	0.158667233	0.158667233	0.980139585

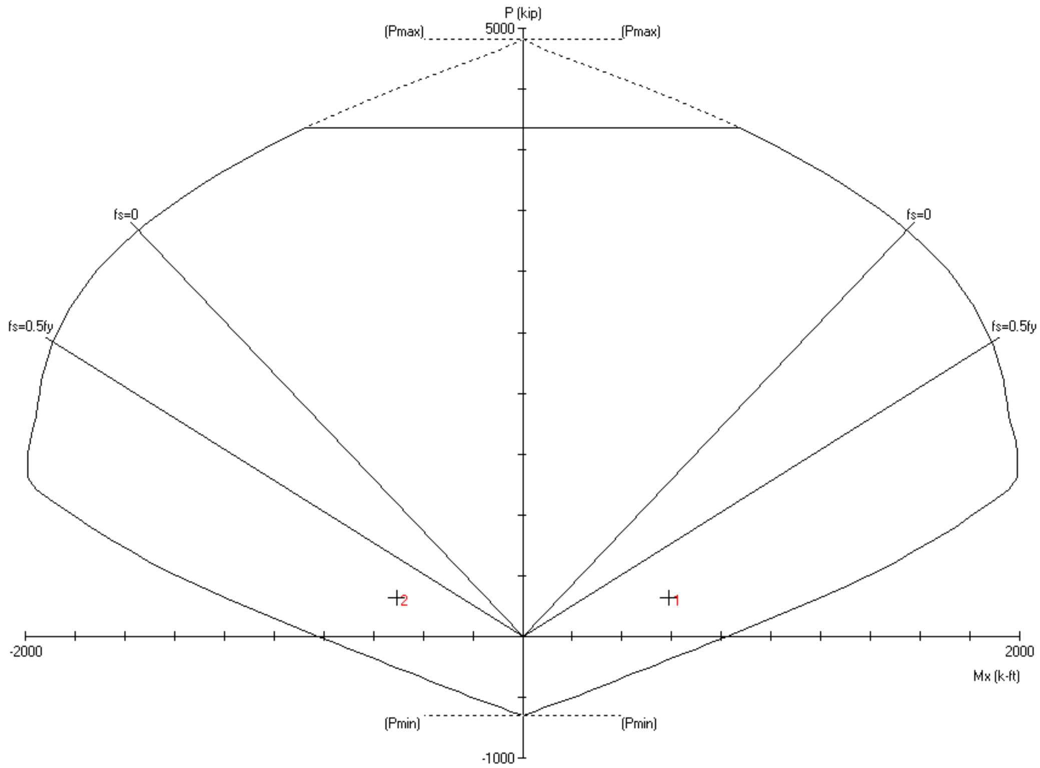
Hospital (E-W)		Column AQ	Column AR	Column AS	Column AT	Column AU	Column AV	Column AW
Level 6	b_o				124	124	160	140
	d				12	12	12	12
	c				22	17	17	26
	γ_v				0.47	0.47	0.52	0.46
	M_u				1414	1414	1414	1414
	V_u				53.33	106.5	106.5	53.33
	J_c				72794	324224	324224	96862
	b_1				34	34	34	38
	b_2				34	34	34	38
	c_1				22	22	22	26
	c_2				22	22	22	26
	v_u				0.240854434	0.10667191	0.094009136	0.20826942
Level 5	b_o				124	124	160	140
	d				12	12	12	12
	c				22	17	17	26
	γ_v				0.47	0.47	0.52	0.46
	M_u				2562	2562	2562	2562
	V_u				53.33	106.5	106.5	53.33
	J_c				72794	324224	324224	96862
	b_1				34	34	34	38
	b_2				34	34	34	38
	c_1				22	22	22	26
	c_2				22	22	22	26
	v_u				0.407317411	0.135171075	0.125302294	0.351600533
Level 4	b_o				140	140	176	156
	d				12	12	12	12
	c				26	19	19	30
	γ_v				0.46	0.46	0.51	0.46
	M_u				4023	4023	4023	4023
	V_u				53.33	106.5	106.5	53.33
	J_c				96862	449920	449920	125874
	b_1				38	38	38	42
	b_2				38	38	38	42
	c_1				26	26	26	30
	c_2				26	26	26	30
	v_u				0.533913622	0.142293933	0.136599298	0.464079477
Level 3	b_o	124	160	160	176	176	176	156
	d	12	12	12	12	12	12	12
	c	21	17	17	19	19	19	30
	γ_v	0.49	0.52	0.52	0.51	0.51	0.51	0.46
	M_u	5786	5786	5786	5786	5786	5786	5786
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33
	J_c	75643.34948	324224	324224	449920	449920	449920	125874
	b_1	36	34	34	38	38	38	42
	b_2	32	34	34	38	38	38	42
	c_1	24	22	22	26	26	26	30
	c_2	20	22	22	26	26	26	30
	v_u	0.815752739	0.213160995	0.213160995	0.149194244	0.174369433	0.174369433	0.655001327
Level 2	b_o	140	176	160	192	192	176	172
	d	12	12	12	12	12	12	12
	c	26	19	17	21	21	19	34
	γ_v	0.46	0.51	0.52	0.50	0.50	0.51	0.45
	M_u	10127	10127	10127	10127	10127	10127	10127
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33
	J_c	96862	449920	324224	604800	604800	449920	160310
	b_1	38	38	34	42	42	38	46
	b_2	38	38	34	42	42	38	46
	c_1	26	26	22	30	30	26	34
	c_2	26	26	22	30	30	26	34
	v_u	1.295934673	0.26736342	0.331476635	0.221052954	0.221052954	0.26736342	0.984053998
Level 1	b_o	140	176	176	192	192	176	172
	d	12	12	12	12	12	12	12
	c	26	19	19	21	21	23	34
	γ_v	0.46	0.51	0.51	0.50	0.50	0.51	0.45
	M_u	12553	12553	12553	12553	12553	12553	12553
	V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33
	J_c	96862	449920	449920	604800	604800	791936	160310
	b_1	38	38	38	42	42	46	46
	b_2	38	38	38	42	42	46	46
	c_1	26	26	26	30	30	34	34
	c_2	26	26	26	30	30	34	34
	v_u	1.598768461	0.319330219	0.319330219	0.262932814	0.262932814	0.235360171	1.213592266

D.5 Clinic 110mph

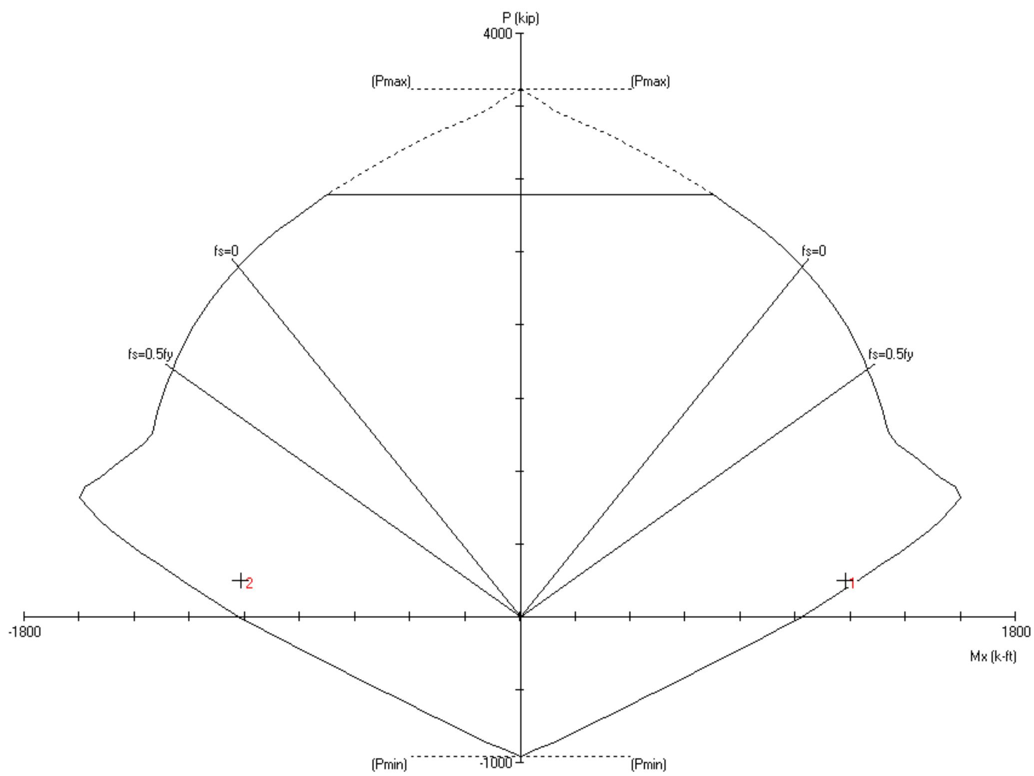
Clinic (N-S)							Clinic (E-W)										
		Column A	Column B	Column C	Column D				Column BG	Column BH	Column BI	Column BJ	Column BK	Column BL	Column BM	Column BN	Column BO
Level 6	b_o	124	160	160	124		Level 6	b_o	132	160	160	176	160	160	155		
	d	12	12	12	12			d	12	12	12	12	12	12	12		
	c	24	17	17	24			c	29	17	17	19	17	17	27		
	γ_v	0.46	0.52	0.52	0.46			γ_v	0.42	0.52	0.52	0.51	0.52	0.52	0.48		
	M_u	1482	1482	3018	1482			M_u	2139	2139	2139	2139	2139	2139	2139		
	V_u	53.33	106.5	106.5	53.33			V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33		
	J_c	67991.47405	324224	324224	67991.47405			J_c	65002.5	324224	324224	449920	324224	324224	128600.3294		
	b_1	32	34	34	32			b_1	30	34	34	38	34	34	45.5		
	b_2	36	34	34	36			b_2	42	34	34	38	34	34	38		
	c_1	20	22	22	20			c_1	18	22	22	26	22	22	33.5		
	c_2	24	22	22	24			c_2	30	22	22	26	22	22	26		
	V_u	0.272737289	0.095850882	0.137732013	0.272737289	k		V_u	0.433588348	0.11375567	0.11375567	0.096238618	0.11375567	0.11375567	0.242428613		
Level 5	b_o	124	160	160	124		Level 5	b_o	132	160	160	176	160	160	155		
	d	12	12	12	12			d	12	12	12	12	12	12	12		
	c	24	17	17	24			c	29	17	17	19	17	17	27		
	γ_v	0.46	0.52	0.52	0.46			γ_v	0.42	0.52	0.52	0.51	0.52	0.52	0.48		
	M_u	2685	2685	5467	2685			M_u	2871	2871	2871	2871	2871	2871	2871		
	V_u	53.33	106.5	106.5	53.33			V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33		
	J_c	67991.47405	324224	324224	67991.47405			J_c	65002.5	324224	324224	449920	324224	324224	128600.3294		
	b_1	32	34	34	32			b_1	30	34	34	38	34	34	45.5		
	b_2	36	34	34	36			b_2	42	34	34	38	34	34	38		
	c_1	20	22	22	20			c_1	18	22	22	26	22	22	33.5		
	c_2	24	22	22	24			c_2	30	22	22	26	22	22	26		
	V_u	0.46513302	0.128647169	0.204460192	0.46513302	k		V_u	0.570561092	0.13371894	0.13371894	0.111929393	0.13371894	0.13371894	0.315640238		
Level 4	b_o	144	176	176	144		Level 4	b_o	132	176	176	176	176	176	155		
	d	12	12	12	12			d	12	12	12	12	12	12	12		
	c	32	19	19	32			c	29	19	19	19	19	19	27		
	γ_v	0.41	0.51	0.51	0.41			γ_v	0.42	0.51	0.51	0.51	0.51	0.51	0.48		
	M_u	4217	4217	8582	4217			M_u	4509	4509	4509	4509	4509	4509	4509		
	V_u	53.33	106.5	106.5	53.33			V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33		
	J_c	77733.11243	449920	449920	77733.11243			J_c	65002.5	449920	449920	449920	449920	449920	128600.3294		
	b_1	32	38	38	32			b_1	30	38	38	38	38	38	45.5		
	b_2	46	38	38	46			b_2	42	38	38	38	38	38	38		
	c_1	20	26	26	20			c_1	18	26	26	26	26	26	33.5		
	c_2	34	26	26	34			c_2	30	26	26	26	26	26	26		
	V_u	0.758789897	0.140753786	0.23425897	0.758789897	k		V_u	0.876833479	0.147014118	0.147014118	0.147014118	0.147014118	0.147014118	0.479342144		
Level 3	b_o	144	176	176	144		Level 3	b_o	132	176	176	176	176	176	155		
	d	12	12	12	12			d	12	12	12	12	12	12	12		
	c	32	19	19	32			c	29	19	19	19	19	19	27		
	γ_v	0.41	0.51	0.51	0.41			γ_v	0.42	0.51	0.51	0.51	0.51	0.51	0.48		
	M_u	6065	6065	12342	6065			M_u	6485	6485	6485	6485	6485	6485	6485		
	V_u	53.33	106.5	106.5	53.33			V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33		
	J_c	77733.11243	449920	449920	77733.11243			J_c	65002.5	449920	449920	449920	449920	449920	128600.3294		
	b_1	32	38	38	32			b_1	30	38	38	38	38	38	45.5		
	b_2	46	38	38	46			b_2	42	38	38	38	38	38	38		
	c_1	20	26	26	20			c_1	18	26	26	26	26	26	33.5		
	c_2	34	26	26	34			c_2	30	26	26	26	26	26	26		
	V_u	1.077869636	0.180348001	0.314804099	1.077869636	k		V_u	1.2464266	0.189352486	0.189352486	0.189352486	0.189352486	0.189352486	0.676888841		
Level 2	b_o	144	192	192	144		Level 2	b_o	132	192	192	192	192	192	167		
	d	12	12	12	12			d	12	12	12	12	12	12	12		
	c	32	21	21	32			c	29	21	21	21	21	21	30		
	γ_v	0.41	0.50	0.50	0.41			γ_v	0.42	0.50	0.50	0.50	0.50	0.50	0.47		
	M_u	10616	10616	21600	10616			M_u	11352	11352	11352	11352	11352	11352	11352		
	V_u	53.33	106.5	106.5	53.33			V_u	53.33	106.5	106.5	106.5	106.5	106.5	53.33		
	J_c	77733.11243	604800	604800	77733.11243			J_c	65002.5	604800	604800	604800	604800	604800	154051.2688		
	b_1	32	42	42	32			b_1	30	42	42	42	42	42	47.5		
	b_2	46	42	42	46			b_2	42	42	42	42	42	42	42		
	c_1	20	30	30	20			c_1	18	30	30	30	30	30	35.5		
	c_2	34	30	30	34			c_2	30	30	30	30	30	30	30		
	V_u	1.86348481	0.229491179	0.41911715	1.86348481	k		V_u	2.156412187	0.242192868	0.242192868	0.242192868	0.242192868	0.242192868	1.073386648		
Level 1	b_o	144	192	192	144		Level 1	b_o	132	192	192	192	192	192	203	160	124
	d	12	12	12	12			d	12	12	12	12	12	12	12	12	12
	c	32	21	21	32			c	29	21	21	21	21	21	23.75	17	22
	γ_v	0.41	0.50	0.50	0.41			γ_v	0.42	0.50	0.50	0.50	0.50	0.50	0.51	0.52	0.47
	M_u	13159	13159	26773	13159			M_u	14071	14071	14071	14071	14071	14071	14071	14071	14071
	V_u	53.33	106.5	106.5	53.33			V_u	53.33	106.5	106.5	106.5	106.5	106.5	106.5	106.5	53.33
	J_c	77733.11243	604800	604800	77733.11243			J_c	65002.5	604800	604800	604800	604800	604800	796598.75	324224	72794
	b_1	32	42	42	32			b_1	30	42	42	42	42	42	47.5	34	34
	b_2	46	42	42	46			b_2	42	42	42	42	42	42	42	34	34
	c_1	20	30	30	20			c_1	18	30	30	30	30	30	35.5	22	22
	c_2	34	30	30	34			c_2	30	30	30	30	30	30	30	22	22
	V_u	2.302543135	0.273398202	0.508427372	2.302543135	k		V_u	2.664977653	0.289142951	0.289142951	0.289142951	0.289142951	0.289142951	0.234672226	0.438972398	2.075875731

Appendix E: Column Interaction Diagrams

E.1 N-S Clinic Frame 10 Exterior Column Interaction Diagram



E.2 N-S Clinic Frame 10 Interior Column Interaction Diagram



Appendix F: Slab Capacity Check

F.1 Hand Calculation

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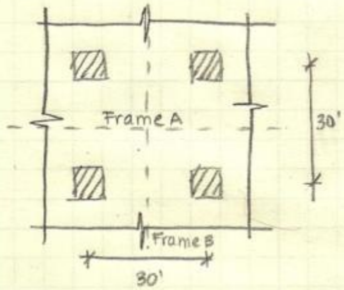
12" NW concrete elevated two-way flat plate



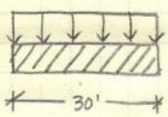
30"x30" columns
$f'_c = 5000$ psi
$f_y = 60{,}000$ psi

typical interior bay

For a generalized gravity spot check Direct Design Method will be used even though not all the requirements were met.

SDL = 12psf (typical floor)
DL = self weight of concrete
LL = 80psf

$LL_R: 80(0.25 + .15/\sqrt{2(30)(30)}) = 48$ psf

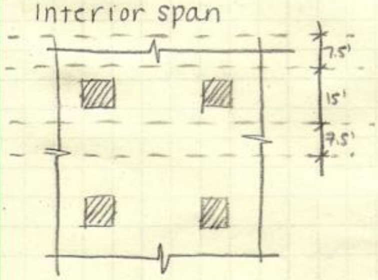


$W_u = 1.2W_D + 1.6W$
$W_u = 1.2[(12''/12'')(145pcf) + 12psf] + 1.6[48psf]$
$W_u = 265.2$ psf

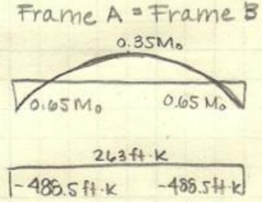
Slab thickness
$\ell_n/33$ (Table 9.5c w/o drop panel int. panels)
$(30' - 30''/12'') \times 12''/33 = 10''$ slab minimum
→ 12" slab used in design ✓

Frame A = Frame B b/c of symmetry
$M_o = 1/8\, w_u\, \ell_2\, \ell_n^2 = 1/8\,(0.265\,ksf)(30')(30' - 30''/12'')^2 = 751.5$ ft·k

Interior span



Frame A = Frame B



Column strip
$\ell_2/2 = 30'/2 = 15'$

Middle strip
$30' - 15' = 15'/2 = 7.5'$
* on each side of CS

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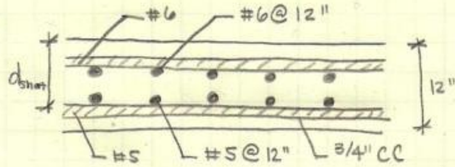
<u>Distribution of moments</u>
α = 0 b/c no beams
positive moment ⇒ 60%
negative moment ⇒ 75%



<u>Frame A = Frame B</u>

Total Moment	-488.5ft·k	263ft·k	-488.5ft·k
Moment in CS	-293.1 ft·k	197.3ft·k	-293.1ft·k
Moment in MS	-195.4ft·k	65.7ft·k	-195.4ft·k

$d_{short} = 12 - 3/4 - 0.5(0.625) = 10.94"$
$d_{long} = 12 - 3/4 - 0.625 - 0.5(0.625) = 10.31"$

<u>Reinforcement Design & Distribution</u>

Column Strip (Frame A = Frame B)

Description	Neg. Moment		Positive Moment	
width of strip (b)	180"		180"	
effective depth	10.94"	10.31"	10.94"	10.31"
$R = Mu/bd^2$	163.26	183.83	109.9	123.74
ρ (from Table A.5a)	0.0035	0.0035	0.0035	0.0035
Ⓐ $A_s = \rho bd$	6.89 in²	6.50 in²	6.89 in²	6.50 in²
Ⓑ $A_{s,min} = 0.0018bt$	3.89 in²	3.89 in²	3.89 in²	3.89 in²
N = larger A or B	6.89 in²	6.50 in²	6.89 in²	6.50 in²
N_{min} = width strip/2t	7.5 in²	7.5 in²	7.5 in²	7.5 in²

adequate reinforcing exceeding these values. See slab detail.

Middle strip (Frame A = Frame B)

Description	Neg. Moment		Positive Moment	
width of strip (b)	180"		180"	
effective depth	10.94"	10.31"	10.94"	10.31"
$R = Mu/bd^2$	108.84	122.55	36.60	41.21
ρ (from Table A.5a)	0.0035	0.0035	0.0035	0.0035
Ⓐ $A_s = \rho bd$	6.89 in²	6.50 in²	6.89 in²	6.50 in²
Ⓑ $A_{s,min} = 0.0018bt$	3.89 in²	3.89 in²	3.89 in²	3.89 in²
N = larger A or B	6.89 in²	6.50 in²	6.89 in²	6.50 in²
N_{min} = width strip/2t	7.5 in²	7.5 in²	7.5 in²	7.5 in²

adequate reinforcing exceeding these values, see slab detail

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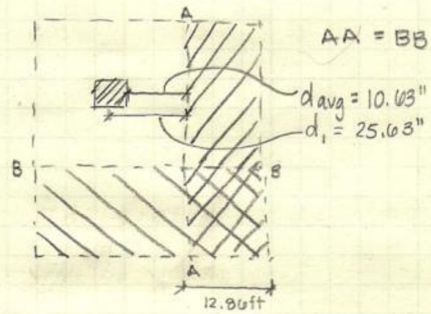
wide beam action



AA = BB

[AA & BB]

$V_u = (0.265\text{ksf})(12.86')(30')$

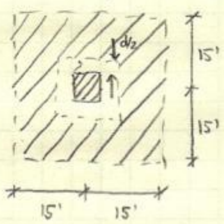
$V_u = 102.2\text{K}$

$\phi V_n = 0.6(2\sqrt{5000})(30 \times 12)(10.63)$

$\phi V_n = 324.7\text{K}$

$\phi V_n > V_u$ ✓

punching shear



$d/2 = 10.63/2 = 5.32\text{ in}$

$b_o = 2(d/2) + \text{col. width}$

$b_o = 2(5.32) + 30 = 40.64$

$4(40.64) = 163"$ (perimeter)

$V_c = 4\sqrt{f'c}\, b_o d$

$V_c = 4\sqrt{5000}(163)(10.63)$

$V_c = 490\text{K}$

$V_u = W_u \cdot \text{Area}$

$V_u = (0.265\text{ksf})[(30' \times 30') - (40.64\text{in}/12)^2]$

$V_u = 235.5\text{K}$

$V_c > V_u$ NG

* This agrees with the portal method calculations and sp slab analyses because punching shear was the predominant mode of failure. This why stud rails and edge beams are presented as methods of solving this failure.

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Appendix G: Stud Rail Check

G.1 Hand Calculation

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Select the critical section for two-way shear around the column

$d = (12in - 0.75in - 1in) = 10.25in$ — cover = 0.75in

$d/2 = 5.125in$ → critical shear section — #8 = 1in

$[30 + (2 \times 5.125)] = 40.25in$

→ length of one side of the critical shear section

$b_o = 4 \times 40.25 = 161''$ → shear perimeter

Compute the shear acting on the critical section

maximum value of ϕV_n allowed w/ headed-shear stud

$\phi V_n = \phi 8 \sqrt{f'c}\, b_o d$

$\phi V_n = (0.75)(8)\sqrt{5000}\,(161)(10.25)$

$\phi V_n = 700K$

shear in slab

SDL = (12 psf)(30') = 360plf

DL = (145 pcf)(12"/12")(30') = 4350plf

LL = (80 psf)(30') = 2400plf

$V_u = (9492\ plf)(30')/2 = 143k$

shear from column slab tranfer

see V_u values from shear & moment tranfer spreadsheet

total shear

143k + shear from column slab transfer < 700K

↳ for stud rails to be used

E.g.

Clinic (N-S) 110mph

	Col. 1	Col. 2
Story 6	177.2+0 = 177.2 K	221.2+6 = [227.2 K]
Story 5	157.9+4.9 = 162.8 K	198.3+6.3 = 204.6 K
Story 4	158.6+4.2 = 162.8 K	198.6+12.4 = 211 K
Story 3	206.9+8.5 = [215.4 K]	189.2+13.2 = 202.4K
Story 2	149.2+8.7 = 157.9 K	169.3+19.2 = 188.5K
Story 1	216.7+14.7 = [231.4 K]	319.3+18.7 = [338 K]

Col. 3 is similar to Col. 2

Col. 4 is similar to Col. 4

[ ] - requires shear studs b/c greater than punching shear (212.1k)

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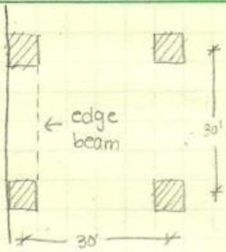
Appendix H: Edge Beam Design

H.1 Hand Calculation

Caitlin Behm | AE Senior Thesis | Edge Beam Design | 1/6



Slab loading:
SDL: 12psf
DL: self weight of concrete
LL: 80psf

$W_u = 1.2 W_D + 1.6 W_L$

$W_u = 1.2[(12"/12")(145pcf) + 12psf] + 1.6[48psf]$

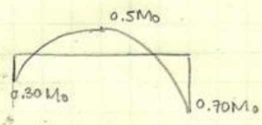
$W_u = 265$ psf

$L_{LR} = 80(0.25 + 15/\sqrt{2(30)(30)})$

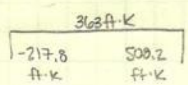
$L_{LR} = 48$ psf

$M_o = 1/8\, w_u \, l_2 l_n^2$

$M_o = 1/8(0.256 ksf)(30')(30' - 30"/12")^2 = 726$ ft·K



Slab w/o beams between interior supports w/ edge beams

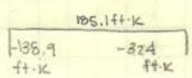


negative moment → 0.75M goes to CS
positive moment → 0.60M goes to CS

Total Moment	-217.8 ft·K	363ft·K	-508.2ft·K
Moment in CS	-163.4ft·K	217.8ft·K	-381.2ft·K
Moment in MS	-54.4ft·K	145.2ft·K	-127ft·K

total width = 30'
Col. strip = 15'
mid. strip = 7.5'

85% of CS to beam



Design for compatability torsion

ext. end neg: -138.9ft·K
mid span pos: 185.1ft·K
first Int. neg: -324ft·K

assume beam dimensions

$h \approx$ between $l/12$ to $l/18$

$h = 30 \times 12/12 = 30"$ to $30 \times 12/18 = 20"$

$b = 0.75h = 18"$

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try 24" x 18" edge beam

$w(\text{beam web}) = \frac{(24-12)\times 18}{144\,in^2/ft^2} \times 145\ pcf = 217.5\ psf / 1\ ft.\ width$ (12 = slab thickness)

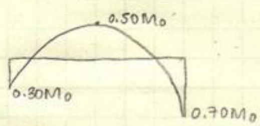
$W_u = 1.2W_D + 1.6W_L$

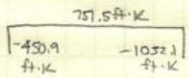
$W_u = 1.2[(12''/12'')(145\ pcf) + 12\ psf + 217.5\ psf] + 1.6[48\ psf]$

$W_u = 0.53\ ksf$

$M_o = 1/8\, w_u\, l_2\, l_n^2$

$M_o = 1/8(0.53\ ksf)(30')(30' - 30/12)^2 = 1503\ ft{\cdot}k$

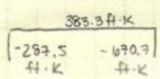




Total Moment	-450.9 ft·k	751.5 ft·k	-1052.1 ft·k
Moment in CS	-338.2 ft·k	450.9 ft·k	-789.1 ft·k
Moment in MS	-112.7 ft·k	300.6 ft·k	-263 ft·k

{ total width = 30', col. strip = 15', mid. strip = 7.5' }

85% of CS to beam



$\rho = \frac{\beta f'_c}{4f_y} = \frac{(0.8)(5\ ksi)}{(4)(60\ ksi)} = 0.017$

$\omega = \rho\, f_y/f'_c = 0.017(60\ ksi/5\ ksi) = 0.204$

$R = \omega f'_c (1 - 0.59\omega)$

$R = (0.204)(5)(1 - 0.59(0.204)) = 0.897\ ksi$

$bd^2 \geq M_u/\phi R = \frac{(670.7\ k{\cdot}ft \times 12''/1')}{(0.9 \times 0.897\ ksi)} = 9969.5\ in^3$

d = 23.5" NG when h = 24"

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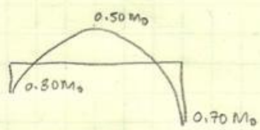
Caitlin Behm	AE Senior Thesis	Edge Beam Design	3/6

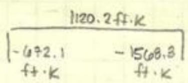
∴ try 30" x 24" edge beam

$w(\text{beam web}) = \frac{(30-12)\times 24}{144\ in^2/ft^2} \times 145\ pcf = 435\ psf / 1ft\ width$

$W_u = 1.2\,W_D + 1.6\,W_L$
$W_u = 1.2[(12"/12")(145pcf) + 12\ psf + 435] + 1.6[48\ psf]$
$W_u = 0.79\ ksf$

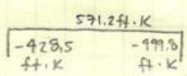
$M_o = 1/8\, W_u\, l_2\, l_n^2$
$M_o = 1/8\,(0.79ksf)(30')(30' - 30"/12")^2 = 2240.4\ ft\cdot K$





Total Moment	-672.1 ft·k	1120.2ft·k	-1568.3ft·k
Moment in CS	-504.1ft·k	672.1ft·k	-1176.2ft·k
Moment in MS	-168ft·k	448.1ft·k	-392.1ft·k

85% of CS to beam



$\rho \approx 0.017$
$\omega = 0.204$
$R = 0.897\ ksi$

$bd^2 \geq M_u/\phi R = \frac{(999.8ft\cdot k \times 12"/1')}{(0.9 \times 0.897ksi)} = 14861.4\ in^3$

d = 24.8"　　　assume d = 27"

compute required As for flexure

$R = M_u/\phi bd^2$
$R = \frac{(999.8k\cdot ft \times 12"/1')}{(0.9 \times 24 \times 27^2)} = 0.762 = 762psi$

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Caitlin Behm	AE Senior Thesis	Edge Beam Design	4/6

Table A.3 "Values of flexural resistance factor k (psi) for grade-60 reinforcement."

$\rho = 0.0141$
$A_s = \rho bd = (0.0141)(24)(27) = 9.14\ in^2$
- repeat for each condition (mid span & ext. neg.)

First interior support negative moment: $A_s = 9.14 in^2$
Midspan positive moment: $A_s = 4.99 in^2$
Exterior support negative moment: $A_s = 3.69 in^2$

W/ this estimate iterate once to have a better estimate of the lever arm jd.

$a = A_s f_y / (0.85 f'_c b) = (9.14 in^2)(60{,}000) / (0.85(5000)(24)) = 5.38 in$
$A_s = M_u / \phi f_y \cdot (d - a/2) = (999.8 ft\cdot k) / [(0.9(60)) \cdot [27" - 5.38/2]] = 9.14 in^2$

No further iterations are necessary, since the estimated lever arm was very reasonable. Use b = 24" h = 30", and $A_s = 9.14 in^2$. Bars will be selected later.

Using ACI 318-08 Eq. 10-3 to check that the reinforcement provided is more than the minimum required

For $f'_c = 5000$, $3\sqrt{5000} = 212.2 > 200$ ∴ use 212.1 psi

$A_{s,min} = 212.1/f_y\ b_w d = 212.1/60{,}000 \times 24 \times 27 = 2.29 in^2 \leq 9.14 in^2$ ✓

Also calculate the strain in the extreme layer of tension steel to verify that assuming $\phi = 0.9$ is valid.

$a = A_s f_y / 0.85 f'_c b = (9.14)(60{,}000)/[(0.85)(5000)(24)]$
$= 5.38 in$
$\beta = 0.8$ b/c $F'_c = 5000 psi$
$c = a/\beta = 5.38/0.8 = 6.73 in$

$\varepsilon_t = (d-c)/c \times \varepsilon_{cu} = (27 - 6.73)/6.73 \times 0.003 = 0.009 \geq 0.005$ ✓

∴ permitted to use $\phi = 0.9$ for this beam design

Design for torsion & shear

At d = 27" away from the face the factored torsion is:
$T_u = 138.9 ft\cdot k$ (ext. end neg. calc on pg. 1)
At d = 27" away from the face, the factored shear is
$V_u = 1.2[30ft - 27"/12" ft) \times 24"/12 \times 0.435 ksf + 1.6[0.048 ksf][30][24"/12"]$
$V_u = 70 k$

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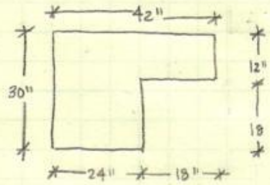
Should torsion be considered?

$T_{th} = \phi \lambda \sqrt{f'c}\,(A_{cp}^2/P_{cp})$



$A_{cp} = 30 \times 24 + 12 \times 18 = 936 in^2$

$P_{cp} = 30 + 24 + 18 + 18 + 12 + 42 = 144"$

$T_{th} = 0.75 \times 1 \sqrt{5000}\,(936^2/144) = 26.9 k \cdot ft$

Since $T_u \geq T_{th}$, torsion must be considered.

Check whether the section dimensions are sufficient to withstand the combined stresses due to shear and torsion.

$$\sqrt{\left[\frac{V_u}{b_w d}\right]^2 + \left[\frac{T_u P_h}{1.7 A_{oh}^2}\right]^2} \leq \phi \left[\frac{V_c}{b_w d} + 8\sqrt{f'c}\right]$$

assuming #4 stirrups

$P_h = 2[30" - 2 \times 1.5" - 2 \times 0.25" + 24" - 2 \times 1.5" - 2 \times 0.25"] = 94"$

$A_{oh} = [30" - 2 \times 1.5" - 2 \times 0.25"] \times [24 - 2 \times 1.5" - 2 \times 0.25"] = 543 in^2$

$$\sqrt{\left[\frac{70k}{24 \times 27}\right]^2 + \left[\frac{138.9(94)}{1.7(543)^2}\right]^2} \leq 0.75 \left[\frac{2\sqrt{5000} \times 24 \times 27}{24 \times 27} + 8\sqrt{5000}\right]$$

$0.114 ksi \leq 0.530 ksi$ ∴ the section is sufficiently large

Determine the area of stirrups required to resist V_u:

$V_c = 2\sqrt{f'c}\, b_w d = 2\sqrt{5000} \times 24 \times 27 = 91.6K$

$V_s = V_u/\phi - V_c = 70/0.75 - 91.6k = 1.73K$

$A_v/s = V_s/f_{yt} d = 1.73K/[(60ksi)(27 in)] = 0.001 in^2/in$

Determine the additional area of stirrups required to resist T_u:

$T_n = T_u/0.75$

$T_n = 138.9/0.75 = 185.2 ft \cdot K$

Using $A_o = 0.85 A_{oh}$

$A_t/s \geq T_n/2A_o f_{yt} \cot\theta \Rightarrow (185 ft \cdot k \times 12"/ft)/(2 \times 0.85 \times 543 \times 60 \times \cot 45°)$

$\Rightarrow 0.040 in^2/in$

Evaluate the total required area of stirrups:

for strength: $0.001 in^2/in + 2 \times 0.040 in^2/in = 0.081 in^2/in$ ⟵ Controls

minimum required: $50 b_w / f_{yt} = 50 \times 24/60{,}000 = 0.02 in^2/in$

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Determine stirrup size and spacing

$$S_{max} \le \begin{cases} 12" \\ P_n/8 = 94/8 = 11.75" \\ d/2 = 27/2 = 13.5" \end{cases}$$

try #3 stirrups, $s \le \frac{2 \times 0.11 in^2}{0.081 in^2/in} = 2.72 in$

try #4 stirrups, $s \le \frac{2 \times 0.20 in^2}{0.081 in^2/in} = 4.94 in$ ← use #4@4"

Determine the need for longitudinal reinforcement resisting torsion:

for strength: $A_\ell = \left[\frac{A_t}{s}\right] P_h \left[\frac{f_{yt}}{f_{y\ell}}\right] \cot^2\theta = (0.040 in^2/in)(94 in)(1.0)(1.0) = 3.76 in^2$

min. req'd: $A_{\ell min} = \frac{5\sqrt{f'c}\,A_{cp}}{f_{y\ell}} - \frac{A_t}{s}\left[P_h\left(\frac{f_{yt}}{f_{y\ell}}\right)\right]$

#4@4" → $\frac{0.20 in^2}{4 in} = 0.05 in^2/in \ge \frac{25(24)}{60,000} = 0.01 in^2/in$

↑ controls

$$A_{\ell min} = \frac{5\sqrt{5000} \times 936 in^2}{60 ksi} - \frac{0.05 in^2}{in} \times 94 in \times 1.0 = 0.97 in^2$$

use $A_\ell = 3.76 in^2$

longitudinal bars are required in the corner of each stirrup. longitudinal bars must be spaced no more than 12" apart around the perimeter of the section, so a bar is needed in the middle of each face. So 30 bars are required.

Area/bar = $3.76 in^2 / 30 bars = 0.125 in^2/bar$

Select #4 bars along the bottom

The reinforcement required along the top of the beam for resisting moment and torsion is:

$A_s = 9.14 in^2 + 3 \times 0.125 in^2 = 9.52 in^2$

select 10(#9) bars along the top of the beam such that,

$A_s = 10 A_b = 10(1.0 in^2) = 10 in^2 \ge 9.52 in^2$ ✓

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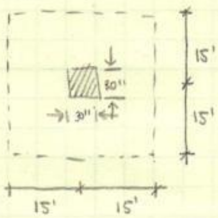
Appendix I: Foundation Check

I.1 Hand Calculation

Caitlin Behm | AE Senior Thesis | Foundation Check | 1/1

Typical Interior Column (Both Hospital & Clinic):



Trib Area = 900 ft^2

Floors 1-6

SDL = 12 psf (typical floor)

DL = self weight of concrete = 145 pcf (12"/1') = 145 psf

LL = 80 psf

$LL_R = 80\,(0.25 + 15/\sqrt{2(30)(30)}) = 48$ psf

Floor 7

SDL = 12 psf (typical floor)

DL = 62 psf (mechanical)

LL = 150 psf (mechanical)

$LL_R = 150\,(0.25 + 15/\sqrt{2(30)(30)}) = 91$ psf

Floor 8

SDL = 24 psf (typical roof)

DL = 75 psf (deck weight)

LL = 20 psf (typical roof)

$W_u = 1.2W_D + 1.6W_L$

$W_u = 1.2[145\text{ psf} + 12\text{ psf}] + 1.6[48\text{ psf}]$

$W_u = 265.2$ psf → typical for floors 1-6

$W_u = 1.2W_D + 1.6W_L$

$W_u = 1.2[12\text{ psf} + 62\text{ psf}] + 1.6[91\text{ psf}]$

$W_u = 234.4$ psf → floor 7

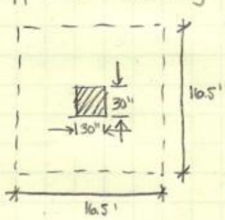
$W_u = 1.2W_D + 1.6W_L$

$W_u = 1.2[24\text{ psf} + 75\text{ psf}] + 1.6[20\text{ psf}]$

$W_u = 150.8$ psf → floor 8

P_u @ foundation = $6[(900ft^2(265.4\text{ psf})] + [(900ft^2)(234.4\text{ psf})] + [(900ft^2)(150.8\text{ psf})]$
= 1780K

Typical Footing (Both Hospital & Clinic)



Footing Area = 272.25 ft^2

P/A = 1780,000 lbs / 272.25 ft^2 = 6538 psf

q_a = 8000 psf → given in structural drawings

P/A = 6538 psf < q_a = 8000 psf ✓

anchor bolts: #5@12"

reinforcement: 12 #9

Additionally, P/A ≈ q_a & minimal reinforce. so pinned base assumption when developing computer models of NCHTNF.

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Appendix J: Daylighting Spreadsheet

J.1 Sun Angle Calculations – Summer Solstice Example

Solar Time, Solar Geometry, and Daylight Availability

= User entered values
= Computed values

Chose Month	Enter Day of Month	Enter Local Clock Time	Choose Time Zone	Check for Daylight Savings Time	Enter Latitude (degrees)	Enter Longitude (degrees)	Enter Building Elevation Azimuth (a_e) (degrees)	Choose Sky Condition
June	21	12:00 PM	Eastern Standard (GMT-5:00)	✓	28.5°	81.4°	0.0°	Clear

Solar Time (Decimal Format)	Solar Time (Clock Format)	Sunrise (Clock Format)	Sunset (Clock Format)
10.55	10:33 AM	6:32 AM	8:21 PM

Solar Declination Angle (δ)	Solar Altitude Angle (a_t)	Solar Azimuth Angle (a_s)	Solar Elevation Azimuth (a_z)	Incident Angle (a_i)	Profile Angle (a_p)
23.4°	69.9°	-80.5°	-80.5°	86.7°	86.5°

Direct Horizontal Solar Illuminance (E_{dh})	Direct Horizontal Illuminance from an Unobstructed Sky (E_{kh})	Total Horizontal Illuminance (E_{total})	Direct Vertical Solar Illuminance (E_{dv})	
8,977	1,470	10,447	546	= fc
51,524	15,818	67,342	5,877	= lx

Note: Calculations determine by Caitlin Behm. Excel template created during AE497D with Professor Kevin Houser.

J.2 Sun Angle Calculations – Summer Solstice Complete 24 Hours Study

Available Illuminance Calculations

= User entered values
= Computed values

			Chart Titles ==>		Solar Altitude	Solar Azimuth	Elevation Azimuth	Incident	Profile		Sun	Sun	Sky	Total
Clock Time (AM/PM Format)	Clock Time (Decimal Format)	Solar Time (Decimal Format)	Solar Time (Clock Format)	Solar Time Angle (radians)	Altitude Angle	Azimuth Angle	Solar Elevation Azimuth (degrees)	Incident Angle (degrees)	Profile Angle (degrees)	Direct Normal Solar Illuminance (lx)	Direct Horizontal Solar Illuminance (lx)	Direct Vertical Solar Illuminance (lx)	Horizontal Unobstructed Sky Illuminance (lx)	Total Horizontal Illuminance (lx)
12:00 AM	0.00	-1.45	-		-34.0°	-24.2°	-24.2°	40.8°	No Sun	0	0	0	0	0
12:30 AM	0.50	-0.95	-		-36.3°	-16.2°	-16.2°	39.3°	No Sun	0	0	0	0	0
1:00 AM	1.00	-0.45	-		-37.6°	-7.8°	-7.8°	38.3°	No Sun	0	0	0	0	0
1:30 AM	1.50	0.05	12:03 AM		-38.0°	0.9°	0.9°	38.0°	No Sun	0	0	0	0	0
2:00 AM	2.00	0.55	12:33 AM		-37.4°	9.6°	9.6°	38.5°	No Sun	0	0	0	0	0
2:30 AM	2.50	1.05	1:03 AM		-35.9°	17.9°	17.9°	39.5°	No Sun	0	0	0	0	0
3:00 AM	3.00	1.55	1:33 AM		-33.4°	25.7°	25.7°	41.2°	No Sun	0	0	0	0	0
3:30 AM	3.50	2.05	2:03 AM		-30.2°	32.9°	32.9°	43.5°	No Sun	0	0	0	0	0
4:00 AM	4.00	2.55	2:33 AM		-26.3°	39.3°	39.3°	46.1°	No Sun	0	0	0	0	0
4:30 AM	4.50	3.05	3:03 AM		-21.9°	45.1°	45.1°	49.1°	No Sun	0	0	0	0	0
5:00 AM	5.00	3.55	3:33 AM		-17.0°	50.2°	50.2°	52.3°	No Sun	0	0	0	0	0
5:30 AM	5.50	4.05	4:03 AM		-11.8°	54.9°	54.9°	55.7°	No Sun	0	0	0	0	0
6:00 AM	6.00	4.55	4:33 AM		-6.2°	59.0°	59.0°	59.2°	No Sun	0	0	0	0	0
6:30 AM	6.50	5.05	5:03 AM		-0.5°	62.8°	62.8°	62.8°	No Sun	0	0	0	0	0
7:00 AM	7.00	5.55	5:33 AM		5.5°	66.2°	66.2°	66.4°	13.4°	14,257	1,361	5,717	5,589	6,950
7:30 AM	7.50	6.05	6:03 AM		11.6°	69.5°	69.5°	69.9°	30.3°	45,209	9,076	15,542	7,745	16,821
8:00 AM	8.00	6.55	6:33 AM		17.8°	72.5°	72.5°	73.3°	46.9°	64,767	19,811	18,567	9,373	29,184
8:30 AM	8.50	7.05	7:03 AM		24.1°	75.4°	75.4°	76.7°	60.6°	77,008	31,498	17,762	10,713	42,211
9:00 AM	9.00	7.55	7:33 AM		30.6°	78.2°	78.2°	79.8°	70.8°	85,138	43,286	15,041	11,852	55,138
9:30 AM	9.50	8.05	8:03 AM		37.0°	80.9°	80.9°	82.8°	78.2°	90,803	54,696	11,408	12,830	67,526
10:00 AM	10.00	8.55	8:33 AM		43.6°	83.8°	83.8°	85.5°	83.5°	94,882	65,397	7,443	13,668	79,065
10:30 AM	10.50	9.05	9:03 AM		50.1°	86.8°	86.8°	87.9°	87.3°	97,879	75,131	3,513	14,380	89,511
11:00 AM	11.00	9.55	9:33 AM		56.7°	-89.9°	-89.9°	89.9°	89.9°	100,097	83,685	130	14,972	98,658
11:30 AM	11.50	10.05	10:03 AM		63.3°	-85.9°	-85.9°	88.1°	87.9°	101,725	90,886	3,304	15,451	106,337
12:00 PM	12.00	10.55	10:33 AM		69.9°	-80.5°	-80.5°	86.7°	86.5°	102,887	96,592	5,877	15,818	112,410
12:30 PM	12.50	11.05	11:03 AM		76.3°	-71.6°	-71.6°	85.7°	85.6°	103,661	100,693	7,754	16,076	116,769
1:00 PM	13.00	11.55	11:33 AM		82.1°	-51.6°	-51.6°	85.1°	85.1°	104,096	103,112	8,871	16,227	119,338
1:30 PM	13.50	12.05	12:03 PM		84.9°	8.0°	8.0°	84.9°	84.9°	104,218	103,804	9,192	16,269	120,073
2:00 PM	14.00	12.55	12:33 PM		81.0°	57.6°	57.6°	85.2°	85.2°	104,033	102,755	8,706	16,205	118,960
2:30 PM	14.50	13.05	1:03 PM		75.0°	73.9°	73.9°	85.9°	85.8°	103,531	99,986	7,429	16,032	116,018
3:00 PM	15.00	13.55	1:33 PM		68.5°	81.7°	81.7°	87.0°	86.8°	102,682	95,548	5,403	15,752	111,300
3:30 PM	15.50	14.05	2:03 PM		62.0°	86.8°	86.8°	88.5°	88.3°	101,432	89,525	2,698	15,362	104,887
4:00 PM	16.00	14.55	2:33 PM		55.4°	-89.4°	-89.4°	89.7°	89.6°	99,695	82,034	585	14,860	96,894
4:30 PM	16.50	15.05	3:03 PM		48.8°	-86.2°	-86.2°	87.5°	86.6°	97,336	73,222	4,303	14,244	87,466
5:00 PM	17.00	15.55	3:33 PM		42.2°	-83.2°	-83.2°	85.0°	82.6°	94,146	63,271	8,264	13,507	76,778
5:30 PM	17.50	16.05	4:03 PM		35.7°	-80.4°	-80.4°	82.2°	76.9°	89,791	52,402	12,196	12,641	65,043
6:00 PM	18.00	16.55	4:33 PM		29.2°	-77.6°	-77.6°	79.2°	69.0°	83,709	40,883	15,698	11,632	52,516
6:30 PM	18.50	17.05	5:03 PM		22.8°	-74.8°	-74.8°	76.0°	58.1°	74,905	29,071	18,128	10,456	39,527
7:00 PM	19.00	17.55	5:33 PM		16.5°	-71.9°	-71.9°	72.6°	43.6°	61,494	17,489	18,346	9,066	26,555
7:30 PM	19.50	18.05	6:03 PM		10.3°	-68.8°	-68.8°	69.2°	26.7°	39,836	7,134	14,163	7,360	14,494
8:00 PM	20.00	18.55	6:33 PM		4.2°	-65.6°	-65.6°	65.6°	10.2°	7,526	557	3,106	5,016	5,572
8:30 PM	20.50	19.05	7:03 PM		-1.7°	-62.0°	-62.0°	62.1°	No Sun	0	0	0	0	0
9:00 PM	21.00	19.55	7:33 PM		-7.4°	-58.2°	-58.2°	58.5°	No Sun	0	0	0	0	0
9:30 PM	21.50	20.05	8:03 PM		-12.9°	-54.0°	-54.0°	55.0°	No Sun	0	0	0	0	0
10:00 PM	22.00	20.55	8:33 PM		-18.0°	-49.2°	-49.2°	51.6°	No Sun	0	0	0	0	0
10:30 PM	22.50	21.05	9:03 PM		-22.8°	-44.0°	-44.0°	48.4°	No Sun	0	0	0	0	0
11:00 PM	23.00	21.55	9:33 PM		-27.1°	-38.1°	-38.1°	45.5°	No Sun	0	0	0	0	0
11:30 PM	23.50	22.05	10:03 PM		-30.9°	-31.5°	-31.5°	43.0°	No Sun	0	0	0	0	0

Note: Calculations determine by Caitlin Behm. Excel template created during AE497D with Professor Kevin Houser.

J.3 Sun Angle Calculations – Winter Solstice Example

Solar Time, Solar Geometry, and Daylight Availability

(orange)	= User entered values
(light orange)	= Computed values
(green)	

Chose Month	Enter Day of Month	Enter Local Clock Time	Choose Time Zone	Check for Daylight Savings Time	Enter Latitude (degrees)	Enter Longitude (degrees)	Enter Building Elevation Azimuth (a_e) (degrees)	Choose Sky Condition
December	21	12:00 PM	Eastern Standard (GMT-5:00)		28.5°	81.4°	0.0°	Clear

Solar Time (Decimal Format)	Solar Time (Clock Format)	Sunrise (Clock Format)	Sunset (Clock Format)
11.61	11:36 AM	7:18 AM	5:29 PM

Solar Declination Angle (δ)	Solar Altitude Angle (a_t)	Solar Azimuth Angle (a_s)	Solar Elevation Azimuth (a_z)	Incident Angle (a_i)	Profile Angle (a_p)
-23.4°	37.7°	-6.9°	-6.9°	38.3°	37.9°

Direct Horizontal Solar Illuminance (E_{dh})	Direct Horizontal Illuminance from an Unobstructed Sky (E_{kh})	Total Horizontal Illuminance (E_{total})	Direct Vertical Solar Illuminance (E_{dv})	
5,551	1,201	6,753	7,121	= fc
22,781	12,927	35,708	76,617	= lx

Note: Calculations determine by Caitlin Behm. Excel template created during AE497D with Professor Kevin Houser.

J.4 Sun Angle Calculations – Winter Solstice Complete 24 Hours Study

Available Illuminance Calculations

= User entered values
= Computed values

			Chart Titles ==>		Solar Altitude	Solar Azimuth	Elevation Azimuth	Incident	Profile		Sun	Sun	Sky	Total
Clock Time (AM/PM Format)	Clock Time (Decimal Format)	Solar Time (Decimal Format)	Solar Time (Clock Format)	Solar Time Angle (radians)	Altitude Angle	Azimuth Angle	Solar Elevation Azimuth (degrees)	Incident Angle (degrees)	Profile Angle (degrees)	Direct Normal Solar Illuminance (lx)	Direct Horizontal Solar Illuminance (lx)	Direct Vertical Solar Illuminance (lx)	Horizontal Unobstructed Sky Illuminance (lx)	Total Horizontal Illuminance (lx)
12:00 AM	0.00	-0.39	-		-82.7°	-47.7°	-47.7°	85.1°	No Sun	0	0	0	0	0
12:30 AM	0.50	0.11	12:06 AM		-84.7°	16.0°	16.0°	84.9°	No Sun	0	0	0	0	0
1:00 AM	1.00	0.61	12:36 AM		-80.4°	60.2°	60.2°	85.2°	No Sun	0	0	0	0	0
1:30 AM	1.50	1.11	1:06 AM		-74.3°	75.0°	75.0°	86.0°	No Sun	0	0	0	0	0
2:00 AM	2.00	1.61	1:36 AM		-67.8°	82.3°	82.3°	87.1°	No Sun	0	0	0	0	0
2:30 AM	2.50	2.11	2:06 AM		-61.2°	87.2°	87.2°	88.7°	No Sun	0	0	0	0	0
3:00 AM	3.00	2.61	2:36 AM		-54.7°	-89.1°	-89.1°	89.5°	No Sun	0	0	0	0	0
3:30 AM	3.50	3.11	3:06 AM		-48.1°	-85.8°	-85.8°	87.2°	No Sun	0	0	0	0	0
4:00 AM	4.00	3.61	3:36 AM		-41.5°	-82.9°	-82.9°	84.7°	No Sun	0	0	0	0	0
4:30 AM	4.50	4.11	4:06 AM		-35.0°	-80.1°	-80.1°	81.9°	No Sun	0	0	0	0	0
5:00 AM	5.00	4.61	4:36 AM		-28.5°	-77.3°	-77.3°	78.9°	No Sun	0	0	0	0	0
5:30 AM	5.50	5.11	5:06 AM		-22.1°	-74.5°	-74.5°	75.6°	No Sun	0	0	0	0	0
6:00 AM	6.00	5.61	5:36 AM		-15.8°	-71.6°	-71.6°	72.3°	No Sun	0	0	0	0	0
6:30 AM	6.50	6.11	6:06 AM		-9.6°	-68.5°	-68.5°	68.8°	No Sun	0	0	0	0	0
7:00 AM	7.00	6.61	6:36 AM		-3.6°	-65.2°	-65.2°	65.3°	No Sun	0	0	0	0	0
7:30 AM	7.50	7.11	7:06 AM		2.3°	-61.6°	-61.6°	61.7°	4.8°	743	30	353	3,909	3,939
8:00 AM	8.00	7.61	7:36 AM		8.0°	-57.8°	-57.8°	58.1°	14.8°	30,396	4,229	16,055	6,581	10,810
8:30 AM	8.50	8.11	8:06 AM		13.4°	-53.5°	-53.5°	54.6°	21.9°	55,709	12,945	32,248	8,272	21,217
9:00 AM	9.00	8.61	8:36 AM		18.6°	-48.7°	-48.7°	51.3°	27.0°	71,117	22,645	44,490	9,546	32,191
9:30 AM	9.50	9.11	9:06 AM		23.3°	-43.4°	-43.4°	48.1°	30.7°	80,899	32,016	54,009	10,551	42,567
10:00 AM	10.00	9.61	9:36 AM		27.6°	-37.4°	-37.4°	45.2°	33.3°	87,387	40,467	61,536	11,348	51,815
10:30 AM	10.50	10.11	10:06 AM		31.3°	-30.7°	-30.7°	42.7°	35.3°	91,779	47,654	67,428	11,969	59,623
11:00 AM	11.00	10.61	10:36 AM		34.3°	-23.4°	-23.4°	40.7°	36.6°	94,727	53,354	71,858	12,433	65,787
11:30 AM	11.50	11.11	11:06 AM		36.5°	-15.4°	-15.4°	39.2°	37.5°	96,595	57,413	74,908	12,750	70,163
12:00 PM	12.00	11.61	11:36 AM		37.7°	-6.9°	-6.9°	38.3°	37.9°	97,587	59,732	76,617	12,927	72,658
12:30 PM	12.50	12.11	12:06 PM		38.0°	1.8°	1.8°	38.1°	38.0°	97,804	60,255	76,999	12,966	73,221
1:00 PM	13.00	12.61	12:36 PM		37.3°	10.5°	10.5°	38.6°	37.8°	97,267	58,971	76,059	12,869	71,840
1:30 PM	13.50	13.11	1:06 PM		35.7°	18.8°	18.8°	39.7°	37.2°	95,923	55,909	73,787	12,633	68,543
2:00 PM	14.00	13.61	1:36 PM		33.1°	26.5°	26.5°	41.5°	36.1°	93,632	51,143	70,162	12,255	63,399
2:30 PM	14.50	14.11	2:06 PM		29.8°	33.6°	33.6°	43.7°	34.5°	90,133	44,794	65,129	11,727	56,521
3:00 PM	15.00	14.61	2:36 PM		25.8°	40.0°	40.0°	46.4°	32.3°	84,960	37,042	58,576	11,035	48,076
3:30 PM	15.50	15.11	3:06 PM		21.4°	45.7°	45.7°	49.4°	29.2°	77,276	28,151	50,269	10,155	38,307
4:00 PM	16.00	15.61	3:36 PM		16.4°	50.8°	50.8°	52.7°	25.0°	65,503	18,545	39,723	9,047	27,593
4:30 PM	16.50	16.11	4:06 PM		11.2°	55.3°	55.3°	56.1°	19.2°	46,549	9,024	25,971	7,624	16,648
5:00 PM	17.00	16.61	4:36 PM		5.6°	59.4°	59.4°	59.6°	11.0°	16,139	1,582	8,165	5,653	7,234
5:30 PM	17.50	17.11	5:06 PM		-0.2°	63.2°	63.2°	63.2°	No Sun	0	0	0	0	0
6:00 PM	18.00	17.61	5:36 PM		-6.1°	66.6°	66.6°	66.8°	No Sun	0	0	0	0	0
6:30 PM	18.50	18.11	6:06 PM		-12.2°	69.8°	69.8°	70.3°	No Sun	0	0	0	0	0
7:00 PM	19.00	18.61	6:36 PM		-18.5°	72.8°	72.8°	73.7°	No Sun	0	0	0	0	0
7:30 PM	19.50	19.11	7:06 PM		-24.8°	75.7°	75.7°	77.0°	No Sun	0	0	0	0	0
8:00 PM	20.00	19.61	7:36 PM		-31.3°	78.5°	78.5°	80.2°	No Sun	0	0	0	0	0
8:30 PM	20.50	20.11	8:06 PM		-37.7°	81.3°	81.3°	83.1°	No Sun	0	0	0	0	0
9:00 PM	21.00	20.61	8:36 PM		-44.3°	84.1°	84.1°	85.8°	No Sun	0	0	0	0	0
9:30 PM	21.50	21.11	9:06 PM		-50.8°	87.1°	87.1°	88.2°	No Sun	0	0	0	0	0
10:00 PM	22.00	21.61	9:36 PM		-57.4°	-89.5°	-89.5°	89.7°	No Sun	0	0	0	0	0
10:30 PM	22.50	22.11	10:06 PM		-64.0°	-85.3°	-85.3°	88.0°	No Sun	0	0	0	0	0
11:00 PM	23.00	22.61	10:36 PM		-70.6°	-79.7°	-79.7°	86.6°	No Sun	0	0	0	0	0
11:30 PM	23.50	23.11	11:06 PM		-76.9°	-70.2°	-70.2°	85.6°	No Sun	0	0	0	0	0

Note: Calculations determine by Caitlin Behm. Excel template created during AE497D with Professor Kevin Houser.

Appendix K: Aluminum Mullion Design

K.1 Hand Calculation

Caitlin Behm | AE Senior Thesis | Mullion Design | 1/2

Mullion Design

wind load : 18psf

$18psf \times 5' = 90 plf$

$90plf \times 14.5939 = 1.31\ kN/m$

assumption: it has been assumed that the expansion joint of a mullion is rigid (i.e. $M \neq 0$)

Bending

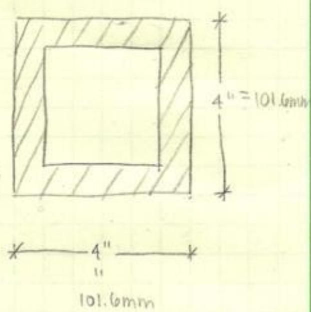
assumption: T5 alum.

$+M_{max} = \gamma_m \times q \times L^2$
$= 0.0703 \times (1.31\ kN/m) \times (4.57m)^2$
$= 1.92\ kN \cdot m$

$-M_{max} = \gamma_m \times q \times L^2$
$= -0.125 \times (1.31\ kN/m) \times (4.57m)^2$
$= -3.42\ kN \cdot m$ ← controls

$\sigma_{bending} = Mc/I = M/S$

$69{,}000\ kN/m^2 = 3.42\ kN \cdot m / S$
$S = 4.96E{-5}\ m^3$
$S = 49{,}565\ mm^3$



$S \leq I/y$

$49{,}565\ mm^3 \leq \dfrac{(1/12)(101.6)(101.6)^3 - (1/12)(101.6-2t)(101.6-2t)^3}{50.8}$

$2517902 \leq 8879603.7 - (1/12)(101.6-2t)(101.6-2t)^3$

$-6361701.7 \leq -(1/12)(101.6-2t)(101.6-2t)^3$

$93.47 \geq 101.6 - 2t$

$-8.13 \geq -2t$

$t \geq 4.06\ mm$ ← unrealistic   try $t = 8mm$

Shear

$Q_{max} = \gamma_q \times q \times L$
$= 0.625 \times (1.31\ kN/m) \times (4.57m)^2$
$= 3.74\ kN$

$T = (3/2)(V/A)$
$37\ N/mm^2 = 3/2\ (3740N)/A$
$A = 151.6\ mm^3$

$151.6 \leq (101.6)(101.6) - [(101.6-2t)(101.6-2t)]$
$10170.96 \leq [(101.6-2t)^2]$
$t \geq 0.37\ mm$ ← unrealistic

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Deflection

$f_{max} = \alpha_f \times q \times L^4 / 100EI$

$= 0.521 \times (1.31\ kN/m)(4.57)^4 / 100EI$

$= 2.98\ (kN \cdot m^3) / EI\ (kN \cdot m^2)$

$f_{allow} = span/180$ or $20\ mm$ (controls)

$= \frac{4570}{180} = 25.4\ mm$

$f_{max} = \frac{2.98 \times 10^{12}\ (N \cdot mm^3)}{(70{,}000\ N/mm^2)\left[\frac{1}{12}(101.6)(101.6)^3 - \frac{1}{12}(101.6-2(8))(101.6-2(8))^3\right]}$

$9.66\ mm < 20\ mm$ ✓

$\therefore$ t = 8mm for aluminum mullion design