Kyle MacDonald
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November 16, 2015

Dr. Thomas Boothby
The Pennsylvania State University
209 Engineering Unit A
University Park, PA 16802

Dear Dr. Boothby,

The following document, Technical Report IV – Lateral System Analysis Study, is a detailed analysis of the lateral load resisting system of The Medical Center by means of applicable building codes and reference design standards. Through manipulation of a computer model and presentation of hand calculations as well as diagrammatic sketches, inclusive of material submitted in Notebook A and B, this report documents strength and serviceability analyses of the existing lateral framing system of the building.

The computer modeling process will be documented and presented in order to provide clarity of thinking and present any assumptions that were made during the modeling process. Assumptions and thought process sequence will be documented within the body of the report, and additional supplementary material, with respect to modeling process, will be located within the appendices of the report.

Thank you for your consideration and evaluation of this report.

Sincerely,

Kyle MacDonald

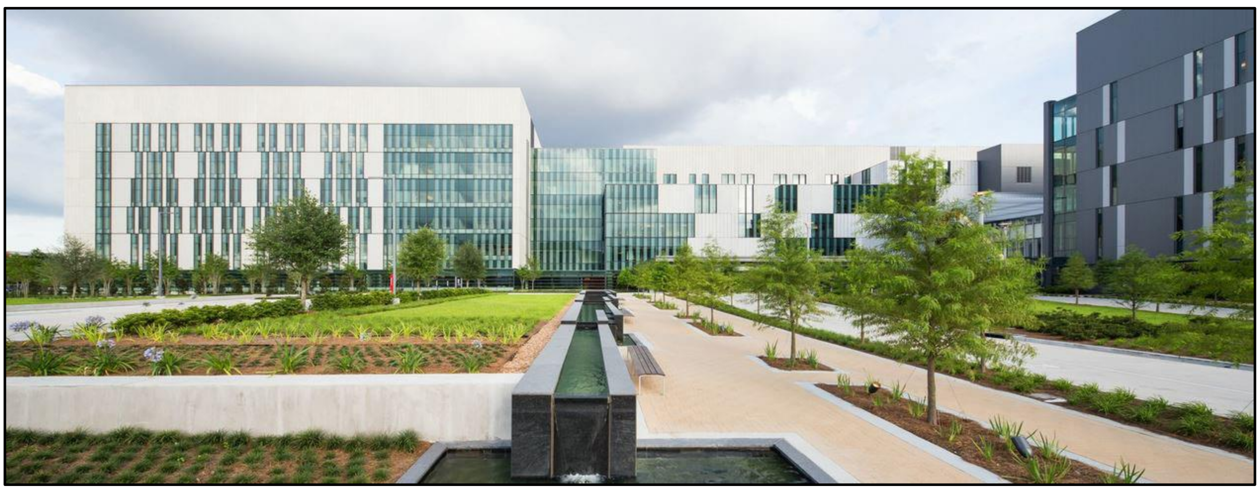
The Pennsylvania State University

Schreyer Honors College | Class of 2016

The Medical Center | Southeast, USA

Lateral System Analysis Study

Structural Notebook Submission C



Submitted to: Dr. Thomas Boothby, Advisor

Prepared by: Kyle M. MacDonald [Structural Option]

Prepared on: November 16th, 2015

Executive Summary

The Medical Center is a 570,000 square foot hospital located at the cornerstone of an expanding medical district. The building site is woven into the urban fabric of Southeast, USA. The urban context of the site, totaling 37 acres in size, influences the boundaries of design of this building project. Programmatically, The Medical Center houses 446 hospital beds as well as inpatient facilities such as medical offices, intensive care units, and dietary facilities. A high degree of programmatic intuition is demonstrated through the relationship between the environmental concerns of the region and the location of all mission-critical components within the building. The Medical Center was budgeted at $190 million.

Comprised of three identical, structurally isolated, L-shaped inpatient towers, The Medical Center is designed utilizing a reinforced concrete (RC) structural system. The structure features concrete slabs with pan joists, RC beams, RC girders, and vertical RC columns. These structural elements frame into composite timber piles and pre-cast, prestressed concrete piles, by means of a varied pile cap system, which are driven into the earth until a depth, below the original grade, of 62 ft. Concrete moment frames and concrete walls serve as the lateral force resisting system.

NBBJ Architects and Blitch Knevel Architects served as the joint-venture architects on this building project. Structural, MEP, and Fire Protection engineering services were provided by URS Corporation (recently AECOM), and IBA Consultants served as the exterior envelope design experts. The project was delivered by means of design-bid-build contract, and Skanska served as the Construction Manager at Risk on the project. The Medical Center began construction in December 2012 and is scheduled to be completed in November 2015.

The Medical Center was designed based on the Southeast, USA Building Code, associated with the International Building Code (IBC), 2009 edition. The American Society of Civil Engineers (ASCE) 7-05 was utilized as a reference standard. The building is scheduled to be completed in August 2015.

THE MEDICAL CENTER | SOUTHEAST, USA

GENERAL INFORMATION

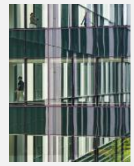
Full Height	113 ft.
Number of Stories	7 above grade
Size of Building	570,000 sq. ft.
Cost of Building	$190,000,000
Date of Construction	Dec. 2012-Nov. 2015
Project Delivery Method	Design-Bid-Build

PROJECT TEAM

Owner	State of Louisiana
Construction Manager (at risk)	Skanska
Architect	NBBJ Architects
Architect (Joint Venture)	Blitch Knevel Architects
Structural Engineers	URS Corporation (AECOM)
MEP Engineers	URS Corporation (AECOM)
Fire Protection	URS Corporation (AECOM)
Exterior Envelope	IBA Consultants

ARCHITECTURE

The inpatient towers feature a polished and refined design that influences the form and shape of the medical district of Southeast, USA. The L-shaped orthogonal design scheme introduces order and logic into the overall program of the building. A high degree of programmatic intuition is demonstrated through the relationship between the environmental concerns of the region and the location of the mission-critical components within the building.



IMAGES COURTESY OF NBBJ ARCHITECTS

MECHANICAL SYSTEMS

The indoor design conditions are defined as seen below:
Summer: 75°F db/50% RH | Winter: 70°F db/30% RH

LIGHTING AND ELECTRICAL SYSTEMS

The hospital is equipped with emergency power capable of sustaining mission-critical operation after a category 3 hurricane for up to a week with no outside support.

CONSTRUCTION

Due to the unfavorable and unpredictable conditions of the site soil, a 7.5% structural foundation allowance was allotted to account for any variability in pile length.

STRUCTURAL SYSTEMS

Foundation: Timber Composite Piles, Precast/Prestressed Concrete Piles, Pile Cap, Grade Beams

Framing: Concrete Frame Horizontal – Joist, Beam, Girder | Concrete Frame Vertical – Column | Concrete Slab

Lateral: Concrete Moment Frame – Detailed Lateral Connection at Column and Beam Interface

Kyle M. MacDonald | Structural Option | http://www.kym5182.wix.com/thesis

Table of Contents

[1] Introduction

1.1 Purpose

This report functions as a detailed analysis of typical bay framing of The Medical Center. Spot checks of typical members of the existing gravity framing system of The Medical Center will be performed, and evaluations of additional gravity framing design alternatives will be addressed. The Medical Center utilizes an existing pan joist, beam, girder, and slab reinforced concrete framing system. The alternate framing schemes are the following: non-composite steel framing system, composite steel framing system, and two-way flat plate concrete slab system.

1.2 Scope

The content of this report is divided into three major sections: gravity loads, typical member spot checks for gravity loads, and alternate framing systems for gravity loads. All gravity load information being presented was extracted from the previous documentation, Technical Report II – Building Codes, Specifications, and Loads (Notebook A). Additionally, this document discusses pertinent information with respect to site location and resource documentation. This information is framed by the context of the member analysis and alternate design of a typical bay of The Medical Center. Appendices are included at the end of the document in order to display original load calculations executed by URS Corporation (AECOM).

1.3 Site Location and Plan

The Medical Center sits at the cornerstone of an expanding medical district, contributing to an expansive network of hospitals in Southeast, USA. Nestled in between pockets of urban residential construction, The Medical Center briefly interrupts the major urban grid of the existing environment. Existing as a mission-critical facility, the building's proximity to a major network of highways enhances its public accessibility. The urban context of the site, totaling 37 acres in size, influences the boundaries of design of this building project (as seen in Figure 1 and Figure 2).

Figure 1 - Site Context (Macro)

Figure 2 - Site Context (Aerial)

1.4 Document List

- IBC 2009 (for existing analysis)
- IBC 2012 (for alternate design study)
- ASCE 7-05 (for existing analysis)
- ASCE 7-10 (for alternate design study)
- AISC Steel Manual, 14th Edition
- ACI 301, ACI 315, ACI 318
- USGS Seismic Design Maps
- Vulcraft Steel Deck Catalogue, 2008 Edition

[2] Gravity Loads

This section investigates the gravity loading of the structural system, inclusive of dead, live, and snow loads. Each load case is investigated separately but applied to the building structure in combination. The gravity loading information being presented was extracted directly from Technical Report II – Building Codes, Specifications, and Loads (Notebook A).

2.1 Dead Loads

Table 1 - Dead Loads

Dead Load	Load Value (psf)
Exterior Glazed Framing System	20
Exterior Precast Concrete Panel	50
Exterior Composite Metal Panel	15
Hospital Floor	60
Hung Load Allowance (Typical Floors)	8
Hung Load Allowance (Main Roof)	13
Roofing Allowance (W/O Pavers)	12
Roofing Allowance (W/ Pavers)	37

2.2 Live Loads

Table 2 - Live Loads

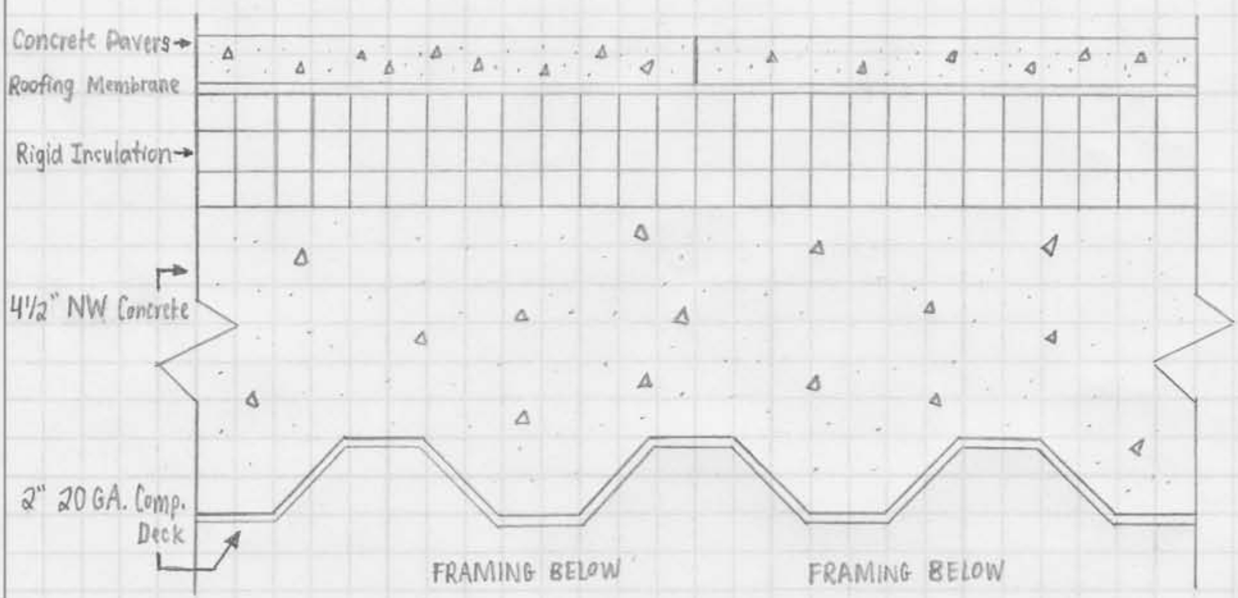
Live Load	Load Value (psf)
Offices	50
Corridors (1st Floor)	100
Corridors (Other)	80
Operating Rooms	60
Patient Rooms	40
Lobbies, Stair and Exit Ways	100
Mechanical Rooms	125 (or equipment weight)

2.3 Snow Loads

Due to the climate region of the building site, the applicable reference standard dictates a ground snow load equal to zero pounds per square foot; therefore, snow conditions will not imposed any load on the building structure (and can be rightly omitted from design load considerations).

GRAVITY LOADS

- Roof Construction (Diagram & Loading)



- Roof Loading (Dead)

Concrete Pavers	:	13 psf
Roofing Membrane	:	1 psf
Rigid Insulation	:	1½ psf
4½" NW Concrete	:	57 psf
2" 20GA Comp. Deck	:	2 psf
Framing	:	6½ psf
Miscellaneous	:	9 psf

Total Assembly Dead Load = 90 psf

Framing per Typical Bay

Area : approx. 30' x 32' = 960 sf → 6½psf

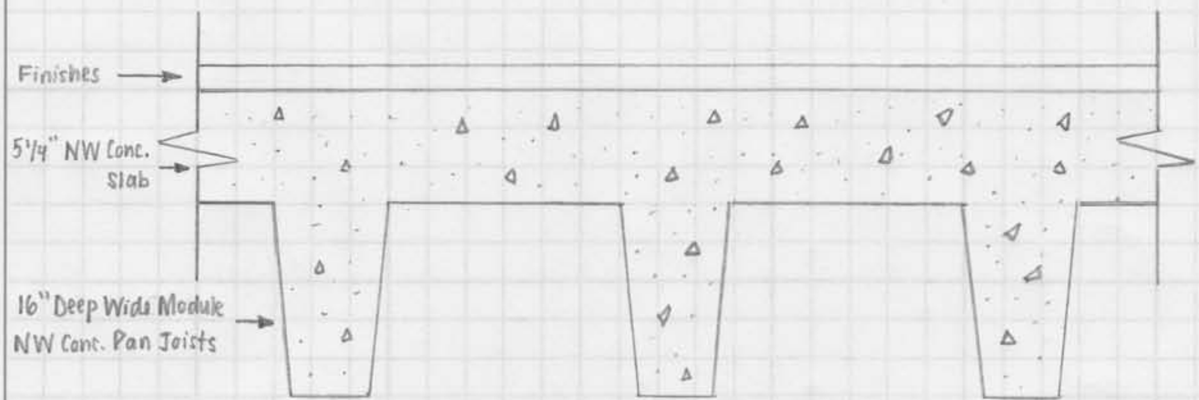
- Roof Loading (Live)

Roof Live Load : 20 psf

(according to ASCE 7-05 Table 4-1 → Minimum Uniformly Distributed Live Loads

GRAVITY LOADS (cont.)

• Floor Construction (Pan Joist System)



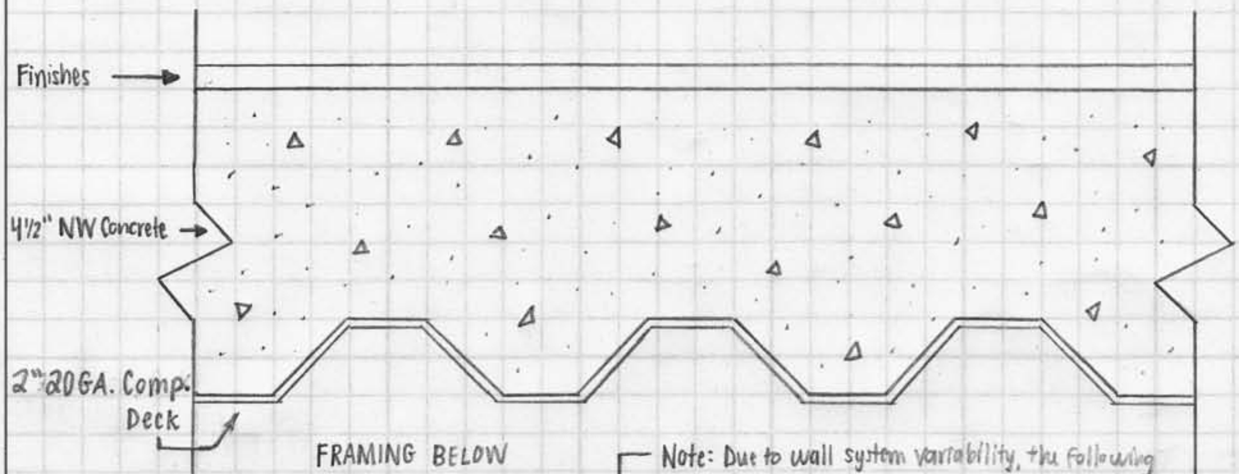
• Floor Loading (Pan Joist System)

Finishes	:	2 psf	Total Assembly Dead Load = 110 psf
Conc. Slab	:	67 psf	
Pan Joists	:	14 1/2 psf	
Framing	:	6 1/2 psf	
Ceiling	:	5 psf	
Miscellaneous	:	15 psf	

The pan joist floor assembly system relies on 16 inch deep pan joists, spaced at 66 inches apart, to provide sections of increased stiffness. The framed floor (structural) follows a defined module that dictates the framing pattern of the building.

GRAVITY LOADS (cont.)

- Floor Construction (Slab and Deck System)



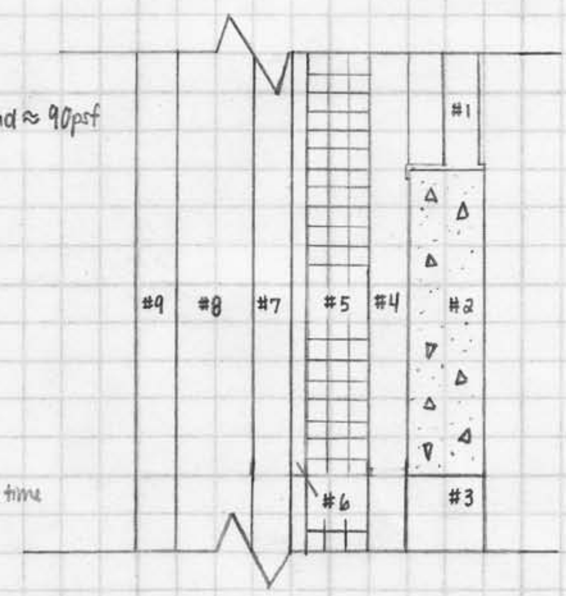
Note: Due to wall system variability, the following diagram is representative of the types of material included in exterior enclosure wall assemblies

- Floor Loading (Slab and Deck System)

Finishes	:	2 psf
Conc. Slab	:	57 psf
Steel Deck	:	2 psf
Framing	:	6½ psf
Ceiling	:	5 psf
Miscellaneous	:	15 psf

Total Dead Load ≈ 90 psf

- Exterior Enclosure Construction



- Exterior Enclosure Loading

Curtain Wall / GFS	:	20 psf
Precast Conc. Panel	:	50 psf
Comp. Metal Panel	:	15 psf
Air Gap	:	0 psf
Insulation	:	1½ psf
Vapor Barrier	:	½ psf
Gypsum Board	:	5½ psf (2¾ psf each)
Metal Stud Framing	:	5

only consider one at a time (Curtain Wall / GFS, Precast Conc. Panel, Comp. Metal Panel)

Total Dead Load = 62½ psf

#1 : Curtain Wall / Glazed Framing System (GFS)
#2 : Precast Concrete Wall Panel
#3 : Composite Metal Wall Panel
#4 : Air Gap
#5 : Rigid Insulation
#6 : Vapor Barrier
#7 : Gypsum Board
#8 : Metal Stud
#9 : Gypsum Board

SNOW LOADS

- Flat Roof Snow Loads → $p_f = 0.7\,C_e\,C_t\,I_s\,p_g = 0.7(1.0)(1.0)(1.2)(0) = 0$ psf

$p_g = 0$ psf = ZERO (ASCE 7-05 Figure 7-1)

Terrain Category: C (ASCE 7-05 Table 7-2)

$C_e \longrightarrow 1.0$ (ASCE 7-05 Table 7-2)

$C_t \longrightarrow 1.0$ (ASCE 7-05 Table 7-3)

Occupancy Category: IV (ASCE 7-05 Table 1-1)

$I_s \longrightarrow 1.2$ (ASCE 7-05 Table 7-4)

Note: SNOW LOAD WILL NOT CONTROL IN ANY LOAD COMBINATION CASE

[3] Wind Loads

This section investigates the lateral loading, due to wind pressures, of the structural system. Figure 6 illustrates the various lateral force resisting systems used in the building. The original design wind load calculations are recorded in Appendix B.

3.1 Calculations

The following calculations follow the simplified procedure, as outlined in ASCE 7-05. The calculations that follow exist as a representative set of seismic design load calculations.

Table 3 - Wind Design Parameters

Design Parameter	Applicable Information
Occupancy Category	IV
Exposure Category	C
Basic Wind Speed (v)	150mph
Importance Factor (I)	1.15
Directionality Factor (K_d)	0.85
Topographic Factor (K_{zt})	1.0
Enclosure Classification	Enclosed Building

Gust Effect Factor

h =	113.0 ft
B =	62.5 ft
/z (0.6h) =	67.8 ft

Flexible structure if natural frequency < 1 Hz (T > 1 second).
However, if building h/B < 4 then probably rigid structure (rule of thumb).
h/B = 1.81 Therefore, probably rigid structure

Figure 3 - Building Dimensions vs. Rigidity

Rigid Structure

/ε =	0.20	
1 =	500 ft	
z_{min} =	15 ft	
c =	0.20	
g_Q, g_v =	3.4	
L_z =	577.4 ft	
Q =	0.88	
I_z =	0.18	
G =	0.87	use G = 0.85

Figure 4 - Gust Effect Factor Parameters

Surface Pressures (psf) / Surface	Wind Normal to Ridge (psf) B/L = 0.28		h/L = 1.81		Wind Parallel to Ridge (psf) L/B = 3.63			h/L = 0.50	
	Cp	q_hGC_p	w/+q_iGC_{pi}	w/-q_hGC_{pi}	Dist.*	Cp	q_hGC_p	w/ +q_iGC_{pi}	w/ -q_hGC_{pi}
Windward Wall (WW)	0.80	49.7	see table below			0.80	49.7	see table below	
Leeward Wall (LW)	-0.50	-31.1	-44.2	-17.9		-0.22	-13.6	-26.7	-0.4
Side Wall (SW)	-0.70	-43.5	-56.7	-30.3		-0.70	-43.5	-56.7	-30.3
Leeward Roof (LR)		**				Included in windward roof			
Windward Roof: 0 to h/2*	-1.04	-64.6	-77.8	-51.5	0 to h/2*	-0.90	-55.9	-69.1	-42.8
> h/2*	-0.70	-43.5	-56.7	-30.3	h/2 to h*	-0.90	-55.9	-69.1	-42.8
					h to 2h*	-0.50	-31.1	-44.2	-17.9
					> 2h*	-0.30	-18.6	-31.8	-5.5

Figure 5 - Wind Surface Pressure Parameters

Windward Wall Pressures at "z" (psf)

			Windward Wall			Combined WW + LW Normal to Ridge	Combined WW + LW Parallel to Ridge
z	Kz	Kzt	q_zGC_p	w/+q_iGC_{pi}	w/-q_hGC_{pi}	to Ridge	to Ridge
0 to 15'	0.85	1.00	32.5 psf	19.3 psf	45.7 psf	63.6 psf	46.1 psf
20.0 ft	0.90	1.00	34.5	21.4	47.7	65.6	48.1
25.0 ft	0.95	1.00	36.2	23.0	49.4	67.3	49.8
30.0 ft	0.98	1.00	37.6	24.4	50.8	68.7	51.2
40.0 ft	1.04	1.00	40.0	26.8	53.1	71.0	53.5
50.0 ft	1.09	1.00	41.9	28.7	55.0	73.0	55.5
60.0 ft	1.14	1.00	43.5	30.4	56.7	74.6	57.1
70.0 ft	1.17	1.00	45.0	31.8	58.1	76.0	58.5
80.0 ft	1.21	1.00	46.2	33.1	59.4	77.3	59.8
90.0 ft	1.24	1.00	47.4	34.2	60.6	78.5	61.0
100.0 ft	1.27	1.00	48.5	35.3	61.6	79.5	62.0
h= 113.0 ft	1.30	1.00	49.7	36.6	62.9	80.8	63.3

Figure 6 - Wind Pressures

<u>Note</u>: The above Figure 6 includes the windward wall pressures (in both the positive and negative interior pressure cases) as well as the combined windward wall and leeward wall pressures in both the (N-S) and (E-W) directions.

WIND LOADS

- Wind Design Criteria

Occupancy Category : IV (ASCE 7-05 Table 1-1)

Basic Wind Speed (3 sec. gust) : 150 mph (ASCE 7-05 Figure 6-1)

Exposure Category : C (ASCE 7-05 Chapter 6)

Importance Factor (I) : 1.15 (ASCE 7-05 Table 6-1)

Wind Directionality Factor (k_d) : 0.85 (ASCE 7-05 Table 6-4)

Topographic Factor (k_{zt}) : 1.0 (ASCE 7-05 6.5.7.2)

- Wind Parameter Investigation (calculate G)

Rigid or Flexible → Note: Rule of Thumb - if $h/B < 4$, then building probably rigid

$h/B = 113\text{ft.} / 62.5\text{ft} = 1.808 < 4 \therefore$ rigid

Due to rigidity, take $G = 0.85$ or calculate $G = 0.925\left((1 + 1.7 g_Q I_{\bar{z}} Q) / 1 + 1.7 g_v I_{\bar{z}}\right)$

$g_Q = g_v = 3.4$

$I_{\bar{z}} = c\left(33/\bar{z}\right)^{1/6} = 0.2\left(33/0.6(113)\right)^{1/6} = 0.177$

$Q = \sqrt{1/(1 + 0.63((B+h)/L_{\bar{z}})^{0.63})} = \sqrt{1/1 + 0.63((62.5 + 113)/577.45)^{0.63}} = 0.8779$

$L_{\bar{z}} = \ell\left(\bar{z}/33\right)^{\bar{\epsilon}} = 500\left(0.6(113)/33\right)^{(1/5.0)} = 577.45$

$G = 0.925\left((1 + 1.7(3.4)(0.177)(0.8779)) / 1 + 1.7(3.4)(0.177)\right) = 0.867 \rightarrow$ use $G = 0.85$

WIND LOADS (cont.)

- Example Calculation of "P"

at $z = 113'$

$q_h = 0.00256\, k_z k_{zt} k_d V^2$ where $k_z = 1.2925$

interpolate between

$= 0.00256(1.2925)(1)(0.85)(150)^2$ $z = 100$, $k_z = 1.26$

$z = 120$, $k_z = 1.31$

$= 63.3$

at $z = 93'$

$q_z = 0.00256\, k_z k_{zt} k_d V^2$ where $k_z = 1.246$

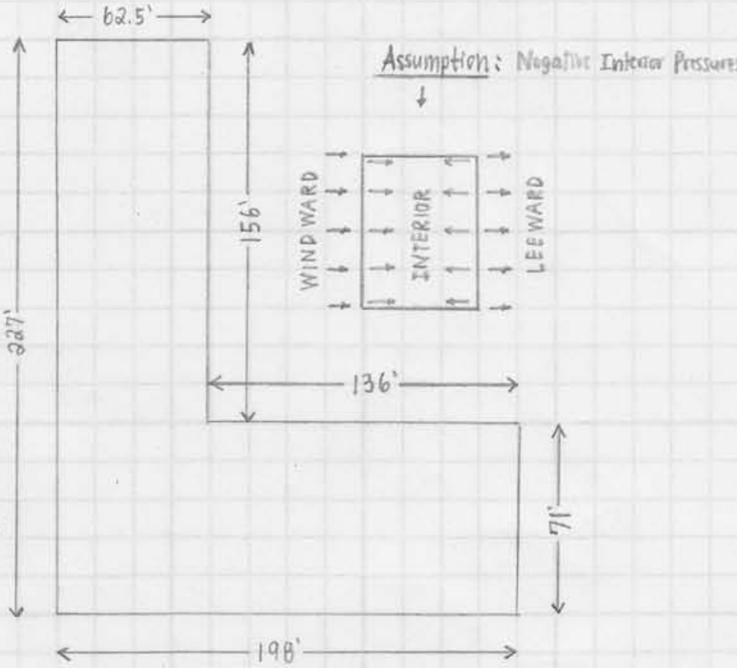
interpolate between

$= 0.00256(1.246)(1)(0.85)(150)^2$ $z = 90$, $k_z = 1.24$

$z = 100$, $k_z = 1.26$

$= 61.0$

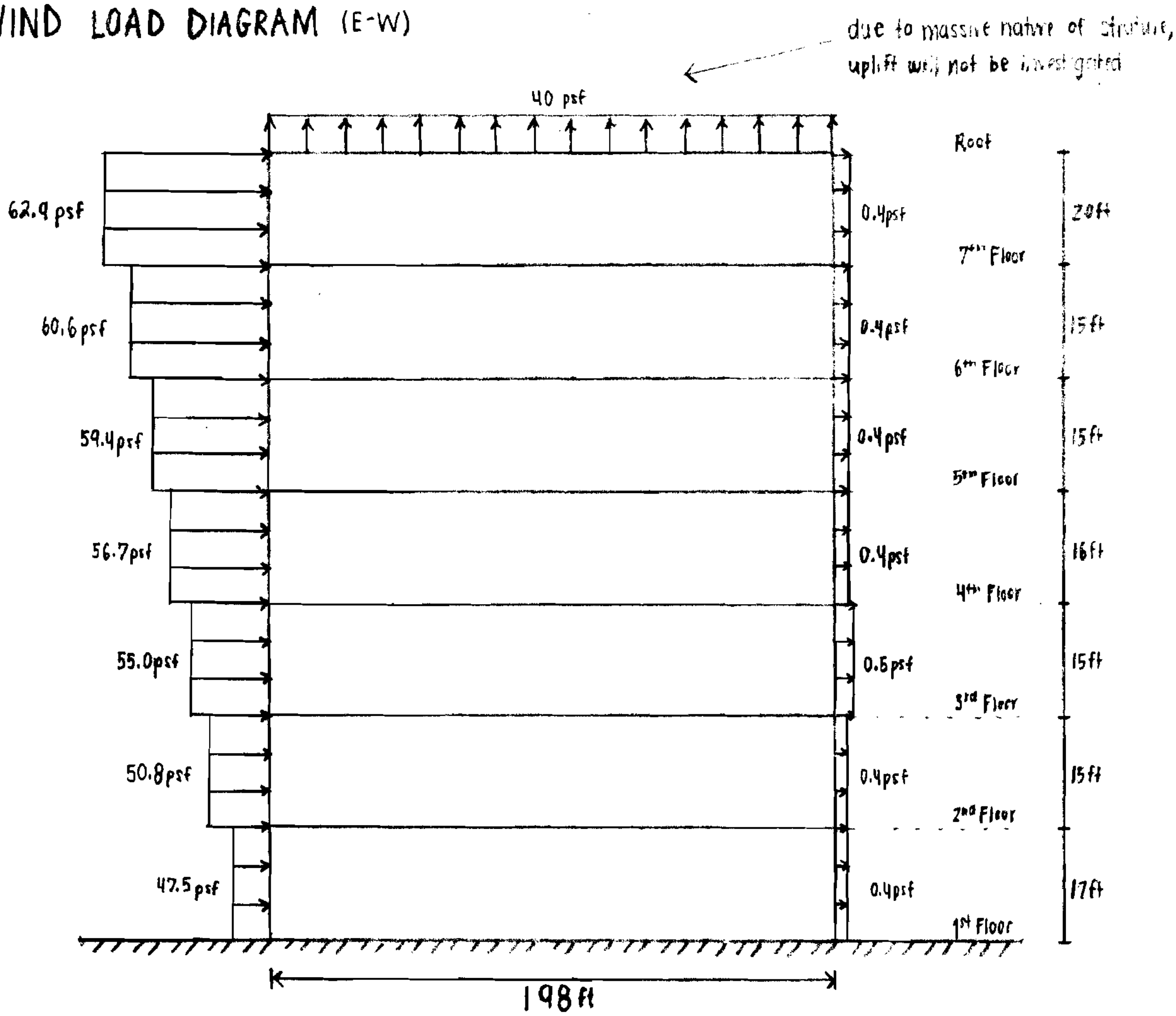
Building Plan - Inpatient Tower



$$P = q\,G C_p - q_i\,(GC_{pi}) = \underset{C_p,\ \text{windward}}{61(0.85)(0.8)} - \underset{\text{enclosed building}}{63.3(-0.18)} = 52.9\text{ k}$$

Note: See Wind Loading Diagram and Base Shear Calculations on next page.

WIND LOAD DIAGRAM (E-W)



Wind Base Shear (E-W) → Representative Calculation

(47.9 psf)(227')(17') + (51.2psf)(227')(15') + (55.5psf)(227')(15') + (57.1psf)(227')(16')

+ (59.8psf)(227')(15') + (61.0psf)(227')(15') + (63.4psf)(227')(20')

= 1468.55 k → 1470 k (Wind Loads control the lateral design of the building)

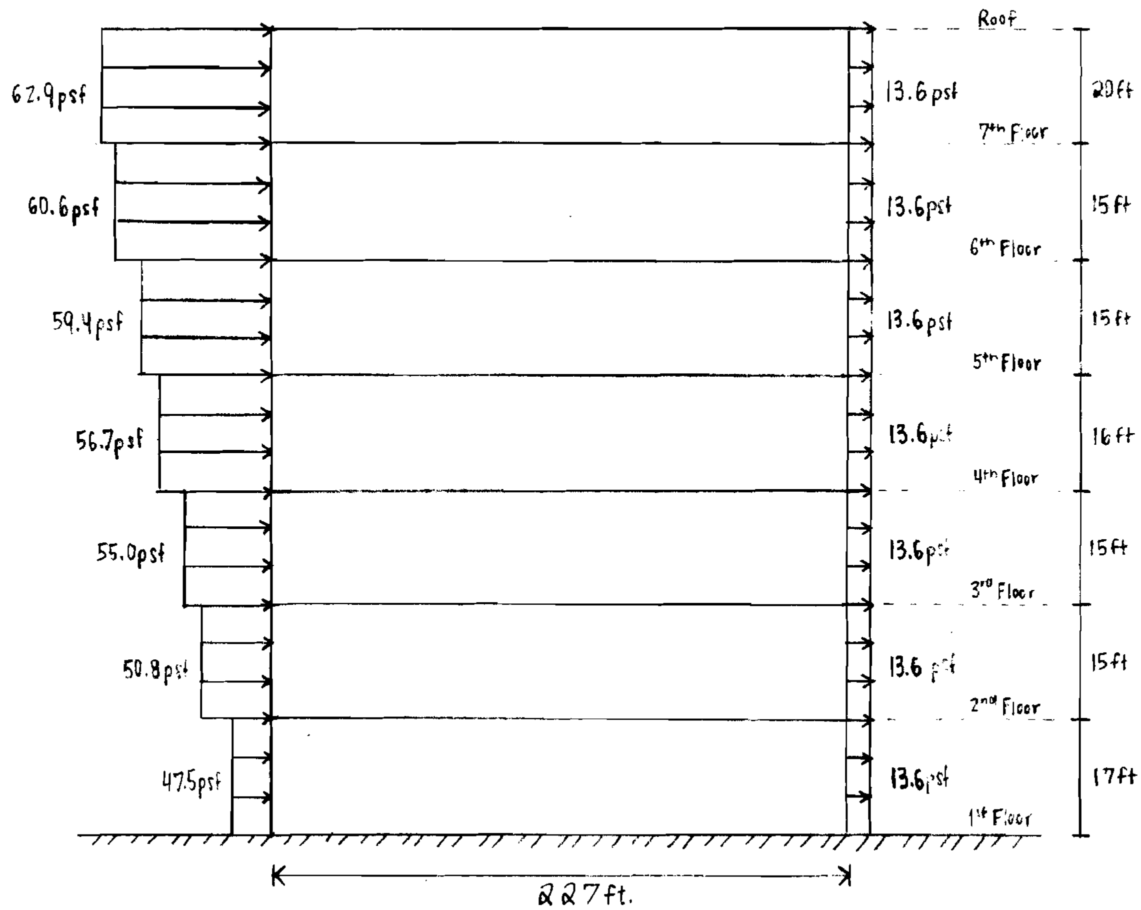
Note: Revision dated 11/13/2015 : Leeward wind pressures were determined w/o the consideration of interior pressure (GCpi); therefore the newly calculated leeward wind pressure is constant and is defined as the following:

leeward wind pressure = 16.2 psf (acting away from building surface)

(0.4 / 0.5 psf no longer applies for leeward pressures)

update Wind (E-W) Base Shear = 1736.4 K ⟷ invalidates base shear calculation (E-W) above

WIND LOAD DIAGRAM (N-S)



Wind Base Shear (N-S) → Representative Calculation

198.5 k + 197.5 k + 213.2 k + 219.8 k + 218.6 k + 261.7 k + 151.5 k

= 1460.8 k

* Calculated base shear based on the distribution of wind pressure along the whole length of the building face acted upon both ½ story below and ½ story above the story (level) in question

[4] Seismic Loads

This section investigates the lateral loading, due to seismic ground accelerations, of the structural system. Table 4 can be referenced for a list of lateral force resisting systems used in the building. The original design seismic load parameters and considerations are recorded in Appendix C.

Table 4 - Lateral Force Resisting Systems

LFRS	Direction of Resistance	R-Value
Intermediate Concrete Moment Frames	North-South	5
Intermediate Concrete Moment Frames	East-West	5

4.1 Calculations

The following calculations follow the Equivalent Lateral Force procedure, as outlined in ASCE 7-05. All ground motion parameters were determined referencing the USGS seismic design maps. The calculations that follow exist as a representative set of seismic design load calculations.

SEISMIC LOADS (ELF according to ASCE 7-05 Table 12.6-1)

- Design Criteria

Occupancy Category : IV (ASCE 7-05 Table 1-1)

Importance Factor (I_e) : 1.5 (ASCE 7-05 Table 11.5-1)

Soil Site Class : E (ASCE 7-05 11.4.2)

Seismic Design Category : C (ASCE 7-05 Table 11.6-2)

- Ground Motion Parameters and Calculations

S_s = 11.0% (USGS Ground Motion Parameter Application - verified by ASCE 7-05 EQ Ground Motion Maps)

S_1 = 4.8% (USGS Ground Motion Parameter Application - verified by ASCE 7-05 EQ Ground Motion Maps)

F_a = 2.5 (ASCE 7-05 Table 11.4-1)

F_v = 3.5 (ASCE 7-05 Table 11.4-2)

$S_{MS} = F_a S_s = (2.5)(0.11) = 0.275$

$S_{M1} = F_v S_1 = (3.5)(0.048) = 0.168$

$S_{DS} = (2/3) S_{MS} = (2/3)(0.275) = 0.183 \longrightarrow 18.3\%$

$S_{D1} = (2/3) S_{M1} = (2/3)(0.168) = 0.112 \longrightarrow 11.2\%$

- Lateral System - Intermediate Reinforced Concrete Moment Frames

Response Modification Factor (R) = 5 (ASCE 7-05 Table 12.2-1)

Overstrength Factor (Ω) = 3 (ASCE 7-05 Table 12.2-1)

Deflection Amplification Factor (C_d) = 4½ (ASCE 7-05 Table 12.2-1)

- Building Period Calculation

$T = C_t h_n^x = (0.016)(113)^{0.9} = 1.127s$ (ASCE 7-05 Table 12.8-2)

$T_L = 12s$ (ASCE 7-05 Figure 22-15)

$T < T_L$ ∴ use $C_s = S_{DS}/(R/I_e) \leq S_{D1}/(R/I_e)(T)$

SEISMIC LOADS (continued)

- Seismic Response Coefficient

$C_s = S_{DS}/(R/I_e) = 0.183/(5/1.5) = 0.0549 \leq C_s = S_{D1}/(R/I_e)(T) = 0.112/(5/1.5)(1.127) = 0.0298$

Use $C_s = 0.0298$

- Total Dead Load (W) = Dead Load + 20% snow load (on roof) for $P_s \geq 30psf$ (in this case, snow load not relevant)

Roof Load: $W_{RF} = [(226.92' \times 62.41') + (136' \times 71.17')](90psf) + (226.92' + 62.41' + 155.75' + 136' + 71.17' + 198.41')(20'/2)(62.5psf)$
$= 2677353 lb = 2677.353 k$

Floor Load: $W_{FL} = [(226.92' \times 62.41') + (136' \times 71.17')](110psf)(7) + (226.92' + 62.41' + 155.75' + 136' + 71.17' + 198.41')(103')(62.5psf)$
$= 23833693 lb = 23833.693 k$

Total Load: $W_{RF} + W_{FL} = 2677.353k + 23833.693k = 26511 k$

- Seismic Base Shear

$V = C_s W = (0.0298)(26511k) = 790 k$ (Seismic Loads do not control the lateral design of the building)

For C_{vx} calculations:

$W_2 = [(226.92' \times 62.41') + (136' \times 71.17')](110psf) + (850.66')(17/2 + 15/2)(62.5psf) = 3473.170$

$W_3 = (23841 ft^2)(110 psf) + (850.66')(15/2 + 15/2)(62.5 psf) = 3420.004k$

$W_4 = (23841 ft^2)(110 psf) + (850.66')(15/2 + 16/2)(62.5 psf) = 3446.587k$

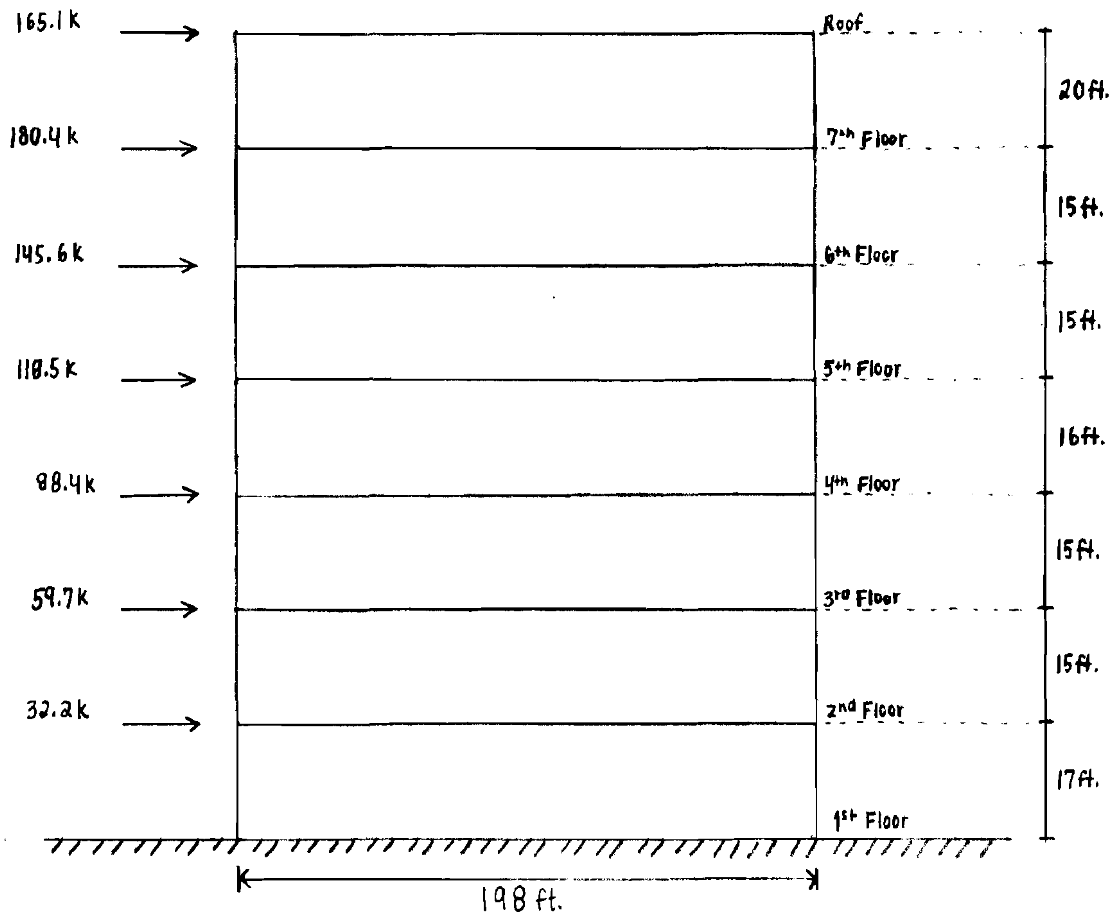
$W_5 = (23841 ft^2)(110 psf) + (850.66')(16/2 + 15/2)(62.5 psf) = 3446.587k$

$W_6 = (23841 ft^2)(110 psf) + (850.66')(15/2 + 15/2)(62.5 psf) = 3420.004k$

$W_7 = (23841 ft^2)(110 psf) + (850.66')(15/2 + 20/2)(62.5 psf) = 3552.919k$

$W_{Roof} = (23841 ft^2)(90 psf) + (850.66')(20/2)(62.5 psf) = 2677.353k$

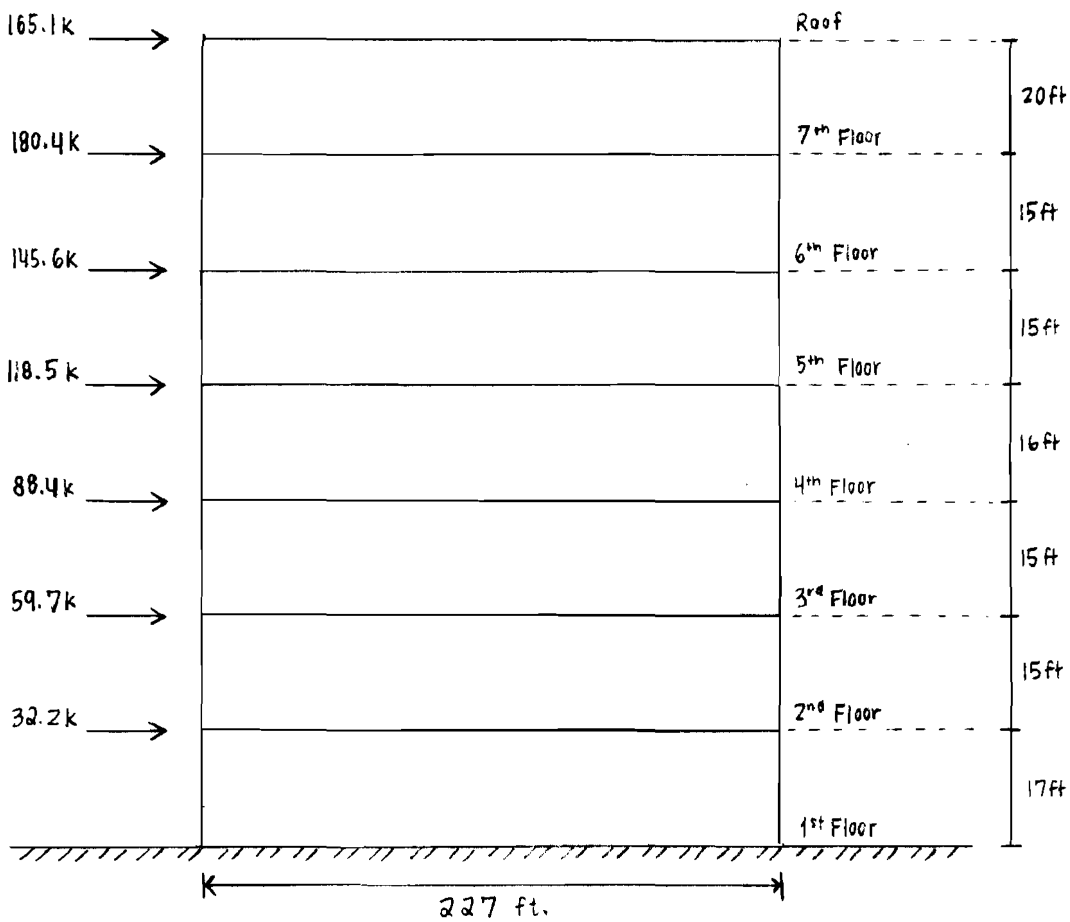
SEISMIC LOAD DIAGRAM (E-W)



Find Story Weights

Level	$C_{vx} = W_x h_x^k / \sum_{i=1}^{n} w_i h_i^k$ where $\sum_{i=1}^{n} w_i h_i^k = 1447231$ (in this case)
2	$C_{vx} = (3473)(17)/1447231 = 0.0408 \times 790k = 32.2k$
3	$C_{vx} = (3420)(37)/1447231 = 0.0756 \times 790k = 59.7k$
4	$C_{vx} = (3446)(47)/1447231 = 0.1119 \times 790k = 88.4k$
5	$C_{vx} = (3446)(63)/1447231 = 0.1500 \times 790k = 118.5k$
6	$C_{vx} = (3420)(78)/1447231 = 0.1843 \times 790k = 145.6k$
7	$C_{vx} = (3553)(93)/1447231 = 0.2283 \times 790k = 180.4k$
Roof	$C_{vx} = (2677)(113)/1447231 = 0.2090 \times 790k = 165.1k$

SEISMIC LOAD DIAGRAM (N-S)



Note: Seismic loading of building structures involves the seismic ground acceleration, rigidity of the building, weight of the building, and [illegible] of the [illegible]. Due to the fact that changing orientation of the loading (E-W vs. N-S) does not alter any one of these properties listed above, the building experiences the same seismic loading in both the E-W and N-S directions.

[5] Flood Loads

Due to the region's environmental conditions, the building is required to withstand flood design loads. The building was designed for hydrodynamic flow per ASCE 24-05. An assumed flood elevation was established at 15 ft. above mean sea level, and the flow velocity was considered to be 10 ft./sec. The advisory base flood elevation map as well as the flood insurance rate map were utilized in the consideration of imposed flood loading on the building.

Due to the scope of the report, no further discussion or consideration of flood loading will take place. The omission of flood loading is in direction response to the scope of the report and does not exist as a commentary on the importance of flood loading consideration within the design conditions of this building.

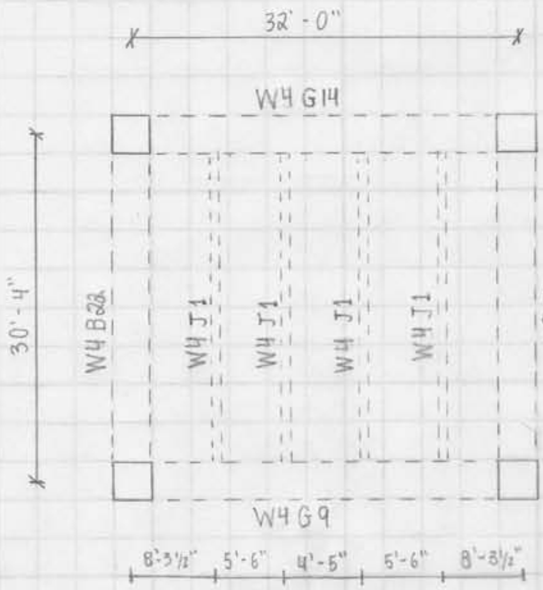
[6] Typical Member Spot Checks for Gravity Loads

This section investigates typical member design for gravity loads applied to the The Medical Center's existing gravity load resisting system. Spot checks will be performed for both strength and serviceability requirements. The spot checks include investigation of the following conditions: slab investigation (in conjunction with pan-joist investigation), joist moment capacity, beam moment capacity, girder moment capacity and deflection limits, and column axial capacity (for an interior and exterior column).

6.1 Calculations

The following calculations exist as spot checks for gravity loads applied to typical members in the building's existing gravity framing system. The calculations that follow exist as a representative set of spot check calculations.

GRAVITY LOAD SPOT CHECKS - typical members for existing gravity framing system



TYPICAL BAY FRAMING

W4 = west tower, 4th floor
J1 = joist one
B22 = beam twenty-two
G9 = girder nine
G14 = girder fourteen

Mark	Width	Depth	Bot. Bars	Top Bars	Stirrups
W4 J1	8"	21.25"	(2) #8	(2) #6	-
W4 B22	35"	21.25"	(4) #9	(4) #9	(19) @ 4"
W4 G9	42"	21.25"	(7) #7	(6) #9	(19) @ 4"
W4 G14	32"	30"	(6) #8	(6) #9	(15) @ 6"

*Note: all stirrups are #4 bars in size

Dead Loads

Slab = ... : 65 psf

Beams = ... : 10 psf (5 psf beam / 5 psf girder)

Ceiling = ... : 2 psf

Finishes = ... : 2 psf

Misc/Equip/Mech/Collateral = ... : 5 psf

Total : 84 psf

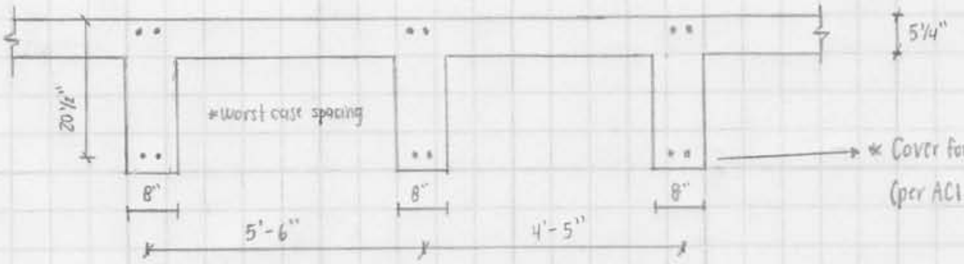
Live Loads

Cooridors (above 1st floor) ...... : 80 psf ← Controlling LL case

Patient Rooms .... : 40 psf

Joist Spot Check (W4J1)

Note: due to pan-joist configuration, treat section as a T-beam and analyze appropriately



* Cover for joist w/ bar size ≤ 11 : 3/4" (per ACI 318 §7.7)

Note: pan joist configuration is tapered (w/ 8" b_w at bottom - tapered end of section) ∴ for simplification and conservatively, a rectangular joist section will be analyzed, w/ a continuous b_w = 8" throughout height of the section

b_w = 8 in
d = 20.5 in
$t_s = h_f$ = 5.25 in

f'_c: 4000 psi = 4 ksi
f_y = 60,000 psi = 60 ksi

Effective Flange Width (b_e)

$b_e = \min \begin{cases} 2(8h_f) + b_w = 2(8 \times 5.25") + 8" = 92" \\ \text{span}/4 = 364"/4 = 91" \\ b_w + \text{clear spacing} = 8" + 58" = 66" \leftarrow \text{controlling } b_e \end{cases}$

Existing Gravity Framing System:

joist details

dimension: depth = 21.25", width = 8"

reinforcement: top: (2) #6, bot: (2) #8, stirrups/transverse: none

spacing: typ. 5½' o.c. (special spacing conditions noted on plans)

Joist Reactions

$1.2D + 1.6L = 1.2(74) + 1.6(80) = 217$ psf OR $1.4D = 1.4(74) = 104$ psf

217 psf (5.5 ft) = 1194 plf = 1.194 klf ↑ Controlling Case

104 psf (5.5 ft) = 574 plf = 0.574 klf

Reaction = 1.194 klf × (30.333) = 36 k

* for sake of simplicity, assume all spacing to be worst case spacing of 5.5 ft between pan joists

Live Load Reductions

joists: do not qualify for live load reduction because $K_{LL} A_T$ equates to $2(5.5)(30.333) = 333.67\ ft^2 < 400 ft^2$

beams: $L_i = \begin{cases} 0.5(80) = 40 psf \\ 80(0.25 + 15/\sqrt{30.333 \times 64}) = 49 psf \end{cases}$ where $30.333 \times 64 = 1941 > 400$

girders: $L_i = \begin{cases} 0.5(80) = 40 psf \\ 80(0.25 + 15/\sqrt{32 \times 40.833}) = 54 psf \end{cases}$ where $32 \times 40.833 = 1307 > 400$

Joist Moment Calculations - use $D_{Total} - D_{Beams} = 84 - 10 = 74 psf$

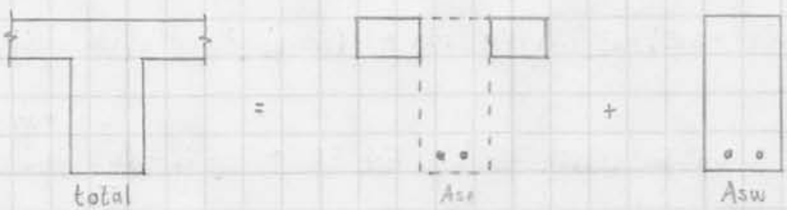
* $1.2D + 1.6L = 1.2(74) + 1.6(80) = 217 psf$

$217 psf\ (5.5 ft) = 1194\ plf = 1.194\ klf$ ← controlling case

* $1.4D = 1.4(74) = 104 psf$

$104 psf\ (5.5 ft) = 574\ plf = 0.574\ klf$

* $M_u = wl^2/8 = 1.194(30.333)^2/8 = 137\ ft\cdot k \times 12 in/ft = 1644\ k\text{-}in$



*Analyze pan joist configuration like a T-section beam (RC)

Assuming $\phi = 0.9$ (tension) - check regular RC section first

$M_n = M_u/\phi = A_s f_y (d - a/2) \Rightarrow A_s = 1644/0.9 \times 60 \times (20.5 - (5.25/2)) = 1.70 in^2$

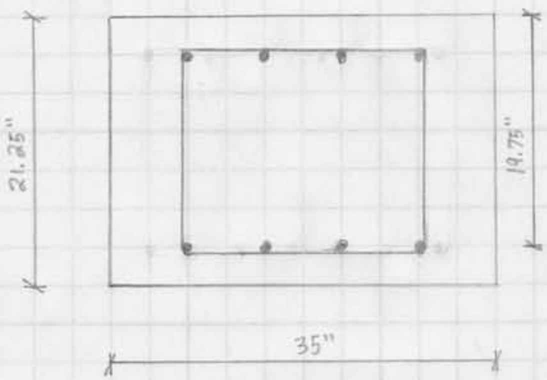
$0.85 f'_c a b = T = A_s f_y \Rightarrow a = A_s f_y / 0.85 a b = (1.70)(60)/0.85(5.25)(8) = 2.86'' < h_f = 5.25''$ ∴ compression zone remains in the flange (slab)

Bot. Bars: (2) #8 : $A_s = 2(0.79) = 1.58 in^2 < 1.70 in^2$ (but loads were calculated very conservatively) → (2) #9

Top Bars: (2) #6 : $A_s = 2(0.44) = 0.88 in^2 > A_{s,min} = [3\sqrt{4000}/60000](8)(20.5) = 0.52 in^2$

Beam Spot Check (W4B22)

Note: due to regularity of beam section, the beam will be analyzed as a rectangular RC section



Top Bars: : (4) #9 = $4in^2$

Bottom Bars: : (4) #9 = $4in^2$

Stirrups: : (19) #4 @ 4" o.c.

*Note: concrete reinforcement cover = 1½" per ACI 318 §7.7

$0.85 f'_c ab + A_s' f_s' = A_s f_y$

$\downarrow$

$0.85 f'_c \beta_1 cb + A_s' (0.003(c-d')/c)(E) = A_s F_y$

$0.85(4)(0.85)c(35) + 4(0.003(c-1.5)/c)\,29000 = 4(60)$

$101.15c + (0.012 - 0.018/c)\,29000 = 240$

$101.15c^2 + 348c - 762 = 0 \longrightarrow c = 1.52in \rightarrow a = \beta_1 c = 0.85(1.52) = 1.30in$

$\varepsilon_s = 0.003(d-c)/c = 0.003(19.75-1.52)/1.52 = 0.035 > 0.005$ ✓

$\varepsilon_s' = 0.003(c-d')/c = 0.003(1.52-1.5)/1.52 = 3.947\times10^{-5} < 0.005$ ✗ does not yield

$M_{n1} = A_{s1} f_y (d - a/2) = 4(60)(19.75 - 1.3/2) = 4584\ k \cdot in = 382\ k \cdot ft$

$M_{n2} = A_{s2} f_y (d-d') = A_s' f_s' (d-d') = 4(60)(19.75-1.5) = 4380\ k \cdot in = 365\ k \cdot ft$

$M_n = 382\ k \cdot ft + 365\ k \cdot ft = 747\ k \cdot ft$

$\phi M_n = 0.9(747) = 672\ k \cdot ft$

Beam Moment Calculations - use $D_{Total} - D_{Girder} = 84 - 5 = 79 psf$

* $1.2D + 1.6L = 1.2(79) + 1.6(48) = 172$ psf

172 psf $(8.29167) = 1426$ plf $= 1.426$ klf ← controlling case

* $1.4D = 1.4(79) = 111$ psf

111 psf $(8.29167) = 920$ plf $= 0.920$ klf

* $M_u = w l^2/8 = (1.426)(30.333)^2/8 = 164$ ft·k $\times 12$ in/ft $= 1968$ k·in

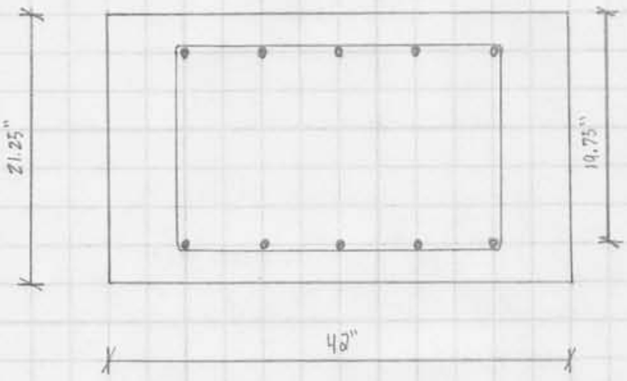
$\phi M_n = 672$ k·ft $> M_u = 164$ k·ft ✓

Reinforcement Check

$A_{s,min} = 3\sqrt{4000}\,/60000\,(35)(19.75) = 2.19 in^2 < 4 in^2$ ✓

Girder Spot Check - spot check only one girder case (W469)

Note: due to regularity of girder section, the girder will be analyzed as a rectangular RC section



Top Bars: (6) #9 = $6 in^2$

Bottom Bars: (7) #7 = $4.2 in^2$

Stirrups: (14) #4 @ 4" o.c.

* Note: concrete reinforcement cover = 1 1/2" per ACI 318 §7.7

$0.85 f'_c a b + A_s' f_s' = A_s f_y$

$0.85 f'_c \beta_1 c b + A_s' (0.003 (c-d')/c) E = A_s f_y$

$0.85 (4)(0.85) c (42) + 6 (0.003 (c-1.5)/c) 29000 = 4.2 (60)$

$121.38c + 522 - 783/c = 252$

$121.38c^2 + 270c - 783 = 0 \rightarrow c = 1.66 in \rightarrow a = \beta_1 c = (0.85)(1.66) = 1.41 in$

$\varepsilon_s = 0.003 (d-c)/c = 0.003 (19.75 - 1.66)/1.66 = 0.0327 > 0.005$ ✓

$\varepsilon_s' = 0.003 (c-d')/c = 0.003 (1.66-1.5)/1.66 = 2.892 \times 10^{-4} < 0.005$ × does not yield

$M_{n1} = A_{s1} f_y (d - a/2) = 4.2 (60)(19.75 - 1.41/2) = 4800\ k \cdot in / 12 = 400\ k \cdot ft$

$M_{n2} = A_{s2} f_y (d - d') = A_s' f_s' (d-d') = 6 (60)(19.75 - 1.5) = 6570\ k \cdot in / 12 = 547.5\ k \cdot ft$

$M_n = 400 + 547.5 = 947.5\ k \cdot ft$

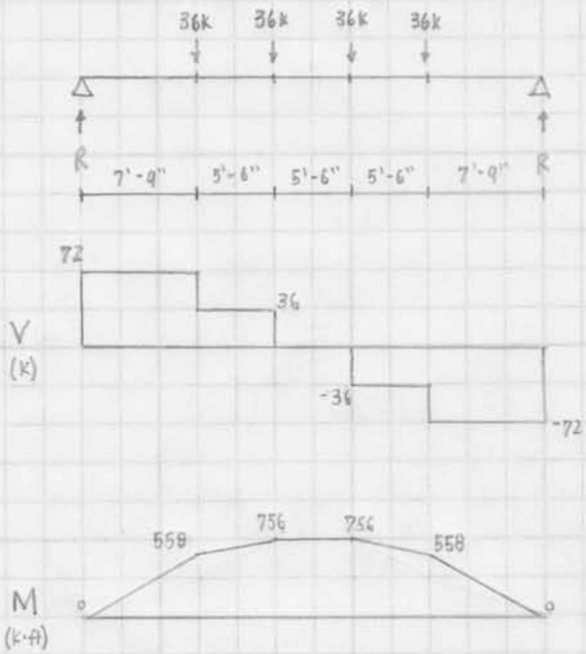
$\phi M_n = 0.9 (947.5) = 853\ k \cdot ft$

$M_u = 756\ k \cdot ft < \phi M_n = 853\ k \cdot ft$ ✓

$A_{s,min} = 3 \sqrt{4000} (42)(19.75) / 60000 = 2.62 in^2 < 4.2 in^2$ ✓

Girder Moment Calculations

Assumption: joist collect gravity load and distribute to girder by applying a concentrated point load
(standard assumption throughout all design alternatives involving girder framing)



M_u = 756 k·ft < ϕM_n = 853 k·ft ✓

Dead Load

74 psf (from previous joist calculations)

Live Load

80 psf (from previous joist calculations)

Point Loads

$P = [1.2(74) + 1.6(80)](5.5\text{ ft})(30.333\text{ ft}) / 1000\text{ lb/k} = 36\text{ k}$

Reactions

$R = 4(P)/2 = 4(36)/2 = 72\text{ k}$

Girder Deflection Calculations

(from previous)

$\Delta_{limit} = L/360 = 32(12in/ft)/360 = 1.067in$ $\quad$ $(74psf + 80psf)5.5ft \times 38.333ft = 25.7k / 32ft = 0.802klf$

$\Delta_{actual} = 5w\ell^4/384EI$ where $w = 0.802 klf$, $\ell = 32ft$ $(384in)$, $E = 29000ksi$, $I = bh^3/12 = 42(21.25)^3/12 = 33585 in^4$

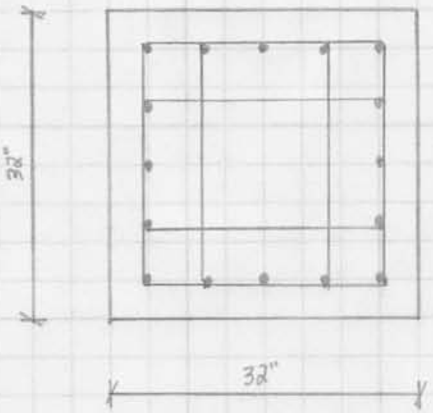
$= 5(0.802)(384)^4/384(29000)(33585)$

$= 0.233in < 1.067in$ ✓

Note: due to member section properties, flexural bending will be the controlling failure mode ∴ shear is not investigated due to efficiency of report

Column Spot check - interior

Typical Column (interior) at base of building : Type V



Longitudinal: (16) #10 = 20.32 in² } reinforcement   5ksi = concrete

Transvers: #4 @ 8"

Height of Column : 17 ft ← longest unbraced length
(story)

Per ACI 318 S.10.3.6.2:

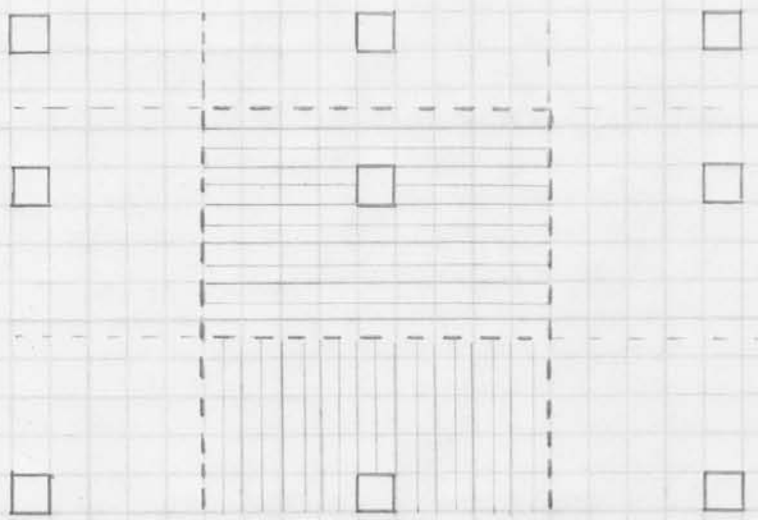
$\phi P_{n,max} = 0.8\,\phi\,[0.85 f'c\,(Ag - Ast) + Ast\,fy]$ (eq. 10-2)

$= 0.8(0.65)\,[0.85(5)\,(32\times32 - 20.32) + 20.32(60)]$

$= 2852\text{k}$

Column Axial Calculations - interior

Typical Column (interior) at base of building : Type V



Interior Column Trib. Area

32'-0" x 20'-5"

Exterior Column Trib. Area

32'x0" x 15'-2"

Story	Dead (psf)	Live (psf)	Area (sf)
roof	90	50	653
7	85	80	653
6	85	80	653
5	85	80	653
4	85	80	653
3	85	80	653
2	85	80	653

LL Reduction: $80(0.5) = 40$ ← use 40 psf (can only reduce 50%)

max $80(0.25 + 15/\sqrt{653(6)}) = 39.17$

min roof live load per structural notes in CD's

$P_u = [1.2(85) + 1.6(40)](6)(653) + [1.2(90) + 1.6(50)](653) =$

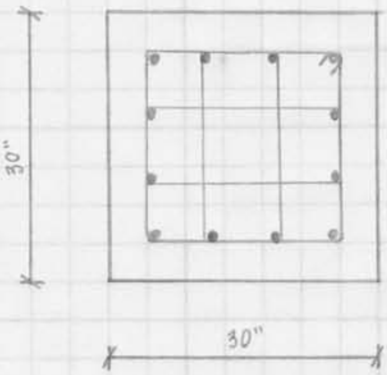
$= 650388 + 122764$

$= 773152 / 1000 = 773\text{k}$

$\emptyset P_n = 2852\text{k} > P_u = 773\text{k}$ ✓

Column Spot Check - exterior

Typical Column (exterior) at base of building: Type III



Longitudinal: (12) #9 = 9 in^2 } reinforcement

Transverse: #4 @ 8"

5 ksi = concrete

Height of Column (story) : 17 ft ← longest unbraced length

Per ACI 318 S10.3.6.2 :

$\phi P_{n,max} = 0.8\,\phi\,[0.85\,f'_c\,(A_g - A_{st}) + A_{st} f_y]$ (eq. 10-2)

$= 0.8\,(0.65)\,[0.85\,(5)\,(30 \times 30 - 9) + 9(60)]$

$= 2250$ k

Column Axial Calculations - exterior

Typical Column (exterior) at base of building: Type III

(see previous page - interior column - for diagram and information on tributary area)

Story	Dead (psf)	Live (psf)	Area (sf)	Facade (psf)	Facade Area (sf)
roof	90	50	485	43.4	640
7	85	80	485	43.4	480
6	85	80	485	43.4	480
5	85	80	485	43.4	512
4	85	80	485	43.4	480
3	85	80	485	43.4	480
2	85	80	485	43.4	544

Exterior Glazed Framing System (GFS) = 20 psf

Average % of wall area covered by fenestration = 45% $\therefore$ $0.45(20) + 0.55(62.5) = 43.38$ psf ≈ 43.4 psf

LL Reduction: $80(0.5) = 40$

max $80(0.25 + 15/\sqrt{485(6)}) = 42.25$ psf

$P_u = [1.2(85) + 1.6(42.25)](6)(485) + [1.2(90) + 1.6(50)](485) + (544 + 512 + 640 + (480 \times 4))(43.4)(7)(1.2)$

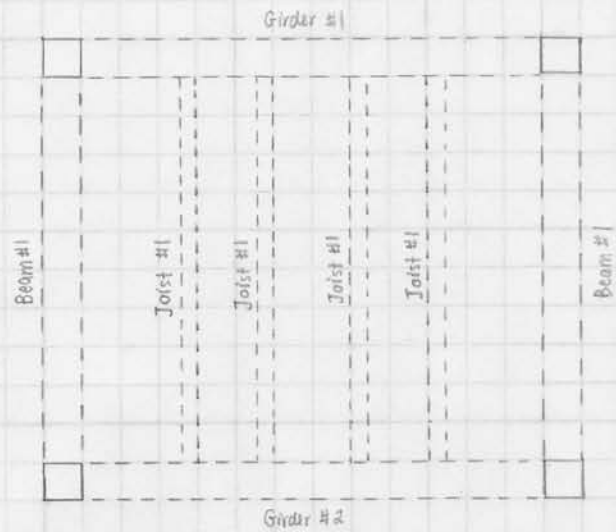
$= 403536 + 91180 + 1318249$

$= 1902965 / 1000 = 1903$ k

$= 1903$ k

$\phi P_n = 2250$ k $> P_u = 1903$ k ✓

Summary: Concrete Slab w/ Pan Joists



Framing Assembly: 5 1/4" NWC slab w/ 16" deep wide module NWC pan joists @66" o.c. (typ) unless otherwise noted

Joist #1: 8" wide x 21.25" deep

(2) #8 bottom reinforcement
(2) #6 top reinforcement

Beam #1: 35" wide x 21.25" deep

(4) #9 bottom reinforcement
(4) #9 top reinforcement
(19) #4 @ 4" o.c. stirrups

Girder #1: 32" wide x 30" deep

(6) #8 bottom reinforcement
(6) #9 top reinforcement
(15) #4 @ 6" o.c. stirrups

Girder #2: 42" wide x 21.25" deep

(7) #7 bottom reinforcement
(6) #9 top reinforcement
(19) #4 @ 4" o.c. stirrups

[7] Alternate Framing Systems for Gravity Loads

This section investigates three alternate framing systems for gravity loads within The Medical Center. This study is performed in order to determine the best approach to further consider an alternative system redesign. All assumptions and evaluation criteria may be seen directly below or within the body of the calculation package.

7.1 Assumptions

The following calculations are representative of a typical bay design for three alternate gravity framing systems. Using ultimate strength design, the following alternate systems were designed under pure gravity loading (vertical dead and live loads). The typical bay utilized for design of alternate systems reflects a typical bay within the existing design of The Medical Center. Column design was not considered during the design of alternate gravity framing systems.

7.2 System Comparison

An evaluation of each gravity framing system considered within the scope of this report was performed in order to determine the most appropriate system. The systems involved in comparison are the following: concrete slab with pan joist framing system, non-composite steel framing system, composite steel framing system, and two-way flat plate concrete slab system. The criteria considered for use in the system comparison are as follows: weight, depth, cost, fire protection, and fire rating.

Table 5 - System Comparison

Criteria	**Concrete Slab w/ Pan Joists**	**Non-Composite Steel Framing**	**Composite Steel Framing**	**2-Way Flat Plate Concrete Slab**
Weight (psf)	75	63	64	150
Depth	30”	24”	21”	12”
Cost	$11.32/SF	$9.69/SF	$12.34/SF	$17.12/SF
Fire Protection	None	None	None	None
Fire Rating	4 Hr	2 Hr	1 Hr	4 Hr

Note: Cost comparison data extracted from RS Means Building Construction Cost Data (2015)

7.3 Decision Matrix

The decision matrix is organized to compute a weighted-value corresponding to the efficiency and appropriateness of each gravity framing system design. The decision matrix assigns values, on a scale of 1 to 4, depending on the performance of the system for the given criteria. A value of 1 represents poor performance, and a value of 4 represents exceptional performance. Each value can only be used once per each criterion (exception: durability).

Table 6 - Decision Matrix

Criteria	Importance Factor	Concrete Slab w/ Pan Joists	Non-Composite Steel Framing	Composite Steel Framing	2-Way Flat Plate Concrete Slab
Weight - Site	1.25	2	4	3	1
Weight - Uplift	1.25	3	1	2	4
Constructability	1.00	1	4	2	3
Cost	1.50	3	4	2	1
Fire Resistivity	1.00	3	2	1	4
Durability	1.00	2	2	2	2
		16.75	20.25	14.25	16.75

7.4 Calculations

The following design calculations are representative of the design of a typical bay for three alternate gravity framing systems. Each system-specific calculation follows the same sequence of calculation:

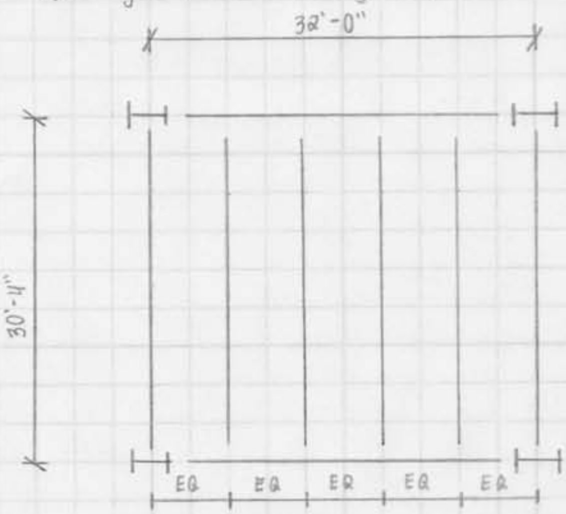
- Layout/Sketch of Typical Bay
- Determination of Loading Conditions
- Slab/Deck Design or Check
- Joist/Beam Design or Check
- Girder Design or Check
- Design Summary

The calculation packages for each alternate system can be seen below. The order of presentation of these calculations follows the order of presentation of these systems throughout the body of the report thus far.

ALTERNATE SYSTEM STUDY - non-composite steel framing system

Purpose: analyze steel framing option to improve economy (consideration of poor soil conditions - heavy vs. light structure)

Note: girder and beam framing configuration will remain the same, except beam spacing will be equal across the bay (typ.)



TYPICAL BAY FRAMING - non-composite

Selection of Deck Assembly: acheive at least a 2hr - fire rating (mission critical space - ICU) - life safety

Original Slab Assembly: 5 1/4" concrete slab

* Use Vulcraft 2 C Conform → 2C22 non-composite deck w/ 6x6 - W2.9 x W2.9 WWF
w/ 3.5 in NWC topping (total slab depth: 5.5in > 5.25in)

Dead Load

Deck Assembly : .... : 56 psf

Beams : .... : 5 psf

Girders : .... : 2 psf

Finishes : .... : 2 psf

Misc/Equip/Mech/Collateral : .... : 5 psf

Total: 70 psf (or 68 psf w/o girders → beam condition)

Live Load

Corridors (above 1st floor) ... : 80 psf ← Controlling LL case

Patient Rooms : .... : 40 psf

LL Reductions (see previous pages for calculations) → conservative due to original spacing configuration

Beam Condition : 48 psf
Girder Condition : 54 psf

Beam Design

Find Mu : $1.2(D) + 1.6(L) = 1.2(68) + 1.6(48) = 158.4\text{psf} \approx 160\text{psf} \rightarrow 160(6.4) = 1024 = 1.024\text{klf}$

$1.4(D) = 1.4(68) = 95.2\text{ psf}$

$M_u = wl^2/8 = (1.024)(30.333)^2/8 = 117.78 \approx 118\text{ k}\cdot\text{ft}$

$M_u = \phi M_n \rightarrow M_n = M_u/\phi = 118/0.9 = 131\text{ k}\cdot\text{ft}$

Try W12x26 $\rightarrow \phi M_{px} = 140\text{ k}\cdot\text{ft}$ (Table 3-2)

Check LL Deflections → distributed Load

$w_{LL} = 48(6.4) = 307\text{ plf}$

$\Delta_{LL} = 5wl^4/384EI = 5(0.307)(30.333)^4(1728)/384(29000)(204) = 0.988\text{in}$

$\Delta_{allow} = l/360 = 30.333 \times 12/360 = 1.01\text{in} > 0.988\text{in}$ ✓

Check TL Deflections → distributed Load

$w_{TL} = (68+49)(6.4) = 743\text{ plf}$

$\Delta_{TL} = 5wl^4/384EI = 5(0.743)(30.333)^4(1728)/384(29000)(204) = 2.39\text{in}$

$\Delta_{allow} = l/240 = (30.333 \times 12)/240 = 1.52\text{in} < 2.39\text{in}$ ✗

Try W16x31

Check LL Deflections → distributed Load

$w_{LL} = 307\text{plf}$

$\Delta_{LL} = 5wl^4/384EI = 5(0.307)(30.333)^4(1728)/384(29000)(375) = 0.53\text{ in}$

$\Delta_{allow} = l/360 = 30.333 \times 12/360 = 1.01\text{ in} > 0.53\text{ in}$ ✓

Check TL Deflections → distributed Load

$w_{TL} = 743\text{plf}$

$\Delta_{TL} = 5wl^4/384EI = 5(0.743)(30.333)^4(1728)/384(29000)(375) = 1.31\text{in}$

$\Delta_{allow} = l/240 = 30.333 \times 12/240 = 1.52\text{in} > 1.31\text{in}$ ✓

Weight Check → $31/6.4 = 4.84\text{ psf} < 5\text{ psf}$ ✓

Summary: Use W16x31 sections for beams

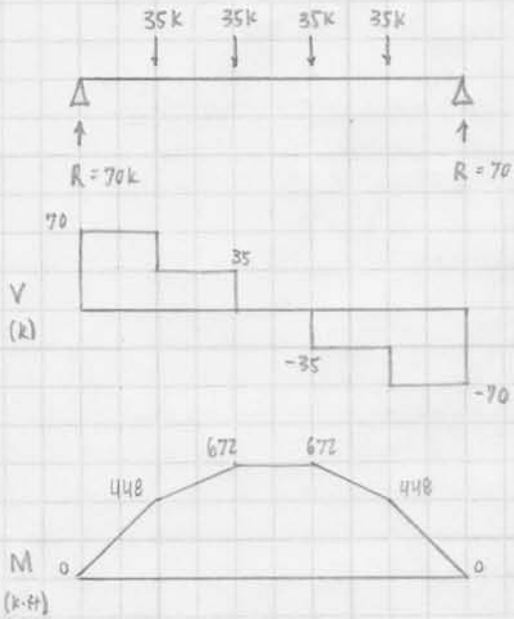
Girder Design

Point Loads:

$P_{LL} = 54(6.4)(32) = 11.1k$

$P_{DL} = 70(6.4)(32) = 14.3k$

$P_u = 1.2(14.3) + 1.6(11.1) = 34.92k = 35k$



where $R = 4(35)/2 = 70k$

Try W24×76 → $\phi M_{px} = 750\text{ k·ft} > M_u = 672\text{ k·ft}$

Check Wet Concrete Deflections → $w_{wc} = 56(6.4) + 31 = 390\text{ plf} = 0.390\text{ klf}$

$\Delta_{wc} = 5wl^4/384EI = 5(0.390)(30.333)^4(1728)/384(29000)(375) = 0.68\text{in}$

$\Delta_{allow} = l/360 = 32 \times 12/360 = 1.067\text{in} > 0.68\text{in}$ ✓

Check LL Deflections → $w_{LL} = 11.1/32 = 0.35\text{ klf}$

$\Delta_{LL} = 5wl^4/384EI = 5(0.35)(32)^4(1728)/384(29000)(2100) = 0.14\text{in}$

$\Delta_{allow} = l/360 = 32 \times 12/360 = 1.067\text{in} > 0.14\text{in}$ ✓

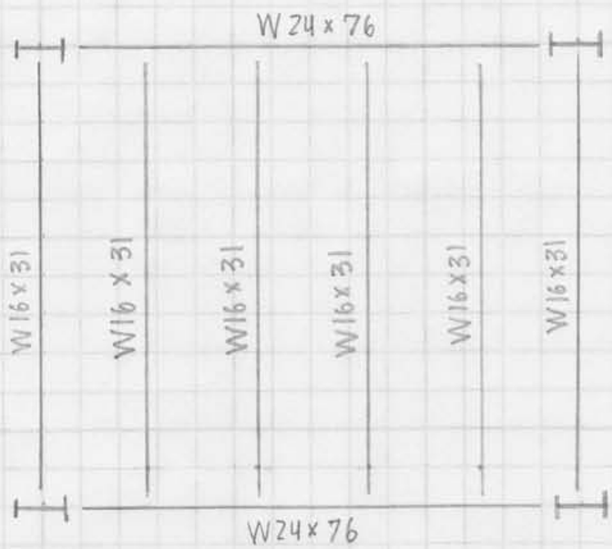
Check TL Deflections → $w_{TL} = (11.1 + 14.3)/32 = 0.73\text{ klf}$

$\Delta_{TL} = 5wl^4/384EI = 5(0.73)(32)^4(1728)/384(29000)(2100) = 0.28\text{in}$

$\Delta_{allow} = l/240 = 32 \times 12/240 = 1.6\text{in} > 0.28\text{in}$ ✓

Summary → use W24×76

Summary: Non-Composite System Design



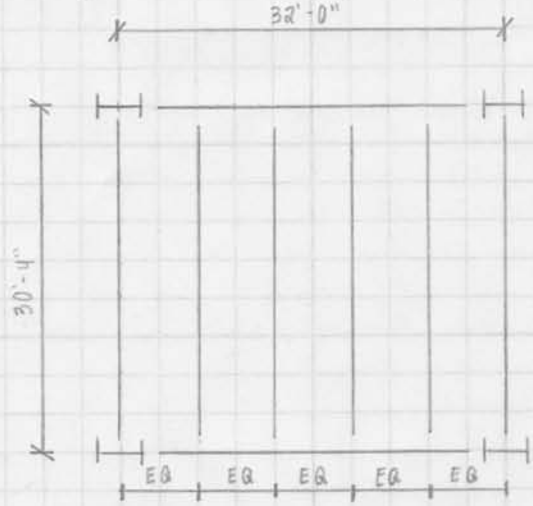
Deck Assembly:

2C22 Non-Composite Deck w/ 3 1/2" NWC topping (total slab depth 5 1/2 in > 5 1/4 in)
w/ 6x6 - W2.9xW2.9 WWF

ALTERNATE SYSTEM STUDY - composite steel framing system

Purpose: analyze steel framing option to improve economy - investigate intermediate economic option due to consideration of environmental factors (loads) and potential uplift

Note: girder and beam framing configuration will remain the same, except beam spacing will be equal across the bay (typ)



TYPICAL BAY FRAMING - composite

Selection of Deck Assembly: acheive at least a 2 hr - fire rating (mission-critical spaces - ICU) - life safety

Original slab Assembly: 5 1/4" concrete slab

* Use 2VLI20 w/ 3.5" NWC topping w/ 6x6 - W2.1x W2.1 WWF (recommended by SDI Vulcraft)

Dead Load

Deck Assembly : .... : 57 psf

Beams : .... : 5 psf

Girders : .... : 2 psf

Finishes : .... : 2 psf

Misc/Equip/Mech/Collateral : ... : 5 psf

Total : 71 psf (or 69 psf w/o girders → beam condition)

Live Load

Corridors (above 1st floor) ..... : 80 psf ← Controlling LL case

Patient Rooms .... : 40 psf

Deck Consideration

From Vulcraft 2008 Steel Deck Catalogue

2VL120 w/ 3.5" NWC topping

Span	SDI Max Unshored Span
1	7'-5"
2	9'-5"
3	9'-9"

span: 6'-4 4/5" < 7'-5" ∴ any span condition may be used with this deck

Note: 2VL122 w/ 3.5" NWC topping could be used in the 2 and 3 span conditions, but design elects to use 2VL120 w/ 3.5" NWC topping to allow for all span conditions to be available for consideration

2VL122 w/ 3.5" NWC topping → SDI Max Unshored Span - 1span condition = 6'-4" < 6'-4 4/5" X

Beam Design

$1.2D + 1.6L = 1.2(71) + 1.6(48) = 162\text{psf}$

$w = 162\text{psf}(6.4\text{ft}) = 1036.8/1000 = 1.04 \text{ klf}$

$M_u = w\ell^2/8 = (1.04)(30.333)^2/8 = 120 \text{ k}\cdot\text{ft}$ ← controlling case

$1.4D = 1.4(71) = 99.4 \text{ psf} \approx 100\text{psf}$

$w = 100\text{psf}(6.4) = 640/1000 = 0.640 \text{ klf}$

$M_u = w\ell^2/8 = (0.640)(30.333)^2/8 = 73.6 \text{ k}\cdot\text{ft}$

Assuming Composite Action:

assume $a = 1"$

$y_2 = 5\frac{1}{2} - \frac{1}{2} = 5"$

Beam Design (cont.)

Possible Selections

					Composite ↓
X	W10×19	$\Sigma Q_n = 70.3k$	$70.3/17.2 = 4.08$	$2(5\times10) + 19(30.333) = 676$ lbs	$\phi M_n = 127$ k·ft
X	W12×19	$\Sigma Q_n = 69.6k$	$69.6/17.2 = 4.04$	$2(5\times10) + 19(30.333) = 676$ lbs	$\phi M_n = 143$ k·ft
✓	W16×26	$\Sigma Q_n = 96.0k$	$96/17.2 = 5.58$	$2(6\times10) + 26(30.333) = 909$ lbs	$\phi M_n = 244$ k·ft

↳ extra weight on structure will help to counter uplift forces from environmental conditions, therefore I did not elect to go shallower or lighter and camber (do not camber when possible)

Unshored Strength:

$1.4D = 1.4(57\times6.4) + 1.4(26) = 547$ plf

$1.2D + 1.6L = 1.2(57\times6.4 + 26) + 1.6(20)(6.4) = 674$ plf

↑ construction LL

$w\ell^2/8 = (0.674)(30.333)^2/8 = 77.5$ k·ft

166 k·ft > 77.5 k·ft ✓ (capacity check)

Wet Concrete Deflection

$w_{wc} = (57)(6.4) + 26 = 391/1000 = 0.391$ klf

$\Delta_{wc} = 5w\ell^4/384EI_x = 5(0.391)(30.333)^4(1728)/384(29000)(301) = 0.85$ in

$\Delta_{allow} = \ell/360 = 30.333\times12/360 = 1.01$ in > 0.85 in ✓

Live Load Deflection

$w_{LL} = (48)(6.4) = 307.2$ plf $= 0.307$ klf

$I_{LB} = 555$ in^4 (Table 3-20)

$\Delta_{LL} = 5w\ell^4/384EI_{LB} = 5(0.307)(30.333)^4(1728)/384(29000)(555) = 0.36$ in

$\Delta_{allow} = \ell/360 = 30.333\times12/360 = 1.01$ in > 0.36 in ✓

Stud Calculations

Max Spacing: $32(3/4") = 24"$, $8(5.5") = 44"$

# of studs required: $6(2) = 12$ studs → $30.333\times12/12 = 30.333"$ → max spacing $= 24"$ ∴ use 24"

Beam Design (cont.)

Check "a" Assumption

$$b_{eff} = \min \left| \begin{array}{l} (6.4/2)(12) = 38.4in \\ 30.333(12)/8 = 45.5in \end{array} \right\} \times 2 \left\{ \begin{array}{l} = 76.8in \leftarrow use \\ = 91.0in \end{array} \right.$$

$V_c = (3.5")(76.8")(4ksi)(0.85) = 914k$

$V_s = (7.68in^2)(50ksi) = 384k$

12 studs $(17.2k/stud) = 206.4k$

$a = 206.4 / 0.85(3.5)(76.8) = 0.903 < 1.0$ ✓

$\Sigma Q_n < V_s \rightarrow 206.4k < 384k$ ∴ this beam is partially composite

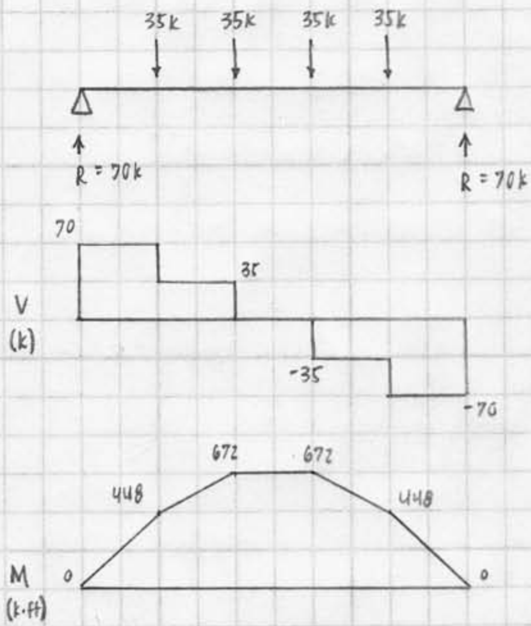
Girder Design

Point Loads:

$P_{LL} = 54(6.4)(32) = 11.1k$

$P_{DL} = 71(6.4)(32) = 14.5k$

$P_u = 1.2(14.5) + 1.6(11.1) = 35.2k$ → enough safety factors are built into process to consider this load as 35 k



where $R = 4(35)/2 = 70k$

Assuming Composite Action:

assume $a = 1''$

$y_2 = 5\frac{1}{2} - \frac{1}{2} = 5''$

Possible Selections

✓ W 21 x 57 $\quad \Sigma Q_n = 209k \quad 209/17.2 = 12.15 \quad 2(13 \times 10) + 57(32) = 2084$ lbs $\quad$ composite ↓ $\phi M_n = 684$ k·ft

Girder Design (cont.)

Unshored Strength → use superposition

Distributed Load

$1.4(57) = 80\ plf$

$1.2(57) + 1.6(0) = 69\ plf$ ← controlling case

Point Load

$1.4\left[(57(6.4) + 26)(30.333)\right] = 16.6k$

$1.2\left[(57(6.4) + 26)(30.333)\right] + 1.6\left[20(6.4)(30.333)\right] = 20.4k$ ← controlling case

Moment Superposition

$(0.069)(32)^2/8 = 8.83\ k\cdot ft$ ← from distributed

$(40.8 \times 6.4) + (20.4 \times 6.4) = 391.7\ k\cdot ft$

$M_u = 8.83 + 391.7 = 400.5\ k\cdot ft$

$484\ k\cdot ft > 400.5\ k\cdot ft$ ✓

Check Wet Concrete Deflection

$w_{wc} = 57\overset{30.333/2 + 10.333/2}{(20.333)} + 26 = 1185\ plf = 1.185\ klf$

$\Delta_{wc} = 5w\ell^4/384EI_x = 5(1.184)(32)^4(1728)/384(29000)\overset{I_x}{(1170)} = 0.82in$

$\Delta_{allow} = \ell/360 = 32 \times 12/360 = 1.067in > 0.82in$ ✓

Check Live Load Deflection

$w_{LL} = (54)(20.333) = 1098\ plf = 1.098\ klf$

$\Delta_{LL} = 5w\ell^4/384EI_{LB} = 5(1.098)(32)^4(1728)/384(29000)\overset{I_{LB}}{(1980)} = 0.45in$

$\Delta_{allow} = \ell/360 = 32 \times 12/360 = 1.067\ in > 0.45\ in$ ✓

Check "a" assumption

$b_{eff} = \begin{cases} (20.333/2) \times 12 = 122'' \times 2 = 244'' \\ \min\ 32(12)/8 = 48 \times 2 = 96'' \leftarrow \text{controls} \end{cases}$

$V_c = 0.85(3.5)(96)(4) = 1142k$

$V_s = 16.7(50) = 835\ k$

$a = 209/0.85(96)(3.5)$

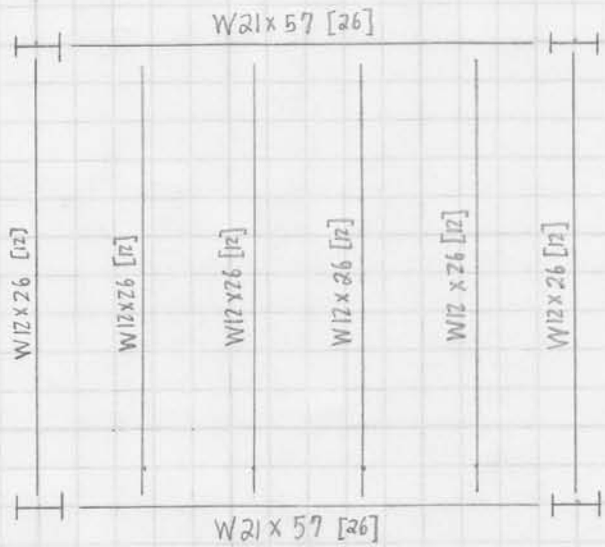
$a = 0.73in < 1in$ ✓

Stud Calculations

Actual Spacing: $(32ft)(12in/ft)/26\ studs$
$= 14.76'' < 24''$ ✓ ok

Stud Spacing: $\begin{cases} 32(3/4'') = 24'' \\ \min\ 8(5.5'') = 44'' \end{cases}$

Summary: Composite System Design



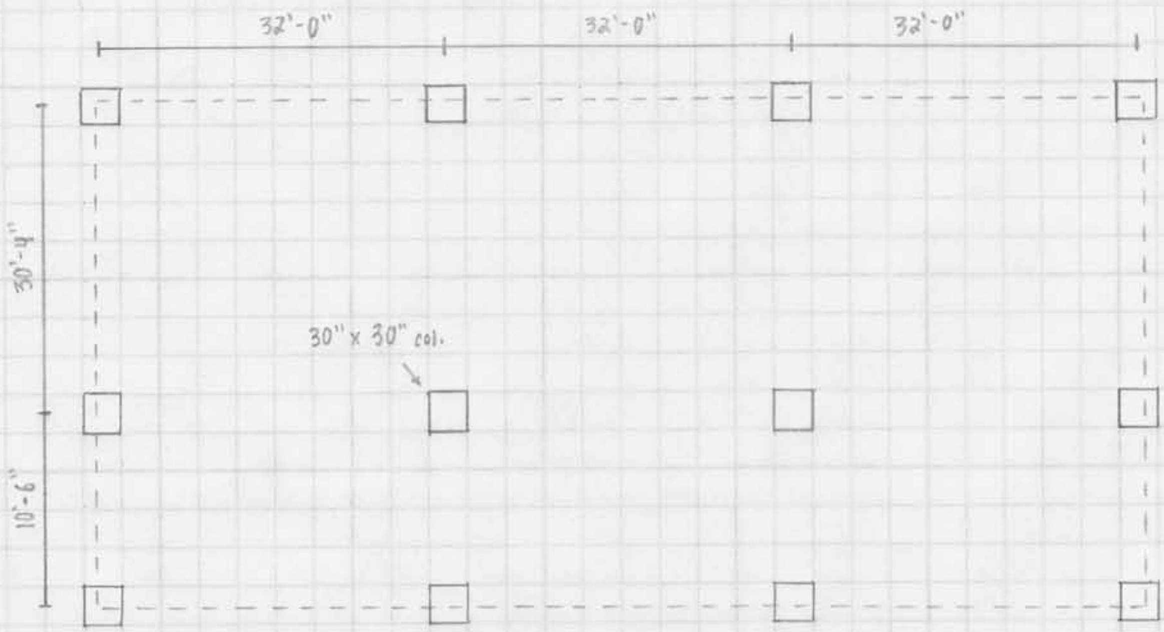
Deck Assembly:

2VLI20 Composite Deck w/ 3 1/2" NWC topping (total slab depth 5 1/2 in > 5 1/4 in)
w/ 6x6 - W2.1 x W2.1 WWF (recommended by SDI Vulcraft)

ALTERNATE SYSTEM STUDY - two-way flat plate concrete slab

Purpose: analyze an additional concrete system, reducing depth of section to increase floor to floor heights (add appeal as necessary)

Note: girder and beam framing (as well as joist members) will be absent from gravity framing assembly



Dead Loads: 150 pcf (12 in / 12 in/ft) = 150 psf

Live Loads: 80 psf (LL reduction need not be applied - deflection is not an issue)

Superimposed Dead Load: 2 psf + 5 psf + 2 psf = 9 psf
(Finishes, MEP, Misc/Collateral)

Factored Load: 1.2(159) + 1.6(80) = 319 psf

Factored Superimposed Load: 1.2(9) + 1.6(80) = 139 psf

Minimum Panel Thickness (ACI Table 9.5(c))

- w/o drop panels, interior panels = $\ell n/33$
- w/o drop panels, exterior w/ edge beams = $\ell n/33$

→ $\ell n/33 = 354/33 = 10.7$ in → 12 in slab

Min Col. = 30"

fy = 60 ksi (reinforcement)

f'c = 4 ksi (slab)

Span col-col: 30.333', 32'

$\ell n = (32 \times 12) - 30 = 354$

Shear Strength

One Way:

$V_u = 0.319\left(32/2 - 30/2(12) - 10.75/12\right)(32) = 141\ k$

$d = (12 - 3/4" - 1/2") = 10.75$

$V_c = 2\lambda\sqrt{f'c}\ b_w d = 2\sqrt{4000}\ (32\times12)(10.75) = 522155/1000 = 522\ K$

$b_w = 32/2 + 32/2 = 32$

$\phi V_c = 0.75(522) = 392\ k > V_u = 141\ k$ ✓

Two Way:

$V_u = 0.319\left((32\times30.333) - (30+10.75/12)\right) = 308\ k$

$V_c = 4\lambda\sqrt{f'c}\ b_w d = 4\sqrt{4000}\ (4(30+8))(10.75) = 413\ k$

$\phi V_c = 0.75(413) = 310\ k > V_u = 308\ k$ ✓

Total Factored Moment

$M_o = q_u\ l_2\ l_n^2/8 = 0.319(30.333)(32 - 30/12)^2/8 = 1053\ k\cdot ft$ (long span - 32 ft)
$M_o = q_u\ l_2\ l_n^2/8 = 0.319(32)(30.333 - 30/12)^2/8 = 988\ k\cdot ft$ (short span - 30.333

Distribute Moments: Direct Design Method for Two-Way Slab - Exterior Edge Fully Restrained

Long Span:

Column Strip: $+M = 0.6(0.35M_o) = 221\ k\cdot ft$
$-M = 0.75(0.65M_o) = -513\ k\cdot ft$

Middle Strip: $+M = 0.4(0.35M_o) = 147\ k\cdot ft$
$-M = 0.25(0.65M_o) = -171\ k\cdot ft$

Short Span:

Column Strip: $+M = 0.6(0.35M_o) = 207\ k\cdot ft$
$-M = 0.75(0.65M_o) = -482\ k\cdot ft$

Middle Strip: $+M = 0.4(0.35M_o) = 138\ k\cdot ft$
$-M = 0.25(0.65M_o) = -161\ k\cdot ft$

Area of Steel

$A_s = M_u / \phi f_y j d \rightarrow jd = 0.95(10.3) = 9.79$

Calculate d

top : $d \approx 12 - 1.7 = 10.3$ ← worst case
bottom : $d \approx 12 - 1.1 = 10.9$

$A_{s,min} = 0.0018\,bh = 0.0018\,(16 \times 12)(12) = 4.14\,in^2$

$S_{max} = \min \begin{cases} 2h = 2(12) = 24'' \\ 18'' \rightarrow \text{use } 18'' \text{ as } S_{max} \end{cases}$

Long Span:

sample calculations for reference

Column Strip : $+ = 221(12)/0.9(60)(9.79) = 5.02\,in^2 \rightarrow (12)\,\#6 = 5.28\,in^2$ ✓
$- = 513(12)/0.9(60)(9.79) = 11.64\,in^2 \rightarrow (15)\,\#8 = 11.85\,in^2$ ✓

Middle Strip : $+ : 3.34\,in^2 \rightarrow (12)\,\#5 = 3.72\,in^2$ ✓
$- : 3.88\,in^2 \rightarrow (5)\,\#8 = 3.95\,in^2$ ✓

Short Span :

Column Strip : $+ = 4.70\,in^2 \rightarrow (6)\,\#8 = 4.74\,in^2$ ✓
$- : 10.94\,in^2 \rightarrow (14)\,\#8 = 11.06\,in^2$ ✓

Middle Strip : $+ = 3.13\,in^2 \rightarrow (4)\,\#8 = 3.16\,in^2$ ✓
$- = 3.65\,in^2 \rightarrow (12)\,\#5 = 3.72\,in^2$ ✓

Strain Check

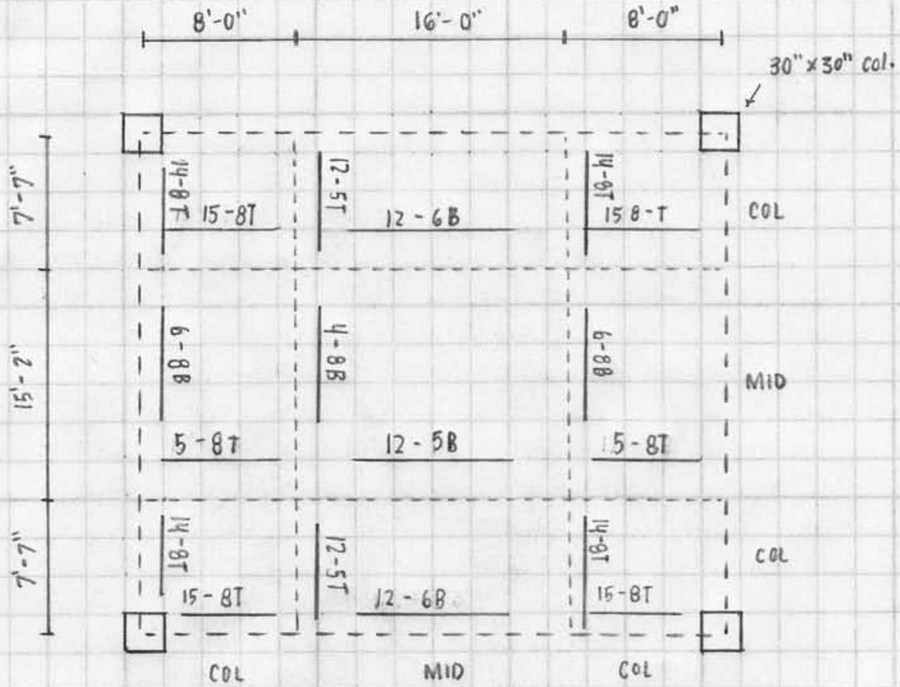
$\varepsilon_s = (d - c/c)\,\varepsilon_{cu} = ((10.3 - 1.28)/1.28)\,0.003 = 0.021 > 0.00207$ and $0.021 > 0.005$ ✓

where $a = 11.85(60)/0.85(4)(16 \times 12) = 1.089'' \rightarrow c = a/\beta = 1.089/0.85 = 1.28''$

$\phi = 0.9$ (assumed)

− col	0.021	0.9	✓
+ col	0.051	0.9	✓
− mid	0.069	0.9	✓
+ mid	0.074	0.9	✓
	↑ ε_s	↑ ϕ	

Summary: two-way flat plate concrete slab system



[8] Computer Modeling

This section outlines the computer modeling process executed to aid the analysis of the lateral force resisting system of The Medical Center. ETABS 2015 was used to generate and manipulate a three dimensional analysis model of The Medical Center.

8.1 Model Development

The lateral force resisting system was constructed and configured in a three-dimensional model using ETABS 2015. Due to the particular lateral framing scheme (Intermediate Reinforced Concrete Moment Frames) of The Medical Center, almost every primary framing element within the structure of the building needed to be modeled. In order to produce the most accurate model possible, the modeling process mirrored the framing process as close as possible (and within the limitations of the software).

Each framing element was assigned the appropriate section properties (per structural documentation), and each member was assigned end fixities matching the conditions of an intermediate moment frame. The pan-joist and slab assembly was modeled as such and defined as a rigid diaphragm, allowing for the distribution of lateral forces to the lateral force resisting elements.

In order to verify the functionality of the model, I applied my hand calculated lateral story forces to the building frame for both cases of wind and seismic forces, in both orthogonal directions (E-W and N-S). After determination of model validity, by means of comparison of hand calculated base shear values and software-generated base shear values, an additional model was generated, featuring automatic generation of lateral loads (per ASCE 7-05) applied by the software.

After discussion with professional consultants representing AECOM, a determination of the base fixity for columns was achieved. Due to significant differences in deflection amplification, the columns were assumed to exhibit a fixed-fixed end connection.

Overall, the final model generated, and utilized for the analysis of the lateral system of The Medical Center, best reflected the design conditions asserted within the structural system documentation of this building. Conclusively, the verified hand calculations produces a level of confidence concerning proper functionality of the model, yielding accurate analysis results for further investigation.

8.2 Modeling Assumption

The following assumptions were considered and executed within the modeling process of the lateral force resisting system model of The Medical Center:

- X-direction relates to the E-W orientation
- Y-direction relates to the N-S orientation
- Origin/Reference Datum: P-0 (on structural documentation) = (0,0)
- Dead Load = Member Self-Weight (self-weight multiplier = 1)
- Base Columns – Fixed
- Rigid Diaphragm
- Continuous diaphragm over the entire level
- Story masses distributed evenly on each floor
- Intermediated Reinforced Concrete Moment Frame – nearly every member is a later force resisting element
- Intermediate Reinforced Concrete Moment Frame – rigid beam

Additional considerations were made based on engineering judgement of building geometry and structure. Due to the massive nature of the structure, uplift was considered as non-controlling case and therefore was not considered within the analysis. Furthermore, reinforcement, within the structural framing members, was not modeled and therefore could cause slight, marginal differences between model values and hand calculated values. On the whole, all levels of The Medical Center are representative of a typical framing plan within the building; therefore, the analysis was limited to Level 3 in order to achieve a sufficient level of detail and investigation.

8.3 Model Validation

Validation of the lateral force resisting system model was executed by comparison with rote hand calculated values of the following concepts: center of mass, center of rigidity, wind load, seismic load, and torsional shear.

8.3.1 Center of Mass and Center of Rigidity

Due to the participation of nearly all framing members within the lateral force resisting framing system, excel spreadsheets were utilized to execute the detailed calculation of the center of mass and center of rigidity of The Medical Center. Each member's dimensional and material properties were entered into the calculation mechanism and related the distance of each member with respect to the reference datum. Center of mass and center of rigidity calculations were performed solely for Level 3. Level 3 was selected as the level of investigation based on the least number of differing sections within the level in comparison to other levels within the building. Due to the consistency of framing through the full height of the building, investigation of one level is a sufficient check of accuracy for consideration of the entire building.

Table 7 - Center of Mass

Member	Width	Depth	Length	Unit Weight	Weight	Dist. From Ref. Datum		Weight * X	Weight * Y
						X	Y		
G1	32	30	19.33	0.15	19.33	9.67	0	186.9211	0
G2	26	30	32.5	0.15	26.40625	35.58	0	939.534375	0
G3	32	30	19.33	0.15	19.33	61.5	0	1188.795	0
G4	32	30	32	0.15	32	87.16	0	2789.12	0
G4	32	30	32	0.15	32	119.16	0	3813.12	0
G4	32	30	32	0.15	32	151.16	0	4837.12	0
G5	32	30	32	0.15	32	183.16	0	5861.12	0
G6	42	30	19.33	0.15	25.37063	9.67	30.33	245.3339438	769.4910563
G6	42	30	19.33	0.15	25.37063	9.67	40.83	245.3339438	1035.882619
G7	42	30	32.5	0.15	42.65625	35.58	30.33	1517.709375	1293.764063
G7	42	30	32.5	0.15	42.65625	35.58	40.83	1517.709375	1741.654688
G8	42	30	19.33	0.15	25.37063	61.5	30.33	1560.293438	769.4910563
G8	42	30	19.33	0.15	25.37063	61.5	40.83	1560.293438	1035.882619
G9	42	30	32	0.15	42	87.16	30.33	3660.72	1273.86
G9	42	30	32	0.15	42	87.16	40.83	3660.72	1714.86
G9	42	30	32	0.15	42	119.16	30.33	5004.72	1273.86
G9	42	30	32	0.15	42	119.16	40.83	5004.72	1714.86
G9	42	30	32	0.15	42	151.16	30.33	6348.72	1273.86
G9	42	30	32	0.15	42	151.16	40.83	6348.72	1714.86
G10	42	30	32	0.15	42	183.16	30.33	7692.72	1273.86
G10	42	30	32	0.15	42	183.16	40.83	7692.72	1714.86
G11	42	30	30.33	0.15	39.80813	15.17	71.16	603.8892563	2832.746175
G12	42	30	10.5	0.15	13.78125	35.58	71.16	490.336875	980.67375
G13	42	30	30.33	0.15	39.80813	56	71.16	2229.255	2832.746175
G14	32	30	32	0.15	32	87.16	71.16	2789.12	2277.12
G14	32	30	32	0.15	32	119.16	71.16	3813.12	2277.12
G14	32	30	32	0.15	32	151.16	71.16	4837.12	2277.12
G15	32	30	32	0.15	32	183.16	71.16	5861.12	2277.12
G16	42	30	30.33	0.15	39.80813	15.17	103.16	603.8892563	4106.606175
G16	42	30	30.33	0.15	39.80813	15.17	135.16	603.8892563	5380.466175
G16	42	30	30.33	0.15	39.80813	15.17	167.16	603.8892563	6654.326175
G17	42	30	10.5	0.15	13.78125	35.58	103.16	490.336875	1421.67375
G17	42	30	10.5	0.15	13.78125	35.58	135.16	490.336875	1862.67375
G17	42	30	10.5	0.15	13.78125	35.58	167.16	490.336875	2303.67375
G18	42	30	30.33	0.15	39.80813	56	103.16	2229.255	4106.606175
G18	42	30	30.33	0.15	39.80813	56	135.16	2229.255	5380.466175
G18	42	30	30.33	0.15	39.80813	56	167.16	2229.255	6654.326175
G19	42	31.25	30.33	0.15	41.4668	15.17	199.16	629.0513086	8258.527266
G20	42	31.25	10.5	0.15	14.35547	35.58	199.16	510.7675781	2859.035156
G21	42	31.25	30.33	0.15	41.4668	56	199.16	2322.140625	8258.527266
G22	42	31.25	19.33	0.15	26.42773	9.67	217.33	255.5561914	5743.539512
G23	42	31.25	32.5	0.15	44.43359	35.58	217.33	1580.947266	9656.75293
G24	42	31.25	19.33	0.15	26.42773	9.67	226.25	255.5561914	5979.274902
G25	42	31.25	32.5	0.15	44.43359	35.58	226.25	1580.947266	10053.10059

B1	35	30	30.33	0.15	33.17344	0	15.17	0	503.2410469
B2	35	30	10.5	0.15	11.48438	0	35.58	0	408.6140625
B3	29	30	30.33	0.15	27.48656	0	56	0	1539.2475
B4	35	30	32	0.15	35	0	87.16	0	3050.6
B4	35	30	32	0.15	35	0	119.16	0	4170.6
B4	35	30	32	0.15	35	0	151.16	0	5290.6
B4	35	30	32	0.15	35	0	183.16	0	6410.6
B5	31	31.25	18.17	0.15	18.33561	0	192.25	0	3525.021403
B5	31	31.25	8.92	0.15	9.001302	0	205.79	0	1852.377956
B6	29	30	30.33	0.15	27.48656	19.33	15.17	531.3152531	416.9711531
B7	29	30	10.5	0.15	9.515625	19.33	35.58	183.9370313	338.5659375
B8	31	31.25	18.17	0.15	18.33561	19.33	192.25	354.4273796	3525.021403
B8	31	31.25	8.92	0.15	9.001302	19.33	205.79	173.9951693	1852.377956
B9	29	30	30.33	0.15	27.48656	30.33	56	833.6674406	1539.2475
B9	29	30	30.33	0.15	27.48656	40.83	56	1122.276347	1539.2475
B9	29	30	32	0.15	29	30.33	87.16	879.57	2527.64
B9	29	30	32	0.15	29	40.83	87.16	1184.07	2527.64
B9	29	30	32	0.15	29	30.33	119.16	879.57	3455.64
B9	29	30	32	0.15	29	40.83	119.16	1184.07	3455.64
B9	29	30	32	0.15	29	30.33	151.16	879.57	4383.64
B9	29	30	32	0.15	29	40.83	151.16	1184.07	4383.64
B10	29	30	32	0.15	29	30.33	183.16	879.57	5311.64
B11	29	30	32	0.15	29	40.83	183.16	1184.07	5311.64
B12	29	30	30.33	0.15	27.48656	51.83	15.17	1424.628534	416.9711531
B13	29	30	10.5	0.15	9.515625	51.83	35.58	493.1948438	338.5659375
B14	31	31.25	18.17	0.15	18.33561	51.83	192.25	950.3347689	3525.021403
B14	31	31.25	8.92	0.15	9.001302	51.83	205.79	466.537487	1852.377956
B15	35	30	30.33	0.15	33.17344	71.16	15.17	2360.621813	503.2410469
B16	35	30	10.5	0.15	11.48438	71.16	35.58	817.228125	408.6140625
B17	35	30	30.33	0.15	33.17344	71.16	56	2360.621813	1857.7125
B18	35	30	32	0.15	35	71.16	87.16	2490.6	3050.6
B18	35	30	32	0.15	35	71.16	119.16	2490.6	4170.6
B18	35	30	32	0.15	35	71.16	151.16	2490.6	5290.6
B18	35	30	32	0.15	35	71.16	183.16	2490.6	6410.6
B19	35	30	30.33	0.15	33.17344	103.16	15.17	3422.171813	503.2410469
B19	35	30	30.33	0.15	33.17344	135.16	15.17	4483.721813	503.2410469
B19	35	30	30.33	0.15	33.17344	167.16	15.17	5545.271813	503.2410469
B20	35	30	10.5	0.15	11.48438	103.16	35.58	1184.728125	408.6140625
B20	35	30	10.5	0.15	11.48438	135.16	35.58	1552.228125	408.6140625
B20	35	30	10.5	0.15	11.48438	167.16	35.58	1919.728125	408.6140625
B21	35	30	30.33	0.15	33.17344	103.16	56	3422.171813	1857.7125
B21	35	30	30.33	0.15	33.17344	135.16	56	4483.721813	1857.7125
B21	35	30	30.33	0.15	33.17344	167.16	56	5545.271813	1857.7125
B22	35	30	30.33	0.15	33.17344	199.16	15.17	6606.821813	503.2410469
B23	35	30	10.5	0.15	11.48438	199.16	35.58	2287.228125	408.6140625
B24	35	30	30.33	0.15	33.17344	199.16	56	6606.821813	1857.7125
Slab1	621.96	7.67	325.08	0.15	1615.388	25.92	212.71	41870.85547	343609.1692
Slab2	853.92	7.67	2389.92	0.15	16305.15	35.58	99.58	580137.0788	1623666.394
Slab3	1536	7.67	853.92	0.15	10479.31	135.16	35.58	1416383.031	372853.716
					SUM			**SUM**	**SUM**
					31040.59			**2225146.134**	**2569387.175**
								X-COM	**Y-COM**
								71.68504274	**82.77507114**
								ETABS X-COM	**ETABS Y-COM**
								71.6855	**83.6845**

Table 8 - Center of Rigidity

Member	Column 1		Column 2		Column 1 Moment of Inertia	Column 2 Momemnt of Inertia	Rigidity - X	Rigidity - Y	Dist. From Ref. Datum		Rigidity - X * Y	Rigidity - Y * X
	Width	Depth	Width	Depth					X	Y		
G1	32	32	30	30	87381.33333	67500	2219552.761	0	9.67	0	0	0
G2	30	30	30	30	67500	67500	1934640	0	35.58	0	0	0
G3	30	30	32	32	67500	87381.33333	2219552.761	0	61.5	0	0	0
G4	32	32	32	32	87381.33333	87381.33333	2504465.522	0	87.16	0	0	0
G4	32	32	32	32	87381.33333	87381.33333	2504465.522	0	119.16	0	0	0
G4	32	32	32	32	87381.33333	87381.33333	2504465.522	0	151.16	0	0	0
G5	32	32	32	32	87381.33333	87381.33333	2504465.522	0	183.16	0	0	0
G6	32	32	30	30	87381.33333	67500	2219552.761	0	9.67	30.33	67319035.24	0
G6	32	32	30	30	87381.33333	67500	2219552.761	0	9.67	40.83	90624339.23	0
G7	30	30	30	30	67500	67500	1934640	0	35.58	30.33	58677631.2	0
G7	30	30	30	30	67500	67500	1934640	0	35.58	40.83	78991351.2	0
G8	30	30	32	32	67500	87381.33333	2219552.761	0	61.5	30.33	67319035.24	0
G8	30	30	32	32	67500	87381.33333	2219552.761	0	61.5	40.83	90624339.23	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	87.16	30.33	75960439.28	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	87.16	40.83	102257327.3	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	119.16	30.33	75960439.28	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	119.16	40.83	102257327.3	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	151.16	30.33	75960439.28	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	151.16	40.83	102257327.3	0
G10	32	32	32	32	87381.33333	87381.33333	2504465.522	0	183.16	30.33	75960439.28	0
G10	32	32	32	32	87381.33333	87381.33333	2504465.522	0	183.16	40.83	102257327.3	0
G11	32	32	32	32	87381.33333	87381.33333	2504465.522	0	15.17	71.16	178217766.5	0
G12	32	32	32	32	87381.33333	87381.33333	2504465.522	0	35.58	71.16	178217766.5	0
G13	32	32	32	32	87381.33333	87381.33333	2504465.522	0	56	71.16	178217766.5	0
G14	32	32	32	32	87381.33333	87381.33333	2504465.522	0	87.16	71.16	178217766.5	0
G14	32	32	32	32	87381.33333	87381.33333	2504465.522	0	119.16	71.16	178217766.5	0
G14	32	32	32	32	87381.33333	87381.33333	2504465.522	0	151.16	71.16	178217766.5	0
G15	32	32	32	32	87381.33333	87381.33333	2504465.522	0	183.16	71.16	178217766.5	0
G16	32	32	32	32	87381.33333	87381.33333	2504465.522	0	15.17	103.16	258360663.2	0
G16	32	32	32	32	87381.33333	87381.33333	2504465.522	0	15.17	135.16	338503559.9	0
G16	32	32	32	32	87381.33333	87381.33333	2504465.522	0	15.17	167.16	418646456.6	0
G17	32	32	32	32	87381.33333	87381.33333	2504465.522	0	35.58	103.16	258360663.2	0
G17	32	32	32	32	87381.33333	87381.33333	2504465.522	0	35.58	135.16	338503559.9	0
G17	32	32	32	32	87381.33333	87381.33333	2504465.522	0	35.58	167.16	418646456.6	0
G18	32	32	32	32	87381.33333	87381.33333	2504465.522	0	56	103.16	258360663.2	0
G18	32	32	32	32	87381.33333	87381.33333	2504465.522	0	56	135.16	338503559.9	0
G18	32	32	32	32	87381.33333	87381.33333	2504465.522	0	56	167.16	418646456.6	0
G19	32	32	32	32	87381.33333	87381.33333	2504465.522	0	15.17	199.16	498789353.3	0
G20	32	32	32	32	87381.33333	87381.33333	2504465.522	0	35.58	199.16	498789353.3	0
G21	32	32	32	32	87381.33333	87381.33333	2504465.522	0	56	199.16	498789353.3	0
G22	32	32	32	32	87381.33333	87381.33333	2504465.522	0	9.67	217.33	544295491.8	0
G23	32	32	32	32	87381.33333	87381.33333	2504465.522	0	35.58	217.33	544295491.8	0
G24	32	32	32	32	87381.33333	87381.33333	2504465.522	0	9.67	226.25	566635324.3	0
G25	32	32	32	32	87381.33333	87381.33333	2504465.522	0	35.58	226.25	566635324.3	0

B1	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	15.17	0	0
B2	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	35.58	0	0
B3	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	56	0	0
B4	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	87.16	0	0
B4	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	119.16	0	0
B4	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	151.16	0	0
B4	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	183.16	0	0
B5	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	192.25	0	0
B5	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	205.79	0	0
B6	30	30	30	30	67500	67500	0	1934640	19.33	15.17	0	37396591.2
B7	30	30	30	30	67500	67500	0	1934640	19.33	35.58	0	37396591.2
B8	32	32	32	32	87381.33333	87381.33333	0	2504465.522	19.33	192.25	0	48411318.54
B8	32	32	32	32	87381.33333	87381.33333	0	2504465.522	19.33	205.79	0	48411318.54
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	30.33	56	0	75960439.28
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	40.83	56	0	102257327.3
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	30.33	87.16	0	75960439.28
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	40.83	87.16	0	102257327.3
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	30.33	119.16	0	75960439.28
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	40.83	119.16	0	102257327.3
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	30.33	151.16	0	75960439.28
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	40.83	151.16	0	102257327.3
B10	32	32	32	32	87381.33333	87381.33333	0	2504465.522	30.33	183.16	0	75960439.28
B11	32	32	32	32	87381.33333	87381.33333	0	2504465.522	40.83	183.16	0	102257327.3
B12	30	30	30	30	67500	67500	0	1934640	51.83	15.17	0	100272391.2
B13	30	30	30	30	67500	67500	0	1934640	51.83	35.58	0	100272391.2
B14	32	32	32	32	87381.33333	87381.33333	0	2504465.522	51.83	192.25	0	129806448
B14	32	32	32	32	87381.33333	87381.33333	0	2504465.522	51.83	205.79	0	129806448
B15	32	32	32	32	87381.33333	87381.33333	0	2504465.522	71.16	15.17	0	178217766.5
B16	32	32	32	32	87381.33333	87381.33333	0	2504465.522	71.16	35.58	0	178217766.5
B17	32	32	32	32	87381.33333	87381.33333	0	2504465.522	71.16	56	0	178217766.5
B18	32	32	32	32	87381.33333	87381.33333	0	2504465.522	71.16	87.16	0	178217766.5
B18	32	32	32	32	87381.33333	87381.33333	0	2504465.522	71.16	119.16	0	178217766.5
B18	32	32	32	32	87381.33333	87381.33333	0	2504465.522	71.16	151.16	0	178217766.5
B18	32	32	32	32	87381.33333	87381.33333	0	2504465.522	71.16	183.16	0	178217766.5
B19	32	32	32	32	87381.33333	87381.33333	0	2504465.522	103.16	15.17	0	258360663.2
B19	32	32	32	32	87381.33333	87381.33333	0	2504465.522	135.16	15.17	0	338503559.9
B19	32	32	32	32	87381.33333	87381.33333	0	2504465.522	167.16	15.17	0	418646456.6
B20	32	32	32	32	87381.33333	87381.33333	0	2504465.522	103.16	35.58	0	258360663.2
B20	32	32	32	32	87381.33333	87381.33333	0	2504465.522	135.16	35.58	0	338503559.9
B20	32	32	32	32	87381.33333	87381.33333	0	2504465.522	167.16	35.58	0	418646456.6
B21	32	32	32	32	87381.33333	87381.33333	0	2504465.522	103.16	56	0	258360663.2
B21	32	32	32	32	87381.33333	87381.33333	0	2504465.522	135.16	56	0	338503559.9
B21	32	32	32	32	87381.33333	87381.33333	0	2504465.522	167.16	56	0	418646456.6
B22	32	32	32	32	87381.33333	87381.33333	0	2504465.522	199.16	15.17	0	498789353.3
B23	32	32	32	32	87381.33333	87381.33333	0	2504465.522	199.16	35.58	0	498789353.3
B24	32	32	32	32	87381.33333	87381.33333	0	2504465.522	199.16	56	0	498789353.3
							SUM	**SUM**			**SUM**	**SUM**
							106777529.8	**112926111.9**			**9178712895**	**7313286795**
											Y-COR	**X-COR**
											85.9610904	**64.76169835**
											ETABS Y-COR	**ETABS X-COR**
											85.773	**71.3006**

8.3.2 Wind Load Comparison

Automatic generation and application of wind loading was utilized within ETABS 2015 in order to create potential for validation of the lateral force resisting system model. Wind loading was automatically generated and applied in accordance with ASCE 7-05. Both X-direction (E-W) and Y-direction (N-S) components of the wind loading were considered. ETABS applied the wind loading to the center of pressure of each exterior frame and diaphragm edge of each respective level of the building. Taking into consideration floor to floor heights of each floor as well as projected wall area applicable to receiving lateral loading due to wind, ETABS completed the generation and application of several wind loading cases. The following comparison between the wind loading base shear values generated by ETABS and by manual calculation validate the applied wind loads within the model.

	F_X (kips)	**F_Y (kips)**	**F_Z (kips)**
ETABS (E-W)	1741.4	0	0
Manual (E-W)	1736.4	0	0
ETABS (N-S)	0	1497.8	0
Manual (N-S)	0	1460.8	0

8.3.3 Seismic Load Comparison

Automatic generation and application of seismic loading was utilized within ETABS 2015 in order to create potential for validation of the lateral force resisting system model. Seismic loading was automatically generated and applied in accordance with ASCE 7-05. Although equal in value, both X-direction (E-W) and Y-direction (N-S) components of the seismic loading were considered. ETABS applied the seismic loading at the center of mass of each level of the building. Taking into consideration building seismic weight, inclusive of the self-weight multiplier utilized within the software, ETABS completed the generation and application of several seismic loading cases. The following comparison between the seismic loading base shear values generated by ETABS and by manual calculation, although differing in value, validate the applied seismic loads within the model.

	F_X (kips)	**F_Y (kips)**	**F_Z (kips)**
ETABS (E-W)	1031	0	0
Manual (E-W)	790	0	0
ETABS (N-S)	0	1031	0
Manual (N-S)	0	790	0

By comparison of seismic response coefficients (C_S) used to calculate the respective base shear values (ETABS vs. manual), the model is validated. Demonstration of this validation can be seen in Appendix C.

8.3.4 Direct and Torsional Shear

Direct shear and torsional shear were considered in the analysis of the lateral force resisting system of The Medical Center. Level 3 was utilized for the analysis of direct shear and torsional shear. The following illustrates the calculated direct shear and torsional shear for Level 3 of The Medical Center.

Direct Shear

$F_{v,\,Direct} = [K_i / \Sigma K](F_i)$ where K = rigidity = stiffness

Note: must consider direct shear for both wind loading and seismic loading

Note: must consider direct shear for both E-W and N-S directions

Note: F_i will vary, depending on both loading case (wind or seismic) as well as loading direction (E-W or N-S)

Note: $[K_i/\Sigma K]$ (relative stiffness) will vary based on the lateral element being investigated

Torsional Shear

$F_{v,\,Torsional} = M_i K_i d_i / I_P$ where $I_P = \Sigma K_{iy} x_i^2 + \Sigma K_{ix} y_i^2$

K = Equivalent Stiffness of Frame

F_i = Lateral Story Force

$M_i = (F_i)(d_{com} - d_{COR})$

d_i = distance of center of rigidity to element

Note: must consider torsional shear for both wind loading and seismic loading

Note: must consider torsional shear for both E-W and N-S directions

Note: F_i will vary, depending on both loading case (wind or seismic) as well as loading direction (E-W or N-S)

Note: M_i, K_i, d_i will vary based on the lateral element being investigated.

Table 9 - Direct Shear

Member	Column 1		Column 2		Column 1 Moment of Inertia	Column 2 Momemnt of Inertia	Rigidity - X	Rigidity - Y	Relative Stiffness - X	Relative Stiffness - Y	F_V - Wind - X	F_V - Wind - Y	F_V - Seismic - X	F_V - Seismic - Y
	Width	Depth	Width	Depth										
G1	32	32	30	30	87381.33333	67500	2219552.761	0	0.020786703	0	4.895268471	0	1.240966147	0
G2	30	30	30	30	67500	67500	1934640	0	0.018118419	0	4.266887619	0	1.0816696	0
G3	30	30	32	32	67500	87381.33333	2219552.761	0	0.020786703	0	4.895268471	0	1.240966147	0
G4	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G4	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G4	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G5	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G6	32	32	30	30	87381.33333	67500	2219552.761	0	0.020786703	0	4.895268471	0	1.240966147	0
G6	32	32	30	30	87381.33333	67500	2219552.761	0	0.020786703	0	4.895268471	0	1.240966147	0
G7	30	30	30	30	67500	67500	1934640	0	0.018118419	0	4.266887619	0	1.0816696	0
G7	30	30	30	30	67500	67500	1934640	0	0.018118419	0	4.266887619	0	1.0816696	0
G8	30	30	32	32	67500	87381.33333	2219552.761	0	0.020786703	0	4.895268471	0	1.240966147	0
G8	30	30	32	32	67500	87381.33333	2219552.761	0	0.020786703	0	4.895268471	0	1.240966147	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G9	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G10	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G10	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G11	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G12	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G13	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G14	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G14	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G14	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G15	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G16	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G16	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G16	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G17	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G17	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G17	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G18	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G18	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G18	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G19	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G20	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G21	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G22	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G23	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G24	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0
G25	32	32	32	32	87381.33333	87381.33333	2504465.522	0	0.023454987	0	5.523649323	0	1.400262695	0

B1	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B2	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B3	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B4	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B4	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B4	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B4	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B5	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B5	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B6	30	30	30	30	67500	67500	0	1934640	0	0.01713191	0	3.38355225	0	1.022775034
B7	30	30	30	30	67500	67500	0	1934640	0	0.01713191	0	3.38355225	0	1.022775034
B8	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B8	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B9	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B10	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B11	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B12	30	30	30	30	67500	67500	0	1934640	0	0.01713191	0	3.38355225	0	1.022775034
B13	30	30	30	30	67500	67500	0	1934640	0	0.01713191	0	3.38355225	0	1.022775034
B14	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B14	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B15	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B16	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B17	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B18	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B18	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B18	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B18	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B19	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B19	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B19	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B20	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B20	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B20	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B21	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B21	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B21	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B22	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B23	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
B24	32	32	32	32	87381.33333	87381.33333	0	2504465.522	0	0.022177913	0	4.380137881	0	1.324021425
							SUM	**SUM**	**SUM**	**SUM**	**SUM**	**SUM**	**SUM**	**SUM**
							106777529.8	**112926111.9**	1	1	**235.5**	**197.5**	**59.7**	**59.7**

Table 10 - Torsional Shear

Member	Dist. From Ref. Datum		Dist. From COM		Dist. From COR		M_i - Wind - X	M_i - Wind - Y	M_i - Seismic - X	M_i - Seismic - Y	F_{VT} - Wind - X	F_{VT} - Wind - Y	F_{VT} - Seismic - X	F_{VT} - Seismic - Y
	X	Y	$D_{X,COM}$	$D_{Y,COM}$	$D_{X,COR}$	$D_{Y,COR}$								
G1	9.67	0	-62.02	-82.78	-55.09	-85.96	748.254	-1368.675	189.846	-413.721	0	0	-3.53277E-10	0
G2	35.58	0	-36.11	-82.78	-29.18	-85.96	748.254	-1368.675	189.846	-413.721	0	0	-3.07928E-10	0
G3	61.5	0	-10.19	-82.78	-3.26	-85.96	748.254	-1368.675	189.846	-413.721	0	0	-3.53277E-10	0
G4	87.16	0	15.47	-82.78	22.4	-85.96	748.254	-1368.675	189.846	-413.721	0	0	-3.98625E-10	0
G4	119.16	0	47.47	-82.78	54.4	-85.96	748.254	-1368.675	189.846	-413.721	0	0	-3.98625E-10	0
G4	151.16	0	79.47	-82.78	86.4	-85.96	748.254	-1368.675	189.846	-413.721	0	0	-3.98625E-10	0
G5	183.16	0	111.47	-82.78	118.4	-85.96	748.254	-1368.675	189.846	-413.721	0	0	-3.98625E-10	0
G6	9.67	30.33	-62.02	-52.45	-55.09	-55.63	748.254	-1368.675	189.846	-413.721	4.91291E-10	0	-2.28627E-10	0
G6	9.67	40.83	-62.02	-41.95	-55.09	-45.13	748.254	-1368.675	189.846	-413.721	6.61372E-10	0	-1.85474E-10	0
G7	35.58	30.33	-36.11	-52.45	-29.18	-55.63	748.254	-1368.675	189.846	-413.721	4.28226E-10	0	-1.99279E-10	0
G7	35.58	40.83	-36.11	-41.95	-29.18	-45.13	748.254	-1368.675	189.846	-413.721	5.76475E-10	0	-1.61666E-10	0
G8	61.5	30.33	-10.19	-52.45	-3.26	-55.63	748.254	-1368.675	189.846	-413.721	4.91291E-10	0	-2.28627E-10	0
G8	61.5	40.83	-10.19	-41.95	-3.26	-45.13	748.254	-1368.675	189.846	-413.721	6.61372E-10	0	-1.85474E-10	0
G9	87.16	30.33	15.47	-52.45	22.4	-55.63	748.254	-1368.675	189.846	-413.721	5.54355E-10	0	-2.57975E-10	0
G9	87.16	40.83	15.47	-41.95	22.4	-45.13	748.254	-1368.675	189.846	-413.721	7.46269E-10	0	-2.09283E-10	0
G9	119.16	30.33	47.47	-52.45	54.4	-55.63	748.254	-1368.675	189.846	-413.721	5.54355E-10	0	-2.57975E-10	0
G9	119.16	40.83	47.47	-41.95	54.4	-45.13	748.254	-1368.675	189.846	-413.721	7.46269E-10	0	-2.09283E-10	0
G9	151.16	30.33	79.47	-52.45	86.4	-55.63	748.254	-1368.675	189.846	-413.721	5.54355E-10	0	-2.57975E-10	0
G9	151.16	40.83	79.47	-41.95	86.4	-45.13	748.254	-1368.675	189.846	-413.721	7.46269E-10	0	-2.09283E-10	0
G10	183.16	30.33	111.47	-52.45	118.4	-55.63	748.254	-1368.675	189.846	-413.721	5.54355E-10	0	-2.57975E-10	0
G10	183.16	40.83	111.47	-41.95	118.4	-45.13	748.254	-1368.675	189.846	-413.721	7.46269E-10	0	-2.09283E-10	0
G11	15.17	71.16	-56.52	-11.62	-49.59	-14.8	748.254	-1368.675	189.846	-413.721	1.30062E-09	0	-6.86325E-11	0
G12	35.58	71.16	-36.11	-11.62	-29.18	-14.8	748.254	-1368.675	189.846	-413.721	1.30062E-09	0	-6.86325E-11	0
G13	56	71.16	-15.69	-11.62	-8.76	-14.8	748.254	-1368.675	189.846	-413.721	1.30062E-09	0	-6.86325E-11	0
G14	87.16	71.16	15.47	-11.62	22.4	-14.8	748.254	-1368.675	189.846	-413.721	1.30062E-09	0	-6.86325E-11	0
G14	119.16	71.16	47.47	-11.62	54.4	-14.8	748.254	-1368.675	189.846	-413.721	1.30062E-09	0	-6.86325E-11	0
G14	151.16	71.16	79.47	-11.62	86.4	-14.8	748.254	-1368.675	189.846	-413.721	1.30062E-09	0	-6.86325E-11	0
G15	183.16	71.16	111.47	-11.62	118.4	-14.8	748.254	-1368.675	189.846	-413.721	1.30062E-09	0	-6.86325E-11	0
G16	15.17	103.16	-56.52	20.38	-49.59	17.2	748.254	-1368.675	189.846	-413.721	1.8855E-09	0	7.97621E-11	0
G16	15.17	135.16	-56.52	52.38	-49.59	49.2	748.254	-1368.675	189.846	-413.721	2.47038E-09	0	2.28157E-10	0
G16	15.17	167.16	-56.52	84.38	-49.59	81.2	748.254	-1368.675	189.846	-413.721	3.05526E-09	0	3.76551E-10	0
G17	35.58	103.16	-36.11	20.38	-29.18	17.2	748.254	-1368.675	189.846	-413.721	1.8855E-09	0	7.97621E-11	0
G17	35.58	135.16	-36.11	52.38	-29.18	49.2	748.254	-1368.675	189.846	-413.721	2.47038E-09	0	2.28157E-10	0
G17	35.58	167.16	-36.11	84.38	-29.18	81.2	748.254	-1368.675	189.846	-413.721	3.05526E-09	0	3.76551E-10	0
G18	56	103.16	-15.69	20.38	-8.76	17.2	748.254	-1368.675	189.846	-413.721	1.8855E-09	0	7.97621E-11	0
G18	56	135.16	-15.69	52.38	-8.76	49.2	748.254	-1368.675	189.846	-413.721	2.47038E-09	0	2.28157E-10	0
G18	56	167.16	-15.69	84.38	-8.76	81.2	748.254	-1368.675	189.846	-413.721	3.05526E-09	0	3.76551E-10	0
G19	15.17	199.16	-56.52	116.38	-49.59	113.2	748.254	-1368.675	189.846	-413.721	3.64014E-09	0	5.24946E-10	0
G20	35.58	199.16	-36.11	116.38	-29.18	113.2	748.254	-1368.675	189.846	-413.721	3.64014E-09	0	5.24946E-10	0
G21	56	199.16	-15.69	116.38	-8.76	113.2	748.254	-1368.675	189.846	-413.721	3.64014E-09	0	5.24946E-10	0
G22	9.67	217.33	-62.02	134.55	-55.09	131.37	748.254	-1368.675	189.846	-413.721	3.97224E-09	0	6.09206E-10	0
G23	35.58	217.33	-36.11	134.55	-29.18	131.37	748.254	-1368.675	189.846	-413.721	3.97224E-09	0	6.09206E-10	0
G24	9.67	226.25	-62.02	143.47	-55.09	140.29	748.254	-1368.675	189.846	-413.721	4.13527E-09	0	6.50571E-10	0
G25	35.58	226.25	-36.11	143.47	-29.18	140.29	748.254	-1368.675	189.846	-413.721	4.13527E-09	0	6.50571E-10	0

B1	0	15.17	-71.69	-67.61	-64.76	-70.79	748.254	-1368.675	189.846	-413.721	0	2.0472E-09	0	6.18823E-10
B2	0	35.58	-71.69	-47.2	-64.76	-50.38	748.254	-1368.675	189.846	-413.721	0	2.0472E-09	0	6.18823E-10
B3	0	56	-71.69	-26.78	-64.76	-29.96	748.254	-1368.675	189.846	-413.721	0	2.0472E-09	0	6.18823E-10
B4	0	87.16	-71.69	4.38	-64.76	1.2	748.254	-1368.675	189.846	-413.721	0	2.0472E-09	0	6.18823E-10
B4	0	119.16	-71.69	36.38	-64.76	33.2	748.254	-1368.675	189.846	-413.721	0	2.0472E-09	0	6.18823E-10
B4	0	151.16	-71.69	68.38	-64.76	65.2	748.254	-1368.675	189.846	-413.721	0	2.0472E-09	0	6.18823E-10
B4	0	183.16	-71.69	100.38	-64.76	97.2	748.254	-1368.675	189.846	-413.721	0	2.0472E-09	0	6.18823E-10
B5	0	192.25	-71.69	109.47	-64.76	106.29	748.254	-1368.675	189.846	-413.721	0	2.0472E-09	0	6.18823E-10
B5	0	205.79	-71.69	123.01	-64.76	119.83	748.254	-1368.675	189.846	-413.721	0	2.0472E-09	0	6.18823E-10
B6	19.33	15.17	-52.36	-67.61	-45.43	-70.79	748.254	-1368.675	189.846	-413.721	0	1.10938E-09	0	3.35342E-10
B7	19.33	35.58	-52.36	-47.2	-45.43	-50.38	748.254	-1368.675	189.846	-413.721	0	1.10938E-09	0	3.35342E-10
B8	19.33	192.25	-52.36	109.47	-45.43	106.29	748.254	-1368.675	189.846	-413.721	0	1.43614E-09	0	4.34113E-10
B8	19.33	205.79	-52.36	123.01	-45.43	119.83	748.254	-1368.675	189.846	-413.721	0	1.43614E-09	0	4.34113E-10
B9	30.33	56	-41.36	-26.78	-34.43	-29.96	748.254	-1368.675	189.846	-413.721	0	1.0884E-09	0	3.29001E-10
B9	40.83	56	-30.86	-26.78	-23.93	-29.96	748.254	-1368.675	189.846	-413.721	0	7.56476E-10	0	2.28666E-10
B9	30.33	87.16	-41.36	4.38	-34.43	1.2	748.254	-1368.675	189.846	-413.721	0	1.0884E-09	0	3.29001E-10
B9	40.83	87.16	-30.86	4.38	-23.93	1.2	748.254	-1368.675	189.846	-413.721	0	7.56476E-10	0	2.28666E-10
B9	30.33	119.16	-41.36	36.38	-34.43	33.2	748.254	-1368.675	189.846	-413.721	0	1.0884E-09	0	3.29001E-10
B9	40.83	119.16	-30.86	36.38	-23.93	33.2	748.254	-1368.675	189.846	-413.721	0	7.56476E-10	0	2.28666E-10
B9	30.33	151.16	-41.36	68.38	-34.43	65.2	748.254	-1368.675	189.846	-413.721	0	1.0884E-09	0	3.29001E-10
B9	40.83	151.16	-30.86	68.38	-23.93	65.2	748.254	-1368.675	189.846	-413.721	0	7.56476E-10	0	2.28666E-10
B10	30.33	183.16	-41.36	100.38	-34.43	97.2	748.254	-1368.675	189.846	-413.721	0	1.0884E-09	0	3.29001E-10
B11	40.83	183.16	-30.86	100.38	-23.93	97.2	748.254	-1368.675	189.846	-413.721	0	7.56476E-10	0	2.28666E-10
B12	51.83	15.17	-19.86	-67.61	-12.93	-70.79	748.254	-1368.675	189.846	-413.721	0	3.15745E-10	0	9.54429E-11
B13	51.83	35.58	-19.86	-47.2	-12.93	-50.38	748.254	-1368.675	189.846	-413.721	0	3.15745E-10	0	9.54429E-11
B14	51.83	192.25	-19.86	109.47	-12.93	106.29	748.254	-1368.675	189.846	-413.721	0	4.08744E-10	0	1.23554E-10
B14	51.83	205.79	-19.86	123.01	-12.93	119.83	748.254	-1368.675	189.846	-413.721	0	4.08744E-10	0	1.23554E-10
B15	71.16	15.17	-0.53	-67.61	6.4	-70.79	748.254	-1368.675	189.846	-413.721	0	-2.02317E-10	0	-6.11561E-11
B16	71.16	35.58	-0.53	-47.2	6.4	-50.38	748.254	-1368.675	189.846	-413.721	0	-2.02317E-10	0	-6.11561E-11
B17	71.16	56	-0.53	-26.78	6.4	-29.96	748.254	-1368.675	189.846	-413.721	0	-2.02317E-10	0	-6.11561E-11
B18	71.16	87.16	-0.53	4.38	6.4	1.2	748.254	-1368.675	189.846	-413.721	0	-2.02317E-10	0	-6.11561E-11
B18	71.16	119.16	-0.53	36.38	6.4	33.2	748.254	-1368.675	189.846	-413.721	0	-2.02317E-10	0	-6.11561E-11
B18	71.16	151.16	-0.53	68.38	6.4	65.2	748.254	-1368.675	189.846	-413.721	0	-2.02317E-10	0	-6.11561E-11
B18	71.16	183.16	-0.53	100.38	6.4	97.2	748.254	-1368.675	189.846	-413.721	0	-2.02317E-10	0	-6.11561E-11
B19	103.16	15.17	31.47	-67.61	38.4	-70.79	748.254	-1368.675	189.846	-413.721	0	-1.2139E-09	0	-3.66937E-10
B19	135.16	15.17	63.47	-67.61	70.4	-70.79	748.254	-1368.675	189.846	-413.721	0	-2.22549E-09	0	-6.72717E-10
B19	167.16	15.17	95.47	-67.61	102.4	-70.79	748.254	-1368.675	189.846	-413.721	0	-3.23707E-09	0	-9.78498E-10
B20	103.16	35.58	31.47	-47.2	38.4	-50.38	748.254	-1368.675	189.846	-413.721	0	-1.2139E-09	0	-3.66937E-10
B20	135.16	35.58	63.47	-47.2	70.4	-50.38	748.254	-1368.675	189.846	-413.721	0	-2.22549E-09	0	-6.72717E-10
B20	167.16	35.58	95.47	-47.2	102.4	-50.38	748.254	-1368.675	189.846	-413.721	0	-3.23707E-09	0	-9.78498E-10
B21	103.16	56	31.47	-26.78	38.4	-29.96	748.254	-1368.675	189.846	-413.721	0	-1.2139E-09	0	-3.66937E-10
B21	135.16	56	63.47	-26.78	70.4	-29.96	748.254	-1368.675	189.846	-413.721	0	-2.22549E-09	0	-6.72717E-10
B21	167.16	56	95.47	-26.78	102.4	-29.96	748.254	-1368.675	189.846	-413.721	0	-3.23707E-09	0	-9.78498E-10
B22	199.16	15.17	127.47	-67.61	134.4	-70.79	748.254	-1368.675	189.846	-413.721	0	-4.24866E-09	0	-1.28428E-09
B23	199.16	35.58	127.47	-47.2	134.4	-50.38	748.254	-1368.675	189.846	-413.721	0	-4.24866E-09	0	-1.28428E-09
B24	199.16	56	127.47	-26.78	134.4	-29.96	748.254	-1368.675	189.846	-413.721	0	-4.24866E-09	0	-1.28428E-09
											SUM	**SUM**	**SUM**	**SUM**
											6.69858E-08	**-2.4208E-12**	**2.15586E-13**	**-7.31755E-13**

8.3.5 Equilibrium Check

An equilibrium check was performed for the wind (E-W) story force at Level 3. The check was performed by analyzing the ETABS output value for cumulative story shears at Level 3 in order to generate the story force reaction of the lateral force resisting frame within ETABS. Additionally, a manual hand calculation was performed to investigate the story force at Level 3 for the wind loading (E-W) applied to the building. By comparison of these values, equilibrium was achieved (accounting for minimal source error equivalent to 0.2% error).

Equilibrium Check

Consideration: Wind (E-W)

ETABS Output

Cumulative Shear for Level 2 ([illegible]): -1741.362k

Cumulative Shear for Level 3 : -1506.531k

Story Shear for Level 3: -1741.362k - (-1506.531k) = -234.831k

Hand Calculation - Story Force Reaction

Level 3 (combine windward & leeward pressure [illegible] loading scenario)

Story Force Reaction = (15ft/2) (227ft) (50.8psf + 16.2psf) + (15ft/2) (227ft) (55.0psf + 16.2psf)

= 235.3k

Equilibrium Check: -234.831k + 235.3k = 0.469k

Note: the residual force resulting from the equilibrium check above (0.469k) is small enough to attribute to rounding and factors of the like; therefore the error is minimal enough to have confidence in the relation between the model output and hand calculated values

[9] Code and Member Checks

9.1 Drift Checks

Drift analysis was performed for wind loading cases as well as seismic loading cases within the lateral force resisting system model. Data plots, representing the relation between building story and maximum displacement, were extracted from ETABS for comparison to code limitations for overall building displacement as well as story drift. Within the plots, the blue curves represent the X-direction (E-W) of loading, and the red curves represents the Y-direction (N-S) of loading.

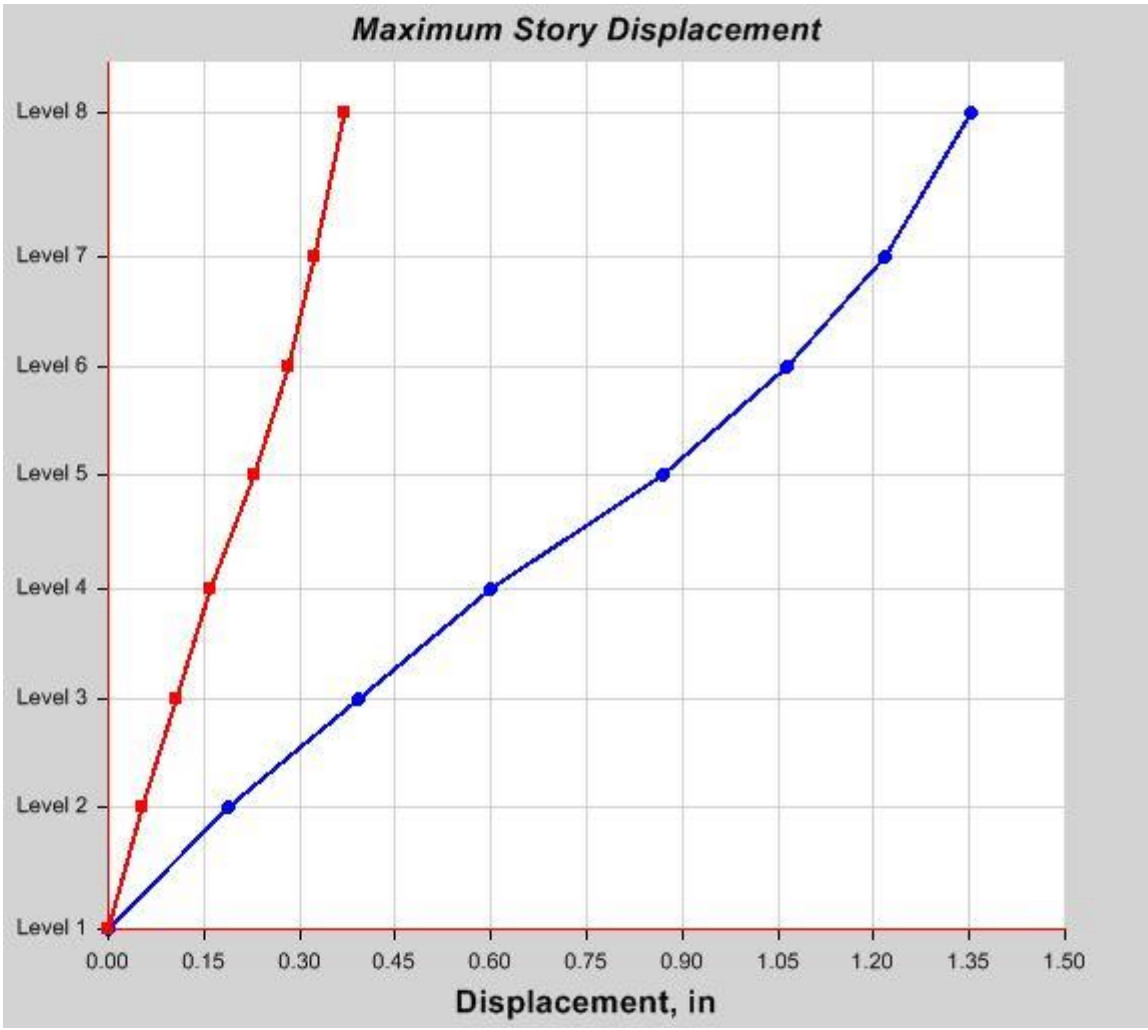


Figure 7 - Wind Loading Max Story Displacement

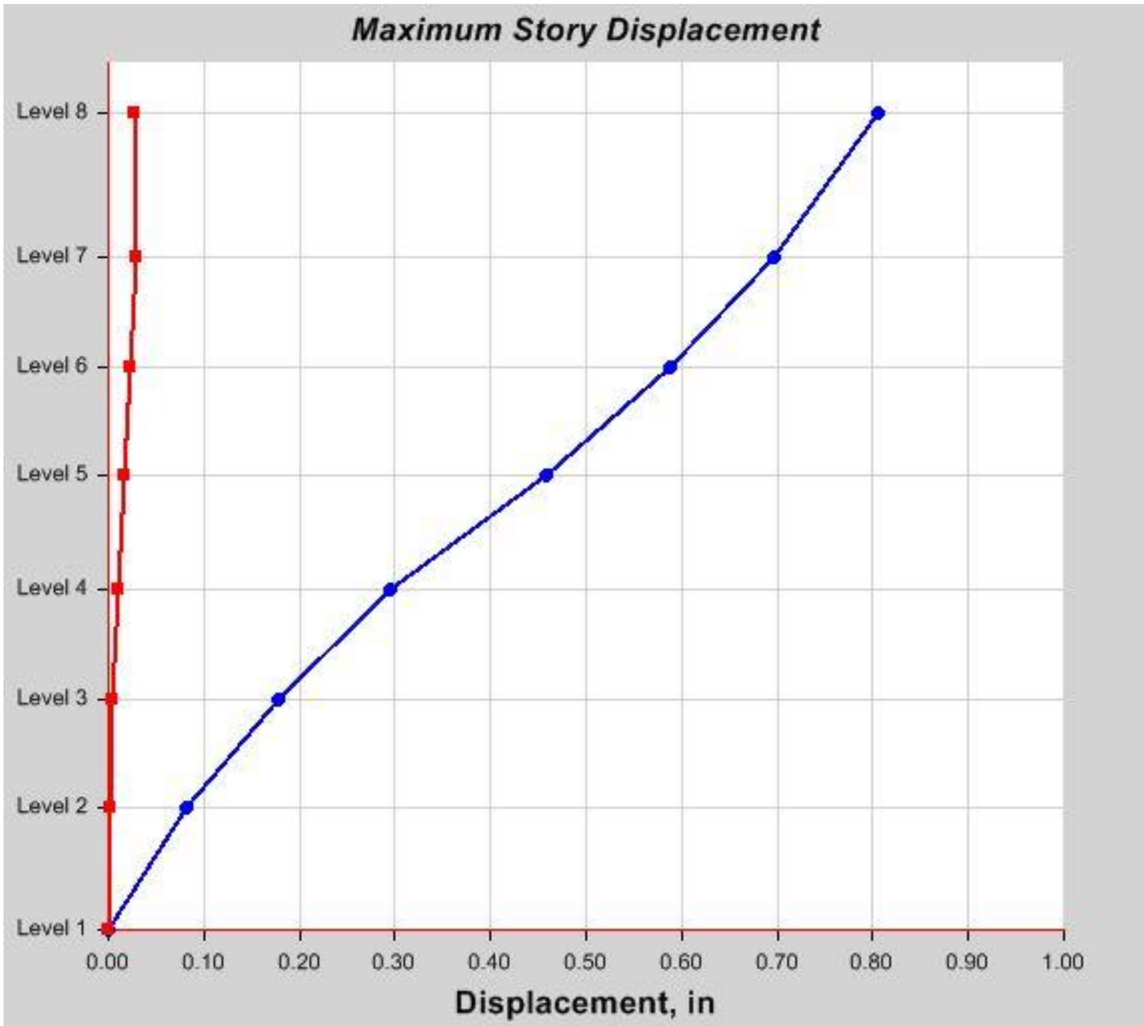


Figure 8 - Seismic Loading Max Story Displacement

The following represents the numerical comparison between the building displacement and building story drift and the code limitations for building displacement and building story drift.

Drift Limitations

Wind Loading

Δ_w = H/400 = allowable story drift = allowable overall building drift

Level 2 : Δ_w = H/400 = (17' × 12 in/ft)/400 = 0.51 in

Level 3 : Δ_w = H/400 = (15' × 12 in/ft)/400 = 0.45 in — 0.96 in

Level 4 : Δ_w = H/400 = (15' × 12 in/ft)/400 = 0.45 in — 1.41 in

Level 5 : Δ_w = H/400 = (16' × 12 in/ft)/400 = 0.48 in — 1.89 in

Level 6 : Δ_w = H/400 = (15' × 12 in/ft)/400 = 0.45 in — 2.34 in

Level 7 : Δ_w = H/400 = (15' × 12 in/ft)/400 = 0.45 in — 2.79 in

Level 8 : Δ_w = H/400 = (20' × 12 in/ft)/400 = 0.60 in — 3.39 in

Overall Bldg: Δ_w = H/400 = (113' × 12 in/ft)/400 = 3.39 in

Seismic Loading

Δ_s = 0.010 h_{sx} = allowable story drift = allowable overall building drift

Level 2 : Δ_s = 0.010 h_{sx} = 0.010 (17') = 0.17 in

Level 3 : Δ_s = 0.010 h_{sx} = 0.010 (15') = 0.15 in — 0.32 in

Level 4 : Δ_s = 0.010 h_{sx} = 0.010 (15') = 0.15 in — 0.47 in

Level 5 : Δ_s = 0.010 h_{sx} = 0.010 (16') = 0.16 in — 0.63 in

Level 6 : Δ_s = 0.010 h_{sx} = 0.010 (15') = 0.15 in — 0.78 in

Level 7 : Δ_s = 0.010 h_{sx} = 0.010 (15') = 0.15 in — 0.93 in

Level 8 : Δ_s = 0.010 h_{sx} = 0.010 (20') = 0.20 in — 1.13 in

Overall Bldg: Δ_s = 0.010 h_{sx} = 0.010 (113') = 1.13 in

Table 11 - Drift Limit - Wind Loading

Level	Story Height (ft.)	Total Height (ft.)	Story Drift (in.)	Code Limitation (in.)	Acceptable?	Total Drift (in.)	Code Limitation (in.)	Acceptable?
8	20	113	0.15	< 0.60	YES	1.43	< 3.39	YES
7	15	93	0.17	< 0.45	YES	1.28	< 2.79	YES
6	15	78	0.2	< 0.45	YES	1.11	< 2.34	YES
5	16	63	0.28	< 0.48	YES	0.91	< 1.89	YES
4	15	47	0.22	< 0.45	YES	0.63	< 1.41	YES
3	15	32	0.21	< 0.45	YES	0.41	< 0.96	YES
2	17	17	0.20	< 0.51	YES	0.20	< 0.51	YES

Note: Code limitation used for wind loading drift: $\Delta_W = H/400$

Table 12 - Drift Limit - Seismic Loading

Level	Story Height (ft.)	Total Height (ft.)	Story Drift (in.)	Code Limitation (in.)	Acceptable?	Total Drift (in.)	Code Limitation (in.)	Acceptable?
8	20	113	0.14	< 0.20	YES	0.89	< 1.13	YES
7	15	93	0.11	< 0.15	YES	0.75	< 0.93	YES
6	15	78	0.14	< 0.15	YES	0.64	< 0.78	YES
5	16	63	0.18	< 0.16	NO	0.50	< 0.63	YES
4	15	47	0.12	< 0.15	YES	0.32	< 0.47	YES
3	15	32	0.11	< 0.15	YES	0.20	< 0.32	YES
2	17	17	0.09	< 0.17	YES	0.09	< 0.17	YES

Note: Code limitation used for seismic loading drift: $\Delta_S = 0.010h_{sx}$

9.2 Member Checks

The following member checks evaluate a critical member on the building level of investigation for the analysis of the lateral force resisting system. Figure 9 outlines the critical members being investigated for the applicable member checks that follow.

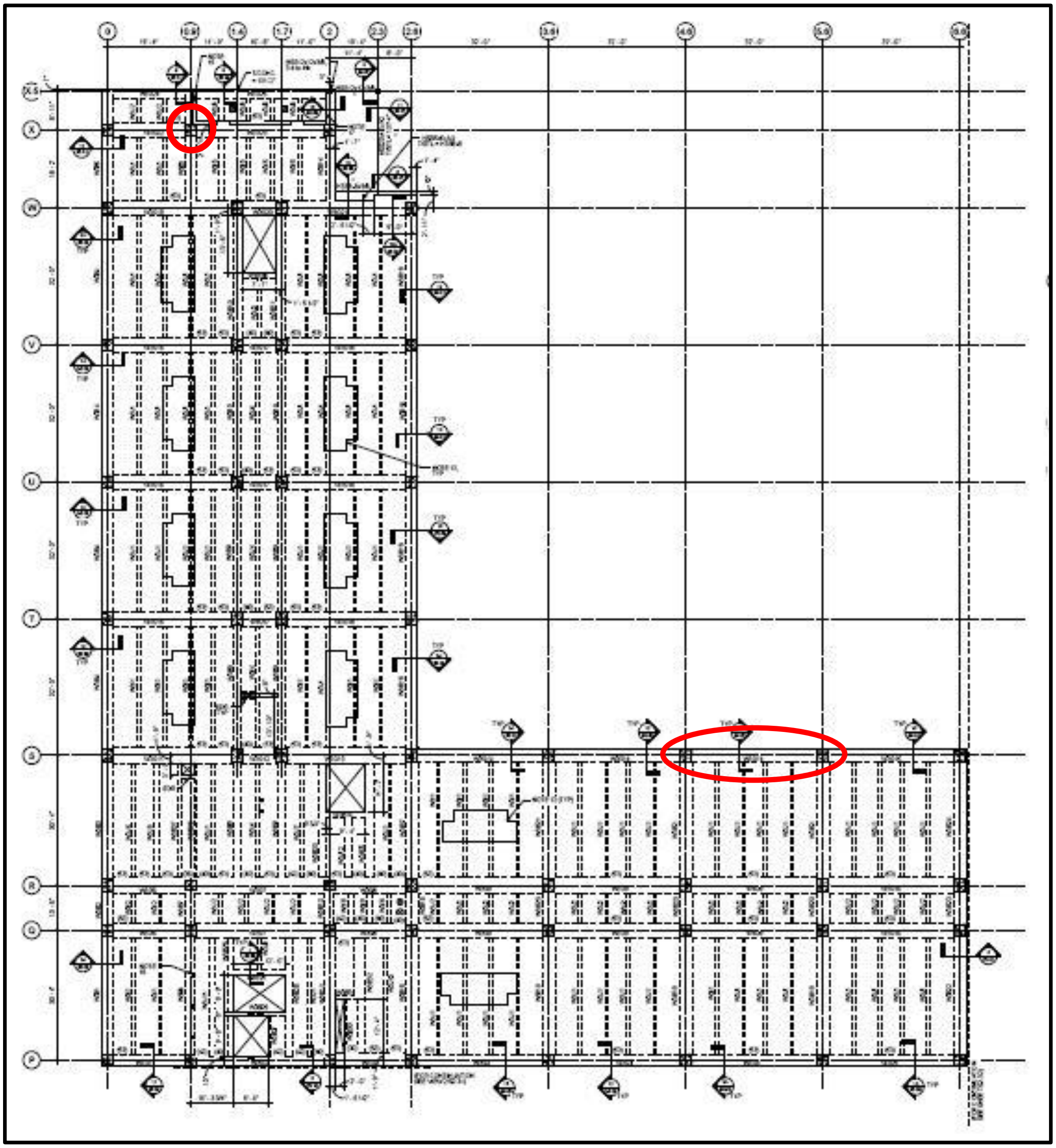


Figure 9 - Critical Members For Evaluation

9.2.1 Column Member Check

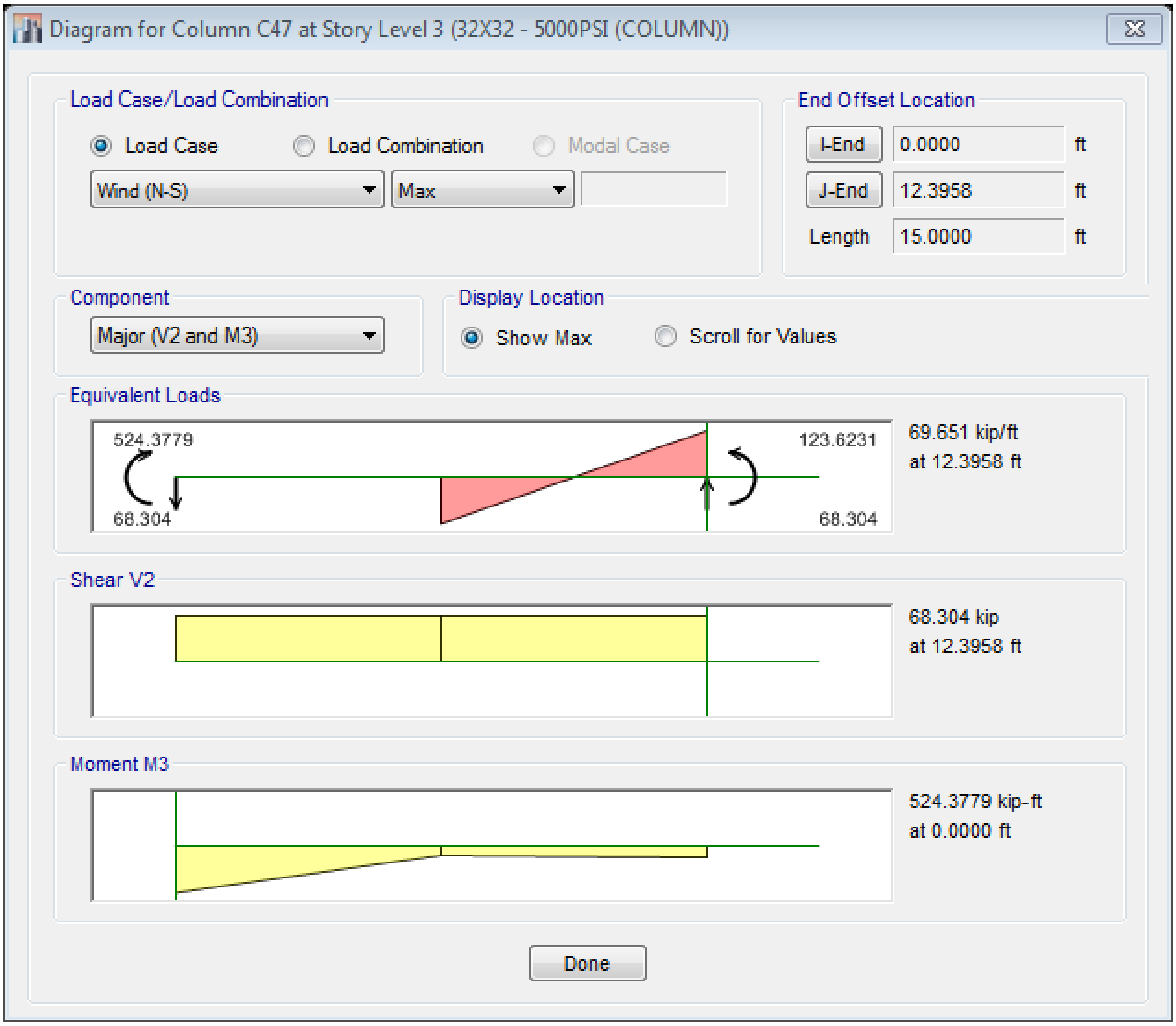
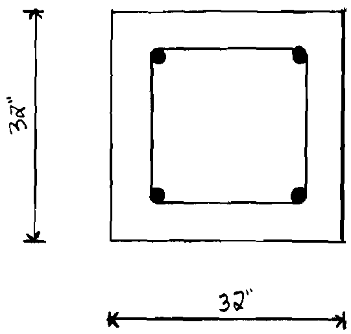


Figure 10 - ETABS Output - Column

Column Member Check (Column X-0.9 denotation on structural documents)



$A_{s,long}$: (16) #9 = 16.00 in^2
$A_{s,trans}$: #4 @ 8"
Length: 15 ft
f'_c: 5,000 psi
f_y: 60,000 psi

Analysis for Column in Sway Frame

$\delta_s M_s = M_s / (1 - (\Sigma P_u / 0.75 \Sigma P_c)) \geq M_s$

P_u = load (vertical) w/in story or number in question

P_c = Euler buckling load for sway resisting columns (use k - effective length - factor)

$M_1 = M_{1ns} + \delta_s M_{1s}$ and $M_2 = M_{2ns} + \delta_s M_{2s}$

Column Tributary Area = $[(19.33/2) + (32.5/2)] \times [(8.92/2) + (18.17/2)]$ = 25.915 × 13.545 = 351 ft^2

$P_u = [(1.2 \times 640) + (1.6 \times 450)] (351 ft^2)$ where dead load = (5 × 110 psf) + 90 psf = 640 psf
[controlling load combination for gravity-intensive loads]
live load = (5 × 80 psf) + 50 psf = 450 psf
min roof LL per structural documents

= 522.3 k

$P_c = \pi^2 EI / (kL)^2 = \pi^2 (4031)(32^4/12) / (0.5 \times 15 \times 12)^2 = 547 k$

$l_u/r > 35/\sqrt{P_u/f'_c A_g} \rightarrow 15 \times 12/9.24 > 35/\sqrt{522.3/(5)(32 \times 32)} \rightarrow 19.49 > 109.6$ ← acceptable because column does not exhibit slender column effects

where $r = \sqrt{I_g/A_g} = \sqrt{[(32^4)/12]/(32 \times 32)} = 9.24$

$\delta_s M_s = M_s / (1 - (\Sigma P_u / 0.75 \Sigma P_c)) \geq M_s \rightarrow \delta_s = 1/(1 - (\Sigma P_u / 0.75 \Sigma P_c))$ (ACI 10.10.7.4)

$\delta_s = 1/0.27 = 3.7$

Secondary Effect = (522.3 k) e = (522.3 k)(0.41 in) = 214 kin / 12 in/ft = 17.8 k·ft

ETABS output

(547)(32/2) / 12 in/ft = 729.3 k·ft > (522.3)(32/2) / 12 in/ft = 696.4 + 17.8 = 714.2 k·ft > 524.4 k·ft ✓

9.2.2 Beam Member Check

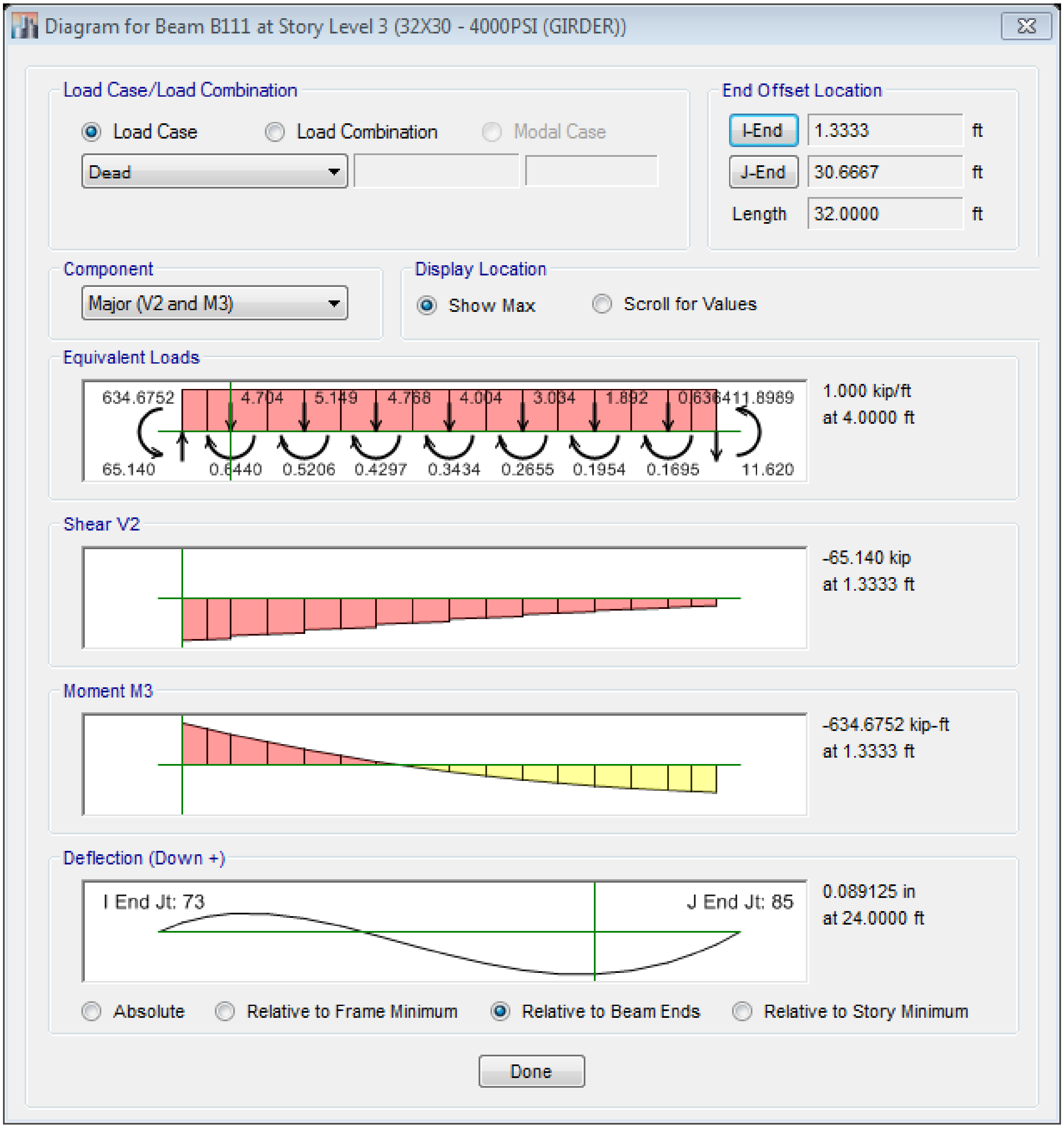
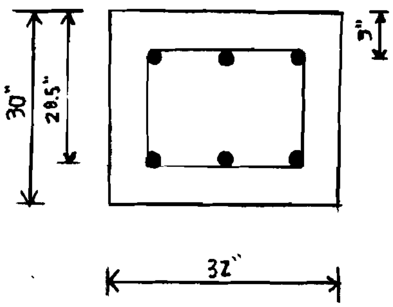


Figure 11 - ETABS Output - Beam

Beam Member Check (W3 G14 denotation on structural documents)



$A_{s,top}$: (5) #9 = 5.00 in^2
$A_{s,bot}$: (6) #9 = 6.00 in^2
Stirrups: (15) #4 @ 6"
Length: 32'-0"
f'_c : 4000psi
f_y : 60000psi

Assume yield in tension & compression: $f_s = f_y$ and $f'_s = f_y$

$A_{s1} = A_s - A_{s2} : 6 - 5 = 1.00 in^2$

$A_{s2} = A'_s = 5.00 in^2$

Equilibrium: $0.85 f'_c ab = A_{s1} f_y$

$0.85(4)(a)(32) = (1)(60) \rightarrow a = 0.55 \rightarrow \beta = 0.85$ for $f'_c = 4ksi \rightarrow c = a/\beta = 0.55/0.85 = 0.65in$

Yield Assumptions: $\varepsilon_y = 60,000 / 29,000,000 = 0.00207$

$\varepsilon'_s = 0.003(0.65 - 3)/0.65 = -0.011 < 0.00207$ and $\varepsilon_s = 0.003(28.5 - 0.65)/0.65 = 0.13 > 0.00207$

Compression steel does not yield, tension steel does yield

Evaluate c using equilibrium (since yield assumptions failed to hold)

$0.85 f'_c b a + A'_s f'_s = A_s f_y$

$0.85(4)(32)(0.85c) + (5)(f'_s) = (6)(60)$ where $f'_s = \varepsilon'_s E$ where $\varepsilon'_s = (0.003/c)(c-3)$

$0.85(4)(32)(0.85c) + (5)[(0.003/c)(c-3)]\,29,000 = (6)(60)$

$92.48c^2 + 435c - 1305 = 360c$

$92.48c^2 + 75c - 1305 = 0 \rightarrow c = 3.37in \rightarrow a = \beta c = 0.85(3.37) = 2.86in$

Accordingly, $f'_s = \varepsilon'_s E = (0.003/3.37)(3.37 - 3)\,29000 = 1.81 ksi < 60ksi$

Calculate $\varepsilon_s = 0.003(28.5 - 3.37)/3.37 = 0.0224 > 0.00207$ ✓

Beam Member Check (W3G14 denotation on structural documents)

$A_{s2} = A_s' f_s'/f_y = (5)(1.81)/60 = 0.151 in$

$A_{s1} = A_s - A_{s2} = 6 - 0.151 = 5.849 in$

$M_n = M_{n1} + M_{n2}$

$M_{n1} = A_{s1} f_y [d - a/2] = (5.849)(60)(28.5 - 2.86/2) = 9500 / 12 in/ft = 791.7 k \cdot ft$

$M_{n2} = A_s' f_s' (d - d') = (5)(1.81)(28.5 - 3) = 230.8 / 12 in/ft = 19.2 k \cdot ft$

$M_n = M_{n1} + M_{n2} = 791.7 + 19.2 = 810.9 k \cdot ft$

$\phi M_n = 0.9(810.9) = 729.8 k \cdot ft$

ETABS Output: W3G14

Flexural Moment: $M_3 = -634.7 k \cdot ft$

$\phi M_n = 729.8 k \cdot ft > M_3 = 634.7 k \cdot ft$ ∴ flexural strength design sufficient

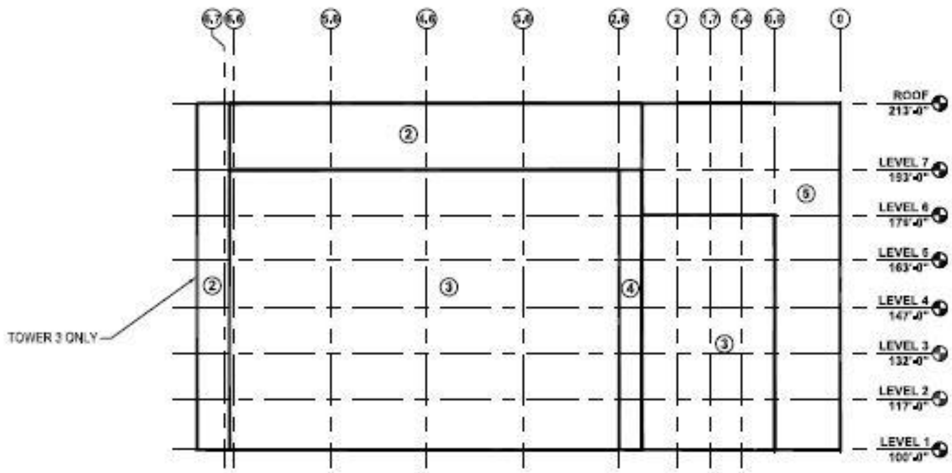
3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

[10] Conclusion

After extensive analysis of the lateral force resisting framing system of The Medical Center, adequacy of design has been established. The intermediate reinforced concrete moment frames (IMF) utilized in The Medical Center engages nearly all framing members to resist the lateral loads (namely wind and seismic loading) that may act upon the building in its lifetime. Utilizing ASCE 7-05 as a design standard and reference, the design of the lateral force resisting system of The Medical Center was controlled by the wind loading in the E-W direction. This controlling loading case is logical due to its orientation orthogonal to the longest side of the building, maximizing the wind force acting on the building in this direction.

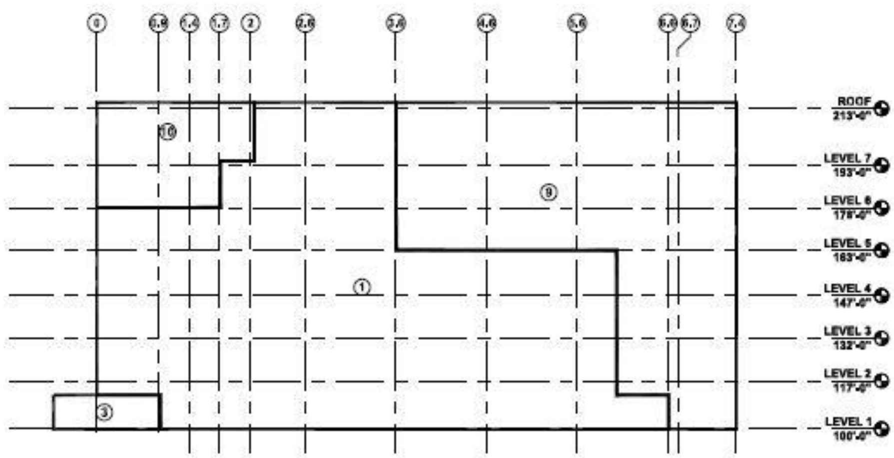
Overall, due to the massive nature of the structure, wind effects, such as uplift forces, are countered in design. Although the degree of rigidity of the structure is high (due to framing scheme and material property), seismic forces are able to be withstood. All in all, the lateral force resisting system of The Medical Center is sufficient to withstand the design loads designated by code.

[11] Appendix A: Wind Loads



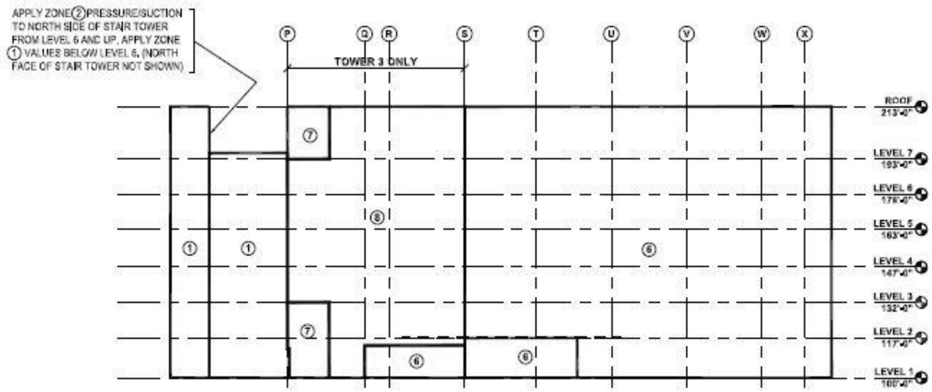
INPATIENT TOWER NORTH ELEVATION PRESSURE ZONES

NOTE:
COLUMN BUBBLES BASED ON
TOWER 1, PRESSURE ZONES ARE
IDENTICAL AT TOWERS 2 AND 3

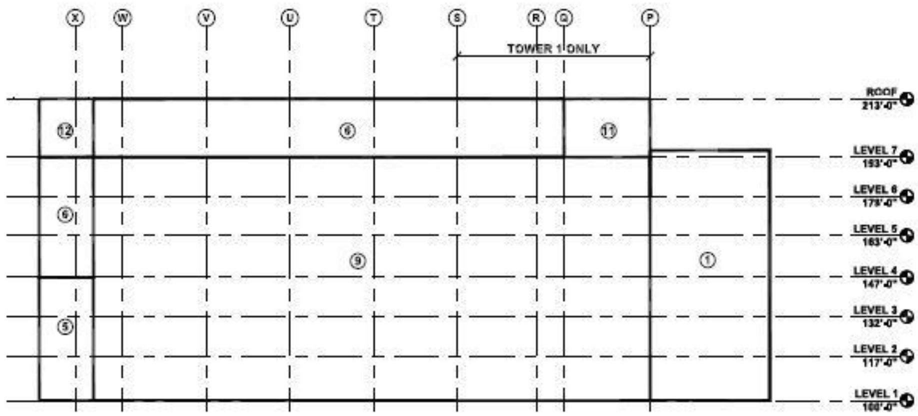


INPATIENT TOWER SOUTH ELEVATION PRESSURE ZONES

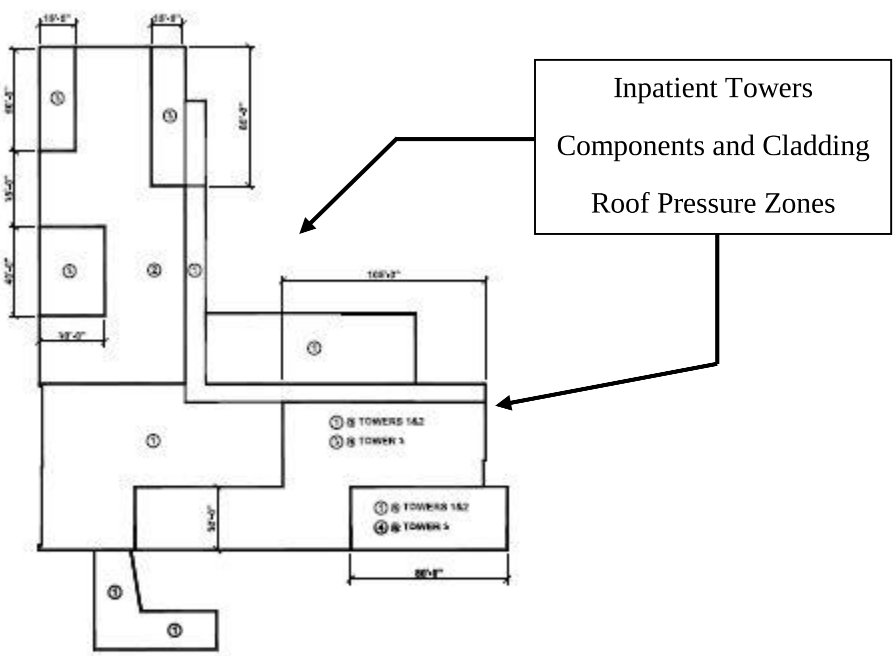
NOTE:
COLUMN BUBBLES BASED ON
TOWER 1, PRESSURE ZONES ARE
IDENTICAL AT TOWERS 2 AND 3



INPATIENT TOWER EAST ELEVATION PRESSURE ZONES



INPATIENT TOWER WEST ELEVATION PRESSURE ZONES



Wind Load Tables for Inpatient Tower

INPATIENT TOWER COMPONENTS AND CLADDING ROOF LOAD CRITERA (PSF)								
COMPONENT	ROOF ZONE 1		ROOF ZONE 2		ROOF ZONE 3		ROOF ZONE 4	
AREA (SQ FT)	PRESSURE	SUCTION	PRESSURE	SUCTION	PRESSURE	SUCTION	PRESSURE	SUCTION
10	38	82	38	-92	38	-104	38	-138
20	38	-77	38	-86	38	-97	38	-129
50	38	-71	38	-79	38	-90	38	-119
100	38	-65	38	-73	38	-82	38	-109
200	38	-62	38	-69	38	-78	38	-104
500	38	-53	38	-60	38	-67	38	-89
700	38	-53	38	-60	38	-67	38	-89

Wind Load Tables for Inpatient Tower

INPATIENT TOWER COMPONENTS AND CLADDING WALL LOAD CRITERIA (PSF)												
COMPONENT	WALL ZONE 1		WAL. ZONE 2		WALL ZONE 3		WALL ZONE 4		WALL ZONE 5		WALL ZONE 6	
AREA (SQ FT)	PRESSURE	SUCTION	PRESSURE	SUCTION	PRESSURE	SUCTION	PRESSURE	SUCTION	PRESSURE	SUCTION	PRESSURE	SUCTION
10	64	-63	64	-82	64	-71	71	-63	71	-94	71	-82
20	64	-63	64	-82	64	-71	71	-63	71	-94	71	-82
50	59	-61	59	-79	59	-68	65	-61	65	-90	65	-79
100	56	-58	56	-75	56	-65	62	-58	62	-85	62	-75
200	53	-55	53	-71	53	-62	59	-55	59	-81	59	-71
500	47	-52	47	-67	47	-59	52	-52	52	-76	52	-67
700	47	-52	47	-67	47	-59	52	-52	52	-76	52	-67

COMPONENT	WALL ZONE 7		WALL ZONE 8		WALL ZONE 9		WALL ZONE 10		WALL ZONE 11		WALL ZONE 12	
AREA (SQ FT)	PRESSURE	SUCTION	PRESSURE	SUCTION	PRESSURE	SUCTION	PRESSURE	SUCTION	PRESSURE	SUCTION	PRESSURE	SUCTION
10	71	-151	71	-117	71	-71	82	-71	71	-105	82	-82
20	71	-151	71	-117	71	-71	82	-71	71	-105	82	-82
50	65	-144	65	-112	65	-68	75	-68	65	-100	75	-79
100	62	-136	62	-106	62	-65	71	-65	62	-95	71	-75
200	59	-128	59	-100	59	-62	67	-62	59	-90	67	-71
500	52	-121	52	-94	52	-59	59	-59	52	-85	59	-67
700	52	-121	52	-94	52	-59	59	-59	52	-85	59	-67

Wind Loading (N-S) - Resultant Story Forces (for Modeling Purposes)

Level 2 : (17ft /2)(198 ft)(47.5 psf + 13.6 psf) + (15ft/2)(198 ft)(50.8psf + 13.6psf) = 198.5 k

Level 3 : (15ft/2)(198 ft)(50.8psf + 13.6psf) + (15ft/2)(198 ft)(55.0psf + 13.6psf) = 197.5 k

Level 4 : (15ft/2)(198ft)(55.0psf + 13.6 psf) + (16ft/2)(198 ft)(56.7psf + 13.6psf) = 213.2 k

Level 5 : (16ft/2)(198ft)(56.7psf + 13.6psf) + (15ft/2)(198 ft)(59.4psf + 13.6psf) = 219.8 k

Level 6 : (15ft/2)(198ft)(59.4psf + 13.6psf) + (15ft/2)(198ft)(60.6psf + 13.6psf) = 218.6 k

Level 7 : (15ft/2)(198ft)(60.6psf + 13.6psf) + (20ft/2)(198ft)(62.9psf + 13.6psf) = 261.7 k

Level 8 : (20ft/2)(198 ft)(62.9psf + 13.6psf) = 151.5 k

* assumption: for modeling purposes, added windward and leeward wind pressures together (to create worst case scenario) in order to apply the wind loading on a single face of the building (South)

Wind Loading (E-W) - Resultant Story Forces (for Modeling Purposes)

Level 2 : (17ft/2)(227ft)(47.5psf + 16.2psf) + (15ft/2)(227ft)(50.8psf + 16.2psf) = 237.0 k

Level 3 : (15ft/2)(227ft)(50.8psf + 16.2psf) + (15ft/2)(227ft)(55.0psf + 16.2psf) = 235.3 k

Level 4 : (15ft/2)(227ft)(55.0psf + 16.2 psf) + (16ft/2)(227ft)(56.7psf + 16.2psf) = 253.6 k

Level 5 : (16ft/2)(227ft)(56.7psf + 16.2psf) + (15ft/2)(227ft)(59.4psf + 16.2psf) = 261.1 k

Level 6 : (15ft/2)(227ft)(59.4psf + 16.2psf) + (15ft/2)(227ft)(60.6psf + 16.2psf) = 259.5 k

Level 7 : (15ft/2)(227ft)(60.6psf + 16.2psf) + (20ft/2)(227ft)(62.9psf + 16.2psf) = 310.3 k

Level 8 : (20ft/2)(227 ft)(62.9psf + 16.2psf) = 179.6 k

* assumption: for modeling purposes, added windward and leeward wind pressures together (to create worst case scenario) in order to apply the wind loading on a slngle face of the building (East)

[12] Appendix B: Seismic Loads

USGS Design Maps Summary Report

View Detailed Report   Print

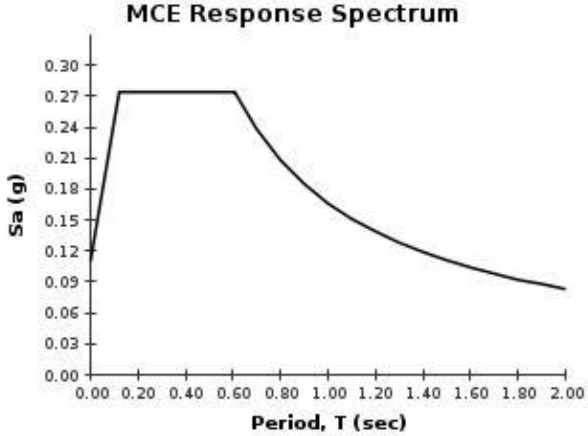
User–Specified Input

Building Code Reference Document	ASCE 7-05 Standard (which utilizes USGS hazard data available in 2002)
Site Coordinates	
Site Soil Classification	Site Class E – "Soft Clay Soil"
Occupancy Category	IV

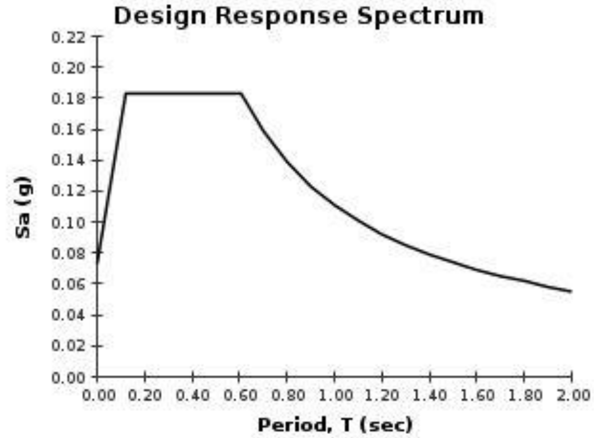
USGS–Provided Output

S_S = 0.110 g	S_{MS} = 0.274 g	S_{DS} = 0.183 g
S_1 = 0.048 g	S_{M1} = 0.166 g	S_{D1} = 0.111 g

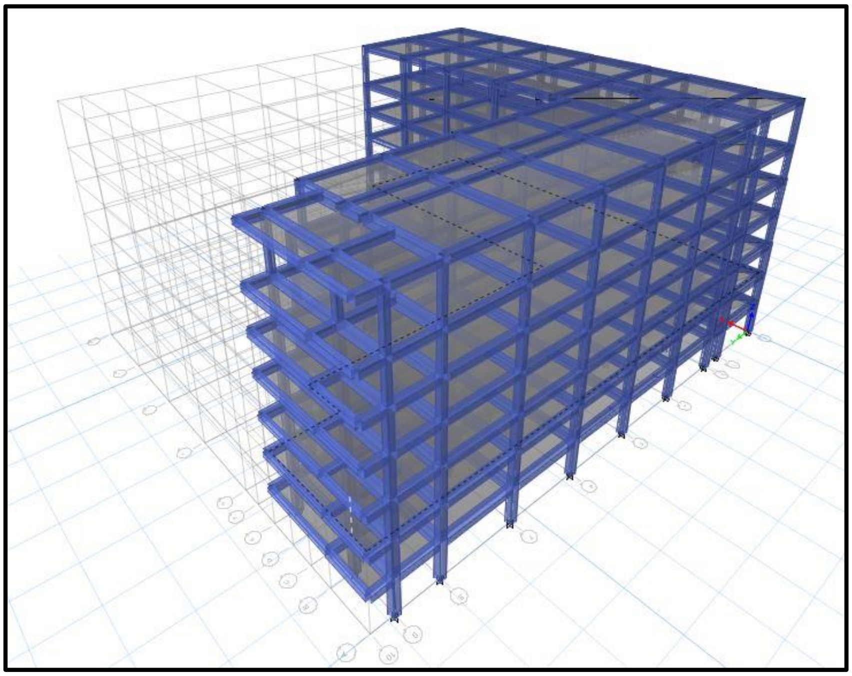
MCE Response Spectrum

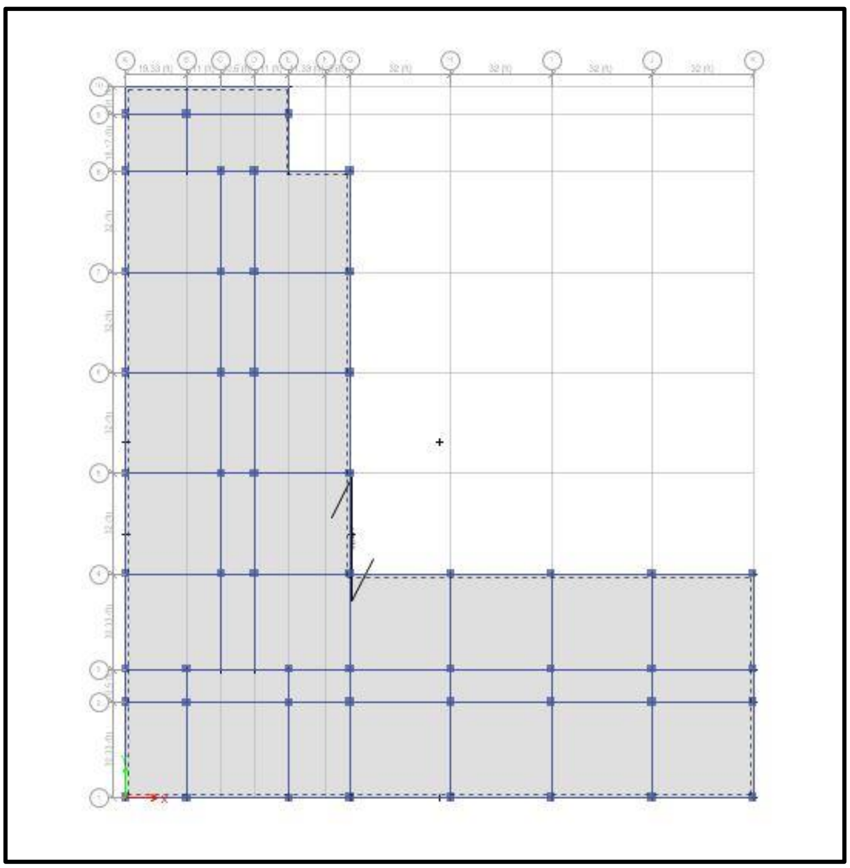


Design Response Spectrum



[13] Appendix C: Computer Model





Level 2

Columns

32 x 32 - 5000 psi
30 x 30 - 5000 psi

Girders

24 x 21.75 - G31
32 x 30 - G1 G2 G3 G4 G5
42 x 30 - G6 G7 G8 G9 G10 G11 G12 G13 G16 G17 G18 G19 G22 G23 G24
49 x 30 - G14 G15
24 x 31.25 - G30
42 x 31.25 - G25 G26 G27 G28
46 x 31.25 - G29

Beams

29 x 30 - B6 B7 B9 B10 B11 B12 B13
35 x 30 - B1 B2 B3 B4 B5 B15 B16 B17 B20 B23 B24 B25 B26 B27 B28
45 x 30 - B18 B19
31 x 31.25 - B5 B8 B14

Level 3

Columns

32 x 32 - 5000 psi
30 x 30 - 5000 psi

Girders

24 x 21.25 - G24 G25
26 x 30 - G2
32 x 30 - G1 G3 G4 G5 G14 G15
42 x 30 - G6 G7 G8 G9 G10 G11 G12 G13 G16 G17 G18
42 x 31.25 - G19 G20 G21 G22 G23

Beams

29 x 30 - B3 B6 B7 B9 B10 B11 B12 B13
35 x 30 - B1 B2 B4 B15 B16 B17 B18 B19 B20 B21 B22 B23 B24
31 x 31.25 - B5 B8 B14

Level 4

Columns

32 x 32 - 5000 psi
30 x 30 - 5000 psi

Girders

24 x 21.25 - G24 G25
42 x 21.25 - G6 G7 G8 G9 G10 G11 G12 G13 G16 G17 G18
26 x 24 - G2
32 x 30 - G1 G3 G4 G5 G14 G15
42 x 31.25 - G19 G20 G21 G22 G23

Beams

21 x 21.25 - B9 B10
29 x 21.25 - B6 B7 B8 B11 B12 B13 B14
35 x 21.25 - B16 B17 B18 B20 B21 B22 B23 B24 B25
33 x 30 - B1 B2 B3 B4 B19
31 x 31.25 - B5 B15

Level 5

Columns

28 x 28 - 4000 psi

Girders

24 x 21.25 - G24 G25
42 x 21.25 - G6 G7 G8 G9 G10 G11 G12 G13 G16 G17 G18
26 x 24 - G2
32 x 30 - G1 G3 G4 G5 G14 G15
42 x 31.25 - G19 G20 G21 G22 G23

Beams

21 x 21.25 - B9 B10
29 x 21.25 - B6 B7 B8 B11 B12 B13 B14
35 x 21.25 - B16 B17 B18 B20 B21 B22 B23 B24 B25
33 x 30 - B1 B2 B3 B4 B19
31 x 31.25 - B5 B15

Level 6

Columns

28 x 28 - 4000psi

Girders

42 x 21.25 - G6 G7 G8 G9 G10 G11 G12 G13 G16 G17 G18
26 x 24 - G2
24 x 30 - G24 G25
32 x 30 - G1 G3 G4 G5 G14 G15 G22 G23
42 x 30 - G19 G20 G21

Beams

21 x 21.25 - B9 B10
29 x 21.25 - B6 B7 B11 B12 B13 B14
35 x 21.25 - B16 B17 B18 B20 B21 B22 B23 B24 B25
33 X 30 - B1 B2 B3 B4 B5 B8 B15 B19

Level 7

Columns

28 x 28 - 4000psi
24 x 24 - 4000 psi

Girders

26x24 - G2
32x30 - G1 G4 G5 G22 G23
37 x 30 - G3 G14 G15
42 x 30 - G6 G7 G8 G9 G10 G11 G12 G13 G16 G17 G18 G19 G20 G21
24 x 30 - G24 G25

Beams

25 x 20.75 - B6 B7 B9 B10 B13 B15
32 x 20.75 - B12 B16 B17 B18 B20 B21 B22 B23 B24 B25
26.5 x 30 - B1 B2 B3 B4 B5 B8
33 x 30 - B11 B14 B19
48 x 30 - B19A

Level 8

Columns

24 x 24 - 4000 psi
20 x 20 - 4000 psi

Girders

24 x 20 - G24 G25
28 x 20 - G22 G23
42 x 20 - G6 G7 G8 G9 G10 G11 G12 G16 G17 G18
32 x 30 - G1 G3 G4 G5 G14 G15
38 x 30 - G2 G13
42 x 30 - G7A G19 G20 G21

Beams

23 x 20 - B9 B10
28 x 20 - B6 B7 B11 B12 B14
35 x 20 - B15 B16 B17 B18 B19 B20 B21 B22 B23
33 x 30 - B1 B2 B3 B4 B5 B8 B13

[14] Appendix D: ETABS Technical Outputs

ETABS Output: COM and COR

STORY	XCM	YCM	XCR	YCR
Level 8	71.2398	80.9237	66.8941	84.6415
Level 7	71.0322	85.4676	67.3891	86.6383
Level 6	71.4112	84.6990	67.8551	86.7635
Level 5	70.0306	84.7765	69.0758	86.6833
Level 4	71.4947	84.4713	70.6727	86.3733
Level 3	71.6878	83.6721	71.3005	85.7728
Level 2	72.1030	83.7231	70.4319	85.1229

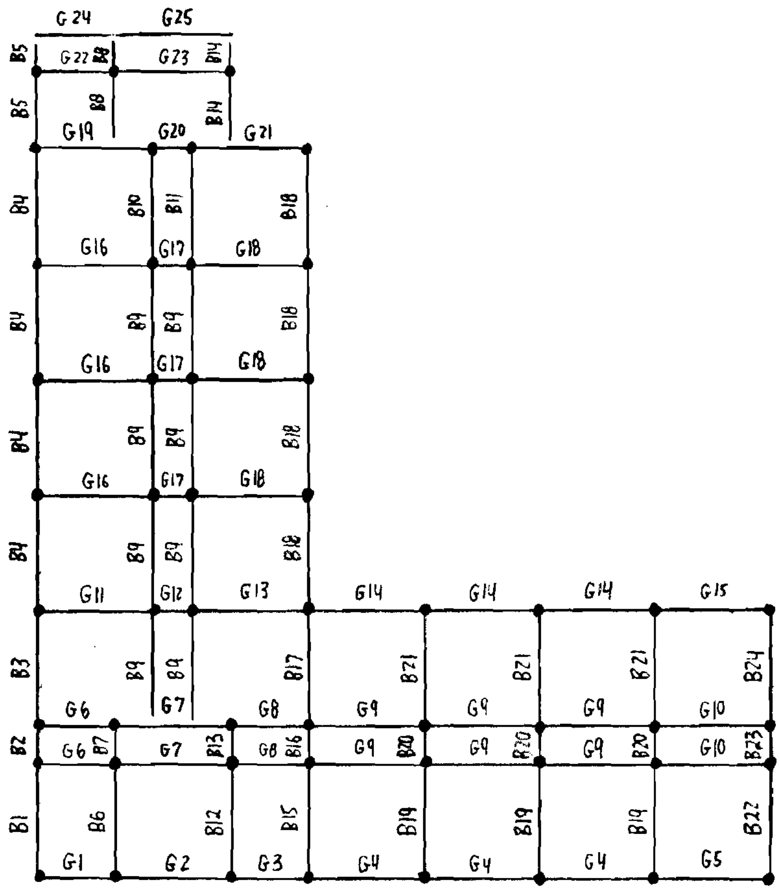
Wind Loading Max Story Displacements

TABLE: Story Max/Avg Displacements					
Story	Load Case/Combo	Direction	Maximum	Average	Ratio
			in	in	
Level 8	Wind (N-S) 10	X	1.425351	0.692044	2.059624
Level 7	Wind (N-S) 10	X	1.27619	0.622839	2.04899
Level 6	Wind (N-S) 10	X	1.111941	0.544946	2.040459
Level 5	Wind (N-S) 10	X	0.908072	0.444124	2.044637
Level 4	Wind (N-S) 10	X	0.626472	0.304884	2.054785
Level 3	Wind (N-S) 10	X	0.411069	0.198778	2.067976
Level 2	Wind (N-S) 10	X	0.199684	0.096157	2.076652

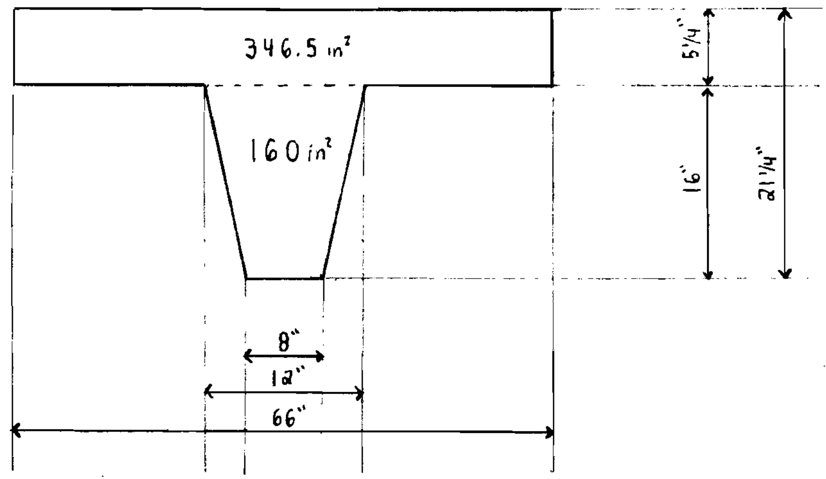
Seismic Loading Max Story Displacements

TABLE: Story Max/Avg Displacements					
Story	Load Case/Combo	Direction	Maximum	Average	Ratio
			in	in	
Level 8	Seismic (N-S) 3	X	0.889074	0.805705	1.103473
Level 7	Seismic (N-S) 3	X	0.758685	0.692657	1.095326
Level 6	Seismic (N-S) 3	X	0.640741	0.585	1.095283
Level 5	Seismic (N-S) 3	X	0.500213	0.456225	1.096419
Level 4	Seismic (N-S) 3	X	0.323245	0.293384	1.10178
Level 3	Seismic (N-S) 3	X	0.200183	0.179931	1.112558
Level 2	Seismic (N-S) 3	X	0.092088	0.082393	1.117669

Center of Mass (COM) → Level 3

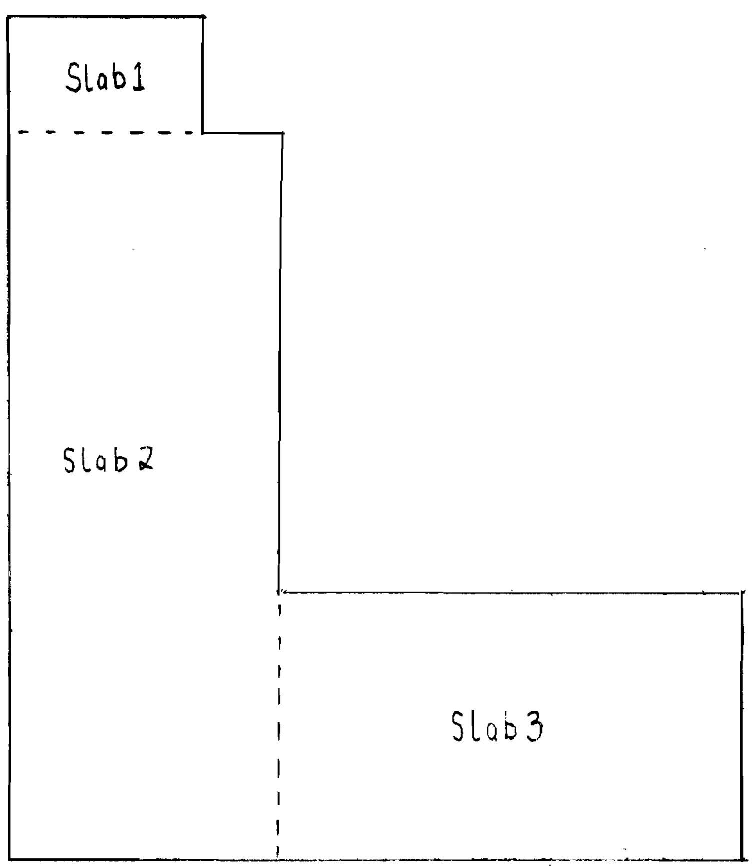


Center of Mass - Slab Consideration



Area Total: $346.5 + 160 = 506.5\ in^2$

Avg. Slab Thickness (per 66" pan spacing) = $506.5\ in^2 / 66\ in = 7.67\ in$



Center of Rigidity (COR) → Level 3