MERCY HEALTH MUSKEGON

MERCY CAMPUS CONSOLIDATION

Muskegon, Michigan

Abby Severyn | Structural Option | Honors

Adviser | Dr. Ryan Solnosky

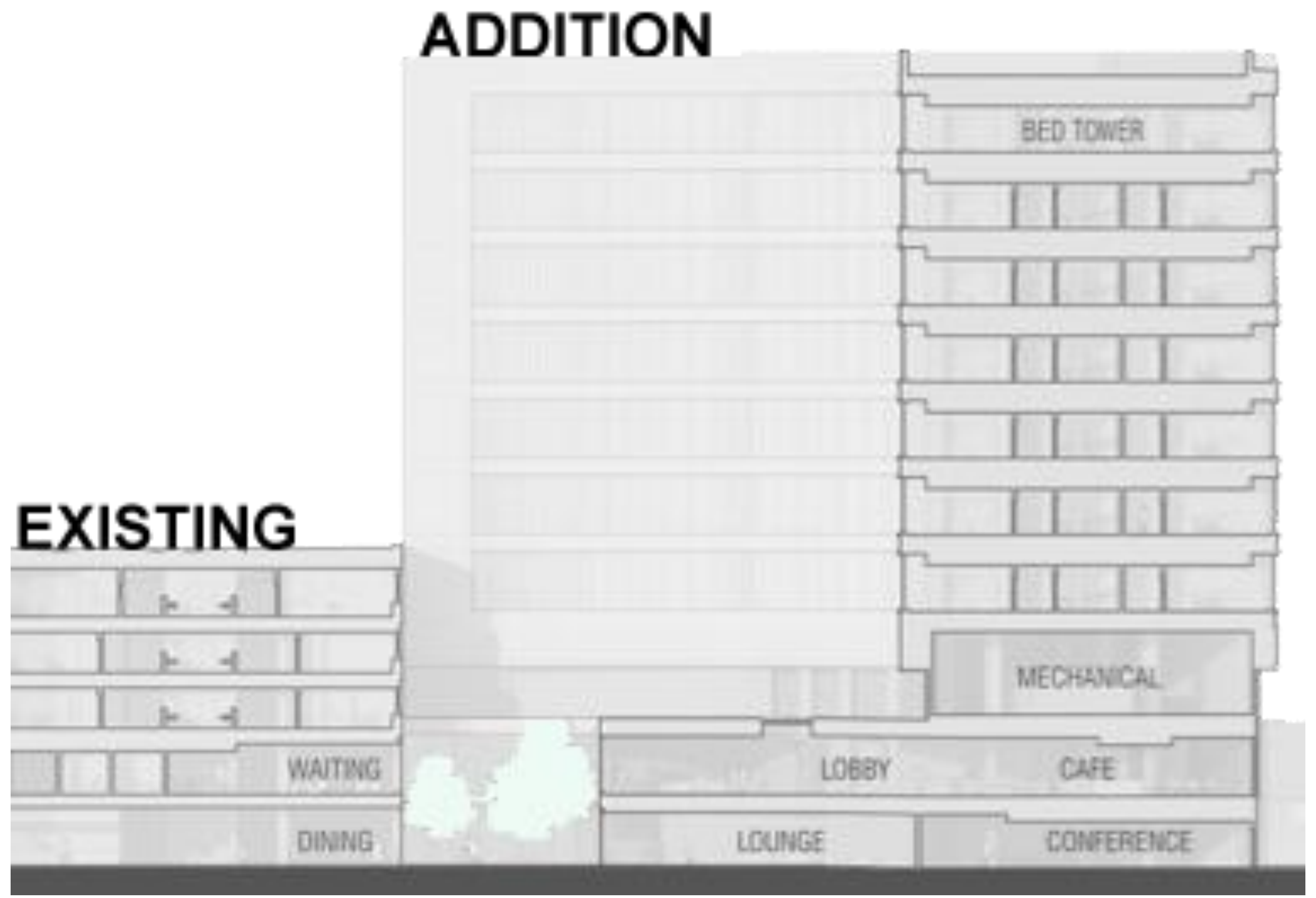
Mercy Health Muskegon

Building Overview

3D Exterior View of New and Existing Facilities

Statistics

- 10-story, 380,000 SF addition
- 2 Diagnostic & Treatment (D&T) Levels
- 1 Mechanical Level
- 7 Inpatient Bed Tower Levels
- Dates of Construction: September 2016 – November 2019
- Approximate Construction Cost: $186,000,000



Building Section

► Building Overview
Alternative Gravity Bay Study
Gravity System Redesign
Decision-Making Study
Lateral System Redesign
Structural System Comparisons
Acoustic Analysis
Prefabrication Study

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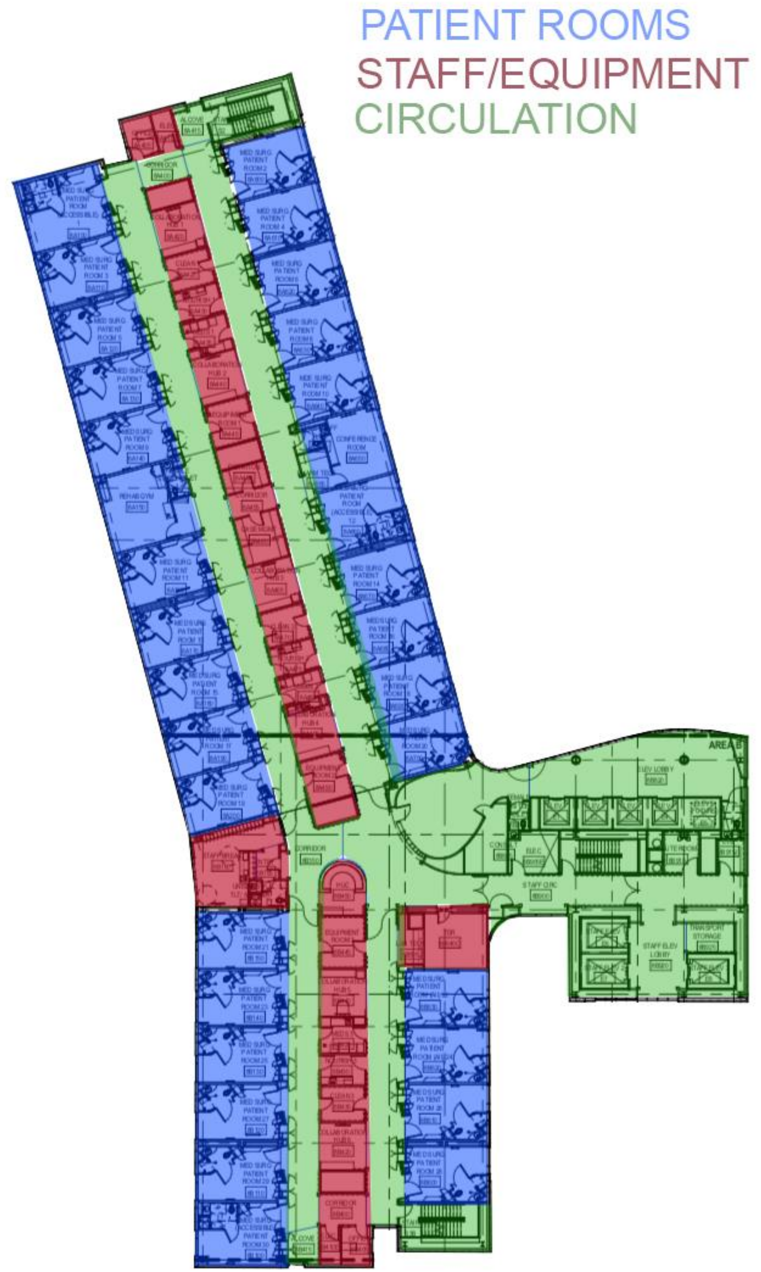

Typical Bed Tower Floor

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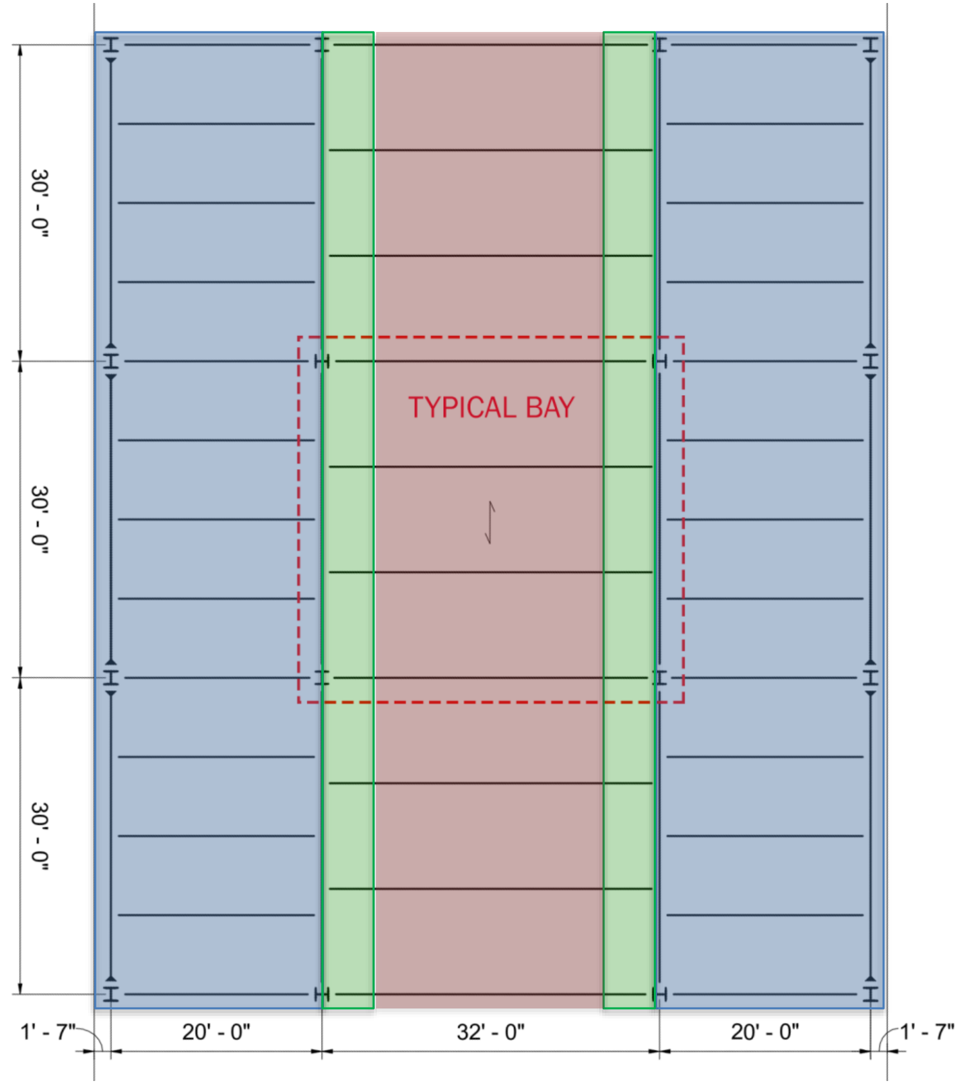

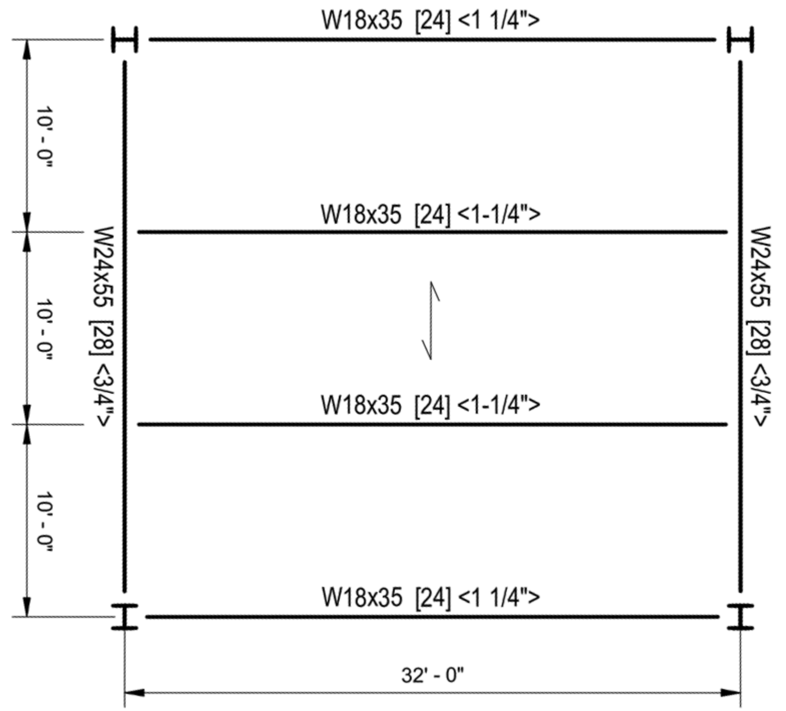

Existing Gravity System

- Composite steel
- W14 columns
- 3VLI18 composite deck with 4½" NWC topping

Typical Bed Tower Floor

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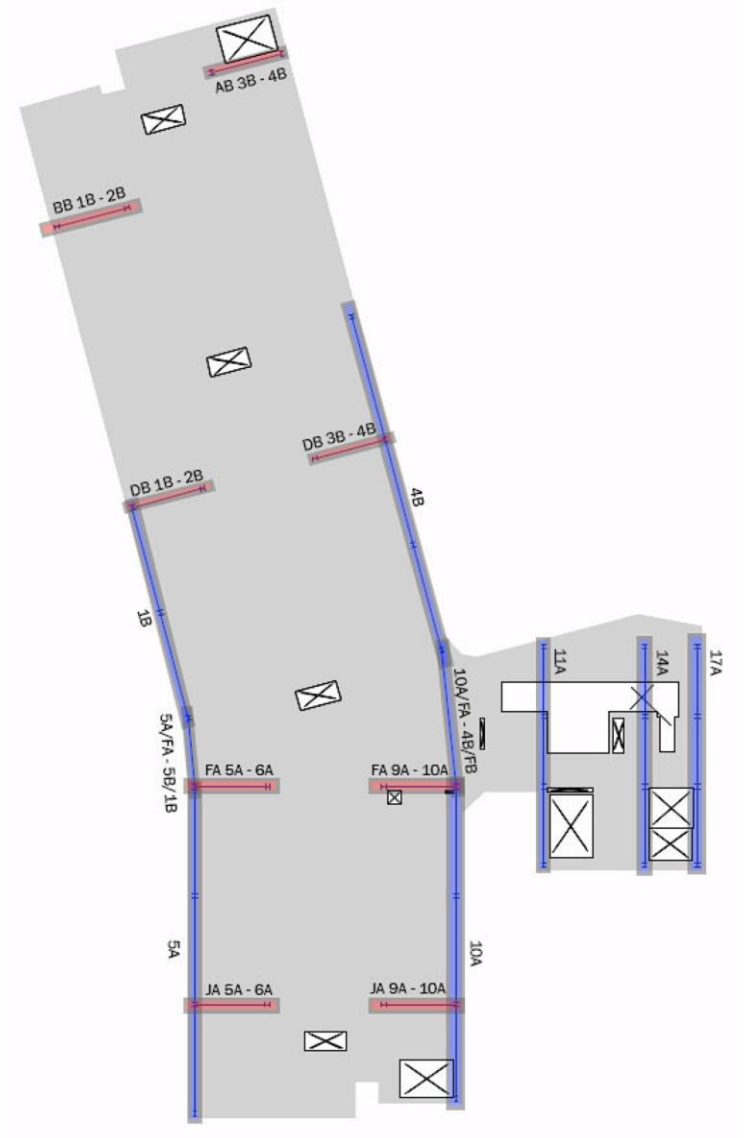
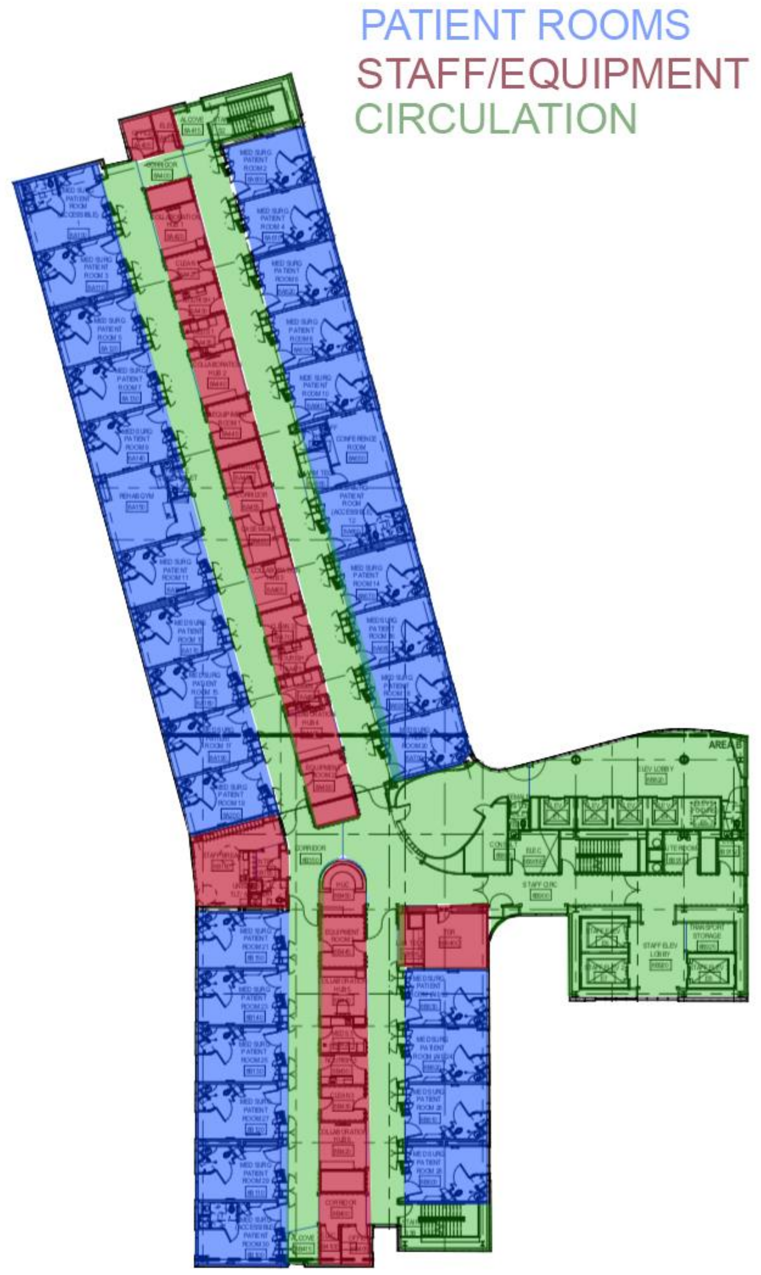


Typical Bed Tower Floor

Existing Lateral System

- Moment frames (blue)
- Braced frames (red)



Typical Bed Tower Floor

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Thesis Goals & Methods

Healing environment for patient centered care
- Vibration and acoustic analyses

HGA Project Mission Statement

*"The project shall provide a **healing environment for patient centered care** that is safe, affordable, and high quality, honoring our great tradition of commitment to community and organizational health."*

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Project Overview

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Healing environment for patient centered care
- Vibration and acoustic analyses

Safe, affordable, and high quality
- Prefabrication study and cost analyses

HGA Project Mission Statement

"The project shall provide a healing environment for patient centered care that is safe, affordable, and high quality, honoring our great tradition of ***commitment to community and organizational health****."*

Thesis Goals & Methods

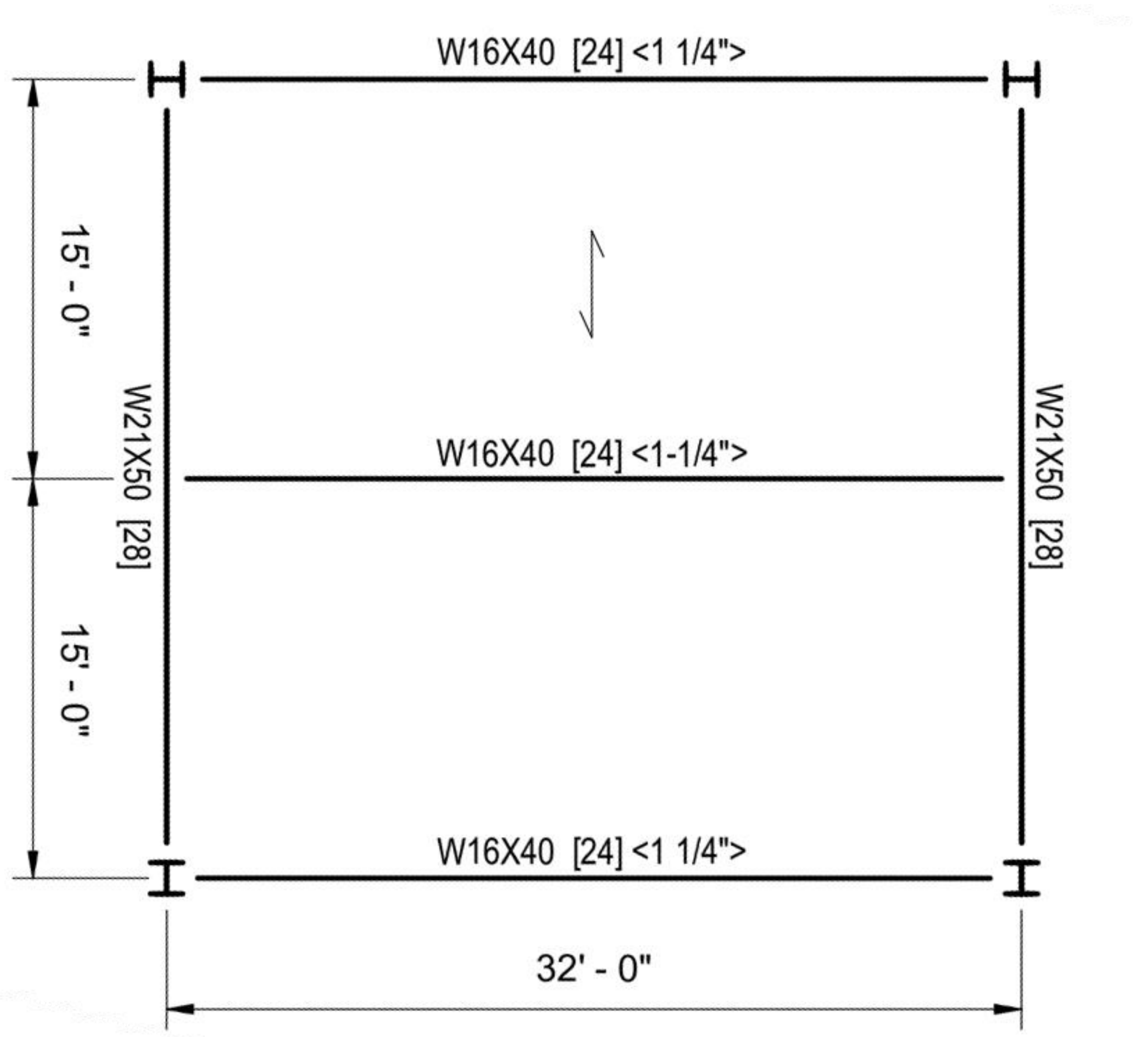
Healing environment for patient centered care
- Vibration and acoustic analyses

Safe, affordable, and high quality
- Prefabrication study and cost analyses

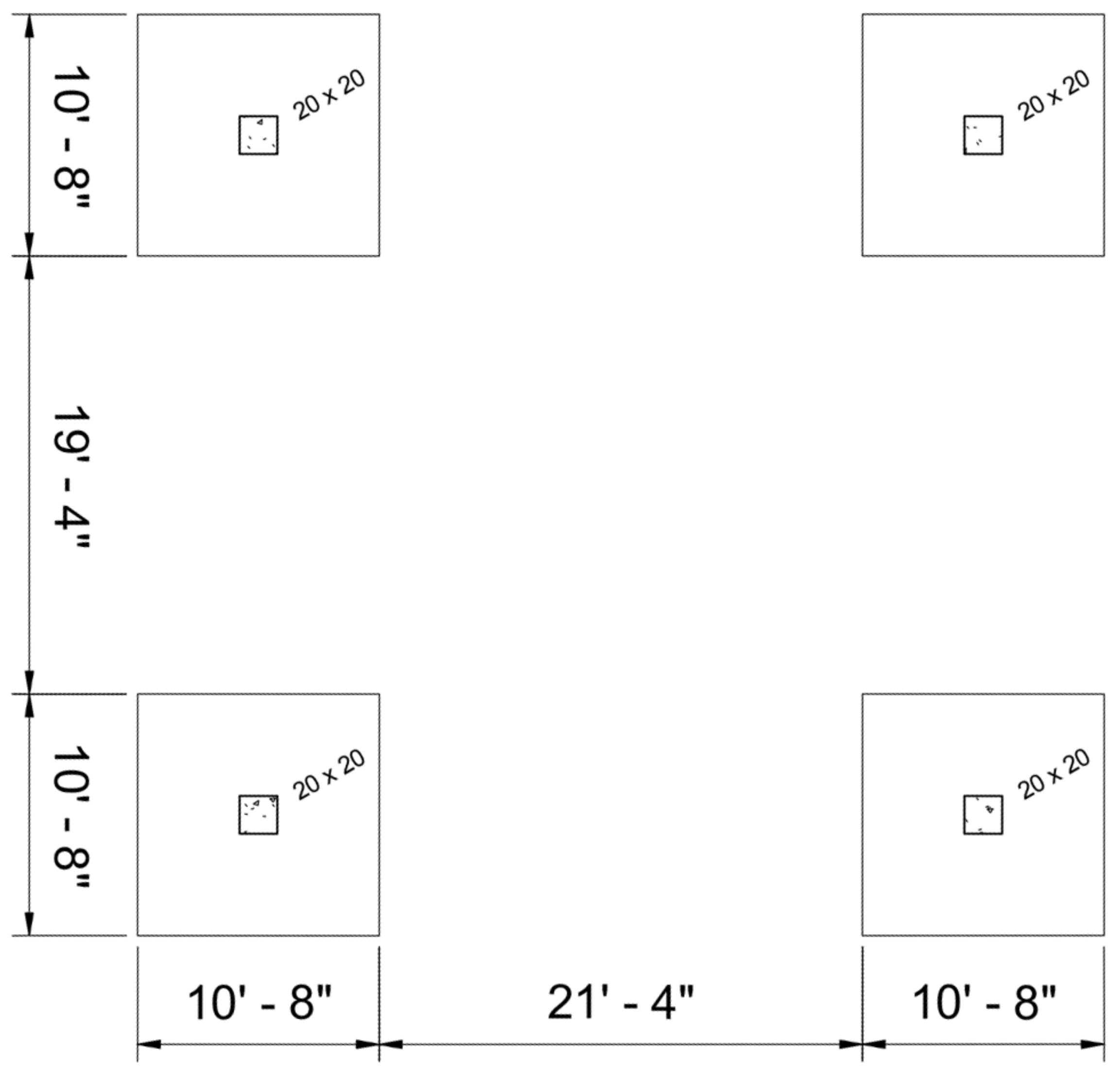
Commitment to community and organizational health
- Consider design impacts for other locations within the health network

Alternative Bay Study

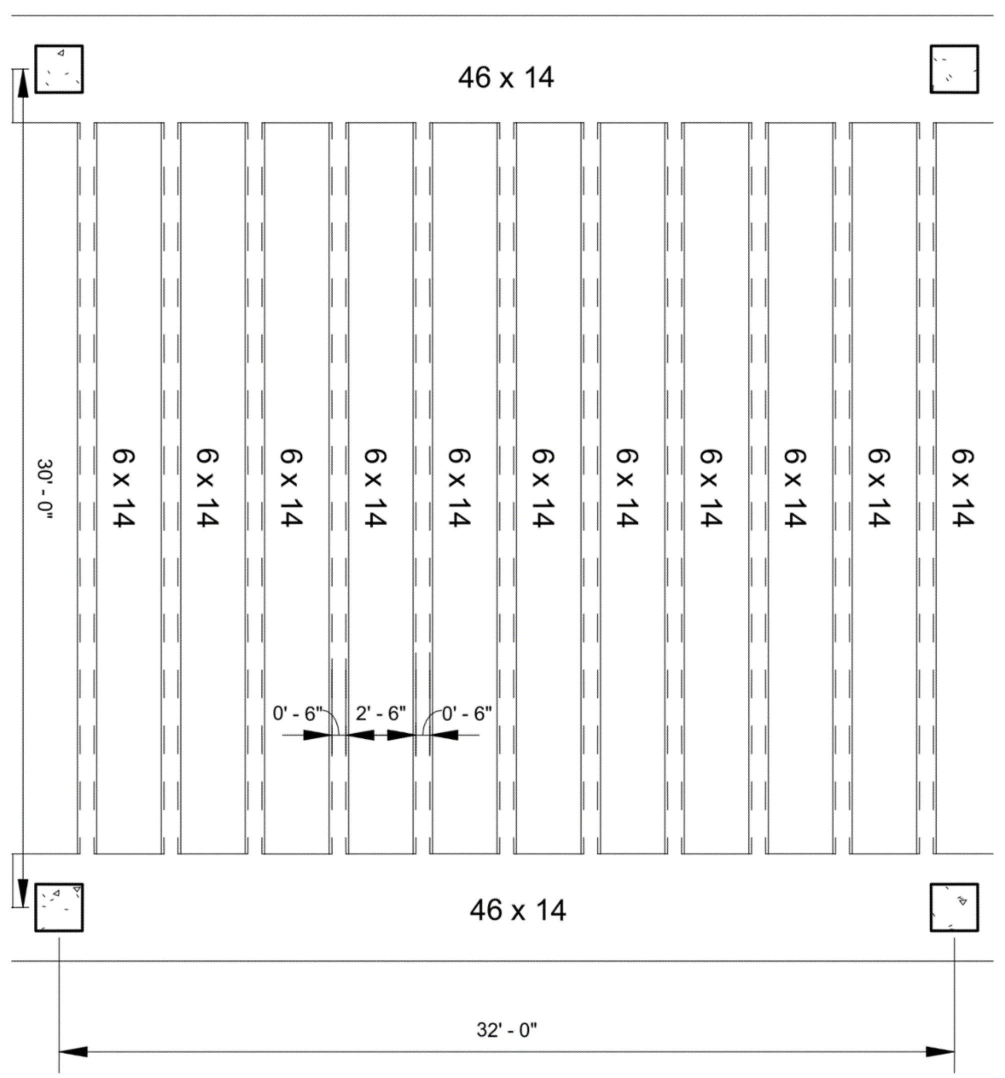
System Comparisons



Composite with Fewer Infills



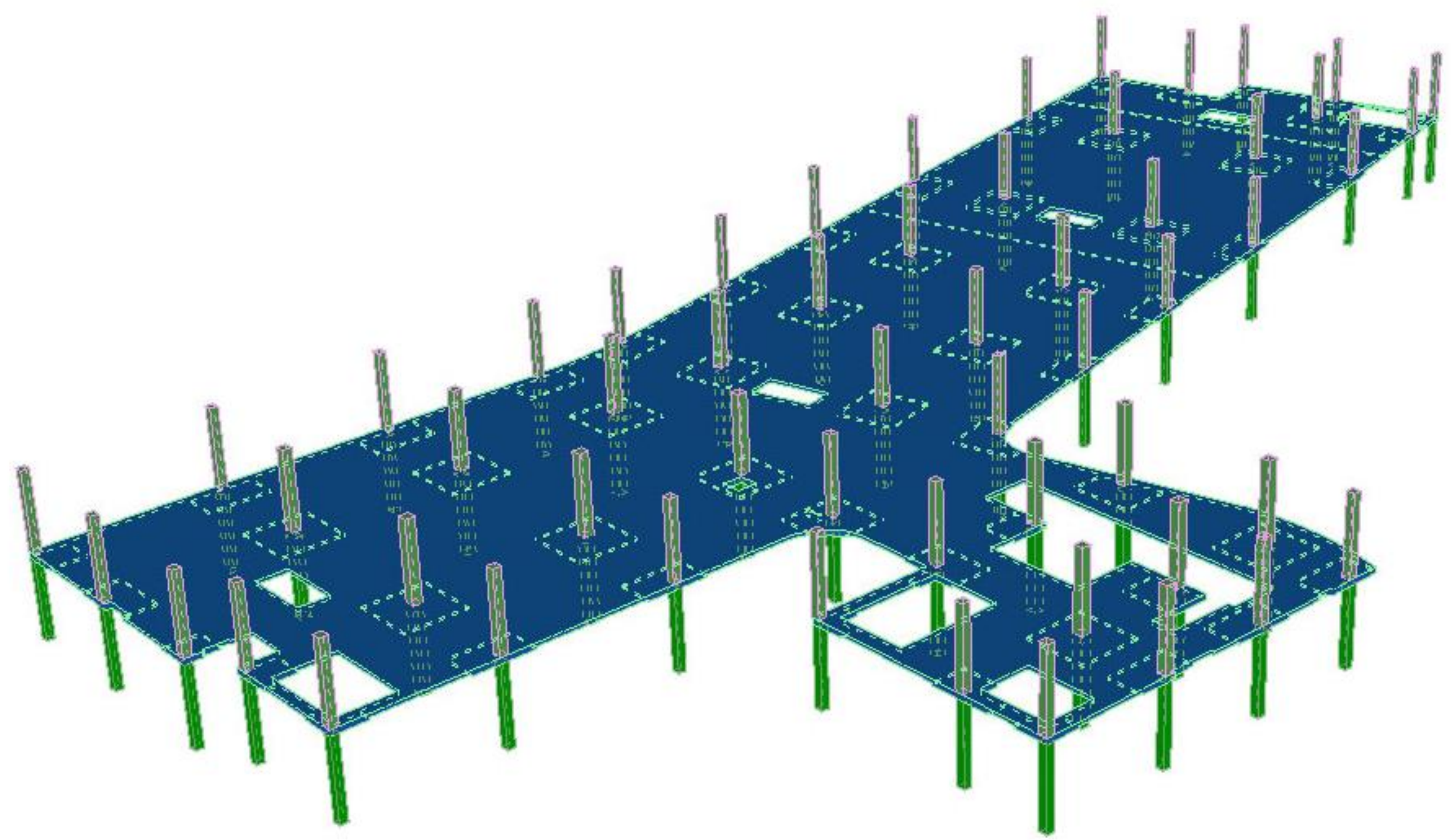
Flat Slab



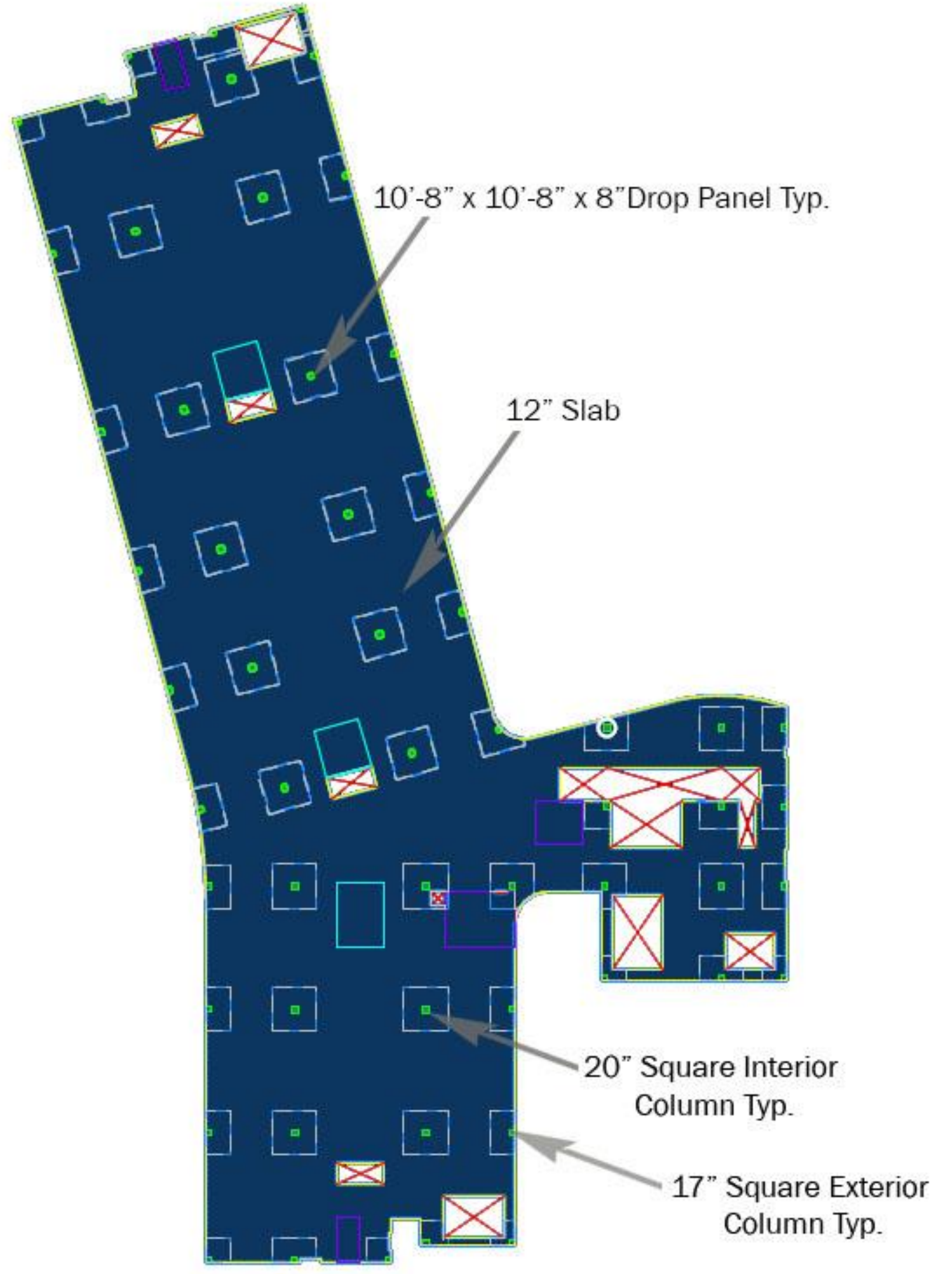
One-Way Pan Joists

Alternative Bay Study

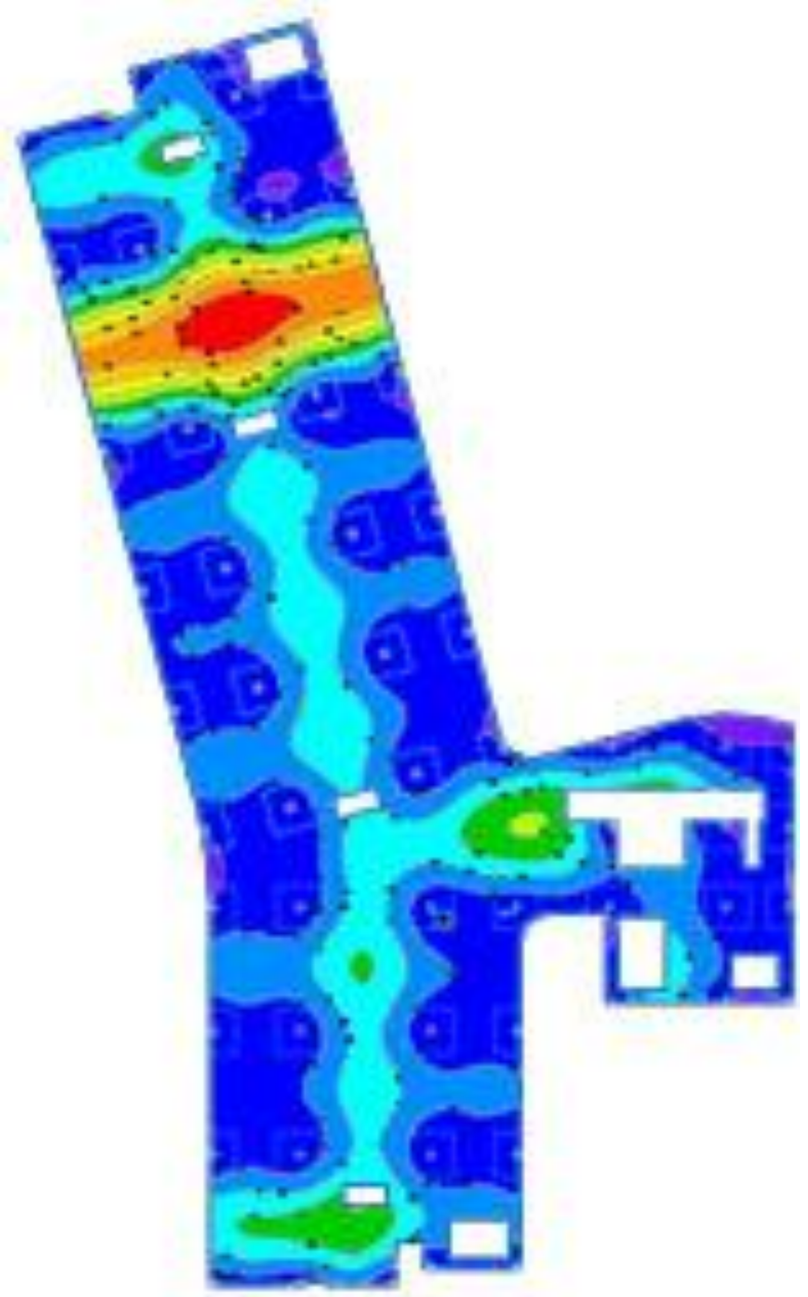
Flat Slab Update



3D View of RAM Concept Model



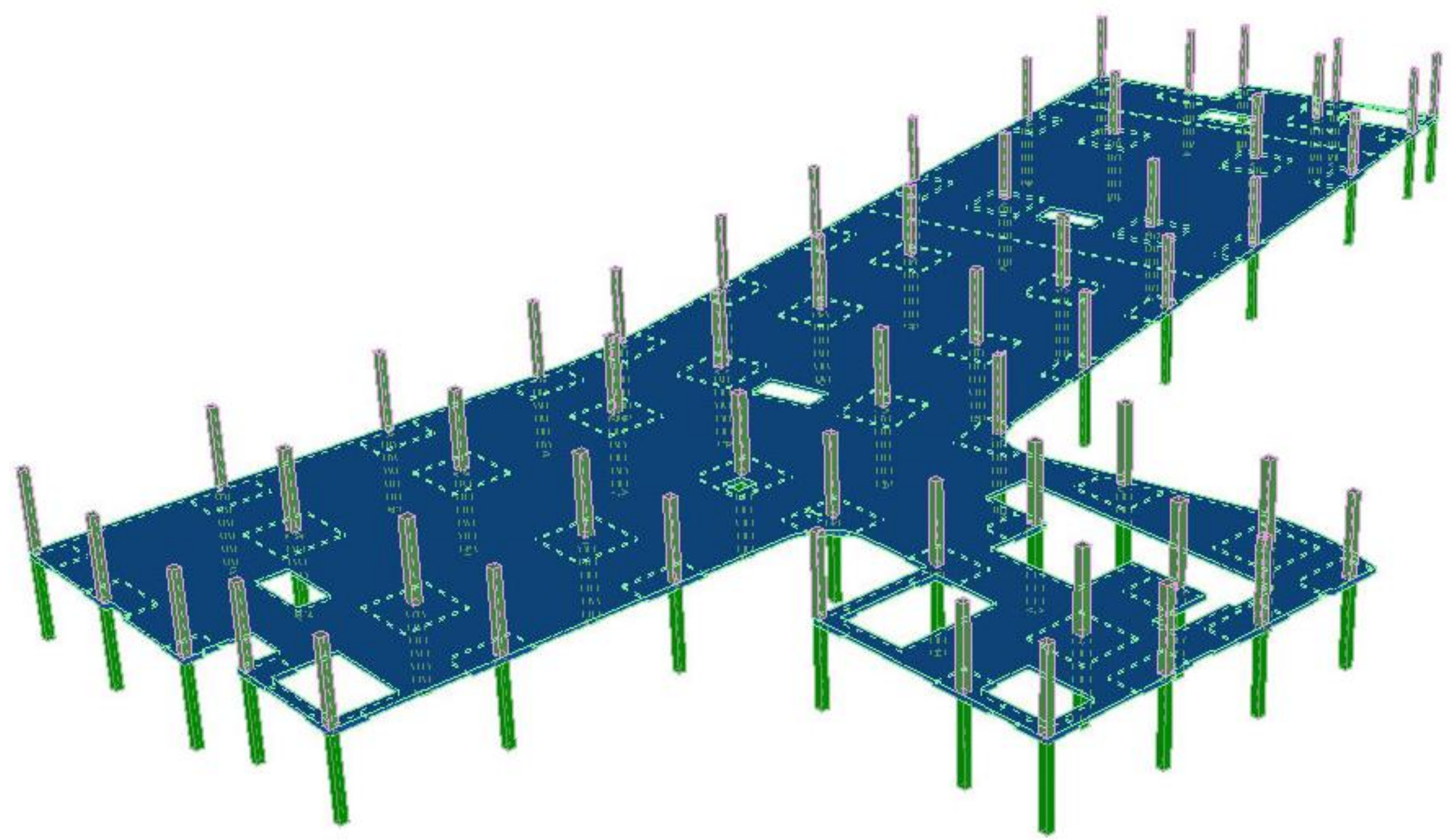
Initial Bed Tower Flat Slab Plan



Total Load Deflection

Alternative Bay Study

Flat Slab Update



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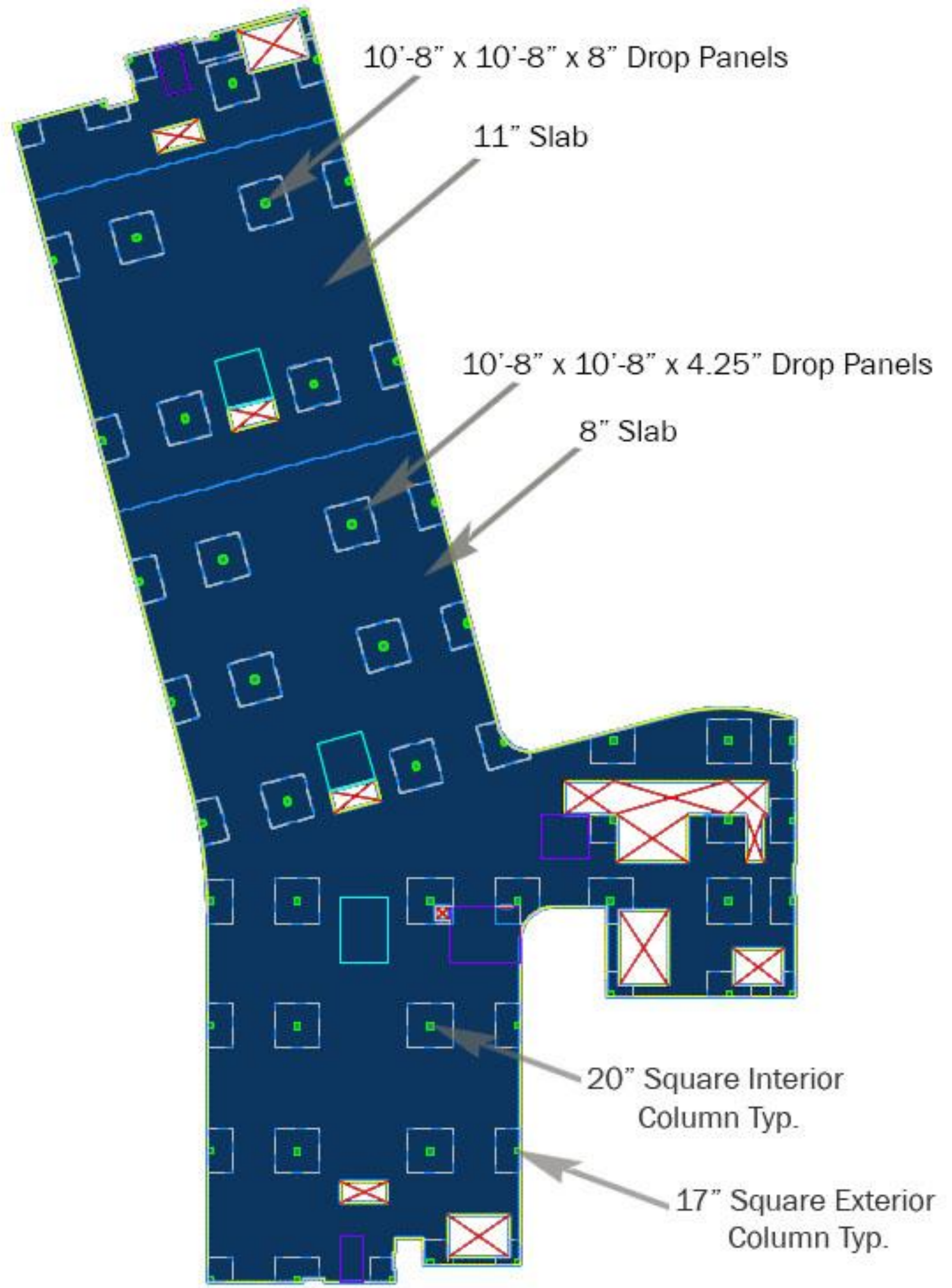
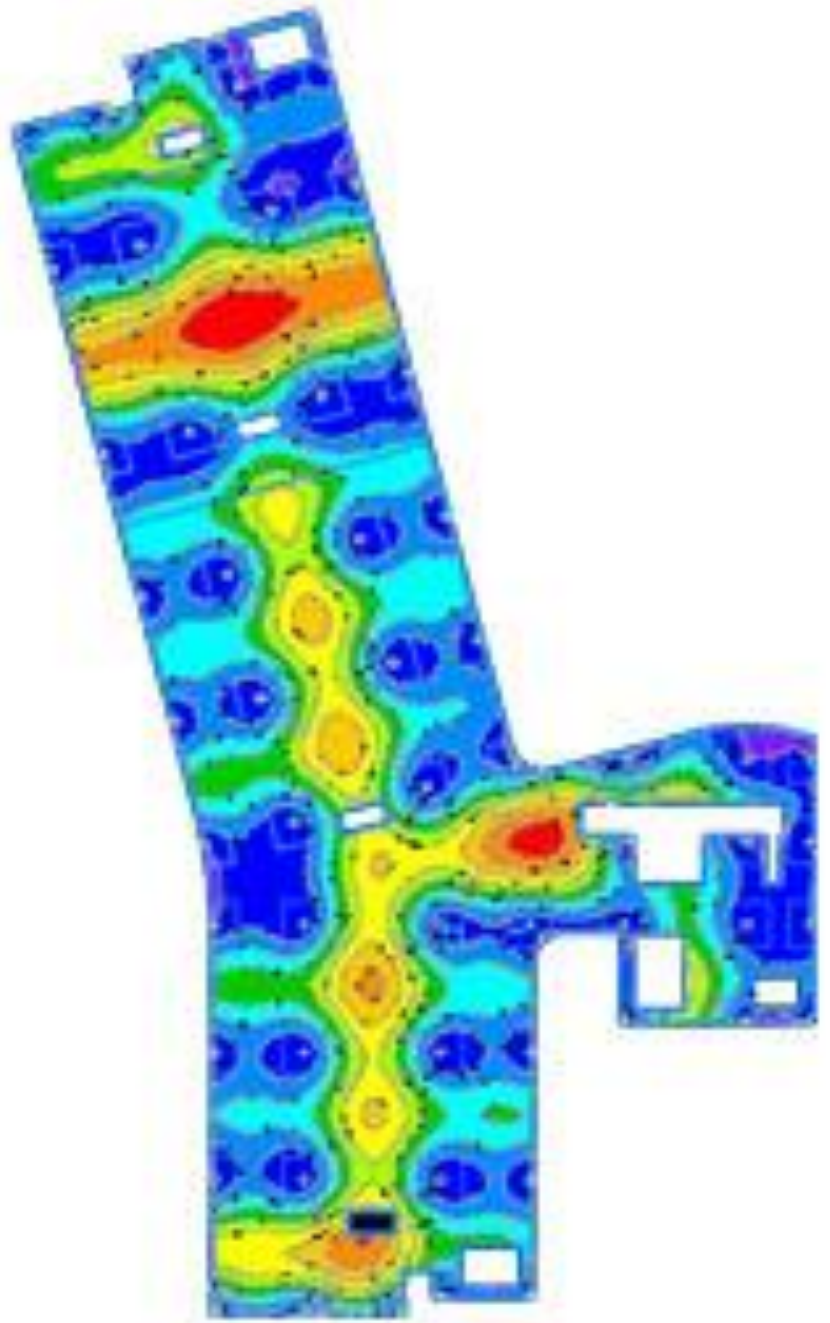


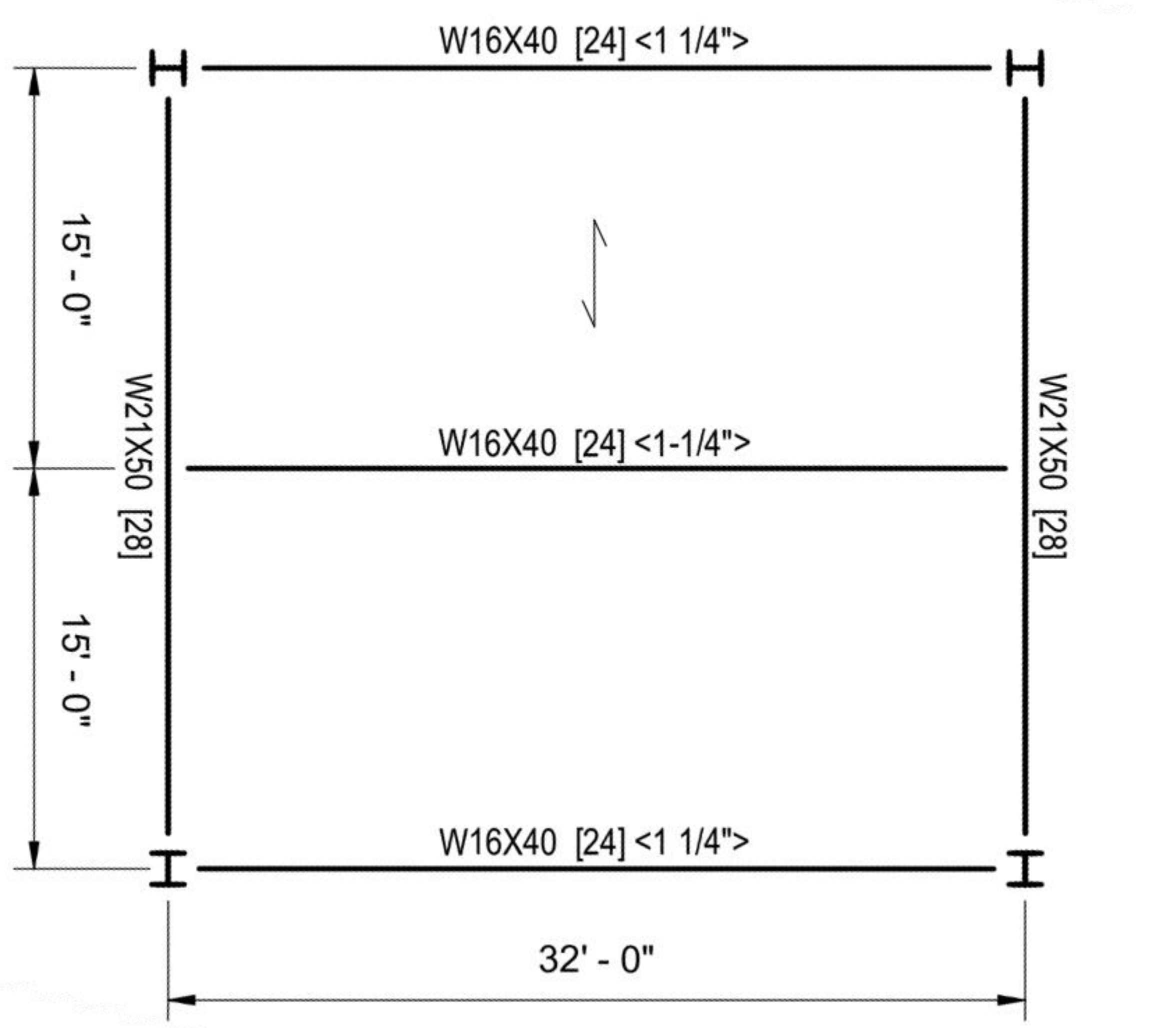
Final Bed Tower Flat Slab Plan



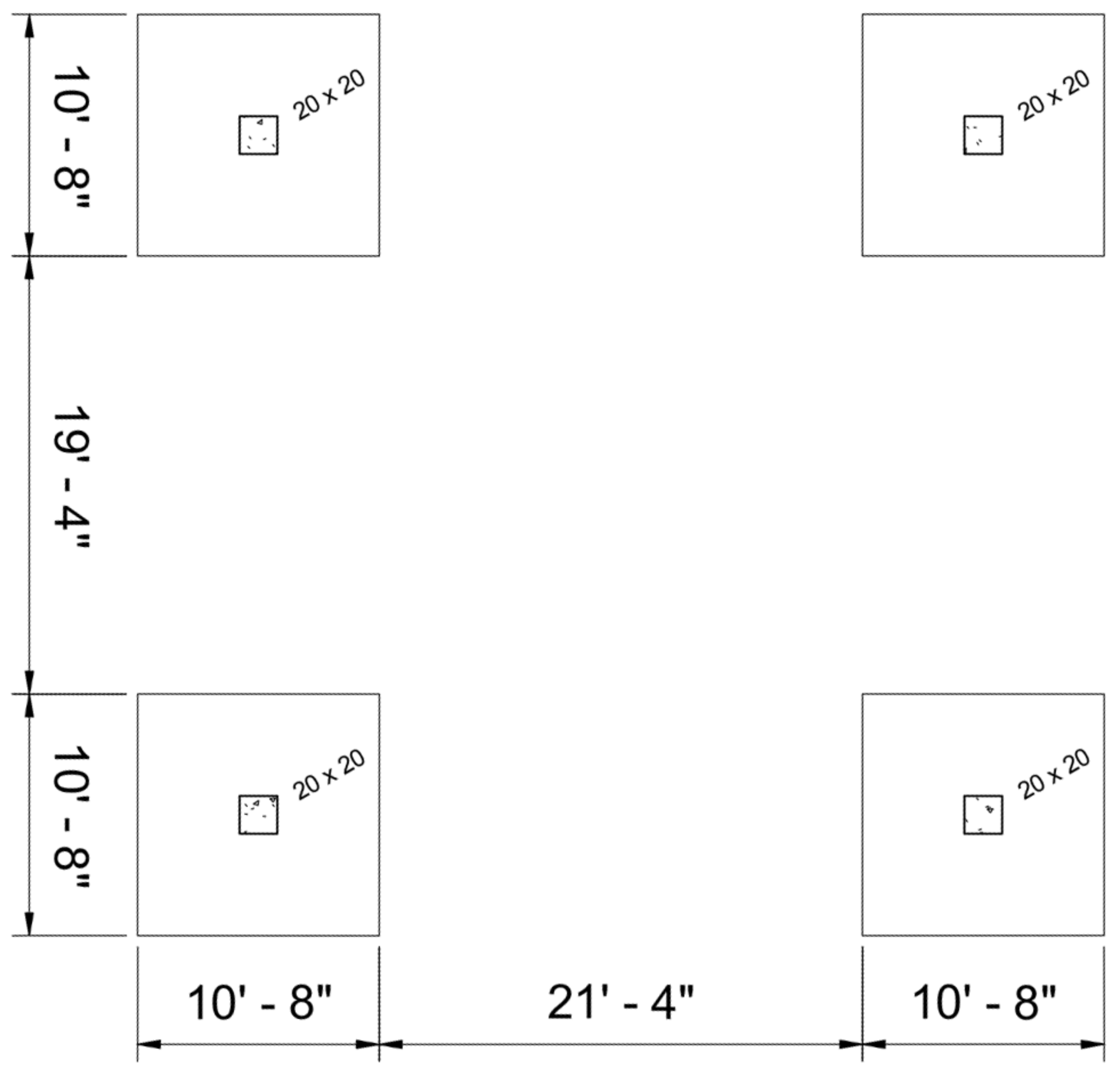
Total Load Deflection

Alternative Bay Study

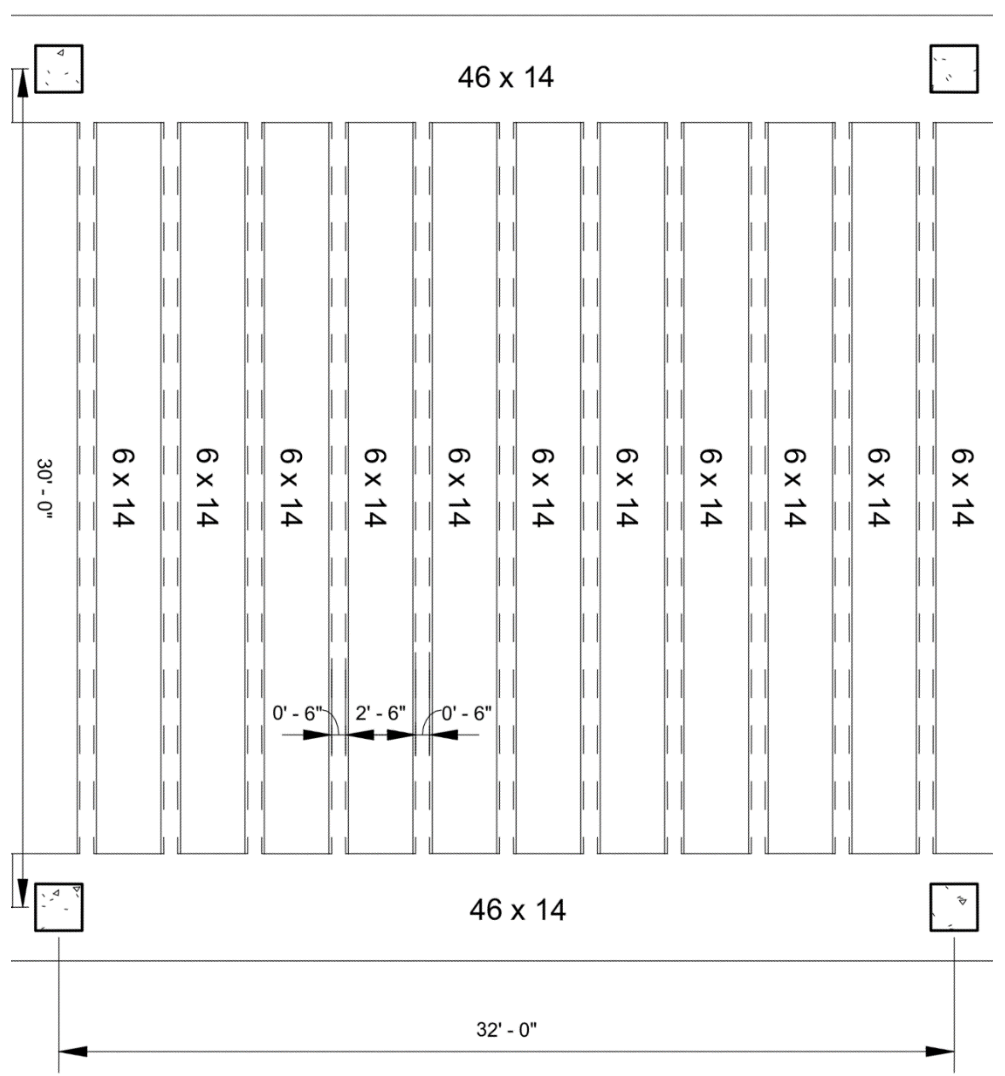
System Selection



Composite with Fewer Infills



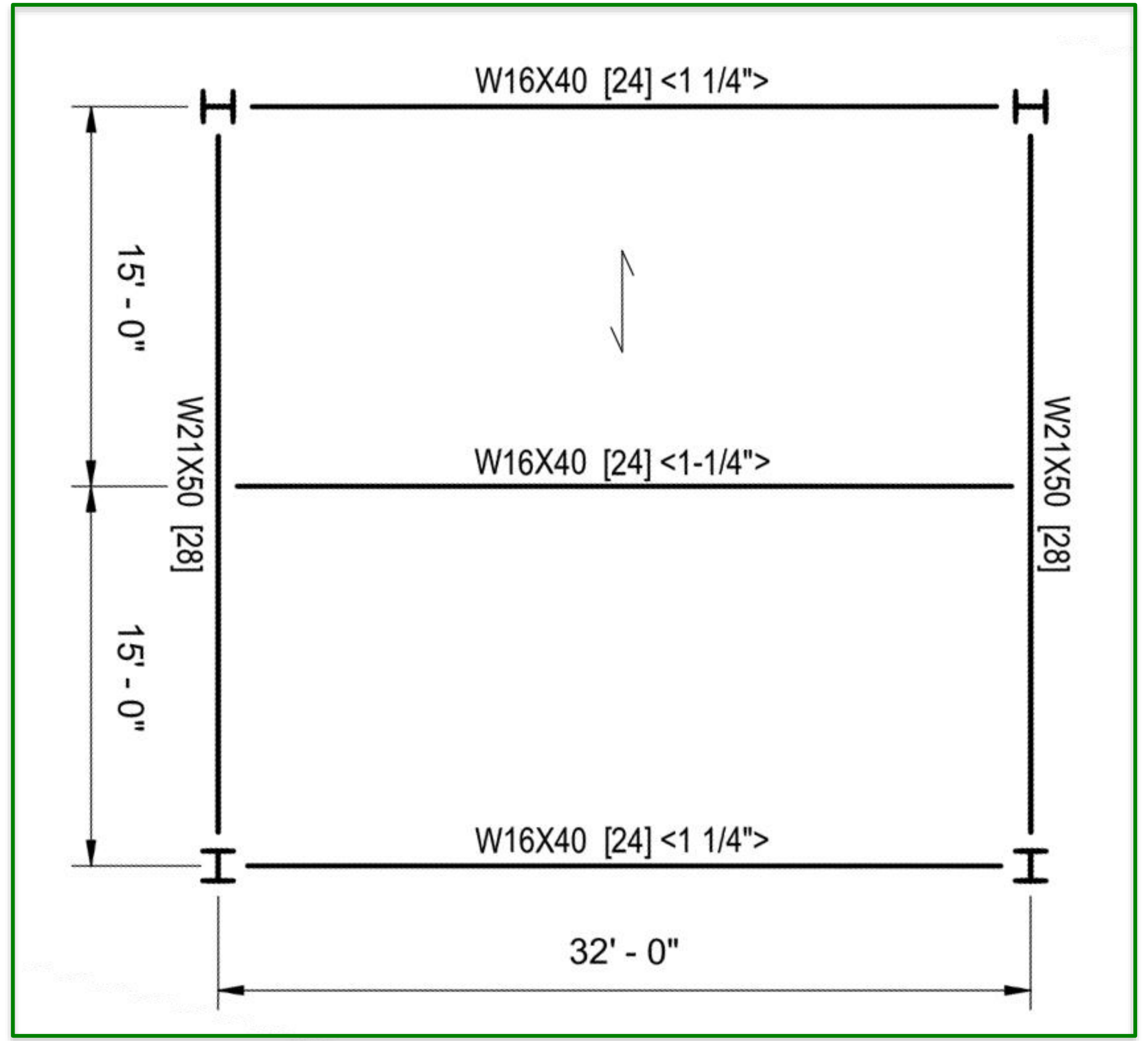
Flat Slab



One-Way Pan Joists

Alternative Bay Study

System Selection



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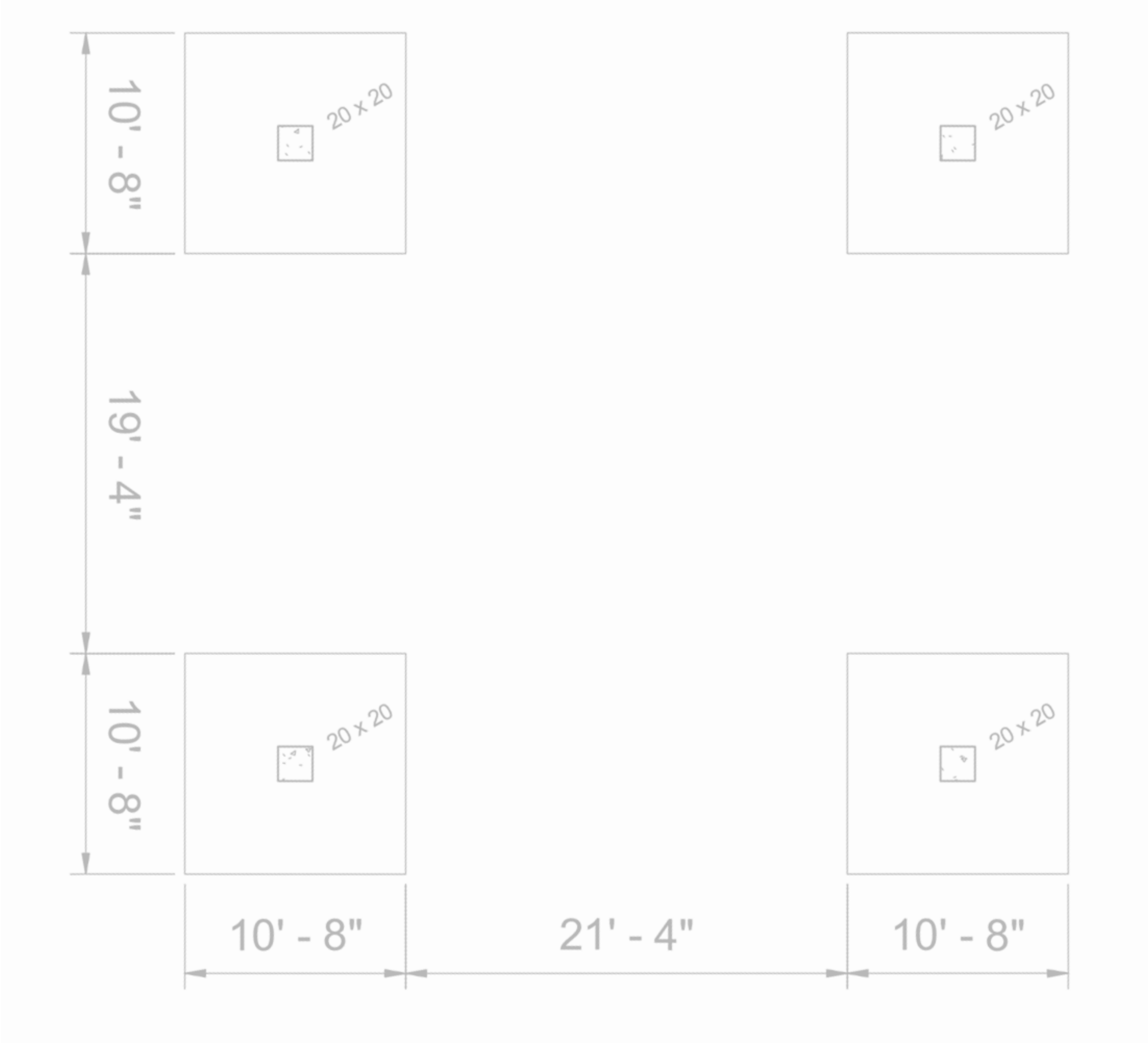
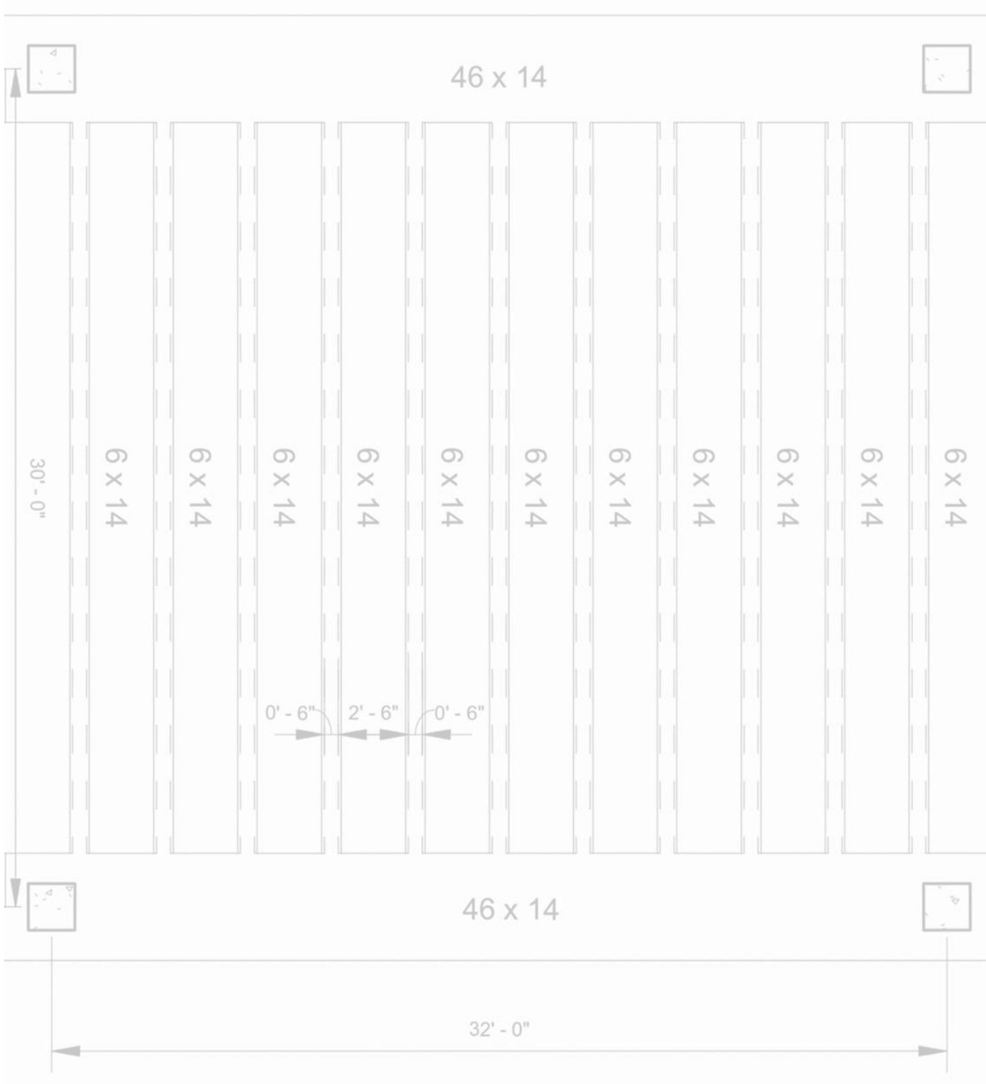


Flat Slab



One-Way Pan Joists

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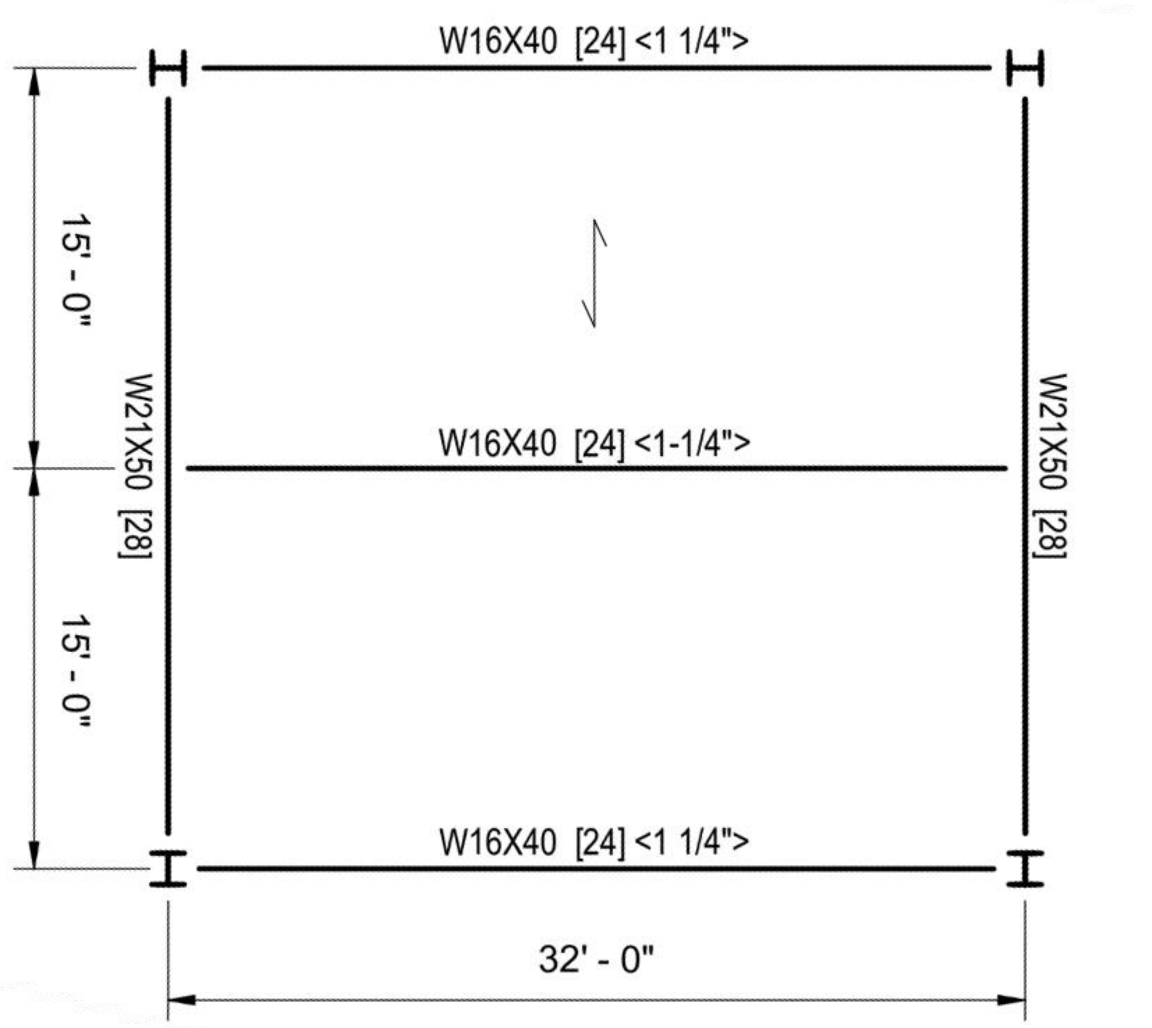


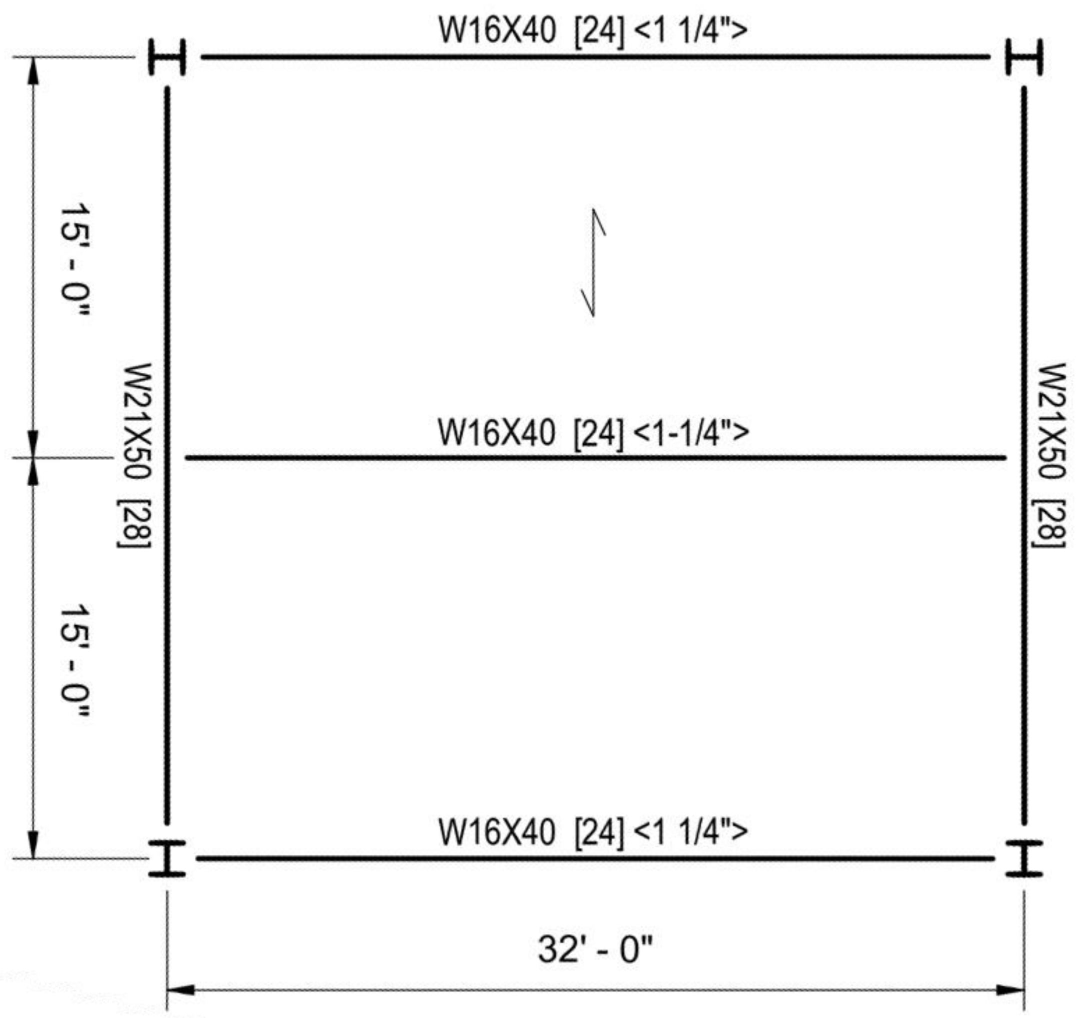
Composite with Fewer Infills

System Category	Specific Options Within System Category	Criteria							Total System Score	System Recommendation
		Cost		Construction	Integration					
		Weight of Framing	Cost Estimate	Ease of Construction	Architectural Integration	Structural Depth	Mechanical Integration	Design Flexibility		
Weight		3	3	1	2	3	4	2		
Structural System	Existing System	4	2	3	4	1	4	4	56	
	Alternative 1: Composite with 1 Infill	5	3	4	4	2	5	4	70	Y
	Alternative 2: Flat Slab with Drops	1	4	4	3	4	3	2	53	N
	Alternative 3: One-Way Pan Joists	3	5	3	2	5	2	2	58	M

Preliminary Decision-Making Method

Alternative Bay Study

System Selection



Composite with Fewer Infills

Criteria	Weight	Baseline: Existing Composite Design	Composite with Fewer Infills	Flat Slab	One-way Pan Joists
G1	0.022	0	-1	1	1
G2	0.037	0	1	-1	-1
G3	0.041	0	1	1	-1
A1	0.200	0	1	1	1
A2	0.200	0	1	1	1
C1	0.098	0	1	-1	1
C2	0.102	0	1	-1	-1
S1	0.096	0	0	1	1
S2	0.105	0	1	-1	-1
S3	0.099	0	-1	1	1
Σ(Weight x Score)		0	0.662	0.316	0.43

Criteria	Weight	Baseline: Composite with Fewer Infills	One-way Pan Joists
G1	0.022	0	1
G2	0.037	0	-1
G3	0.041	0	-1
A1	0.200	0	1
A2	0.200	0	-1
C1	0.098	0	1
C2	0.102	0	-1
S1	0.096	0	-1
S2	0.105	0	-1
S3	0.099	0	1
Σ(Weight x Score)		**0**	-0.162

Detailed Decision-Making Method: Pugh Matrix

Goals

- Patient-centered healing environment
- Sustainability
- System integration

Methods

- Explore iterations of composite and non-composite gravity systems
- Design for increased vibration performance criteria
- Compare formal decision-making methods for the selection of structural systems in healthcare facilities

Gravity Redesign

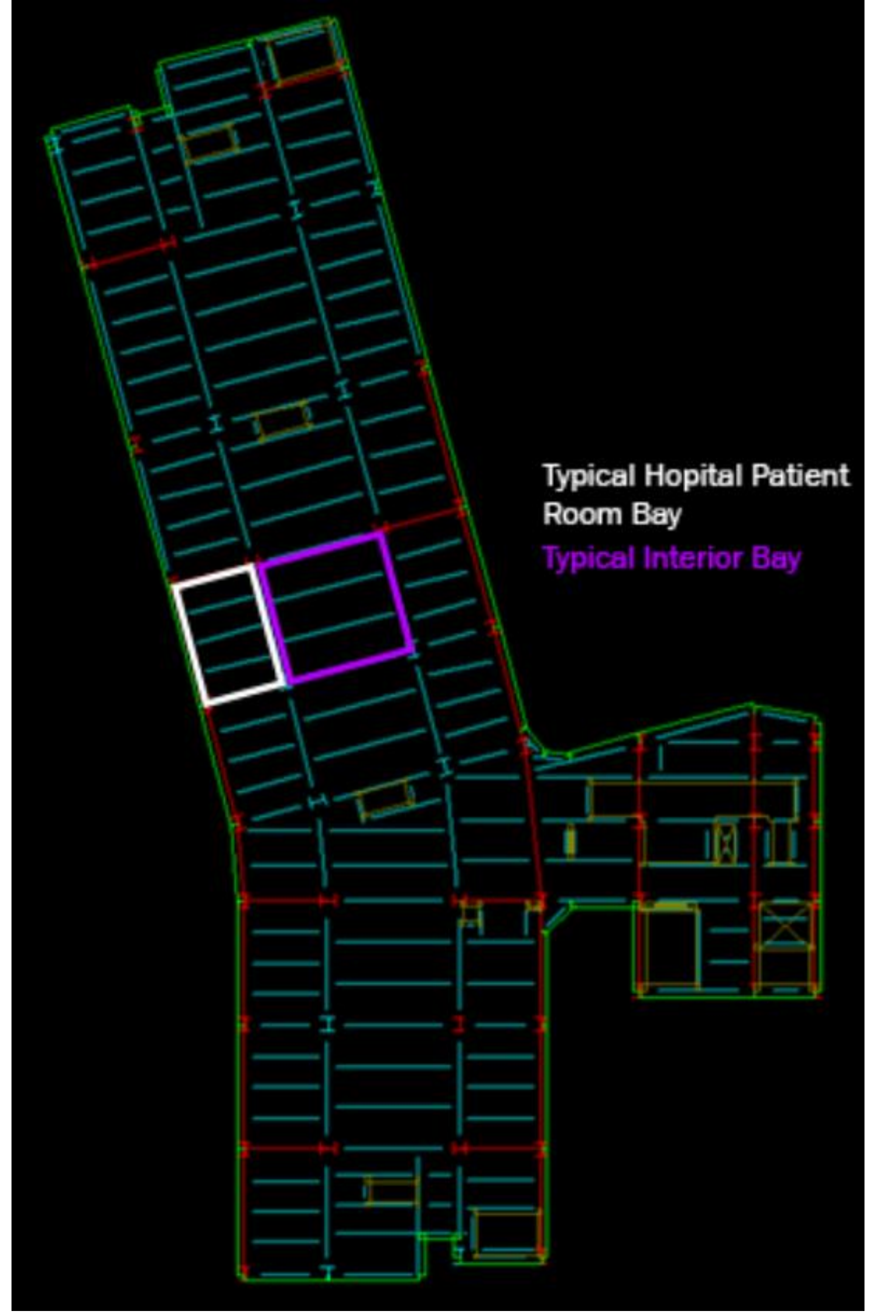
Bay Iterations

Three Typical Bays Considered:

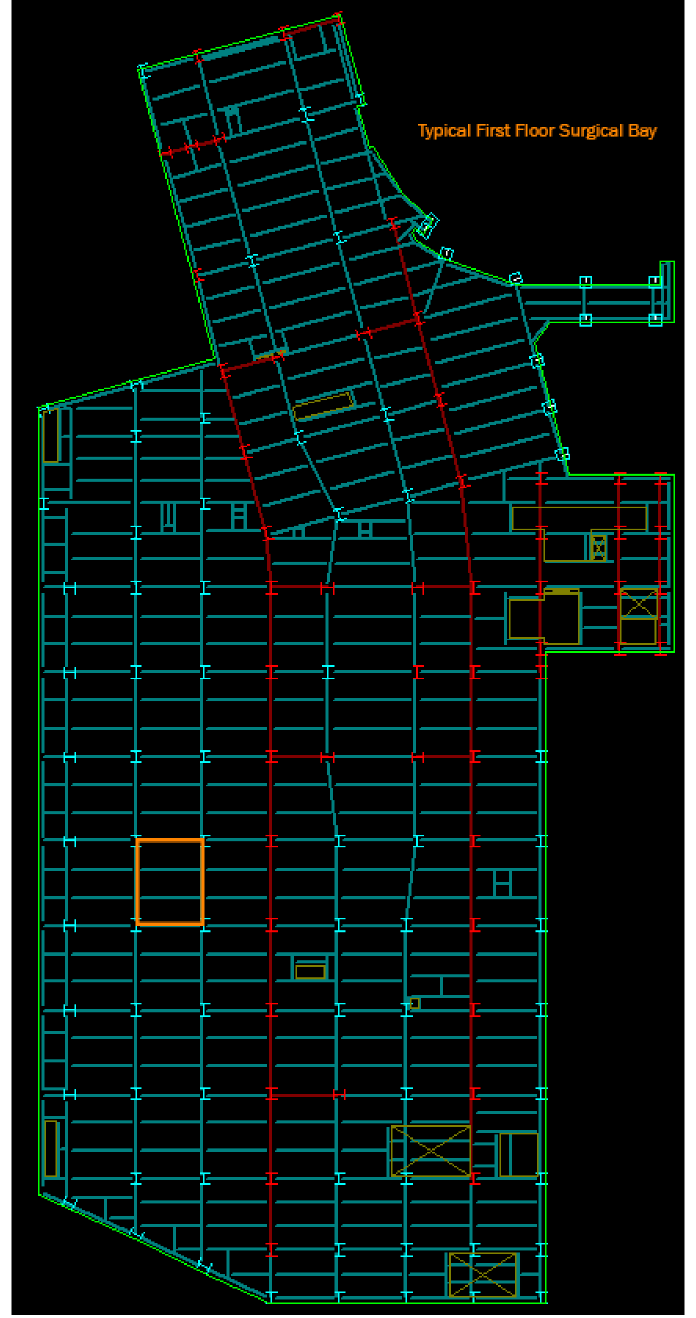
1. Patient Room Bay (Bed Tower)

2. Interior Bay (Bed Tower)

3. Surgical Bay (D&T)



Original Bed Tower Layout



Original First Floor Layout

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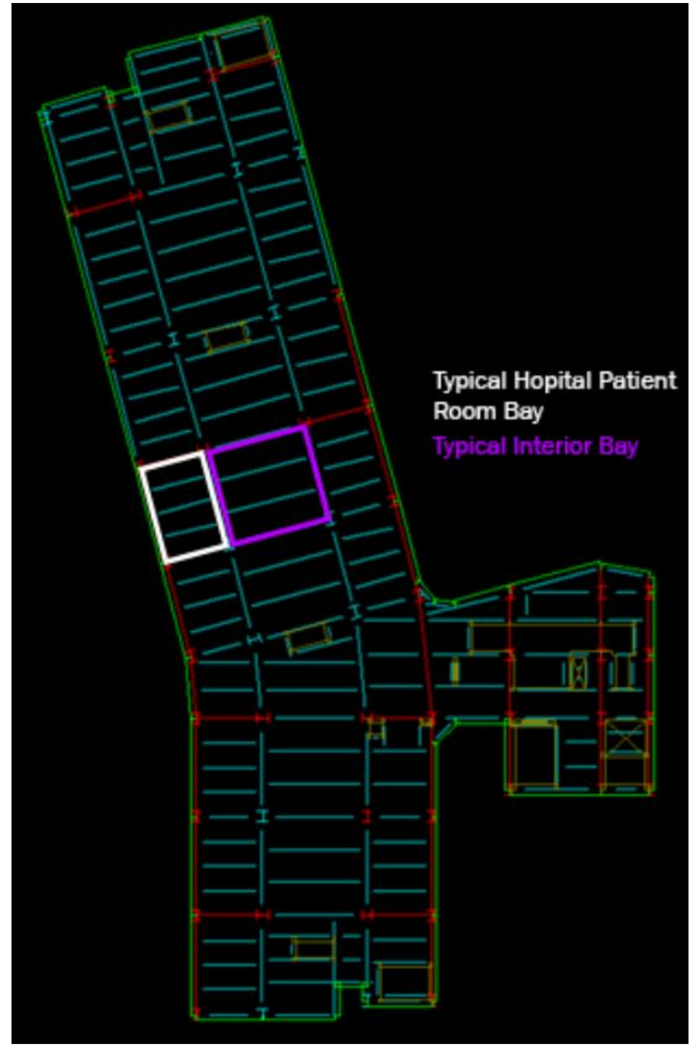
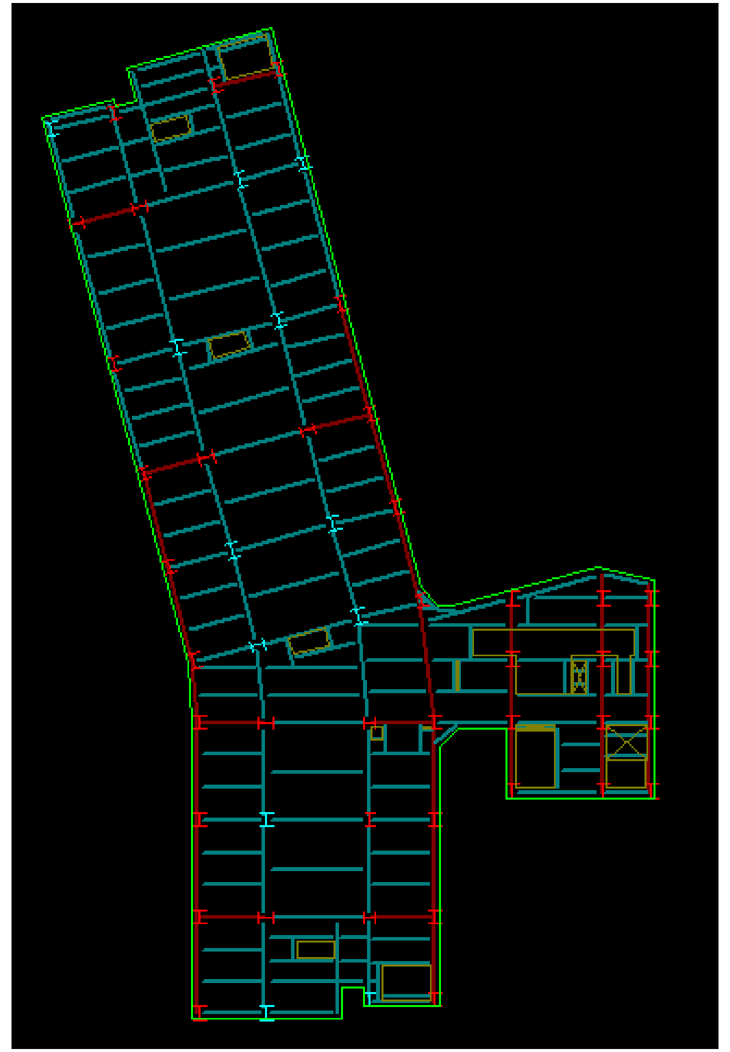
Gravity Redesign

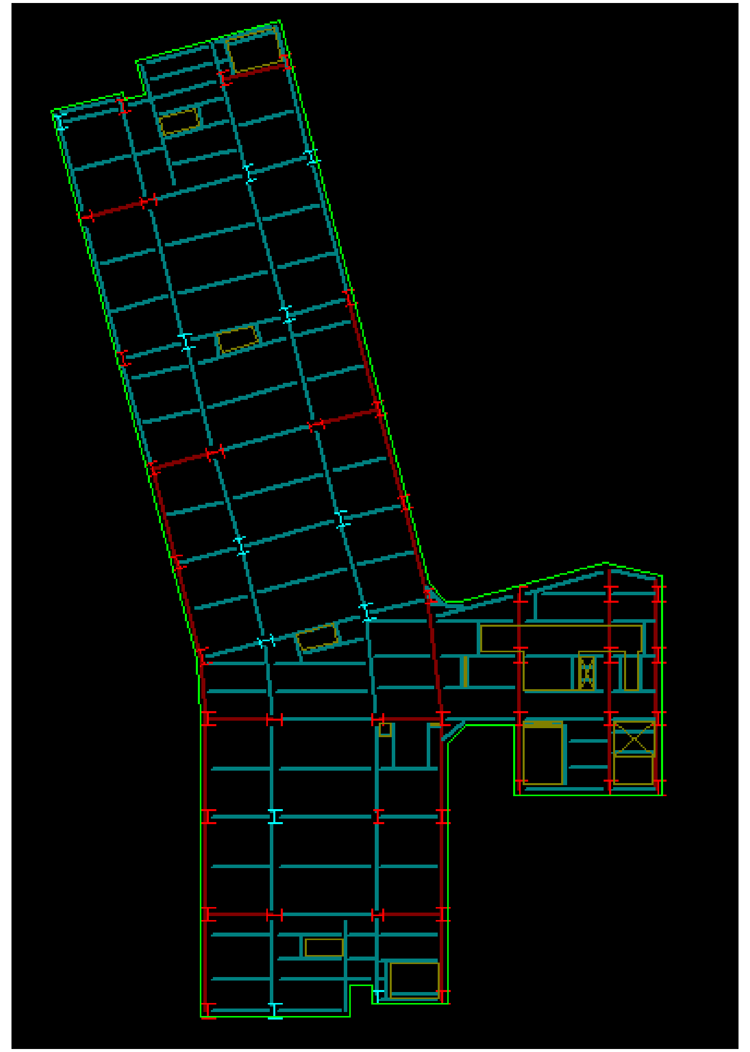
Bay Iterations



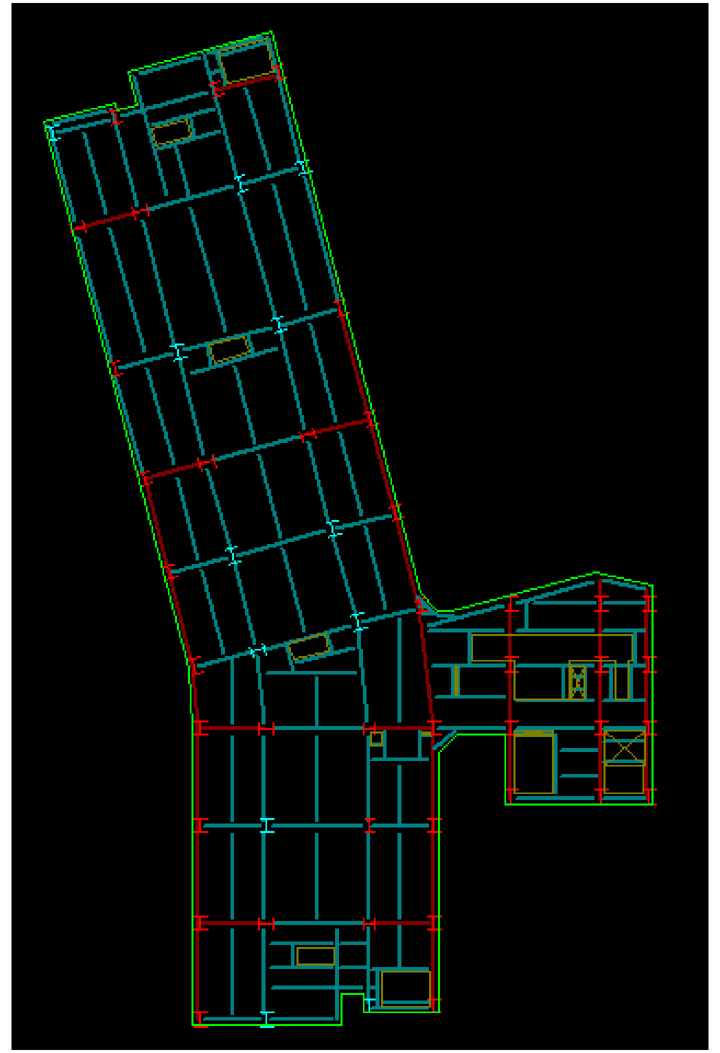
Original Bed Tower Layout



Bed Tower Layout with Fewer Infills



Bed Tower Layout with Fewer Infills - Modified



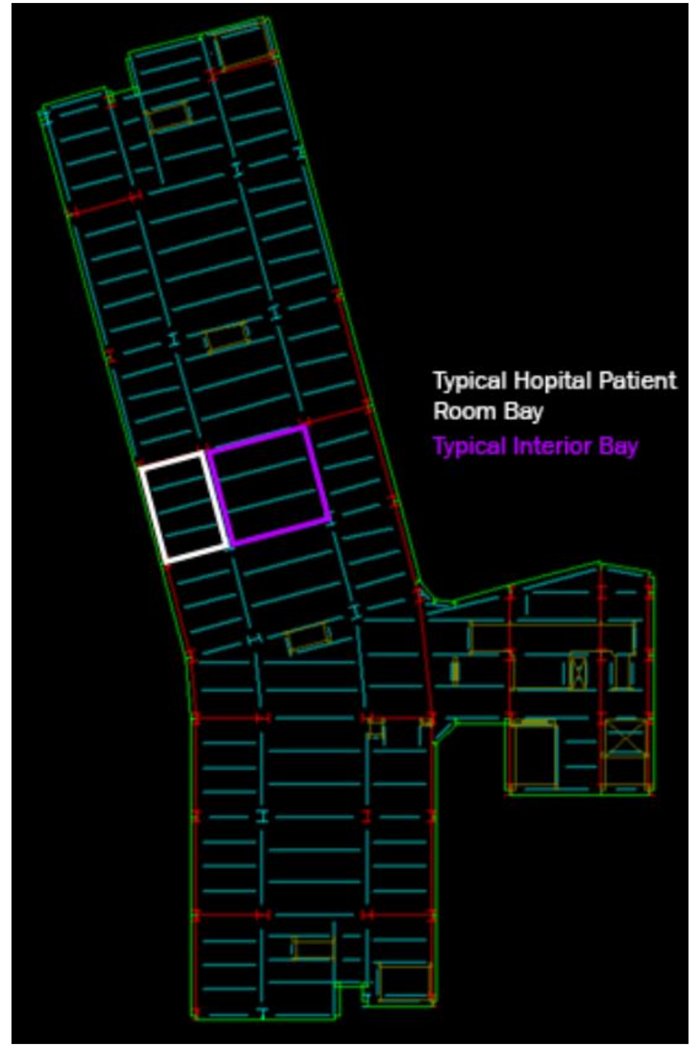
Rotated Bed Tower Layout

Increased Vibration Performance Criteria

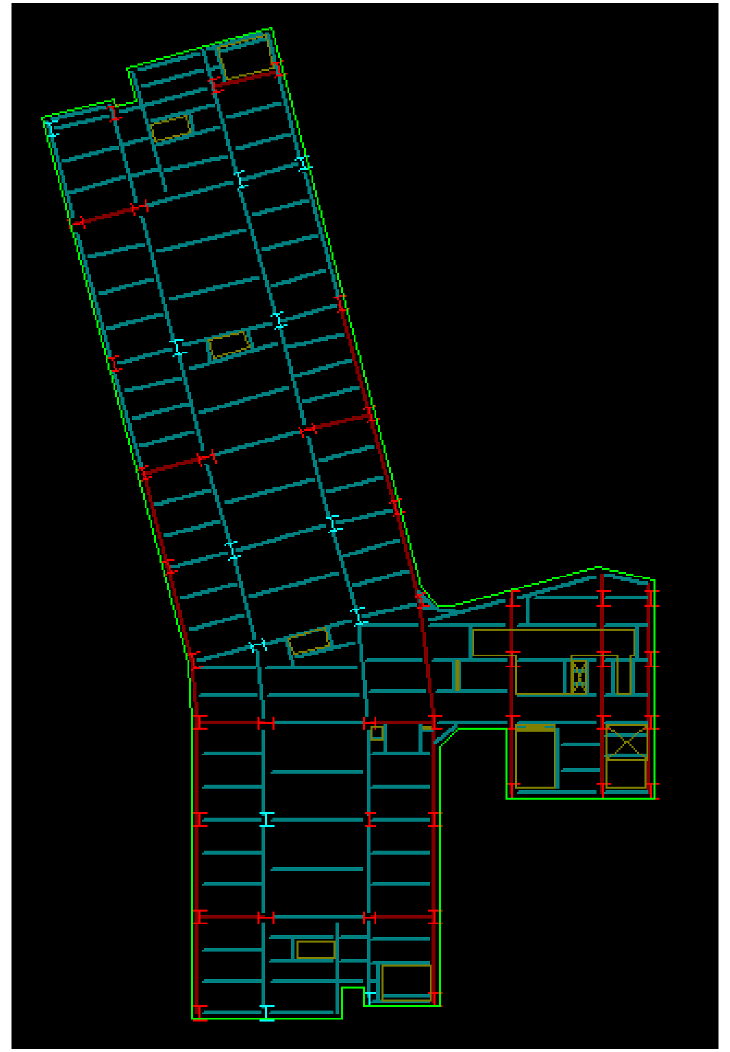
- Surgical Bay: 4000 mips
- Patient Room Bay: 6000 mips
- Interior Bed Tower Bay: 0.5% g

Gravity Redesign

Bay Iterations



Original Bed Tower Layout



Bed Tower Layout with Fewer Infills

Typical Patient Room Comparisons			
		Non-composite Design with Original Layout	Composite with Fewer Infills
	Beam	W14x26	W18x35
	Left Girder	W27x84	W27x84
	Right Girder	W24x68	W24x62
	Studs		86 studs
	Structural Weight	86 psf	75 psf
	Carbon Content	13,090 kg CO_2	15,722 kg CO_2
	Structural Cost, Material	$23.02 / SF	$23.70 / SF
	Structural Cost, Material & Labor	$25.49 / SF	$26.37 / SF
	Number of Total Pieces	7	6
	Average Demand to Capacity Ratio	0.63	0.4
Vibration Response	Slow, 50 steps/min	1557 mips	1552 mips
	Moderate, 75 steps/min	5792 mips	5773 mips
	Fast, 100 steps/min	26063 mips	25976 mips

Increased Vibration Performance Criteria

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Structural System Comparisons
Acoustic Analysis
Prefabrication Study

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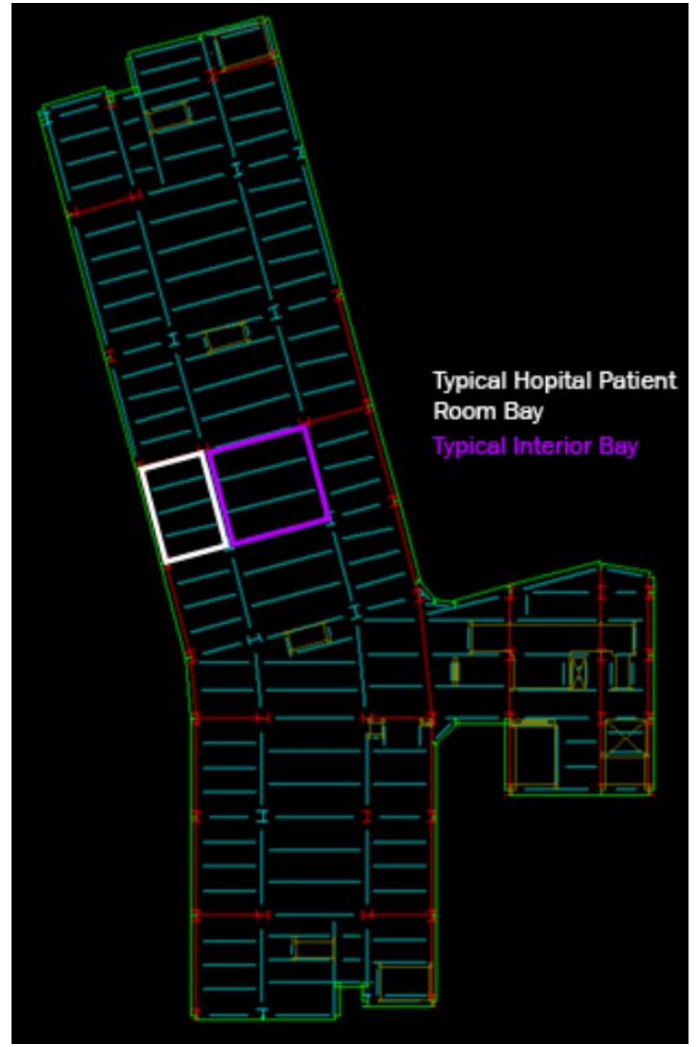
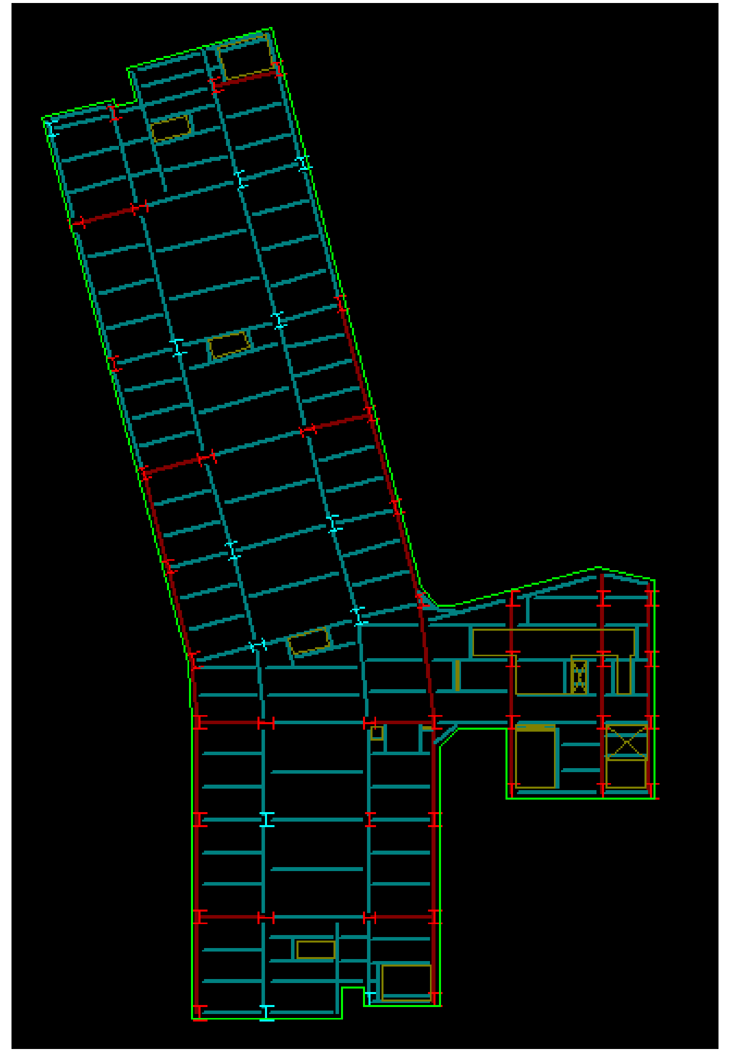
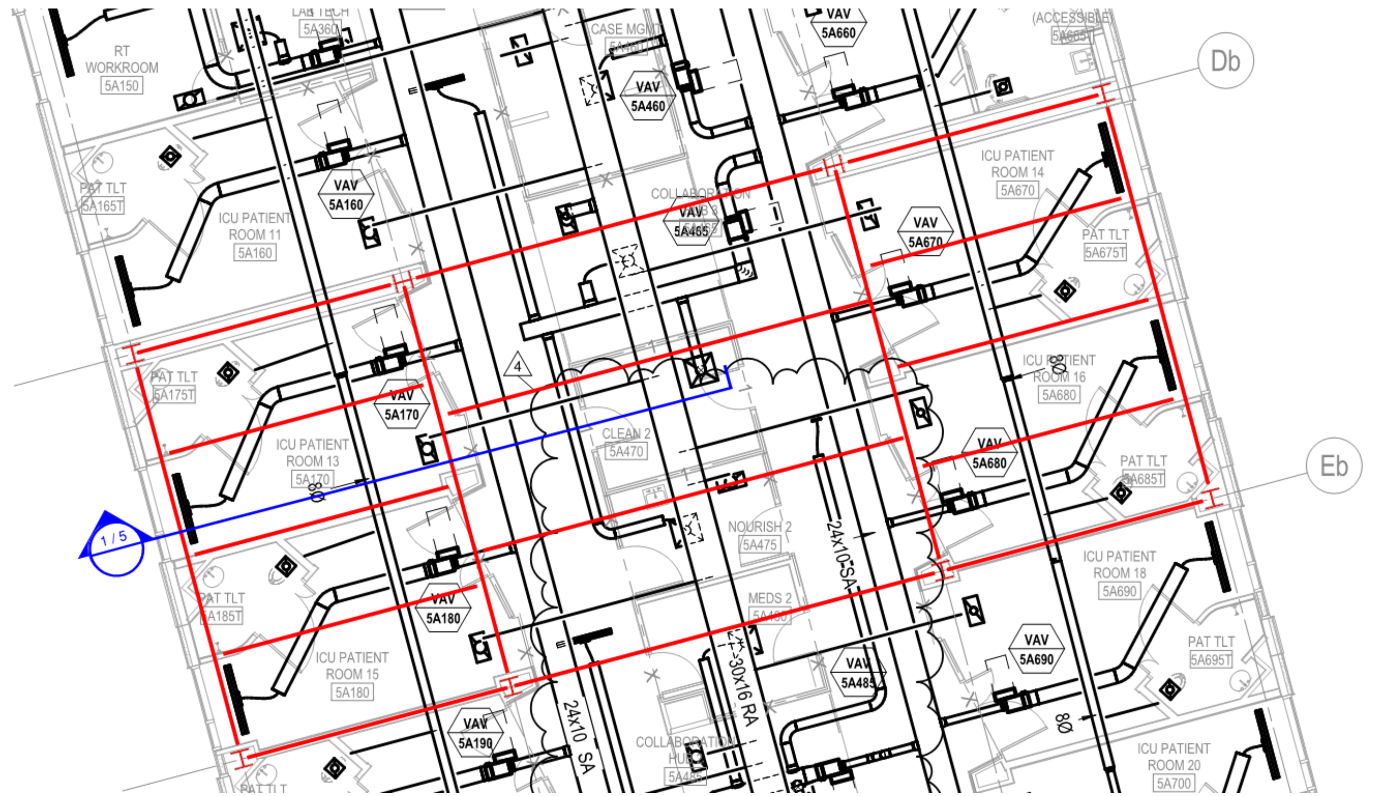


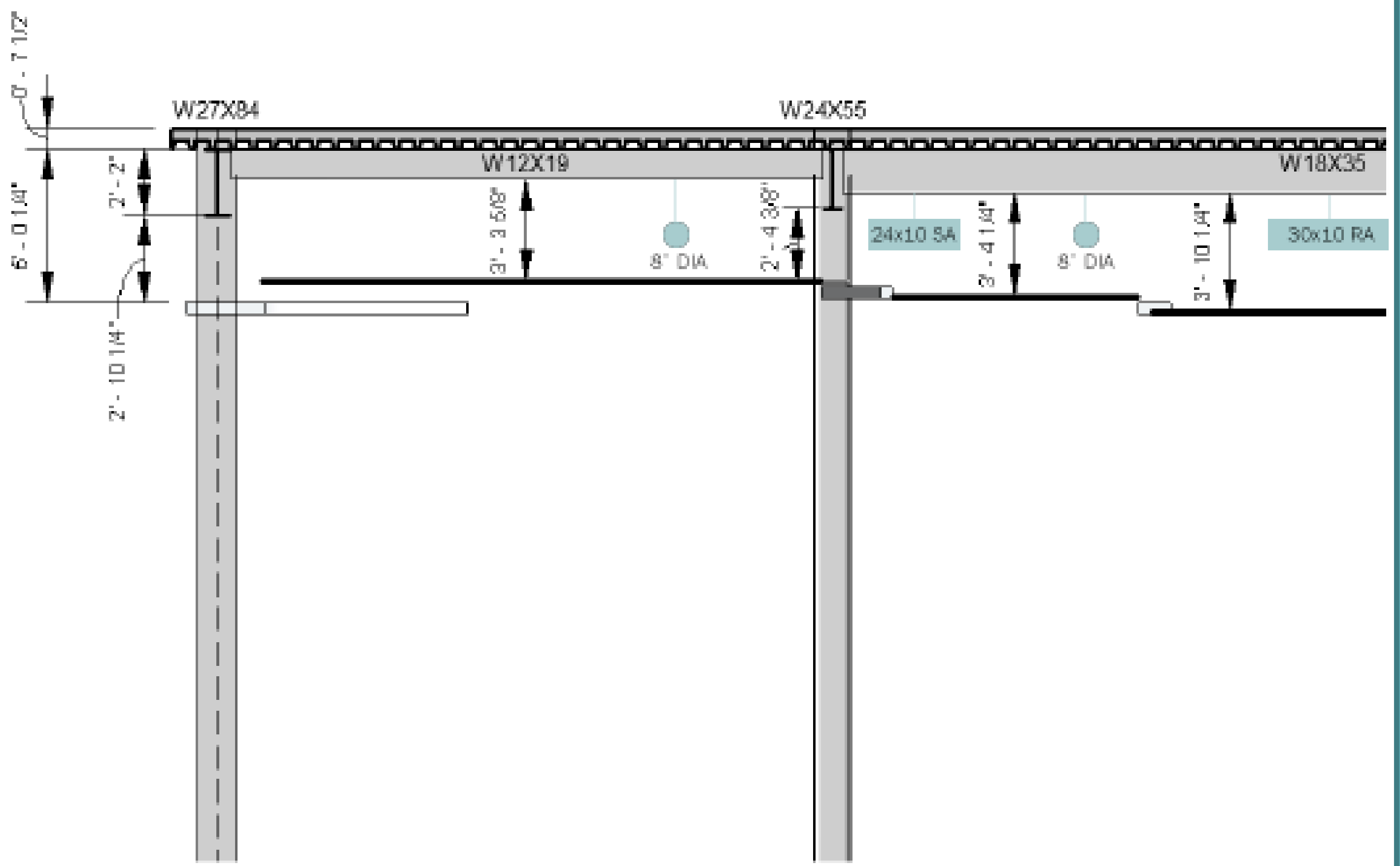
Original Bed Tower Layout



Bed Tower Layout with Fewer Infills



Mechanical Overlay for Original Gravity System Layout



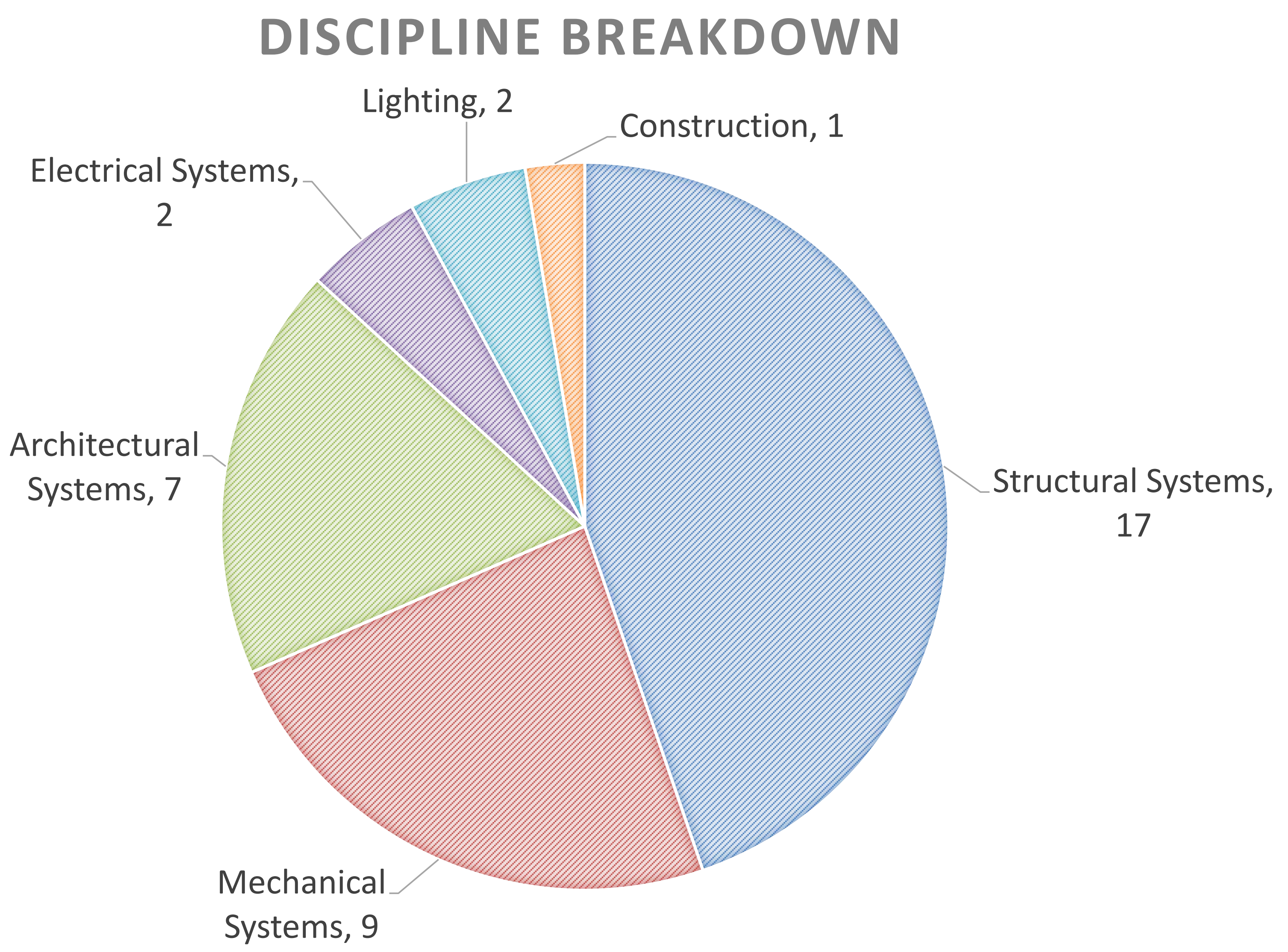
Existing Gravity System Floor Section

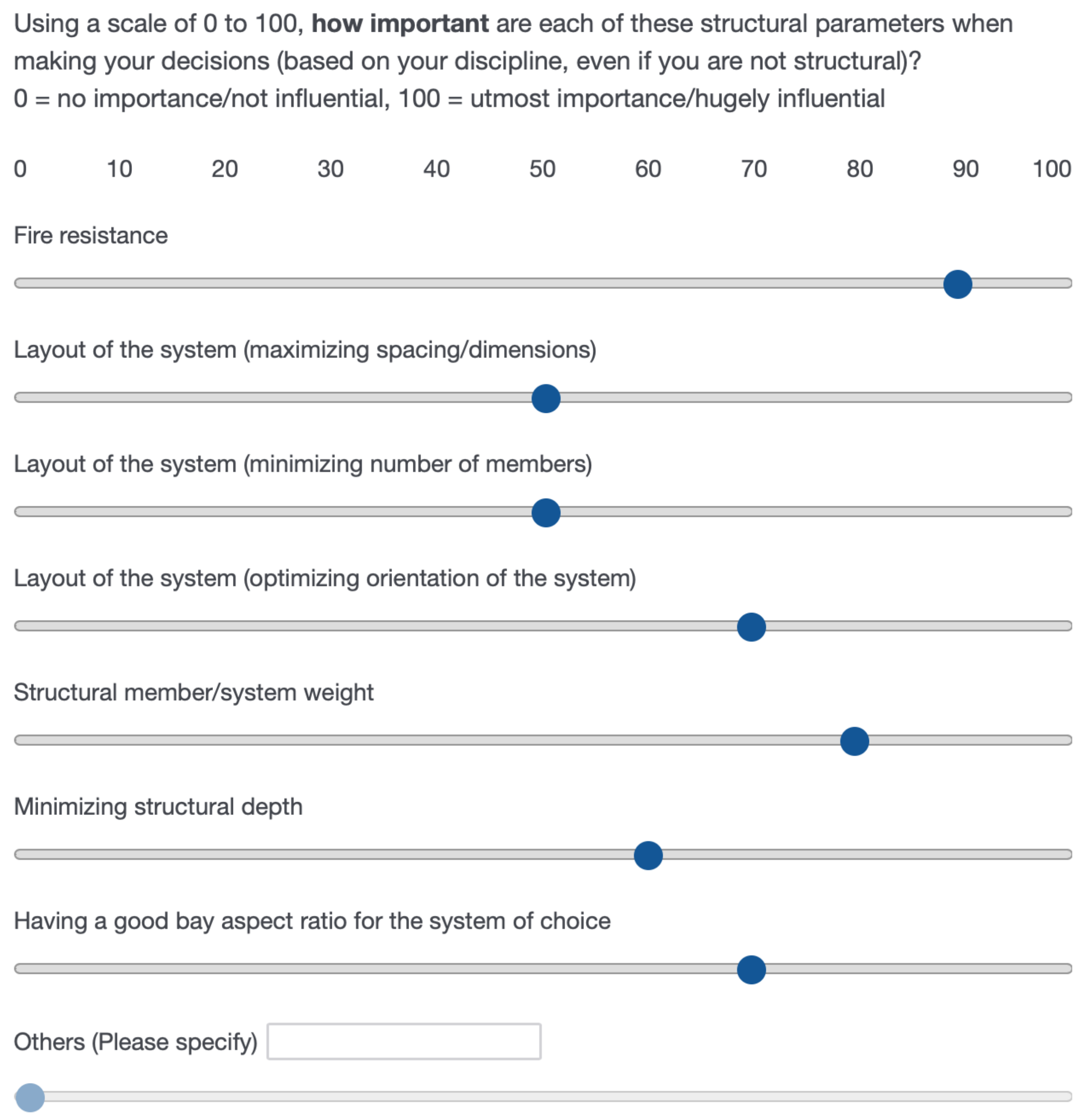
Structural Decision-Making

AEC Industry Healthcare Survey

Parameters Considered

- Healthcare
- General
- Architectural
- Construction
- Structural





Structural Decision-Making

AEC Industry Healthcare Survey

Parameters Considered

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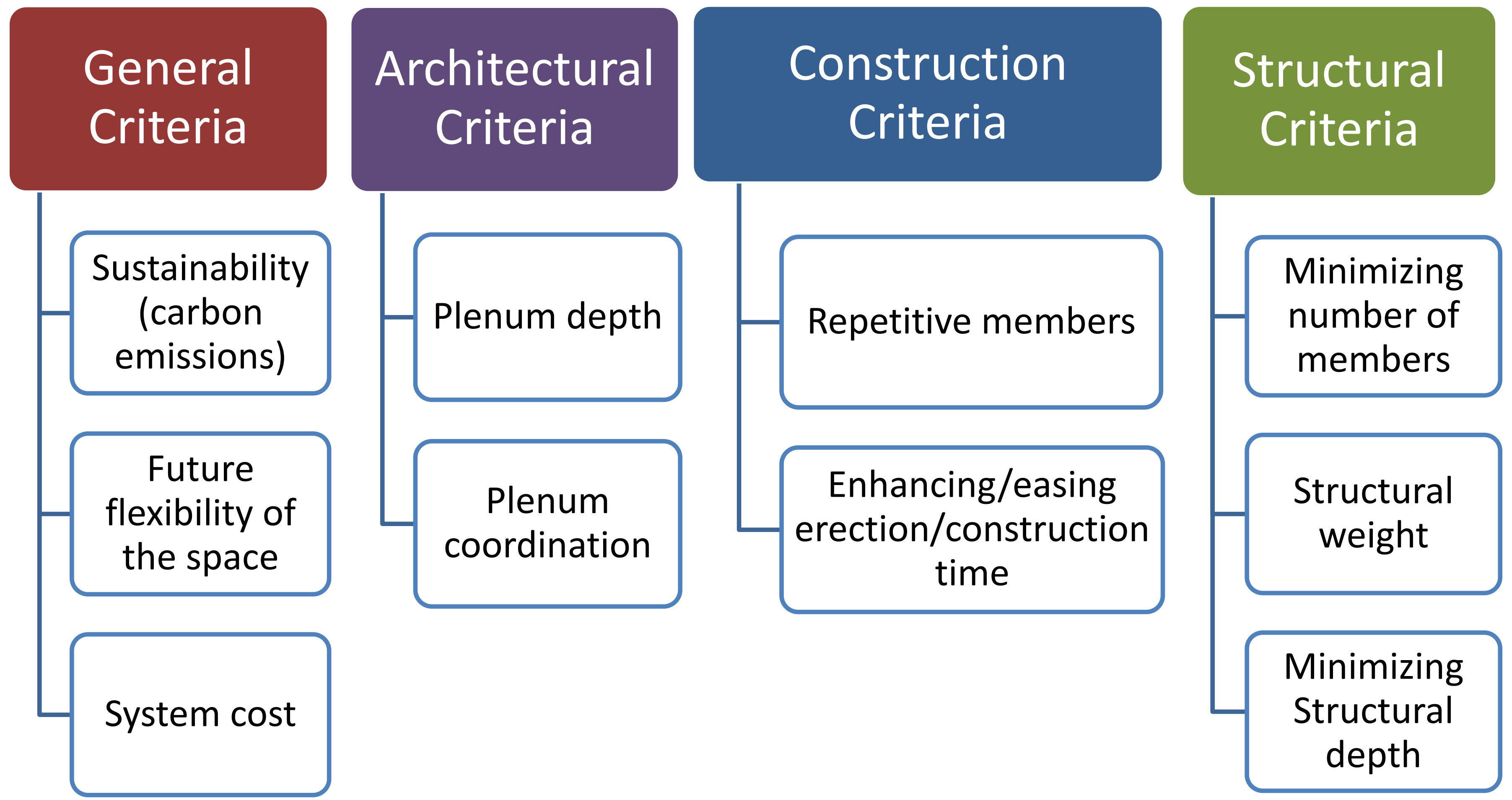
STRUCTURAL SYSTEM SELECTION PARAMETERS



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Structural Decision-Making

AEC Industry Healthcare Survey

STRUCTURAL SYSTEM SELECTION PARAMETERS

General Criteria
- Sustainability (carbon emissions)
- Future flexibility of the space
- System cost

Architectural Criteria
- Plenum depth
- Plenum coordination

Construction Criteria
- Repetitive members
- Enhancing/easing erection/construction time

Structural Criteria
- Minimizing number of members
- Structural weight
- Minimizing Structural depth

1. Plenum depth & coordination
2. Structural weight
3. Enhancing/easing erection/construction time
4. Minimizing structural depth
5. Repetitive members
6. Minimizing number of members
7. System cost
8. Future flexibility of the space
9. Sustainability (carbon emissions)

Structural Decision-Making

MCDM Methods

Criteria	Weight	Baseline: 1B	2	3	4	5	6
G1	0.022	0	-1	-1	-1	1	-1
G2	0.037	0	1	1	1	-1	1
G3	0.041	0	1	1	-1	1	1
A1	0.200	0	1	1	-1	1	1
A2	0.200	0	1	1	-1	0	1
C1	0.098	0	1	0	0	1	1
C2	0.102	0	-1	-1	-1	1	-1
S1	0.096	0	1	1	1	0	1
S2	0.105	0	1	1	1	1	1
S3	0.099	0	1	1	-1	1	1
Σ(Weight x Score)		0	0.752	0.654	-0.426	0.63	0.752

Pugh Matrix (PM)

		System 1b			*Alternative System 2*		
Factor	Criteria	Attributes	Adv.	IoA	Attributes	Adv.	IoA
Sustainability (carbon emissions)	Lower is better	14804 kg CO_2	6% less	50	15722 kg CO_2	--	--
Total		--	--	**50**	--	--	0

Choosing By Advantages (CBA)

Subcriteria G1: Sustainability (carbon emissions)

	1b	2	3	4	5	6
1b	1	5	5	7	1/5	3
2	1/5	1	1	3	1/7	1/3
3	1/5	1	1	3	1/7	1/3
4	1/7	1/3	1/3	1	1/9	1/5
5	5	7	7	9	1	5
6	1/3	3	3	5	1/5	1

Analytic Hierarchy Process (AHP)

Structural Decision-Making

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5	5	7	7	9	1	5
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S1	0.096	0	1	1	1	0	1
S2	0.105	0	1	1	1	1	1
S3	0.099	0	1	1	-1	1	1
Σ(Weight x Score)		0	0.752	0.654	-0.426	0.63	0.752

Pugh Matrix (PM)

		System 1b			*Alternative System 2*		
Factor	Criteria	Attributes	Adv.	IoA	Attributes	Adv.	IoA
Sustainability (carbon emissions)	Lower is better	14804 kg CO_2	6% less	50	15722 kg CO_2	--	--
Total		--	--	**50**	--	--	0

Choosing By Advantages (CBA)

Subcriteria G1: Sustainability (carbon emissions)

	1b	2	3	4	5	6
1b	1	5	5	7	1/5	3
2	1/5	1	1	3	1/7	1/3
3	1/5	1	1	3	1/7	1/3
4	1/7	1/3	1/3	1	1/9	1/5
5	5	7	7	9	1	5
6	1/3	3	3	5	1/5	1

Analytic Hierarchy Process (AHP)

Structural Decision-Making

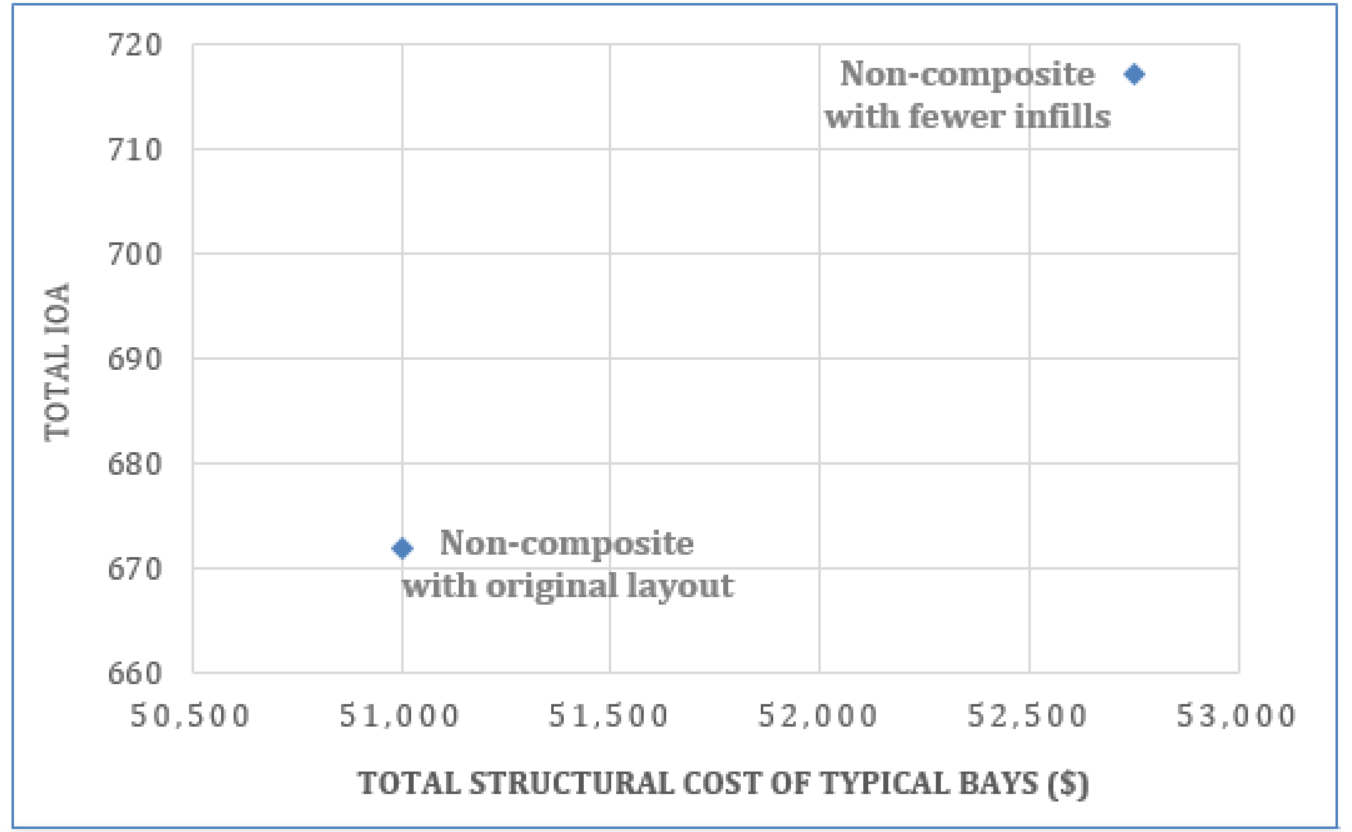
PM, CBA, & AHP Results

1. Non-composite, original layout
2. Composite, fewer infills, modified
3. Non-composite, fewer infills
4. Composite, fewer infills
5. Original composite (modified)
6. Composite, rotated

PM & AHP

1. Non-composite, fewer infills
2. Non-composite, original layout
3. Composite, fewer infills, modified
4. Composite, fewer infills
5. Original composite (modified)
6. Composite, rotated

CBA



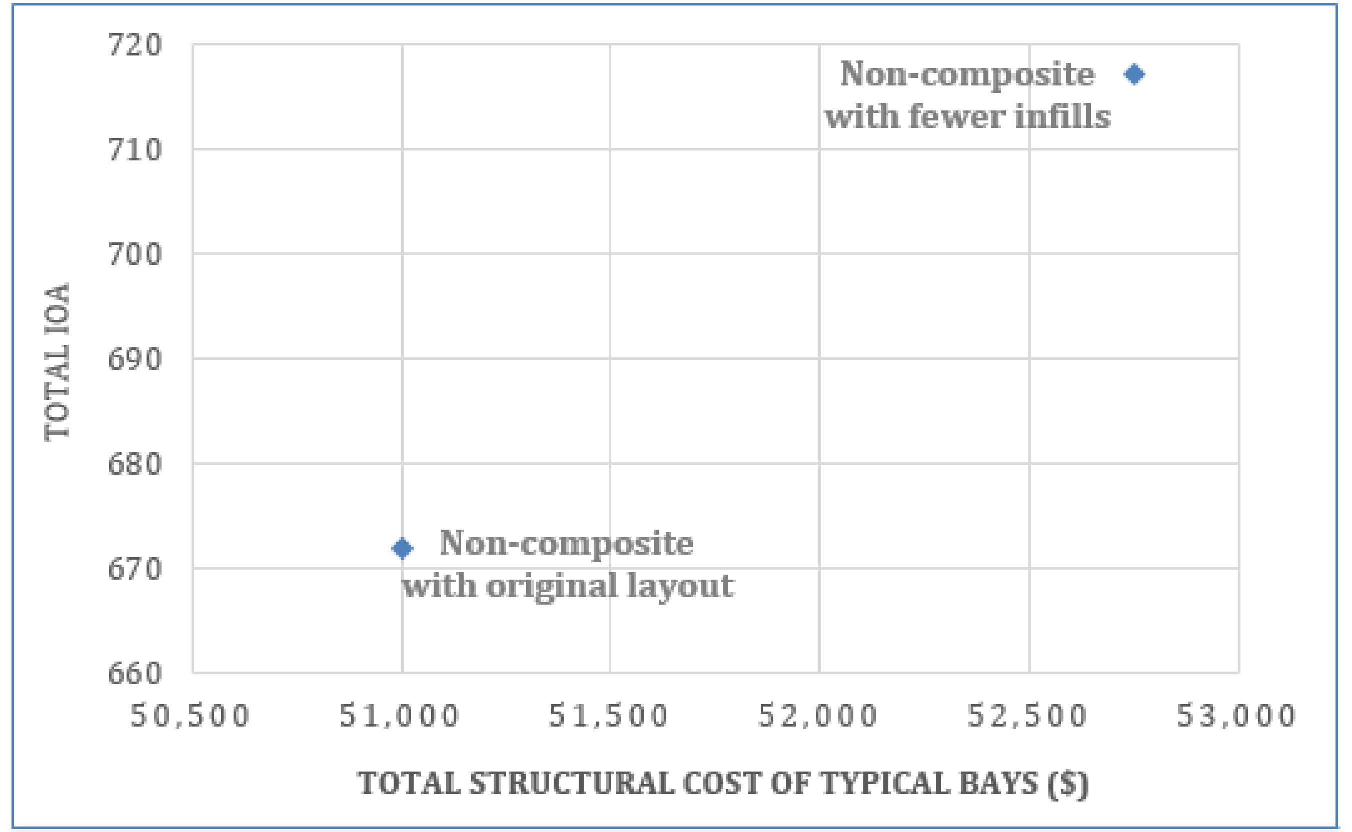
CBA Cost-Advantage Comparison

Structural Decision-Making

PM, CBA, & AHP Results

Non-composite, original layout

Non-composite, original layout



PM & AHP

CBA

CBA Cost-Advantage Comparison

Building Overview

Alternative Gravity Bay Study

► Gravity System Redesign

► Decision-Making Study

Lateral System Redesign

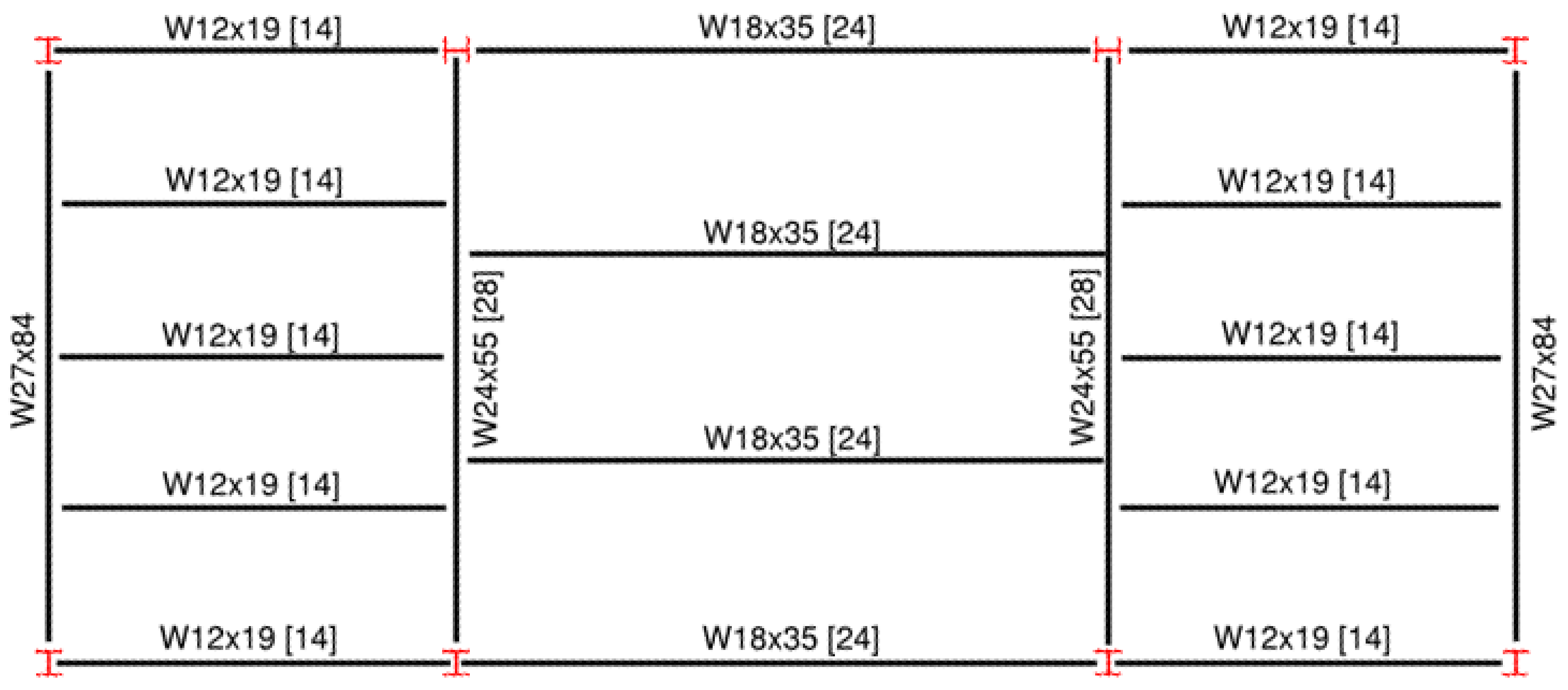
Structural System Comparisons

Acoustic Analysis

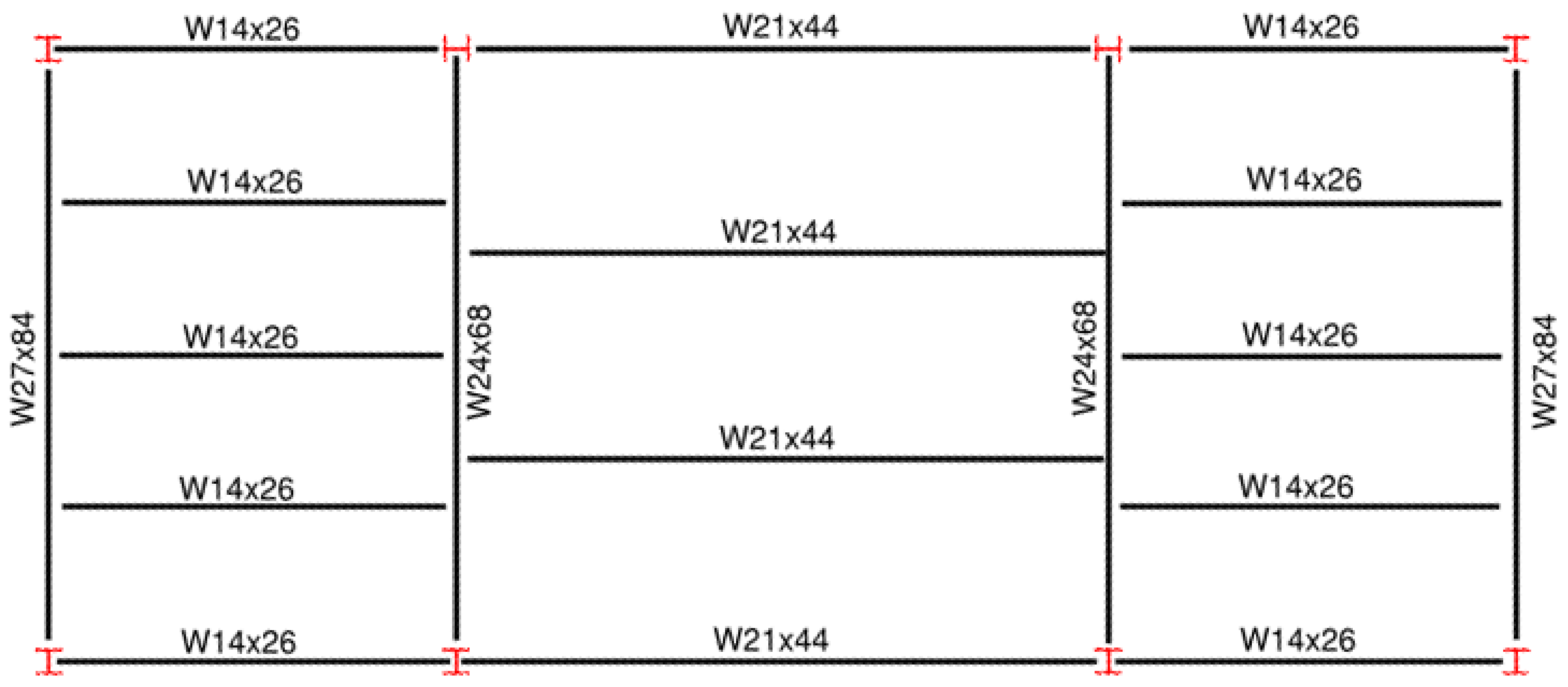
Prefabrication Study

Gravity Redesign

Non-composite with Original Layout



Existing Composite System, Typical Bed Tower Bays



Redesigned Non-composite System, Typical Bed Tower Bays

Typical Patient Room Bay Comparisons			
		Existing	Non-composite Design with Original Layout
	Studs		
	Structural Weight	86 psf	86 psf
	Carbon Content	12,955 kg CO_2	13,090 kg CO_2
	Structural Cost, Material	$22.44 / SF	$23.02 / SF
	Structural Cost, Material & Labor	$25.12 / SF	$25.49 / SF
	Number of Total Pieces	7	7
	Average Demand to Capacity Ratio	0.56	0.63
Vibration Response	Slow, 50 steps/min	2504 mips	1557 mips
	Moderate, 75 steps/min	9316 mips	5792 mips
	Fast, 100 steps/min	41921 mips	26063 mips

Typical Interior Bay Comparisons			
		Existing	Non-composite Design with Original Layout
	Studs		
	Structural Weight	85 psf	85 psf
	Carbon Content	17,871 kg CO_2	18,375 kg CO_2
	Structural Cost, Material	$19.12 / SF	$21.96 / SF
	Structural Cost, Material & Labor	$21.74 / SF	$24.36 / SF
	Number of Total Pieces	6	6
	Average Demand to Capacity Ratio	0.75	0.87
Vibration Response	% g	0.288 % g	0.217 % g

Building Overview
Alternative Gravity Bay Study
► Gravity System Redesign
► Decision-Making Study
Lateral System Redesign
Structural System Comparisons
Acoustic Analysis
Prefabrication Study

Gravity Redesign

Non-composite with Original Layout

Typical Patient Room Bay Comparisons

		Existing- Modified for Vibration Requirements	Non-composite Design with Original Layout ✓
	Beam	W14x26	W14x26
	Left Girder	W27x84	W27x84
	Right Girder	W24x68	W24x68
	Studs	116	
	Structural Weight	88 psf	86 psf
	Carbon Content	14,804 kg CO_2	13,090 kg CO_2
	Structural Cost, Material	$24.23 / SF	$23.03 / SF
	Structural Cost, Material & Labor	$26.86 / SF	$25.49 / SF
	Number of Total Pieces	7	7
	Average Demand to Capacity Ratio	0.4	0.63
Vibration Response	Slow, 50 steps/min	1465 mips	1557 mips
	Moderate, 75 steps/min	5451 mips	5792 mips
	Fast, 100 steps/min	24528 mips	26063 mips

Typical Interior Bay Comparisons

		Existing - Modified for Vibration Requirements	Non-composite Design with Original Layout ✓
	Beam	W18x35	W21x44
	Left Girder	W24x55	W24x68
	Right Girder	W24x55	W24x68
	Studs	148	
	Structural Weight	85 psf	85 psf
	Carbon Content	17,822 kg CO_2	18,375 kg CO_2
	Structural Cost, Material	$21.09 / SF	$21.96 / SF
	Structural Cost, Material & Labor	$23.70 / SF	$24.36 / SF
	Number of Total Pieces	6	6
	Average Demand to Capacity Ratio	0.68	0.87
Vibration Response	% g	0.288 % g	0.217 % g

Lateral Redesign

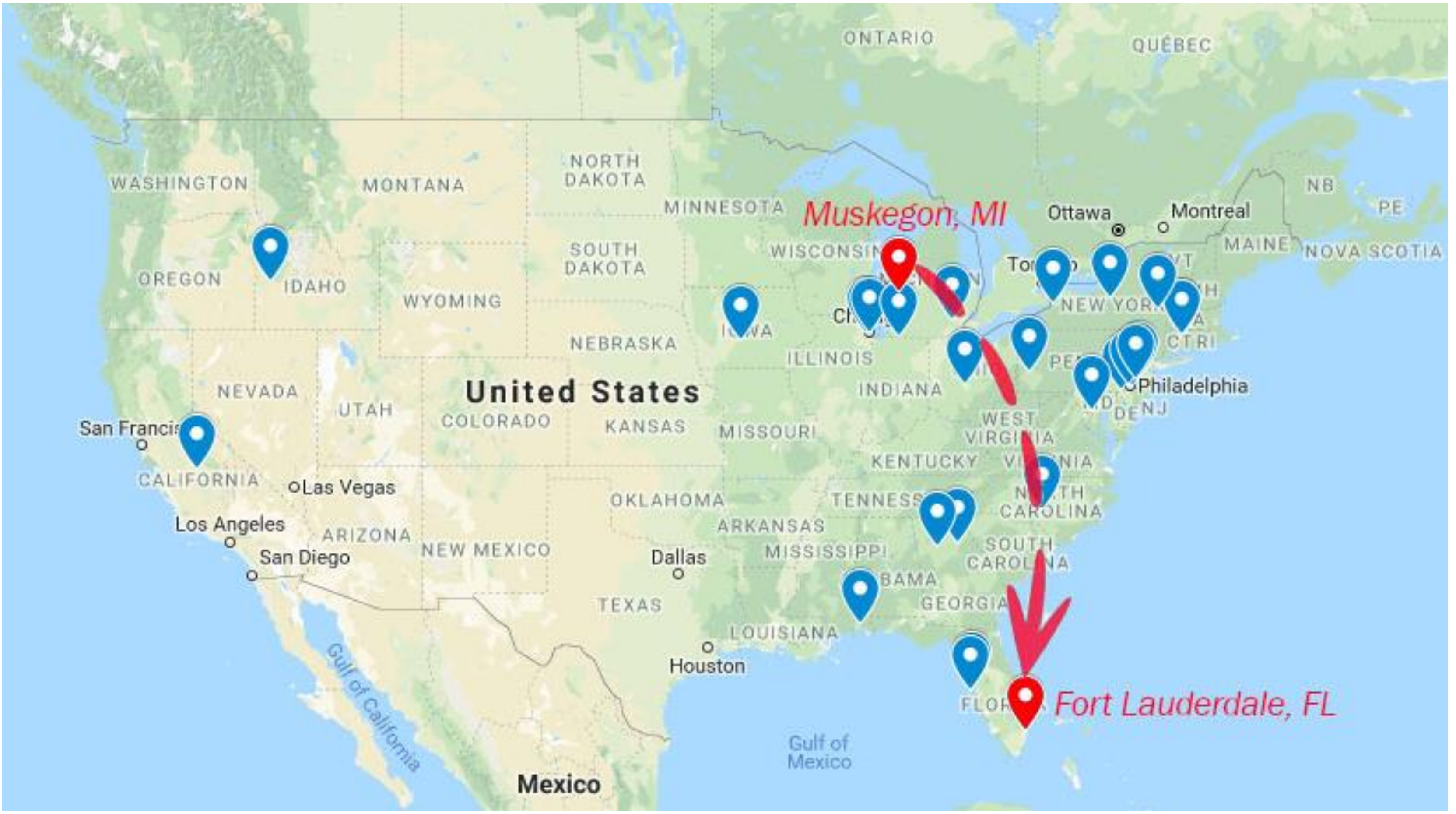
Overview

Goals

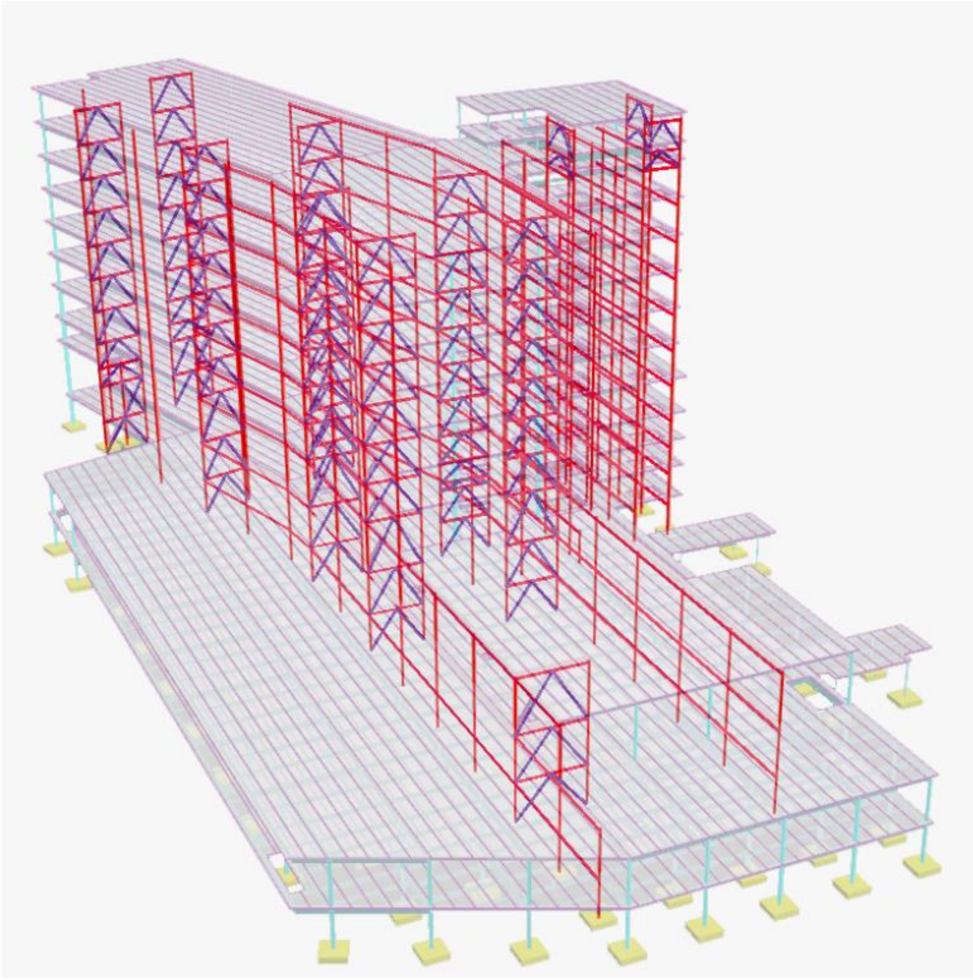
- Redesign the lateral system for a proposed new location within the Mercy Health network
- Consider strength, serviceability, sustainability, and system integration

Methods

- ETABS & RAM SS preliminary analyses
- RAM SS detailed design



Location Map

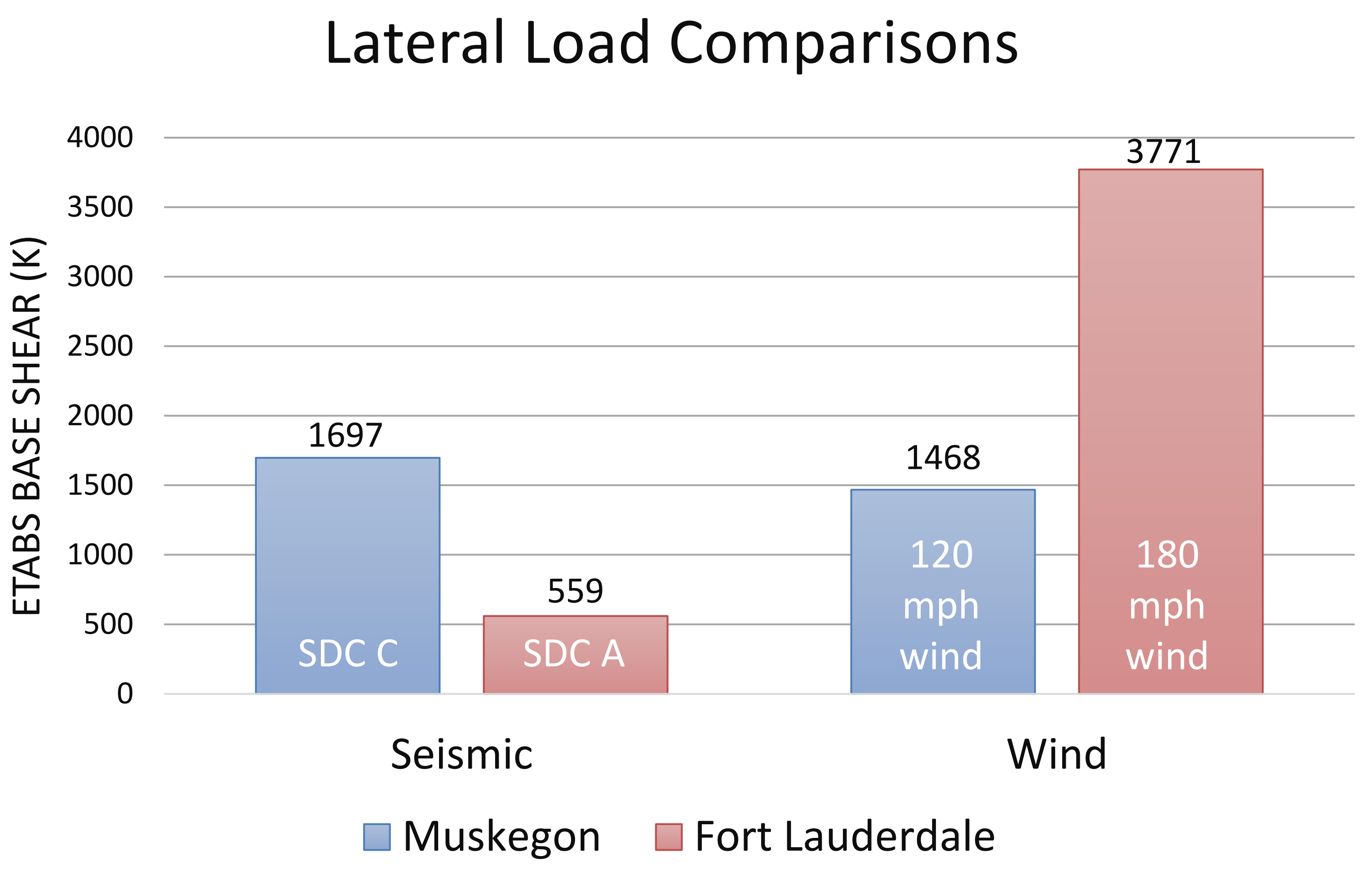


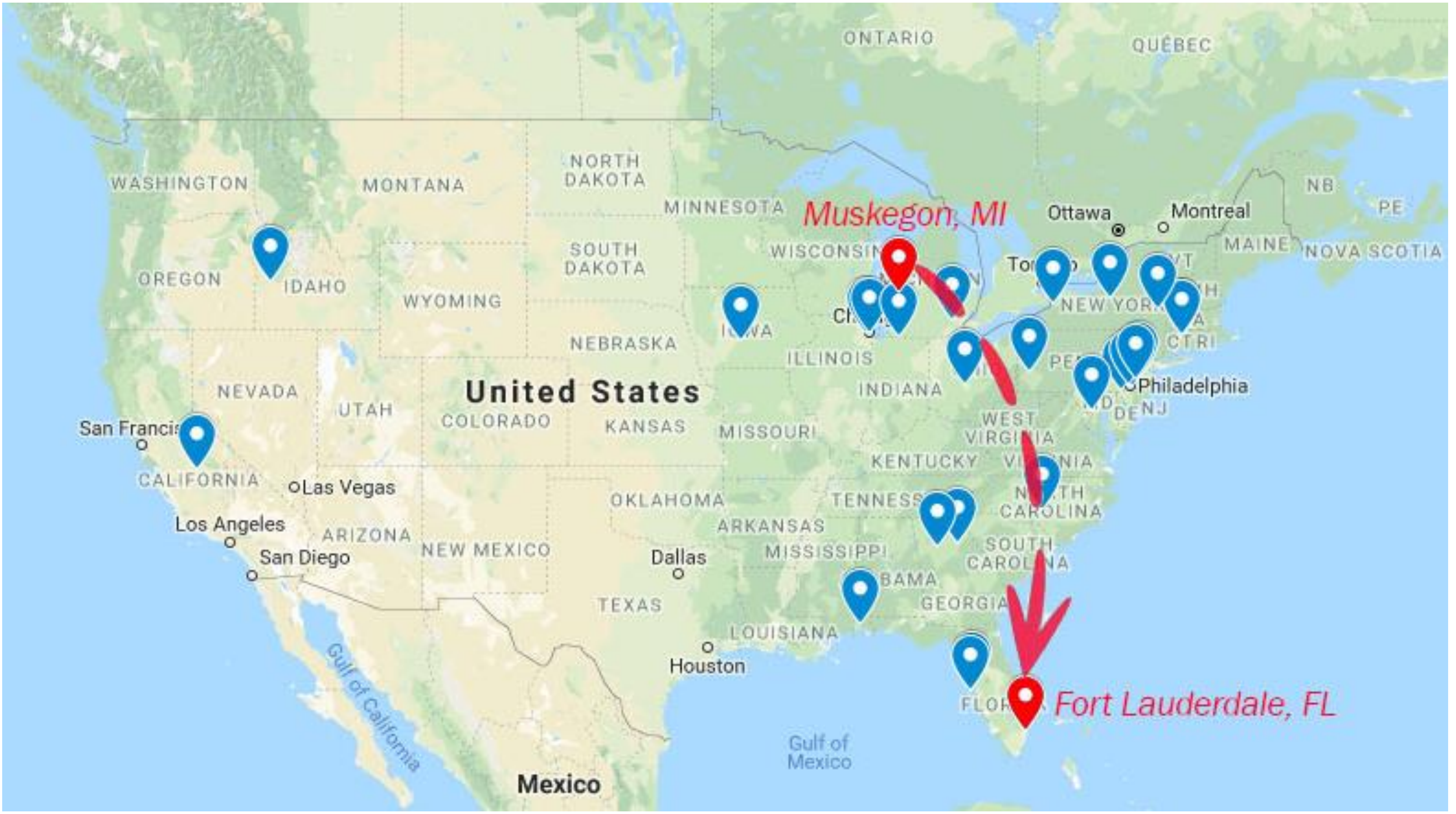
Existing Braced & Moment Frame System

Building Overview
Alternative Gravity Bay Study
Gravity System Redesign
Decision-Making Study
► Lateral System Redesign
Structural System Comparisons
Acoustic Analysis
Prefabrication Study

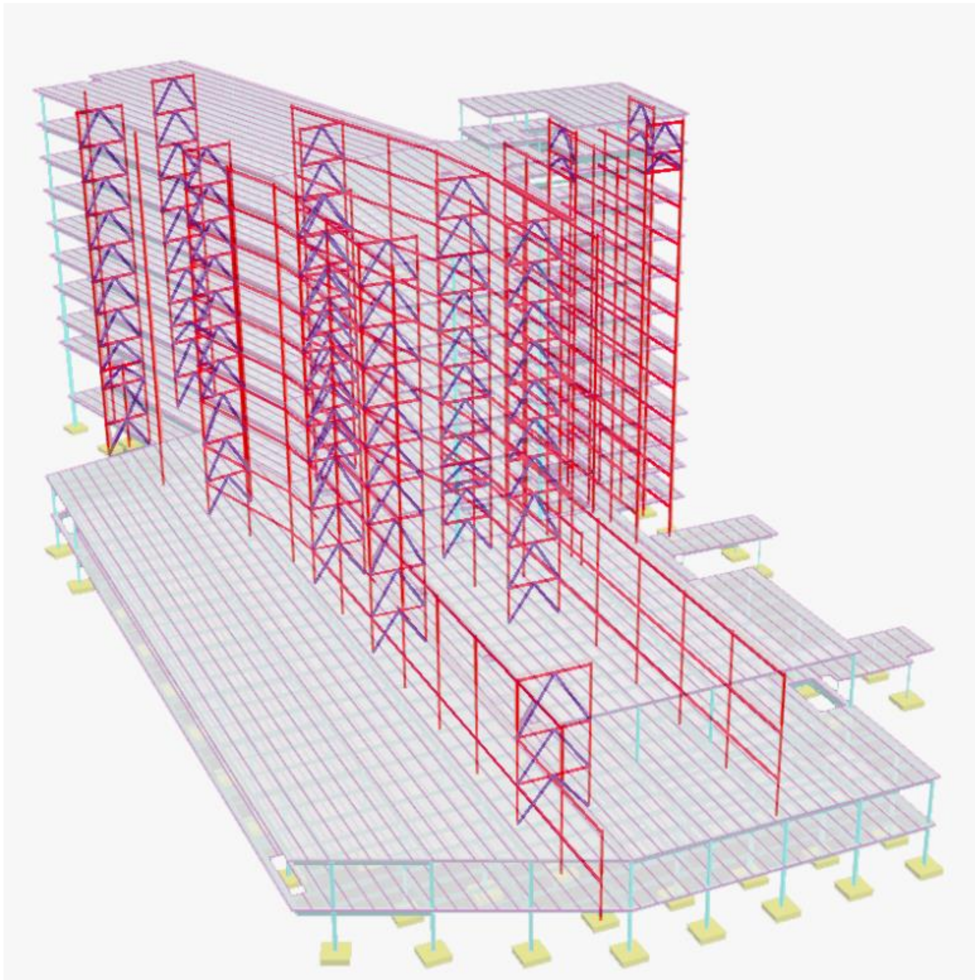
Lateral Redesign

Overview





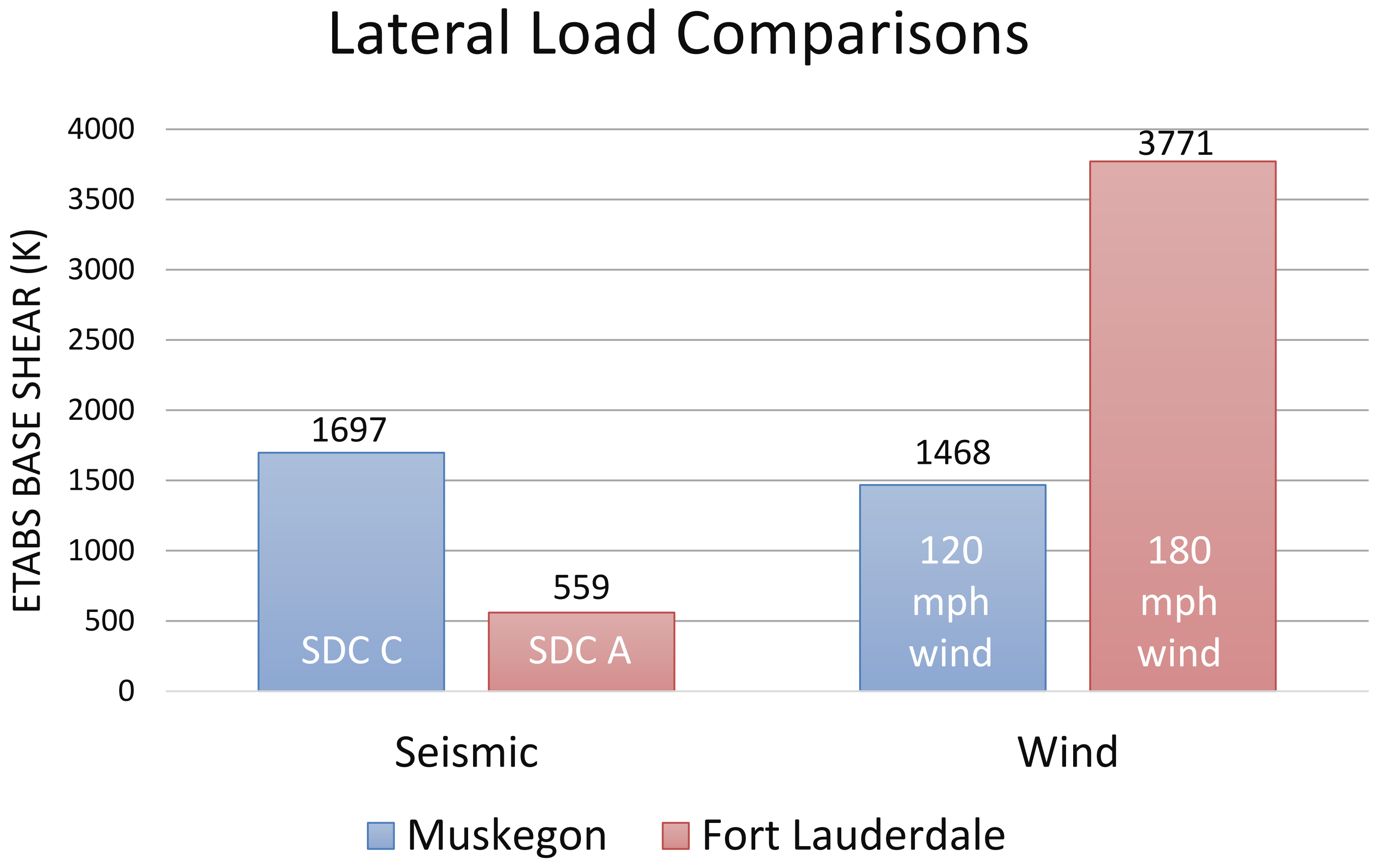
Location Map

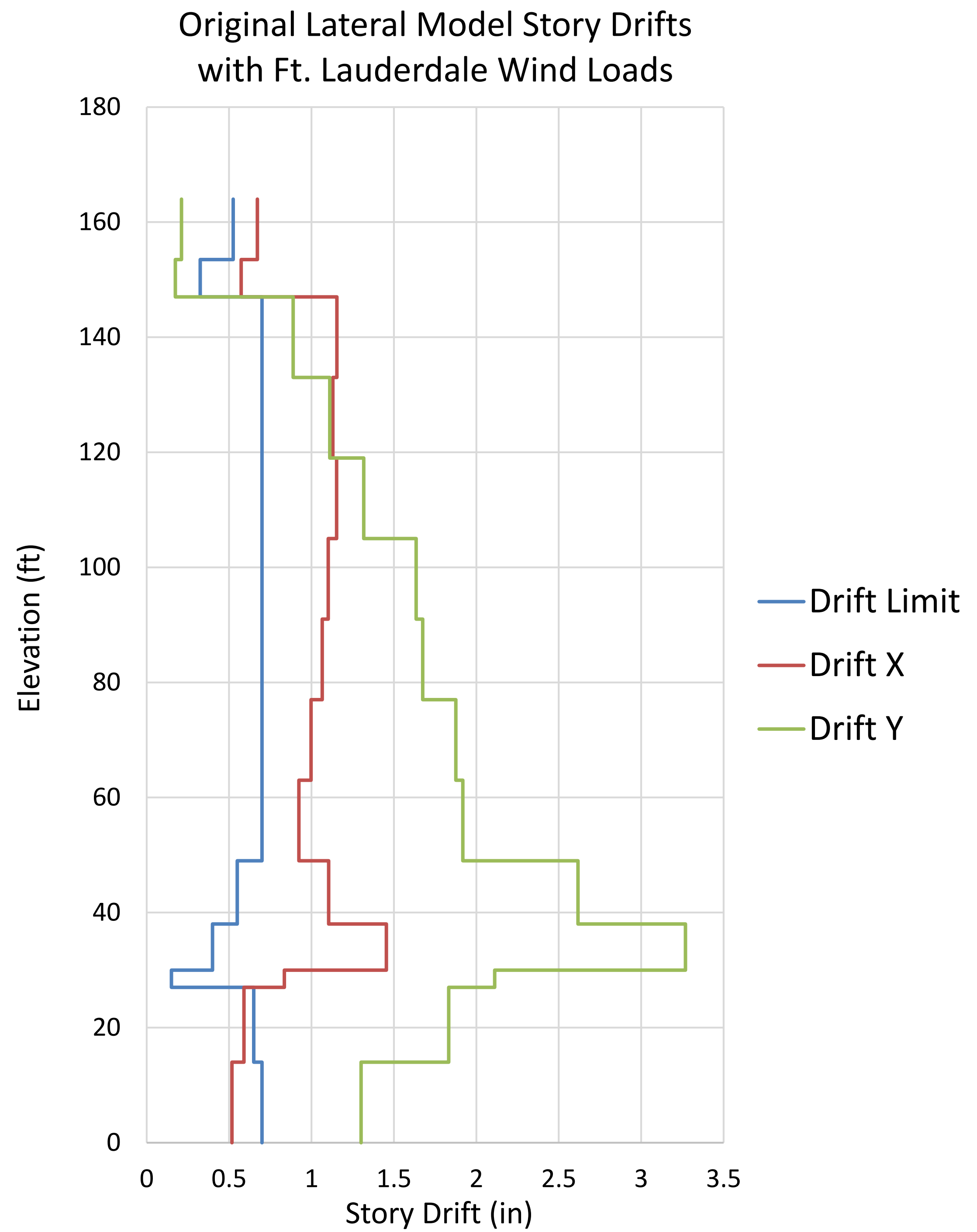


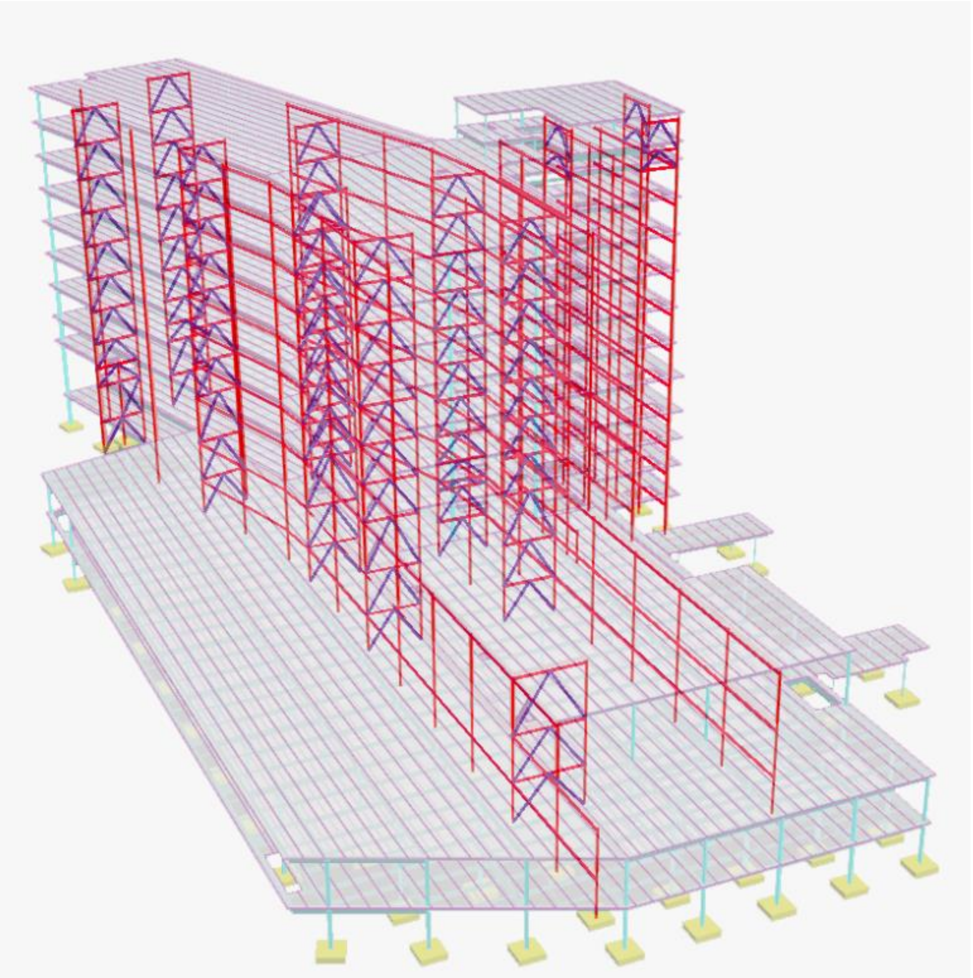
Existing Braced & Moment Frame System

Lateral Redesign

Overview



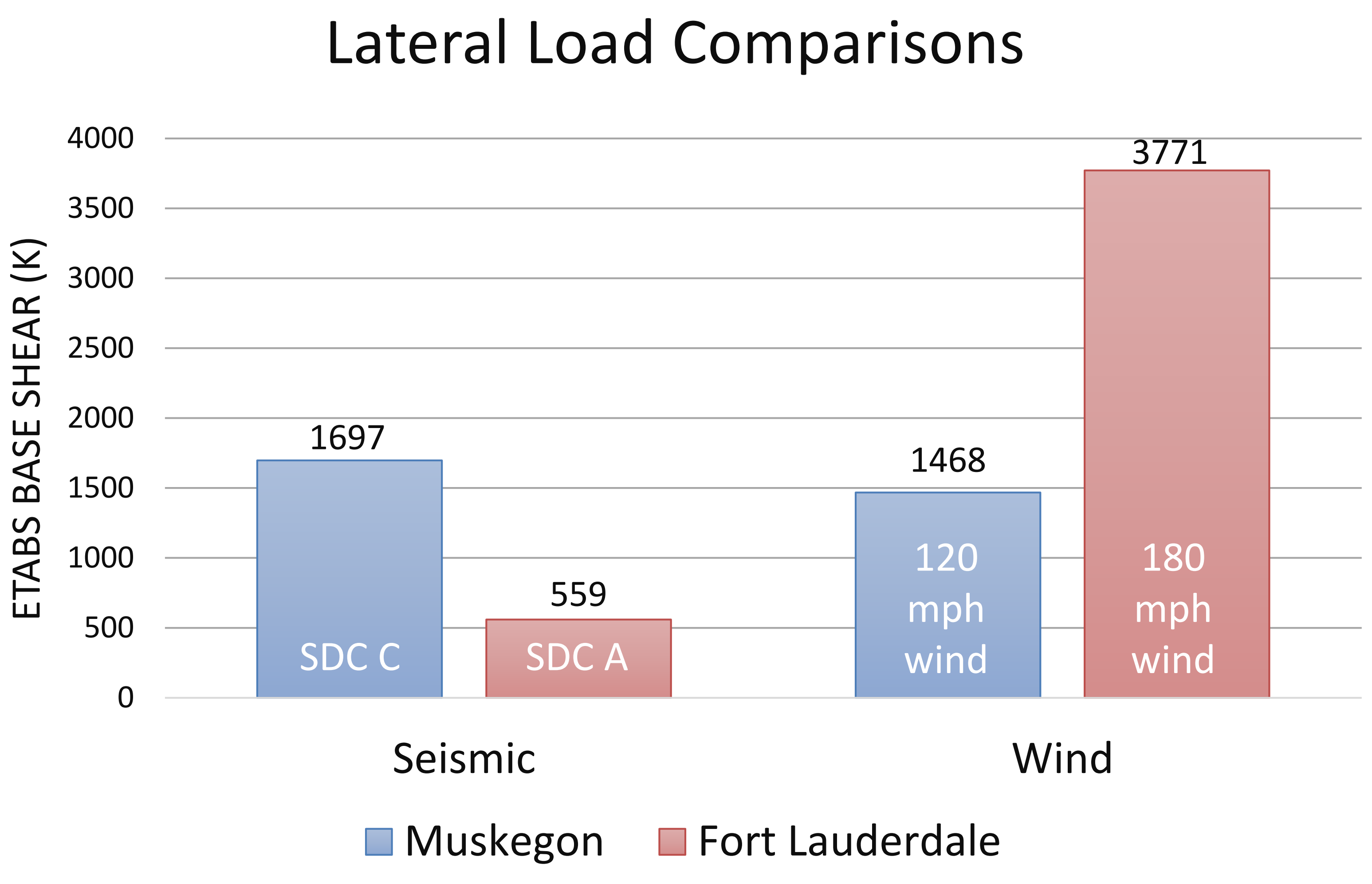


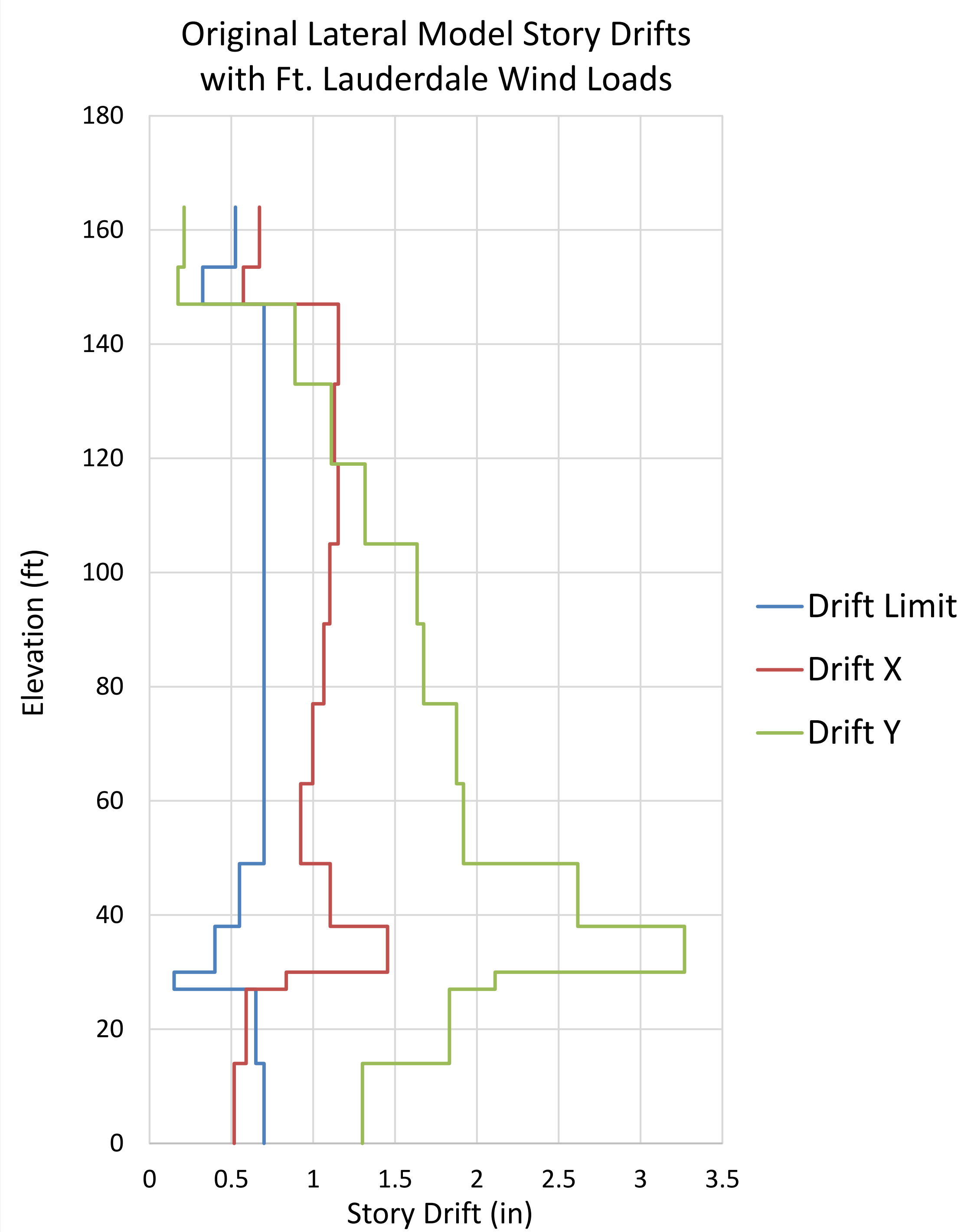


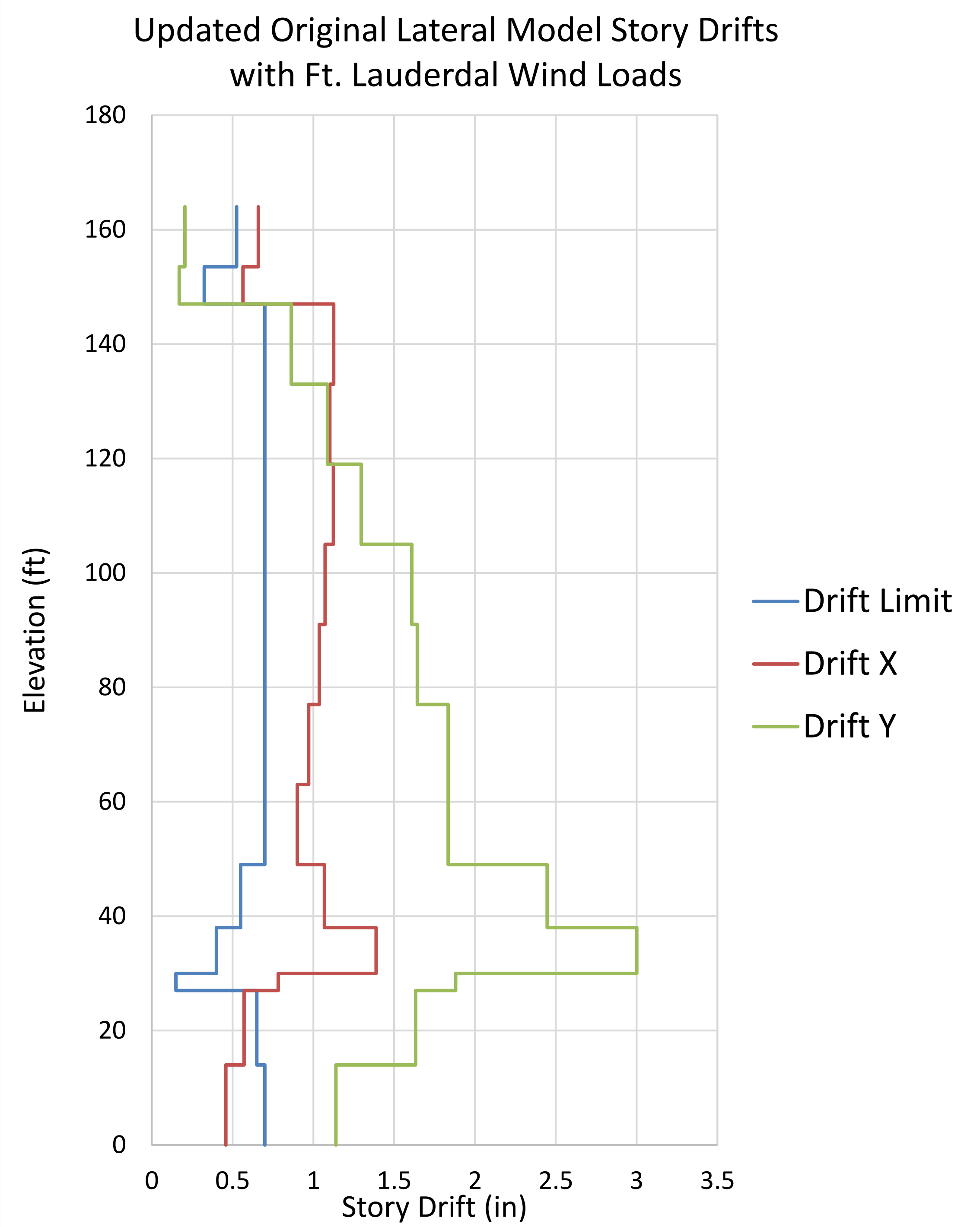
Existing Moment & Braced Frame System

Lateral Redesign

Overview

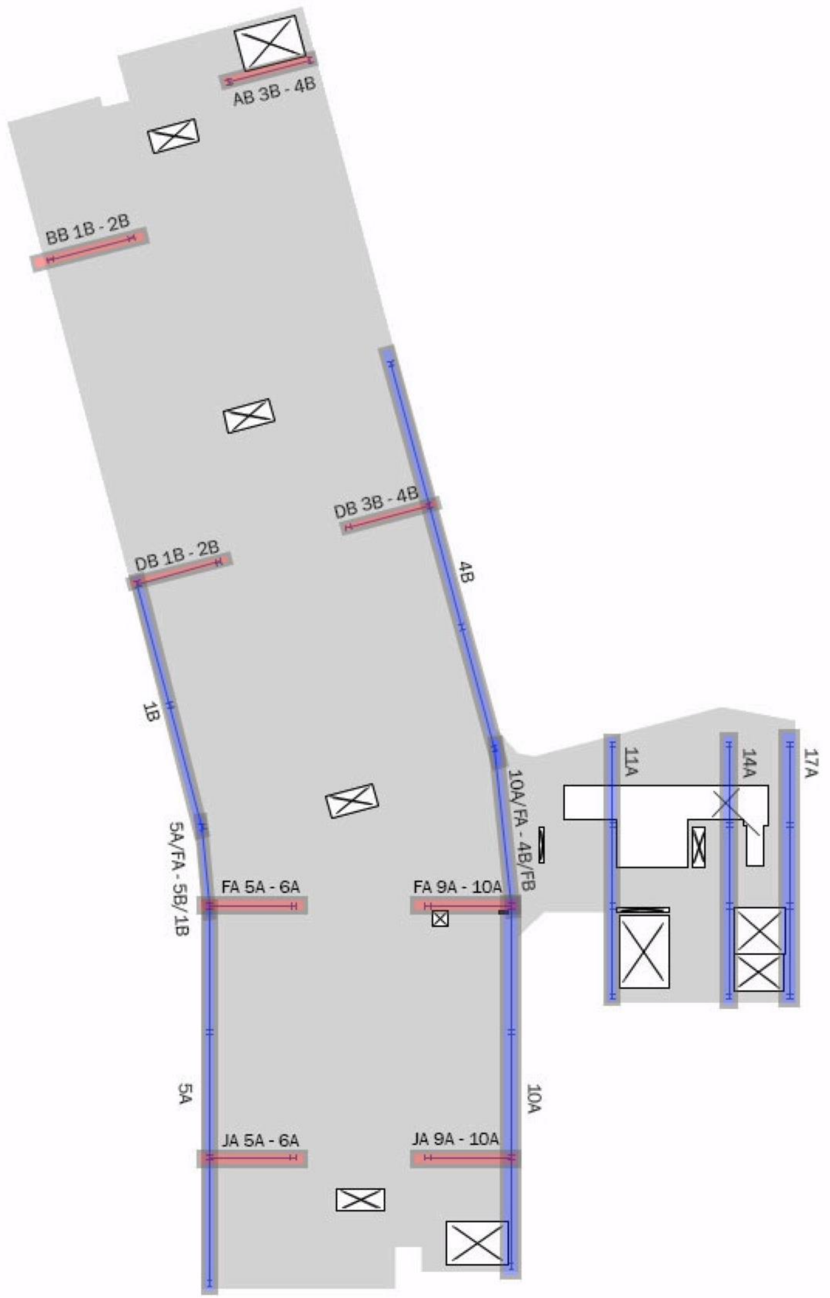




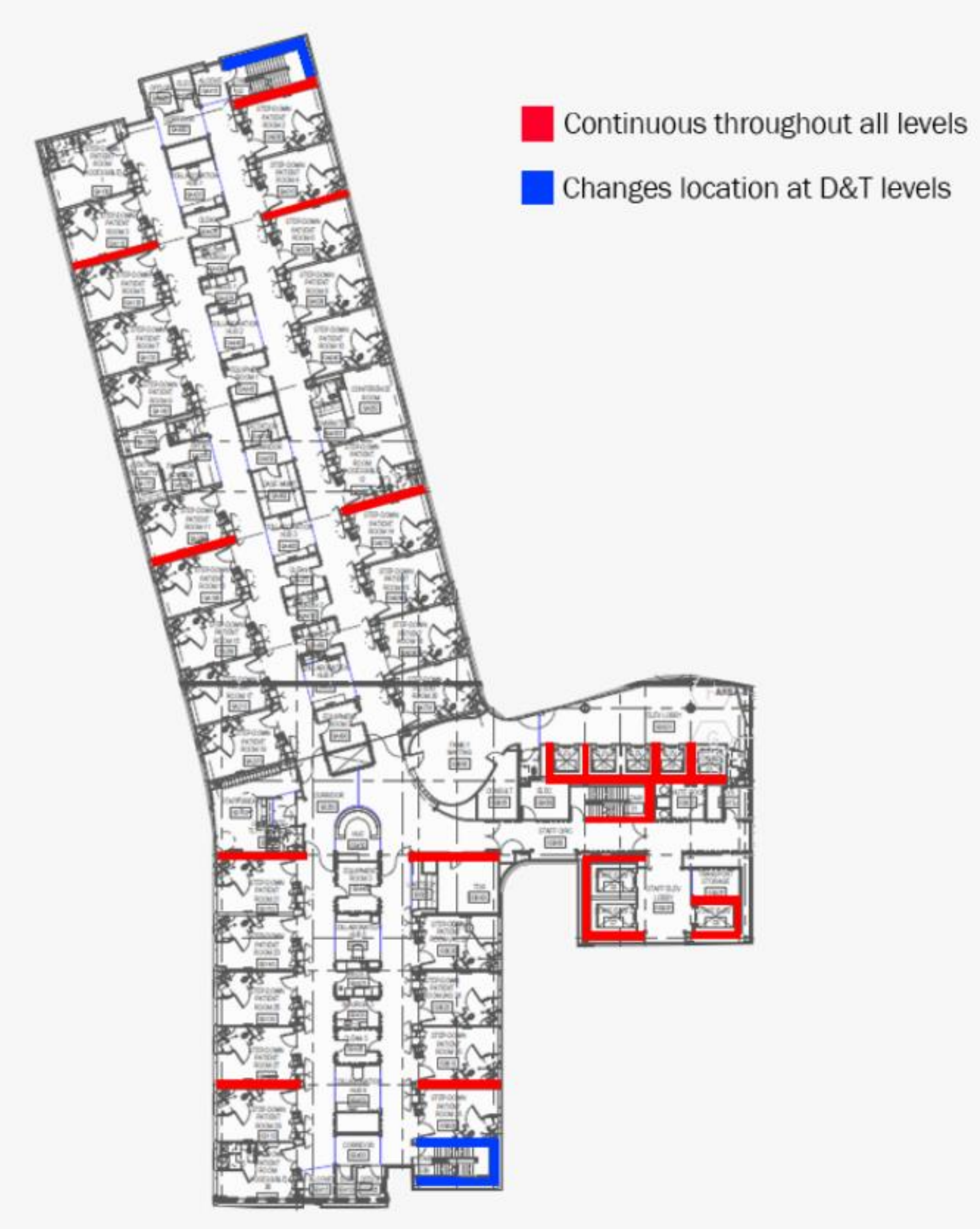


Lateral Redesign

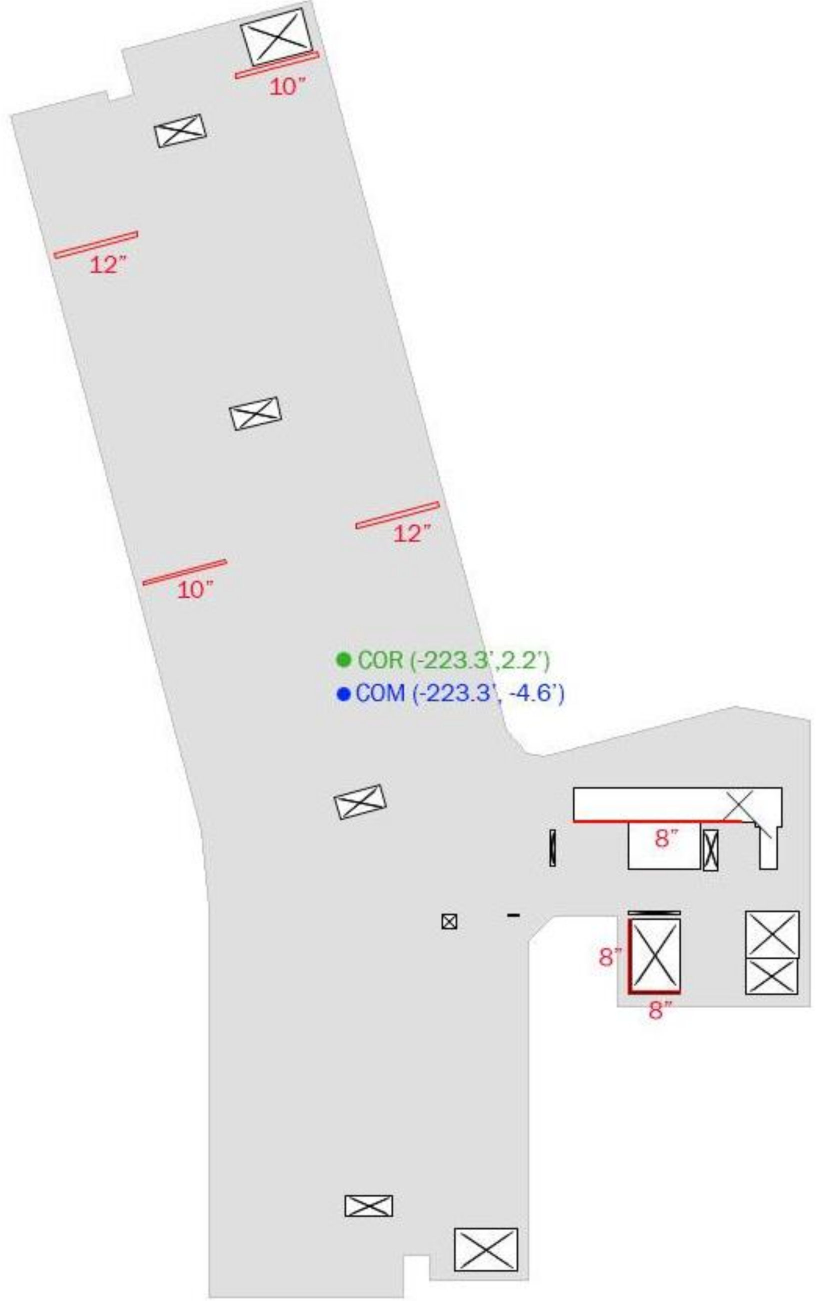
Shear Wall Layout



Existing Braced & Moment Frame Locations



Potential Shear Wall Locations

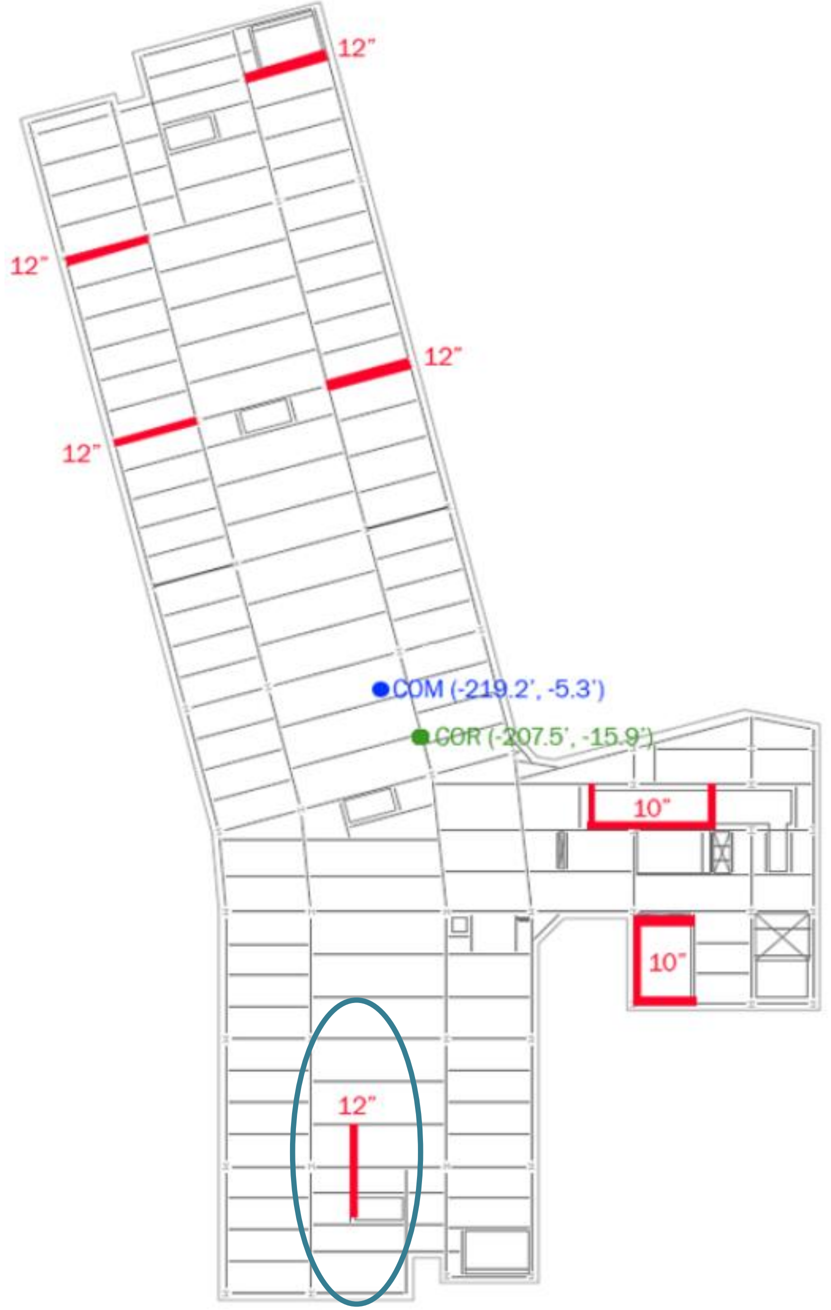


Preliminary Bed Tower Shear Wall Locations

Building Overview
Alternative Gravity Bay Study
Gravity System Redesign
Decision-Making Study
► Lateral System Redesign
Structural System Comparisons
Acoustic Analysis
Prefabrication Study

Lateral Redesign

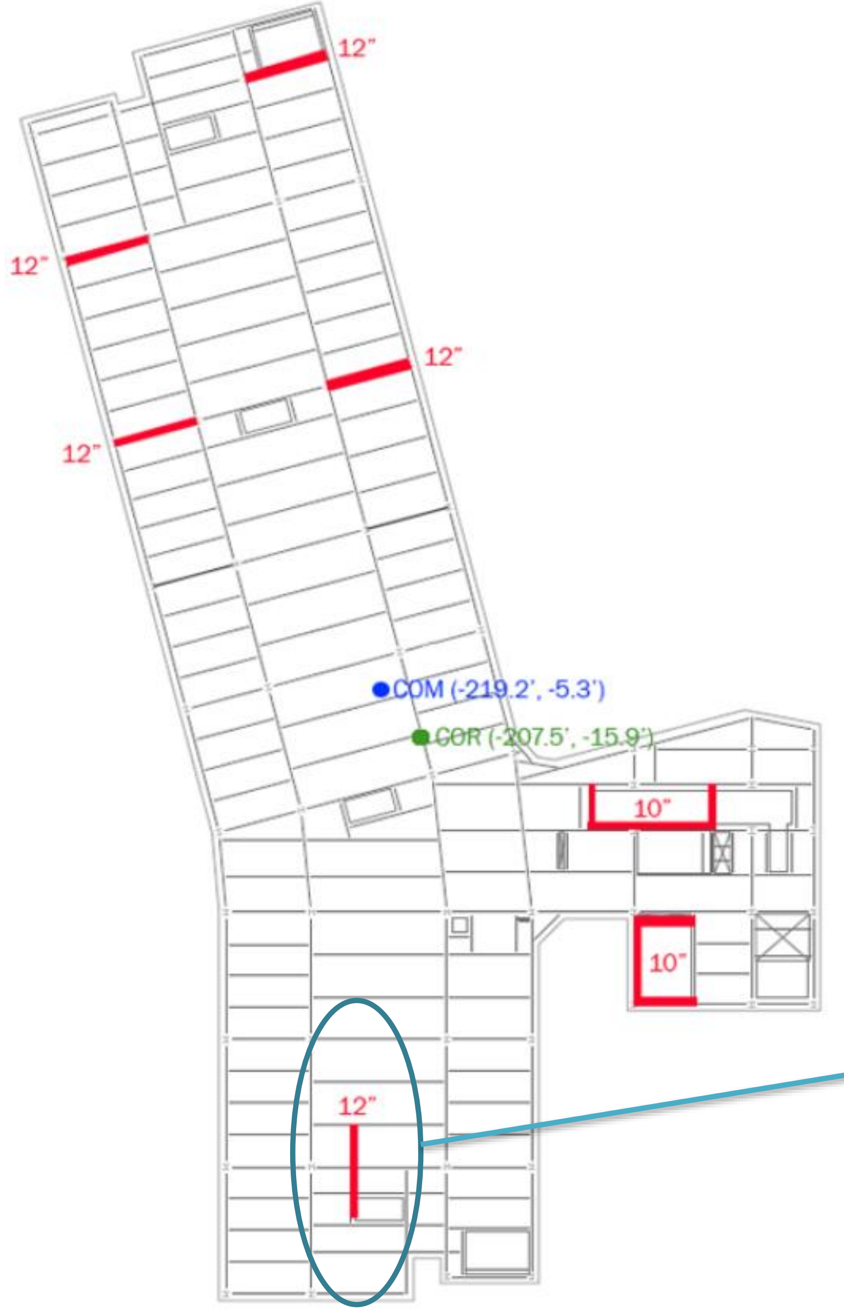
RAM Analysis



Final Shear Wall Locations

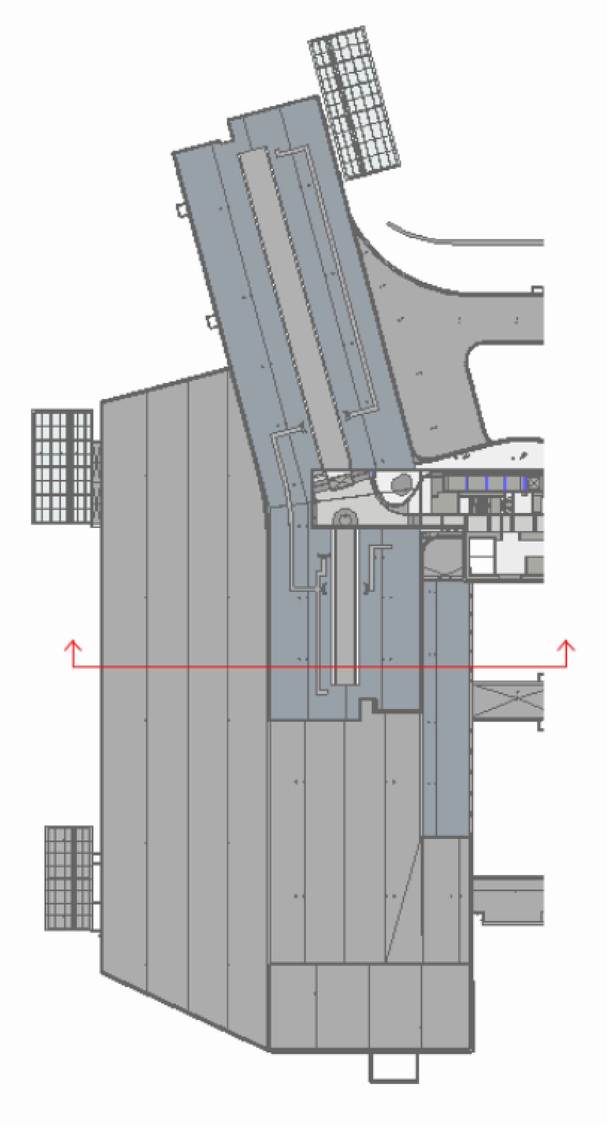
Lateral Redesign

RAM Analysis



Final Shear Wall Locations

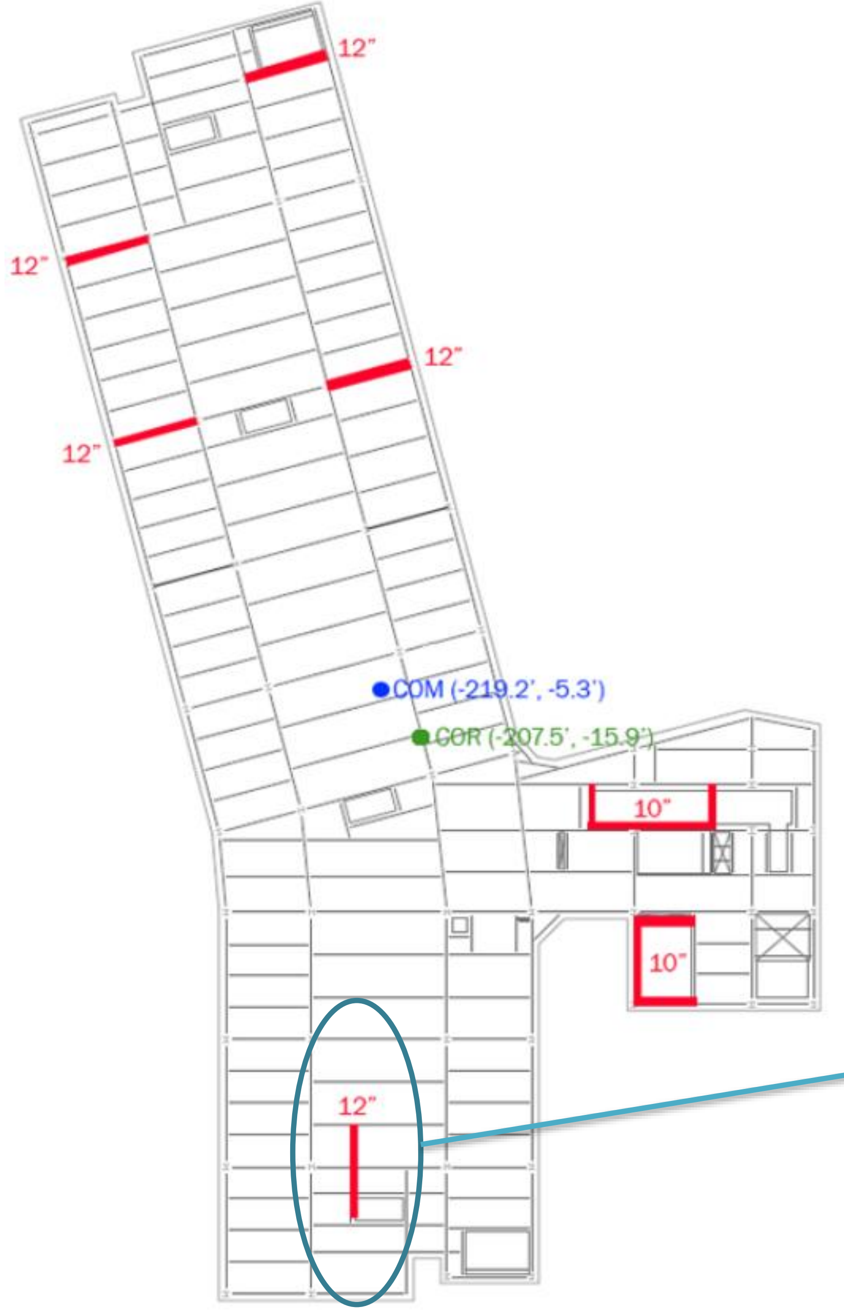
Building Section



Section Cut Location

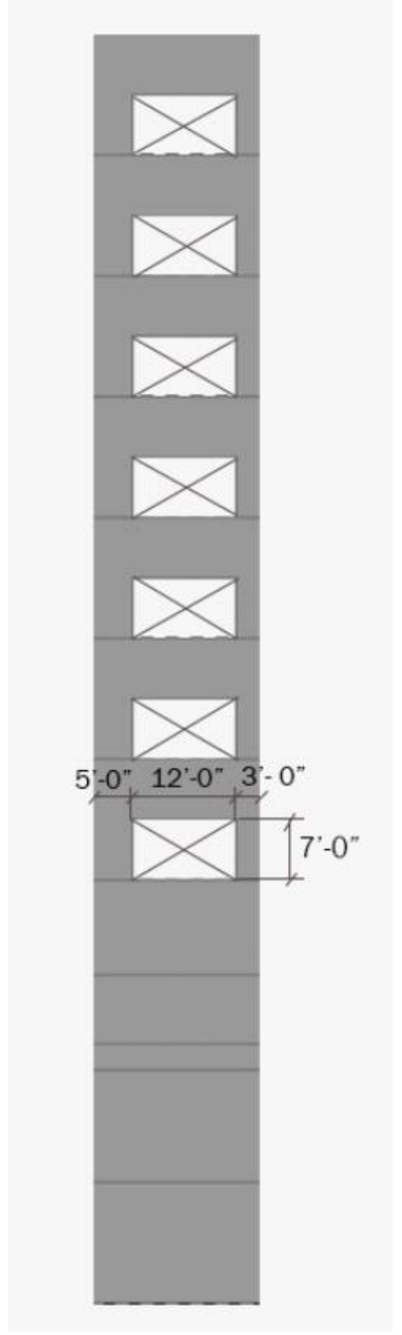
Lateral Redesign

RAM Analysis



Final Shear Wall Locations

Building Section



Shear Wall Elevation

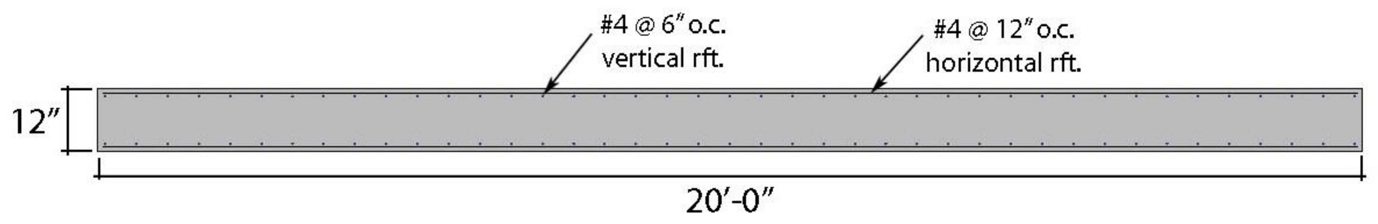
Lateral Redesign

RAM Analysis

Final Shear Wall Locations

Shear Wall Design Summary			
Section Cut Location	*Level 1*	*Level 5*	*Level 9*
Horizontal rft	#4 @ 12"	#4 @ 12"	#4 @ 12"
Vertical rft	#10 @ 12"	#4 @ 6"	#4 @ 12"
M_u (k-ft)	26,302	10,000	1733
V_u (k)	415	194	77
$ØV_n$ (k)	597	597	597

Controlling LC: 0.9D + 1.0W

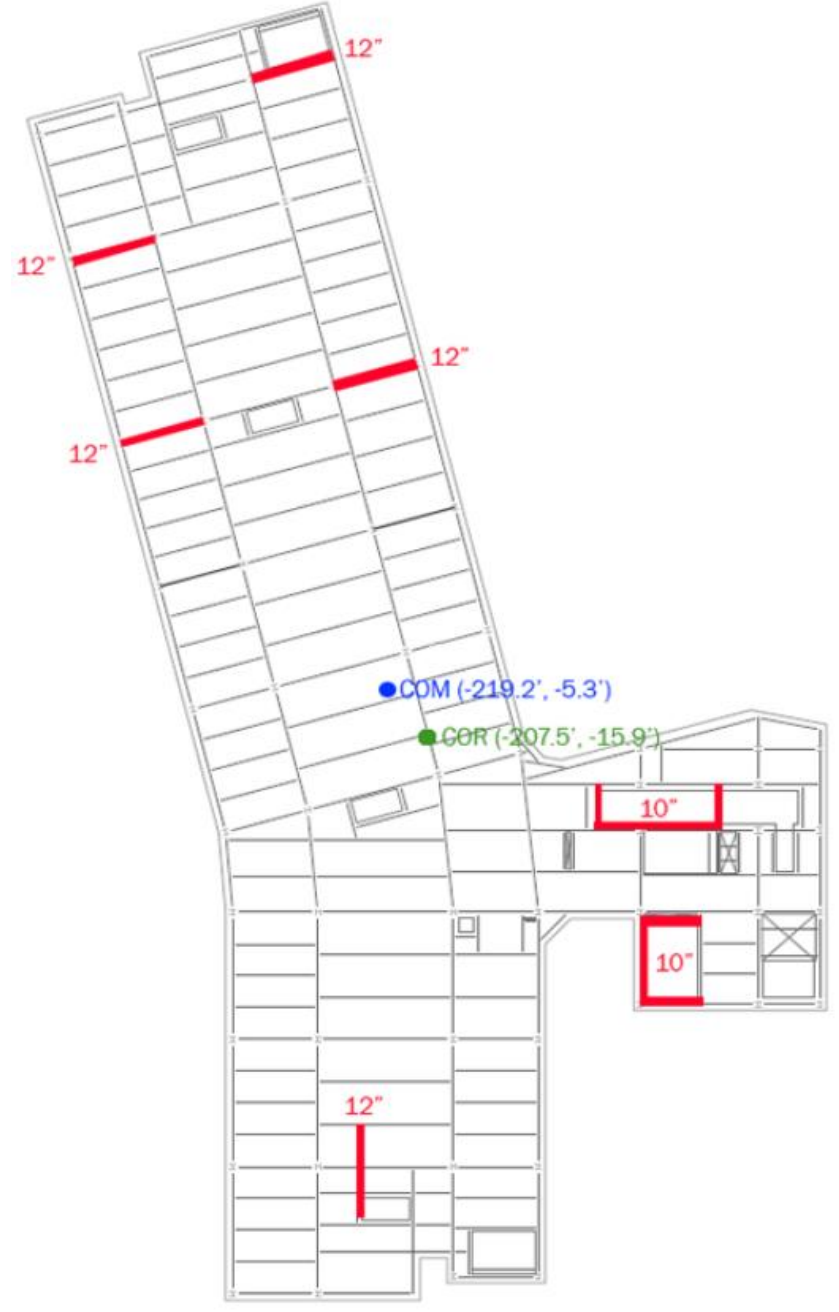


Shear Wall Section – Plan View (Level 5)

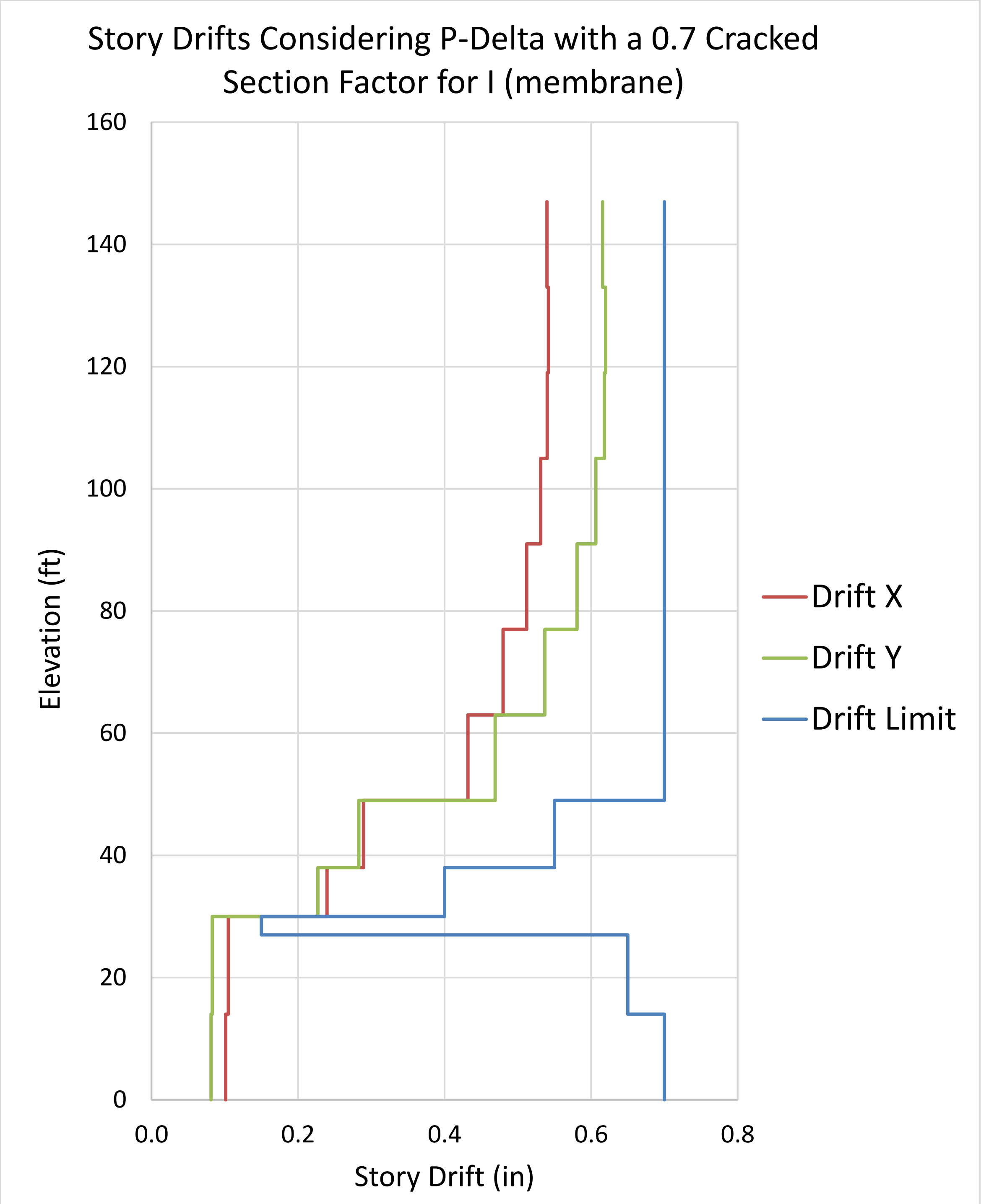
Building Overview
Alternative Gravity Bay Study
Gravity System Redesign
Decision-Making Study
► Lateral System Redesign
Structural System Comparisons
Acoustic Analysis
Prefabrication Study

Lateral Redesign

RAM Analysis

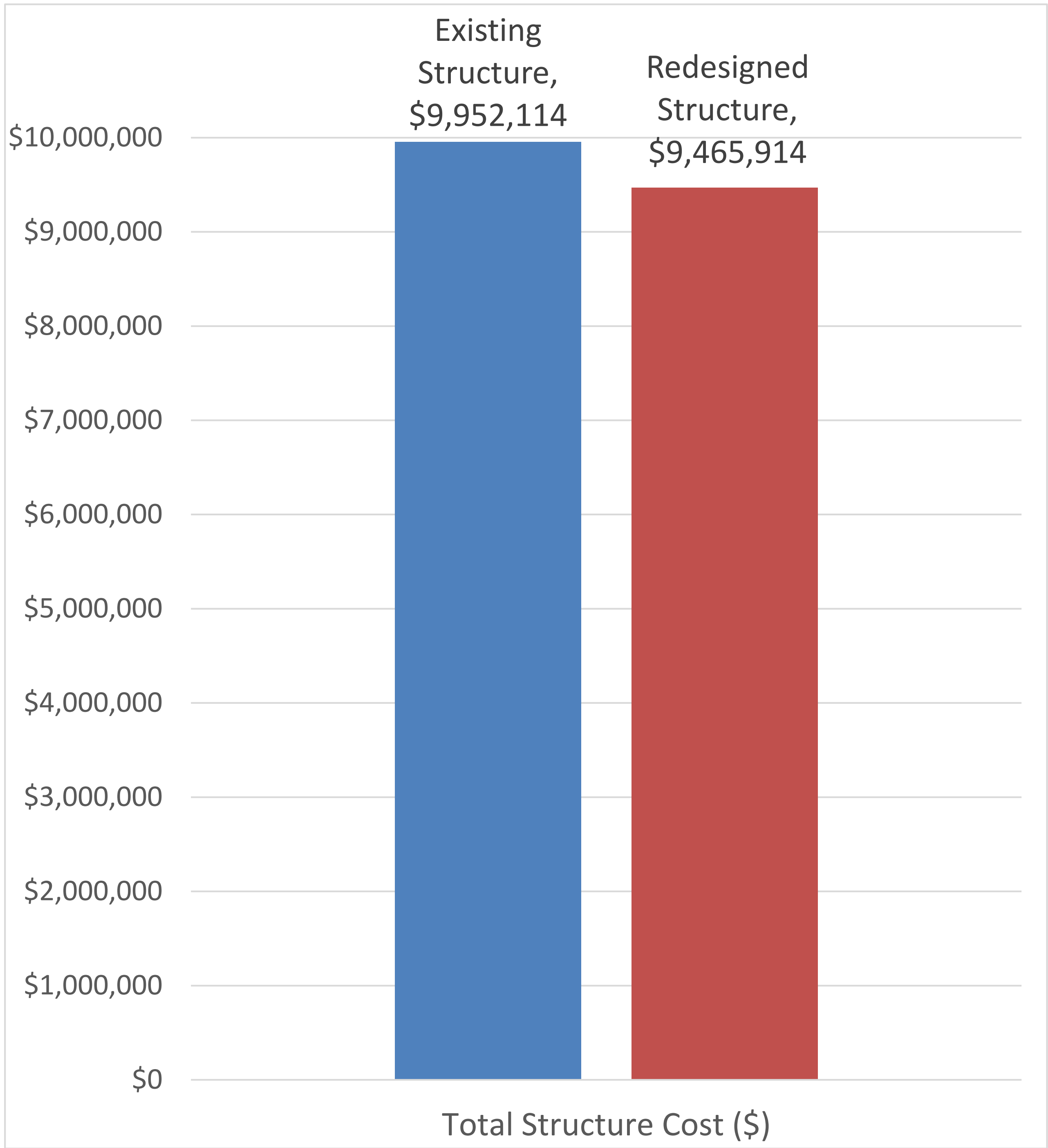


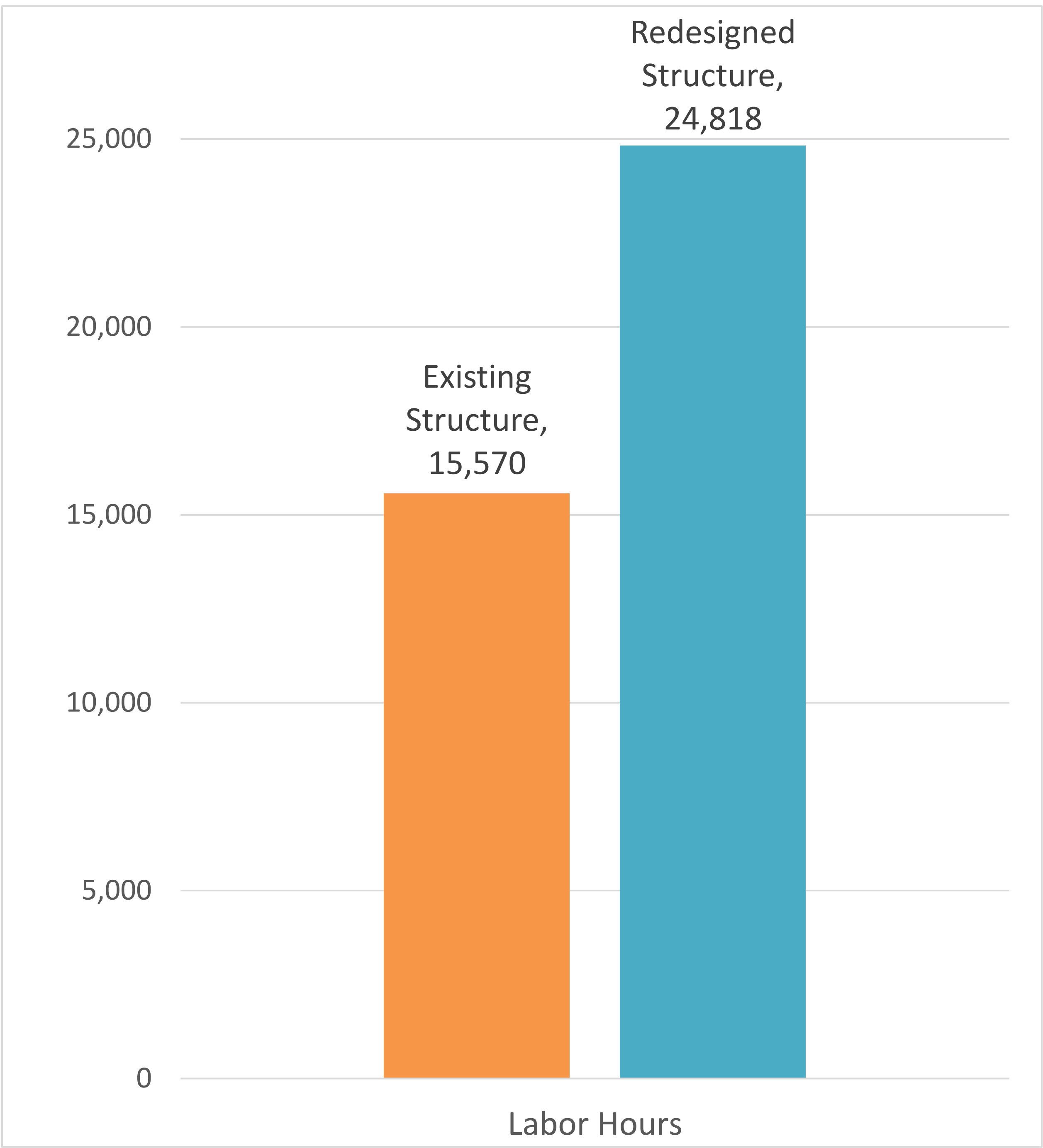
Final Shear Wall Locations



Structural Redesign

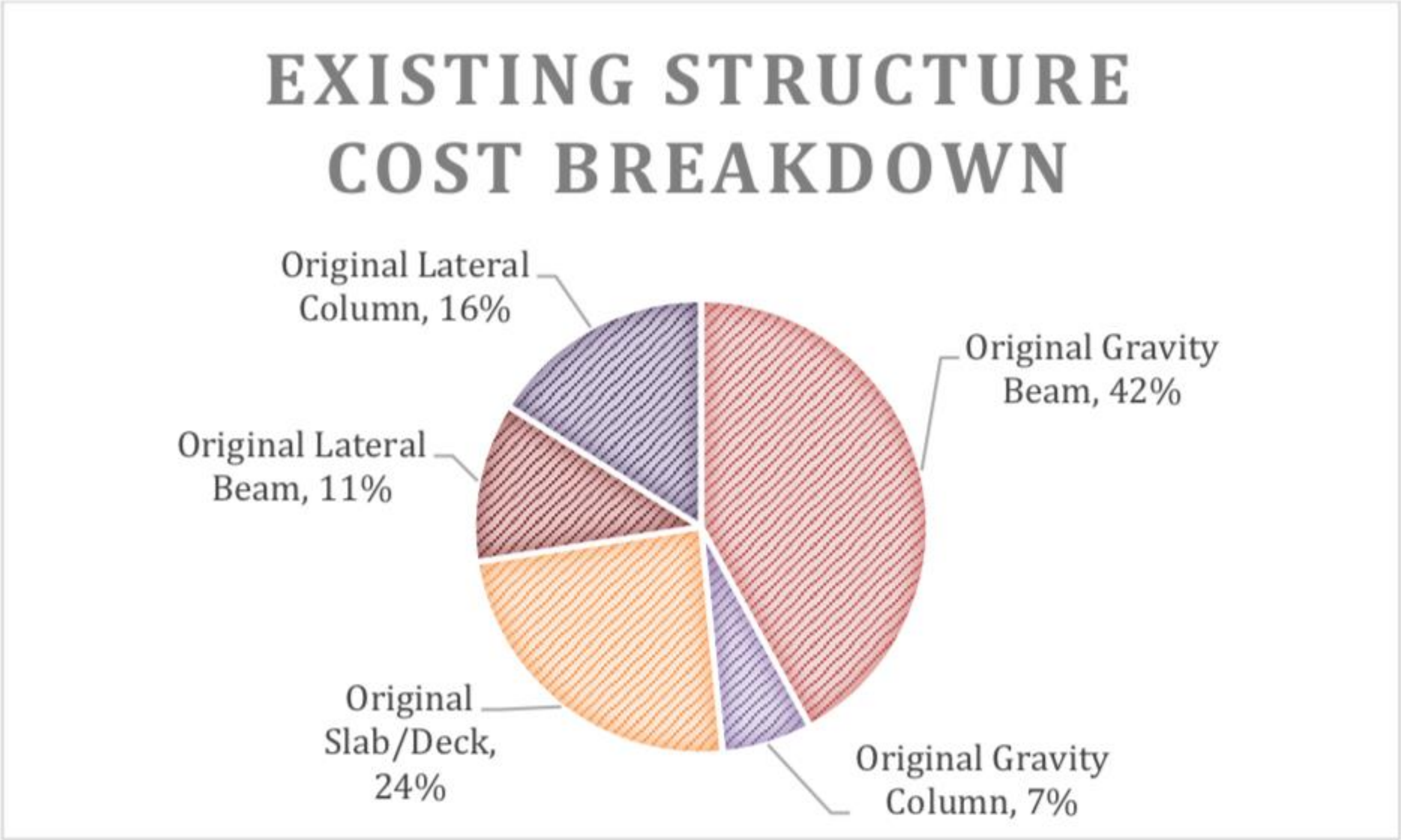
Summary

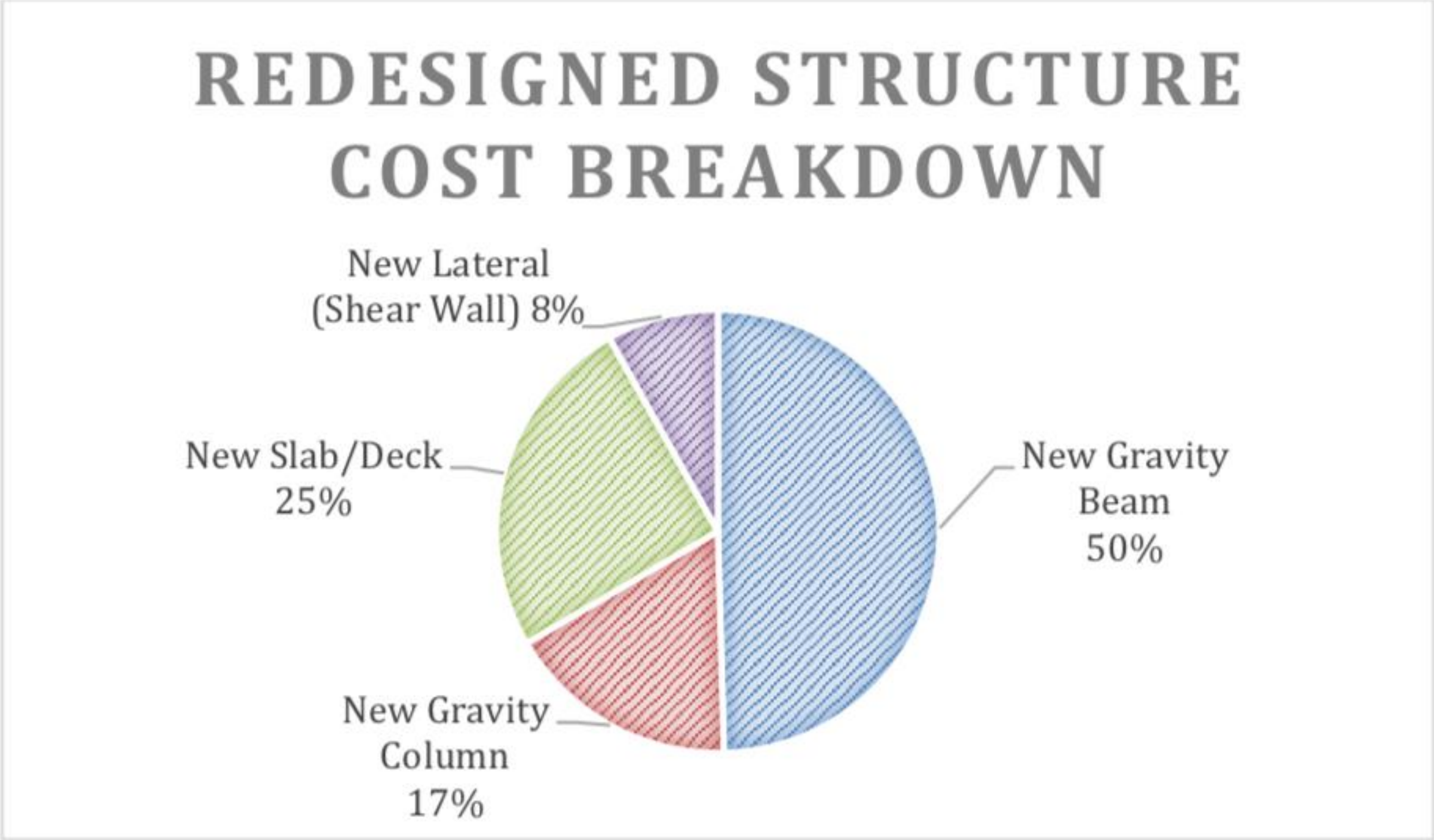


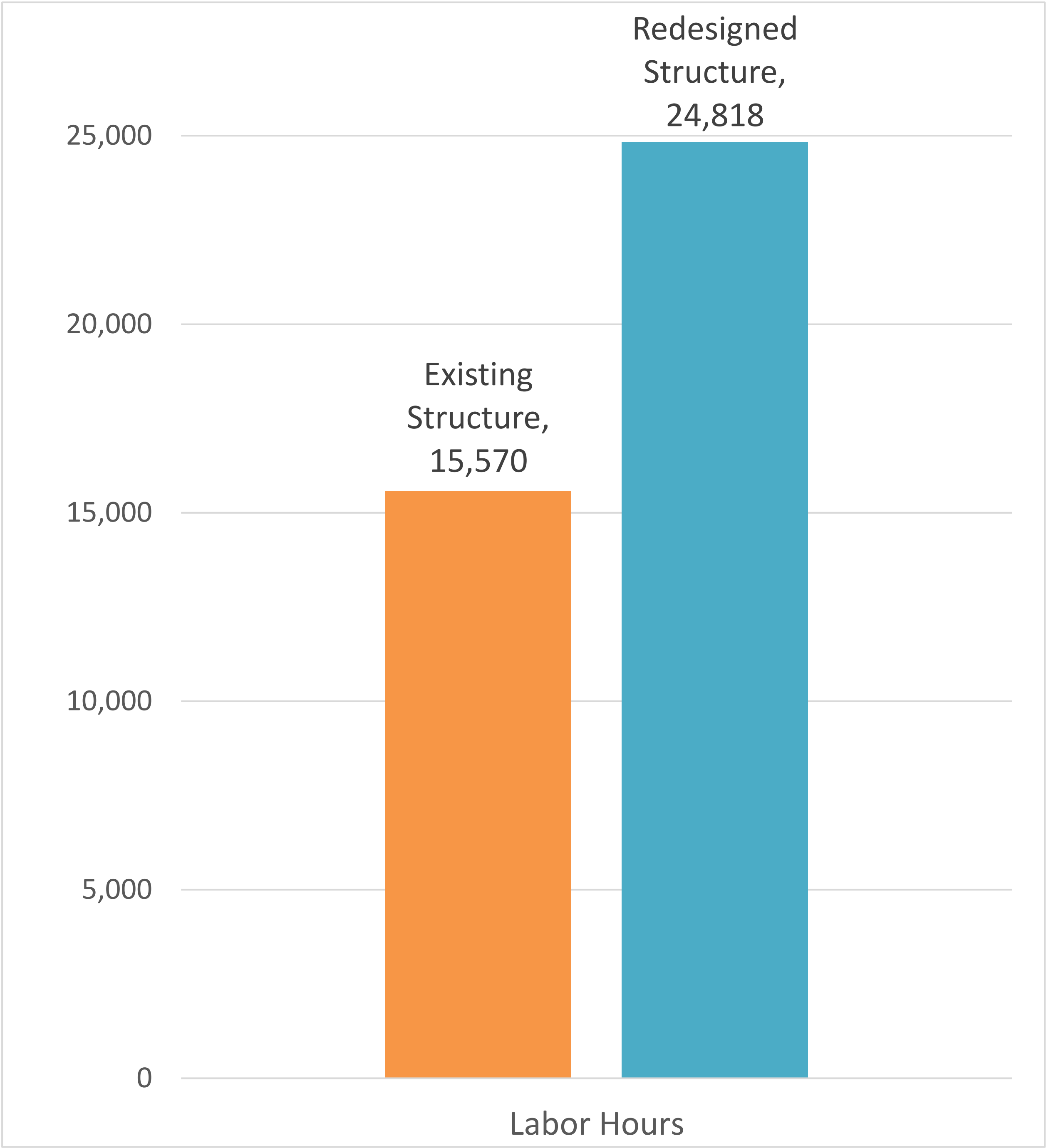


Structural Redesign

Summary

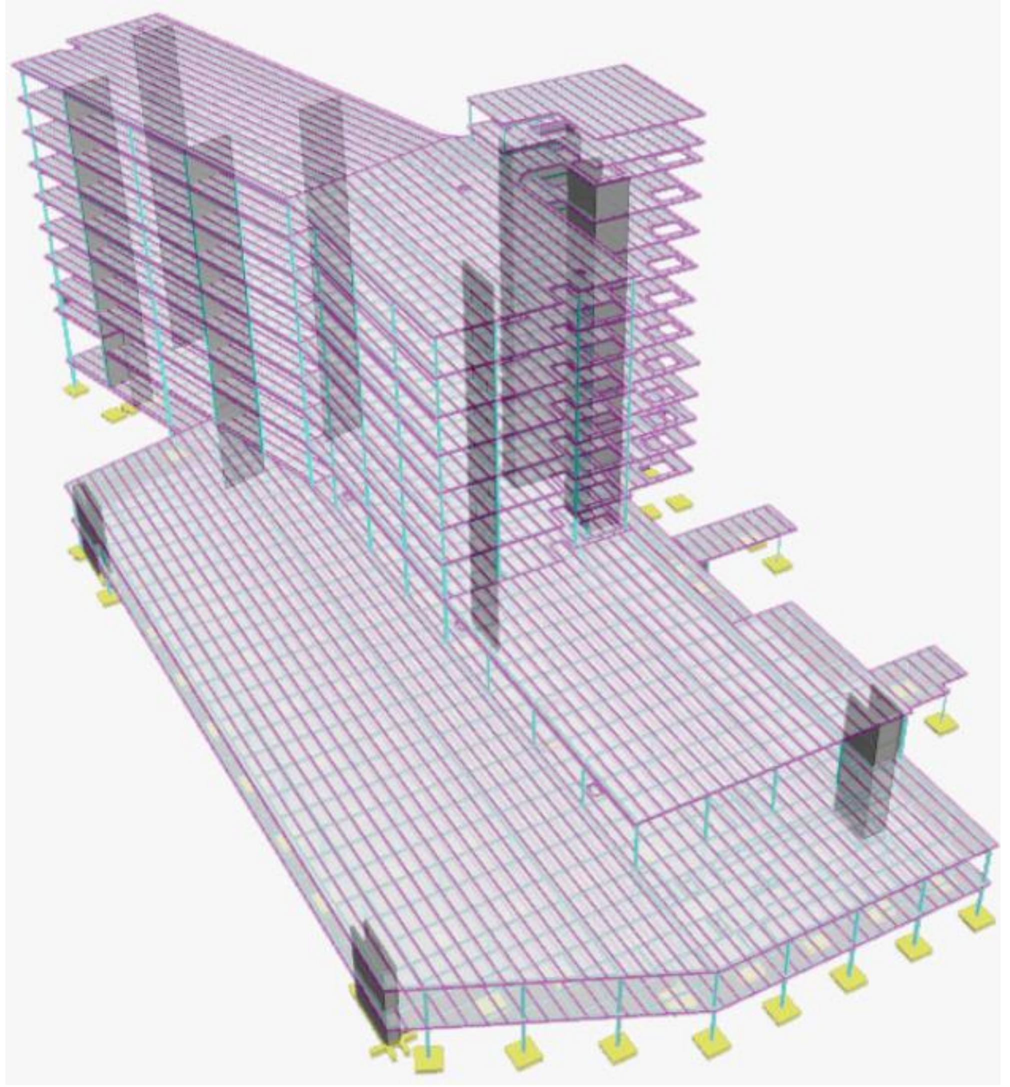






Structural Redesign

Summary



Redesigned Structural System

- ✓ $500,000 cost savings
- ✗ Higher structural weight
- ✓ Reduced column sizes
- ✗ More labor hours
- ✓ Better vibration performance
- ✓ Better drift control in Fort Lauderdale hurricane region

Building Overview

Alternative Gravity Bay Study

Gravity System Redesign

Decision-Making Study

Lateral System Redesign

► **Structural System Comparisons**

Acoustic Analysis

Prefabrication Study

Acoustic Analysis

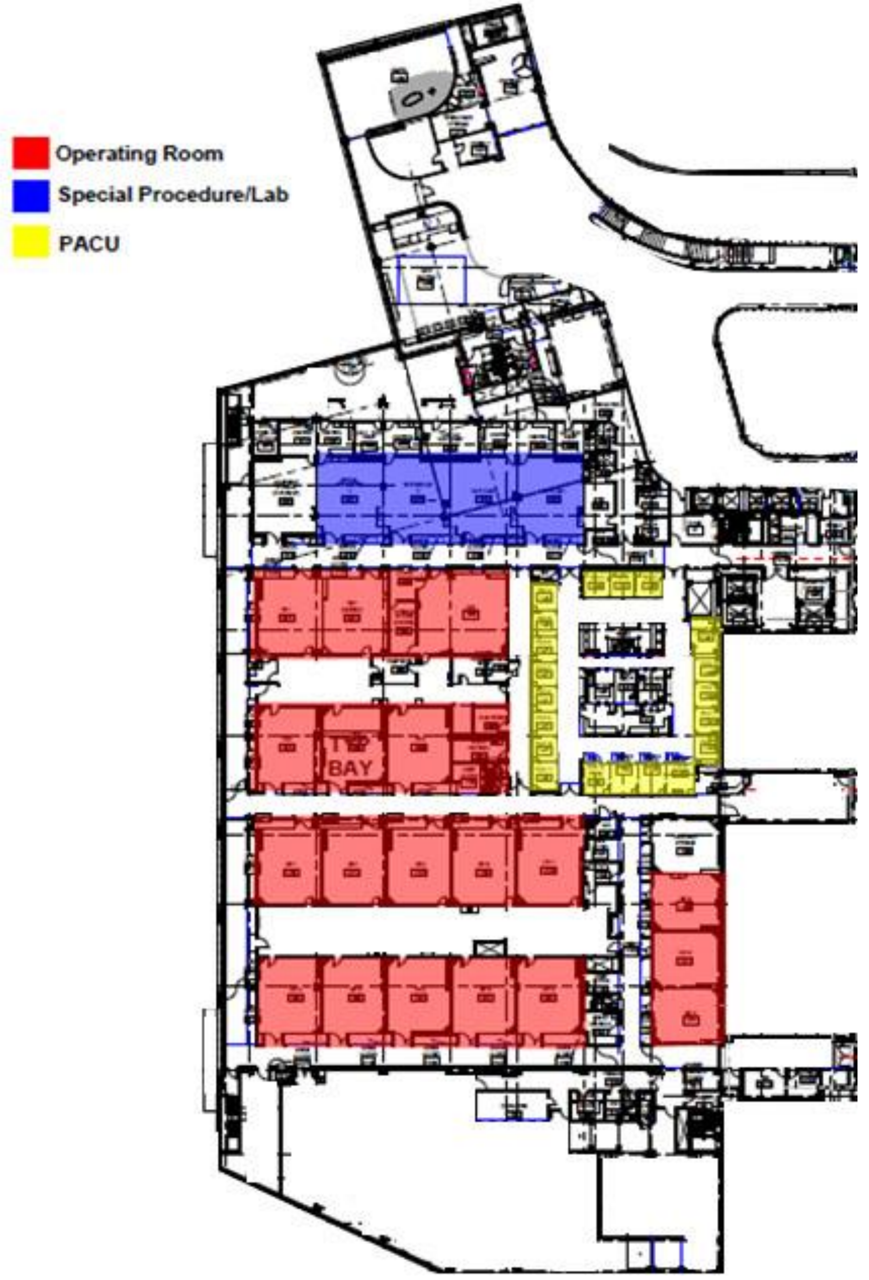
PACU Bay Noise Reduction

Existing PACU Separation: Polyester Privacy Curtains

Image Source: http://eykon.net/haven-59903

Goals

- Increase acoustic performance between PACU bays
- Maintain or increase privacy between PACU bays
- Facilitate circulation so that PACU nurses can provide high quality patient care



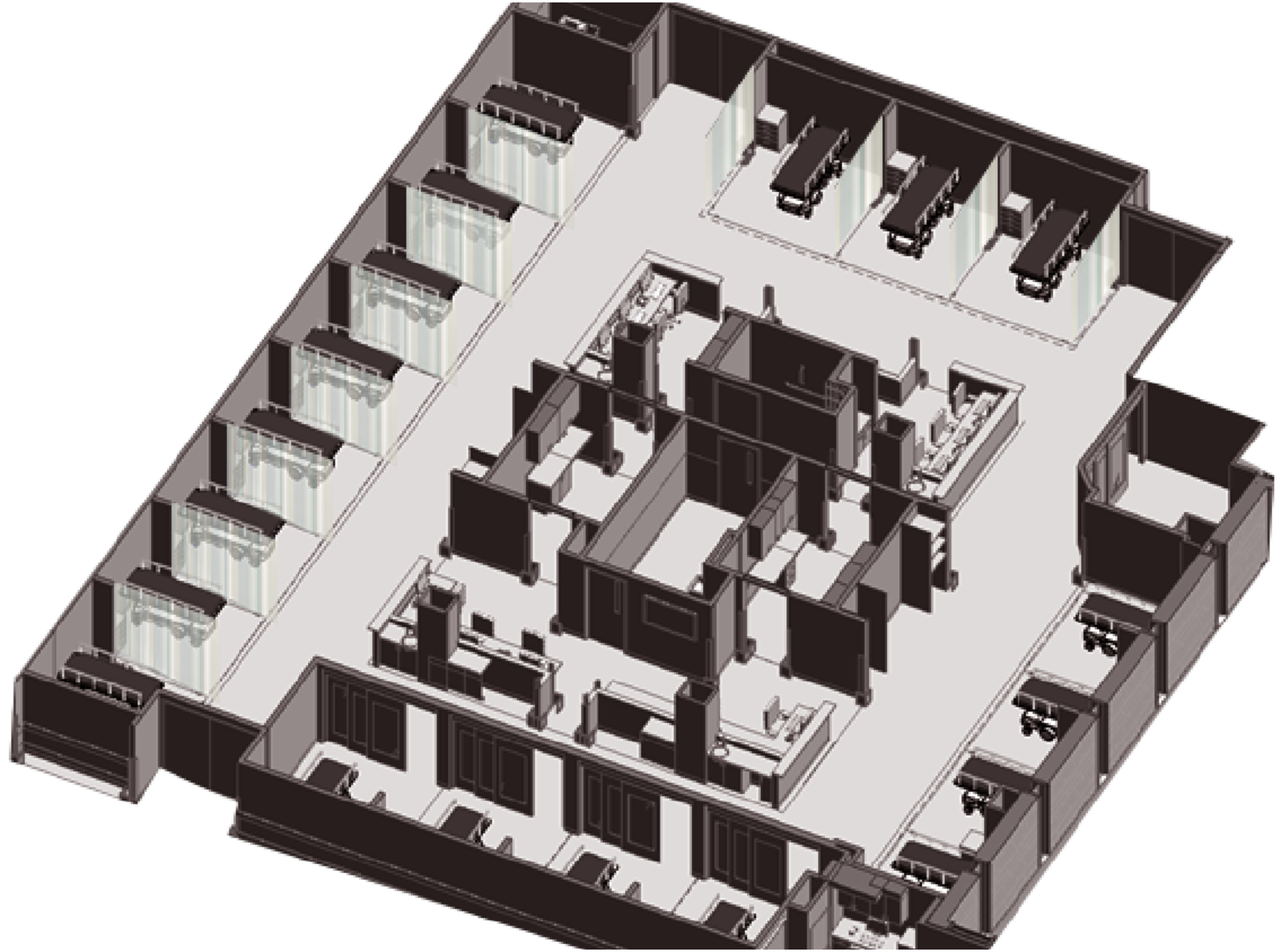
D&T Level One Functional Diagram

Acoustic Analysis

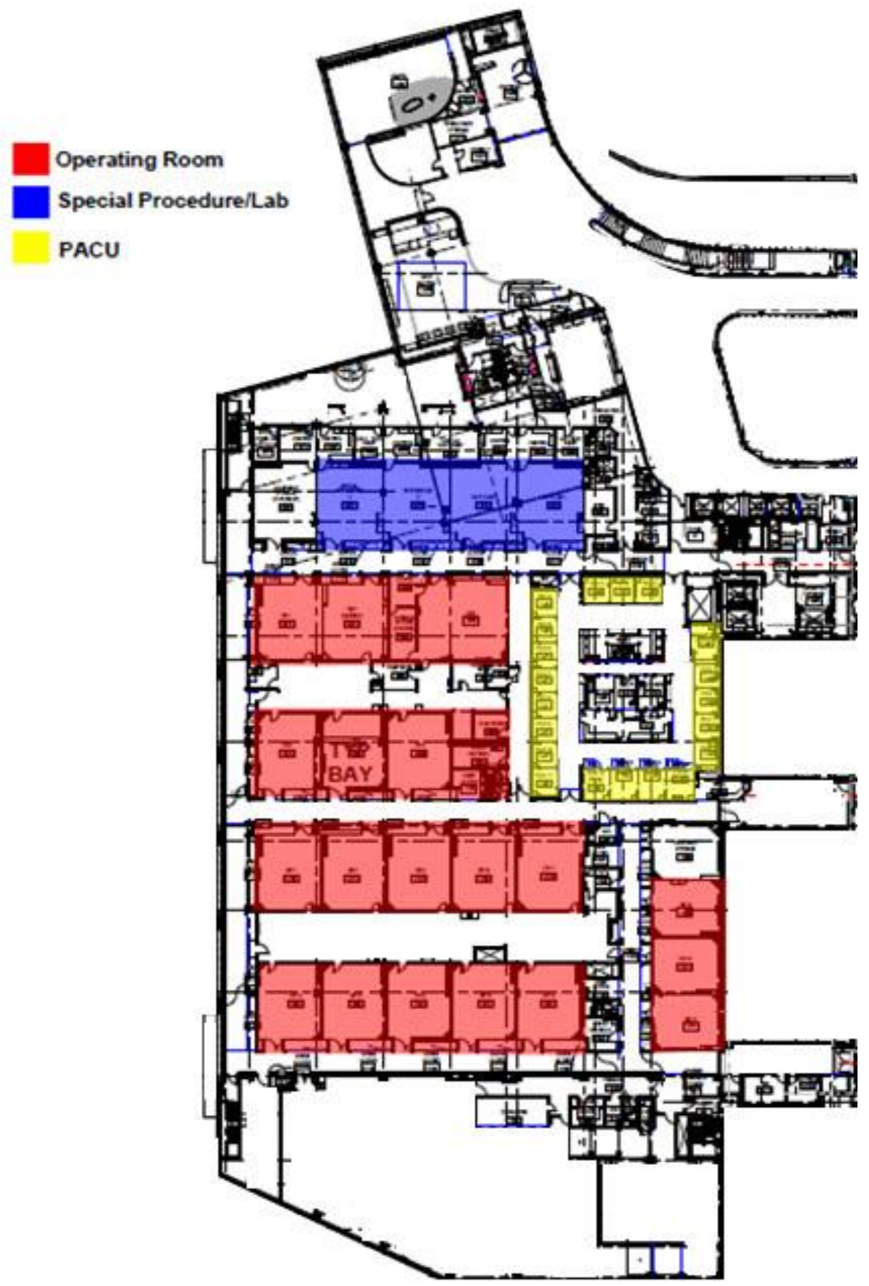
PACU Bay Noise Reduction

Existing PACU Separation: Polyester Privacy Curtains

Image Source: http://eykon.net/haven-59903



3D View of PACU



D&T Level One Functional Diagram

Acoustic Analysis

PACU Bay Noise Reduction

Existing PACU Separation: Polyester Privacy Curtains

Image Source: http://eykon.net/haven-59903

Alternative Separation 1: Acoustic Accordion Doors

Image Source: https://woodfold.com/accordion/series-3300/

Alternative Separation 2a: Partition Assembly

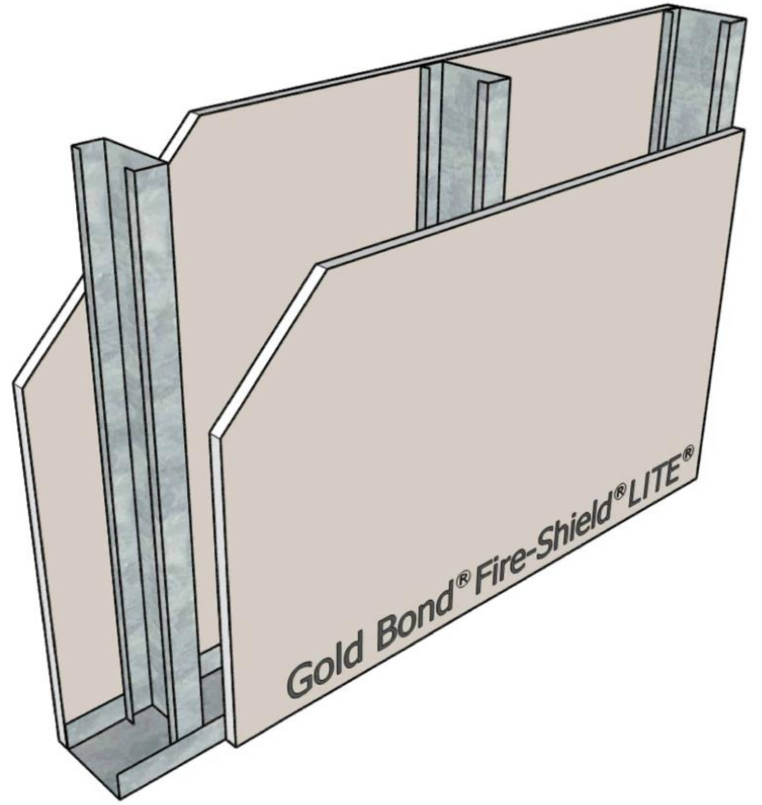


Image Source: National Gypsum, TheSoundBook, Acoustical Assembly Guide

Acoustic Analysis

PACU Bay Noise Reduction

Existing PACU Separation: Polyester Privacy Curtains

Image Source: http://eykon.net/haven-59903

Alternative Separation 1: Acoustic Accordion Doors

Image Source: https://woodfold.com/accordion/series-3300/

Alternative Separation 2b: Insulated Partition Assembly

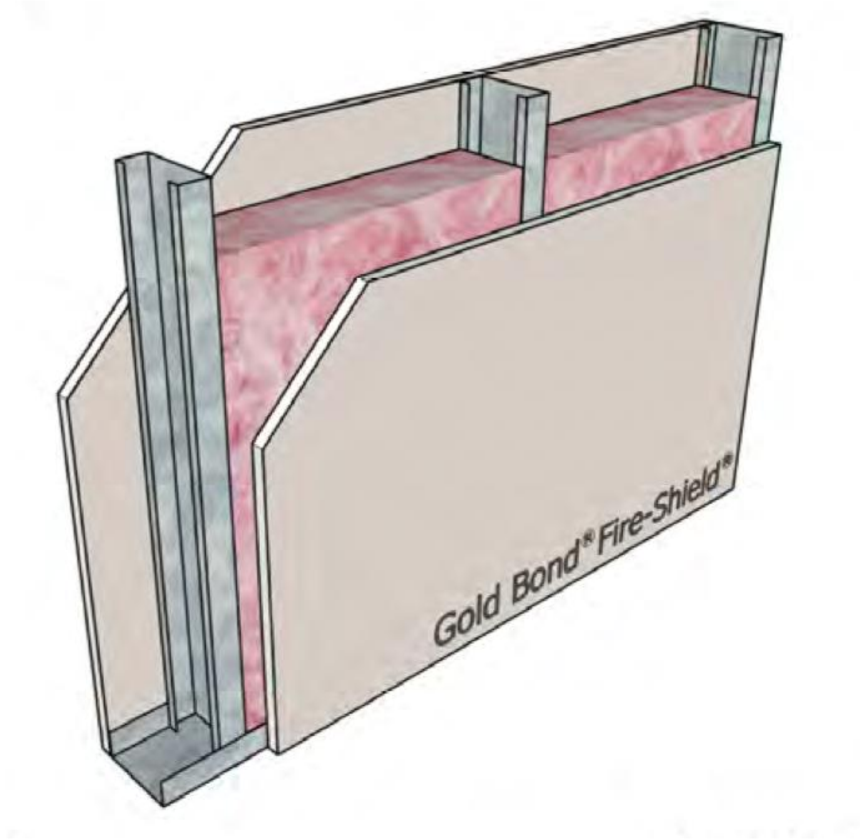
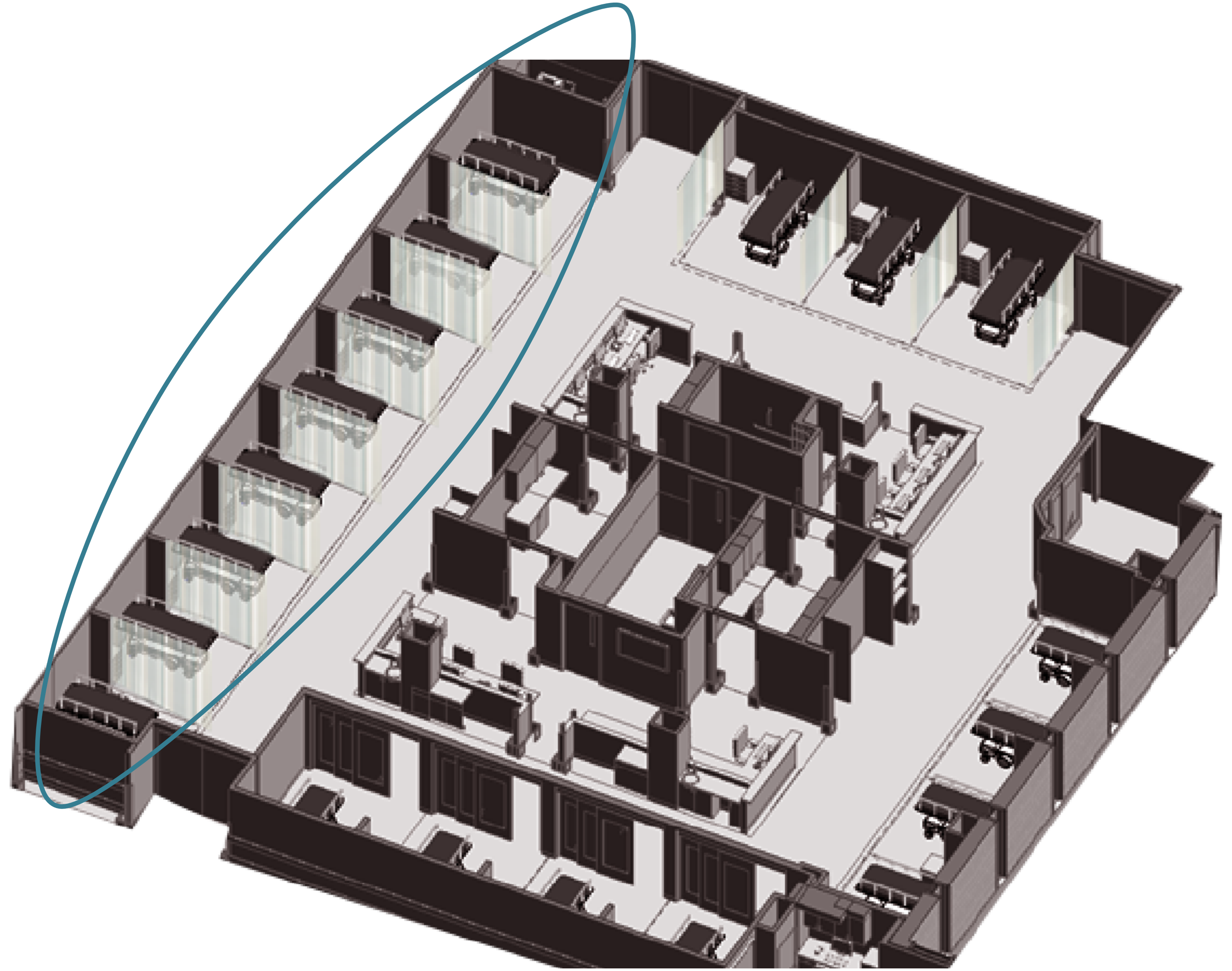


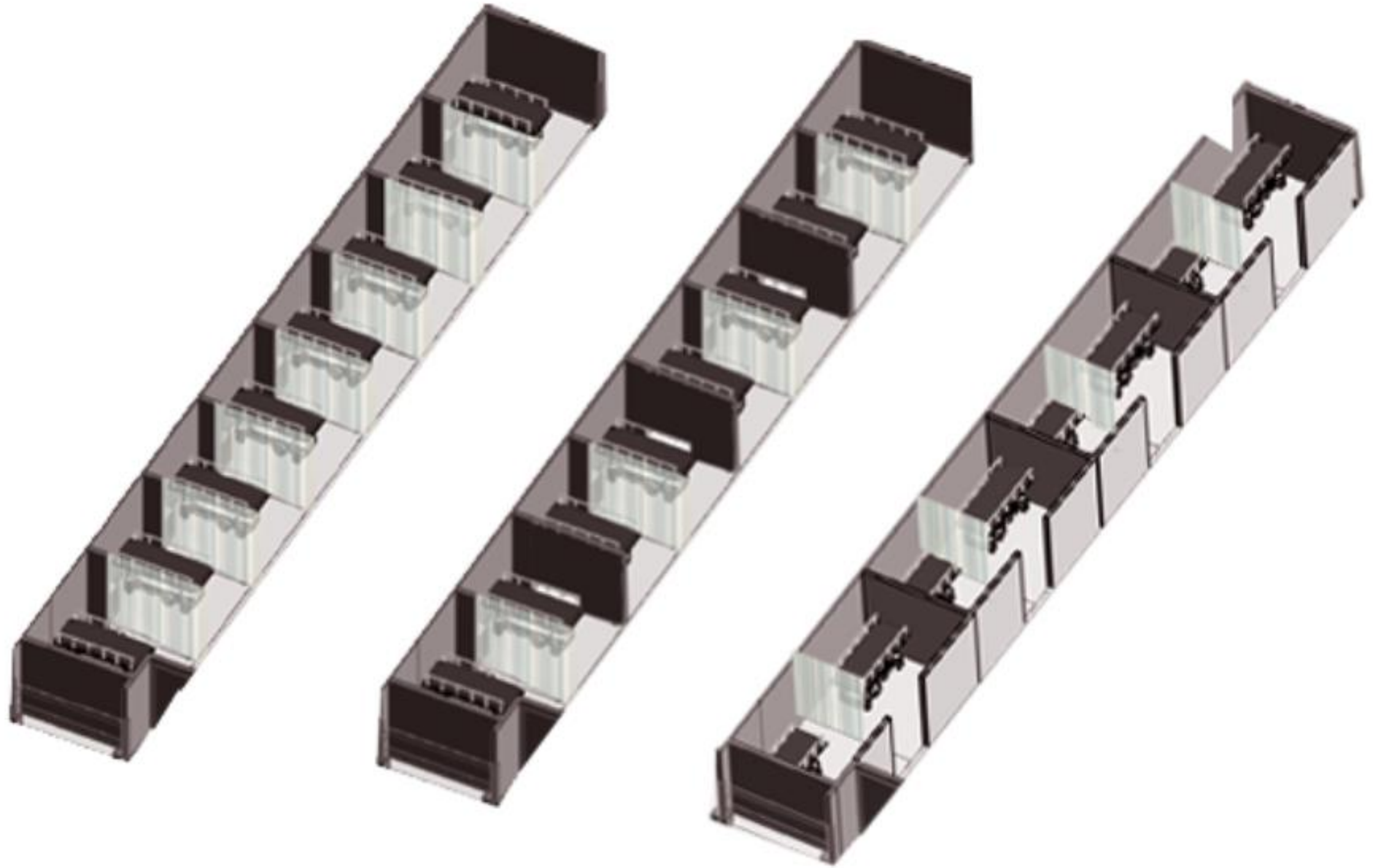
Image Source: National Gypsum, TheSoundBook, Acoustical Assembly Guide

Acoustic Analysis

PACU Bay Noise Reduction



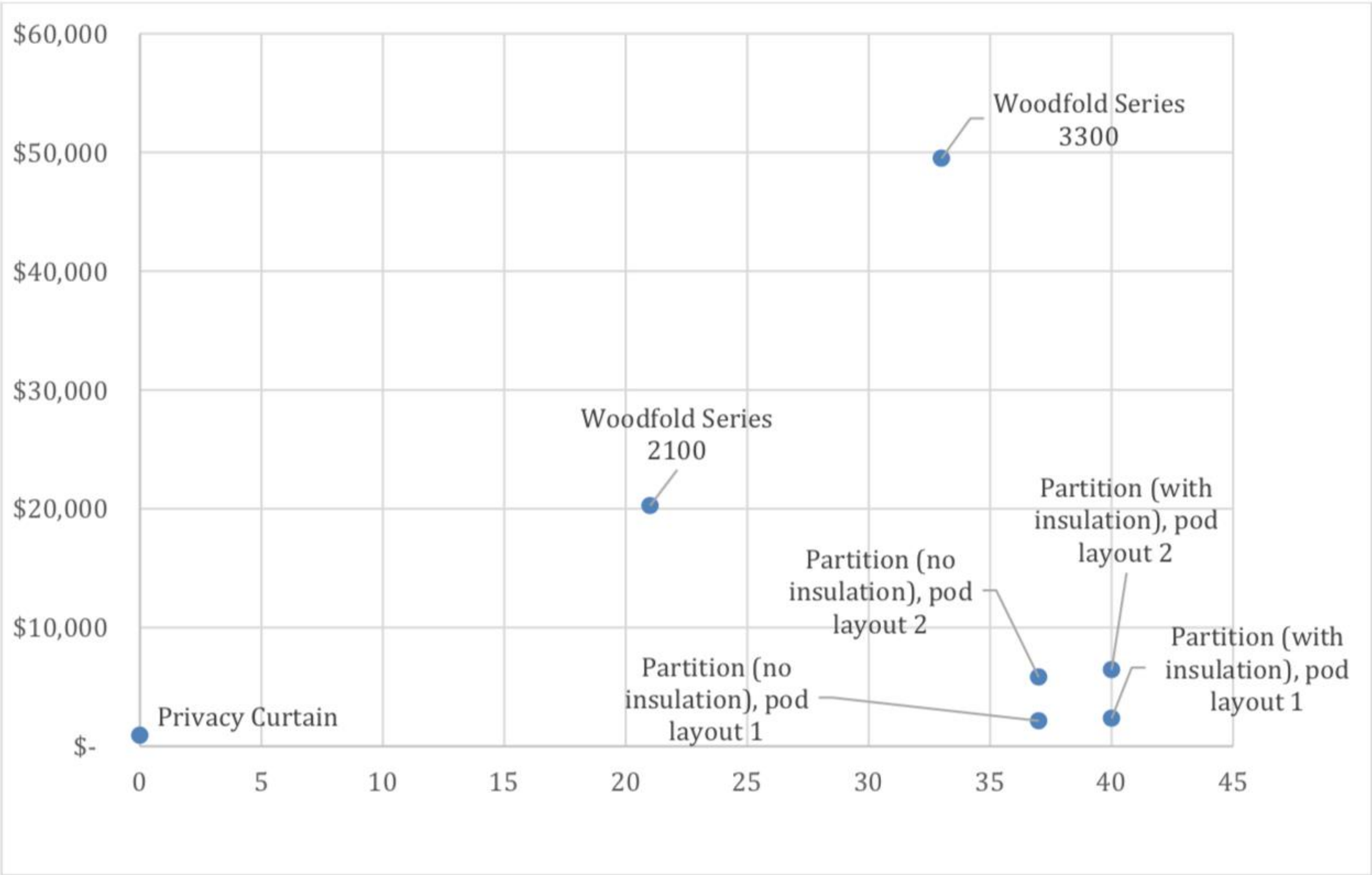
3D View of PACU



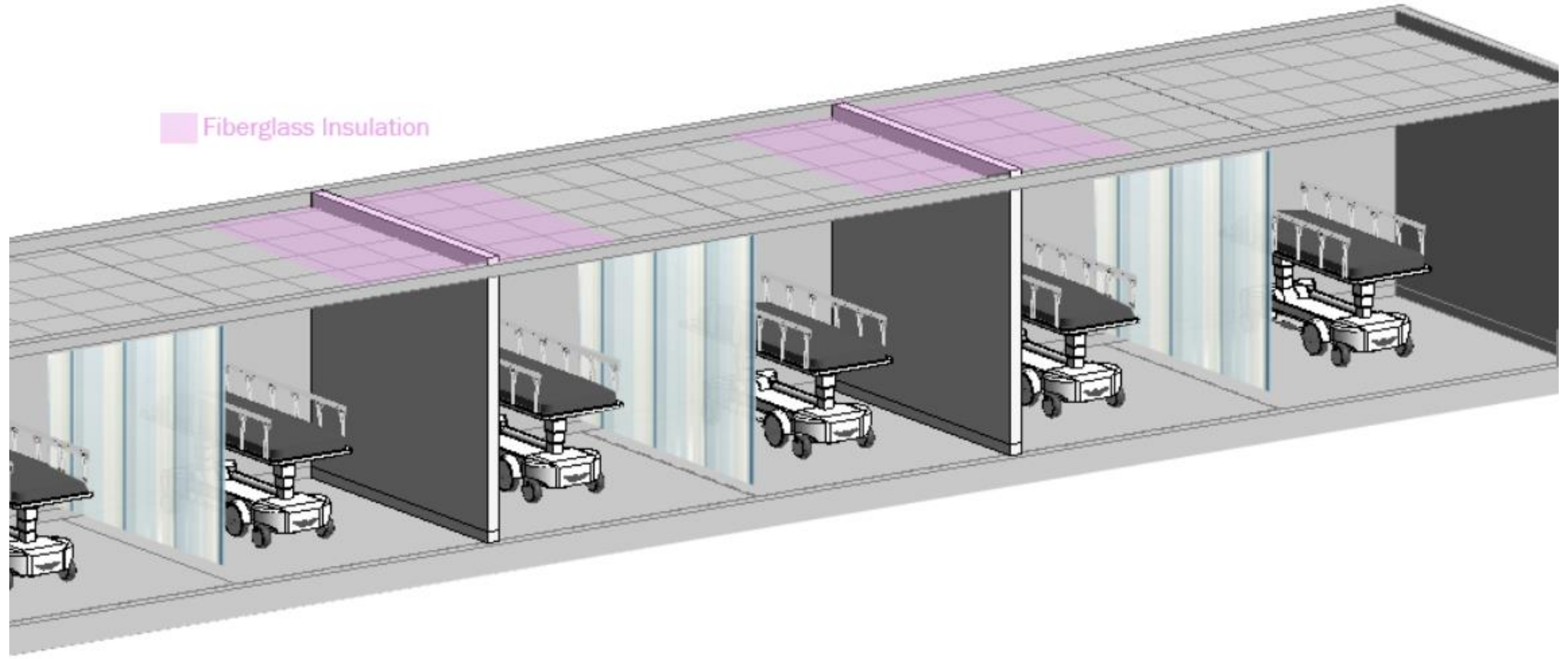
Bay / Pod Layouts

Acoustic Analysis

PACU Bay Noise Reduction



PACU Alternative Cost Comparisons



Proposed PACU Design

Proposed Partition Assembly

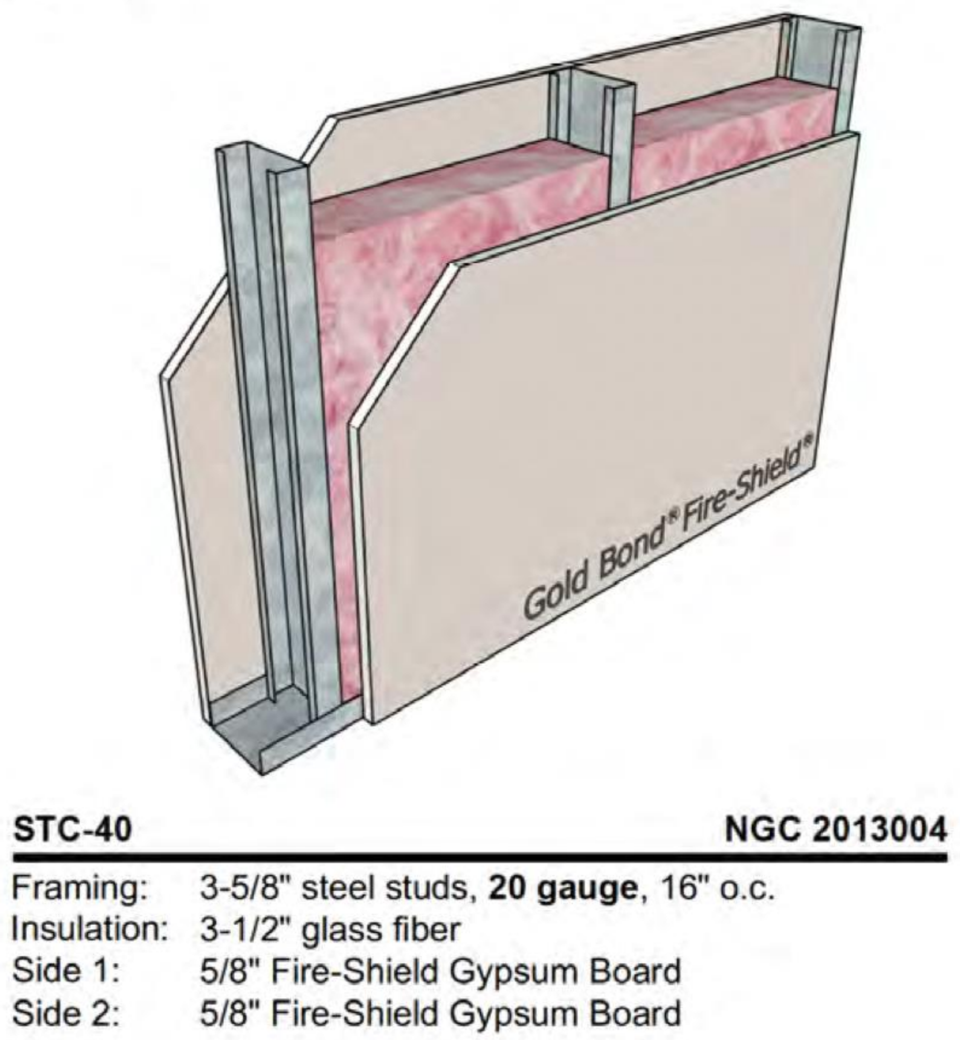
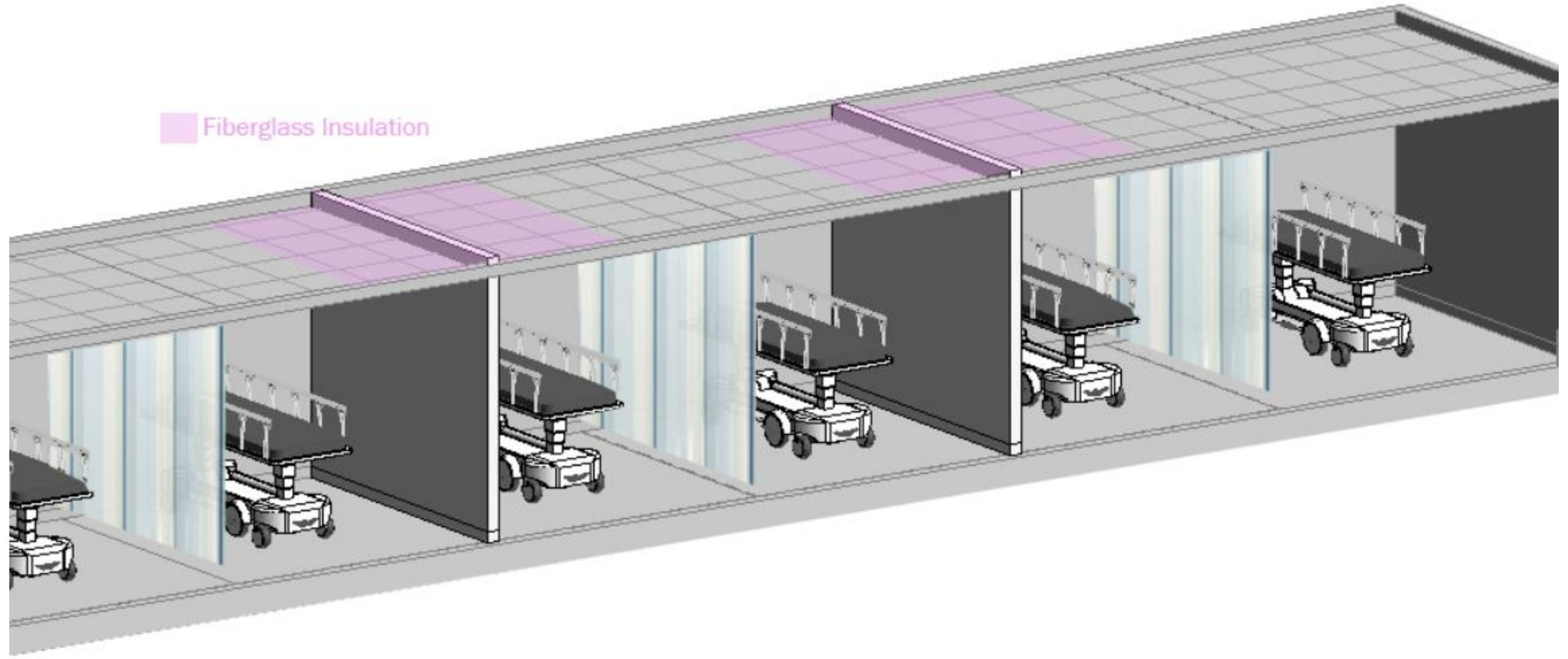


Image Source: National Gypsum, TheSoundBook, Acoustical Assembly Guide

Acoustic Analysis

PACU Bay Noise Reduction



Proposed PACU Design

Recommended PACU Design

- ✓ Better acoustic performance
- ✓ Increased privacy
- ✗ Higher cost
- ✗ More labor hours

Building Overview

Alternative Gravity Bay Study

Gravity System Redesign

Decision-Making Study

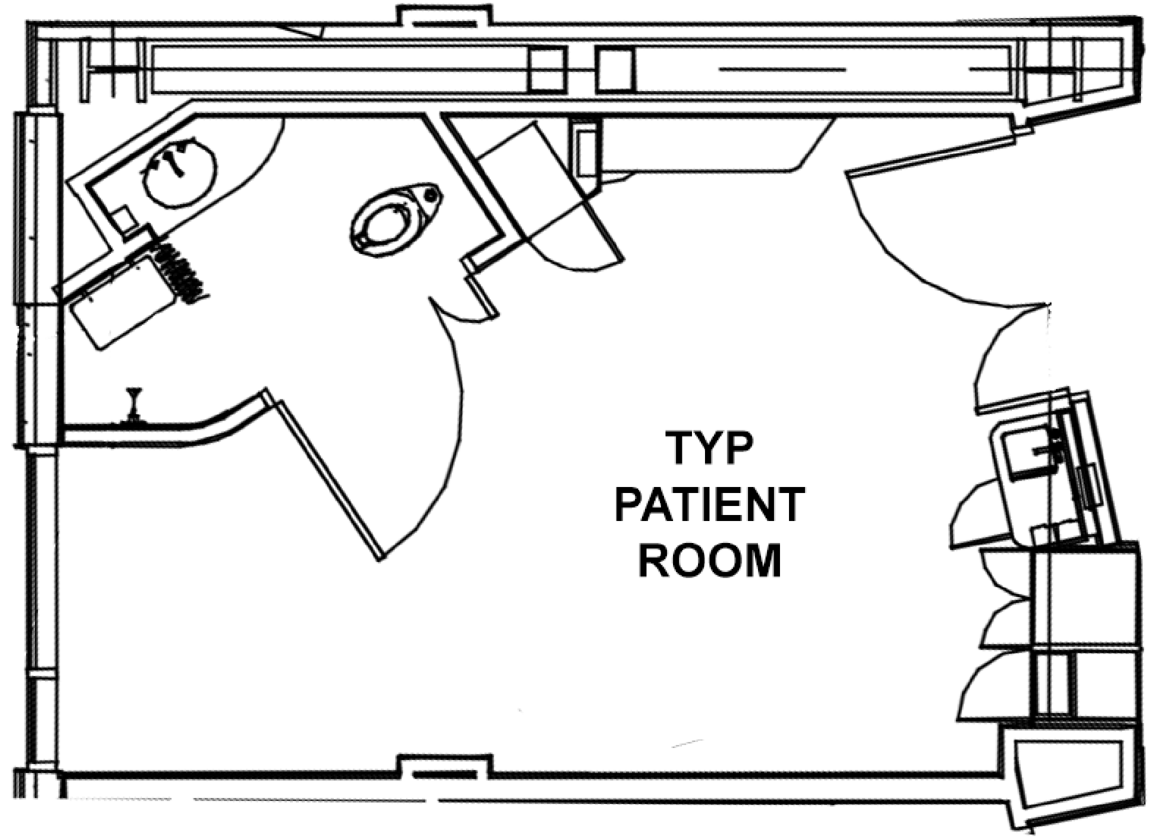
Lateral System Redesign

Structural System Comparisons

► Acoustic Analysis

Prefabrication Study

Prefabrication Study
Modular Bathroom Pods



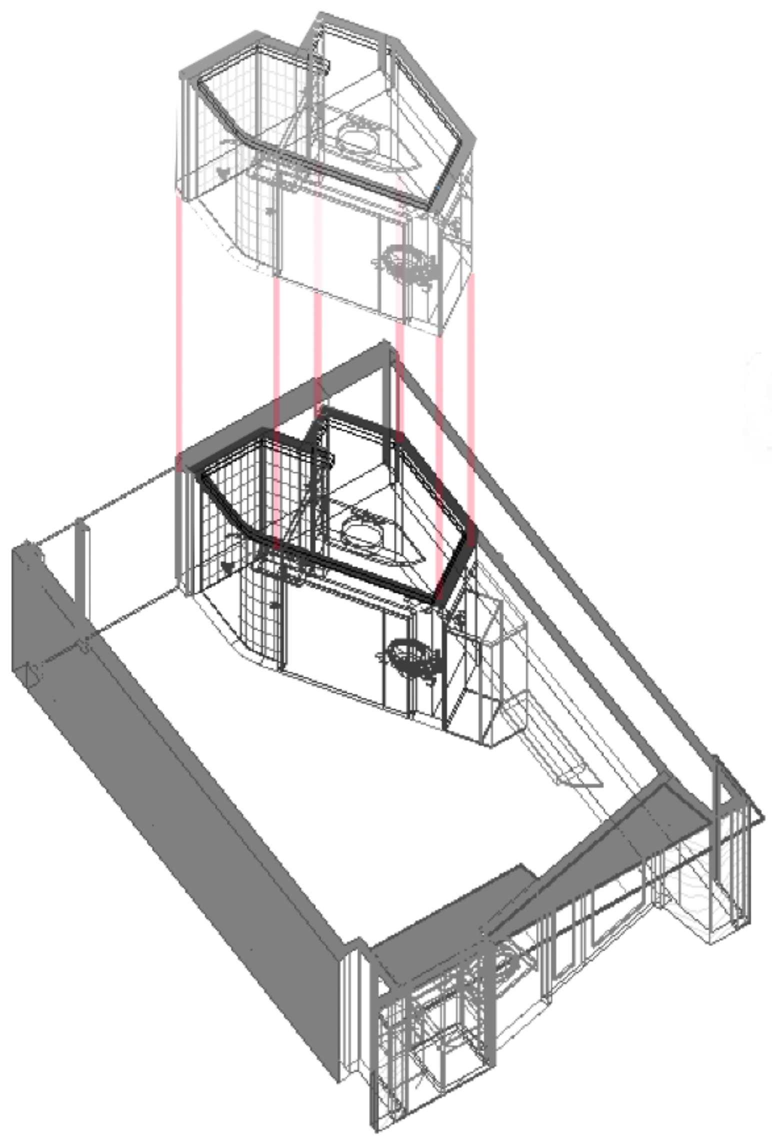
Typical Patient Room Plan

Goals

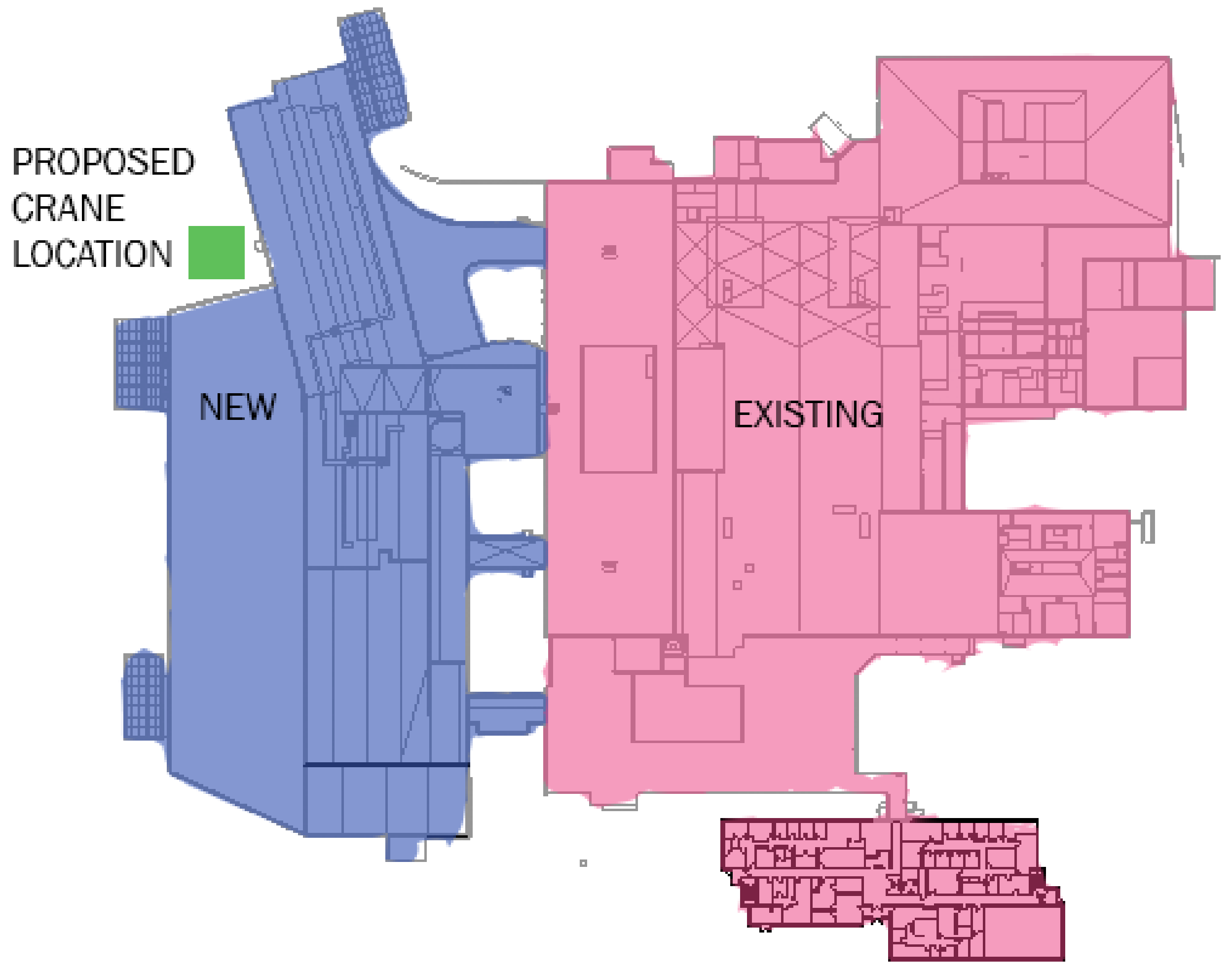
- Examine uses of prefabrication in addition to the existing premanufactured headwalls
- Explore the feasibility of prefabricated bathrooms in place of the 206 private patient room bathrooms
- Shorten the construction schedule to increase hospital time to revenue
- Consider effects on construction waste and safety

Prefabrication Study

Modular Bathroom Pods



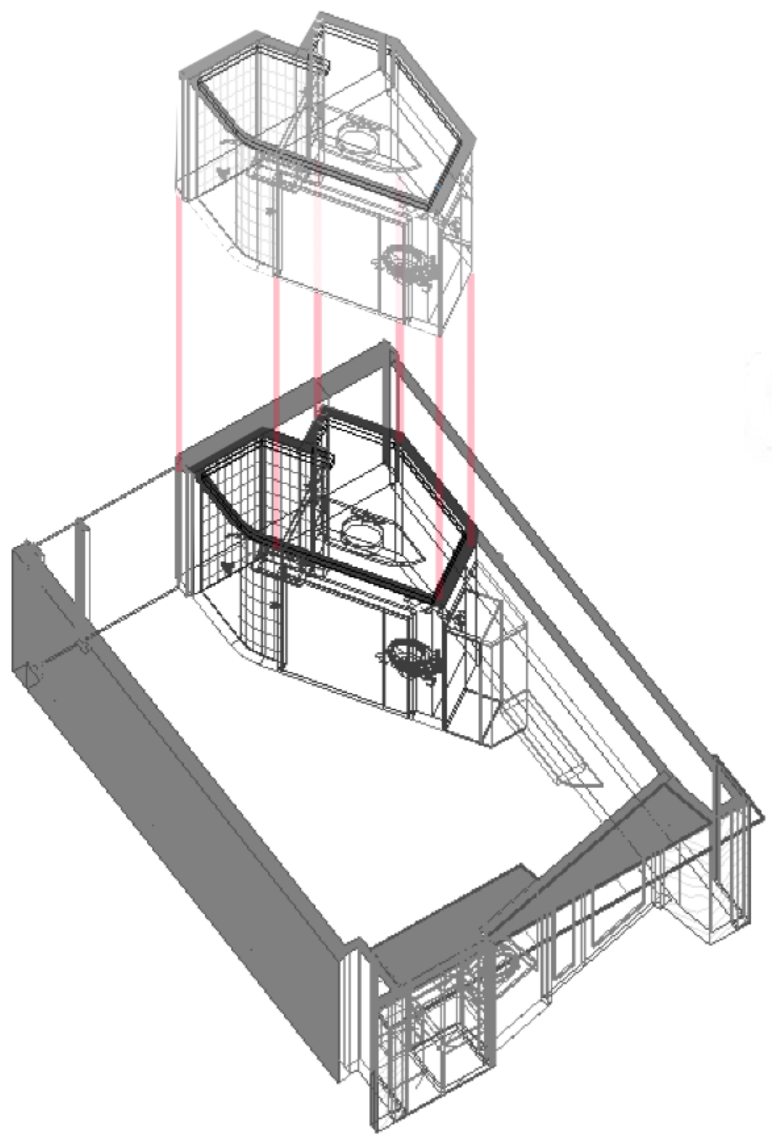
Prefabrication Comparisons		
	On-site Construction	**Prefabricated Bathroom Pods**
Construction Duration	38 months	32 months
Construction Cost	$1.3 million	$6.6 million
Revenue Gained from Shorter Schedule	---	$144 million
Construction Material Waste	7%	1.5%
Crew Size	---	7 people
Equipment	---	Crane: Link-Belt HTC 86100
Installation Duration	---	7 days

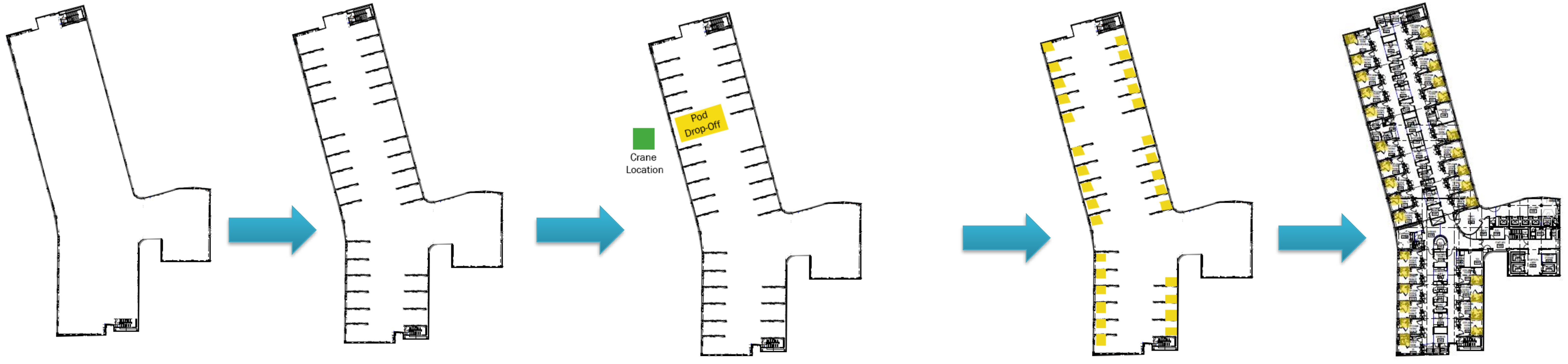


Site Plan with Proposed Crane Location

Prefabrication Study

Modular Bathroom Pods

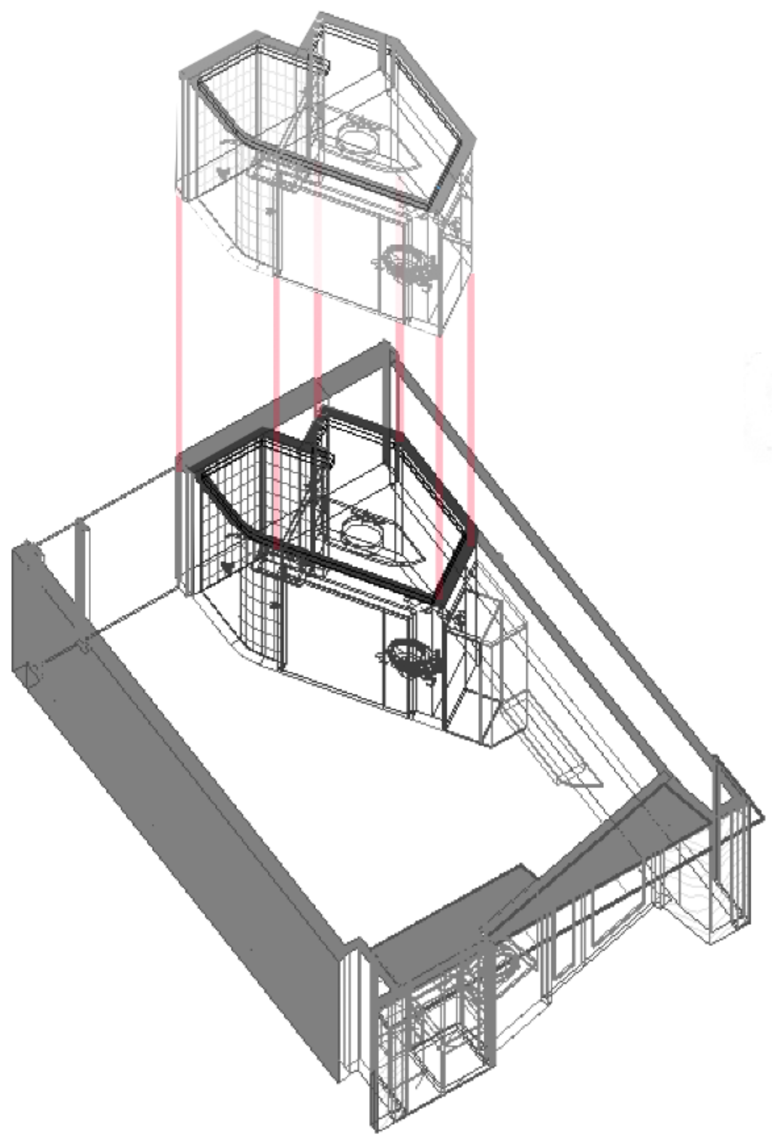




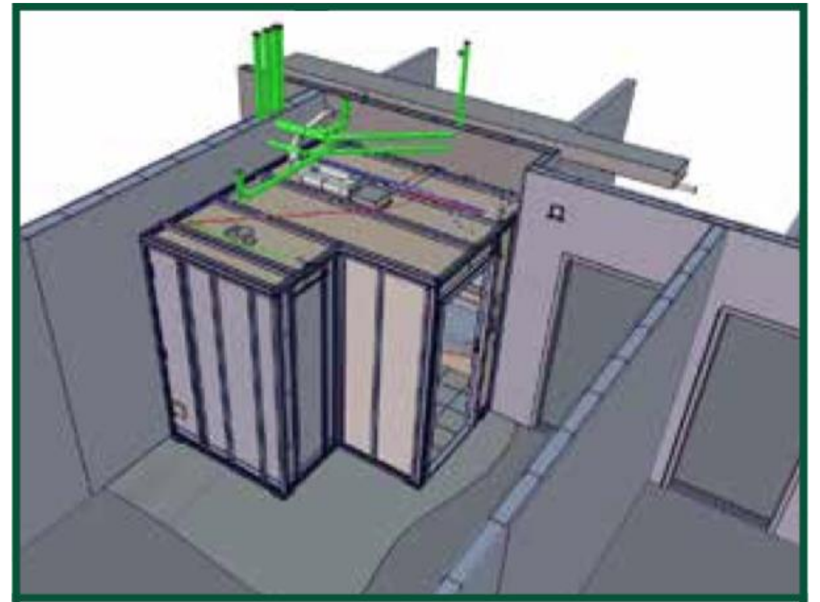
Installation Sequencing

Prefabrication Study

Modular Bathroom Pods



Additional Considerations



Mechanical contractors connect the bathroom pod to the buildings services Early planning of scope helps contractors know where the pod systems will connect.

Mechanical Connections

Image Source: https://oldcastlesurepods.com/wp-content/uploads/2015/02/OCSP-Brochure-1-16-FINAL.pdf

Crane Type & Location

Slab Depressions

https://www.cellulebagno.com/en/bathroom-pods-installation

Building Overview

Alternative Gravity Bay Study

Gravity System Redesign

Decision-Making Study

Lateral System Redesign

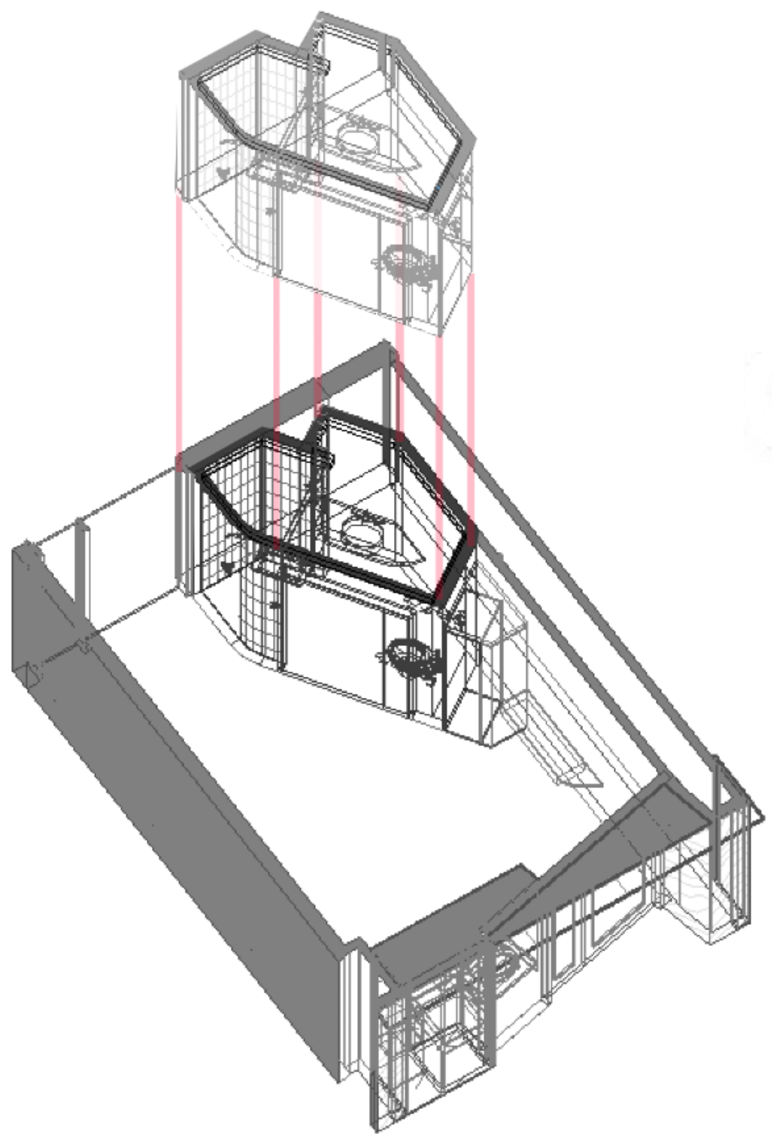
Structural System Comparisons

Acoustic Analysis

► Prefabrication Study

Prefabrication Study

Modular Bathroom Pods



Prefabrication Comparisons		
	On-site Construction	**Prefabricated Bathroom Pods**
Construction Duration	38 months	32 months
Construction Cost	$1.3 million	$6.6 million
Revenue Gained from Shorter Schedule	---	$144 million
Construction Material Waste	7%	1.5%
Crew Size	---	7 people
Equipment	---	Crane: Link-Belt HTC 86100
Installation Duration	---	7 days

Prefabricated Bathroom Pods

- ✓ Shorter construction schedule
- ✗ Higher construction cost
- ✓ Shorter time to revenue
- ✓ Increased safety
- ✓ Less construction waste

Building Overview
Alternative Gravity Bay Study
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Summary

Thesis Goals & Methods

Healing environment for patient centered care

Safe, affordable, and high quality

Commitment to community and organizational health

Results

Gravity Redesign
- Better vibration performance

Lateral Redesign
- System redesigned for alternative location (Ft. Lauderdale) within the Trinity Health Network

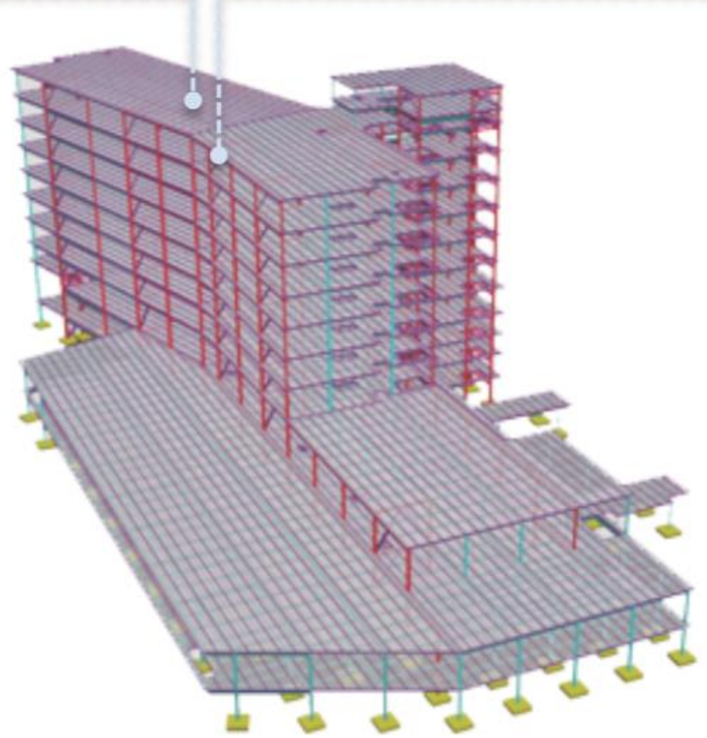
Acoustic Breadth
- Better acoustic performance and patient privacy

Prefabrication Breath
- Cost savings, increased safety, and less construction waste

Summary

Existing Structure: Muskegon, MI

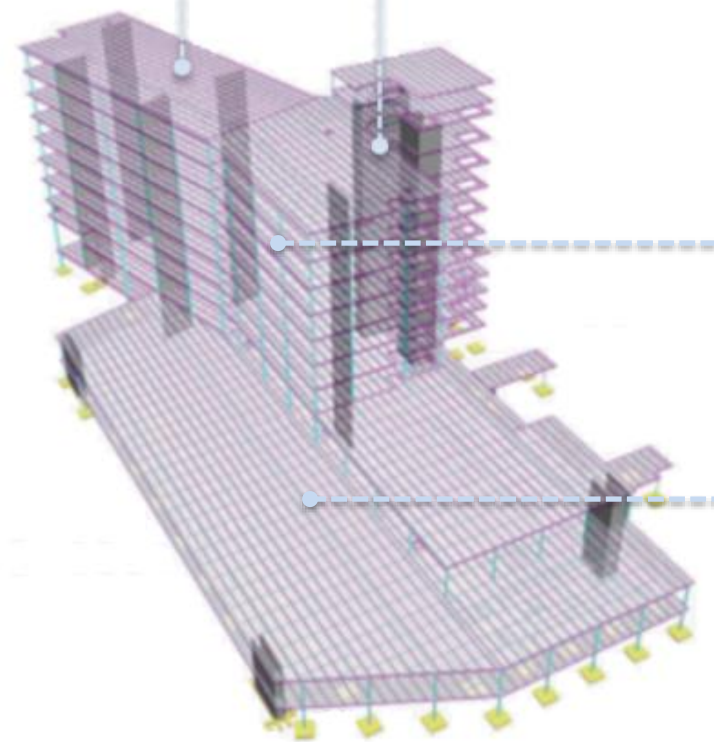
- Composite wide flange beams and girders
- W14 columns
- Steel braced frame (N-S) and steel moment frame (E-W) lateral system
- Shallow concrete spread footings



- Lower structural weight
- Fewer construction labor hours required

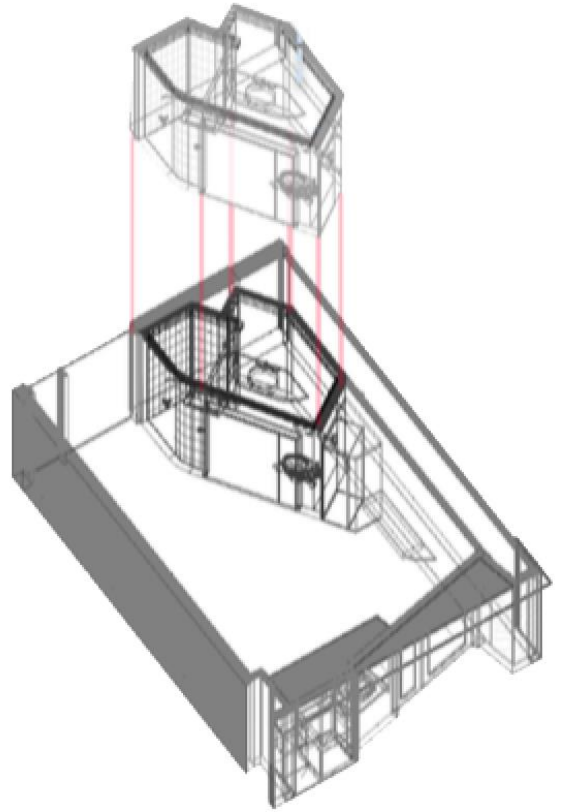
Redesigned Structure: Fort Lauderdale, FL

- Non-composite wide flange beams and girders
- W14 columns
- 8 ksi reinforced concrete shear wall lateral system
- Shallow concrete spread footings

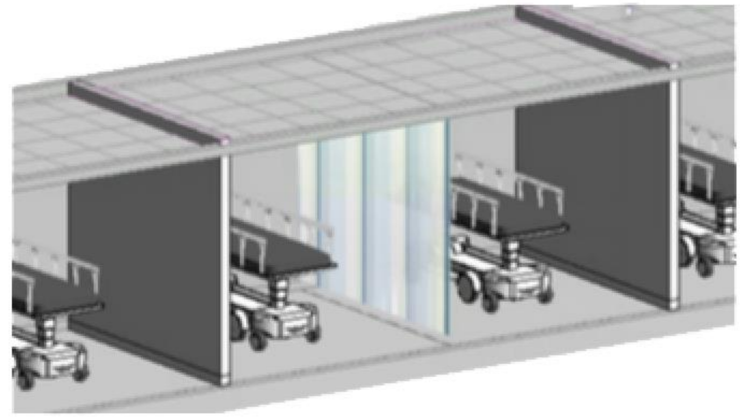


- $500,000 in cost savings
- **Improved vibration performance** in patient rooms and surgical rooms

- **Construction time savings, increased safety,** and **waste reduction** with the application of prefabricated patient bathrooms



- **Improved acoustic performance and privacy** in Post Anesthesia Care Unit bays by creating separate pods



Thank You

Acknowledgements

- HGA
- Mercy Health
- The industry professionals who participated in the decision-making survey
- Dr. Solnosky
- Dr. Hanagan
- The entire AE Faculty and Staff
- Friends and family

Building Overview

Alternative Gravity Bay Study

Gravity System Redesign

Decision-Making Study

Lateral System Redesign

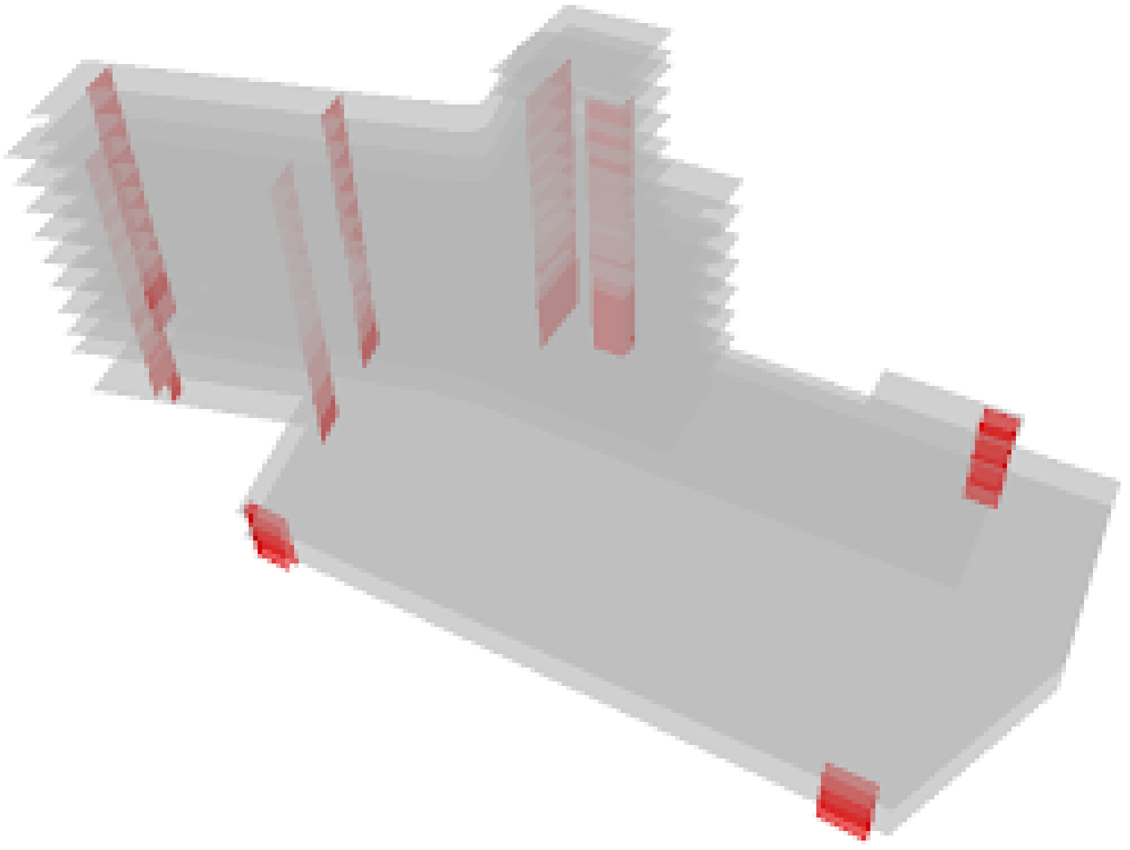
Structural System Comparisons

Acoustic Analysis

Prefabrication Study

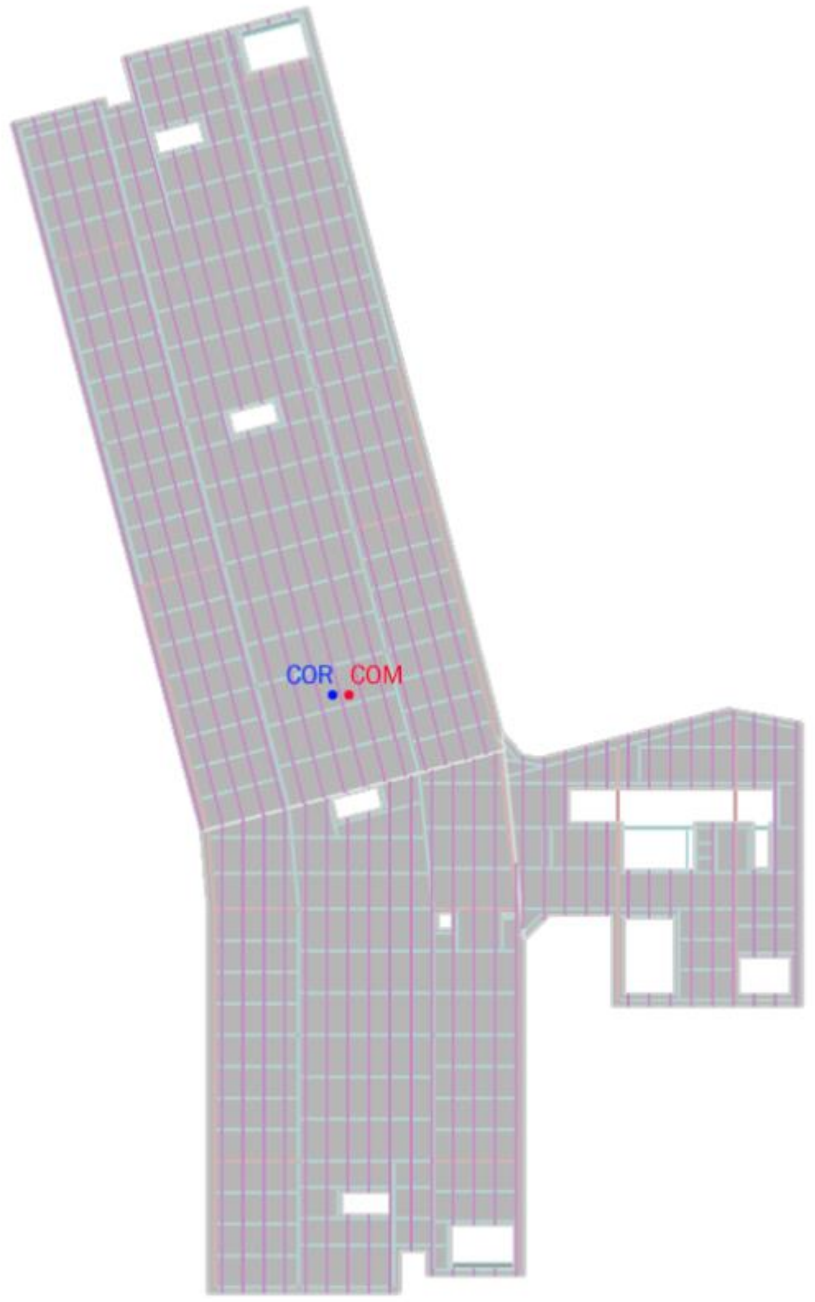
Appendix

Detailed Lateral Load Comparison



3D View of Preliminary Shear Wall Locations

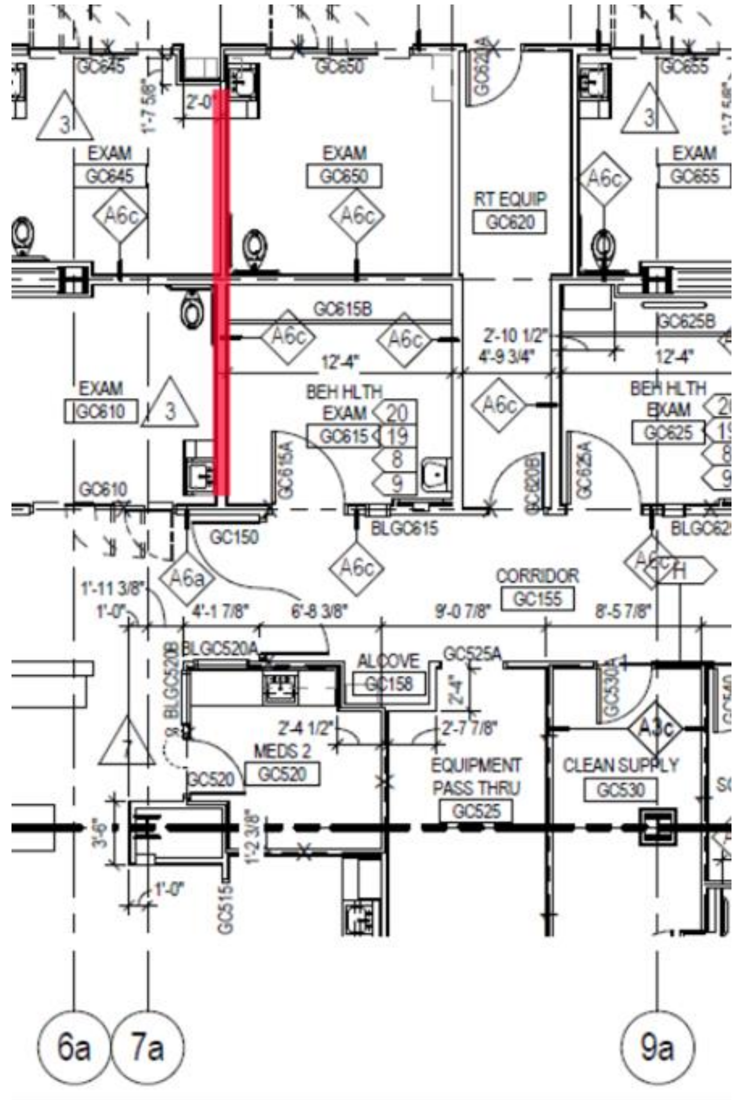
Base Shear Comparison						
	Original Design (Muskegon)			Original Design (Fort Lauderdale)		
Load Case	Manual Force (k)	ETABS Force (k)	RAM Force (k)	Manual Force (k)	ETABS Force (k)	RAM Force (k)
Wind X	1744	1468	1734	3351	3771	4339
Wind Y	1043	883	1168	1776	1986	2656
Seismic X	1695	1697	1105	482	559	514
Seismic Y	1067	1067	742	482	559	593



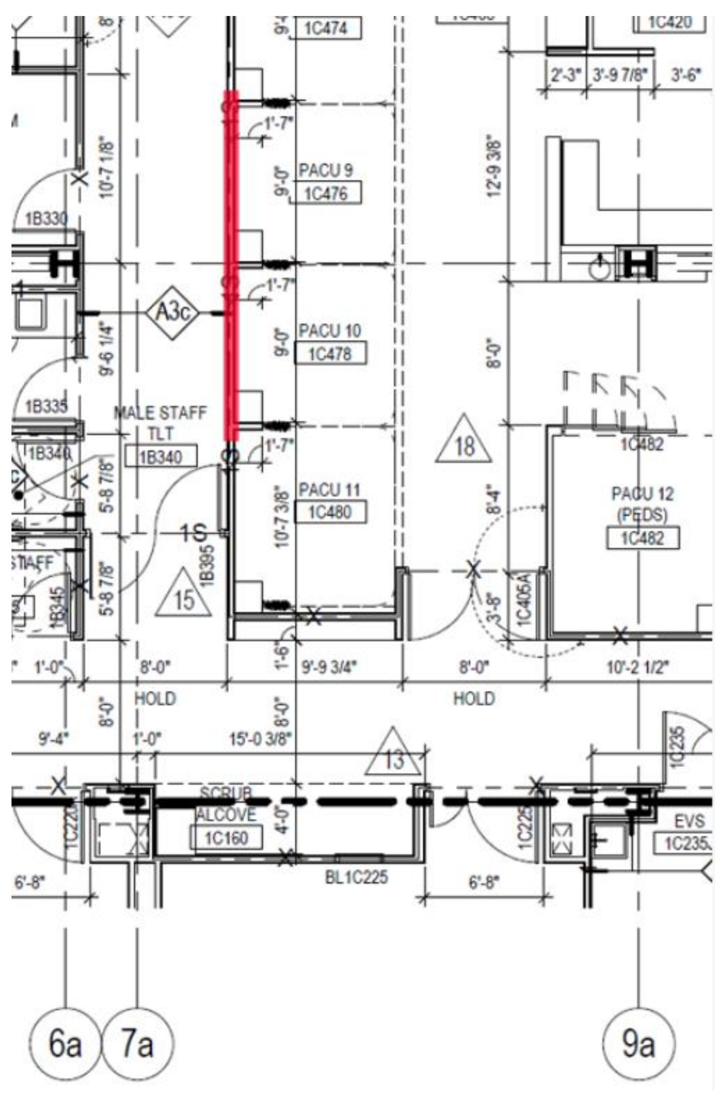
Existing Lateral System COM & COR

Appendix

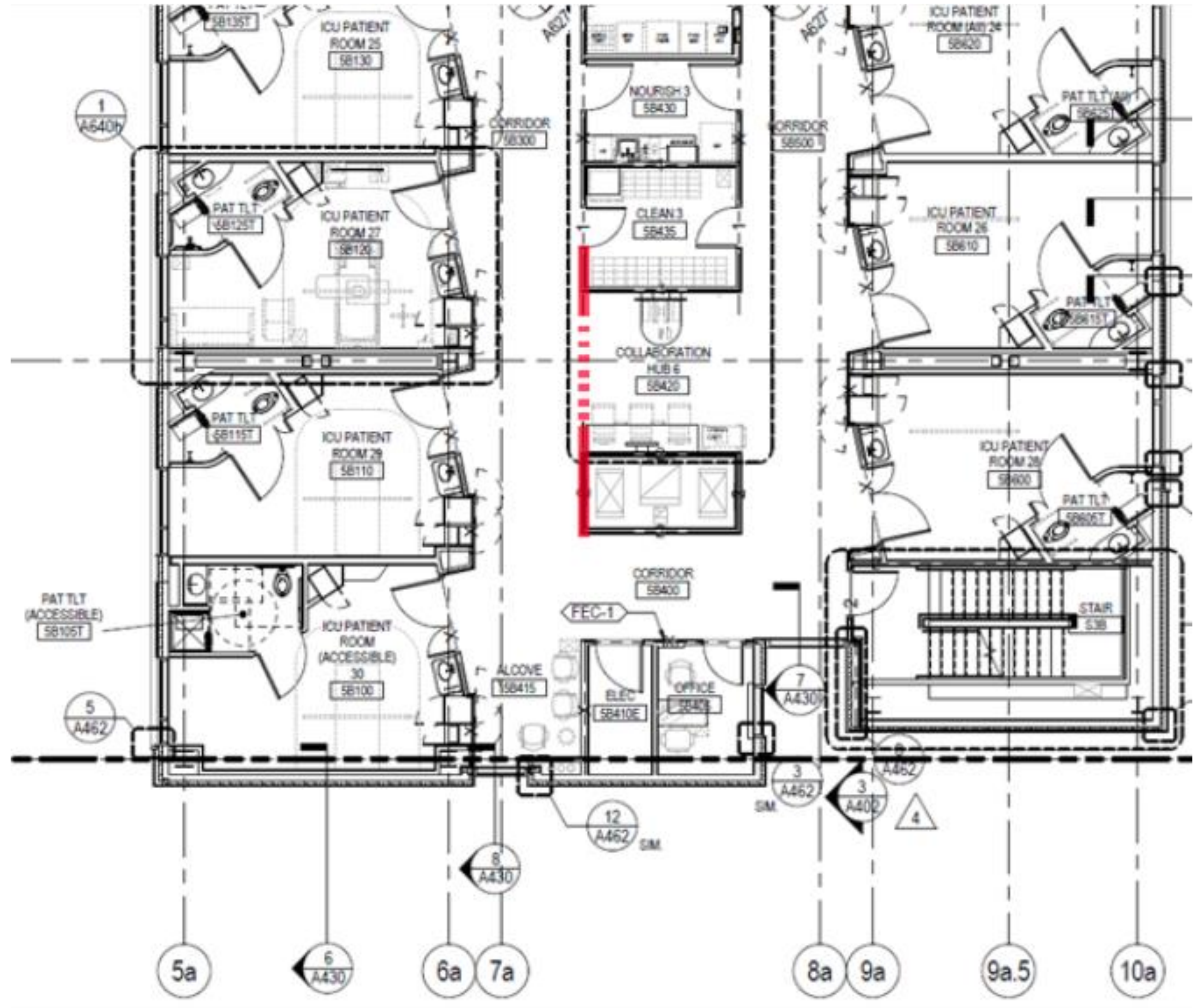
Lateral Redesign



D&T Level 1 Shear Wall Location



D&T Level 2 Shear Wall Location



Typical Bed Tower Shear Wall Location

Building Overview

Alternative Gravity Bay Study

Gravity System Redesign

Decision-Making Study

Lateral System Redesign

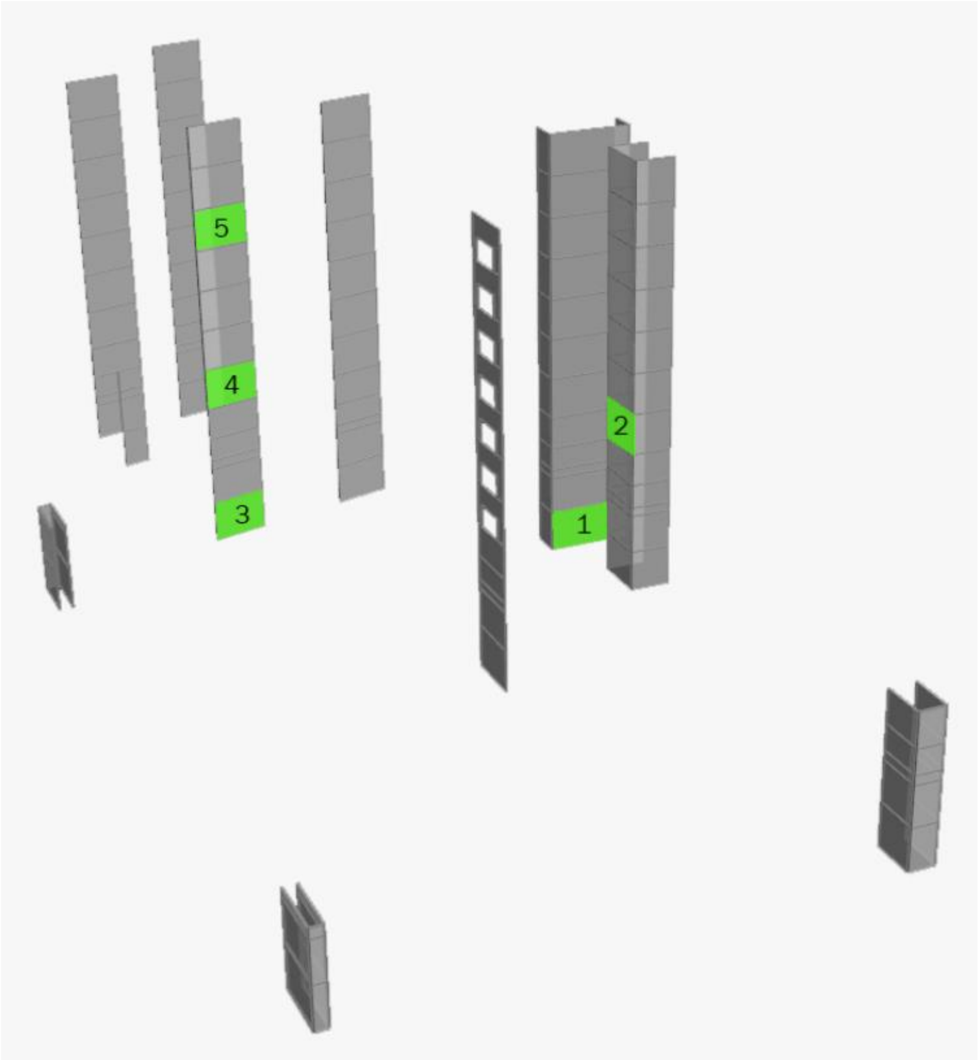
Structural System Comparisons

Acoustic Analysis

Prefabrication Study

Appendix

Lateral Redesign



Shear Wall Section Cut Locations

Shear Wall Design Summary					
Section Cut #	*1*	*2*	*3*	*4*	*5*
Horizontal rft	#9 @ 6”	#9 @ 12”	#4 @ 12”	#4 @ 12”	#4 @ 12”
Vertical rft	#9 @ 6”	#9 @ 12”	#10 @ 12”	#4 @ 6”	#4 @ 12”
M_u (k-ft)	131,842	72,400	26,302	10,000	1733
V_u (k)	1113	840	415	194	77
$ØV_n$ (k)	1833	1213	597	597	597

Strength and Reinforcement Verification:

$$ØV_n \geq V_u$$

$$ØV_n = 0.75\,(V_c + V_s)$$

$$V_c = 2\sqrt{f'_c}hd$$

$h = wall\ thickness\ (in)$
$d = 0.8 l_w$
$l_w = wall\ length\ (in)$

$$V_s = \frac{A_v f_y d}{s_h}$$

$$V_n \leq 10\sqrt{f'_c}hd$$

$$horizontal\ \rho_t\text{:}\ \rho_t = \frac{A_v}{s_h h}$$

$$\rho_t \geq 0.0025$$

$$s_h \leq min\begin{cases} \frac{l_w}{5} \\ 3h \\ 18" \end{cases}$$

$$horizontal\ \rho_l\text{:}\ \rho_l = \frac{A_v}{s_v h}$$

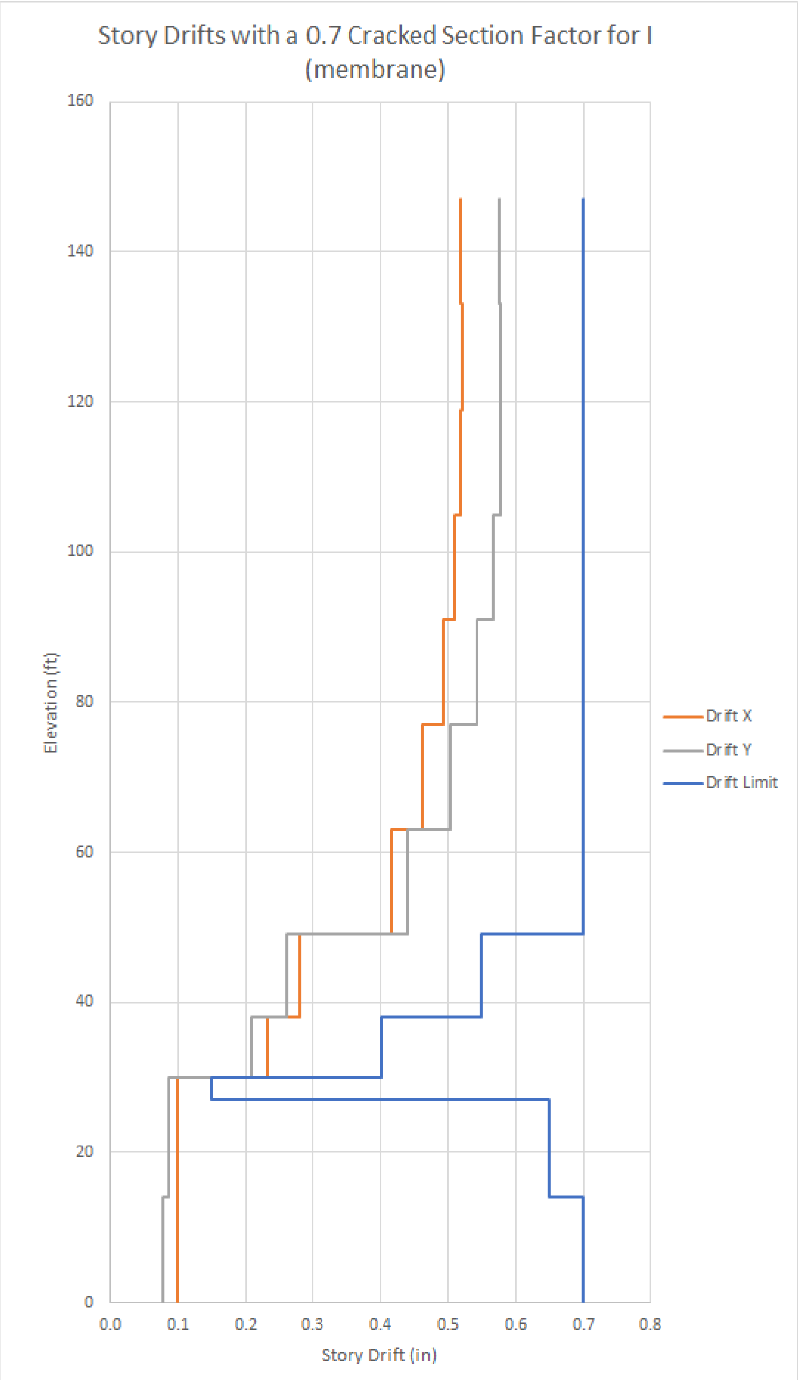
$$\rho_l \geq max\begin{cases} 0.0025 \\ \left[0.0025 + 0.5\left(\frac{2.5 - h_w}{l_w}\right)\right](\rho_t - 0.0025) \end{cases}$$

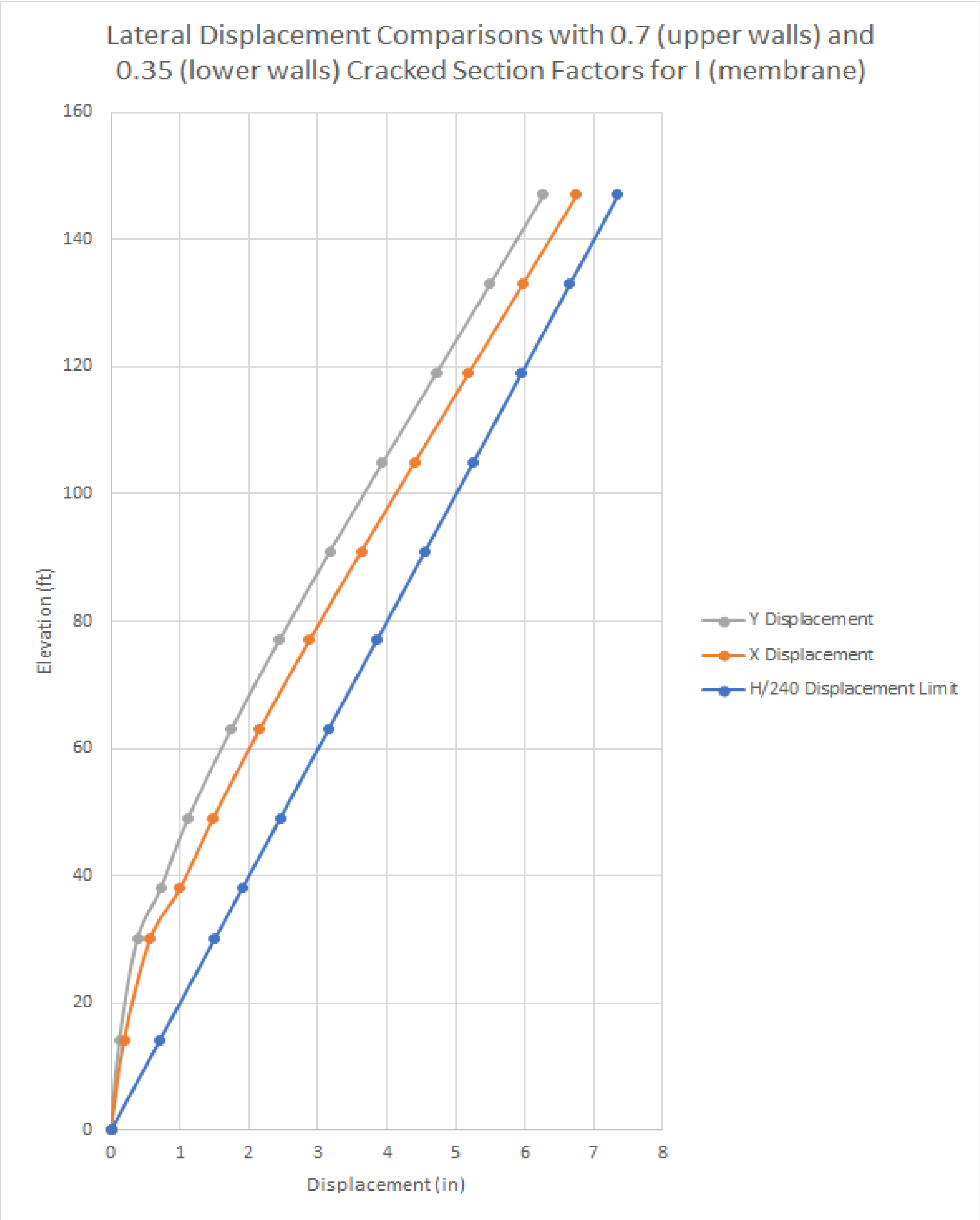
$h_w = wall\ height\ (in)$

$$s_v \leq min\begin{cases} \frac{l_w}{3} \\ 3h \\ 18" \end{cases}$$

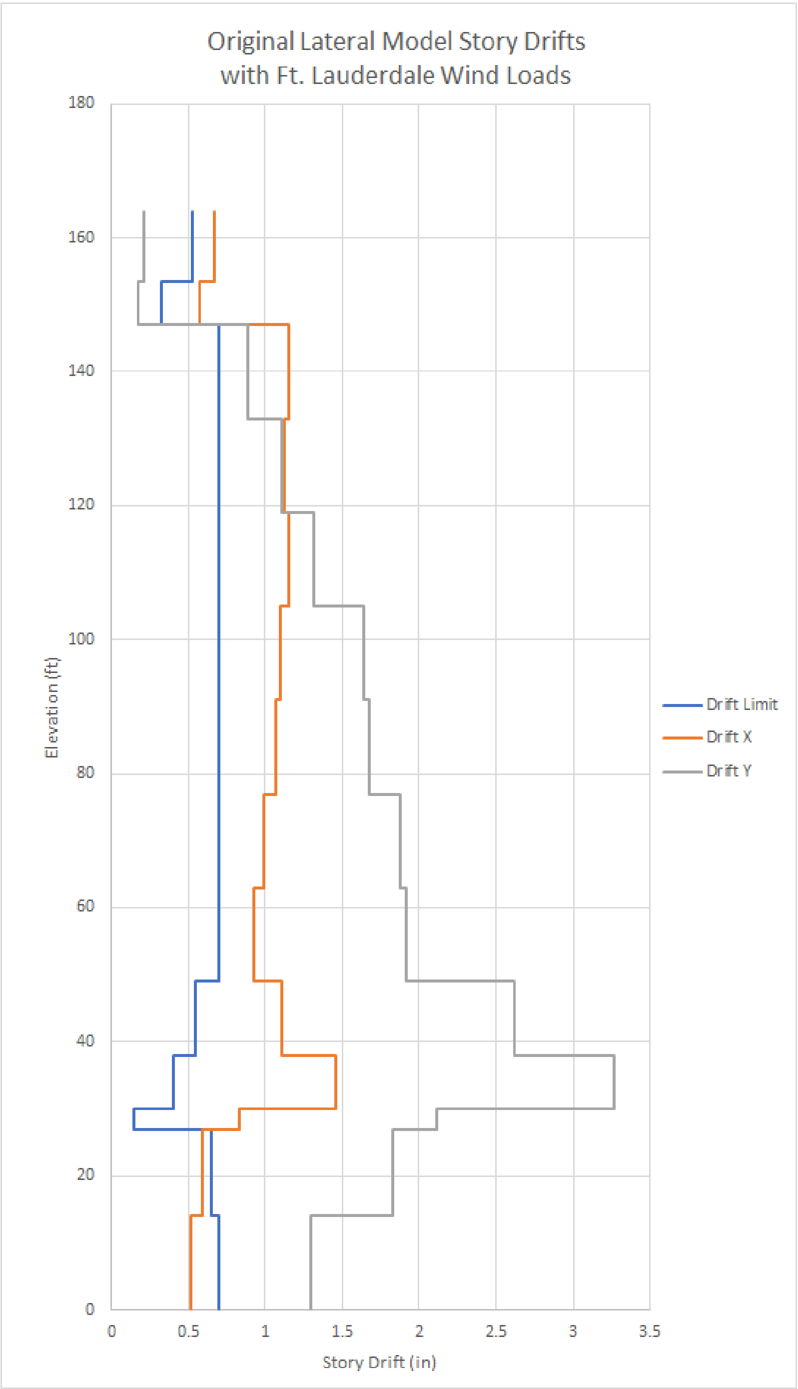
Appendix

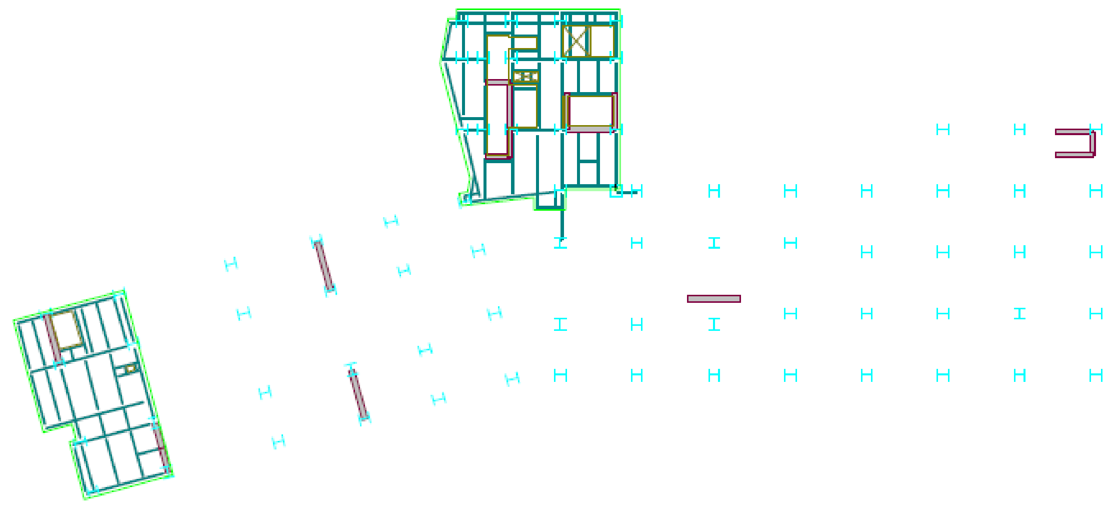
Lateral Redesign



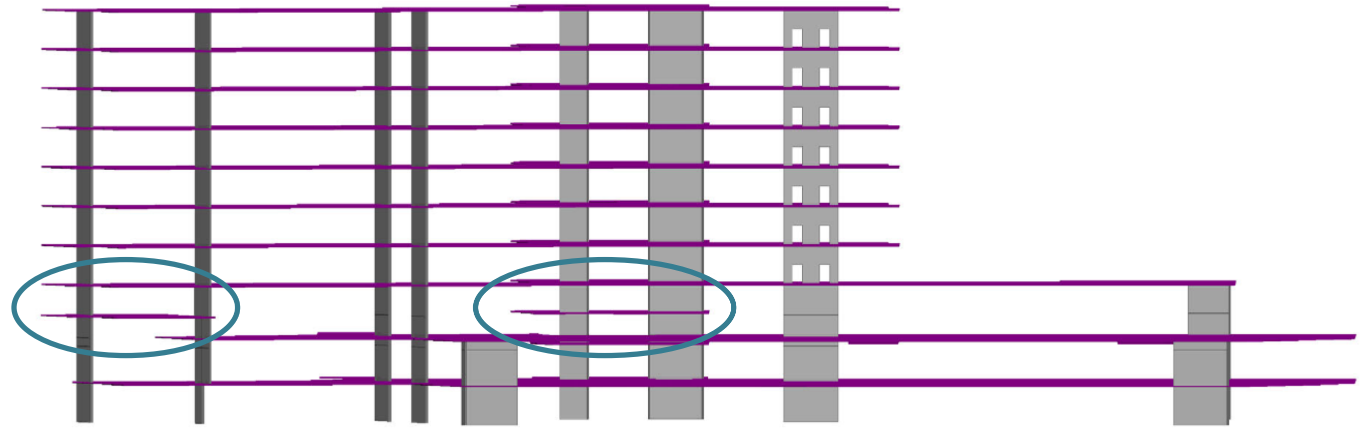


Appendix
Lateral Redesign





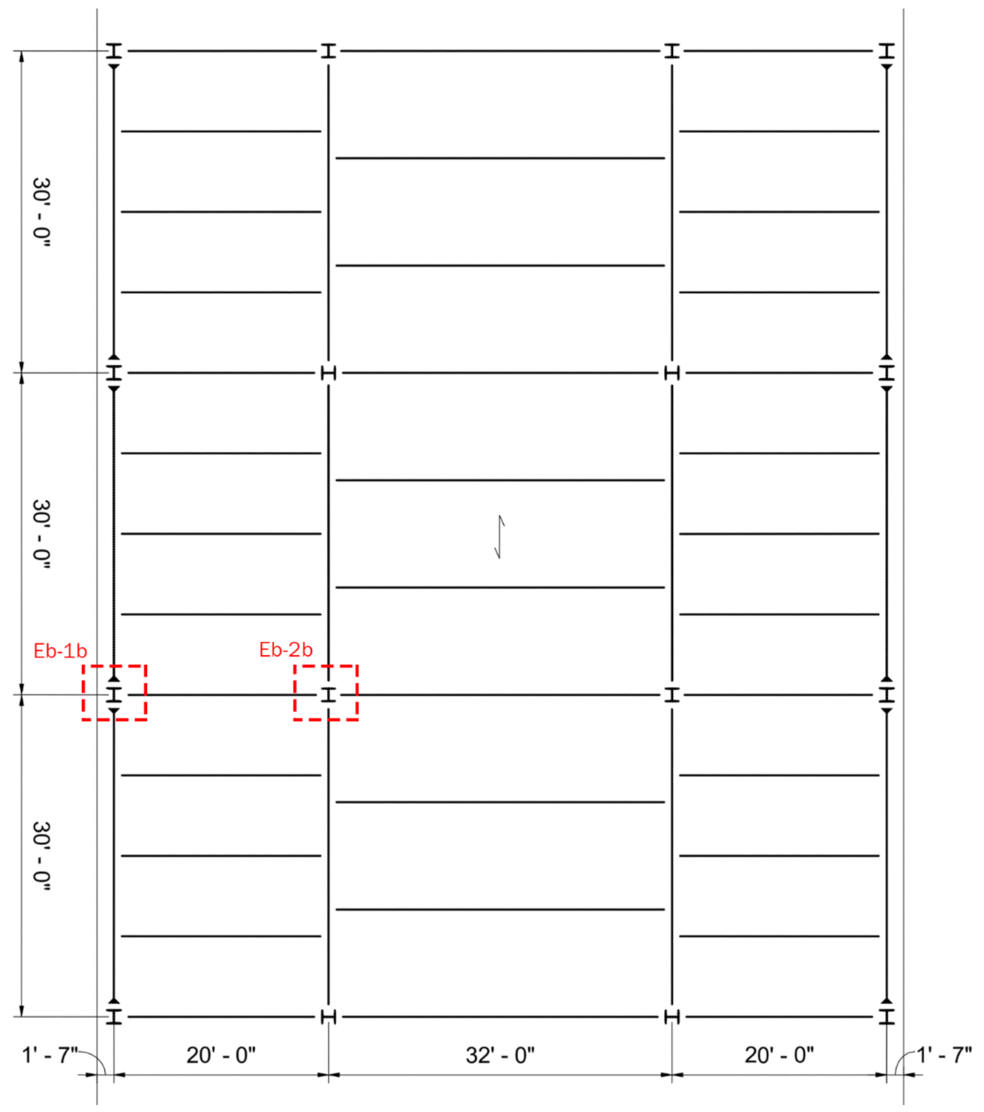
Level 3 Framing Plan

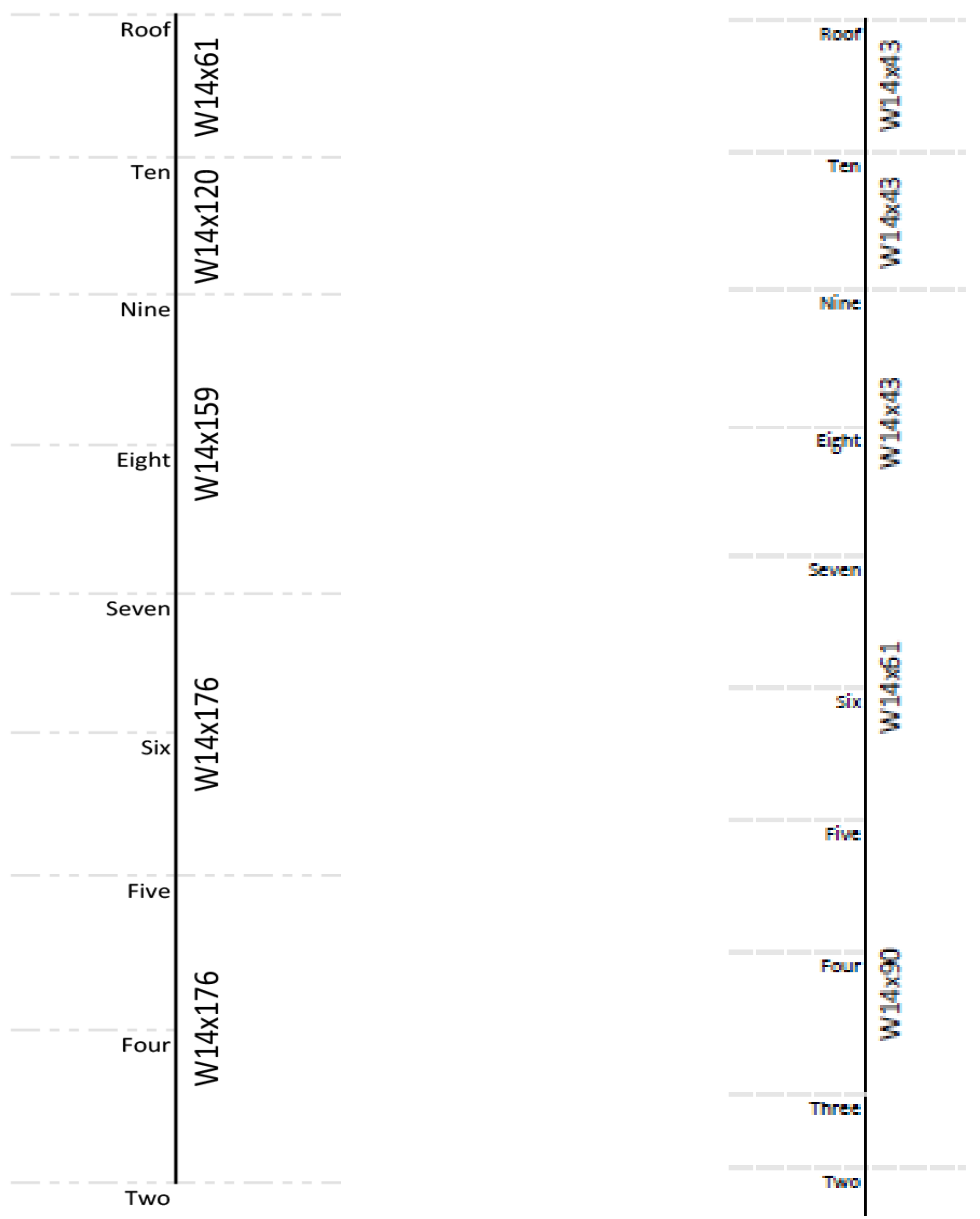


Shear Wall & Diaphragm 3D View

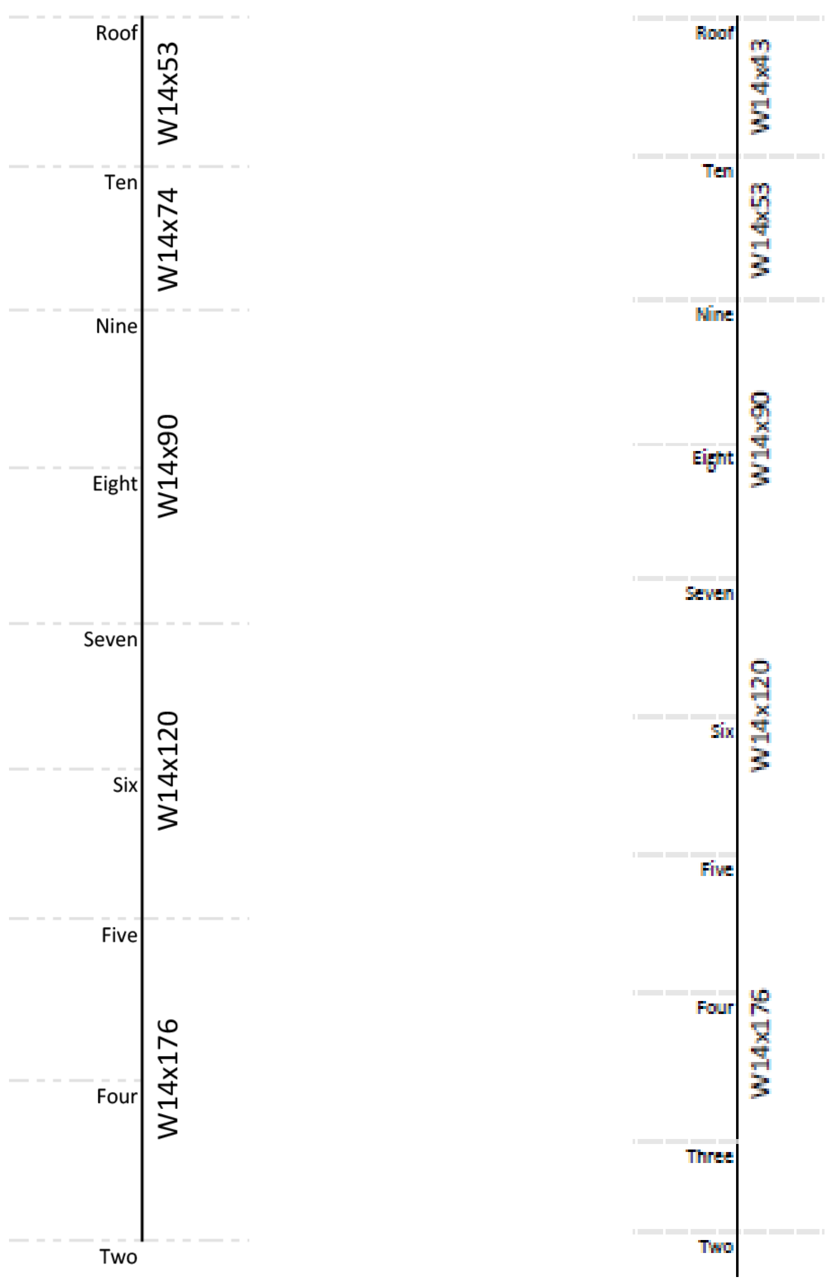
Appendix

Column Comparisons





Typical Exterior Columns: Existing vs. Redesigned



Typical Interior Columns: Existing vs. Redesigned

Appendix

Alternative Gravity Bay Study – System Details

Composite with Fewer Infills

- 3VLI16 composite deck
- 3 ½" LWC topping
- f'c = 4000 psi
- 2-hour fire rating
- ¾" diameter, 5" long headed shear studs
- W14 columns

Flat Slab

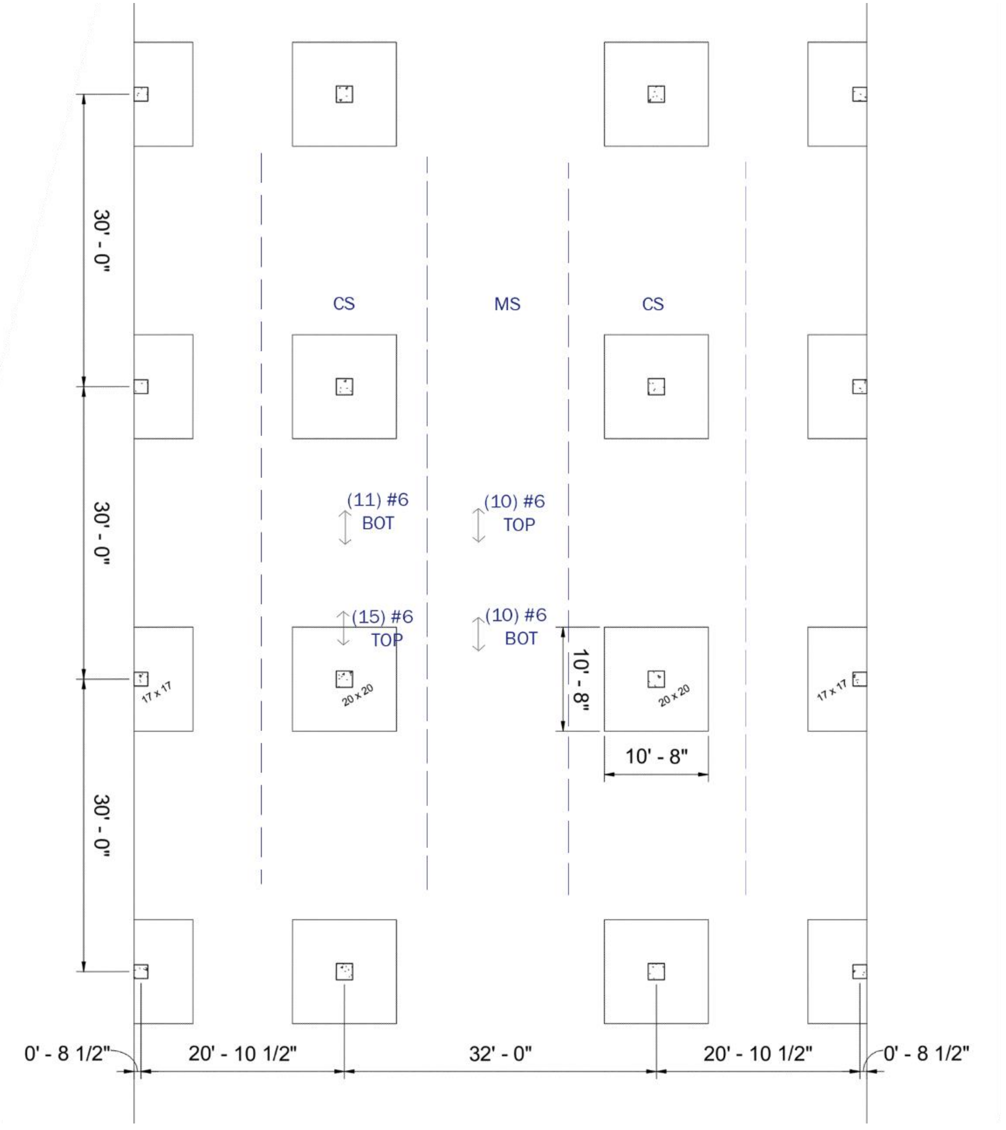
- 12" slab with 8" drops (updated to 8" slab, 4.25" drops / 11" slab, 8.25" drops for 45' span)
- NWC, f'c = 4000 psi
- Reinforcing steel f_y = 60 ksi
- 20"x20" interior columns
- 17"x17" exterior columns

One-Way Pan Joists

- 3" topping slab (reinforcing: #4 @ 7")
- 14" deep rib (reinforcing: (2) #5 per rib)
- 30" forms with 6" wide ribs
- 46"x14" concrete girders
- f'c = 4000 psi
- Reinforcing steel f_y = 60 ksi)

Appendix

Alternative Gravity Bay Study – System Details



Flat Slab

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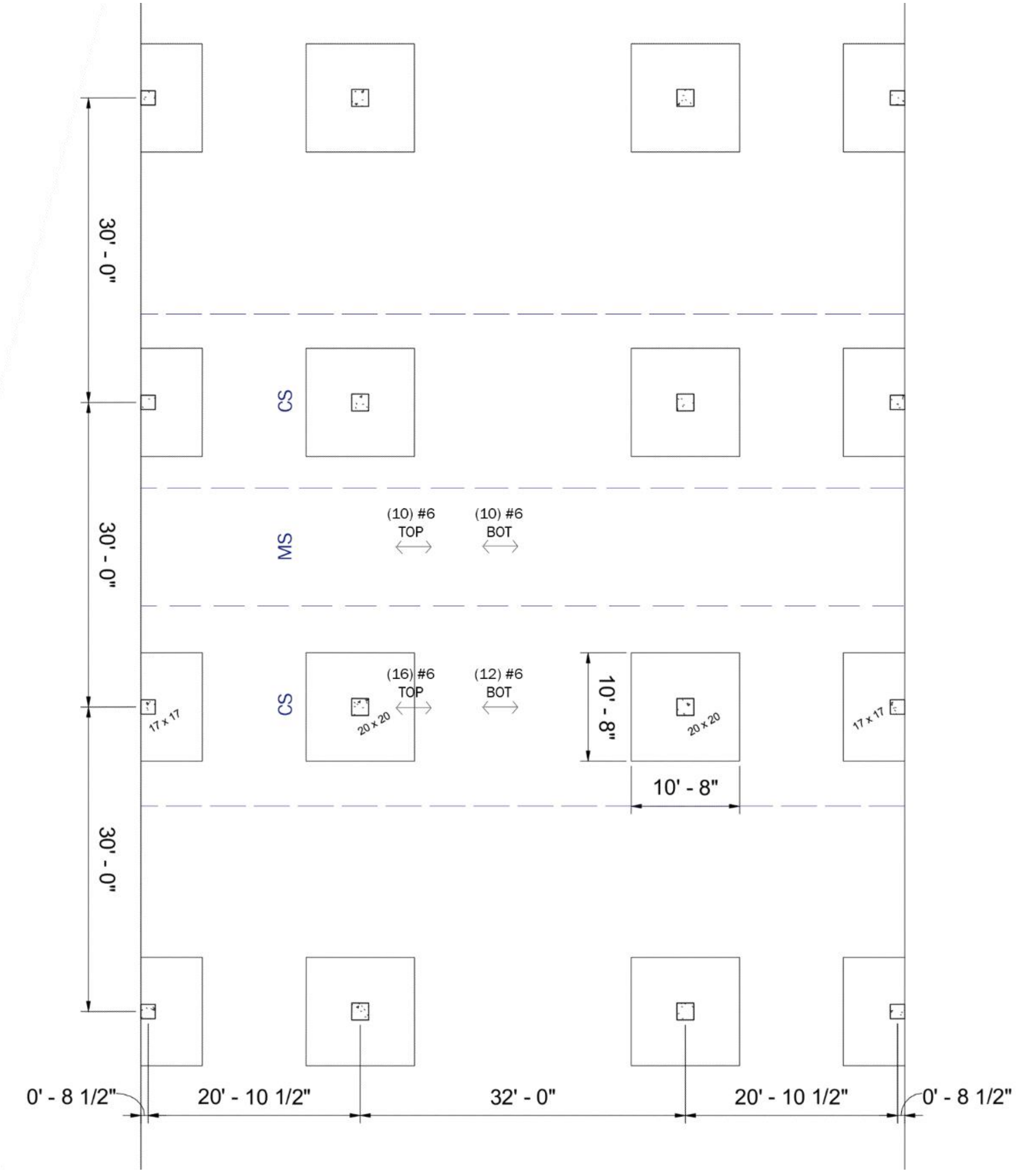


Appendix

Alternative Gravity Bay Study – Updated Flat Slab

RAM Concept - Flat Slab Thickness Analysis

	Maximum Bay Dimension, L (ft)	$\Delta_{LL\ LIMIT}$ = L/360 (in)	$\Delta_{TL\ LIMIT}$ = L/240 (in)	Maximum Bay Deflections (in)									
				Model 1 (12" slab, 8" drop)		Model 2 (10" slab, 6.25" drop)		Model 3 (8" slab, 6.25" drop)		Model 4 (8" slab, 4.25" drop)		Model 5 (6" slab, 4.25" drop)	
				Δ_{LL}	Δ_{TL}	Δ_{LL}	Δ_{TL}	Δ_{LL}	Δ_{TL}	Δ_{LL}	Δ_{TL}	Δ_{LL}	Δ_{TL}
1	30	1.00	1.5	0.06	0.18	0.08	0.3	0.16	0.4	0.18	0.4	0.4	0.8
2	32	1.07	1.6	0.09	0.27	0.16	0.42	0.32	0.6	0.36	0.8	0.6	1.2
1B	35	1.17	1.75	0.06	0.18	0.08	0.3	0.16	0.4	0.18	0.4	0.4	0.8
2B	35	1.17	1.75	0.09	0.27	0.16	0.42	0.32	0.8	0.36	0.8	0.8	1.6
1C	45	1.50	2.25	0.21	0.72	0.36	1.02	0.64	1.6	0.72	1.6	1.6	3.2
2C	45	1.50	2.25	0.27	0.83	0.45	1.24	0.77	1.89	0.87	2.146	1.77	3.81

RAM Concept - Flat Slab Thickness Analysis

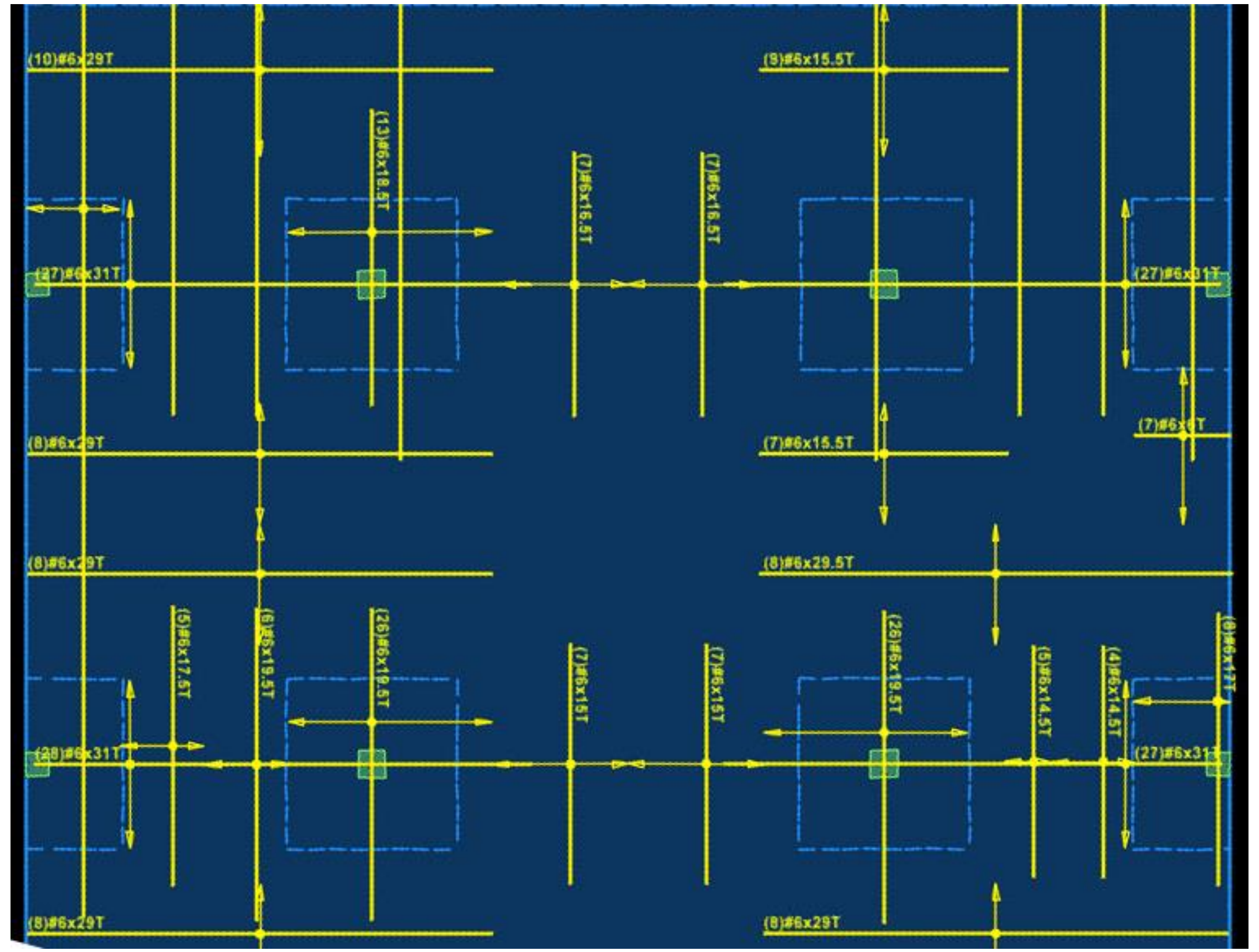
	Maximum Bay Dimension, L (ft)	$\Delta_{LL\ LIMIT}$ = L/360 (in)	$\Delta_{TL\ LIMIT}$ = L/240 (in)	Maximum Bay Deflections (in)									
				Model 6 (7.5" slab, 4.25" drop)		Model 7 (8" slab/4.25" drop & 12" slab/8" drop)		Model 8 (8" slab/4.25" drop & 10" slab/8" drop)		Model 9 (8" slab/4.25" drop & 10.5" slab/8" drop)		Model 10 (8" slab/4.25" drop & 11" slab/8" drop)	
				Δ_{LL}	Δ_{TL}	Δ_{LL}	Δ_{TL}	Δ_{LL}	Δ_{TL}	Δ_{LL}	Δ_{TL}	Δ_{LL}	Δ_{TL}
1	30	1.00	1.5	0.20	0.40	0.15	0.36	0.21	0.30	0.18	0.30	0.18	0.30
2	32	1.07	1.6	0.30	0.60	0.40	0.72	0.35	0.70	0.36	0.70	0.36	0.70
1B	35	1.17	1.75	0.40	0.80	0.15	0.36	0.21	0.40	0.18	0.40	0.18	0.30
2B	35	1.17	1.75	0.50	1.00	0.30	0.54	0.35	0.60	0.30	0.60	0.30	0.60
1C	45	1.50	2.25	0.80	1.60	0.40	0.72	0.56	0.80	0.48	0.80	0.48	0.80
2C	45	1.50	2.25	1.16	2.44	0.48	0.87	0.62	1.11	0.58	1.01	0.54	0.92

Note: Maximum bay deflections assume the maximum value of the deflection range

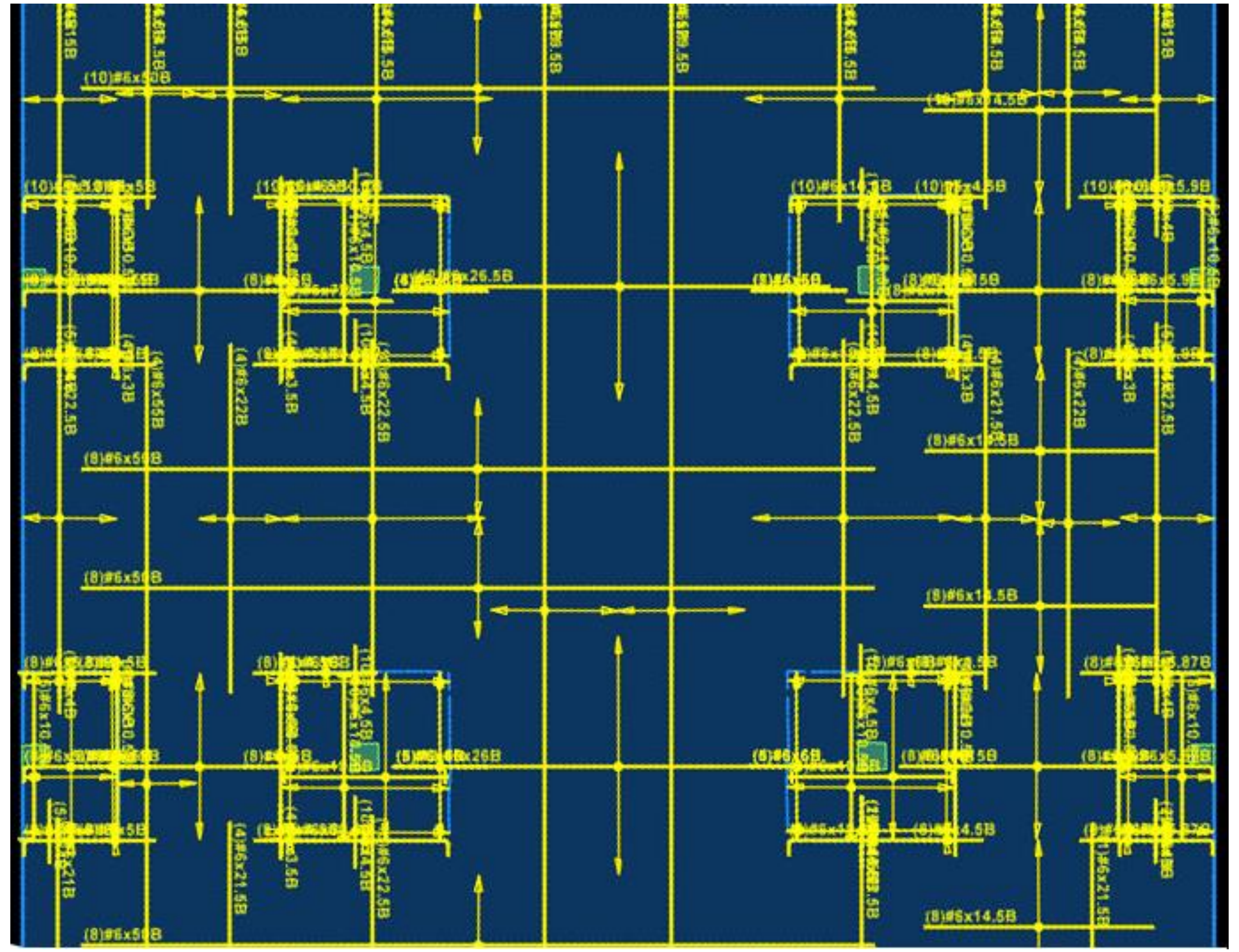
1 Patient Room Bay
2 Nursing Station/HUB/Circulation Bay

Appendix

Alternative Gravity Bay Study – Updated Flat Slab



Top Bars Plan



Bottom Bars Plan

Appendix

Alternative Gravity Bay Study

Alternative Gravity Systems Summary				
	Existing System	**Alternative System 1**	**Alternative System 2**	**Alternative System 3**
Maximum System Depth	31”	27”	20”	17”
Weight (excluding columns)	81 psf	53 psf	161 psf	95 psf
Cost	$16.28/sf	$15.69/sf	$12.37/sf	$10.45
Notable Considerations	Requires fireproofing, possible vibration issues	- Requires fireproofing, possible vibration issues - Reduced number of members	Possible architectural/ mechanical conflicts, limited flexibility	Possible architectural/ mechanical conflicts, limited flexibility

System Category	Specific Options Within System Category	Criteria							Total System Score	System Recommendation
		Cost		Construction	Integration					
		Weight of Framing	Cost Estimate	Ease of Construction	Architectural Integration	Structural Depth	Mechanical Integration	Design Flexibility		
Weight		3	3	1	2	3	4	2		
Structural System	Existing System	4	2	3	4	1	4	4	56	
	Alternative 1: Composite with 1 Infill	5	3	4	4	2	5	4	70	Y
	Alternative 2: Flat Slab with Drops	1	4	4	3	4	3	2	53	N
	Alternative 3: One-Way Pan Joists	3	5	3	2	5	2	2	58	M

Appendix

Alternative Gravity Bay Study – Updated Comparisons

Alternative Gravity System Bay Comparison Values

Model Number and Description	Bay Type	Member Sizes / Bay Design			Column	Bay SF
		Beam	Left Girder	Right Girder		
1 - Original Composite Design (2 infills)	Typical Interior Bay	W18x35	W24x55	W24x55	W14x120	960
2 - Composite with Fewer Infills (1 infill)	Typical Interior Bay	W18x35	W21x50	W21x50	W14x120	960
3 - Flat Slab	Typical Interior Bay	8" slab with 4.25" drop panels (10'-8"x10'-8")			20"x20"	960
4 - One-way Pan Joists	Typical Interior Bay	14+6+30 pan joist, 46"x14" girder, 3" top slab			20"x20"	960

Alternative Gravity System Bay Comparison Values

Model Number and Description	Number of Studs per Bay	Total Structural Weight of Bay (psf)	Carbon Content (kg CO_2)	Labour Hours	Structural Cost, Material Only ($/S.F.)	Structural Cost, Material and Labor ($/S.F.)	Max. System Depth (in)
1 - Original Composite Design (2 infills)	152	86.44	19928.40	50.17	19.12	21.74	24.00
2 - Composite with Fewer Infills (1 infill)	134	70.77	21182.93	47.51	18.03	20.49	21.00
3 - Flat Slab		111.93	4874.12	212.38	9.76	20.90	19.00
4 - One-way Pan Joists		115.93	5047.93	227.13	11.59	23.35	17.00

	Slab+Deck Weight (psf)	Concrete Weight (psf)	Metal Deck Weight (psf)
Original Layout	75	72.16	2.84
Modified Layout	62	56.6	5.4
Modified Layout (rotated)	48	41.3	6.7

Concrete	Labour Hours	Material Cost	Labor Cost	Unit	
Regular concrete (4000 psi) 6" slab	0.022	2.48	0.96	S.F.	*Note: All steel system iterations assume the same slab type*
Elevated slab (4000 psi), flat slab with drops, 125 Sup. Load, 30' span	4.079	298	206	C.Y.	
One way joists, 30" pans, 125 Sup. Load, 25' span	6.677	365	335	C.Y.	
Columns, square (4000 psi), 20"x20" (interpolated between 16" and 24")	10.39	283	525	C.Y.	
Forms in place, flat slab, drop panels, job-built plywood, to 15' high, 4 use	0.088	1.45	4.34	S.F.	
Forms in place, floor slab, with 1-way joist pans, 4 use	0.096	4.95	4.73	S.F.	
Forms in place, columns (use 24"x24" for this calculation), 4 use	0.134	0.95	6.45	S.F.C.A	

	Labour Hours (per S.F.)	Material Cost ($/S.F.)	Labor Cost ($/S.F.)	
3" deep, 16 ga. composite decking	0.012	4.5	0.65	*Note: All iterations assume the same deck type*

Steel Beam/Girder	Labour Hours (per L.F.)	Material Cost ($/L.F.)	Labor Cost ($/L.F.)	
W12x19	0.064	32.5	3.45	
W14x26	0.057	38.5	3.07	*Note: Used data for W12x22*
W16x26	0.056	38.5	3.04	
W16x31	0.062	46	3.38	
W16x50	0.07	74	3.8	
W18x35	0.083	52	4.55	
W18x40	0.083	59	4.55	
W18x60	0.089	96.5	4.85	*Note: Used data for W18x65*
W21x44	0.075	65	4.1	
W21x50	0.075	74	4.1	
W21x62	0.077	92	4.22	
W21x68	0.077	101	4.22	
W24x55	0.072	81.5	3.93	
W24x62	0.072	92	3.93	
W24x68	0.072	101	3.93	
W24x76	0.072	113	3.93	
W24x84	0.074	124	4.04	
W27x84	0.067	124	3.67	
Steel Column				
W14x120	0.058	178	3.17	

Studs	Labour Hours (per stud)	Stud Cost ($/stud)	Labor ($/stud)	
3/4" diameter, 4-7/8" long	0.017	0.72	0.96	*Note: All iterations assume 4-7/8" long*
3/4" diameter, 5-3/16" long	0.017	0.75	0.97	

	Embodied Carbon Factors (kg CO_2/kg)
Concrete	0.1
Steel	2.7
Metal Decking	2.7

Source: Circular Energy, The Inventory of Carbon and Energy (ICE)

Appendix

Alternative Gravity Bay Study – PM Comparison

Criteria	Weight	Baseline: Existing Composite Design	Composite with Fewer Infills	Flat Slab	One-way Pan Joists
G1	0.022	0	-1	1	1
G2	0.037	0	1	-1	-1
G3	0.041	0	1	1	-1
A1	0.200	0	1	1	1
A2	0.200	0	1	1	1
C1	0.098	0	1	-1	1
C2	0.102	0	1	-1	-1
S1	0.096	0	0	1	1
S2	0.105	0	1	-1	-1
S3	0.099	0	-1	1	1
Σ(Weight x Score)		0	0.662	0.316	0.43

Criteria	Weight	Baseline: Composite with Fewer Infills	One-way Pan Joists
G1	0.022	0	1
G2	0.037	0	-1
G3	0.041	0	-1
A1	0.200	0	1
A2	0.200	0	-1
C1	0.098	0	1
C2	0.102	0	-1
S1	0.096	0	-1
S2	0.105	0	-1
S3	0.099	0	1
Σ(Weight x Score)		**0**	-0.162

Appendix

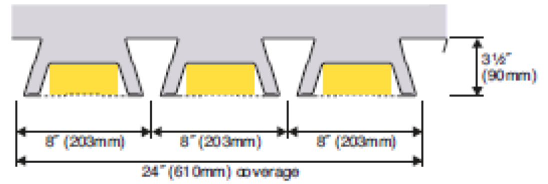
Gravity Redesign – Epicore Deck

Epicore® 3.5 Composite Technical Tables

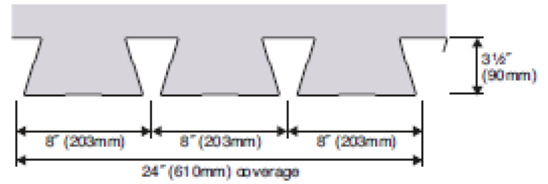
SPANS 10′-25′

ACOUSTIC (EPICORE 3.5A) NON-ACOUSTIC (EPICORE 3.5)

Epicore 3.5A



Epicore 3.5



3.5 Approvals

ICC-ES Approval: ESR-2047

Epicore 3.5A Fire Ratings
(U.L. Design Number D942)

Restrained Fire Rating	Total Slab Depth (in.)	Type and Density of Concrete (pcf)
1 hour	6.25	RW (147)
1 hour	5.5	LW (110)
1½ hours	6.75	RW (147)
1½ hours	5.75	LW (110)
2 hours	7.25	RW (147)
2 hours	6	LW (110)
3 hours	8	RW (147)
3 hours	7	LW (110)

Note: Epicore 3.5A can achieve the loads shown on page 18 with the fire ratings indicated above.

RW = Regular Weight Concrete.
LW = Lightweight Concrete.

Epicore 3.5 Fire Ratings
(U.L. Design Number D942)

Restrained Fire Rating	Total Slab Depth (in.)	Type and Density of Concrete (pcf)
1½ hours	5.5	RW (147)
1½ hours	5.5	LW (110)
2 hours	5.75	RW (147)
2 hours	5.5	LW (110)
3 hours	7.25	RW (147)
3 hours	5.75	LW (110)

Note: Epicore 3.5 can achieve the loads shown on page 19 with the fire ratings indicated above.

RW = Regular Weight Concrete.
LW = Lightweight Concrete.

Epicore 3.5(A) Section Properties

Deck Type	Gage	Weight (psf)	A_s (in.^{2})	I_D (in.^{4})	S_P (in.^{3})	S_N (in.^{3})
Epicore 3.5A	20	4.6	1.36	2.04	0.75	0.83
	18	5.6	1.66	2.66	1.08	1.09
	16	6.7	1.97	3.30	1.42	1.38
Epicore 3.5	20	3.2	0.95	1.83	0.69	0.81
	18	4.3	1.26	2.49	1.01	1.10
	16	5.4	1.59	3.18	1.36	1.41

Appendix

Gravity Redesign – Epicore Deck

Epicore 3.5A Composite Slab & Shoring Tables

Concrete	Slab Depth and Weight	Design Thickness (in.)	Maximum Clear Span Without Shoring (ft.-in.) Single Span	Double Span	Triple Span	Uniform Service Load Slab Capacity (LRFD), psf — Simple Span Condition (See Note 2) 10'0"	11'0"	12'0"	13'0"	14'0"	15'0"	16'0"	17'0"	18'0"	19'0"	20'0"	Continuous Span Condition (Negative Moment Reinforcement REQUIRED. See note 3) (ft.) 21'0"	22'0"	23'0"	24'0"	25'0"
3 ksi Regular Weight Concrete (147 pcf)	5.5" 50 PSF	0.0358	13-5	14-4	14-10	351	316	287	255	195	149	115	88	66	49	–	87	70	55	43	–
		0.0474	15-3	16-4	G	377	340	308	275	210	162	125	96	73	55	40	96	77	61	48	–
		0.0600	16-0	18-3	G	352	316	287	262	226	175	135	104	80	61	45	104	84	67	53	41
	6" 56 PSF	0.0358	12-9	13-8	14-2	400	350	288	239	201	170	144	117	90	69	51	107	94	76	61	47
		0.0474	14-10	15-7	G	400	392	356	326	272	211	164	128	99	76	57	128	104	84	67	53
		0.0600	15-6	17-5	G	400	369	335	306	281	227	177	138	108	83	63	138	113	92	74	59
	6.5" 62 PSF	0.0358	12-2	13-1	13-7	400	397	326	271	228	193	164	140	119	92	71	122	107	94	82	66
		0.0474	14-5	15-0	15-6	400	400	391	326	275	234	200	166	130	102	78	150	133	112	91	73
		0.0600	15-1	16-9	G	400	400	383	350	322	289	227	179	141	111	86	150	141	121	99	81
	7" 68 PSF	0.0358	11-8	12-7	13-1	400	400	366	304	256	216	184	157	135	116	94	137	120	106	93	82
		0.0474	14-1	14-5	14-11	400	400	400	366	309	263	225	193	167	132	104	161	150	133	118	98
		0.0600	14-9	16-1	G	400	400	400	394	362	312	268	227	181	143	113	161	152	143	130	107
	7.5" 74 PSF	0.0358	11-2	12-2	12-7	400	400	400	339	284	241	205	175	151	130	112	153	134	118	104	92
		0.0474	13-8	13-11	14-4	400	400	400	400	344	292	250	215	186	162	133	173	162	148	132	117
		0.0600	14-6	15-7	G	400	400	400	400	400	348	299	258	225	182	145	173	162	153	144	136
	8" 80 PSF	0.0358	10-10	11-9	12-2	400	400	400	373	314	266	227	194	167	144	124	169	149	131	116	102
		0.0474	13-3	13-5	13-11	400	400	400	400	380	323	277	238	206	179	156	184	173	163	146	130
		0.0600	14-2	15-1	15-7	400	400	400	400	400	385	331	286	249	217	182	184	173	163	154	145
3 ksi Light Weight Concrete (110 pcf)	5.5" 39 PSF	0.0358	14-11	15-8	G	360	324	253	191	146	111	85	65	49	–	–	65	52	41	–	–
		0.0474	16-3	17-10	G	385	348	275	208	159	122	94	72	55	41	–	72	58	46	–	–
		0.0600	17-0	20-0	G	360	324	295	225	173	133	103	79	61	46	–	79	64	51	–	–
	6" 44 PSF	0.0358	14-2	15-1	15-7	400	338	279	233	189	146	113	87	67	51	–	87	70	56	45	–
		0.0474	15-9	17-2	G	400	400	351	267	206	159	124	96	74	57	43	96	78	63	50	–
		0.0600	16-6	19-2	G	400	379	344	288	222	172	134	105	81	63	47	105	85	69	56	44
	6.5" 48 PSF	0.0358	13-7	14-6	15-0	400	383	316	264	223	187	146	114	89	69	52	114	93	76	61	49
		0.0474	15-4	16-6	G	400	400	376	315	261	203	159	125	98	76	59	125	102	84	68	55
		0.0600	16-1	18-6	G	400	400	394	361	281	219	172	136	107	83	65	135	112	92	75	61
	7" 53 PSF	0.0358	13-1	14-0	14-6	400	400	355	297	251	214	183	146	115	90	70	139	120	99	81	66
		0.0474	15-0	16-0	G	400	400	400	354	300	255	201	159	126	99	78	159	132	109	89	73
		0.0600	15-9	17-10	G	400	400	400	400	350	275	217	172	137	108	85	172	143	118	98	81
	7.5" 57 PSF	0.0358	12-7	13-7	14-0	400	400	396	331	280	238	204	176	145	115	91	155	137	122	104	86
		0.0474	14-8	15-5	G	400	400	400	395	334	286	246	199	159	126	100	186	165	138	115	95
		0.0600	15-5	17-3	G	400	400	400	400	393	337	269	215	172	138	110	186	175	150	125	104
	8" 62 PSF	0.0358	12-2	13-2	13-7	400	400	400	366	309	264	227	211	169	144	115	163	152	136	121	108
		0.0474	14-5	15-0	15-6	400	400	400	400	370	316	273	236	196	158	127	198	186	166	144	120
		0.0600	15-2	16-9	G	400	400	400	400	400	373	322	264	213	171	138	198	186	177	156	131

No Shoring   Shoring Required in Shaded Areas

Epicore 3.5 Composite Slab & Shoring Tables

Concrete	Slab Depth and Weight	Design Thickness (in.)	Maximum Clear Span Without Shoring (ft.-in.) Single Span	Double Span	Triple Span	Uniform Service Load Slab Capacity (LRFD), psf — Simple Span Condition (See Note 2) 10'0"	11'0"	12'0"	13'0"	14'0"	15'0"	16'0"	17'0"	18'0"	19'0"	20'0"	Continuous Span Condition (Negative Moment Reinforcement REQUIRED. See note 3) (ft.) 21'0"	22'0"	23'0"	24'0"	25'0"
3 ksi Regular Weight Concrete (147 pcf)	5.5" 63 PSF	0.0358	11-6	12-11	13-4	347	312	282	230	172	129	95	70	49	–	–	69	53	–	–	–
		0.0474	14-1	14-11	15-5	369	332	300	261	197	148	111	83	60	42	–	83	64	48	–	–
		0.0600	14-11	16-10	G	340	305	276	251	221	168	127	95	71	51	–	95	75	58	43	–
	6" 69 PSF	0.0358	11-0	12-5	12-10	367	295	240	197	163	135	113	94	72	52	–	80	69	58	44	–
		0.0474	13-8	14-5	14-10	400	385	348	318	259	198	151	115	86	63	44	115	91	71	54	40
		0.0600	14-7	16-2	G	399	358	324	295	270	222	171	131	99	74	54	131	105	83	65	49
	6.5" 75 PSF	0.0358	10-8	12-0	12-4	400	333	271	223	185	154	129	108	90	75	54	92	79	67	57	49
		0.0474	13-2	13-11	14-4	400	400	362	300	251	212	179	153	118	89	66	132	115	99	78	61
		0.0600	14-4	15-8	G	400	400	372	339	311	286	223	173	134	103	77	151	141	114	91	72
	7" 81 PSF	0.0358	10-3	11-7	12-0	400	373	304	250	208	173	145	122	102	86	72	104	89	77	66	56
		0.0474	12-8	13-5	13-11	400	400	400	337	282	238	202	172	147	120	91	149	130	114	100	85
		0.0600	14-0	15-2	15-8	400	400	400	383	351	324	283	223	175	137	106	162	152	143	122	99
	7.5" 87 PSF	0.0358	9-11	11-3	11-7	400	400	338	278	231	193	162	136	115	96	81	116	100	86	74	63
		0.0474	12-3	13-0	13-6	400	400	400	374	314	265	225	192	164	141	121	167	146	128	113	99
		0.0600	13-9	14-8	15-2	400	400	400	400	392	340	291	250	216	176	139	174	163	153	144	131
	8" 93 PSF	0.0358	9-8	10-11	11-3	400	400	372	307	255	214	179	151	127	107	90	129	112	97	83	71
		0.0474	11-11	12-8	13-1	400	400	400	400	347	293	249	213	182	152	135	185	162	143	125	110
		0.0600	13-6	14-3	14-9	400	400	400	400	400	376	322	277	240	208	177	185	174	163	153	144
3 ksi Light Weight Concrete (110 pcf)	5.5" 48 PSF	0.0358	12-11	14-3	14-9	358	321	237	249	229	99	73	53	–	–	–	53	40	–	–	–
		0.0474	15-1	16-7	G	380	342	270	202	153	115	87	64	47	–	–	64	50	–	–	–
		0.0600	15-11	18-7	G	351	316	287	228	173	132	100	75	56	–	–	75	59	46	–	–
	6" 53 PSF	0.0358	12-5	13-10	14-3	360	291	238	197	165	132	100	75	55	–	–	75	59	45	–	–
		0.0474	14-9	16-0	G	400	397	348	262	200	153	117	89	67	49	–	89	70	55	42	–
		0.0600	15-7	18-0	G	400	370	336	293	224	173	133	102	78	58	42	102	82	65	51	–
	6.5" 57 PSF	0.0358	11-11	13-4	13-10	400	328	269	223	187	157	132	101	76	57	41	98	81	64	49	–
		0.0474	14-5	15-6	G	400	400	354	295	249	197	153	118	90	68	51	118	95	76	60	47
		0.0600	15-3	17-5	G	400	400	385	352	285	221	172	134	104	80	60	134	109	88	71	56
	7" 62 PSF	0.0358	11-7	12-11	13-5	400	368	302	251	210	177	150	128	101	77	58	111	97	85	68	54
		0.0474	14-2	15-0	15-6	400	400	397	331	279	237	195	152	119	92	70	152	124	101	82	65
		0.0600	15-0	16-11	G	400	400	400	397	357	278	219	172	135	106	82	172	141	116	95	77
	7.5" 67 PSF	0.0358	11-2	12-7	13-0	400	400	336	279	234	197	168	143	122	101	78	124	109	95	84	73
		0.0474	13-10	14-7	15-1	400	400	400	369	311	265	227	192	151	119	93	171	151	130	107	87
		0.0600	14-9	16-5	G	400	400	400	400	391	334	272	216	171	136	107	189	178	148	122	101
	8" 71 PSF	0.0358	10-11	12-3	12-8	400	400	370	308	258	218	186	159	136	117	100	138	121	106	93	82
		0.0474	13-5	14-2	14-8	400	400	400	400	344	293	251	216	187	150	119	190	168	149	133	112
		0.0600	14-6	16-0	G	400	400	400	400	400	369	318	266	244	170	136	202	190	180	154	128

No Shoring   Shoring Required in Shaded Areas

Appendix

Gravity Redesign

Bay Designs and Vibration Comparisons

Model Number and Description	Bay Type	Member Sizes			Walking Speed (steps/min)			% g
		Beam	Left Girder	Right Girder	Slow, 50	Moderate, 75	Fast, 100	
1a -Original Composite Design	Typical Hospital Patient Room Bay	W12x19	W27x84	W24x55	2504	9316	41921	
	Typical Interior Bay	W18x35	W24x55	W24x55				0.288
	Typical First Floor Surgical Bay	W16x26	W24x55	W24x55	2015	7495	33728	
1b -Original Composite Design (Modified to Meet Vibration Requirements)	Typical Hospital Patient Room Bay	W14x26	W27x84	W24x76	1465	5451	24528	
	Typical Interior Bay	W18x35	W24x55	W24x55				0.288
	Typical First Floor Surgical Bay	W21x44	W24x68	W24x68	993	3695	16625	
2 - Composite with Fewer Infills	Typical Hospital Patient Room Bay	W18x35	W27x84	W24x62	1552	5773	25976	
	Typical Interior Bay	W18x35	W21x50	W21x50				0.421
	Typical First Floor Surgical Bay	W21x62	W24x84	W24x84	1021	3797	17085	
3 - Composite with Fewer Infills and Modified Layout	Typical Hospital Patient Room Bay	W21x44	W27x84	W24x62	1566	5828	26224	
	Typical Interior Bay	W18x35	W21x50	W21x50				0.421
	Typical First Floor Surgical Bay	W21x62	W24x84	W24x84	1021	3797	17085	
4 - Composite with Fewer Infills and Rotated Layout	Typical Hospital Patient Room Bay	W21x50	W24x84	W24x84	1539	5727	25771	
	Typical Interior Bay	W16x31	W24x55	W24x55				0.423
	Typical First Floor Surgical Bay	W21x62	W27x84	W27x84	1057	3932	17694	
5 -Non-composite Design with Original Layout	Typical Hospital Patient Room Bay	W14x26	W27x84	W24x68	1557	5792	26063	
	Typical Interior Bay	W21x44	W24x68	W24x68				0.217
	Typical First Floor Surgical Bay	W18x35	W27x84	W27x84	1001	3722	16750	
6 - Non-composite with Fewer Infills	Typical Hospital Patient Room Bay	W18x35	W27x84	W24x68	1458	5423	24401	
	Typical Interior Bay	W24x55	W24x68	W24x68				0.241
	Typical First Floor Surgical Bay	W18x60	W27x84	W27x84	1063	3955	17797	
7 - Non-composite with Fewer Infills and Modified Layout	Typical Hospital Patient Room Bay	W16x50	W27x84	W24x84	1546	5753	25888	
	Typical Interior Bay	W24x55	W24x68	W24x68				0.241
	Typical First Floor Surgical Bay	W18x60	W27x84	W27x84	1015	3778	16999	
8 - Non-composite with Fewer Infills and Rotated Layout	Typical Hospital Patient Room Bay	W21x50	W24x84	W24x84	1539	5727	25771	
	Typical Interior Bay	W21x50	W24x84	W24x84				0.254
	Typical First Floor Surgical Bay	W21x68	W24x84	W24x84	1050	3906	17578	

Building Overview
Alternative Gravity Bay Study
Gravity System Redesign
Decision-Making Study
Lateral System Redesign
Structural System Comparisons
Acoustic Analysis
Prefabrication Study

Appendix

Gravity Redesign

Weight and Stud Comparisons						
Model Number and Description	Bay Type	Bay SF	Number of Studs per Bay	Total Structural Weight of Bay (psf)	Floor Takeoff	
					Floor Weight (k)	Total Number of Studs
1a -Original Composite Design	Typical Hospital Patient Room Bay	640	98	86.02	152	2968
	Typical Interior Bay	960	152	84.69		
	Typical First Floor Surgical Bay	720	100	82.94	425	9816
1b -Original Composite Design (Modified to Meet Vibration Requirements)	Typical Hospital Patient Room Bay	640	116	88.38	158	3123
	Typical Interior Bay	960	148	84.65		
	Typical First Floor Surgical Bay	720	272	88.20	530	12772
2 - Composite with Fewer Infills	Typical Hospital Patient Room Bay	640	86	74.56	138	2368
	Typical Interior Bay	960	134	70.77		
	Typical First Floor Surgical Bay	720	204	75.60	415	9413
3 - Composite with Fewer Infills and Modified Layout	Typical Hospital Patient Room Bay	640	74	74.13	131	2216
	Typical Interior Bay	960	134	70.77		
	Typical First Floor Surgical Bay	720	204	75.60	415	9413
4 - Composite with Fewer Infills and Rotated Layout	Typical Hospital Patient Room Bay	640	72	61.41	132	2224
	Typical Interior Bay	960	170	56.34		
	Typical First Floor Surgical Bay	720	166	61.17	420	9001
5 -Non-composite Design with Original Layout	Typical Hospital Patient Room Bay	640		86.19	177	
	Typical Interior Bay	960		85.12		
	Typical First Floor Surgical Bay	720		84.49	527	
6 - Non-composite with Fewer Infills	Typical Hospital Patient Room Bay	640		73.50	164	
	Typical Interior Bay	960		71.75		
	Typical First Floor Surgical Bay	720		72.60	510	
7 - Non-composite with Fewer Infills and Modified Layout	Typical Hospital Patient Room Bay	640		74.56	167	
	Typical Interior Bay	960		72.75		
	Typical First Floor Surgical Bay	720		72.60	510	
8 - Non-composite with Fewer Infills and Rotated Layout	Typical Hospital Patient Room Bay	640		60.28	184	
	Typical Interior Bay	960		58.29		
	Typical First Floor Surgical Bay	720		59.47	523	

Building Overview
Alternative Gravity Bay Study
Gravity System Redesign
Decision-Making Study
Lateral System Redesign
Structural System Comparisons
Acoustic Analysis
Prefabrication Study

Appendix

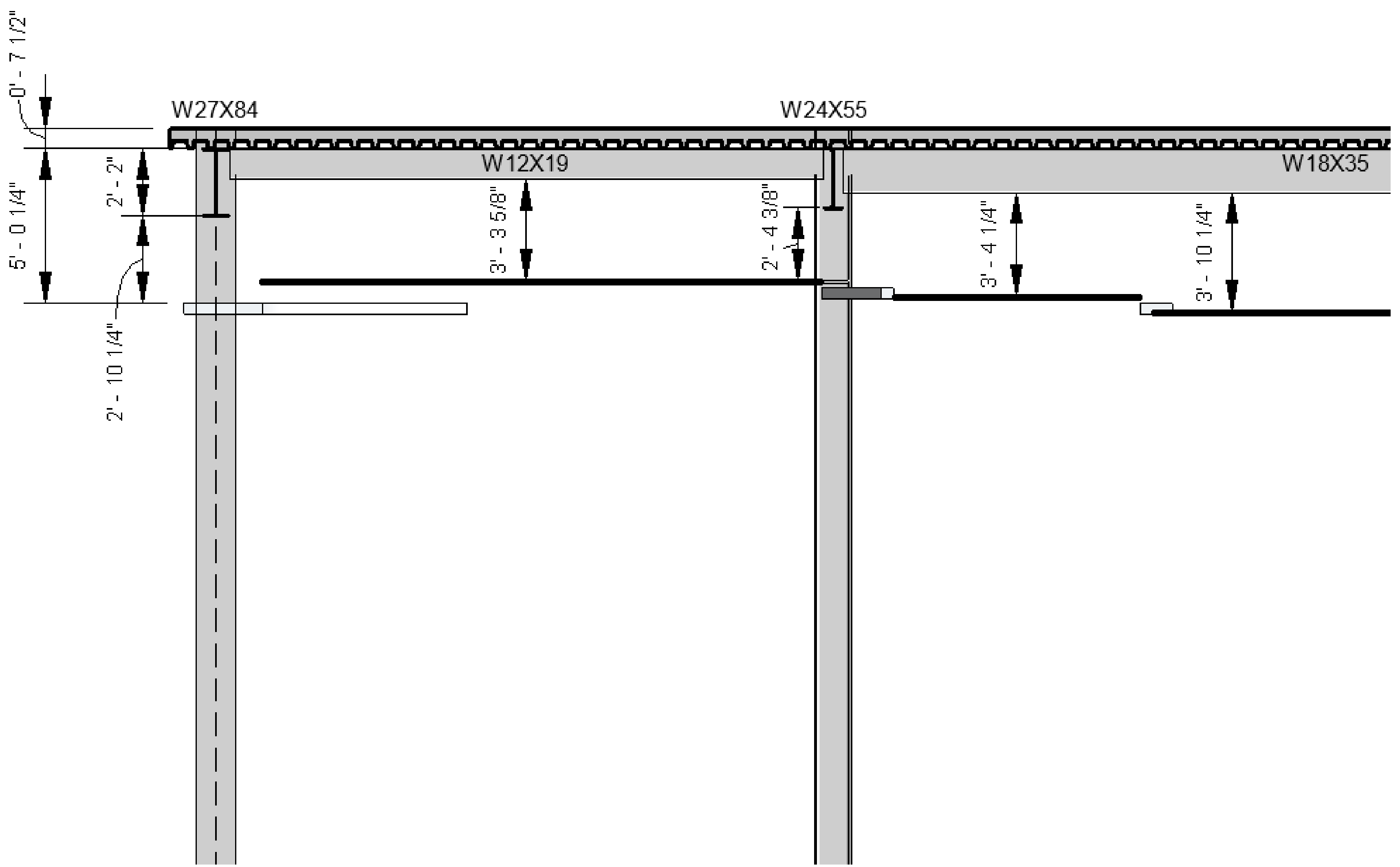
Gravity Redesign

Miscellaneous Bay Comparisons

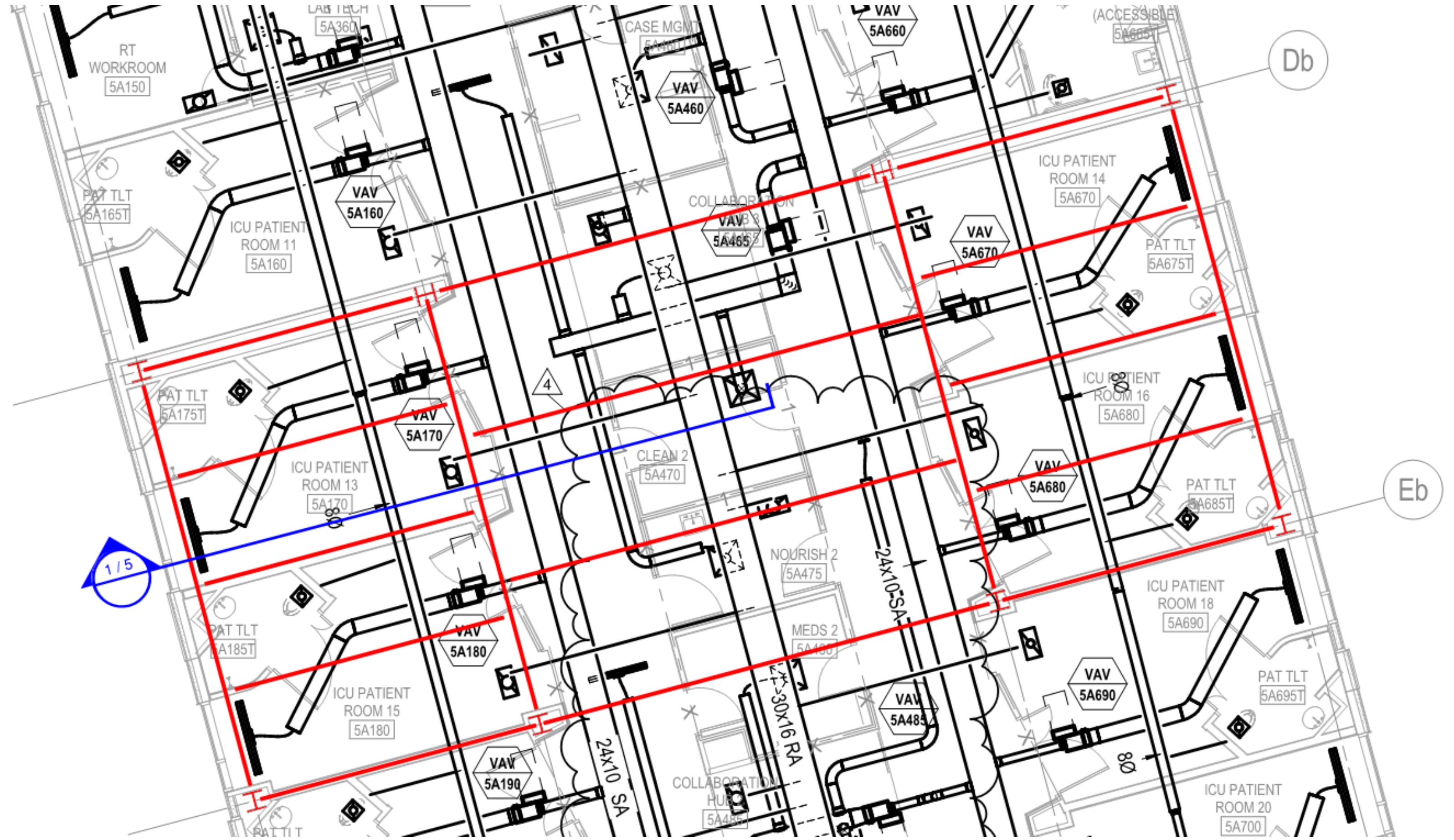
Model Number and Description	Bay Type	Carbon Content (kg CO_2)	Labour Hours	Structural Cost, Material Only ($/S.F.)	Structural Cost, Material and Labor ($/S.F.)	Number of Total Pieces (Beams and Girders)		Number of Different Size Pieces		Average Demand to Capacity Ratio
1a -Original Composite Design	Typical Hospital Patient Room Bay	12954.93	34.27	22.44	25.12	7	19	3	5	0.56
	Typical Interior Bay	17870.91	50.17	19.12	21.74	6		2		0.75
	Typical First Floor Surgical Bay	11866.18	34.12	16.79	19.13	6		2		0.7
1b -Original Composite Design (Modified to Meet Vibration Requirements)	Typical Hospital Patient Room Bay	14804.23	33.60	24.24	26.86	7	19	3	6	0.4
	Typical Interior Bay	17821.92	50.10	21.09	23.70	6		2		0.68
	Typical First Floor Surgical Bay	16500.44	38.56	21.21	23.90	6		2		0.4
2 - Composite with Fewer Infills	Typical Hospital Patient Room Bay	15722.22	34.03	23.70	26.37	6	16	3	5	0.4
	Typical Interior Bay	19125.43	47.51	18.03	20.49	5		2		0.89
	Typical First Floor Surgical Bay	18602.35	36.12	23.12	25.62	5		2		0.44
3 - Composite with Fewer Infills and Modified Layout	Typical Hospital Patient Room Bay	15379.31	31.69	23.28	25.74	5	15	3	6	0.44
	Typical Interior Bay	19125.43	47.51	18.03	20.49	5		2		0.9
	Typical First Floor Surgical Bay	18602.35	36.12	23.12	25.62	5		2		0.44
4 - Composite with Fewer Infills and Rotated Layout	Typical Hospital Patient Room Bay	16958.35	32.69	25.22	27.76	5	15	2	6	0.35
	Typical Interior Bay	19485.50	45.72	16.85	18.95	5		2		0.99
	Typical First Floor Surgical Bay	18871.79	35.53	23.23	25.69	5		2		0.41
5 -Non-composite Design with Original Layout	Typical Hospital Patient Room Bay	13089.65	31.78	23.03	25.49	7	19	3	5	0.63
	Typical Interior Bay	18375.48	46.56	21.96	24.36	6		2		0.87
	Typical First Floor Surgical Bay	13228.05	34.34	21.02	23.38	6		2		0.84
6 - Non-composite with Fewer Infills	Typical Hospital Patient Room Bay	14889.43	32.57	24.03	26.56	6	16	3	5	0.52
	Typical Interior Bay	20276.65	43.87	21.44	23.69	5		2		0.84
	Typical First Floor Surgical Bay	15957.00	33.04	23.29	25.55	5		2		0.69
7 - Non-composite with Fewer Infills and Modified Layout	Typical Hospital Patient Room Bay	15722.22	30.19	25.54	27.87	5	15	3	6	0.51
	Typical Interior Bay	21452.36	43.99	22.88	25.14	5		2		0.77
	Typical First Floor Surgical Bay	15957.00	33.04	23.29	25.55	5		2		0.69
8 - Non-composite with Fewer Infills and Rotated Layout	Typical Hospital Patient Room Bay	16076.57	31.47	25.14	27.58	5	15	2	3	0.31
	Typical Interior Bay	21770.78	44.13	22.18	24.45	5		2		0.83
	Typical First Floor Surgical Bay	17367.86	32.98	23.97	26.23	5		2		0.59

Appendix

Gravity Redesign



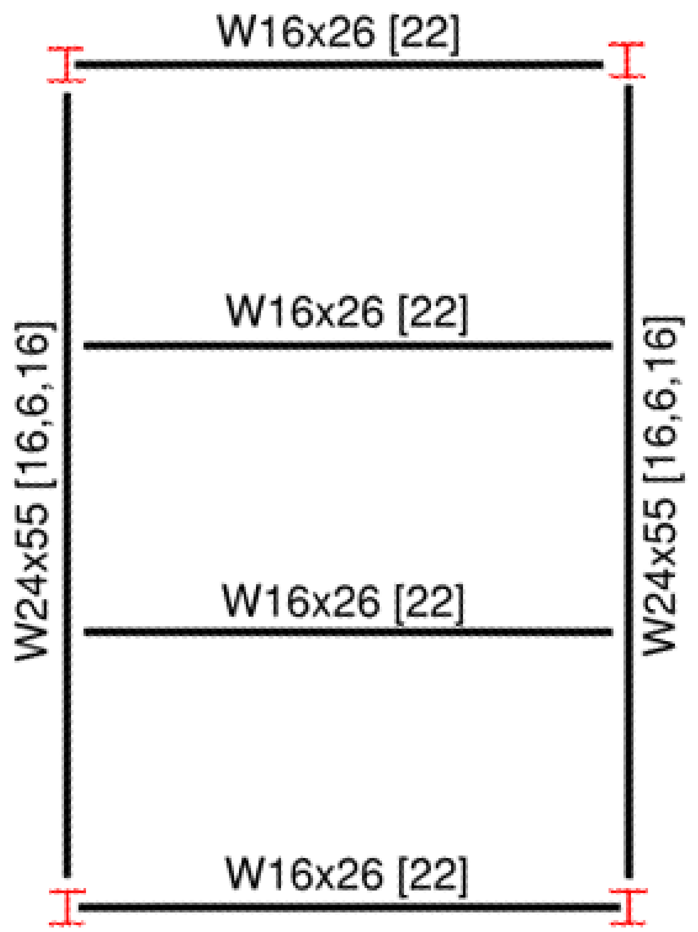
Existing Gravity System Floor Section



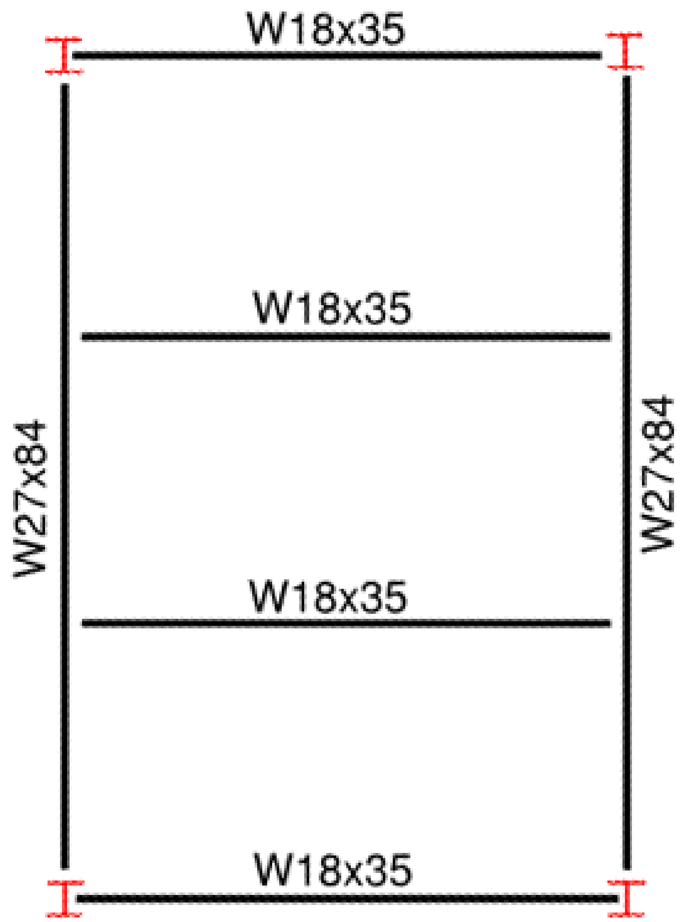
Mechanical Overlay for Original Gravity System Layout

Gravity Redesign

Non-composite with Original Layout



Existing Composite System, Typical Surgical Bay



Redesigned Non-composite System, Typical Surgical Bays

Typical Surgical Bay Comparisons			
		Existing	Non-composite Design with Original Layout
	Studs		
	Structural Weight	83 psf	84 psf
	Carbon Content	11,866 kg CO_2	13,228 kg CO_2
	Structural Cost, Material	$16.79 / SF	$21.02 / SF
	Structural Cost, Material & Labor	$19.13 / SF	$23.38 / SF
	Number of Total Pieces	6	6
	Average Demand to Capacity Ratio	0.7	0.84
Vibration Response	Slow, 50 steps/min	2015 mips	1001 mips
	Moderate, 75 steps/min	7495 mips	3722 mips
	Fast, 100 steps/min	33728 mips	16750 mips

Gravity Redesign

Non-composite with Original Layout

Typical Patient Room Bay Comparisons			
		Existing- Modified for Vibration Requirements	Non-composite Design with Original Layout
	Beam	W21x44	W18x35
	Left Girder	W24x68	W27x84
	Right Girder	W24x68	W27x84
	Studs	272	
	Structural Weight	88 psf	84 psf
	Carbon Content	16,500 kg CO_2	13,228 kg CO_2
	Structural Cost, Material	$21.21 / SF	$21.02 / SF
	Structural Cost, Material & Labor	$23.90 / SF	$23.38 / SF
	Number of Total Pieces	7	6
	Average Demand to Capacity Ratio	0.4	0.84
Vibration Response	Slow, 50 steps/min	993 mips	1001 mips
	Moderate, 75 steps/min	3695 mips	3722 mips
	Fast, 100 steps/min	16625 mips	16750 mips

Appendix

Gravity Redesign – AHP Results

Criteria	General			Architectural		Construction		Structural			Overall Preference
Weight	0.1			0.4		0.2		0.3			
Subcriteria	G1	G2	G3	A1	A2	C1	C2	S1	S2	S3	
Weight	0.22	0.37	0.41	0.5	0.5	0.49	0.51	0.32	0.35	0.33	
Concept 1b	0.231	0.028	0.067	0.361	0.108	0.067	0.053	0.028	0.076	0.036	0.129
Alternative Concept 2	0.061	0.147	0.140	0.090	0.195	0.267	0.028	0.147	0.173	0.090	0.135
Alternative Concept 3	0.061	0.324	0.275	0.036	0.332	0.067	0.333	0.324	0.339	0.036	0.202
Alternative Concept 4	0.030	0.324	0.026	0.036	0.064	0.067	0.127	0.324	0.339	0.036	0.122
Alternative Concept 5	0.487	0.028	0.401	0.361	0.108	0.267	0.333	0.028	0.026	0.361	0.223
Alternative Concept 6	0.131	0.147	0.091	0.116	0.195	0.267	0.127	0.147	0.046	0.116	0.139

Building Overview
Alternative Gravity Bay Study
Gravity System Redesign
Decision-Making Study
Lateral System Redesign
Structural System Comparisons
Acoustic Analysis
Prefabrication Study

Appendix

Gravity Redesign – PM Results

Criteria	Weight	Baseline: 1B	2	3	4	5	6
G1	0.022	0	-1	-1	-1	1	-1
G2	0.037	0	1	1	1	-1	1
G3	0.041	0	1	1	-1	1	1
A1	0.200	0	1	1	-1	1	1
A2	0.200	0	1	1	-1	0	1
C1	0.098	0	1	0	0	1	1
C2	0.102	0	-1	-1	-1	1	-1
S1	0.096	0	1	1	1	0	1
S2	0.105	0	1	1	1	1	1
S3	0.099	0	1	1	-1	1	1
	Σ(Weight x Score)	0	0.752	0.654	-0.426	0.63	0.752

Criteria	Weight	2	3	5	6
G1	0.022	0	1	1	1
G2	0.037	0	1	-1	1
G3	0.041	0	1	1	-1
A1	0.200	0	-1	1	-1
A2	0.200	0	1	-1	0
C1	0.098	0	-1	0	0
C2	0.102	0	1	1	1
S1	0.096	0	1	-1	1
S2	0.105	0	1	-1	1
S3	0.099	0	-1	1	-1
	Σ(Weight x Score)	0	0.206	0.026	0.022

Criteria	Weight	3	5
G1	0.022	0	1
G2	0.037	0	-1
G3	0.041	0	1
A1	0.200	0	1
A2	0.200	0	-1
C1	0.098	0	1
C2	0.102	0	1
S1	0.096	0	-1
S2	0.105	0	-1
S3	0.099	0	1
	Σ(Weight x Score)	0	**0.124**

Appendix

Gravity Redesign – CBA Results

	System 1b			Alternative System 2			Alternative System 3		
Factor	Attributes	Adv.	IoA	Attributes	Adv.	IoA	Attributes	Adv.	IoA
F1	14804	13% less	20	15722	7% less	5	15379	9% less	10
F2	19, 0.4	37% lower UR	10	16, 0.4	16% less, 37% lower	30	15, 0.44	21% less, 30% lower	40
F3	14”	33% less depth	200	18”	14% less depth	100	21”	--	--
F4	3, NR	Non-rotated	67	2, NR	Non-rotated	133	1, NR	Non-rotated	200
F5	6	--	--	5	17% less	100	6	--	--
F6	33.60	1.3% less	30	34.03	--	--	31.69	7% less	150
F7	19	--	--	16	16% less		15	21% less	75
F8	88.38	--	--	74.56	15.6% less	70	74.13	16% less	105
F9	14”	33% less depth	125	18”	14% less depth	63	21”	--	--
Total	--	--	452	--	--	501	--	--	580

	Alternative System 4			Alternative System 5			Alternative System 6		
Factor	Attributes	Adv.	IoA	Attributes	Adv.	IoA	Attributes	Adv.	IoA
F1	16958	--	--	13090	23% less	25	14889	12% less	15
F2	15, 0.35	21% less, 44% lower	50	19, 0.63	--	--	16, 0.52	16% less, 17% lower	20
F3	21”	--	--	14”	33% less depth	200	18”	14% less depth	100
F4	1, R	--	--	3, NR	Non-rotated	67	2, NR	Non-rotated	133
F5	6	--	--	5	17% less	100	5	17% less	100
F6	32.69	4% less	60	31.78	6.7% less	120	32.57	4.3% less	90
F7	15	21% less	75	19	--	--	16	16% less	56
F8	61.41	31% less	175	86.19	2.5% less	35	73.50	17% less	140
F9	21”	--	--	14”	33% less depth	125	18”	14% less depth	63
Total	--	--	360	--	--	672	--	--	717

Appendix

AEC Industry Healthcare Survey

STRUCTURAL SYSTEM SELECTION PARAMETERS

- **General Criteria**
  - Sustainability (carbon emissions)
  - Future flexibility of the space
  - System cost
- **Architectural Criteria**
  - Plenum depth
  - Plenum coordination
- **Construction Criteria**
  - Repetitive members
  - Enhancing/easing erection/construction time
- **Structural Criteria**
  - Minimizing number of members
  - Structural weight
  - Minimizing Structural depth

STRUCTURAL SYSTEM SELECTION WEIGHTS

- **0.1**
  - 0.22
  - 0.37
  - 0.41
- **0.4**
  - 0.5
  - 0.5
- **0.2**
  - 0.49
  - 0.51
- **0.3**
  - 0.32
  - 0.35
  - 0.33

Appendix

Acoustic Cost Estimates

	STC	Cost	Quantity Required	Total Cost
Privacy Curtain	0	$26/curtain	15 + 20 extra to owner	$ 910
Woodfold Series 2100	21	$1350/panel	15	$ 20,250
Woodfold Series 3300	33	$3300/panel	15	$ 49,500
Partition (no insulation), pod layout 1	37	$19.35/LF + $0.76/SF	75 LF/600 SF + 9 curtains	$ 2,141
Partition (with insulation), pod layout 1	40	$19.35/LF + $1.11/SF	75 LF/600 SF + 9 curtains	$ 2,351
Partition (no insulation), pod layout 2	37	$19.35/LF + $0.76/SF	220 LF/1750 SF + 9 curtains	$ 5,821
Partition (with insulation), pod layout 2	40	$19.35/LF + $1.11/SF	220 LF/1750 SF + 9 curtains	$ 6,434

	Partition Cost Data	
8' high, 3-5/8" studs @ 16" o.c.	$19.35/LF	
5/8" gypsum board, on walls, standard, no finish included	$0.76/SF	
Owens Corning sound attenuation batt 24"x96"	$0.35/SF	*Note: material cost only*