Kirk Stauffer

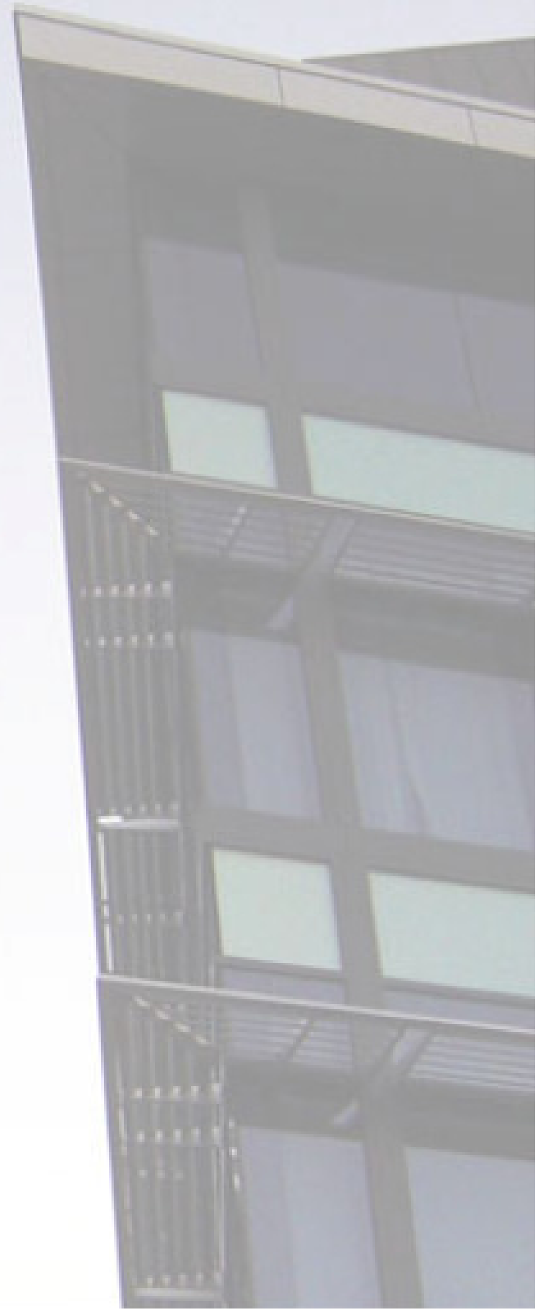
BAE / MAE - Structural Option

Senior Thesis Project

Life Sciences Building

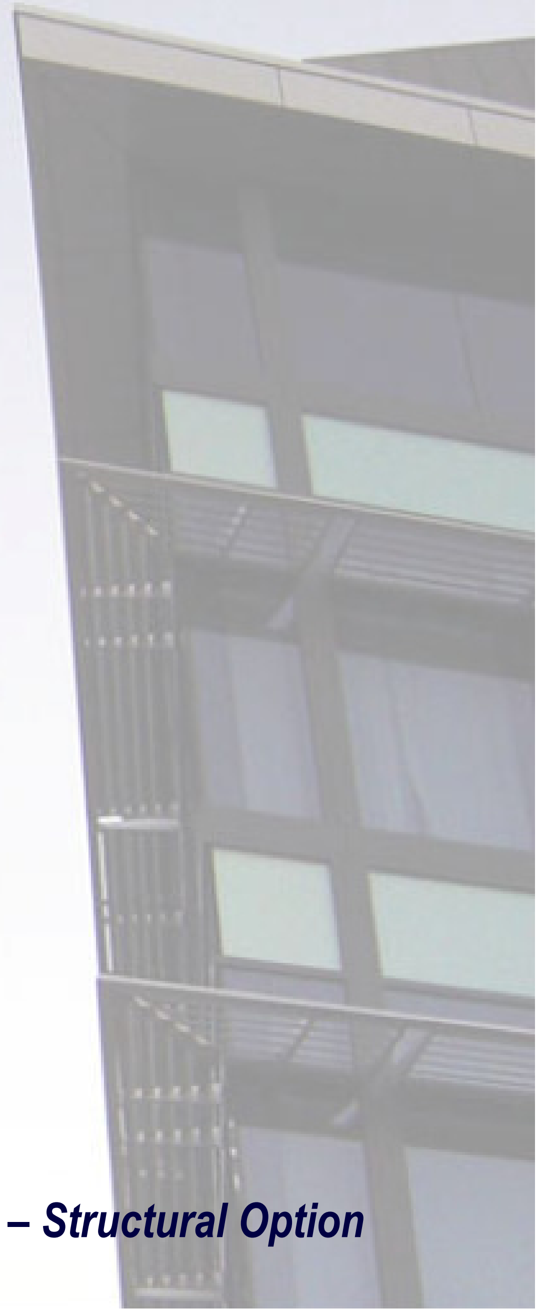
The Pennsylvania State University

University Park Campus



Presentation Outline

- Building Background
- Existing Building Structure
- Thesis Proposal
- Structural Redesign: Lateral
- Structural Redesign: Diaphragms
- Structural Redesign: Architectural Impacts
- Structural Redesign: Cost / Schedule Impacts
- Conclusions



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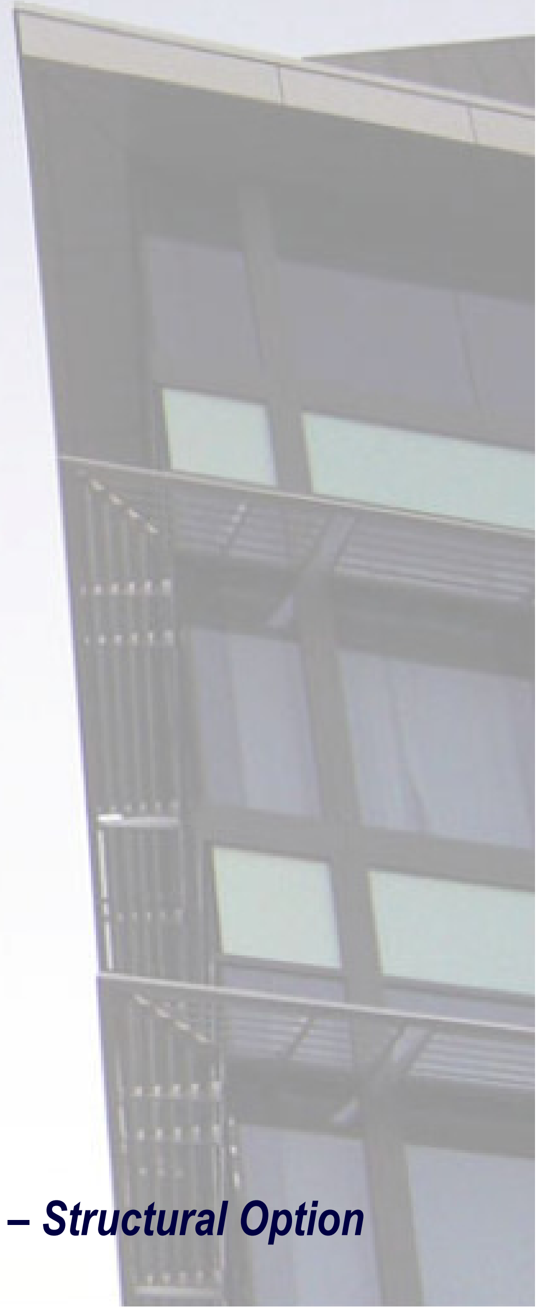
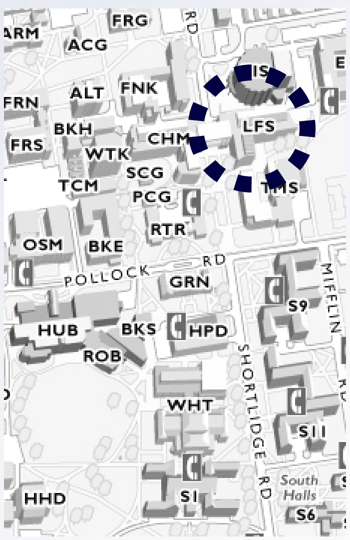


Building Background – Introduction

- Classrooms, Offices, Laboratories
- Basement + 5 Floors + Mechanical Penthouse
- Located on PSU – University Park Campus
- *Gateway to the Sciences* with Chemistry Building



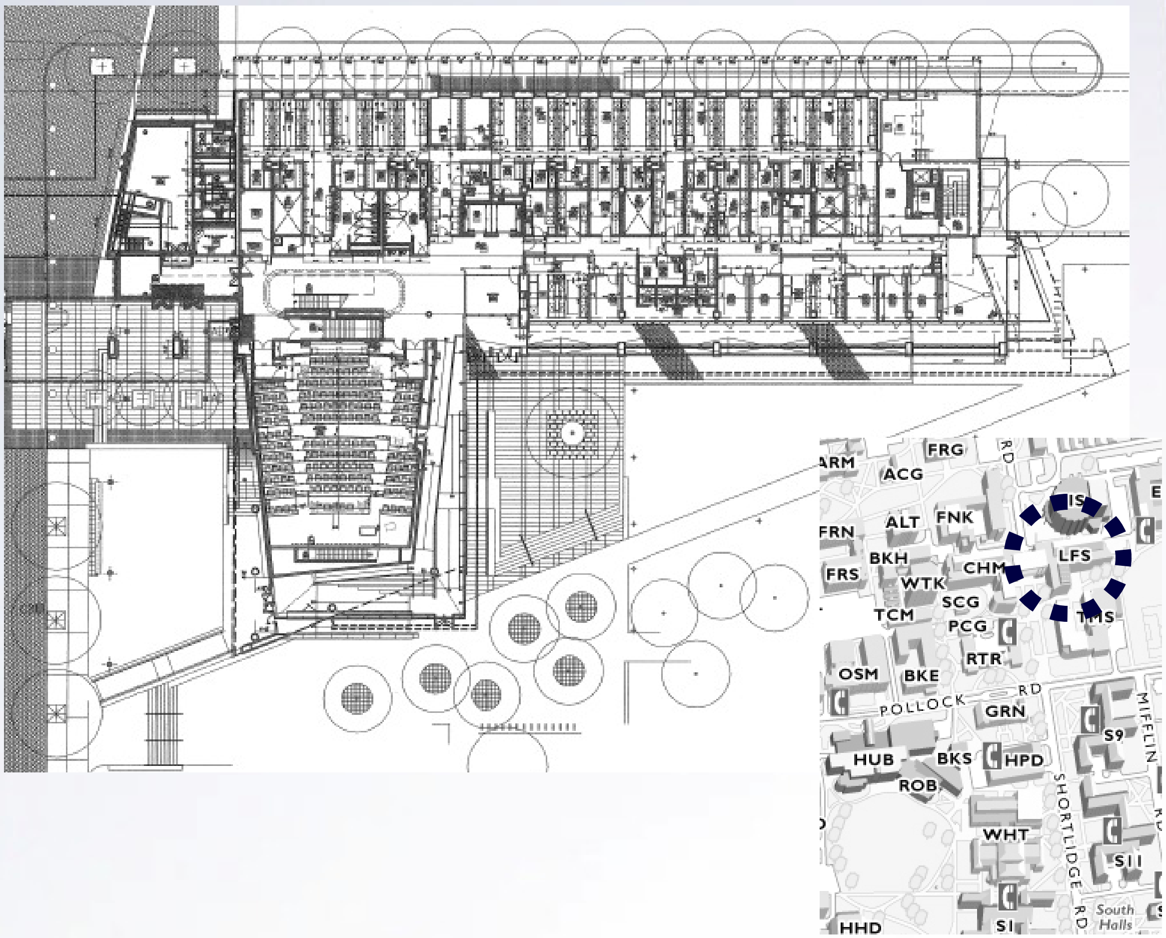
Building Background – Building Statistics

- 154,000 GSF (Basement + 5 Floors + Penthouse)
- Maximum Height Above Grade = 97’
- Maximum Height Above Seismic Base = 83’
- Project Duration: May 1999 - September 2004
- Construction Cost: $37,790,085



Building Background – Site Information

- Various finished grades surround building



Life Sciences Building

Kirk Stauffer – *Structural Option*

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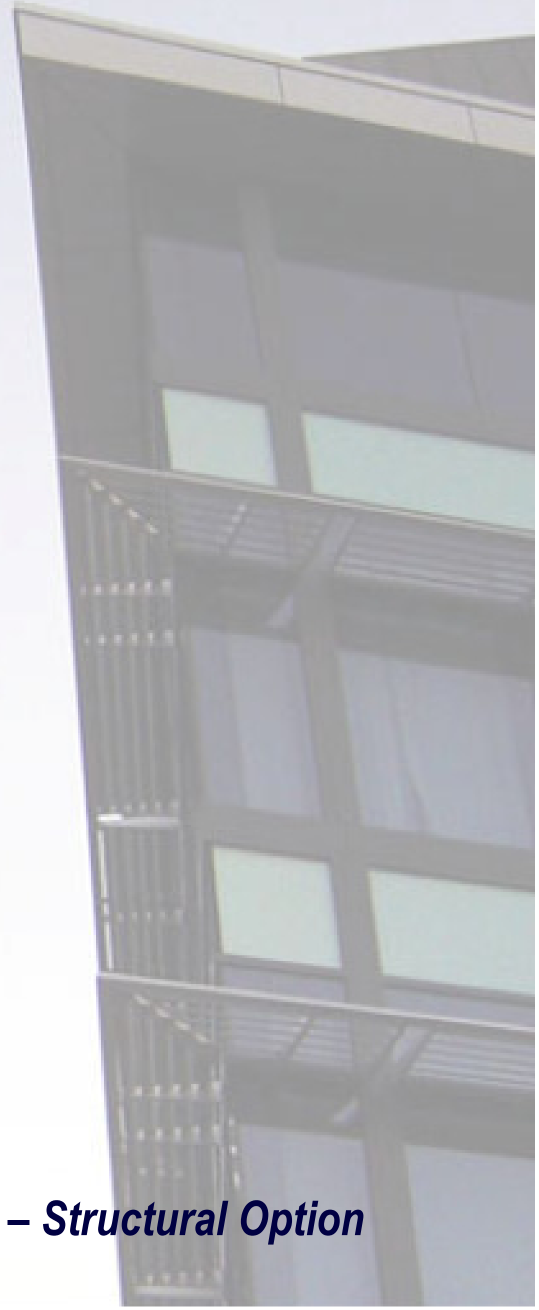
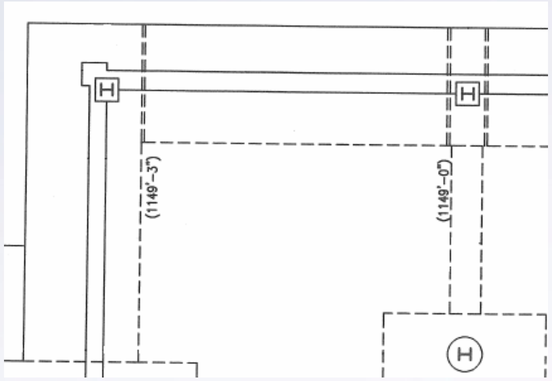


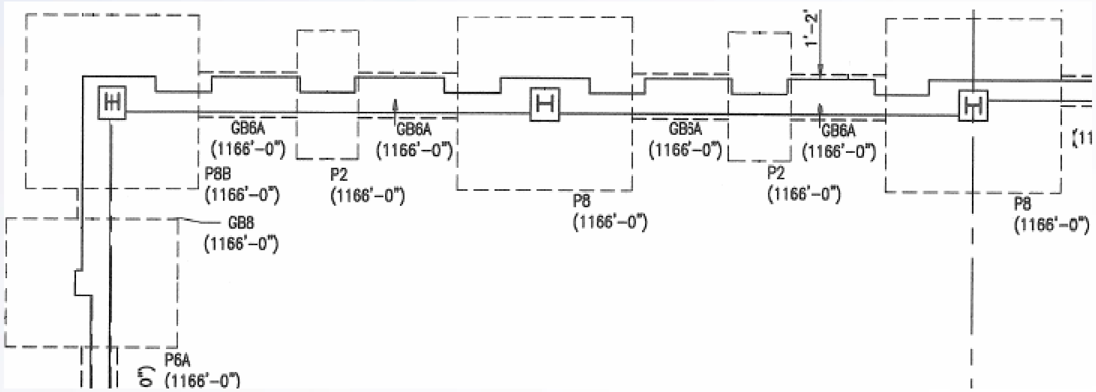
Existing Building Structure – Foundation

- Combination of several foundation systems.

Spread Footings

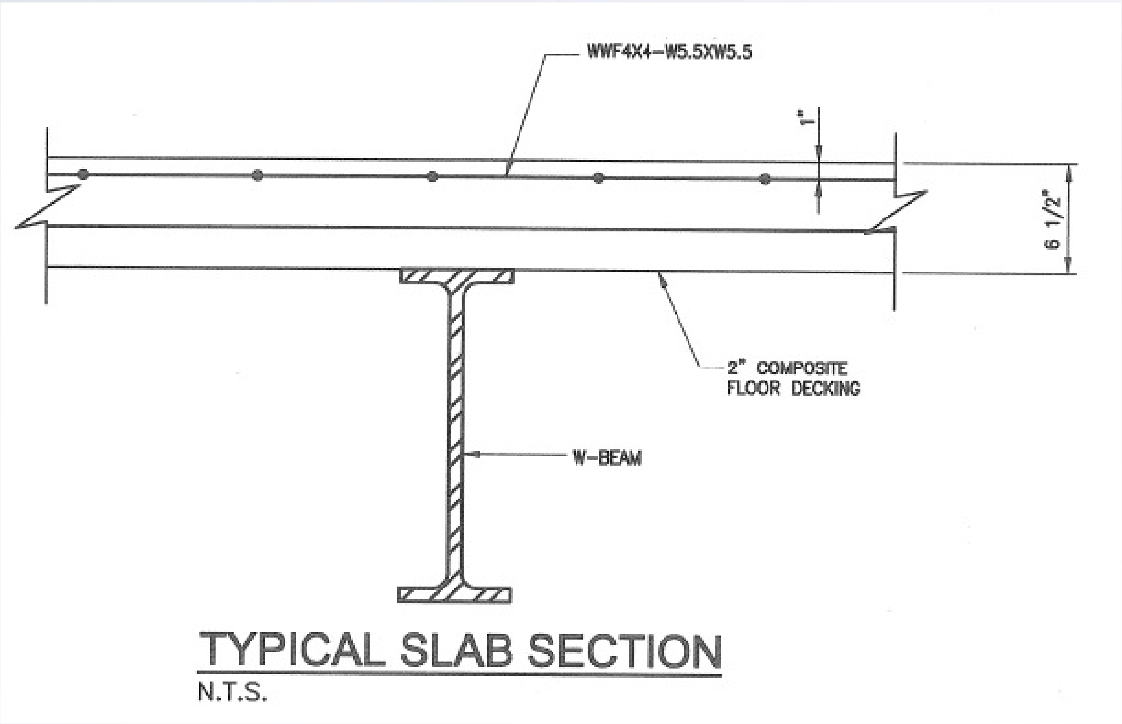


Steel H-Piles, Pile Caps, Grade Beams



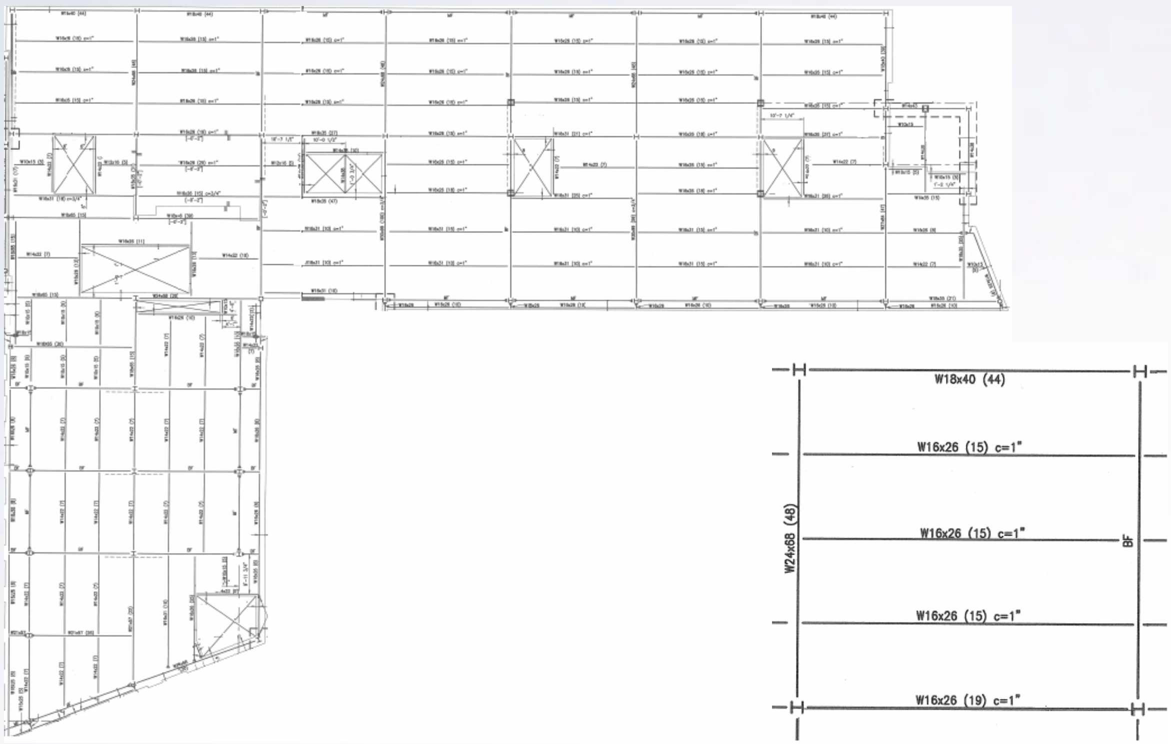
Existing Building Structure – Gravity System

- Basement and ground floor are slab on grade.
- Typically 2” composite steel deck with 4.5” of 4000 psi concrete cover on composite W-shapes.



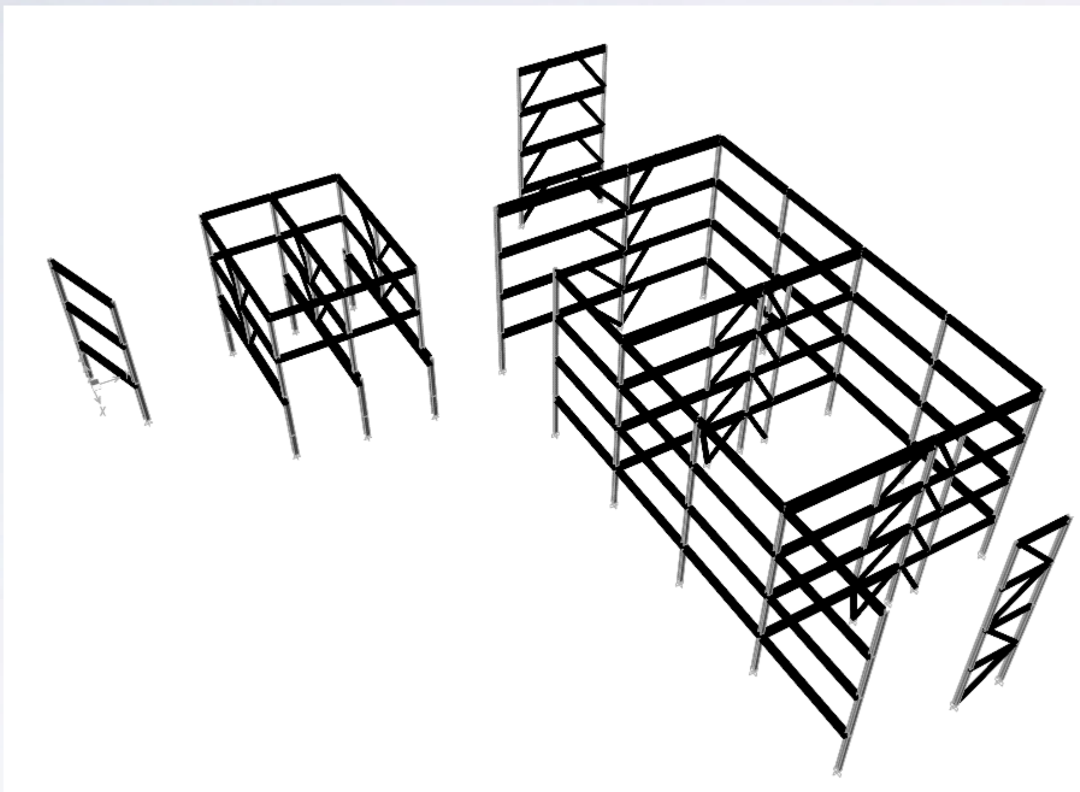
Existing Building Structure – Gravity System

- Typical gravity framing layout has composite steel beams with spans between 20’ and 30’ and a beam spacing of around 8’. Composite steel girders have spans between 20’ and 40’.



Existing Building Structure – Lateral System

- Existing lateral system was steel moment frames, eccentrically braced frames, and concentrically braced frames. 3D view below.



Existing Building Structure – Lateral System

- Existing lateral system was found to be unnecessarily complicated and inefficient.

- Condensed results of Technical Assignment III – Lateral System Analysis are shown below.

From Hand Analysis:	$V_{tot,e-w}$ = 217.11	
	Force (k)	Percentage
Moment Frame 1	56.21	25.9
Moment Frame 4	58.68	27.0
Hybrid Frame 5.3	9.24	4.3
Hybrid Frame 6	8.97	4.1
Hybrid Frame 7	8.84	4.1
Moment Frame 9	12.71	5.9
TOTAL E-W FRAMES	**154.65**	**71.2**
N-S Frames	**62.46**	**28.8**
Interior Columns 2.8	33.66	

From Hand Analysis:	$V_{tot,n-s}$ = 356.11	
	Force (k)	Percentage
Braced Frame C	81.76	23.0
Hybrid Frame C.2	0	0.0
Hybrid Frame D.8	0	0.0
Braced Frame E	17.91	5.0
Braced Frame G	113.14	31.8
Braced Frame J	88.85	25.0
Braced Frame K	50.48	14.2
TOTAL E-W FRAMES	**352.14**	**98.9**
E-W Frames	**3.97**	**1.1**

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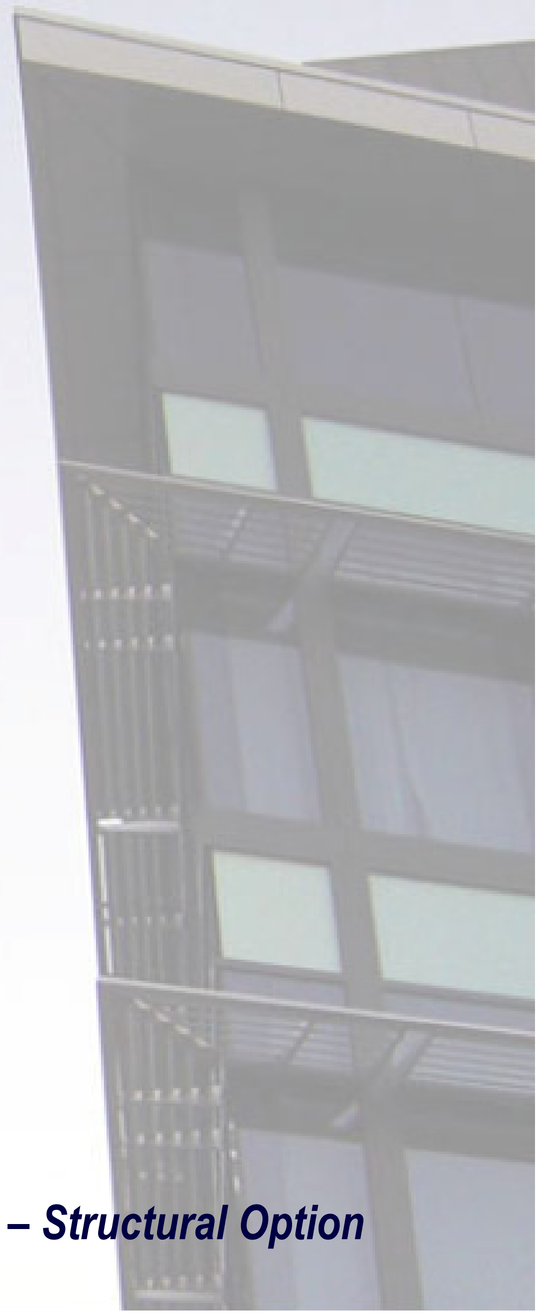


Thesis Proposal – Summary

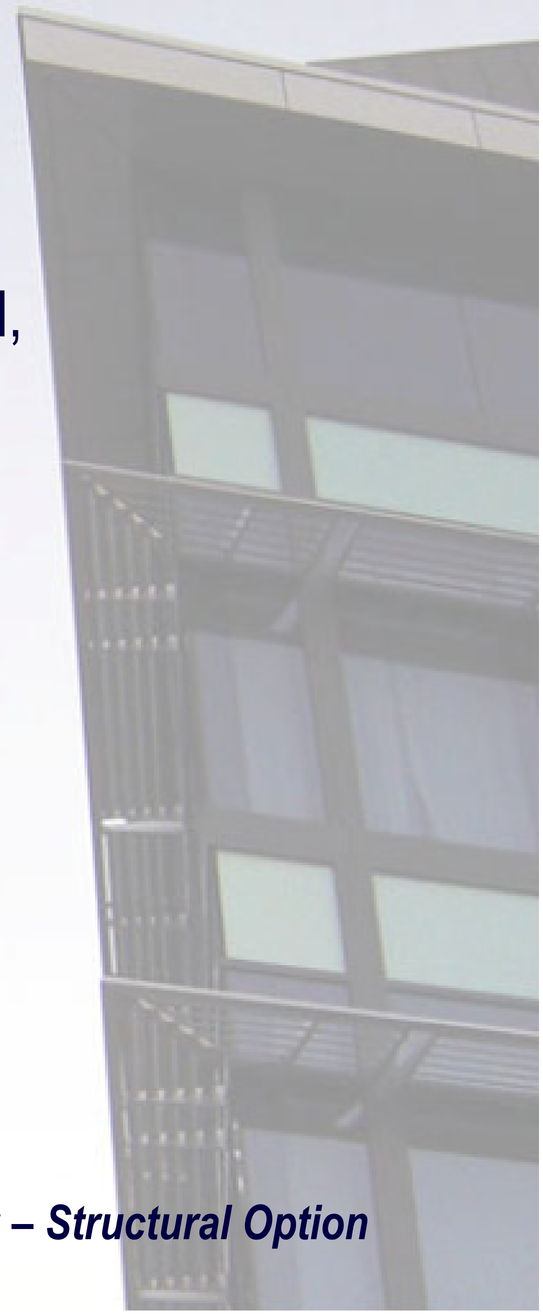
- Relocate building to Seismic Design Category “D”.
- Update design building code from BOCA 1996.
- Redesign lateral system to be more efficient.
- Redesign lateral system to be simpler.
- Verify gravity floor system can be left unchanged.
- Consider structural redesign architectural impact.
- Consider structural redesign cost / schedule impact.

Thesis Proposal – Goals

- Replace existing wind controlled lateral force resisting system with a redesigned lateral force resisting system that is simpler, more economical, and is capable of resisting seismic loads.

- Accomplish successful redesign with minimal changes to existing building architecture.

- Accomplish successful redesign with minimal changes to building cost / construction schedule.



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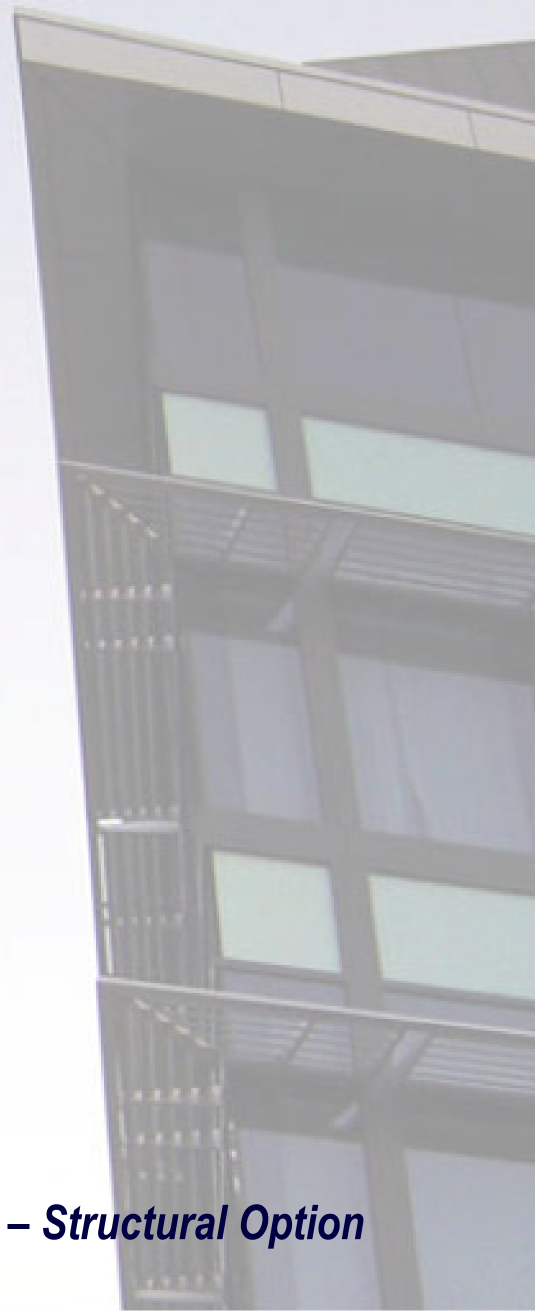


Structural Redesign: Lateral Force Resisting System

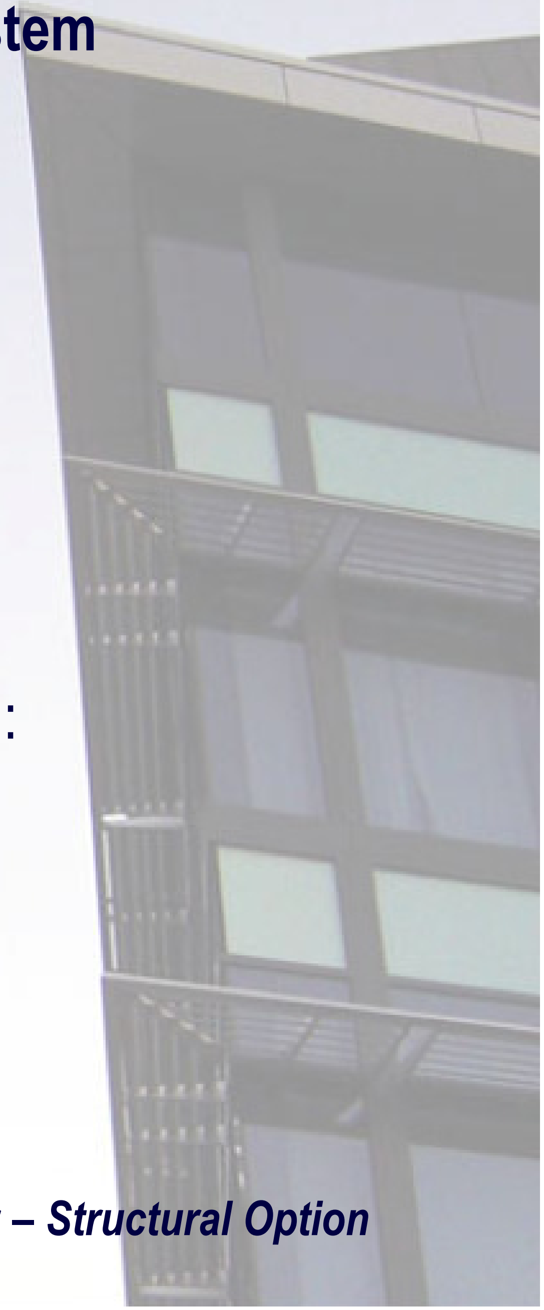
- New site for building with SDC "D" was found at University of Washington in Seattle, Washington.

$S_S = 1.298$
$S_1 = .442$

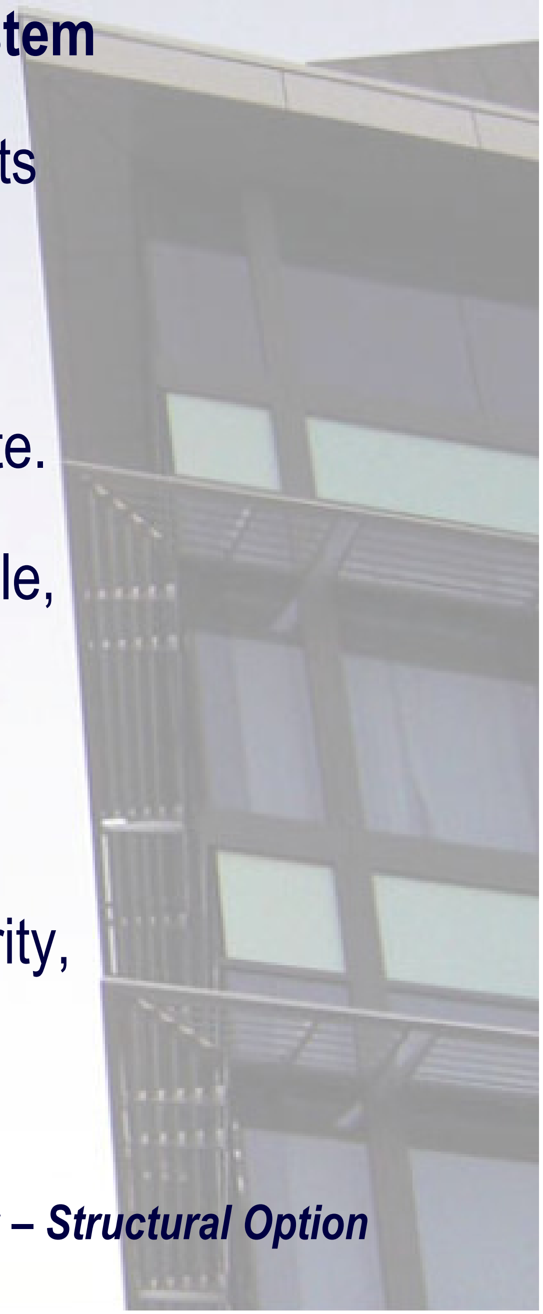
Life Sciences Building **Kirk Stauffer – *Structural Option***

Structural Redesign: Lateral Force Resisting System

- Site Class “C”
- S_S = 1.298, S_1 = .442
- S_{DS} = .865, S_{D1} = .400
- Seismic Design Category “D”
- Occupancy Category “III”, I = 1.25
- North – South Seismic Force Resisting System:
  Special Steel Concentrically Braced Frames
  $R = 6 \quad \Omega_O = 2 \quad C_d = 5.0 \quad \rho = 1.0$
- East – West Seismic Force Resisting System:
  Special Steel Moment Frames
  $R = 8 \quad \Omega_O = 3 \quad C_d = 5.5 \quad \rho = 1.0$



Structural Redesign: Lateral Force Resisting System



- Materials conforming to the stricter requirements of the AISC Seismic Provisions were used.

- All loads including dead, live, snow, wind, and seismic were recalculated for the new building site.

- The basic wind speed per ASCE 7-05 for Seattle, Washington was less than that of State College, Pennsylvania – seismic lateral forces controlled.

- Three irregularities could not be eliminated: Torsional Irregularity, Reentrant Corner Irregularity, Weight (Mass) Irregularity.

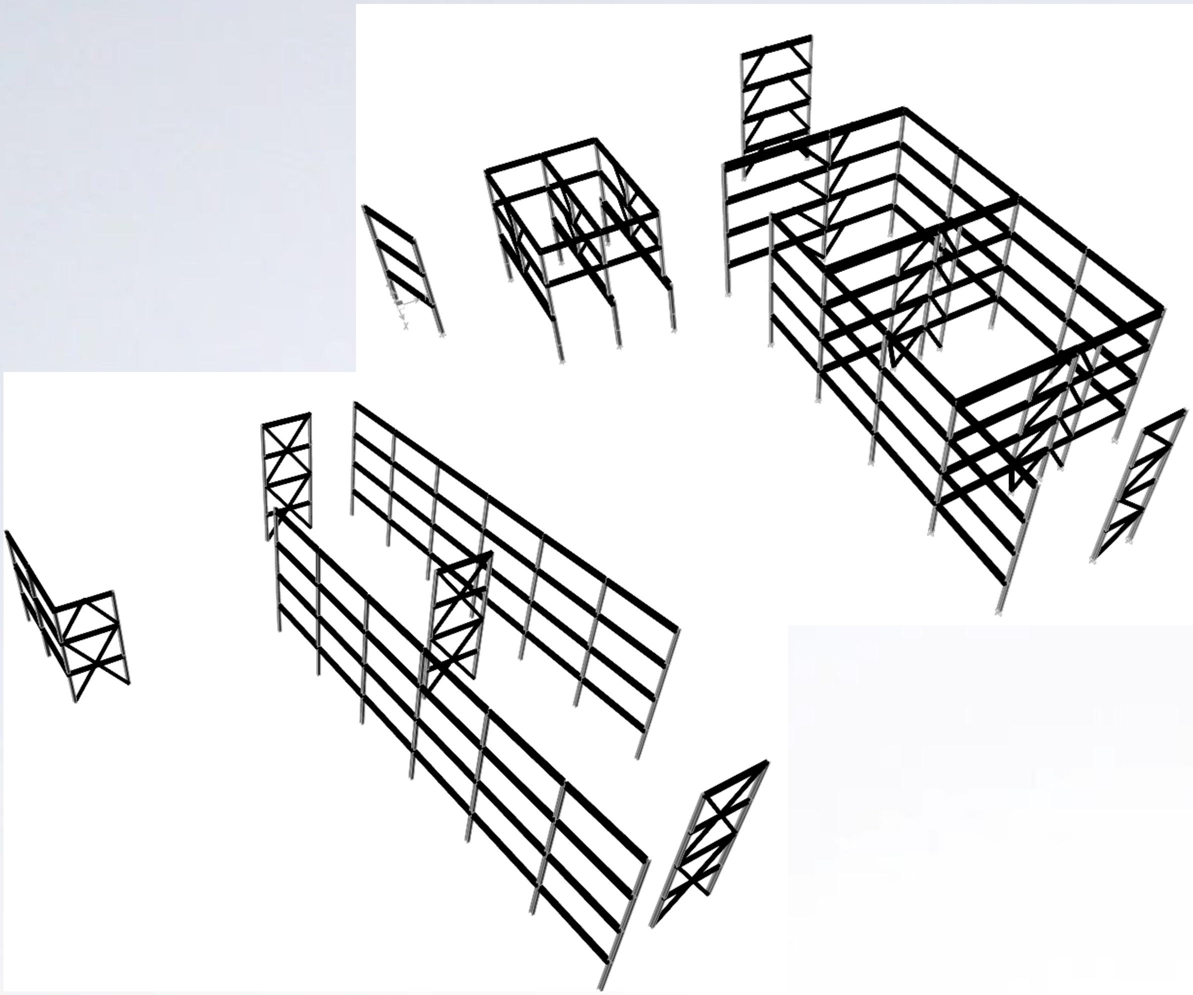
Structural Redesign: Lateral Force Resisting System

- Modal Response Spectrum Analysis was required due to the large number of structural irregularities.

- The ETABS model was used to determine: modal participation, P-delta effects, real periods, torsional effects, force distribution, and displacements.

MODALDISPX Uses real period T = 2.051 s Scaled to equal $V_{Real\ Period}$ * (Cd / I) Participation = 99.99% > 90%	**MODALDISPY** Uses real period T = .770 s Scaled to equal $V_{Real\ Period}$ * (Cd / I) Participation = 99.93% > 90%
MODALFORCEX Uses approx. period T_a = 1.344 s Scaled to equal V_{ELF} * .85 Participation = 99.99% > 90%	**MODALFORCEY** Uses approx. period T_a = .882 s Scaled to equal V_{ELF} * .85 Participation = 99.93% > 90%

Structural Redesign: Lateral Force Resisting System



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Structural Redesign: Lateral Force Resisting System

- For Special Moment Frames, beam design emphasis focused on Reduced Beam Section moment connections.

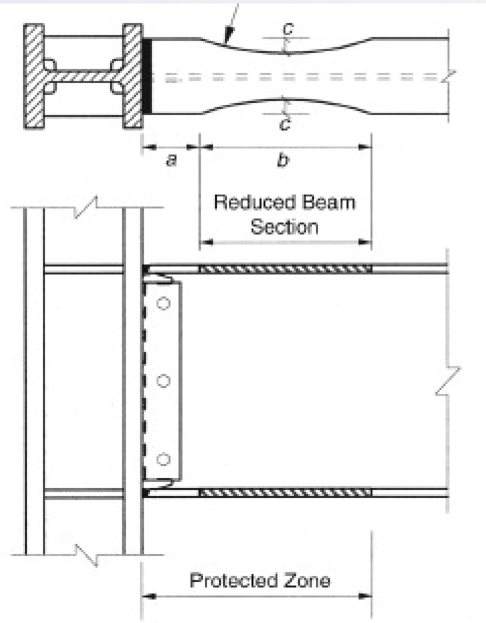


Fig. 5.1. Reduced beam section connection.

Structural Redesign: Lateral Force Resisting System

- For Special Moment Frames, column design emphasis focused on the Beam – Column Moment Ratio.

Column-Beam Moment Ratio

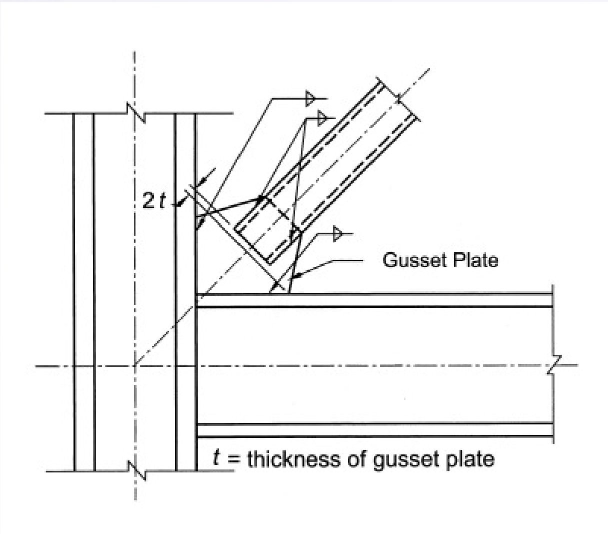
The following relationship shall be satisfied at beam-to-column connections:

$$\frac{\Sigma M^*_{pc}}{\Sigma M^*_{pb}} > 1.0 \tag{9-3}$$

Structural Redesign: Lateral Force Resisting System

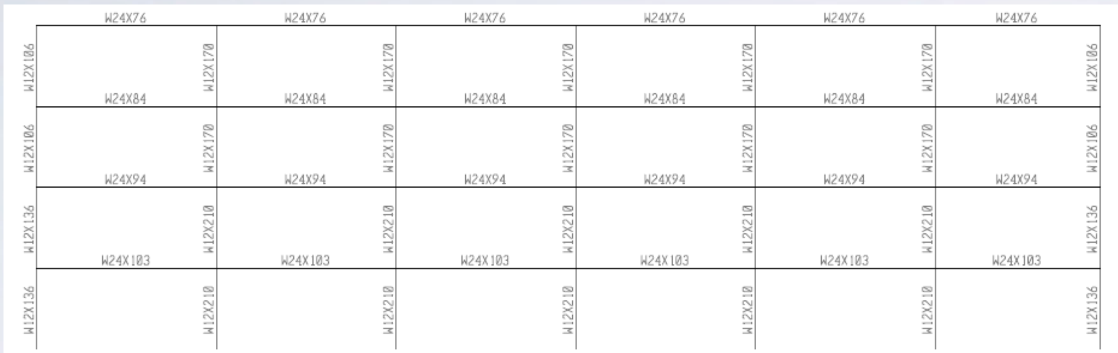
- For Special Concentrically Braced Frames, the design emphasis was on the detailing of the gusset plates.

- Emphasis was also placed on the slenderness of the bracing.

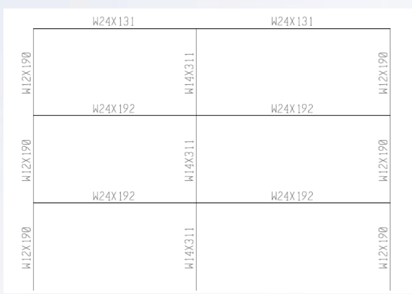


Structural Redesign: Lateral Force Resisting System

- Typical Special Moment Frame elevations are represented below:



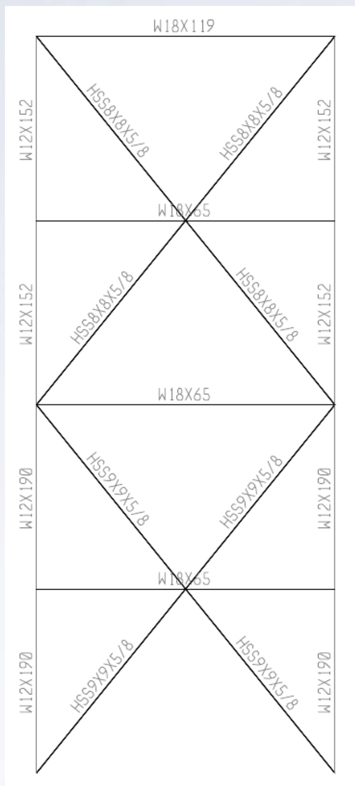
SMF 1 & 4



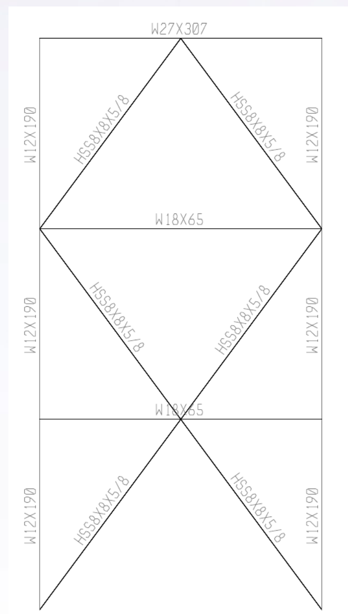
SMF 8

Structural Redesign: Lateral Force Resisting System

- Typical Special Concentrically Braced Frame elevations are represented below:



SCBF C, G, K.6



SCBF E

Structural Redesign: Lateral Force Resisting System

- The redesigned lateral force resisting system was designed to and met all of the requirements of:
  - ASCE 7-05
  - AISC 360-05
  - AISC 341-05
  - AISC 358-05
- The story drifts were less than the allowed 2.52”

$\Delta_{4,NS}$ = 1.6098”	$\Delta_{4,EW}$ = 1.8814”
$\Delta_{3,NS}$ = 1.5091”	$\Delta_{3,EW}$ = 1.9942”
$\Delta_{2,NS}$ = 1.5352”	$\Delta_{2,EW}$ = 1.9707”
$\Delta_{1,NS}$ = .9598”	$\Delta_{1,EW}$ = 1.4832”

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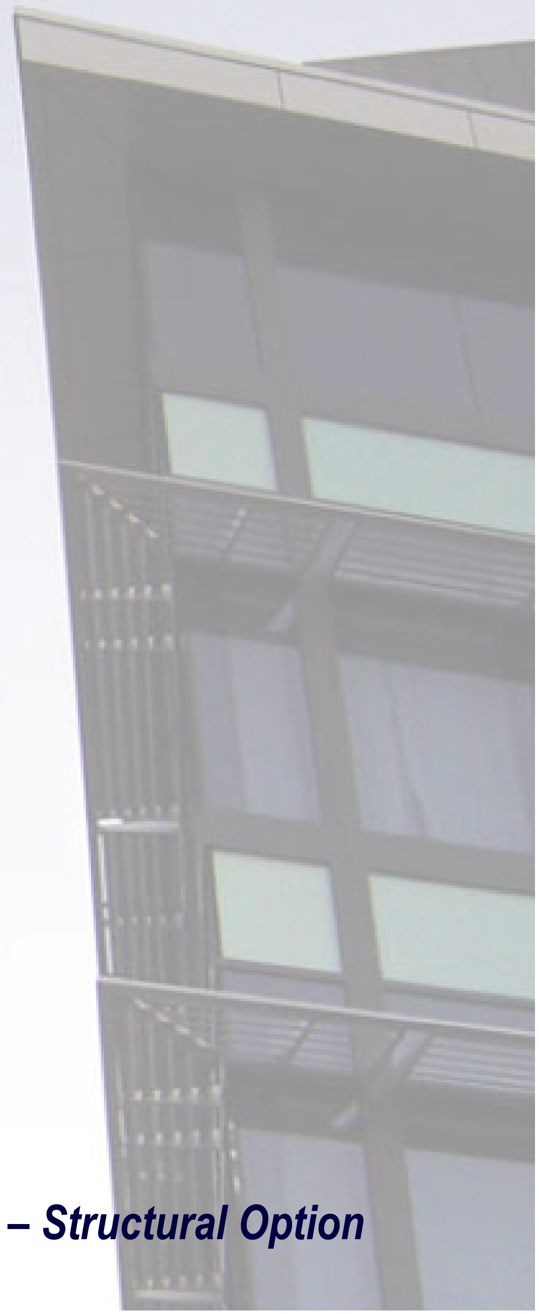


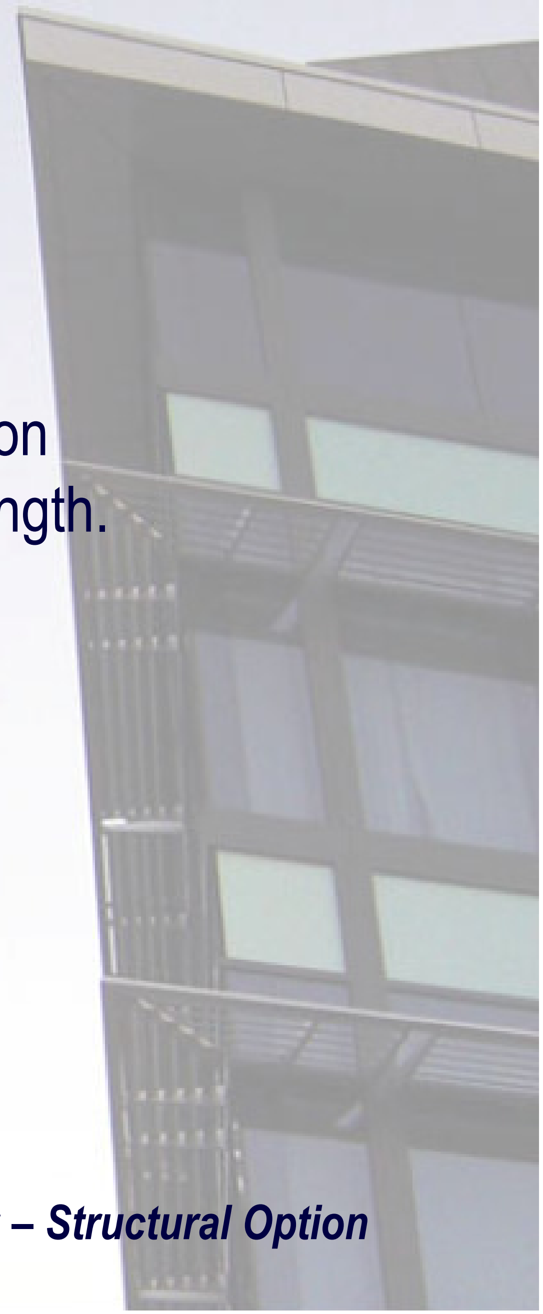
Structural Redesign: Diaphragms

- The existing slab on composite steel deck was checked to verify that it would be an acceptable diaphragm for the increased seismic forces.

- The SDI – Diaphragm Design Manual, 3rd Edition was used as a reference to determine shear strength.

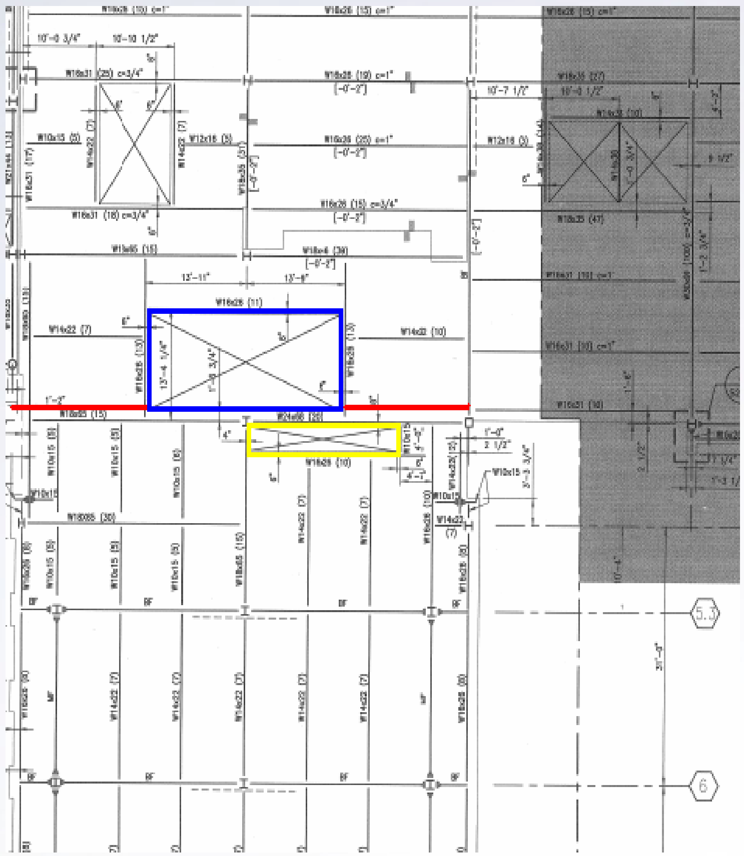
- The diaphragm was checked at every location where it tied into a lateral force resisting frame.

- The diaphragm was also checked at a critical location at the reentrant corner of the building where an opening occurred.



Structural Redesign: Diaphragms

- The critical location where the diaphragm was checked is illustrated below (V = 900 plf):



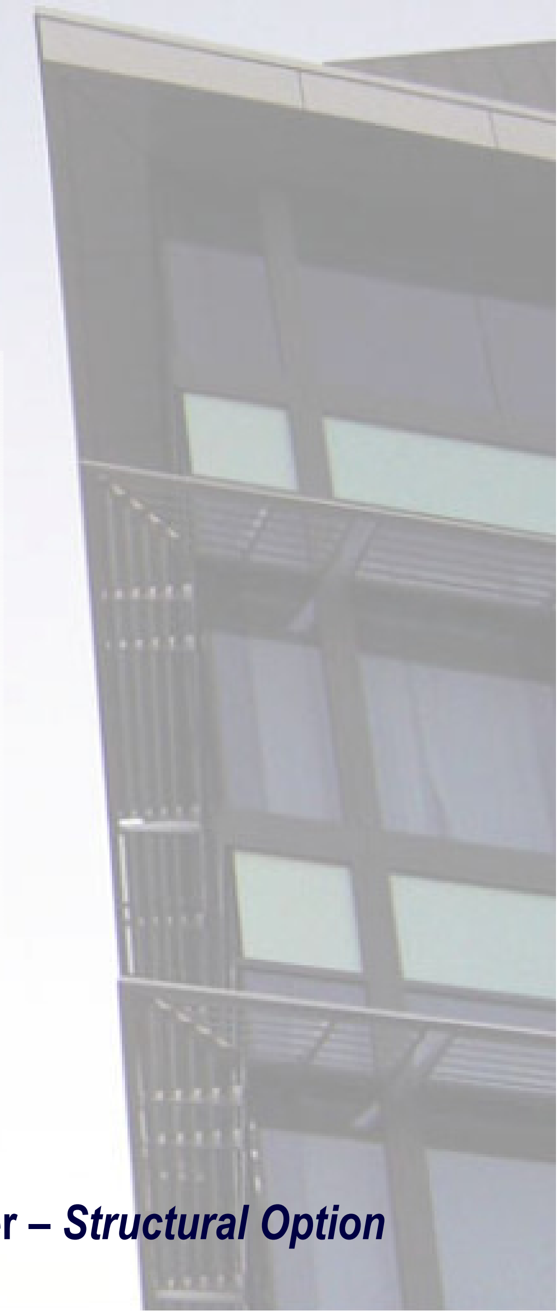
Structural Redesign: Diaphragms

- After collector elements were determined to be needed and added to the SCBFs the diaphragm forces were calculated.

PENTHOUSE DIAPHRAGM				
E-W Frames	***%***	***Shear***	***Length***	***Unit Shear***
SMF - 1	51.5	599.1	186.0	**3220.7 plf**
SMF - 4	48.5	564.2	245.5	**2298.0 plf**
N-S Frames				
SCBF - C	36.2	448.4	72.0	**6227.6 plf**
SCBF - G	29.8	369.1	144.0	**2563.3 plf**
SCBF - K.6	34.0	421.1	72.0	**5849.1 plf**

TYPICAL FLOOR DIAPHRAGM				
E-W Frames	***%***	***Shear***	***Length***	***Unit Shear***
SMF - 1	38.9	260.9	186.0	**1402.9 plf**
SMF - 4	35.3	236.8	245.5	**964.5 plf**
SMF - 8	25.8	173.1	57.0	**3036.3 plf**
N-S Frames				
SCBF - C	22.4	150.3	72.0	**2087.0 plf**
SCBF - E	23.7	159.0	84.7	**1877.8 plf**
SCBF - G	22.8	152.9	144.0	**1062.1 plf**
SCBF - K.6	31.1	208.6	72.0	**2897.5 plf**

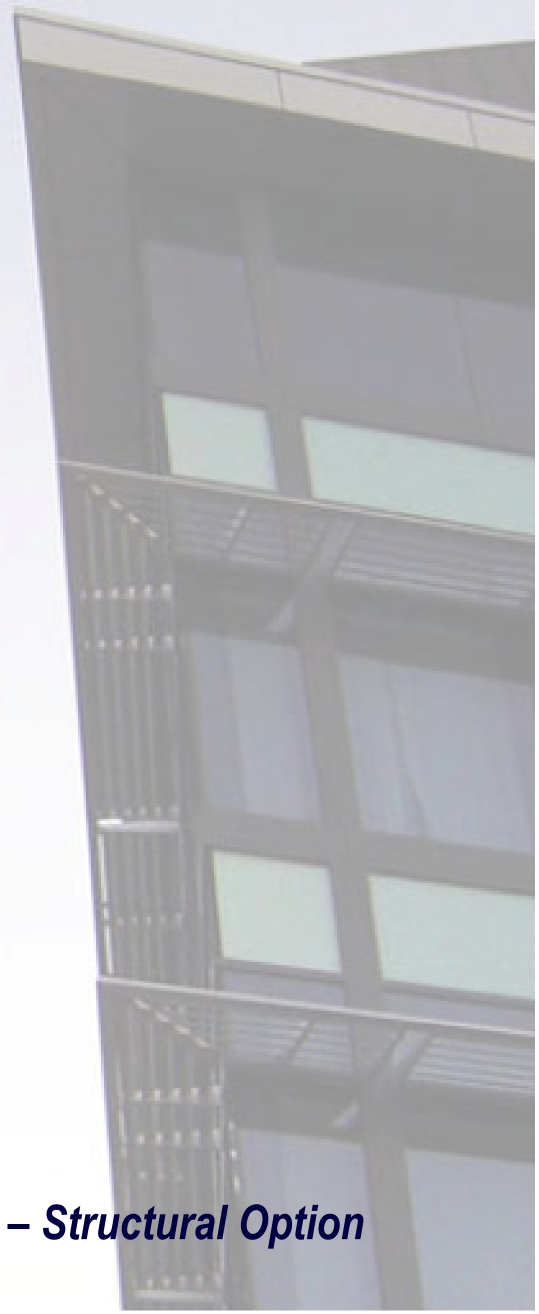
- All forces are below the allowable unit shear of (V = 6115 plf).



Structural Redesign: Diaphragms

- The final design of the diaphragm was determined to be:

2” Composite Metal Deck, 18 gage (t = .0474”)
4.5” Normal Weight Concrete Topping, f’c = 4000 psi
WWF4x4 – W5.5 x W5.5
Span = 10’ (maximum)
8 Side Lap Welds per Span, 5/8” Puddle or 1-1/2” Fillet
1 Structure Weld per 1’ of Bearing, 5/8” Puddle



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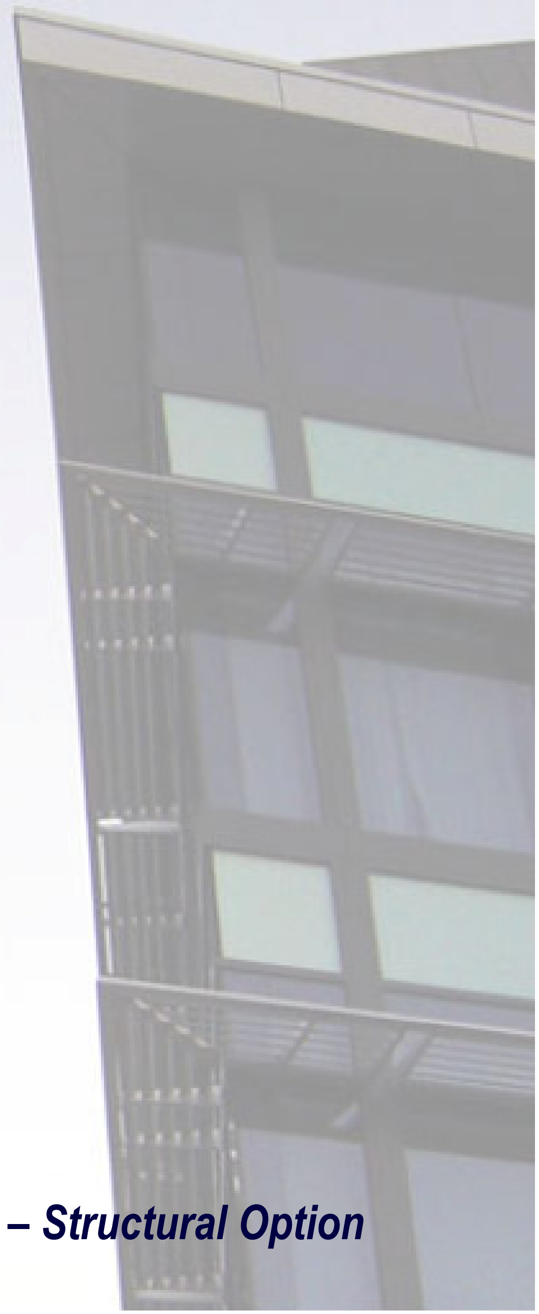
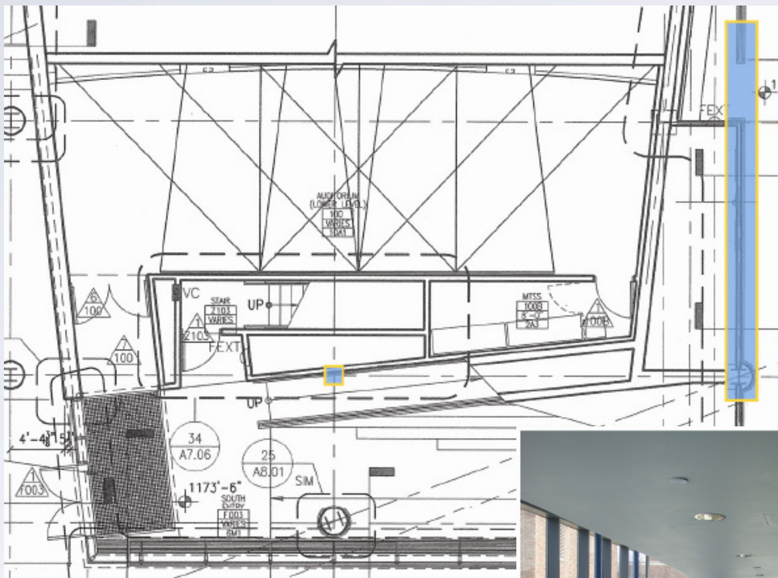
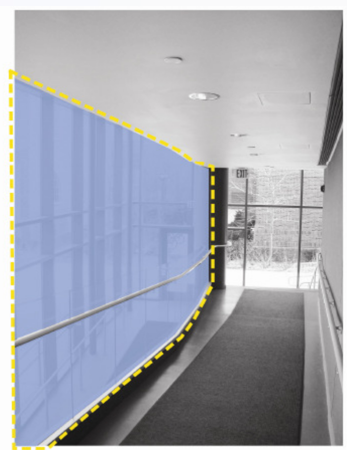
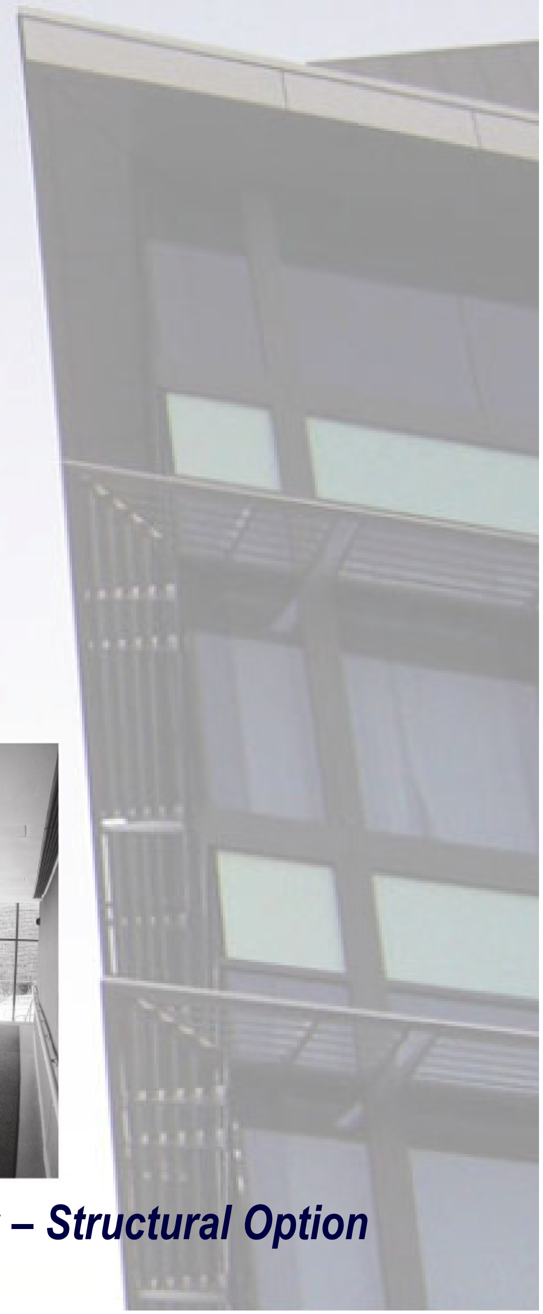


Structural Redesign: Architectural Impacts

- Accomplish successful redesign with minimal changes to existing building architecture.







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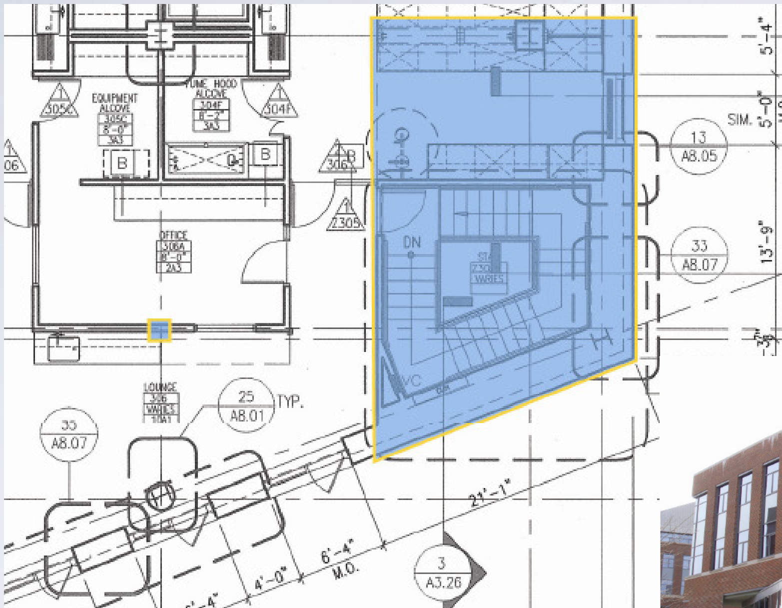

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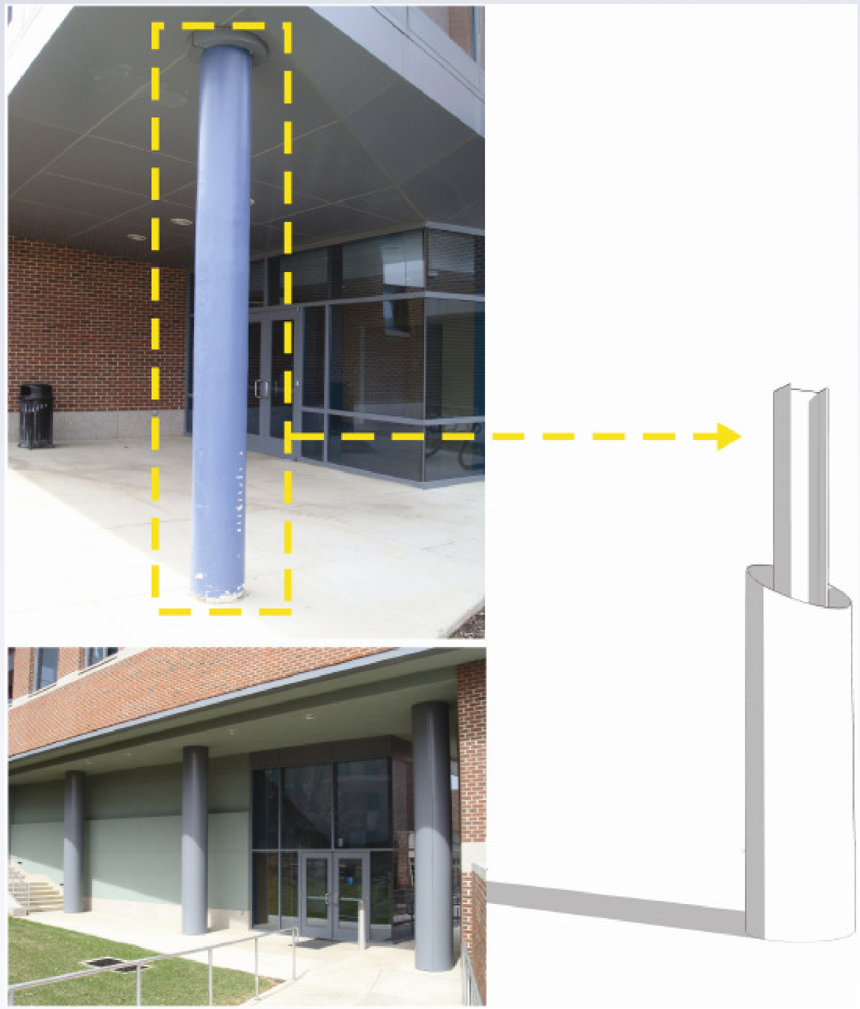
Structural Redesign: Architectural Impacts



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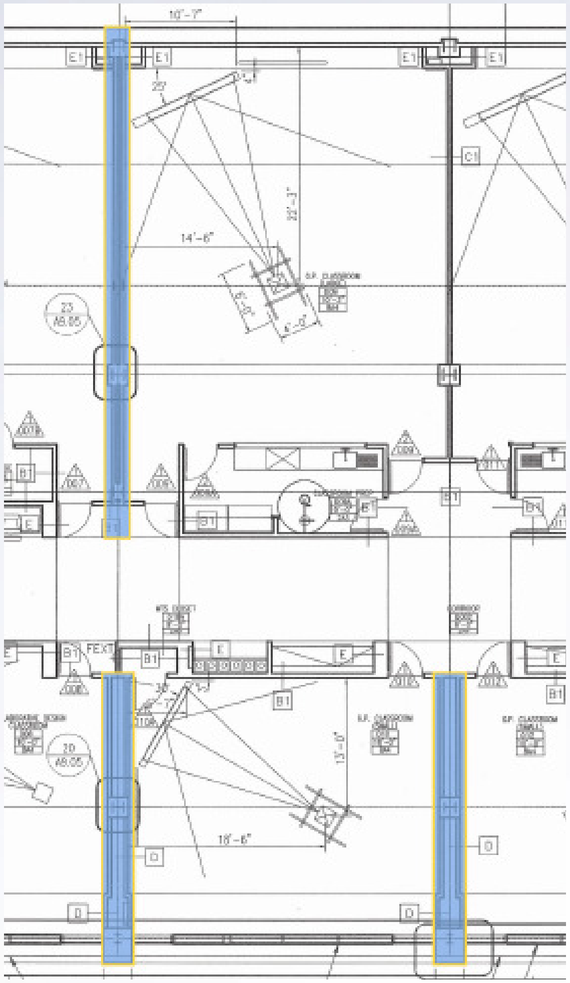

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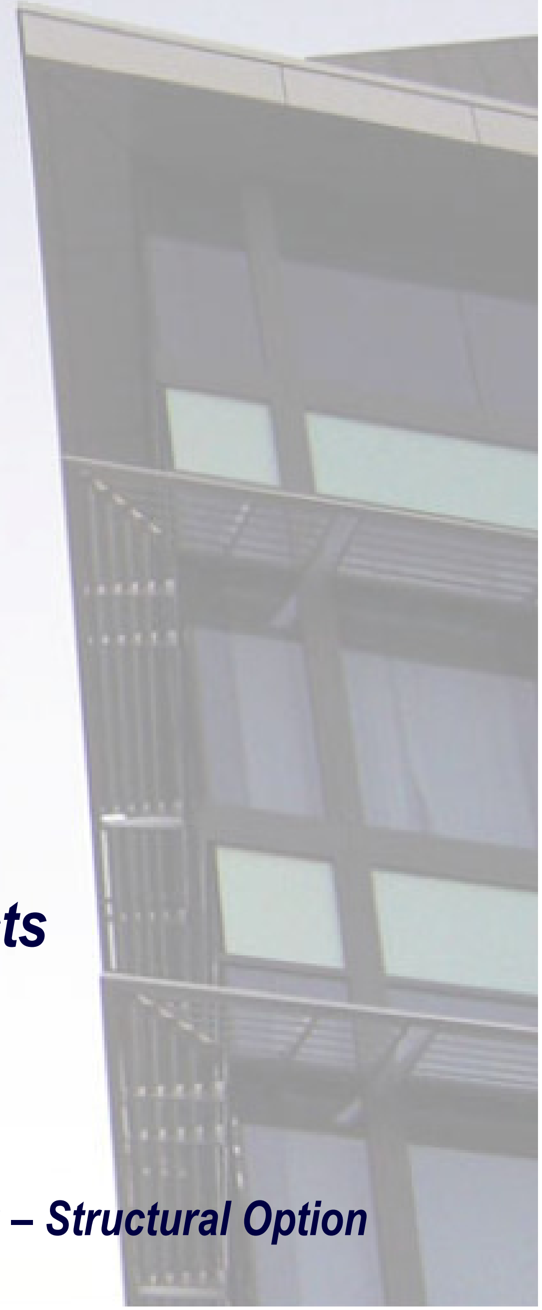


Structural Redesign: Cost / Schedule Impact

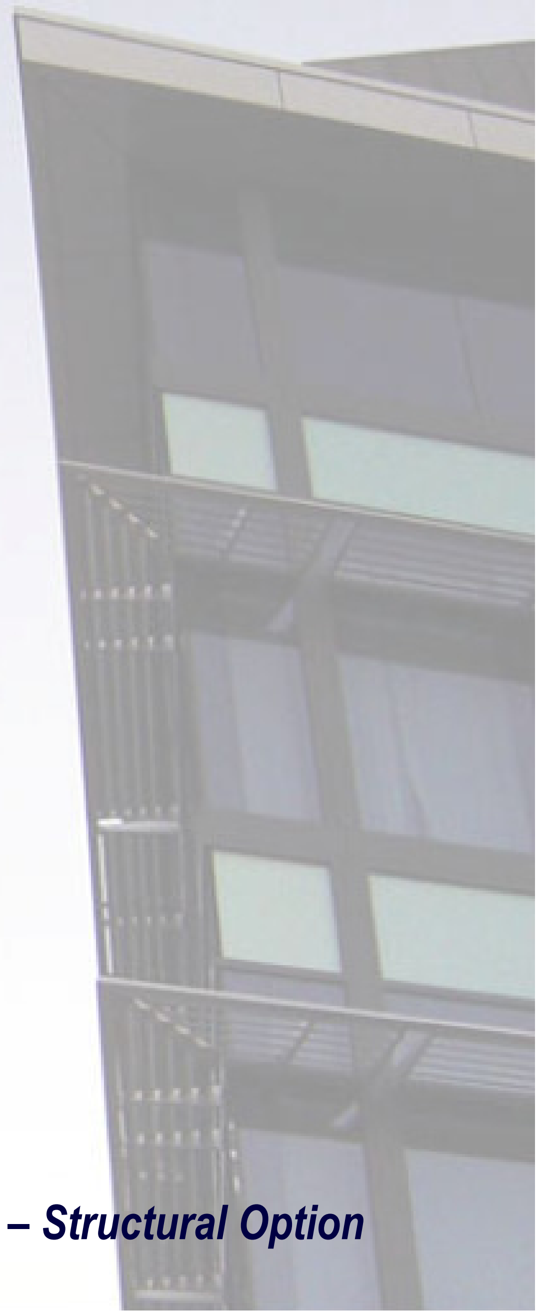
- Accomplish successful redesign with minimal changes to building cost / construction schedule.

New Steel LFRS: $764,496
New Concrete Shear Walls: $161,241

Redesign (Seismic) LFRS = $925,737

Existing (Wind) LFRS = $612,441

Redesign LFRS = + $313,296



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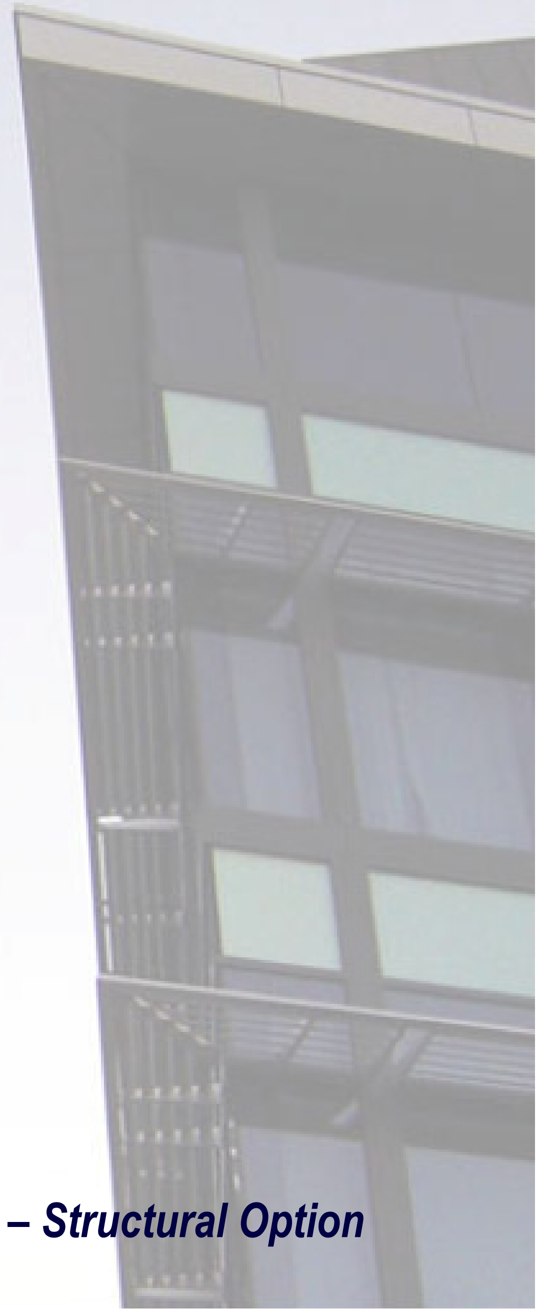


Conclusions

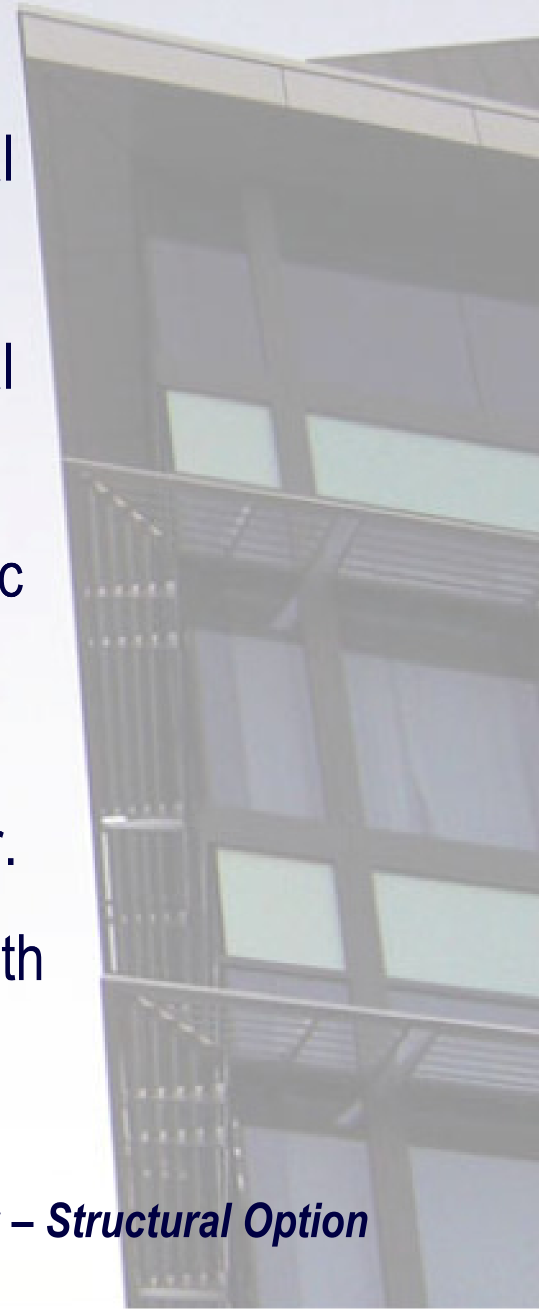
- Accomplishes successful redesign with minimal changes to building cost / construction schedule.

- Accomplishes successful redesign with minimal changes to building architecture.

- Lateral system was redesigned to resist seismic forces with less members and connections.

- Lateral system uses more steel and concrete – however the lateral system is also much stronger.

- Diaphragm assembly can be left unchanged with the addition of collector elements.



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Architectural Engineering Students

Notably Nasser Marafi, Tom Yost, Lee Ressler, and especially Phil Frederick, who constantly went out of his way to help me.

My Friends Who Are Architecture Majors

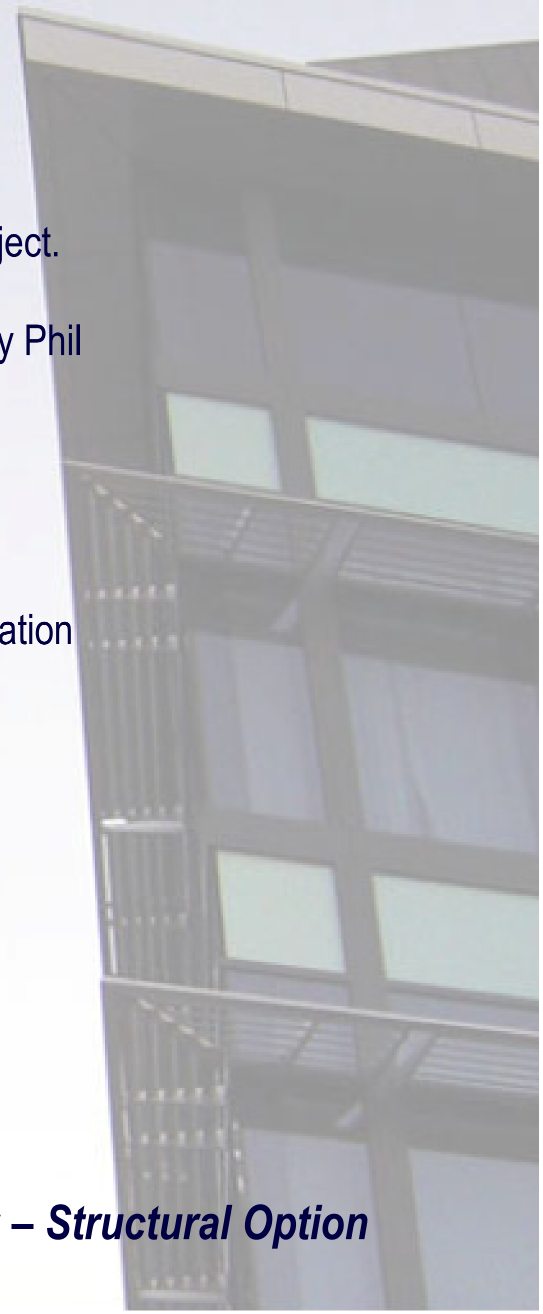
Especially Keith Labutta who was my primary consultant for anything graphic or architecture related.

Penn State Office of the Physical Plant

Especially Lisa Berkey who provided me with all of the information and insight into the Life Sciences Building for this project.

My Family and God

For making my life to this point a pleasant reality.



Questions?