Mike Steehler

Structural Focus

2007 Senior Thesis Capstone Project

Advisor: Prof. Kevin Parfitt

University of Rochester Biomedical Engineering / Optics Building

River Campus Rochester, NY

Presentation Outline

Project Background

- Brief History
- Architecture
- Key Players

Original Structural Design

- Foundations
- Composite Steel Framing
- Braced Frames / Moment Frames

Problem Statement / Proposal

Structural Redesign

- Redesign Ideas Considered
- Cast-In-Place Concrete Flat Slab
- Concrete Columns
- Reinforced Concrete Shear Walls
- Notable Advantages

Cost & Scheduling Effects

Green Building Design

- ETFE Foil Cushion as a “Green” Technology
- Application for BMEO Atrium Roof

Recommendation / Conclusions

Project Background

•*Project Background*

• Original Structural Design

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• Cost & Scheduling Effects

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• Recommendation & Conclusions

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The Institute of OPTICS

- Founded in 1929 as the first optics education program in the United States
- Has expanded into a diverse spectrum of studies, including Biomedical Optics, Fiber Optics, and Nano Optics to name a few
- This world-class institute will combine with the Biomedical Engineering Department to occupy a new, 100,000 square foot facility
- New facility will be an add-on to the existing Wilmot Hall

The New Facility

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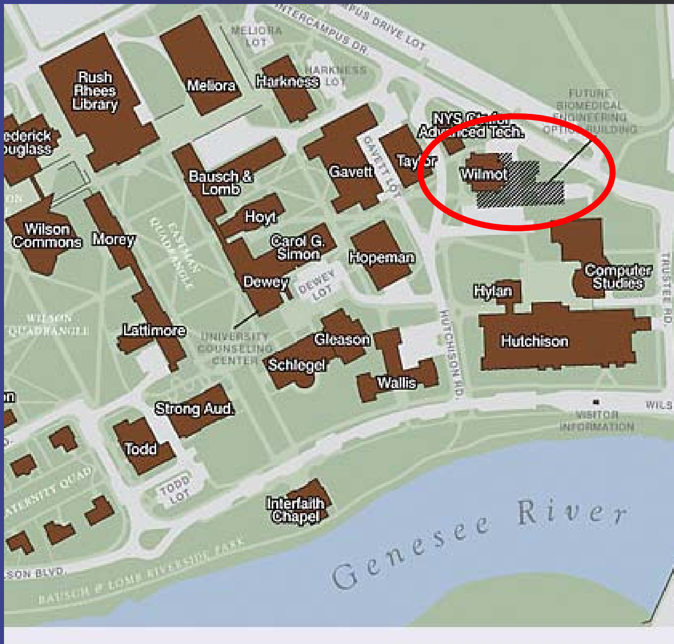
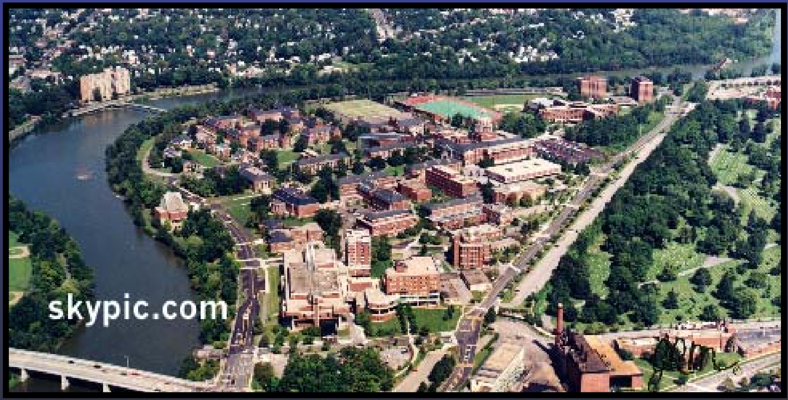
- U of R's scenic River Campus
  - Near Medical Center
  - Adjacent to Wilmot Hall
- 101,000 square feet
- Five stories + mechanical penthouse and partial basement
- $37.7 million total project cost
- Construction began January 2005
- Officially named "Goergen Hall" for the generous contributions of Robert B. Goergen





- Laboratory space
- Offices
- Classrooms
- Large, 155 seat lecture hall

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Key Players

Architect
Perkins & Will
Boston, MA

Structural Engineer
LeMessurier Consultants
Cambridge, MA

Associate Architect/
Structural Engineer
SWBR Architects & Engineers, P.C.
Rochester, NY

General Contractor
LeChase Construction, LLC
Rochester, NY

•*Project Background*

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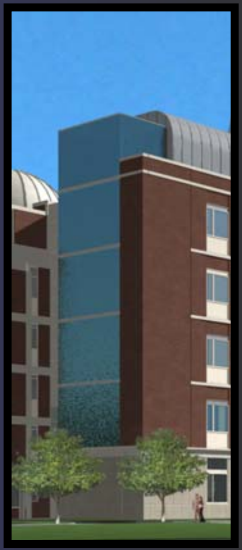
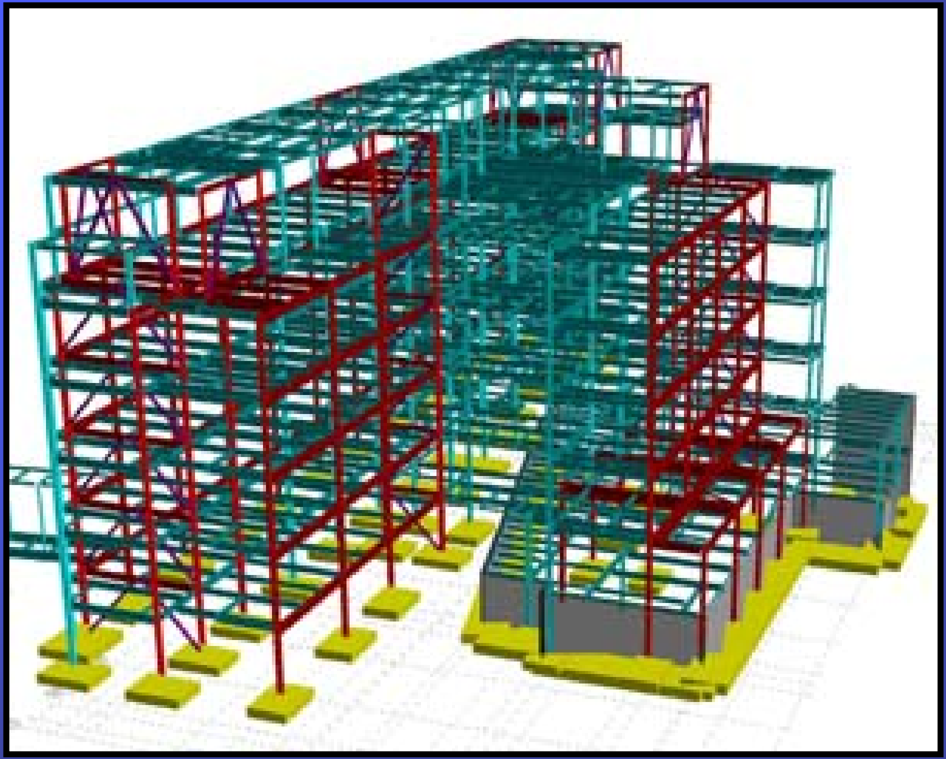
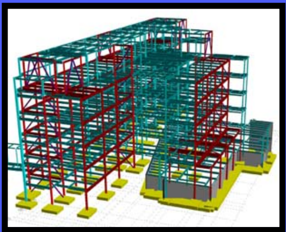
Architectural Features

- Standard red brick façade
  - Metal stud backup
  - Limestone at first floor
- Large atrium inside main entrance
  - 80+ feet tall
  - Lit by skylights
- Channel glass façade at stairwells
- Glass curtain wall at main entrance





Original Structural Design



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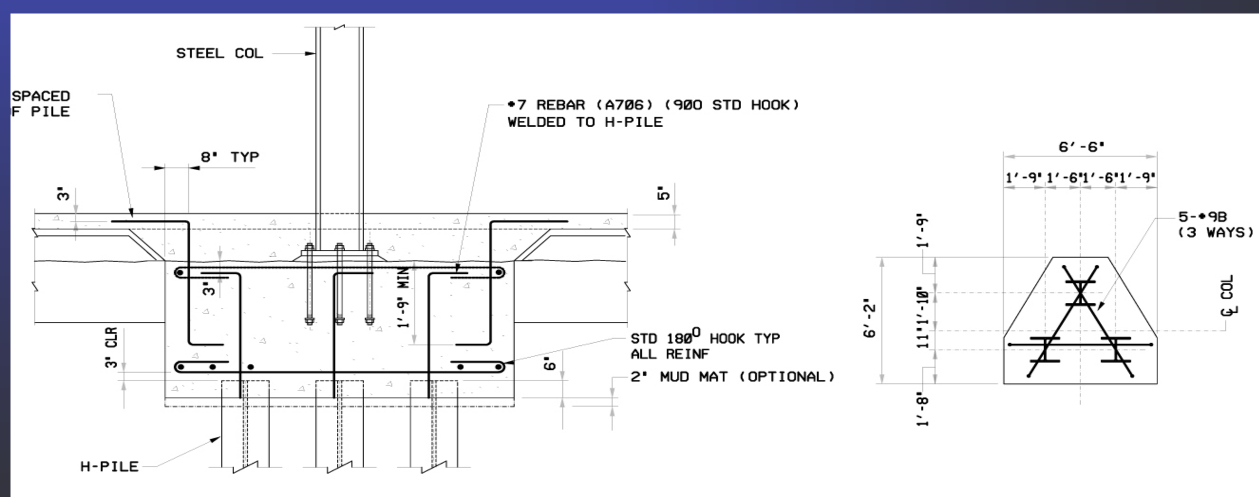
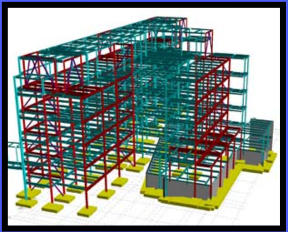
Foundation

- 50 ksi steel H-piles
  - Bearing on Bedrock
  - Various Configurations
- 4000 psi Grade Beams
  - 16” x 48” supporting exterior walls
  - Framing around existing steam tunnel





Floor System

- Project Background
- ***Original Structural Design***
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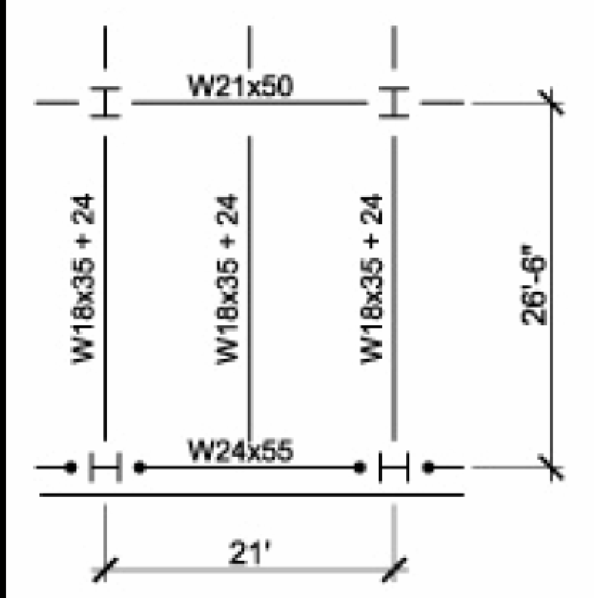
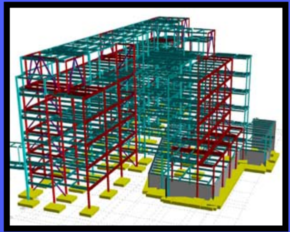
- Composite steel construction
- 4 ½" concrete slab on 3" metal deck (7 ½" total depth)
- ¾ diameter shear studs, full composite action
- Irregular geometric shape – no "typical bay" redundancy
- 21' x 26'-6" bays along west face can be considered the critical condition
- Supported by W12 columns



Critical Bay

Floor System



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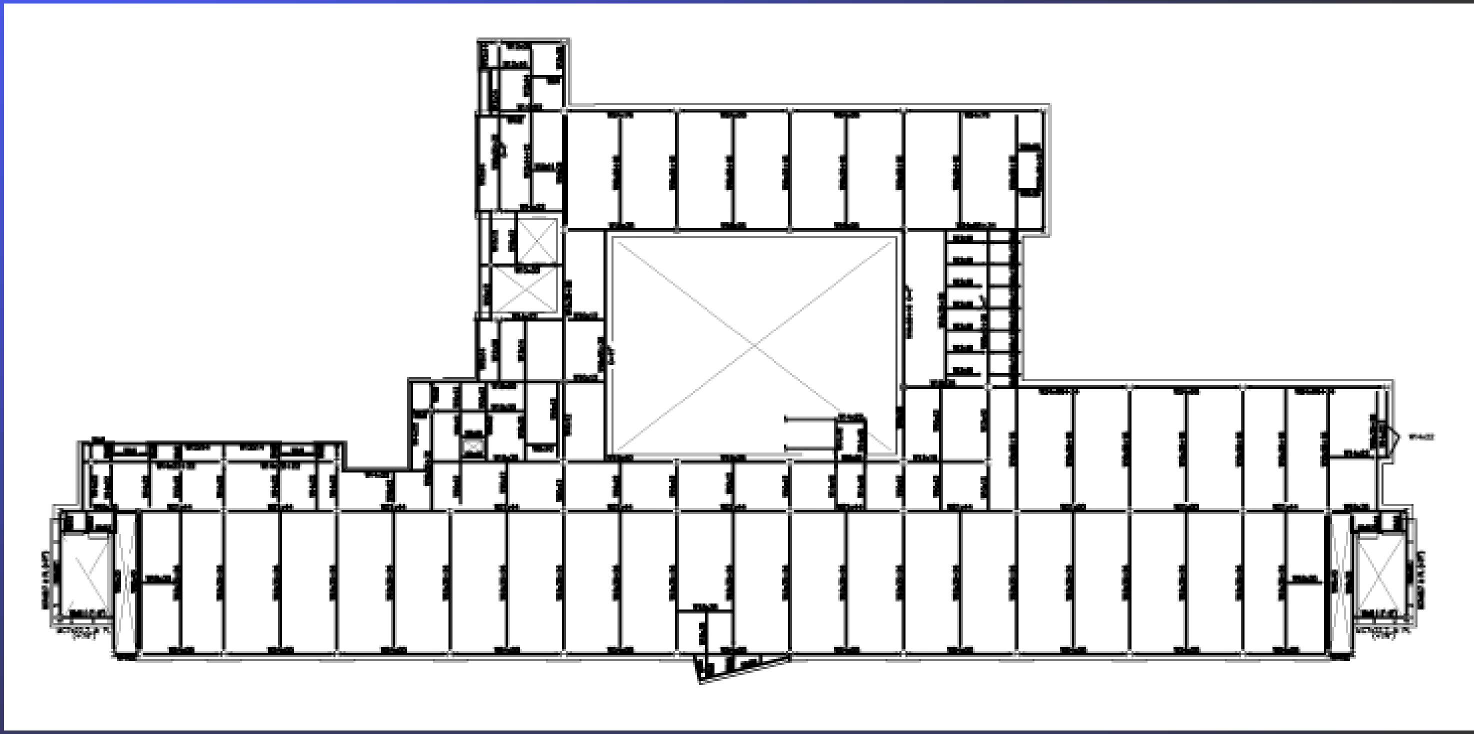

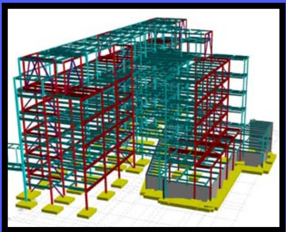

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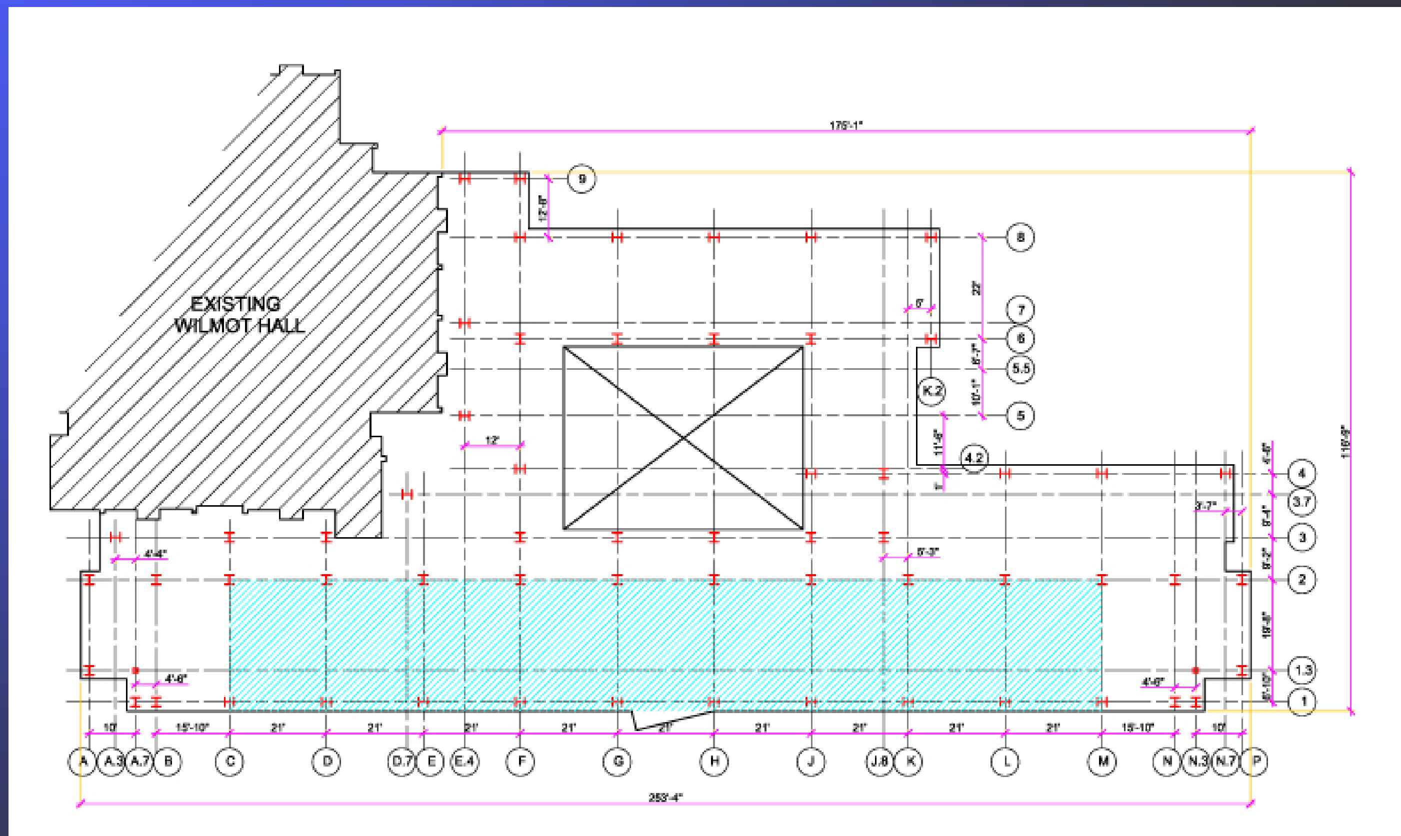
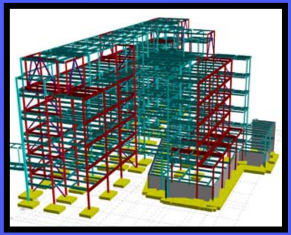
Floor System





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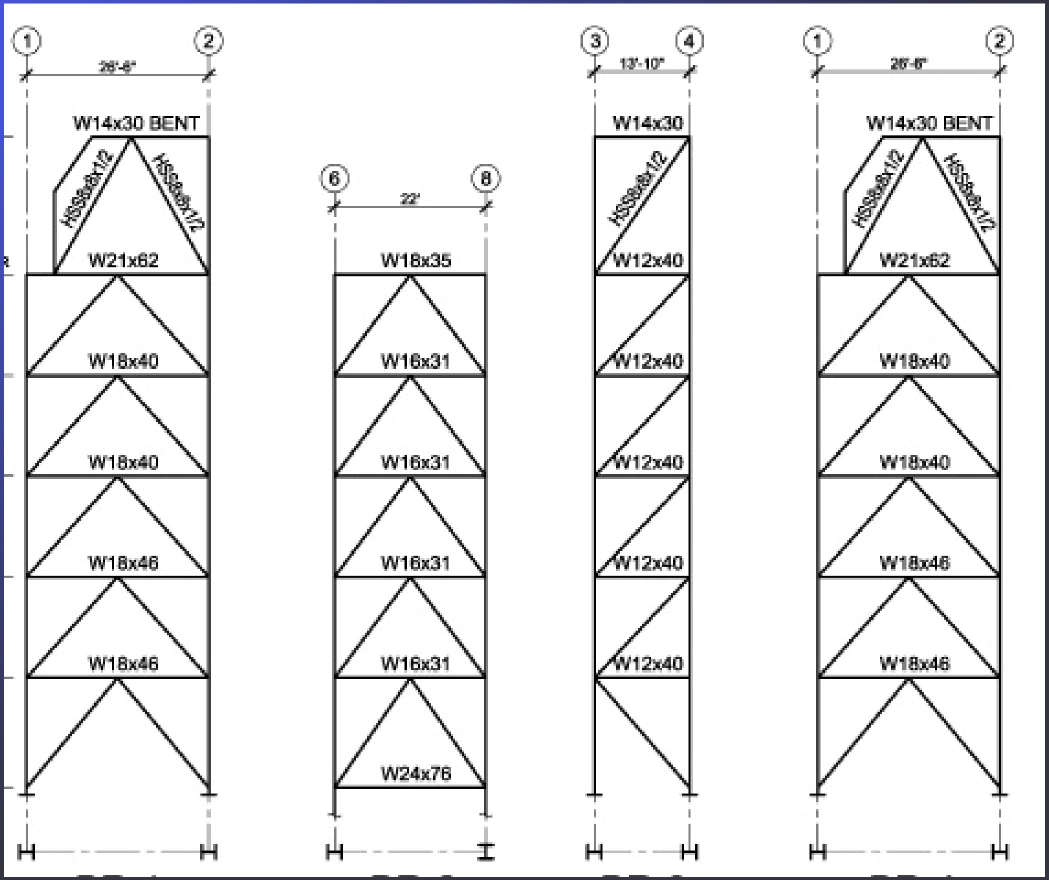
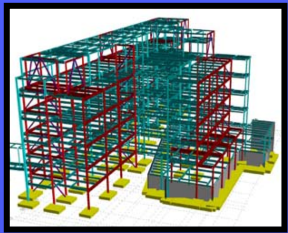
Braced Frames

4 concentrically braced frames support the building in the short, East-West direction





Braced Frames

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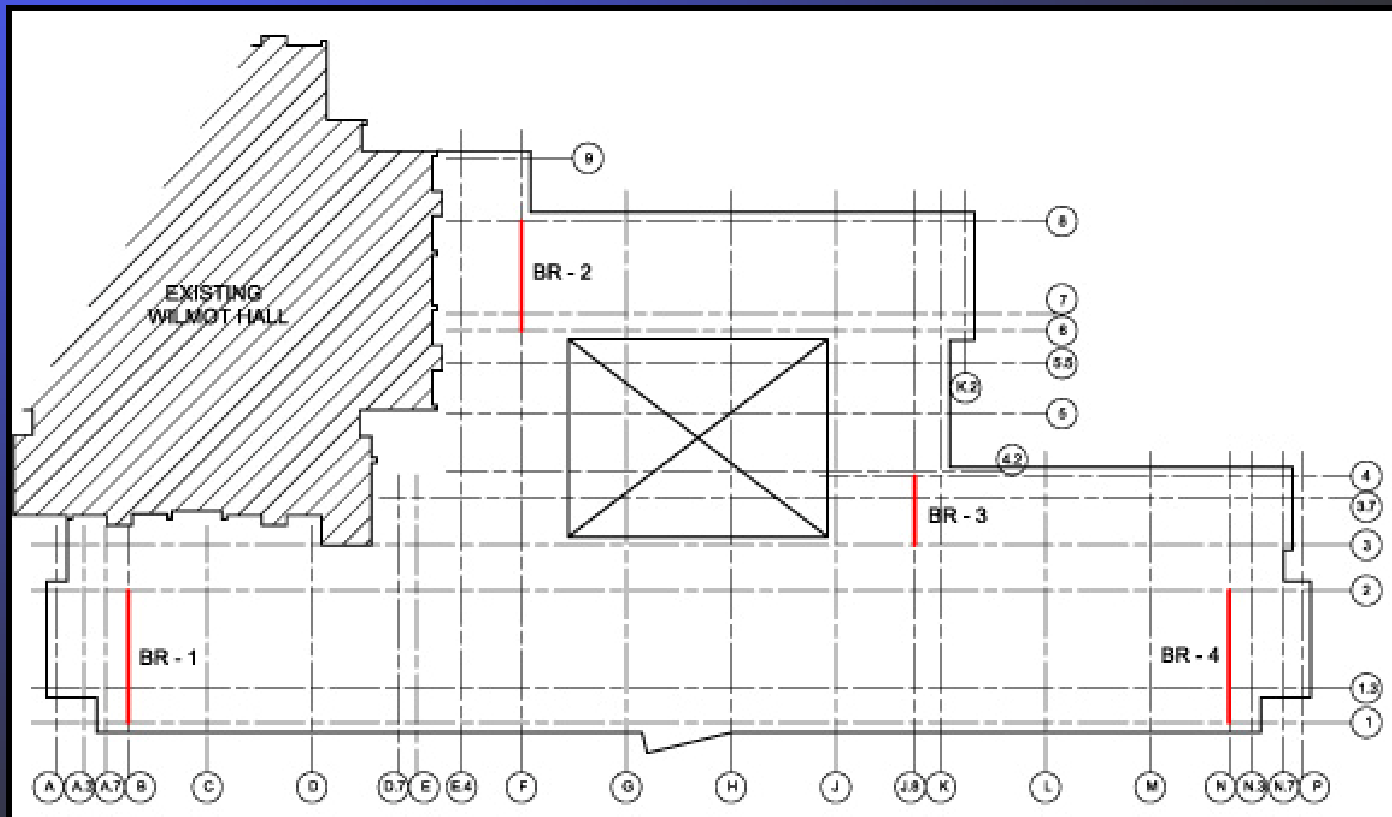
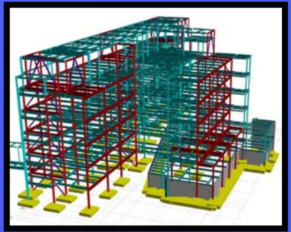
Braced frame locations





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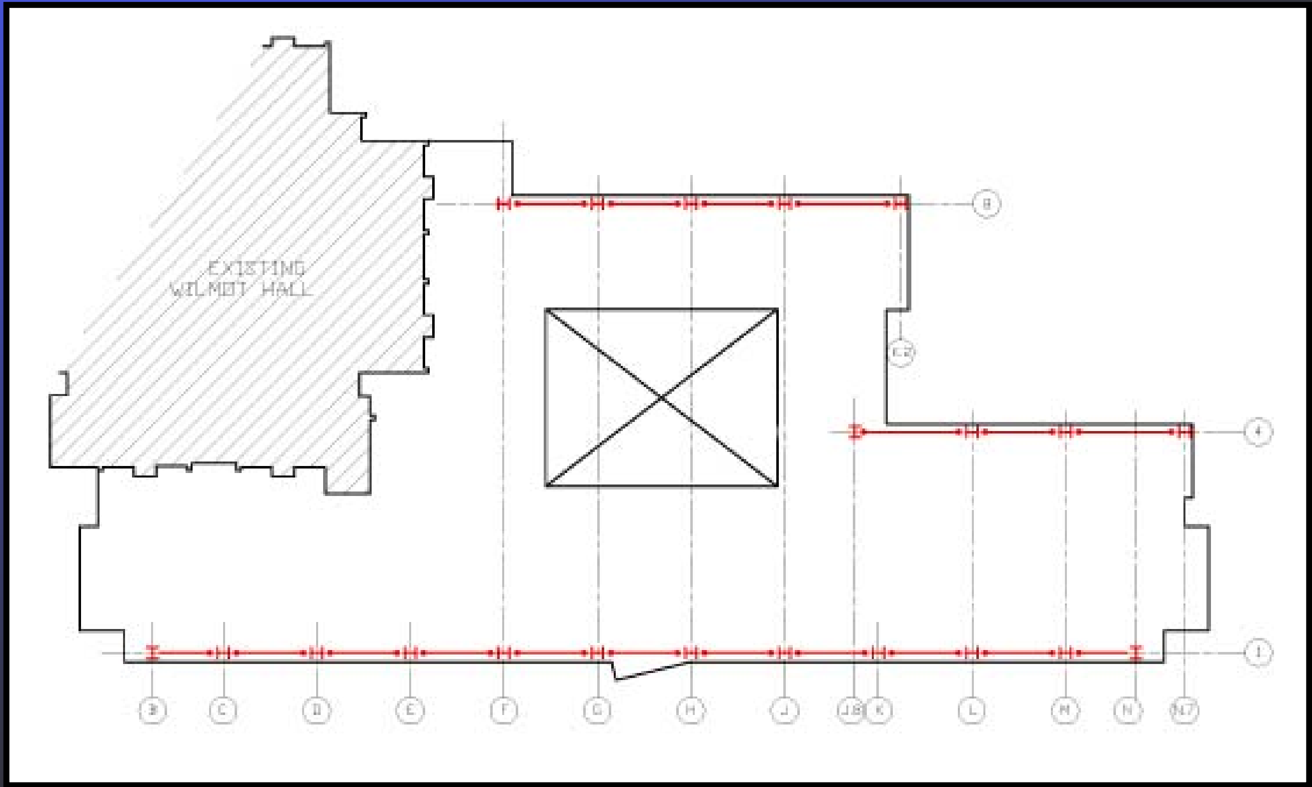
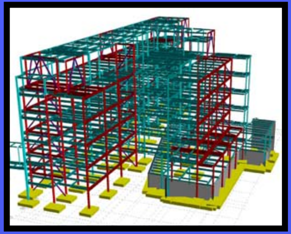
Moment Frames

• 4 Moment frames support the building in the long, North-South direction

• Located along building faces





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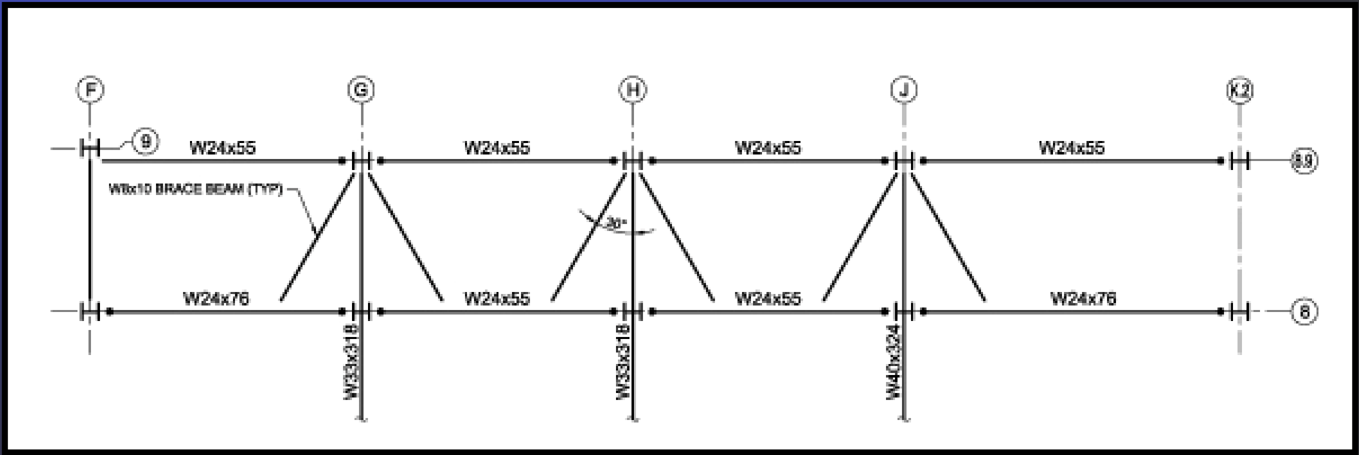
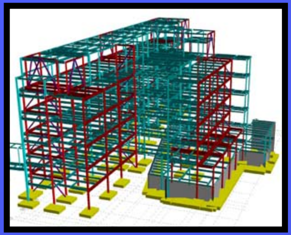
Moment Frames

- Columns at east face of building not continuous to foundation
- Provide column free space to lecture hall
- Also part of a moment frame
- Bracing members form a horizontal truss to transfer lateral load





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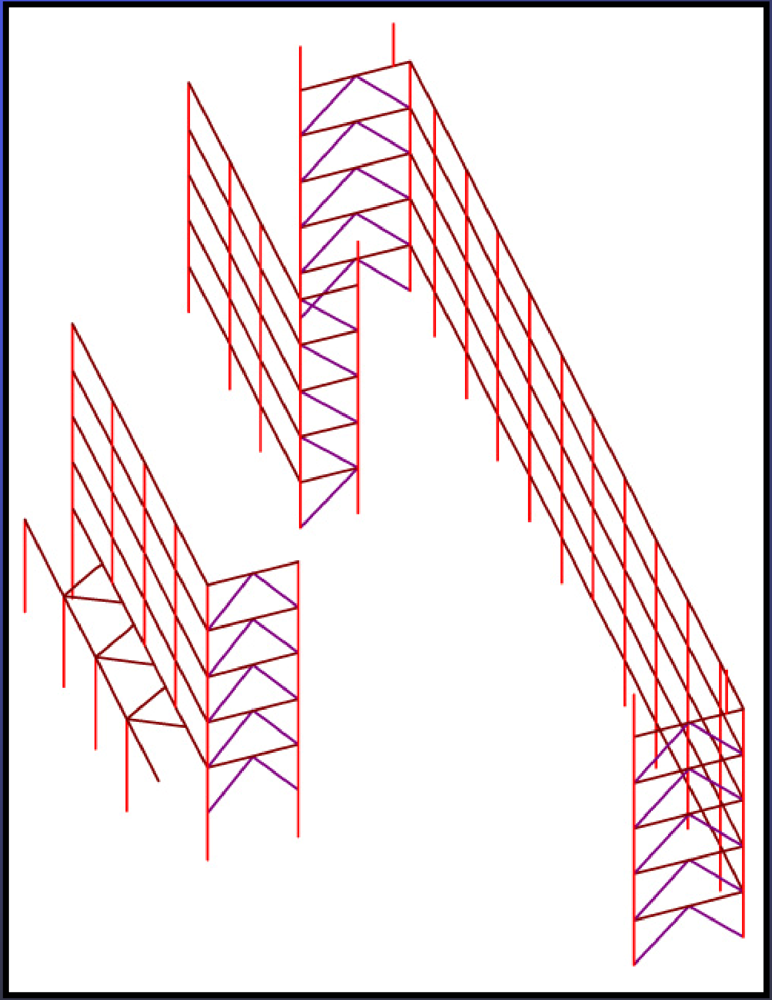
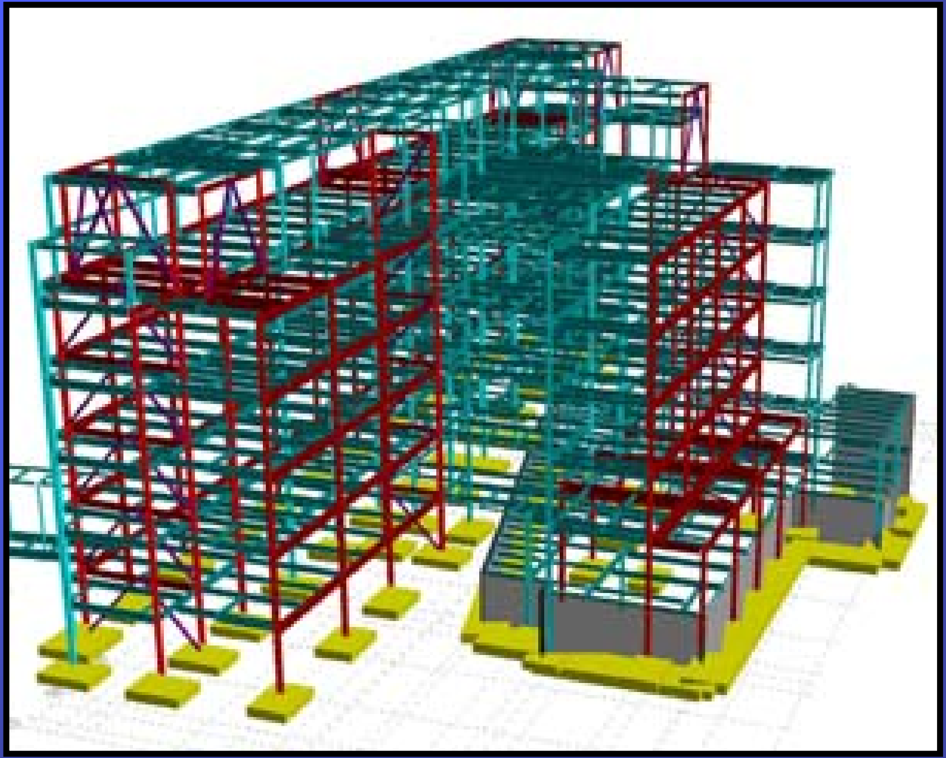
Lateral System





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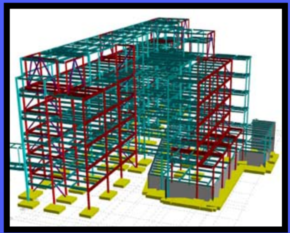


Problem Statement

Pros

• Existing steel design works well with the architecture

• Steel framing is common in the area

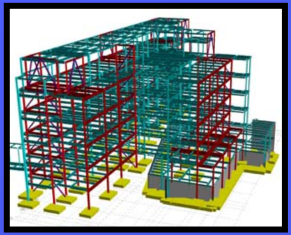
• Nature of steel makes design process relatively easy

Cons

• Several notable areas of BMEO would work better in concrete

•Amount of steel seems excessive for the size of the building

- About 1300 members weighing 300 tons
- Over 6000 shear studs
- Over 400 moment connections
- 7 ½" concrete to achieve full composite action



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Proposal

What if BMEO was an all concrete structure?

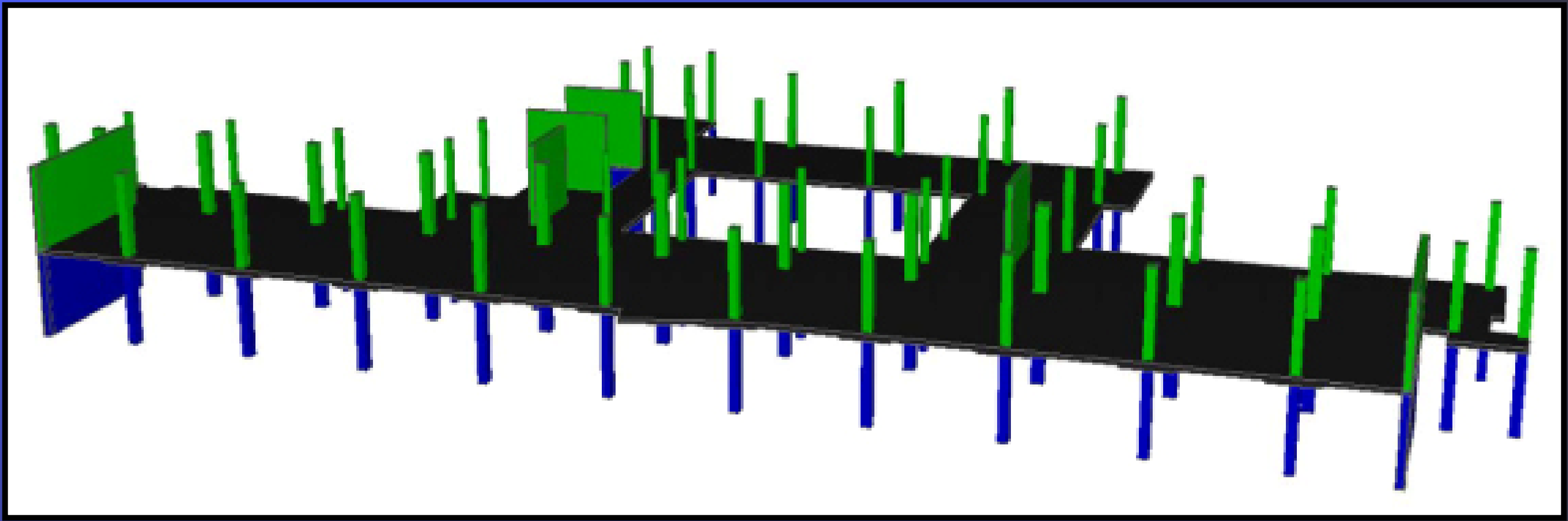
Goals:

• Gain a better understanding of concrete design

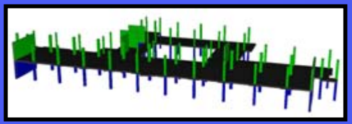
• Design a complete, economical, and structurally sound concrete building

• Compare concrete design with steel framing for a building of irregular geometry

• Analyze BMEO as a “green”, environmentally friendly building



Structural Redesign



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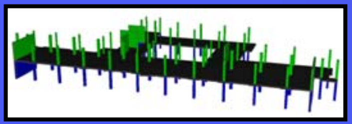
Design Procedure

After considering several steel and concrete options,

cast-in-place flat slab *with drop panels chosen as most efficient.*

Codes and methods:

- ASCE 7-05
- ACI 318-02
- Finite Element Analysis (RAM Concept)
- Equivalent Frame Method as a check
  - PCA Slab
  - Hand Calculations



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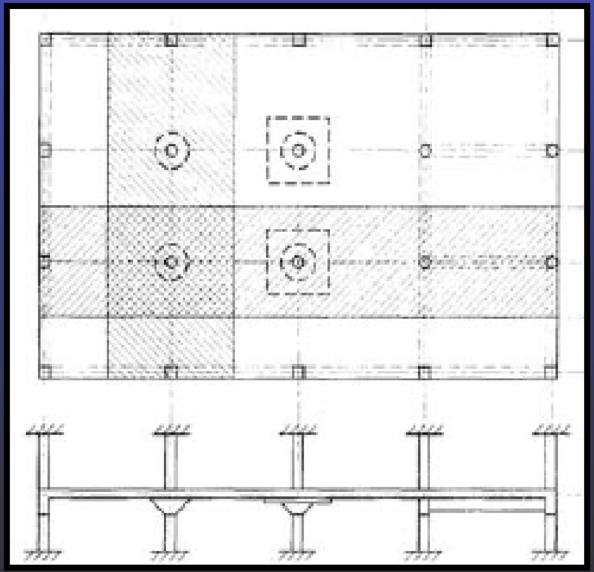
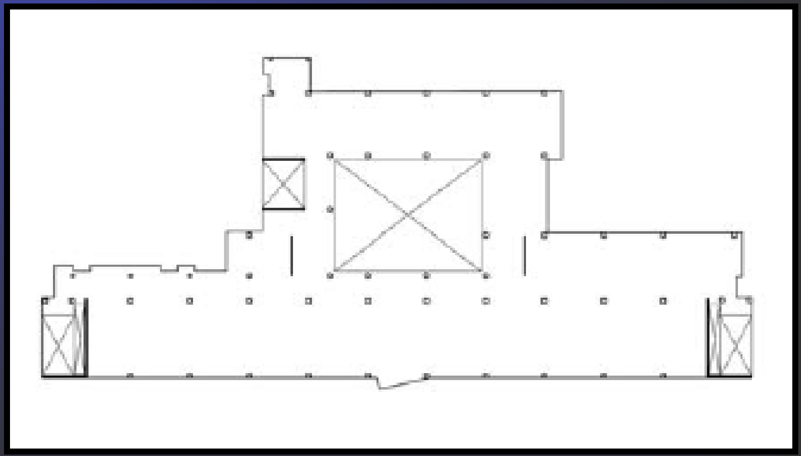
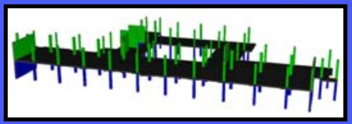
Slab Design

- Traditionally, concrete buildings are designed using the Equivalent Frame Method
- Building approximated as a series of frames in each direction
- Moment is distributed to the slab and columns based on equivalent stiffnesses
- For more complicated structures, finite element analysis can more accurately determine distribution of moments







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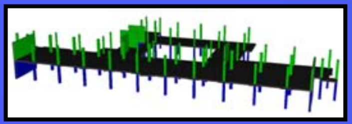
Slab Design

- 4000 psi concrete, 60 ksi steel reinforcing
- 10” thick concrete slab for typical floors based on ACI guidelines
- 12” thick slab at mechanical penthouse floor
- Pattern Loading considered to find critical moments
- Steel Reinforcing
    - Laid out in column strips and middle strips
    - #4 bottom (positive)
    - #5 top (negative)
- Deflection not critical, limited to less than ½“



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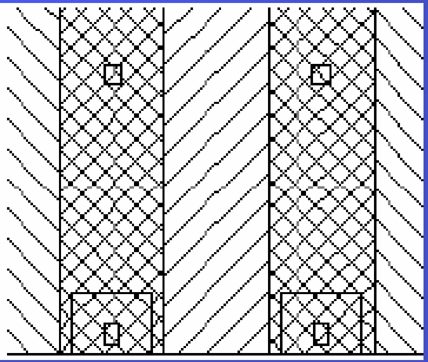
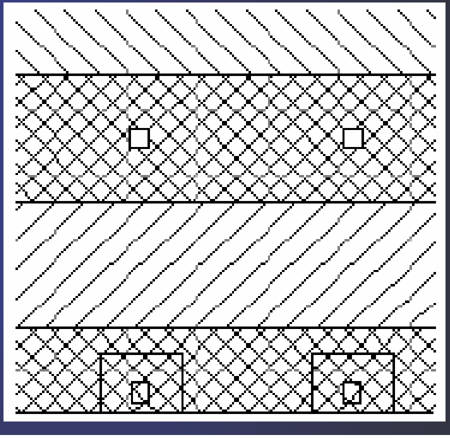
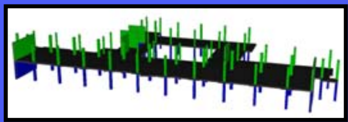
Critical Bay Reinforcing



	Top, Ext Col	Top, Int Col	Bottom
Column Strip	(14) #5	(20) #5	(12) #4
1/2 Middle Strip	(4) #5	(4) #5	(8) #4



	Top, Ext Col	Top, Int Col	Bottom, Ext	Bottom, Int
Column Strip	(9) #5	(17) #5	(8) #4	(12) #4
1/2 Middle Strip	(6) #5	(6) #5	(9) #4	(9) #4



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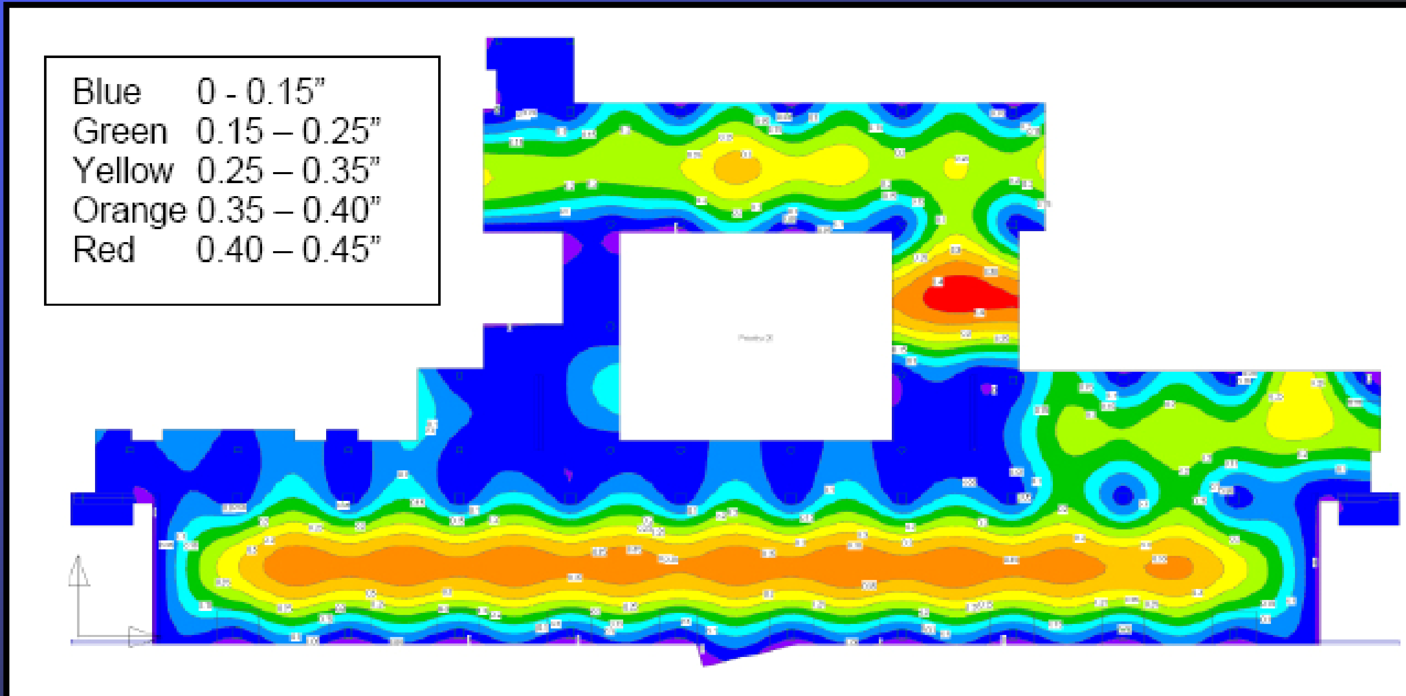
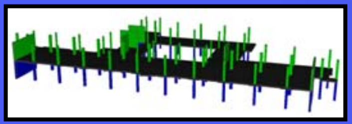
Deflection



Deflection Plan, Typical Floor



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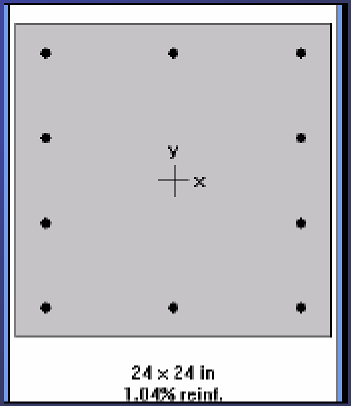
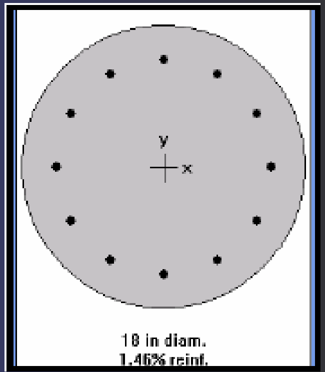
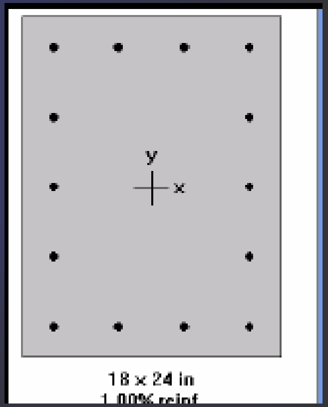
Column Design

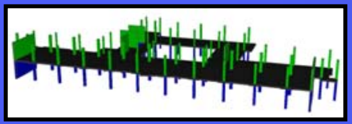
- Designed for axial load and worst case moments
- Biaxial bending interaction diagrams
- Slenderness effects ignored per ACI code
- 4000 psi concrete
- #3 ties

Size	Reinforcing
24x24	(10) #7
22x22	(16) #5
18x24	(14) #5
18x18	(8) #6
14x14	(8) #5
18" Dia.	(12) #5



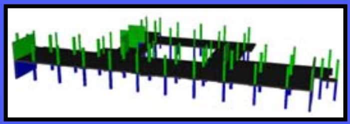






Punching Shear

- Most common type of catastrophic failure in concrete buildings
- Several methods to resist punching shear were considered for BMEO
- Drop panels and SSR both designed for
- Drop panels found to be more economical
    - Project 4” below concrete surface
    - Increase stiffness of columns, thus reducing negative reinforcing in slab
    - Used at west face of building on all floors



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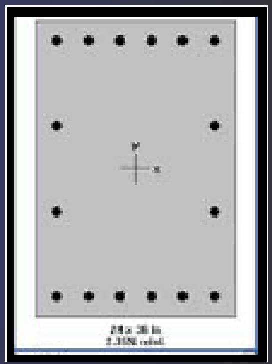
Transfer Girders

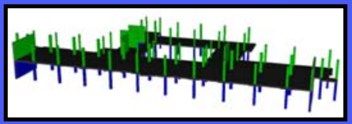
• Lecture hall at first floor required column free space

• Columns at east face of BMEO not continuous to foundation

• Three 24x36 transfer girders with 24x36 columns designed to transfer forces from columns above

Beam	Design Positive Moment	1210	ft-k
	Design Negative Moment	1300	ft-k
	Size	*24x36*	d = 32.5"
	Positive Reinf	*(10) #9*	Top
	Negative Reinf	*(10) #9*	Bottom
Columns	Design Moment	1722	ft-k
	Design Compression	270	k
	Size	24x36	
	Reinf	(16) #10	





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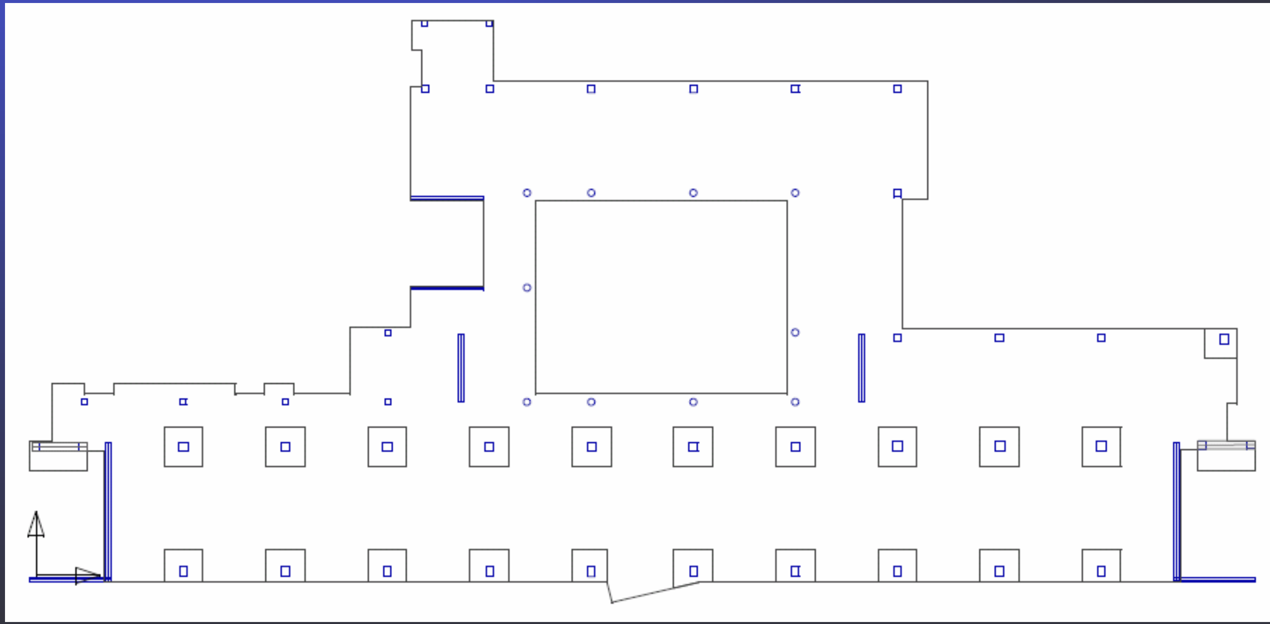
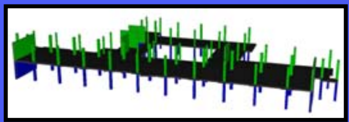
Penthouse Floor

• Similarly, some columns from mechanical penthouse do not line up with columns below

• Low forces could be resisted in flexure by the 12" slab

• Additional drop panels needed to resist punching shear, decrease slab moments





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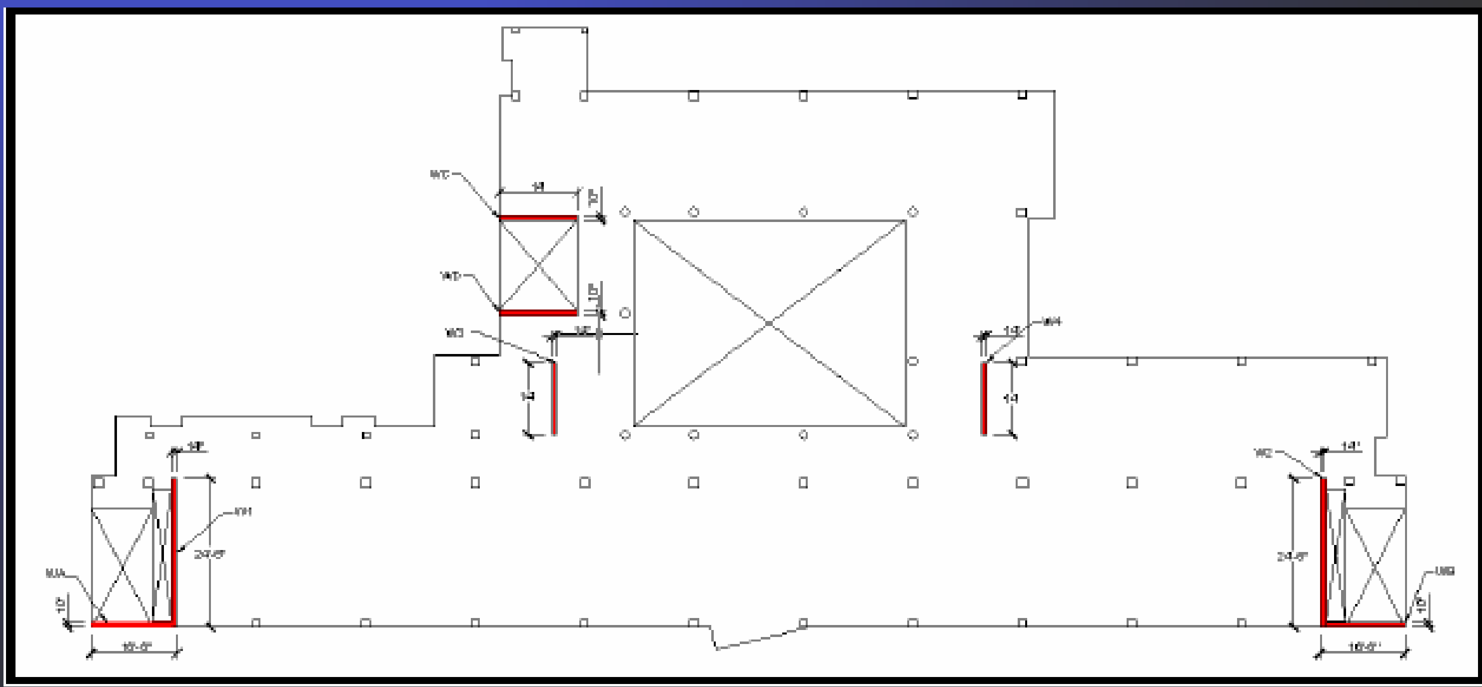
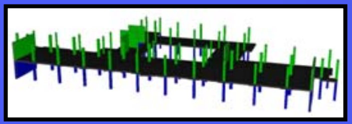
Shear Walls

- Shear walls designed to resist lateral loads in both directions
- Strategically placed adjacent to stairs, elevators, and mechanical openings
- Forces distributed by relative rigidities





•Project Background

• Original Structural Design

• Problem Statement / Proposal

• ***Structural Redesign***

• Cost & Scheduling Effects

• Green Building Design

• Recommendation & Conclusions

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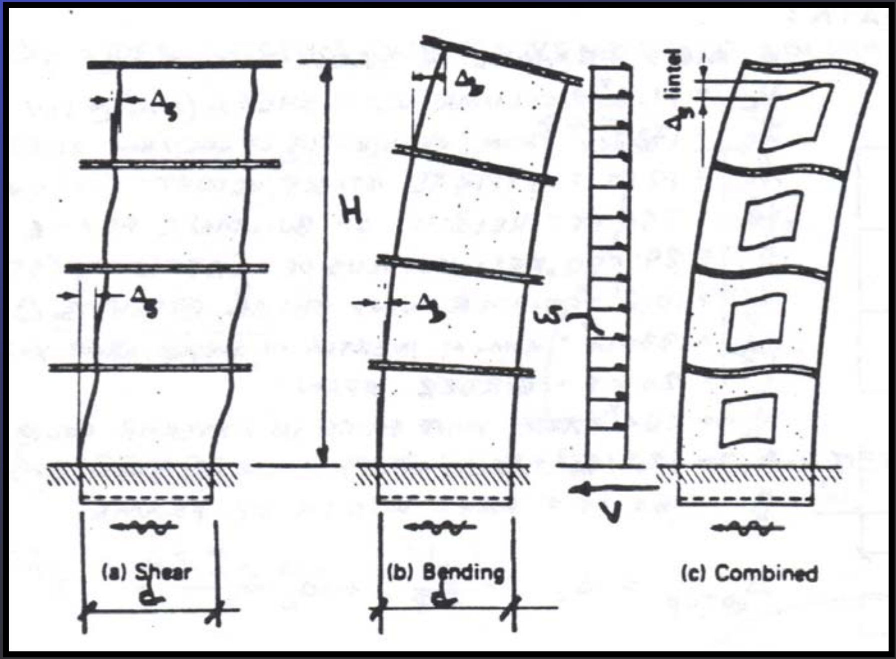
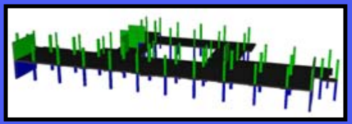
Lateral Drift

- Calculated by hand using approximate formulas
- Combination of shear deflection and bending deflection
- Results compared with computer model
- Drift found to be less than 1” in each direction

$$\Delta_{SHEAR} = \frac{6}{5} \times \frac{1}{2} \times \frac{VH}{A_w G}$$

$$\Delta_{BENDING} = \frac{wH^4}{8EI_w}$$





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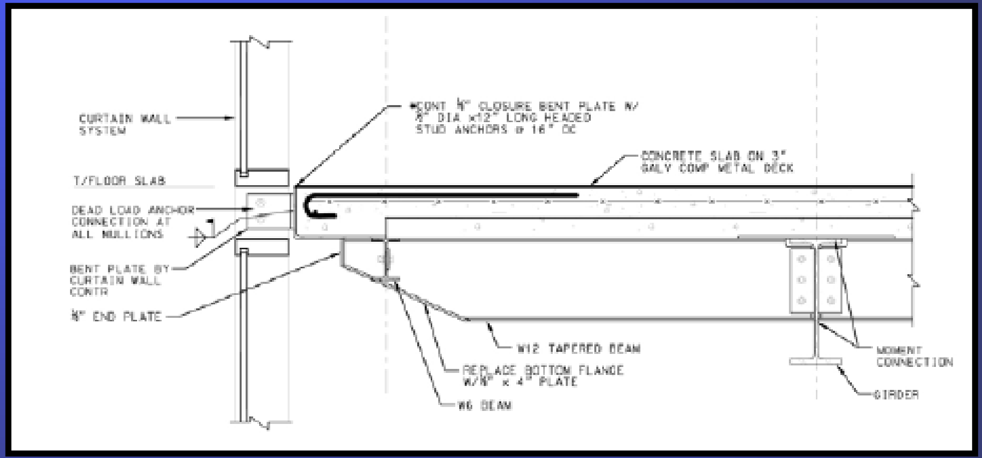
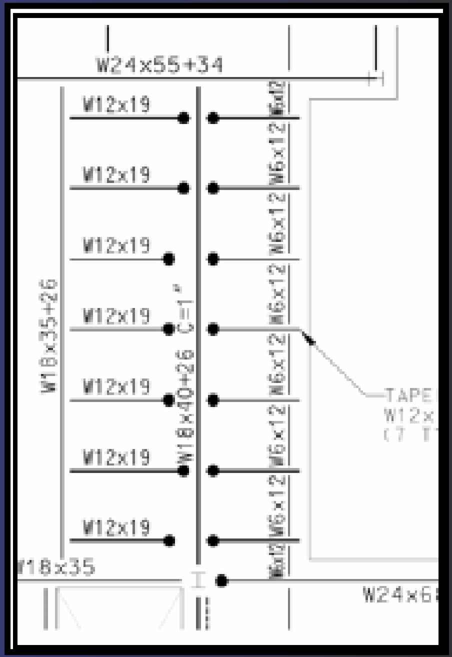
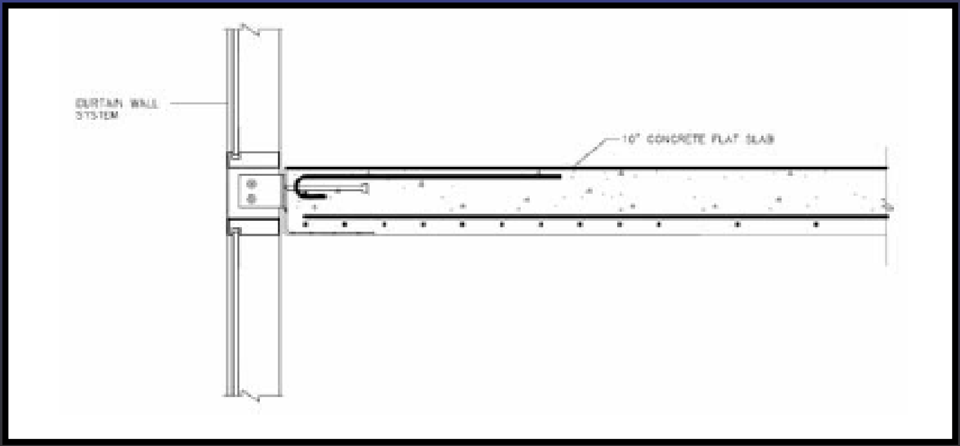
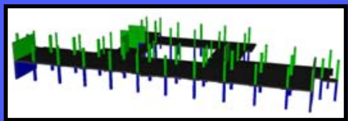
Advantages

Curtain Wall









Advantages

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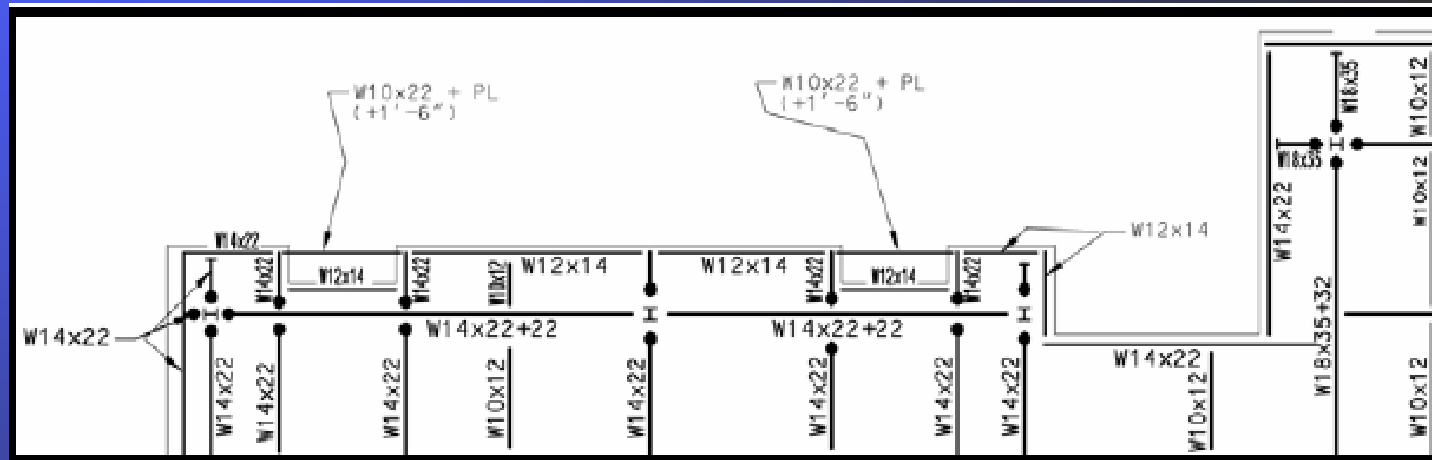
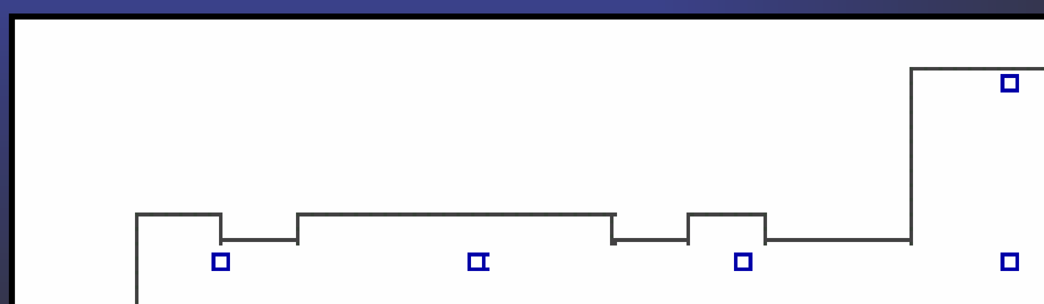
Isolation Joint With Wilmot Hall





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Cost & Scheduling Effects

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Cost Comparison

Concrete System

• Formwork	$785,000
• Concrete	$372,000
• Reinforcing Steel	$242,000

Total Superstructure Cost: $1.5 Million

18 week construction

- Project Background
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Cost Comparison

Steel System

From LeChase Construction, $2.4 million

(6.5% total project cost)

However, RS Means estimate provides a more accurate comparison with concrete estimate

• Steel Tonnage	$648,000
• Composite Deck	$780,000
• Moment Connections	$200,000
• Slab on Deck	$282,000

*Total Superstructure Cost: **$1.9 Million***

15 week construction

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Cost Comparison

- Cost & Scheduling not as critical for this type of building than for office or apartment buildings
- However, concrete structure saves an estimated $400,000 (21%)
- Total project savings: 1%
- Schedule increase of 3 weeks, not critical

Green Building Design

• Project Background

• Original Structural Design

• Problem Statement / Proposal

• Structural Redesign

• Cost & Scheduling Effects

• ***Green Building Design***

• Recommendation & Conclusions

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Green Building Design

What is a "green" building?

A *holistic* approach to building design, focusing on:

- Reduction in energy use
- Minimizing environmental impact
- Reducing embodied energy and resource depletion
- Minimizing internal pollution and health risks

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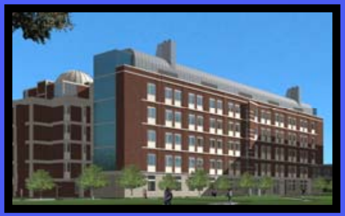
EFTE Foil Cushion



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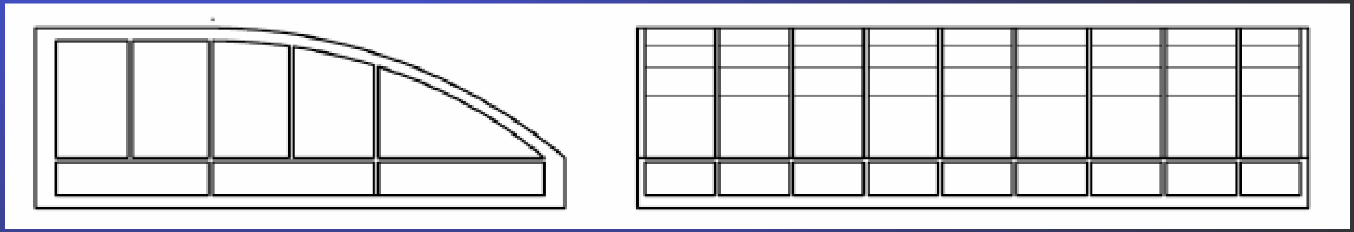
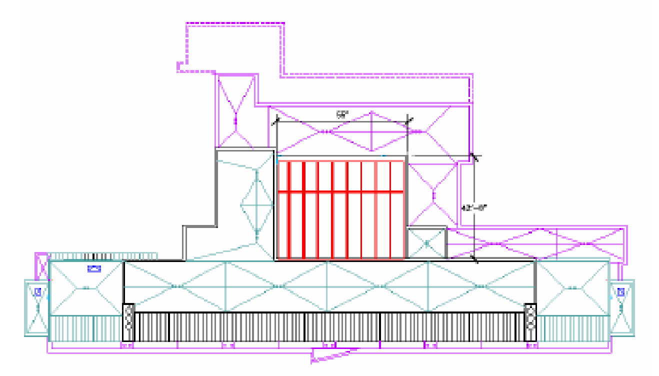
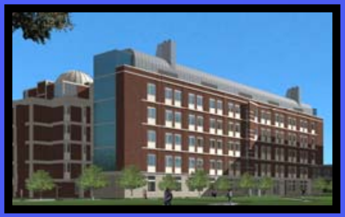
Possibility for BMEO

Atrium Roof

- Will provide more natural light across a wider spectrum than existing skylights
- One of the panels could have a hydraulic lift to provide ventilation







Advantages

- **Natural Light**
  - Transmits 97% of total light across the entire visible spectrum
- **Insulation**
  - Significantly better than glass
- **Extremely Lightweight**
  - Reduces framing members for atrium roof
- **Durability & Maintenance**
  - Almost maintenance free
- **Low Embodied Energy**

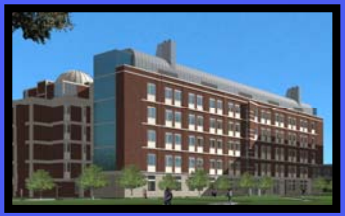
Follows principles of “green” building

Recommendation & Conclusions

Recommendation

The cast-in-place concrete design outlined in this presentation is being recommended for the University of Rochester Biomedical Engineering / Optics Building based on:

- Significant Cost Savings
- Durability
- Inherent Fire Protection
- Limited Deflections
- Vibration Damping
- Quality Control



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Conclusions

- Recent technologies such as finite element analysis make concrete design for more complex structures possible and more efficient

- Although more labor intensive, cast-in-place concrete can be very economical in buildings such as BMEO, that would otherwise require a large quantity of steel

- Technological advancements such as ETFE foil cushion membranes can provide architecturally unique, environmentally friendly, energy-saving building solutions

Acknowledgements

Prof. Kevin Parfitt

The Pennsylvania State University

The entire AE Department

Tom Zimmerman, Mark Kluczinski, and Greg Hale at SWBR

Wayne Goodman and the University of Rochester

Mike Mallon at LeChase Construction

My friends and family

QUESTIONS?