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Structural Option
2006 Senior Thesis
Penn State Architectural Engineering

Eight Tower Bridge
Conshohocken, Pennsylvania

Presentation Outline

- Project Background
  - Project History
  - Architectural Description
- Original Structure
  - System Description
  - Problem Development
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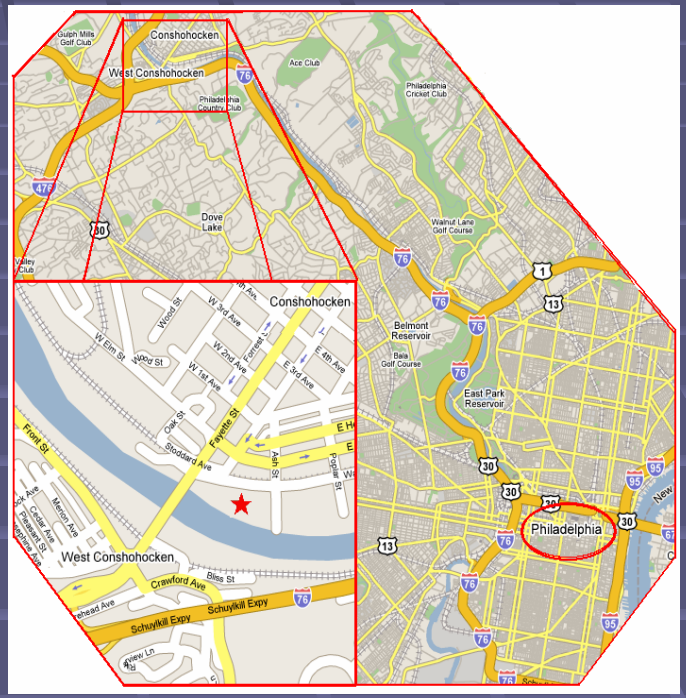
  - Lateral System
- Construction Management
  - Cost Analysis
  - Schedule Comparison
- Final Conclusions
- Questions

Project Background

Project Background

Basic Information

- Conshohocken, Pennsylvania
  - historic area
- 16 stories+ mechanical penthouse
- 345,000 square feet
- Constructed from February 2001 to April 2002
- $43 million total project cost



Key Players

- Owners: Oliver Tyrone Pulver Corporation & Brandywine Realty Trust
- Architect: Skidmore, Owings & Merrill
- Structural Engineers: Skidmore, Owings & Merrill
- Mechanical Engineers: Jaros, Baum & Bolles
- Steel Contractor: Grossi & Sons Steel
- General Contractor: R.M. Shoemaker

Project Background

Project History

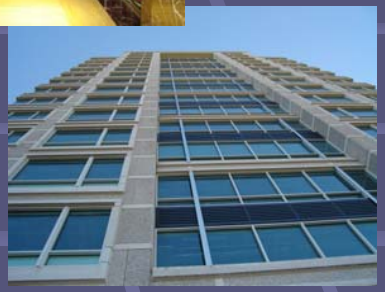
- Building is part of a series of similar office projects
  - Oliver Tyrone Pulver has worked with both SOM and Jaros, Baum & Bolles before

Description

- Multi-tenant office tower
- Open office floor plan, central core construction
- 21,500 square feet/floor
- Ground level doubles as entry and parking area

Architecture

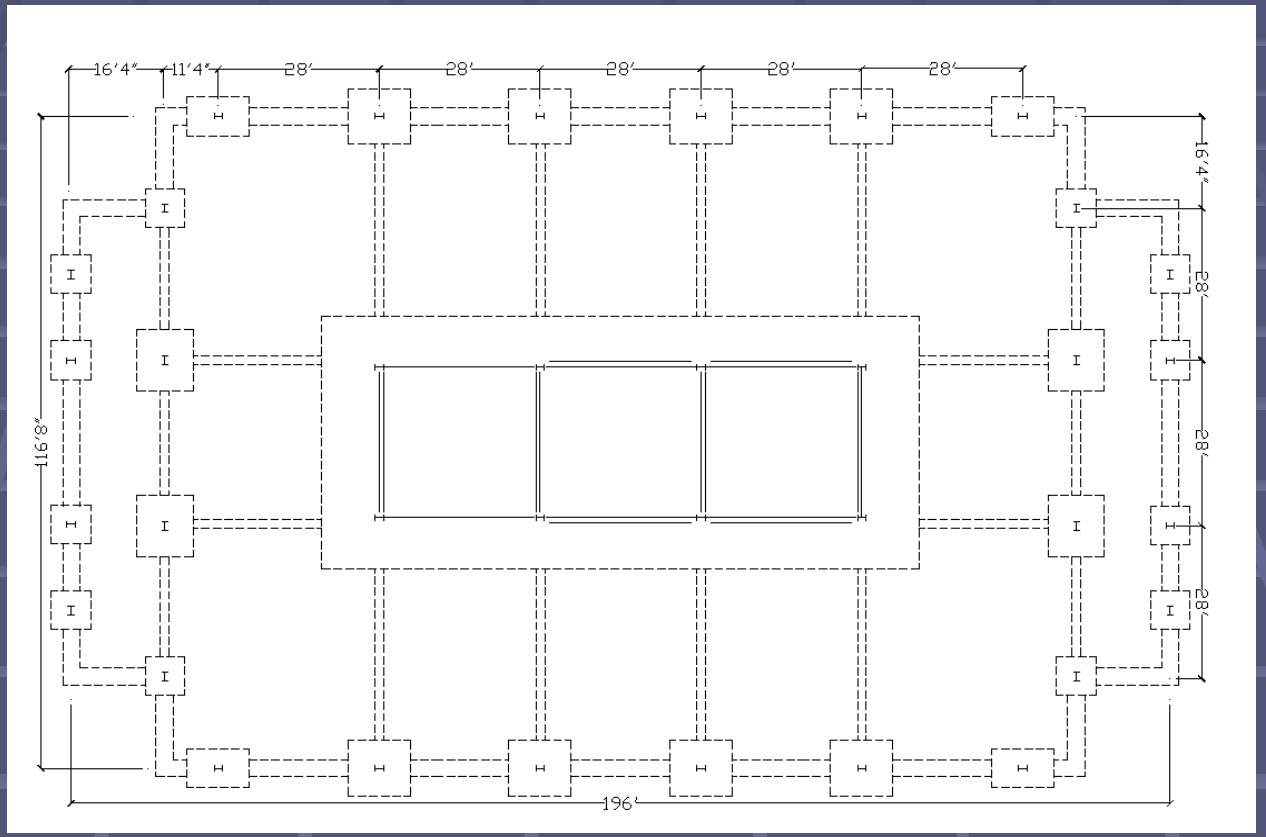
- Features two story entry lobby
- Façade is "signature" precast concrete panel with stone trim and tinted green glass
- Corner terraces located on 16th floor



Original Structure

Foundation

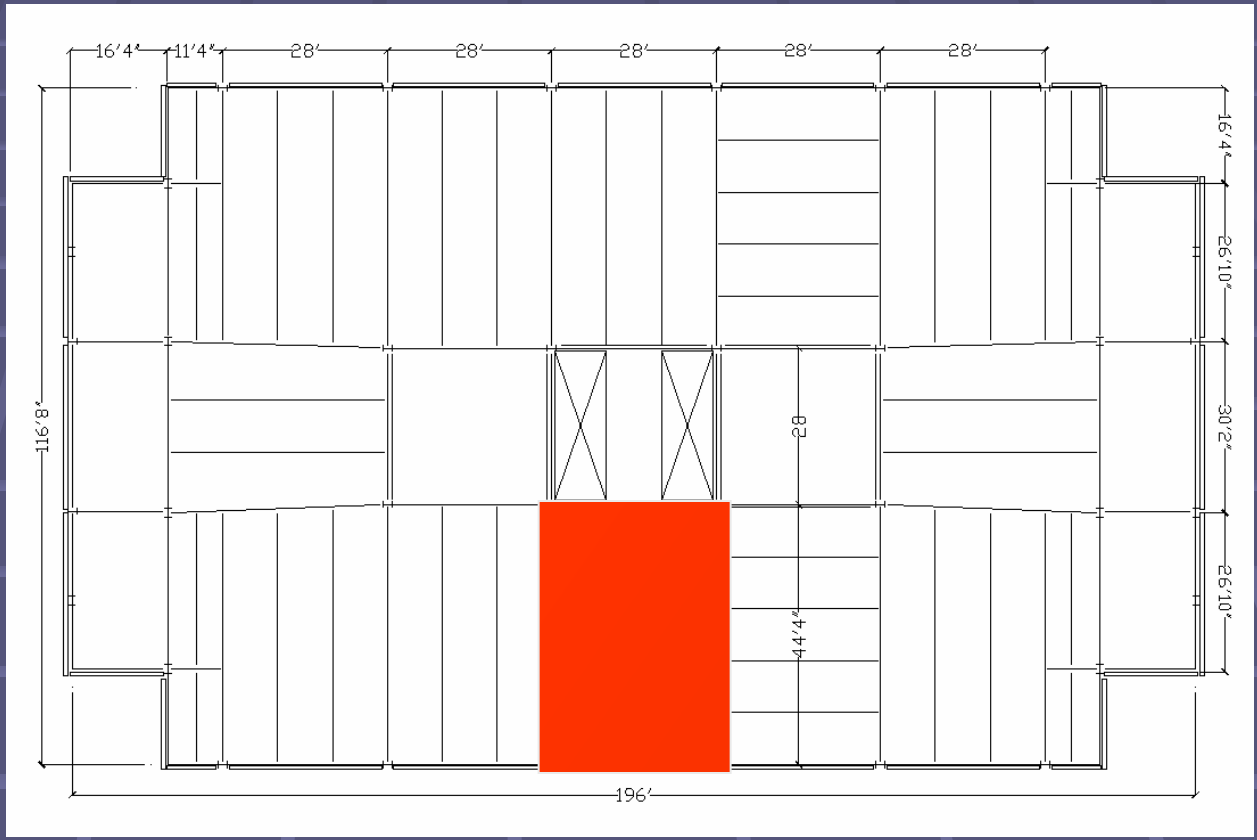
- 4000psi 16” diameter auger cast piles with caps
- 4’3” mat foundation at core
- Connected by various size grade beams



Floor System

Typical Floor Layout

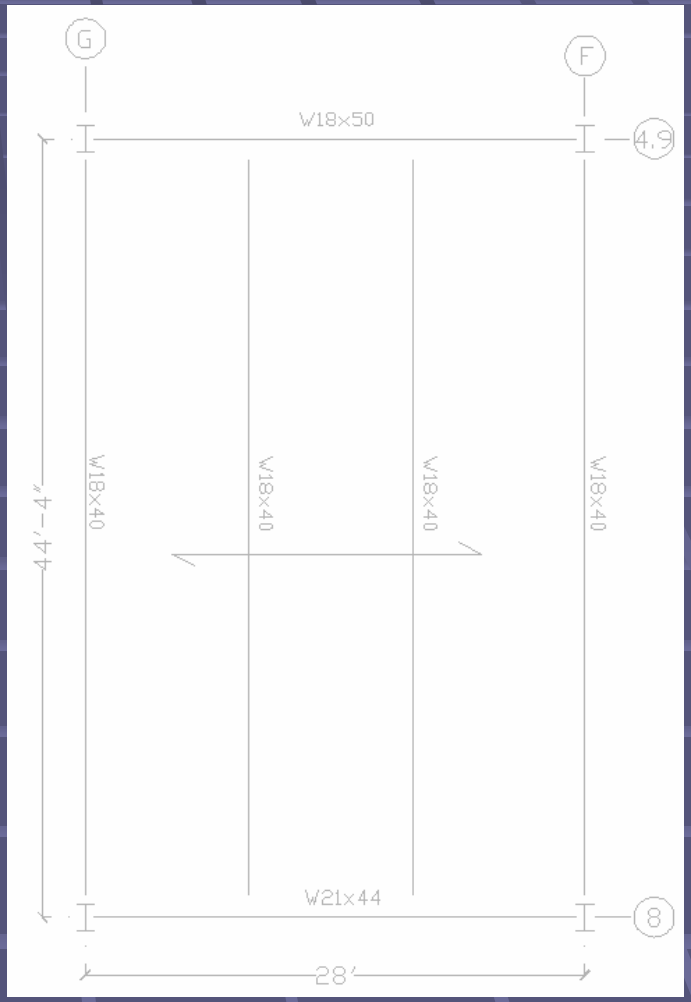
Floors 4-14 designed as typical



Floor System

Typical Bay Plan

- Bay Size: 28' x 44'4"
- Beams: W18x40 spaced @ 9'4"
- Interior Girders: W18x50/86
- Exterior Girders: W21x44

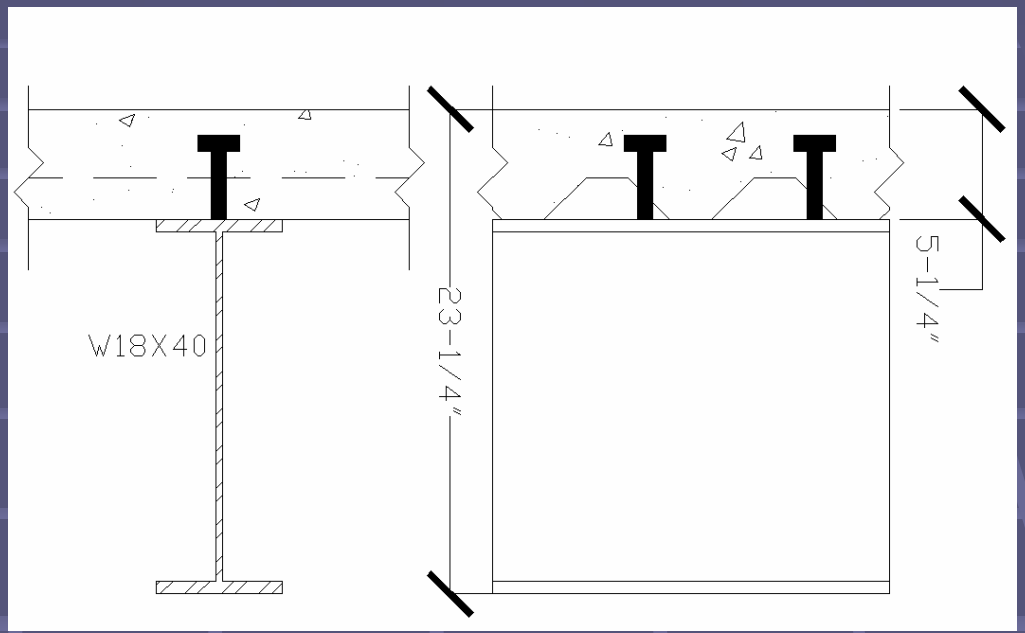


Floor System

Flooring System

- Floor beams act in full composite with slab
- ASTM 992, Grade 50 W18x40 beams, 1¾" upward camber
- 3¼" lightweight concrete slab over 2" metal deck with ¾" shear studs

Total System depth: 23¼"



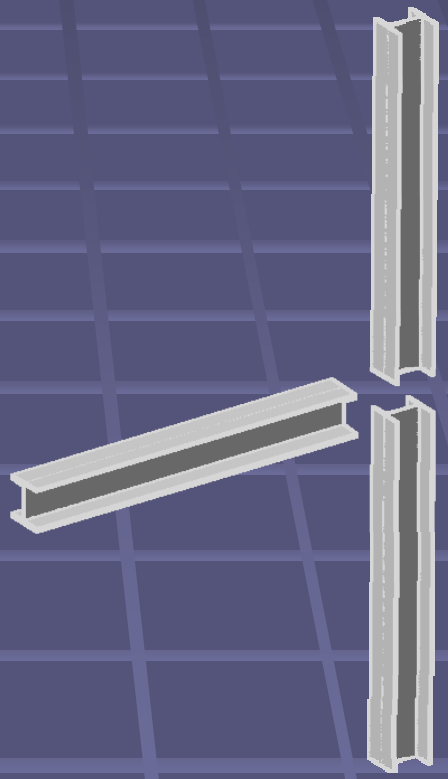
Columns

Columns

- W14 shapes ranging from 550lbs/ft to 90 lbs/ft
- Designed for floor to floor height of 12'1", spanning two stories

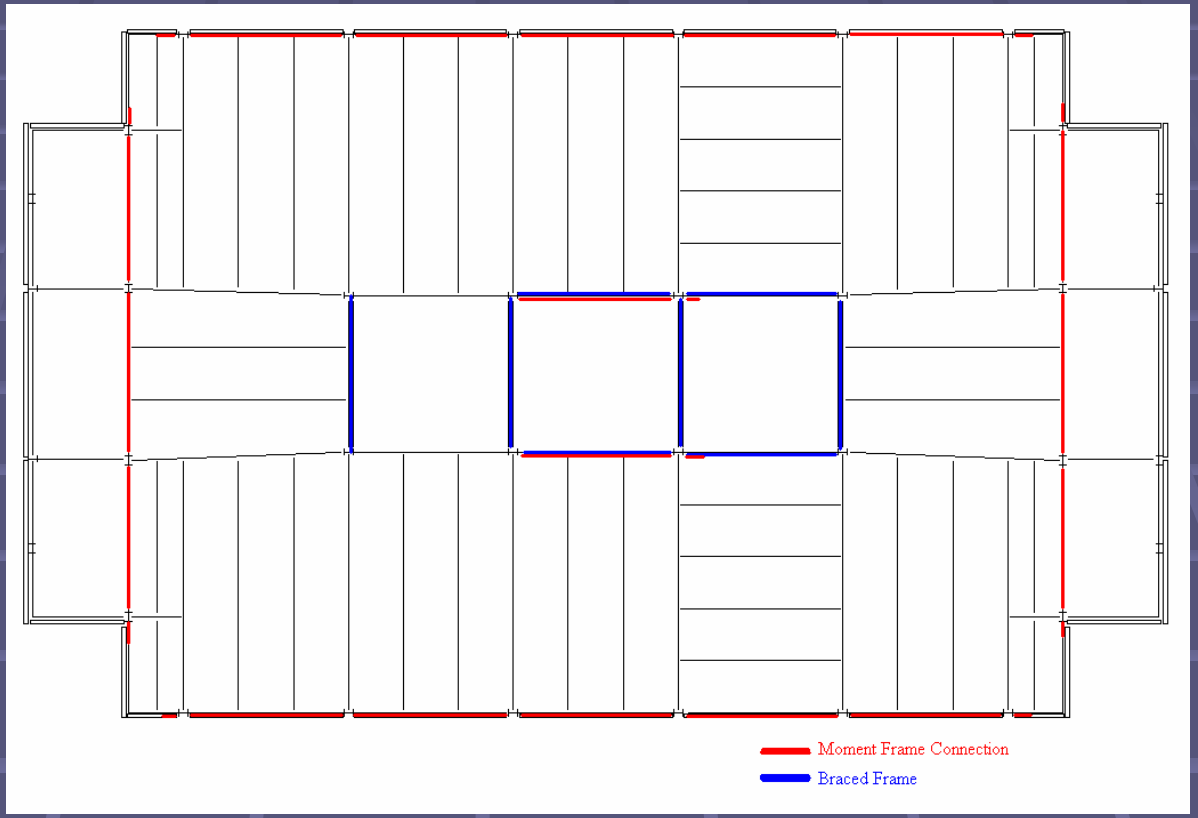
Floor to ceiling height: 9'0"

- 23¼" floor system depth
- 13¾" mechanical plenum space



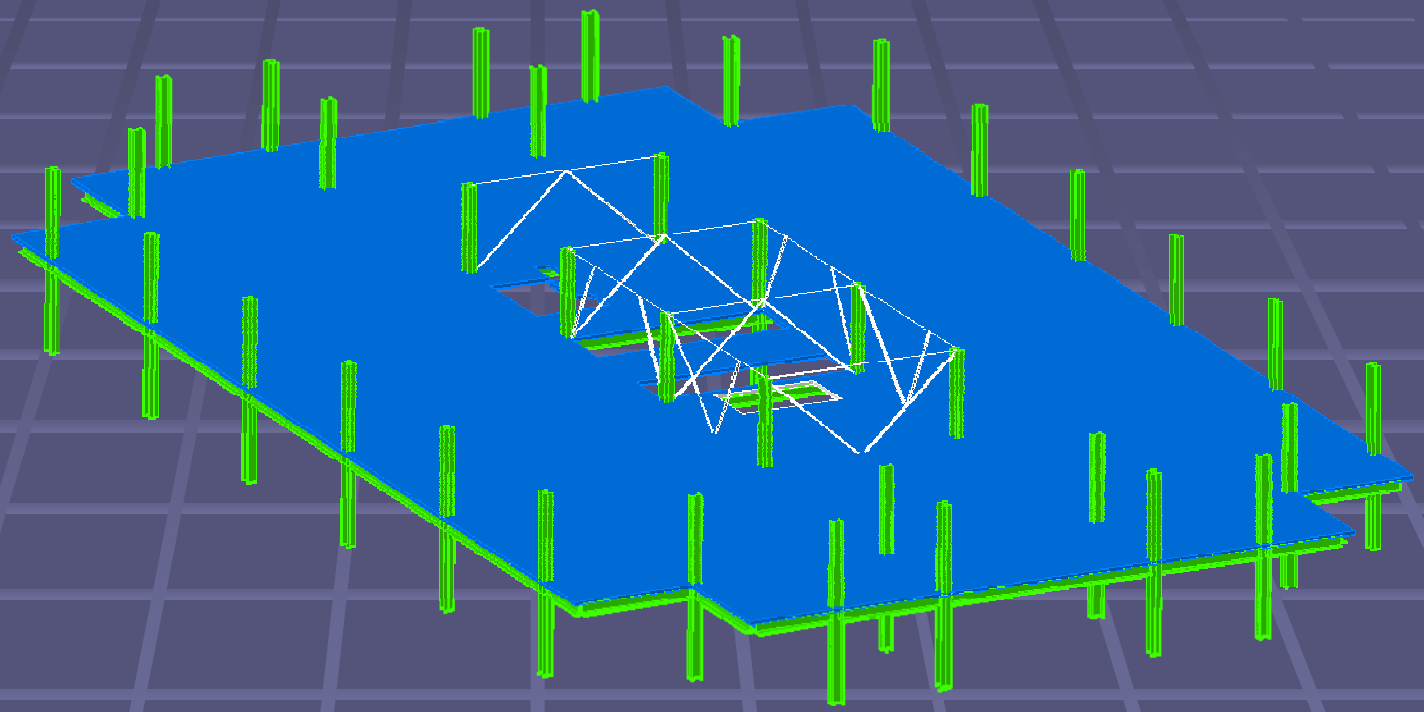
Lateral System

- Combination of braced and moment frames
  - Braced frames found at core of building
  - Moment frames found at building perimeter



Original System

•3D rendering of steel frame



Problem Development

- Eight Tower Bridge has been designed and built as a steel structure
- Steel is a popular material for office buildings in the Philadelphia area
- Most engineers will consider multiple designs

COULD THIS BUILDING BE DESINGED AS A CONCRETE STRUCTURE?

Proposal

Proposal

Design an alternate concrete structural system with the following objectives:

- Maintain an open office layout, free of column obstruction
- Maintain an overall floor system depth less than or equal to the existing 23¼" depth
- Limit floor deflection to l/360
- Limit lateral building drift to l/400
- Minimize cost and schedule

Design the system under the following criteria and codes

- IBC 2000
- ASCE7-2002
- ACI 318-05

Structural Design

Where to begin?

Floor system controls design

- Floor weight determines column size
- Floor to floor height can affect lateral system

Concrete options?

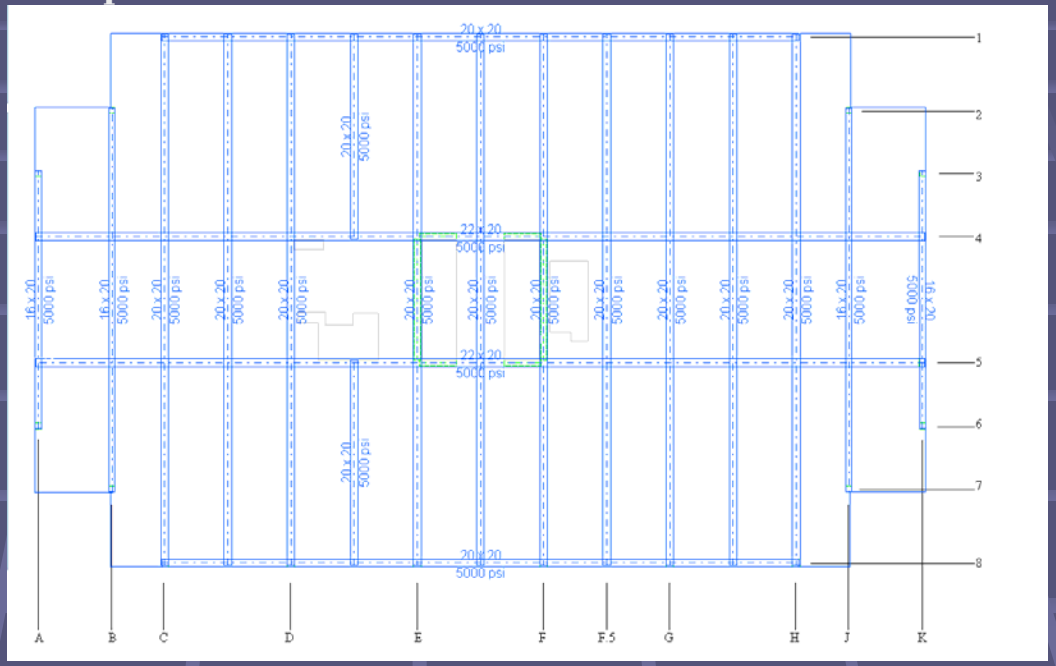
- Two-way flat plate
- Two-way flat plate with drop panels
- Regular reinforced beams (T-beam)
- Post-tensioned system

Floor System Design

Two alternate concrete floor systems were designed

System #1: One-way post-tensioned beam and slab

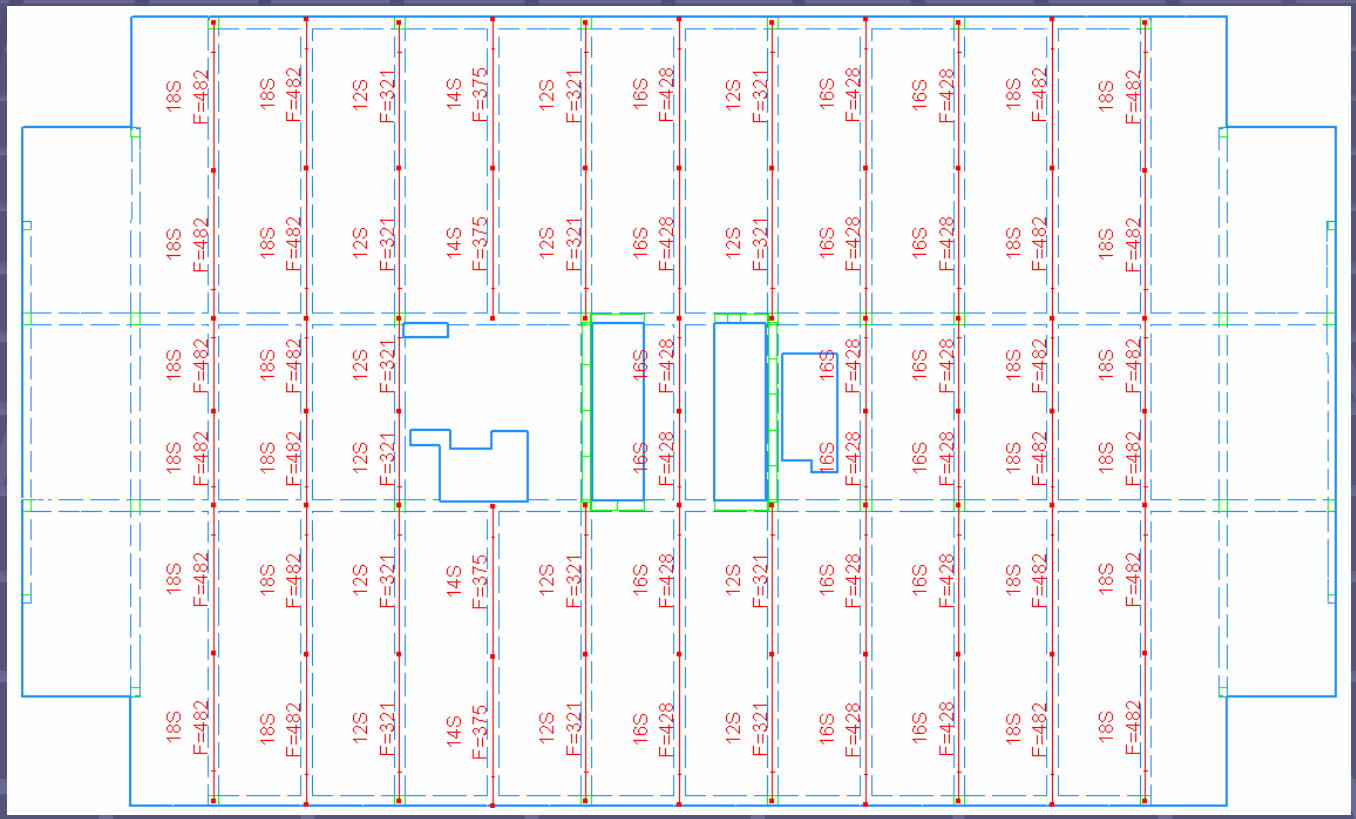
- **Post-tensioning in beams only**
- **6" regular reinforced concrete slab**
- **20"x20" typical beams spaced 14' o.c. (22x20 long span girders)**
- **5000 psi concrete**



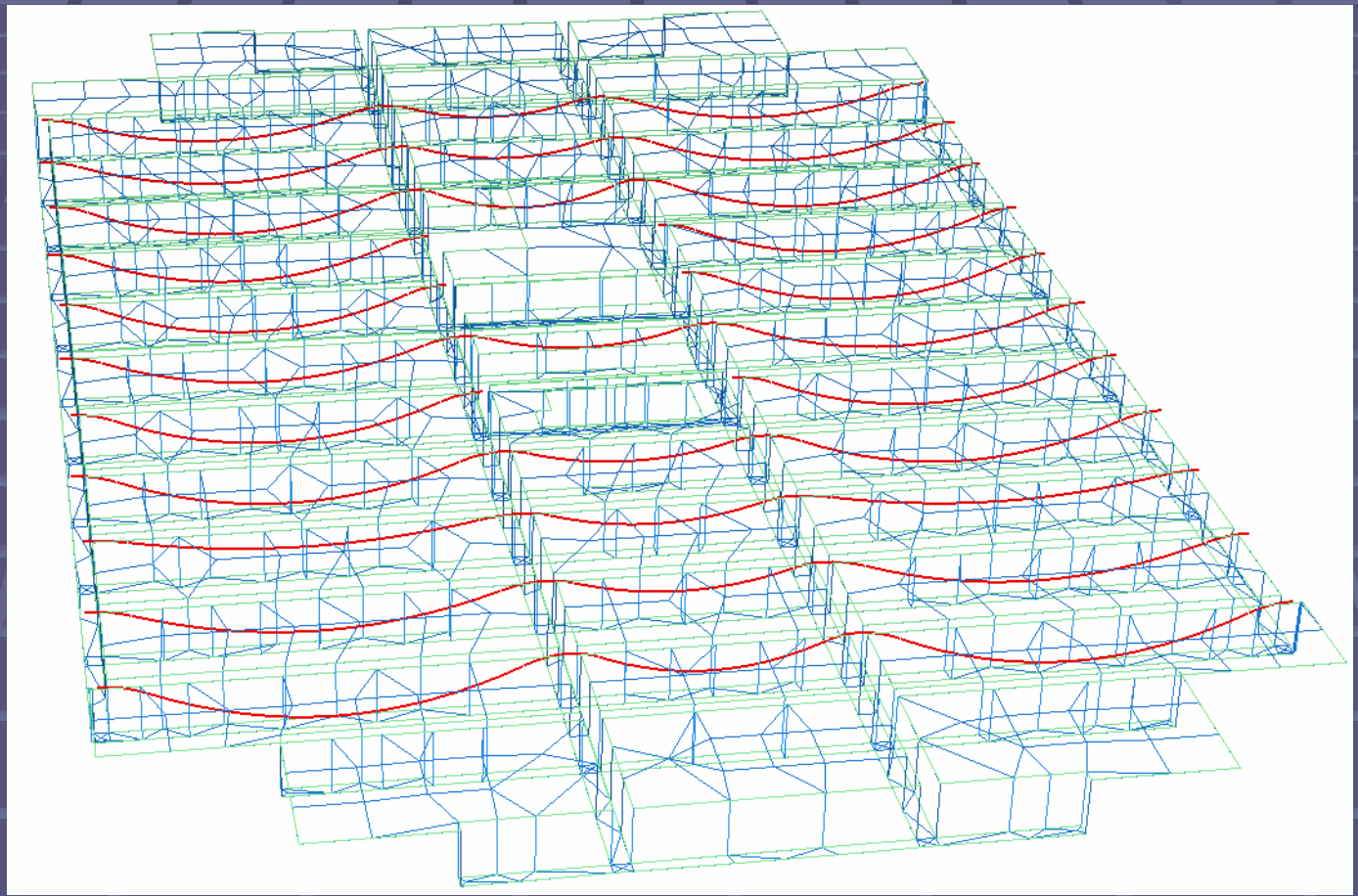
System #1- PT Beam and Slab

Longitude tendon plan

- ½”-7-wire tendons used
- Tendons stressed to 26.6kips/tendon (includes losses)



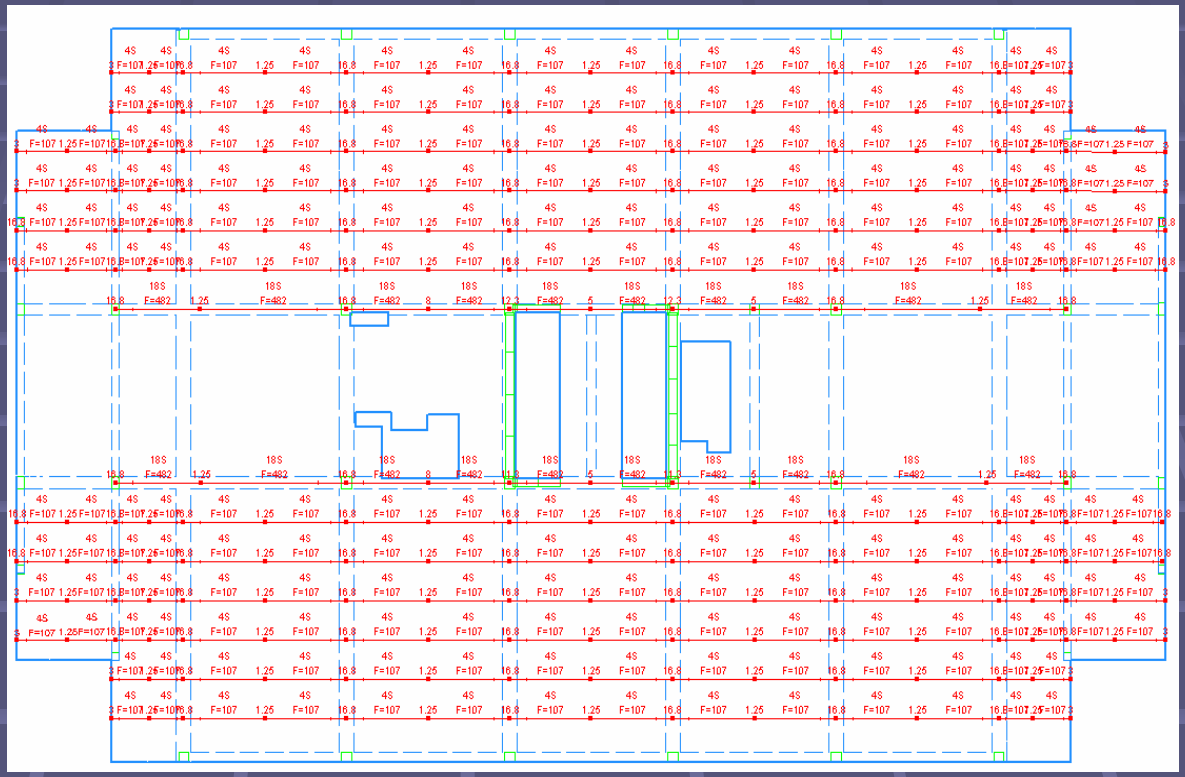
System #1- PT Beam and Slab



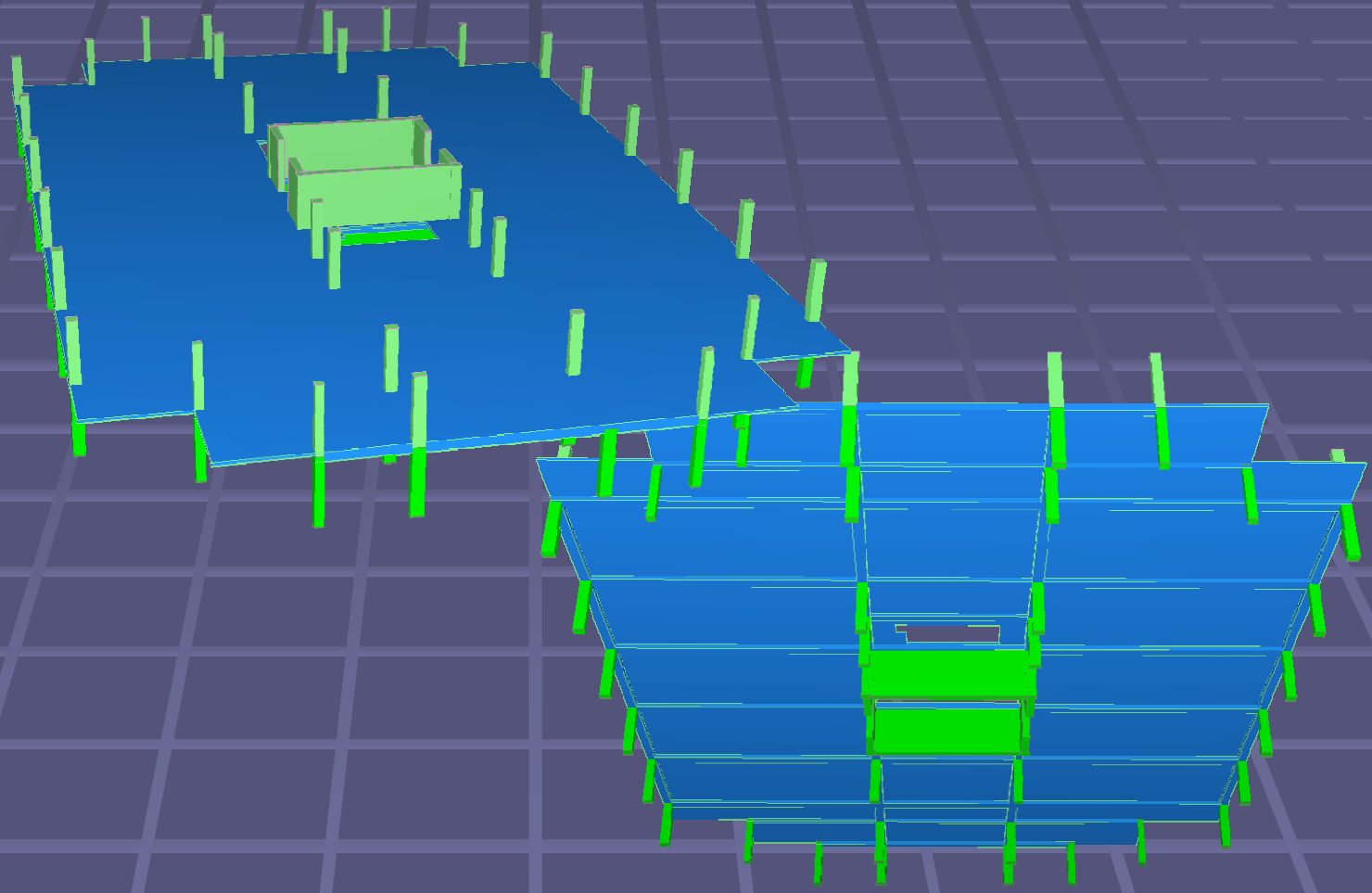
System #2- PT Beam and Slab

System #2: One-way post-tensioned beam and post-tensioned slab

- 6" post tensioned concrete slab with 4 tendons @ 6' o.c
- 18"x30" typical beams spaced 28' o.c.
- 5000 psi concrete

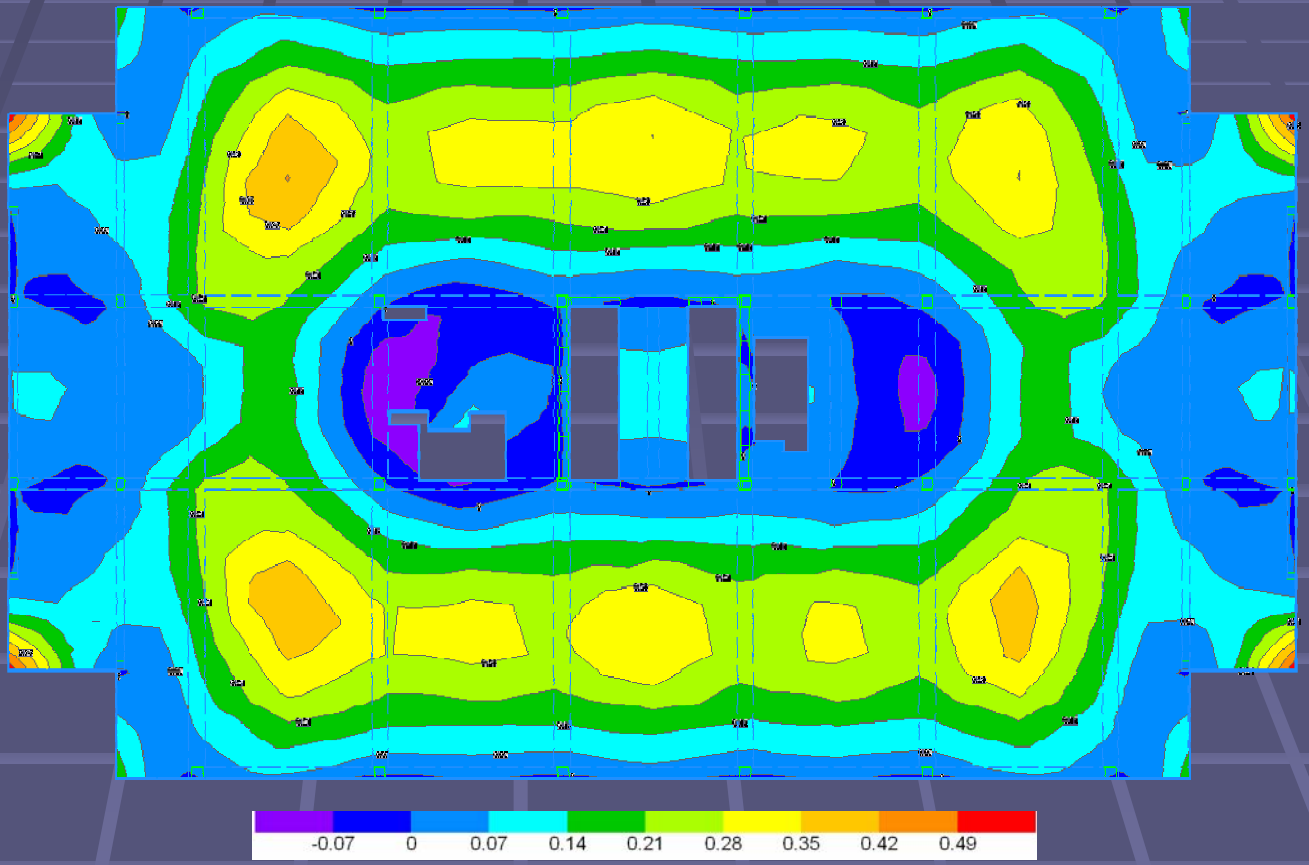


System #2- PT Beam and Slab



Deflection Calculations

RAM Conc*ept* sustained service load deflection plan for system #2



Floor System Summary

	Typical Beam Size	Overall Depth	Sustained Deflection	2 hour fire rating?
System #1	20"x20"	20"	.57"	✔
System #2	18"x30"	18"	.55"	✔

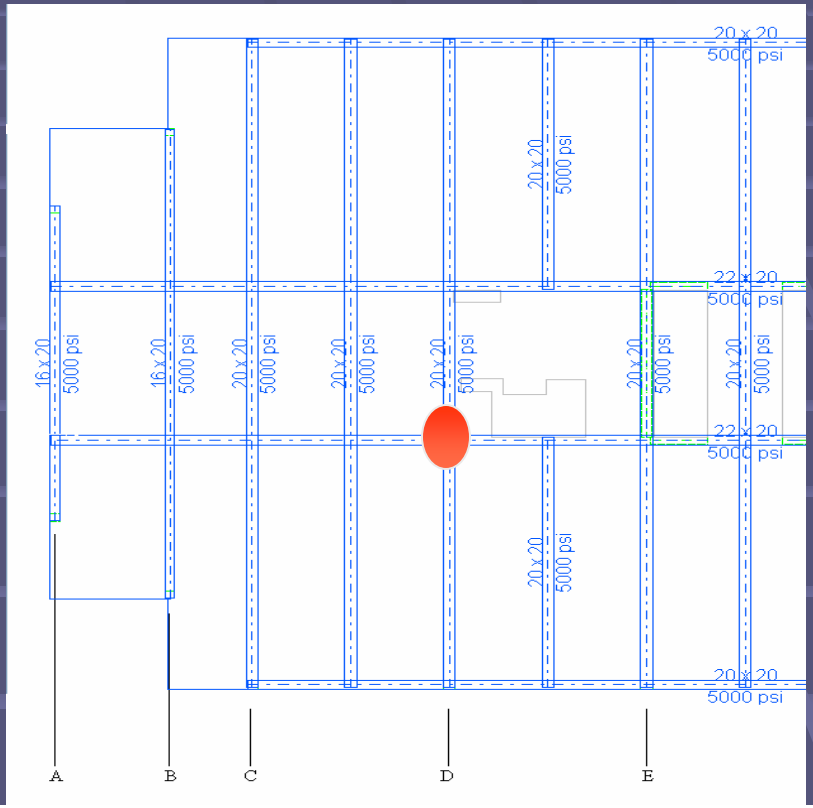
Column Design

Columns were designed using two programs and hand calculations

- Axial load development by hand
- PCA COL with loads and estimated moments
- Finalize design using ETABS and lateral load analysis

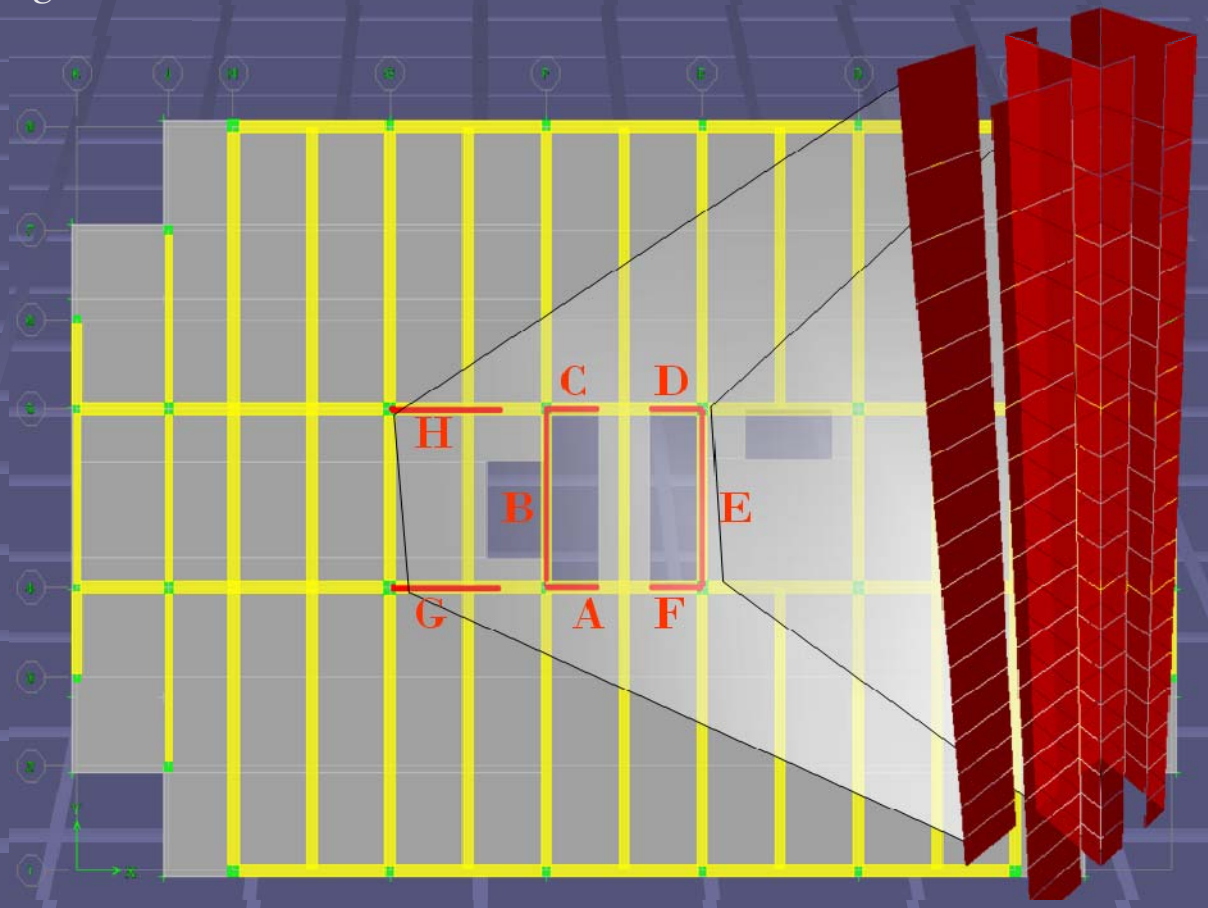
Largest Column: D4, D5

- Base
  - 6000psi concrete
  - 32”x32”
  - 18-#11
- Top
  - 5000psi concrete
  - 18”x18”
  - 4-#11



Shear Wall Design

A series of eight, 12" thick shear walls were designed to resist lateral loads using ETABS



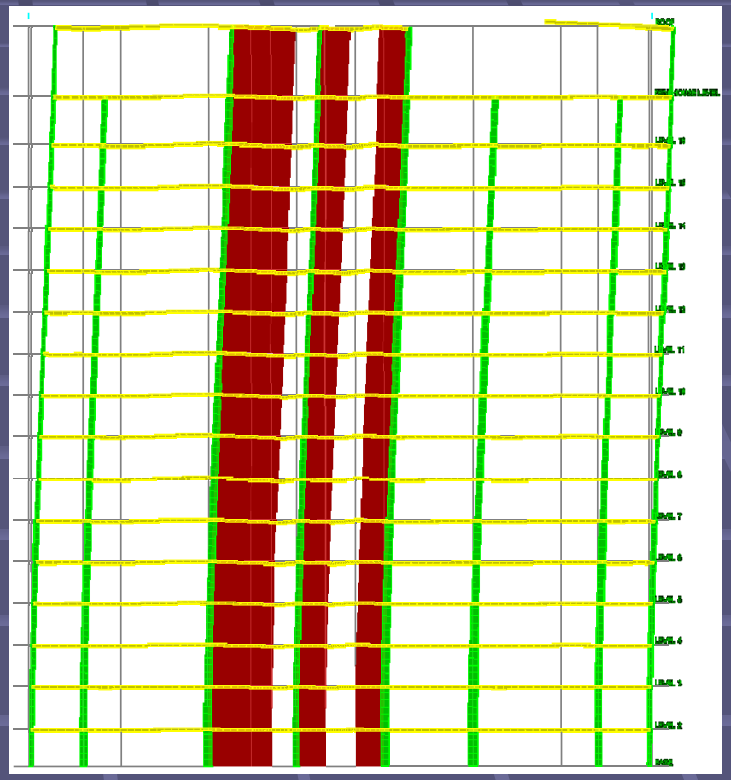
Shear Wall Design

Deflections were calculated under each of the four wind load cases in ASCEE7-02, as well as both seismic directions

Lateral Load Deflection Summary		
	△ X	△ Y
Wind Case 1X	1.76"	-
Wind Case 1Y	-	1.65"
Seismic X	4.66"	-
Seismic Y	-	4.55"
Wind Case 2X	1.32”	-
Wind Case 2Y	-	1.23"
Wind Case 3	1.29"	1.23"
Wind Case 4	0.98"	0.93"

L/400 = (207’*12”)/400=6.21”

Maximum is L/533



Shear Wall Design

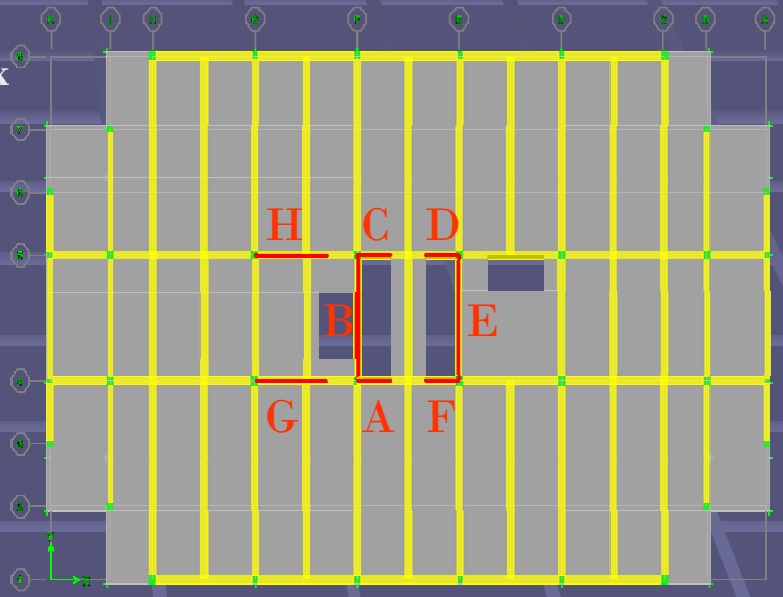
Summary of forces in each wall

Shear Wall Forces under Seismic X Loading (kips)								
	Wall							
Level	A	B	C	D	E	F	G	H
Level 2	99.95	N/A	99.36	97.15	N/A	97.77	266	264.8

Total Base shear under seismic-x loading= 925kips

Shear wall reinforcement was calculated through ETABS

- At base, ρ=.0234
- At top, ρ=.0025



Construction Management

Cost Comparison

A cost estimate was obtained for the original steel system, and the alternate concrete system using both floor systems using RS Means 2005.

The estimate received from Grossi & Sons was in "2001 dollars". Therefore, all estimates using RS Means 2005 were converted into "2001 dollars" using the equation below:

$$(F/P)= 1/ (1+i)^n$$

F= future value
P= present value
i= interest rate
n= time period

Steel Estimate For Eight Tower Bridge			
Steel	**QTY**		
Beams	3200		
Columns	350		
Angle Braces	280		$2,300,000
Moment Conncetions	834		
Instalation			$1,125,000
		TOTAL	$3,425,000
Decking	**QTY**		
Metal Deck			
Shear Studs	48000		$450,000
Instalation			$525,000
		TOTAL	$975,000
Concrete	**QTY**		
4000psi	3451 C.Y.		$310,590
Placing			$103,865
		TOTAL	$414,455
		TOTAL	**$4,814,455**

Cost Comparison

Cost Esitmate for Concrete Structure- Post Tensioned Beams (Crane Placed)

Line Number	Item											
03 310 200 0400	5000 psi Concrete											
	from Beams	2414	C.Y.									
	from Slab	6370	C.Y.									
	from Columns	292	C.Y.									
	from Shear Walls	990	C.Y.									
03 310 220 0411	6000 psi Concrete											
	from Columns	480	C.Y.				$103.00					
											TOTAL	$54,240
03 310 700	Concrete Placing											
0650	Columns, 18", w/ crane	466	C.Y.	C7	55	1309	-	$39.00	$17.45	$55.45	$77.00	$35,882
0850	Columns, 24", w/ crane	308	C.Y.	C7	70	1029	-	$29.50	$13.70	$43.20	$60.50	$18,513
5200	12" walls, w/ crane	990	C.Y.	C7	90	0.8	-	$23.00	$10.65	$33.65	$47.50	$47,025
0250	Beams, w/ crane	2414	C.Y.	C7	65	1108	-	$32.00	$14.75	$46.75	$65.50	$158,117
1550	Slabs, 6", w/ crane	6370	C.Y.	C7	110	0.655	-	$18.90	$8.75	$27.65	$38.50	$245,245
3500	>5 stories, add per floor	8658	C.Y.	C7	2100	0.034	-	$0.99	$0.46	$1.45	$2.02	$17,893
												x 11stories
												$196,825
03 110 410												
												$227,920
												$10,875
											$6.15	$2,122,588
											$7.85	$407,965
												$2,906,146
												div by 4 uses
											BASE	$726,536
										Total w/Adjustment Factor, x 1.295		$940,865
03 210 600	Steel Reinforcement											
0100	Beams/Girders, #3-#7	83.7	TONS	4Rdmn	1.6	20	$800.00	$760.00	-	$1,560.00	$2,125.00	$177,883
0150	Beams/Girders, #8-#18	83.7	TONS	4Rdmn	2.7	11.85	$800.00	$450.00	-	$1,250.00	$1,625.00	$136,013
0250	Columns, #8-#18	92	TONS	4Rdmn	2.3	13.9	$800.00	$530.00	-	$1,330.00	$1,750.00	$161,000
0400	Elevated Slabs, #4-#7	335	TONS	4Rdmn	2.9	11.03	$850.00	$420.00	-	$1,270.00	$1,625.00	$544,375
											BASE	$1,019,250
										10% splice allowance		$1,121,175
										Total w/Adjustment Factor, x 1.2		$1,451,922
03 230 600	Stressing Tendons											
1450	100' span, 300 kip	14070	lbs	C4	1650	0.019	$0.46	$0.75	$0.02	$1.23	$1.77	$24,904
03 350 300	Floor Finishing											
0250	floor, monolitic, machine	21500	SF	1 Cemfi	550	0.015	-	$0.48				
03 150 600	Shoring											
1500	Reshoring	21500	SF Flr	2 Carp	1400	0.011	$0.38	$0				
3060	rent, steel adjust. Per mo	21500	SF Flr	-	-	-	$1.50					

BASE	$701,607
Total w/Adjustment Factor, x 1.1	$771,767

TOTAL STRUCTURE ESTIMATE:	$5,630,561
ESTIMATE IN 2001 DOLLARS:	$5,004,943
COST PER SQUARE FOOT:	$14.51

Comparison Summary

Superstructre System Summary						
	Cost per square foot			Duration (weeks)		
System		Crane	Pump		Crane	Pump
Steel	$13.94	-	-	28	-	-
Concrete System #1	-	$14.51	$13.75	-	28.14	23.7
Concrete System #2	-	$14.21	$13.51	-	28.14	23.7

- All costs are in "2001 dollars"
- The total cost per square foot is based on a 345,000 sq. ft. building
- The estimate does not include foundations
- Schedule and estimate includes shoring costs for concrete

Final Conclusions

Final Conclusions

Advantages

- Both alternate concrete floor system perform better in regards to deflection
- Both floor systems either reduce the overall building height, increase mechanical plenum space, increase floor to ceiling height, or a mix of all 3
- The concrete lateral system will deflect more under seismic loads, but less under wind loads, which it will see more often

However…

- Steel building is cheaper per square foot
- Philadelphia is not extremely booming concrete market
  - Special selection of PT contractor required
- All parties involved are experienced with steel structural system
  - Owner has built similar buildings

It is suggested to use the original steel design

- ✓Introduction
- ✓Outline
- ✓Project Background
- ✓Original Structure
- ✓Proposal
- ✓Structural Design
- ✓Construction Management
- ✓Final Conclusions

Questions

QUESTIONS?