JW Marriott

Greg Kochalski

Structural Option

Thesis Presentation

Spring 2007

OUTLINE

- Introduction
- Existing Structure
  - Floor System
  - Lateral System
- Structural Redesign
  - Floor System
  - Lateral System
- Architectural Redesign
- Cost Analysis
- Conclusions/Recommendations

Project Information

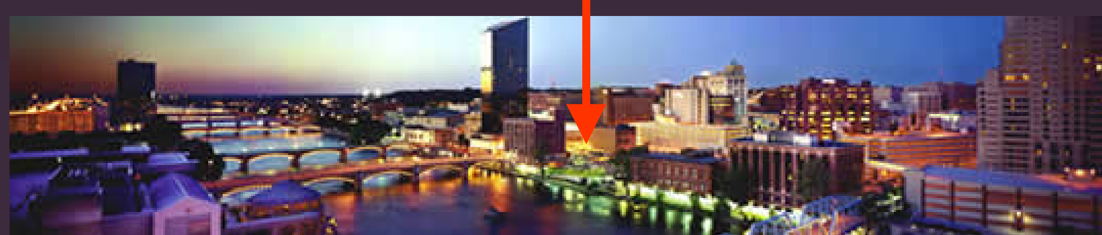
- 24 story Marriott signature series Hotel
- Located along the Grand River in downtown Grand Rapids, MI
- 340 Rooms
- 376,000 sq. ft.
- Amenities include restaurant, lounge, business center, fitness center, and spa
- Stylistic architecture with reflective glass cladding
- Open Air Atrium
- Heated Helipad

Introduction

Site Plan

Downtown

Grand Rapids



Introduction

Project Team

owner- Alticor inc.

Architect- Goettsch Partners and
Beta Design Group

Structural- Thornton Tomasetti Engineers

Contractor- Pepper Construction and
Rockford Construction

MEP- Cosentini Associates

OUTLINE

Introduction

Existing Structure

Floor System

Lateral System

Structural Redesign

Floor System

Lateral System

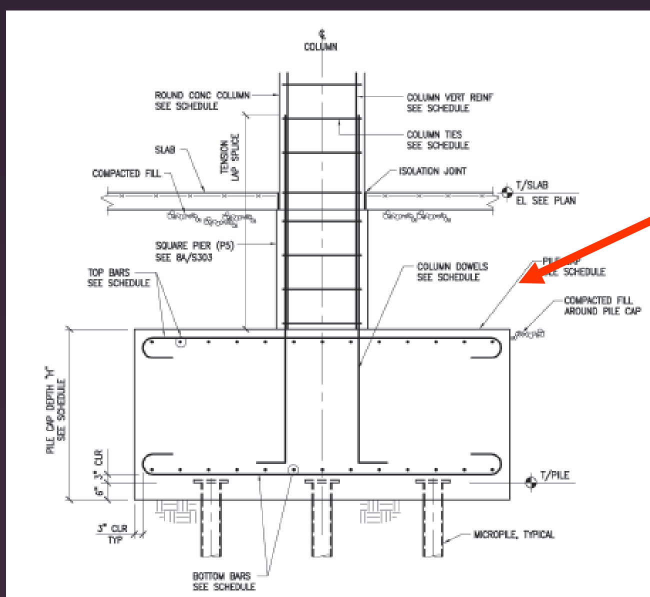
Architectural Redesign

Cost Analysis

Conclusions/Recommendations

Foundation

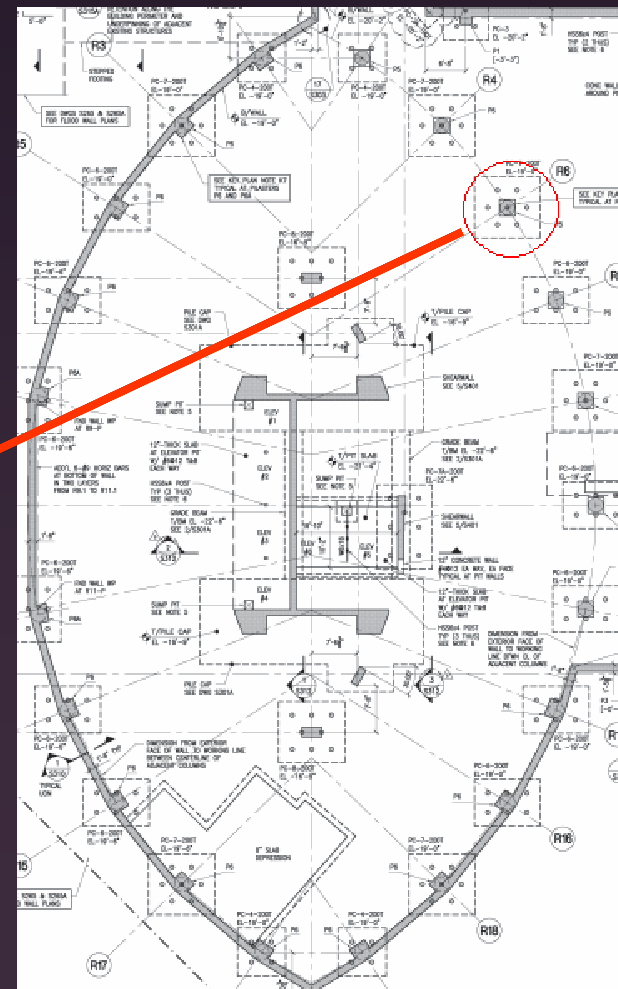
- 200 ton micro piles
- Pile caps located along the perimeter and beneath the core
- 4-7 micro piles per group



6 TYPICAL PILE CAP SECTION AT CONCRETE COLUMN

NOT TO SCALE

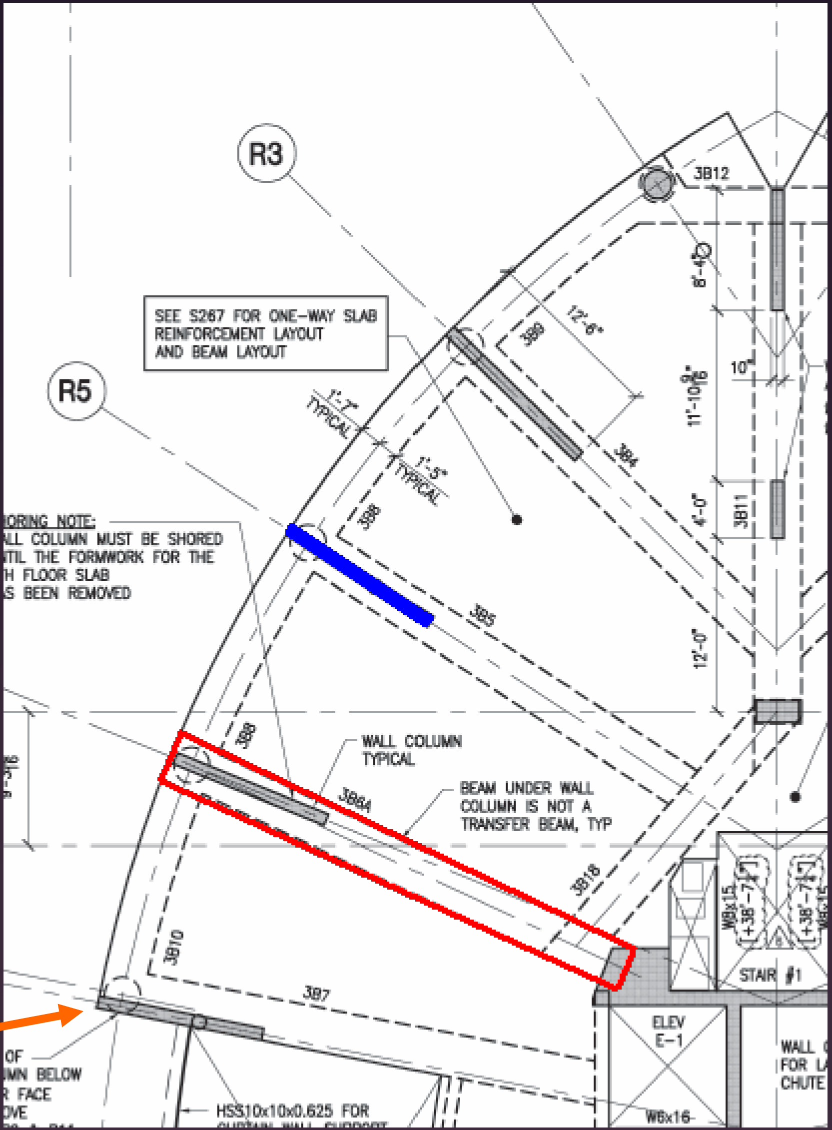
TYPICAL AT PIERS P5
SIMILAR AT PILASTERS ON LINE P



Existing Structure

Floor System

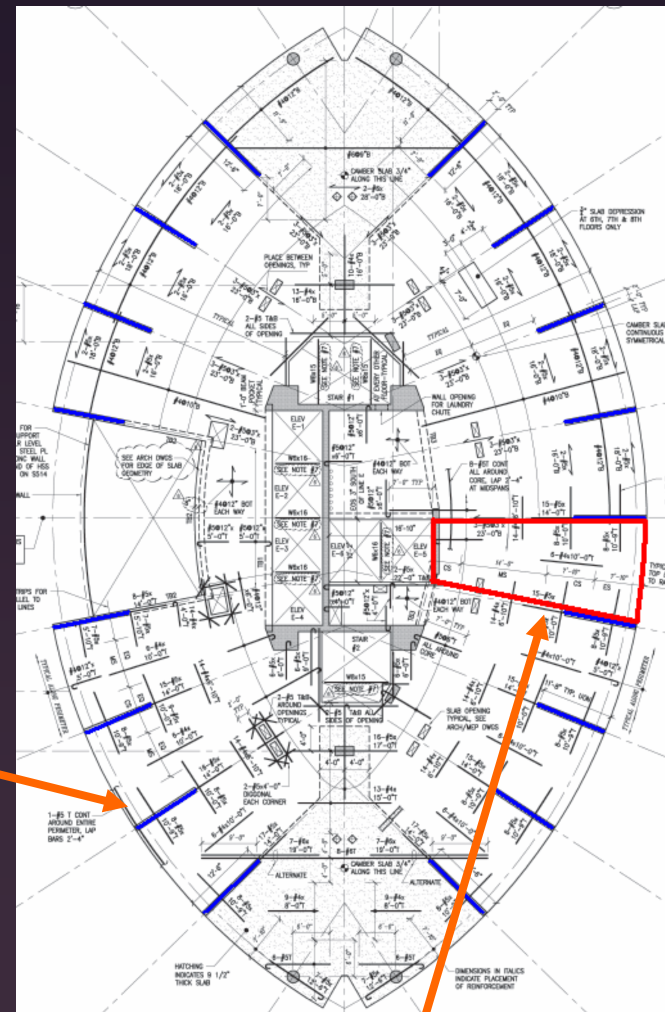
- Flat Plate R.C.
- Short spans- 17 ft.
- One way action
- Typical bay approx 17x35 ft
- 7.5 in. Slab
- f'c = 5700 psi
- Blade-Columns located along perimeter
- Transfer girders at levels 3-5



Eccentric loading requires heavy torsional reinforcing in beam

Blade-Columns

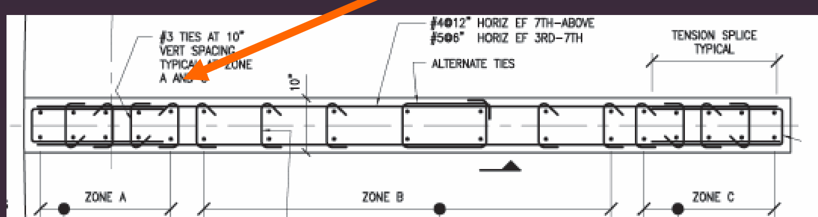
- Reduce spans
- Limit slab thickness
- Maximize patron views
- Fit within interior partitions
- Boundary confinement at edges



Typical Floor with Radial Columns

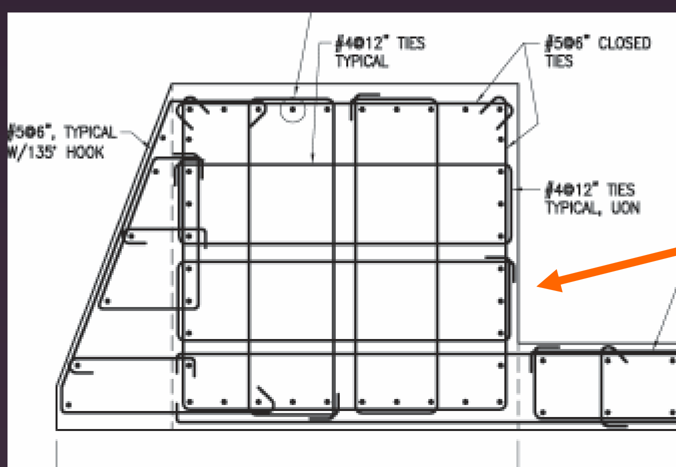
Typical bay

Confinement



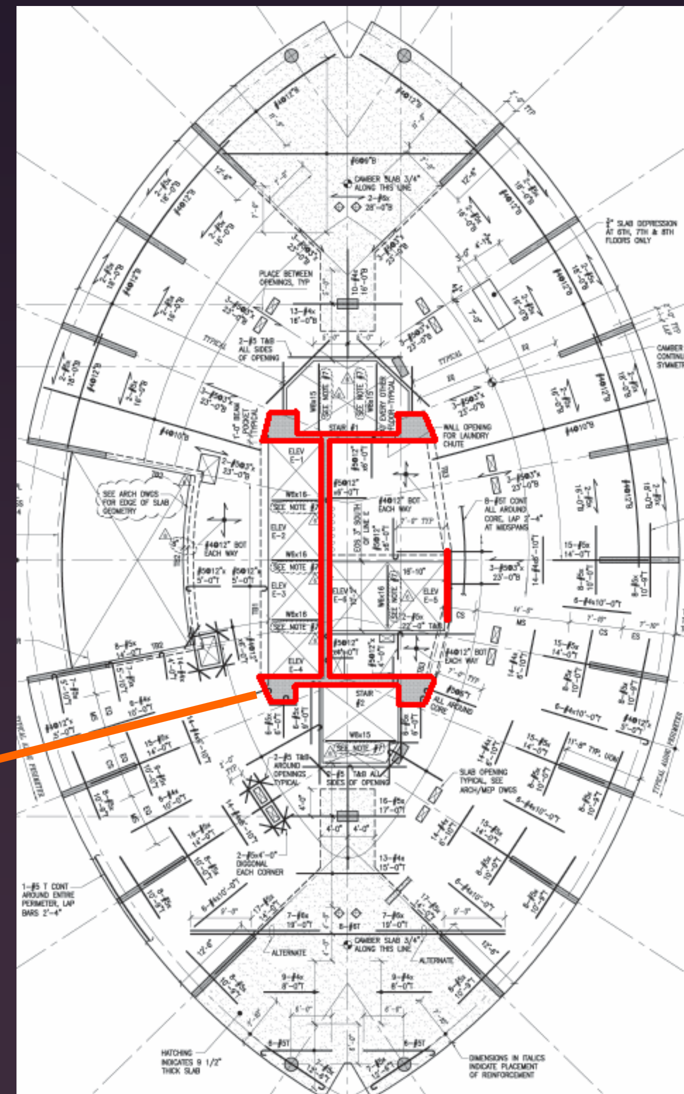
LATERAL SYSTEM

- TWO PAIRS OF SHEAR WALLS
- F'C VARIES FROM 10 KSI TO 6KSI
- BOUNDARY ELEMENTS FOR INCREASED INERTIA IN EAST-WEST
- 12 IN. THICK IN BOTH DIRECTIONS



HEAVY CONFINEMENT

IN BOUNDARY ELEMENTS



OUTLINE

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Existing Structure

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Structural Redesign

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Architectural Redesign

Cost Analysis

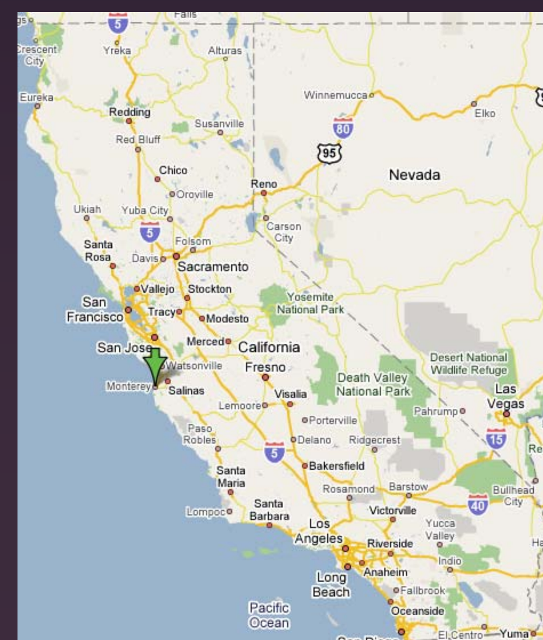
Conclusions/Recommendations

Proposal Summary

- Relocation to Monterey, CA
- New lateral system
- New Post tension floor system
- Use updated building code

Design Goals

- Achieve desired non-linear response
- Avoid pitfalls of peer review
- Limit vertical walls to <3.0% of floor area



Building Codes

Grand Rapids	Monterey
MBC 3003 (IBC 2003)	IBC 2006
ACI318 2002	ACI318 2002
ASCE7 2002	ASCE7 2005

Post Tension System

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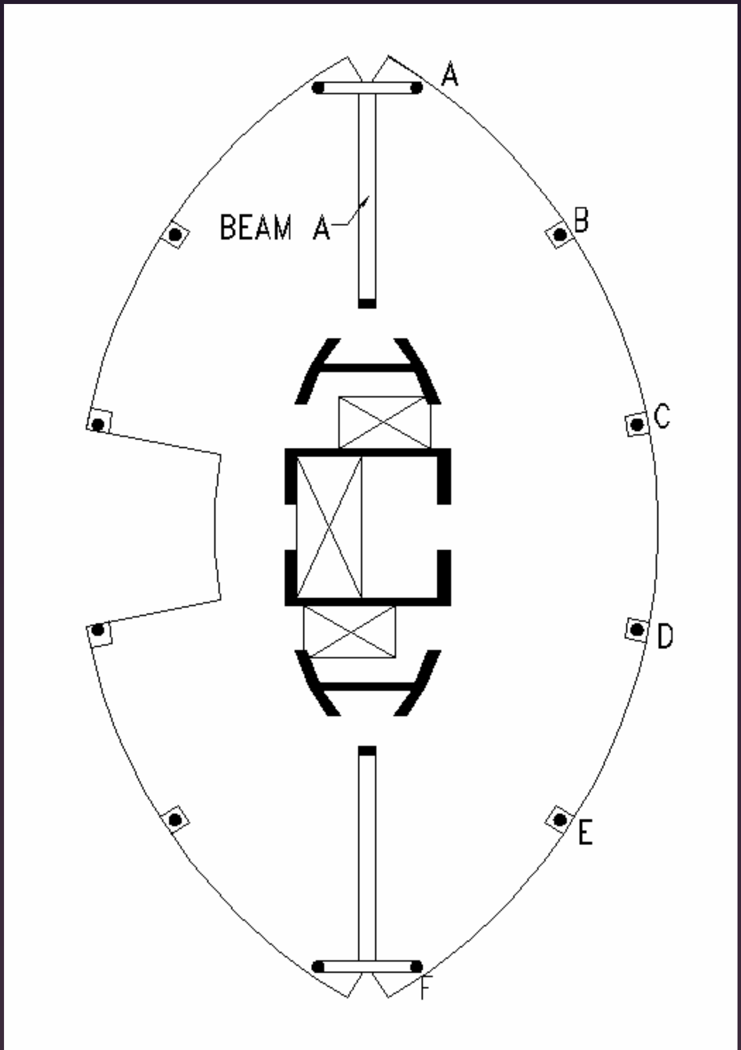
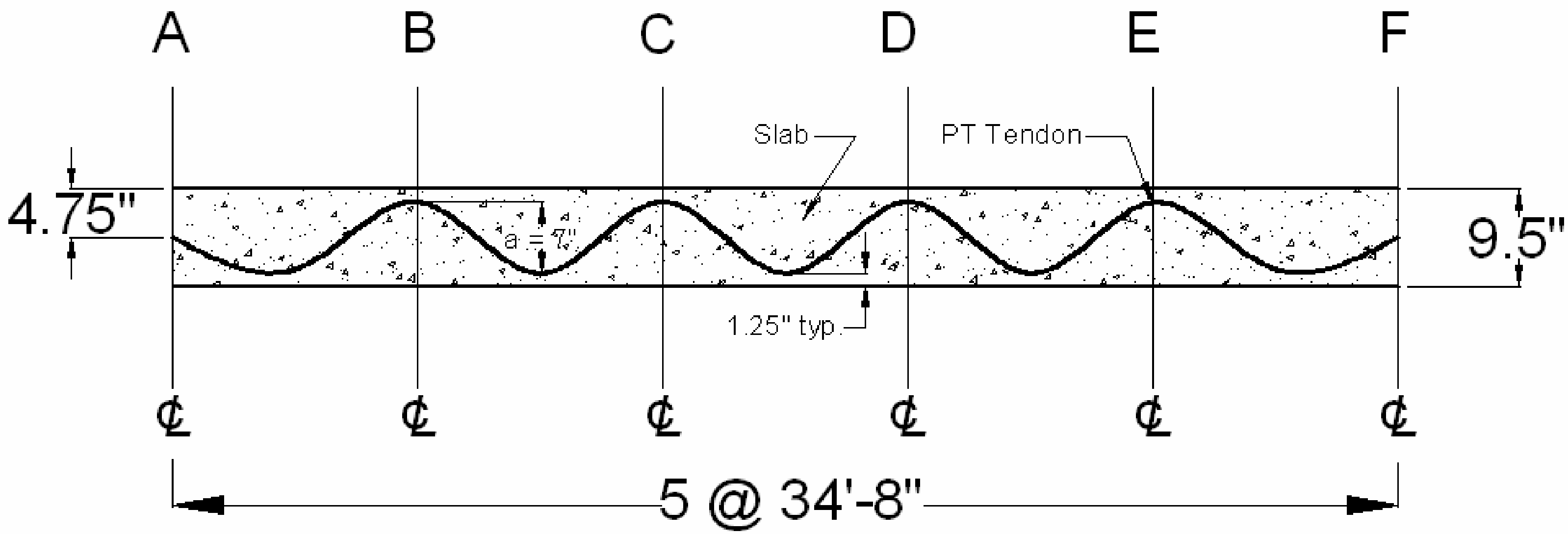


Labeling Scheme

Characteristics

- Typical span = 35 ft.
- 9.5 in. PT flat plate (l/45)
- Class U system
- Balance 85% dead load
- ½ in. 270 ksi strands
- F'c = 4000 psi

PT Floor Loads		
	Design Loads (psf)	ASCE 7 (psf)
Dead	20	20
Live	40	40



Tendon Drape

Post Tension System

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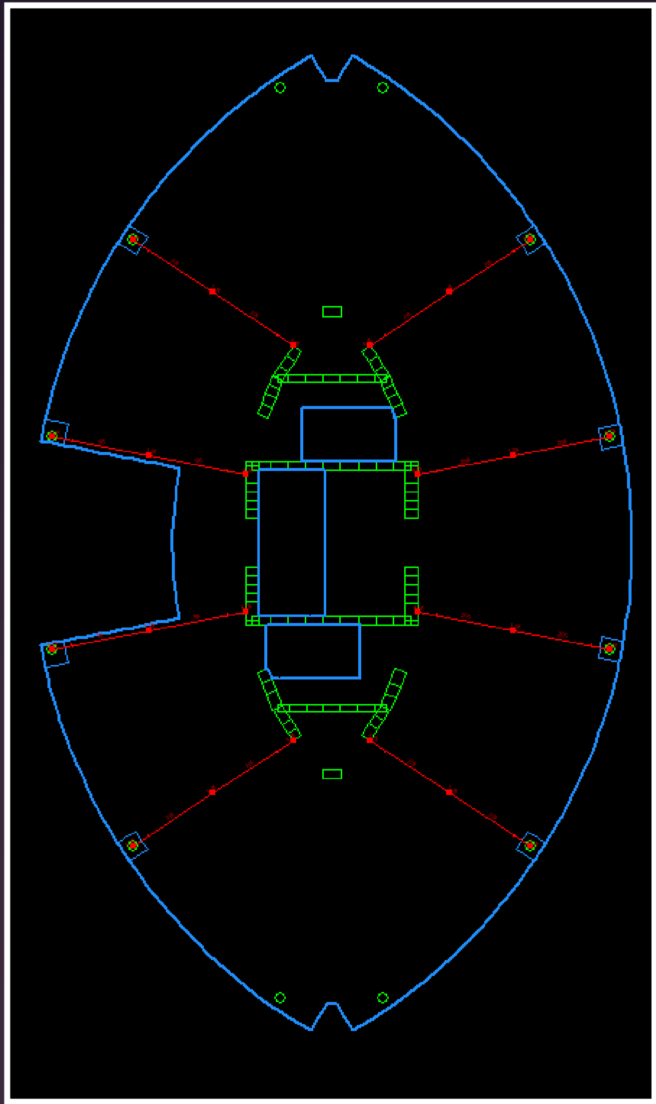
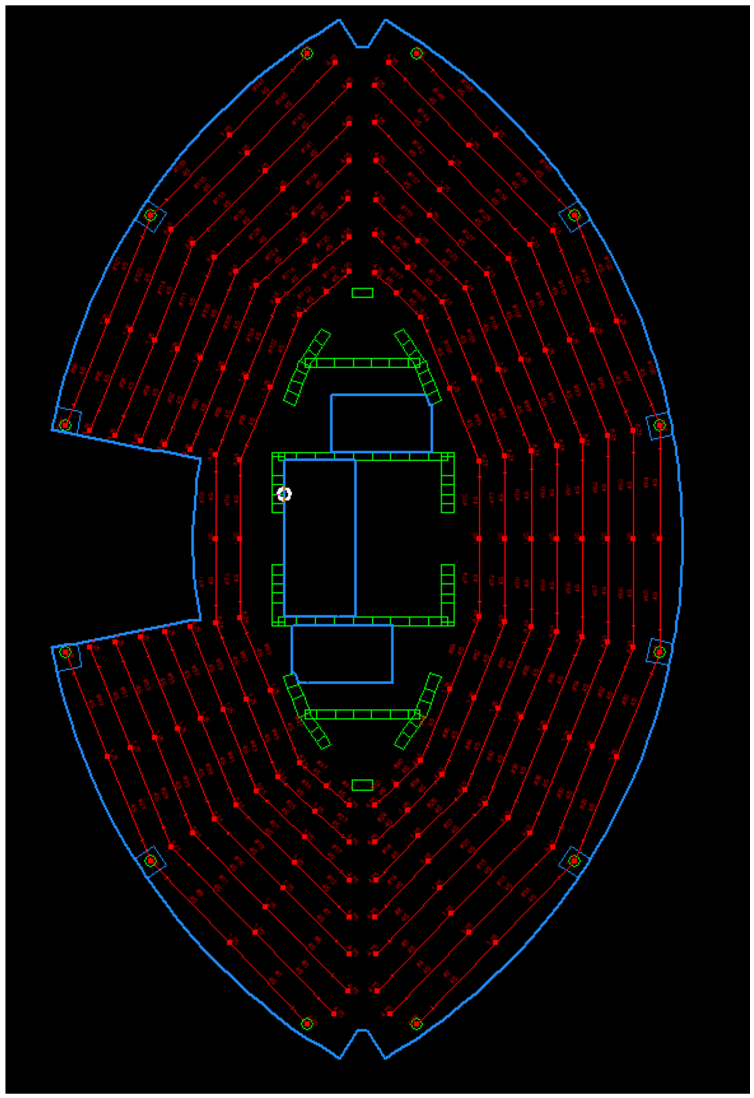
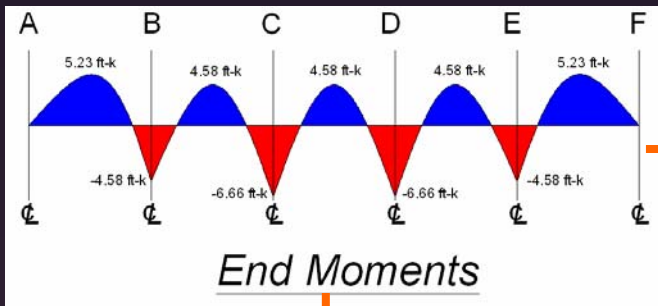


Large banded tendons



Small banded tendons



Average Stresses

$$f = -\frac{F}{A} \pm \frac{M_n}{S}$$

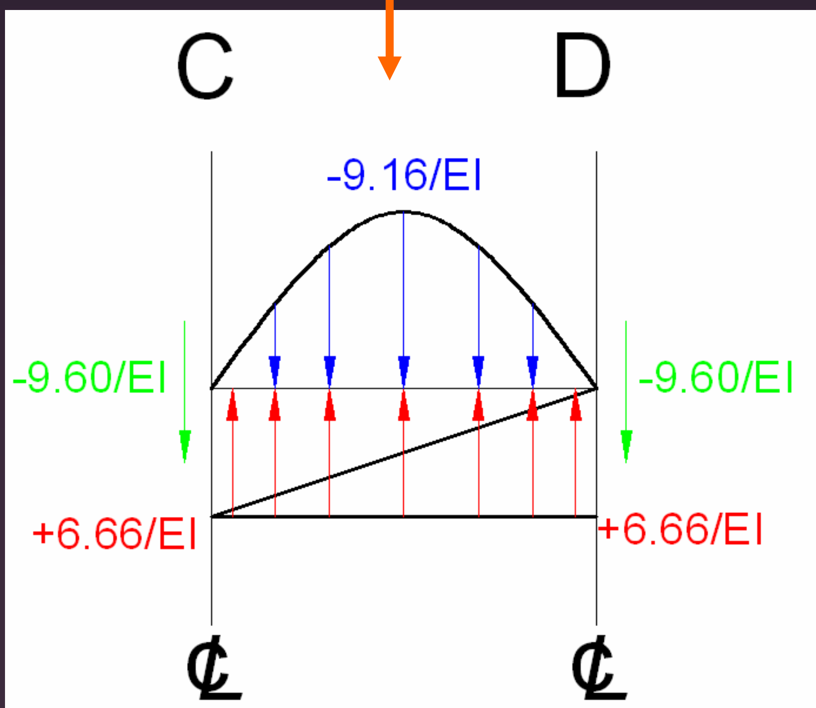
$$\frac{F}{A} = 225\,psi,\ \ \frac{M_n}{S} = (\pm 442\,psi, \pm 79\,psi)$$

$$f = +217 < 6\sqrt{f'_c}$$

$$= -667 < 0.3 f'_c$$

$$= +79 < 2\sqrt{f'_c}$$

$$= -529$$



Slab Deflections		
Span	Deflection (in)	Deflection Equivalent
AB	0.268	L/1150
CD	0.361	L/1150

9.5 in. PT flat slab works

Lateral System

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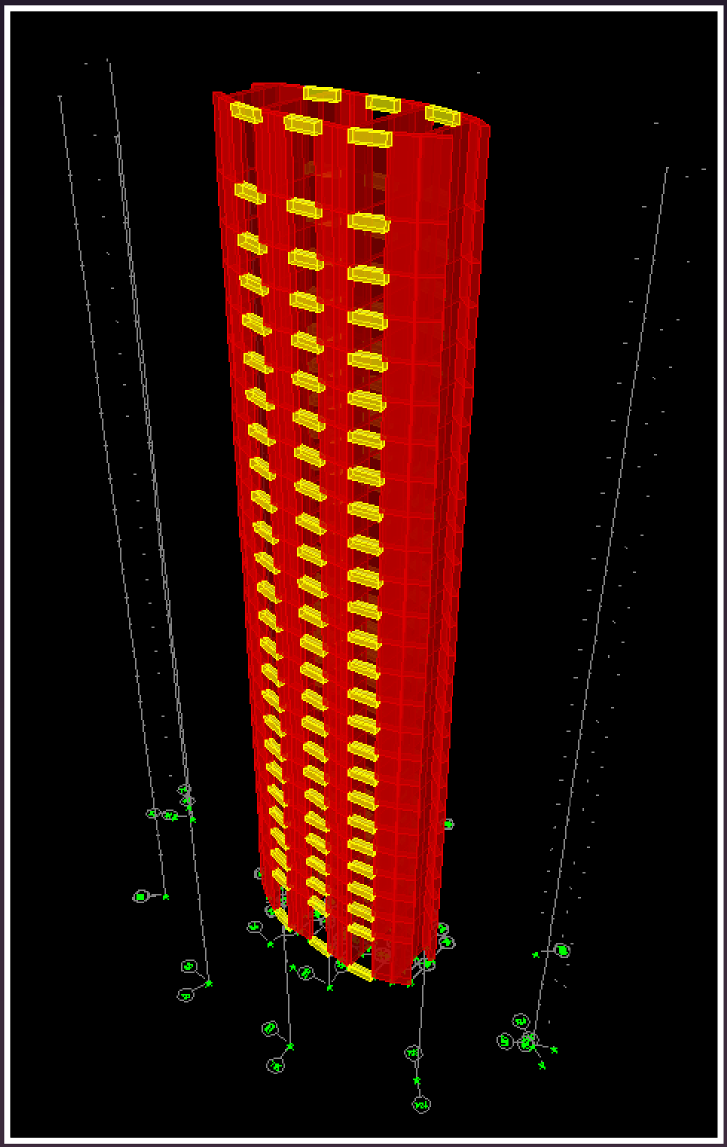
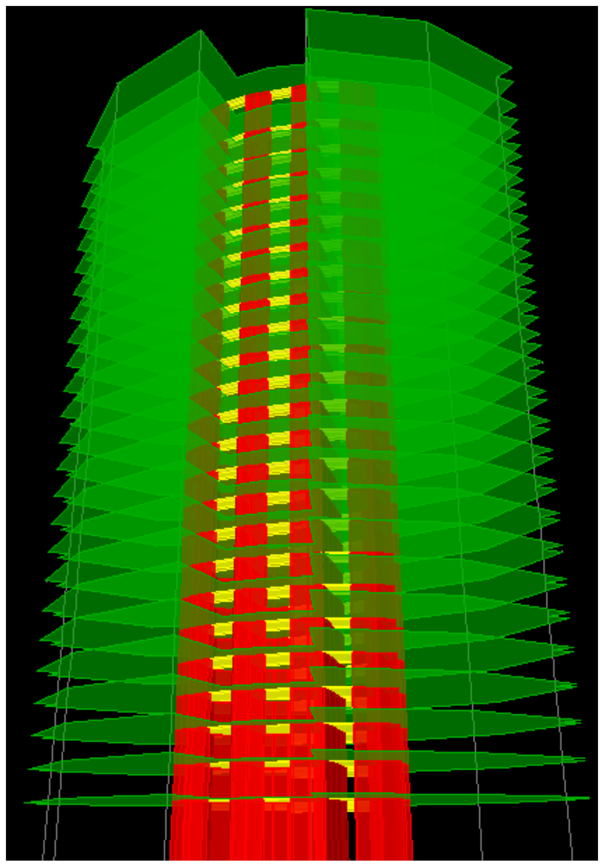


Nonlinear Response

- Force dissipation mechanism ensures integrity
- Plastic hinging in beams, walls approach yielding
- Detailed for proper ductility
- Even deformations over height

Peer Review

- 256 ft exceeds 240 ft height limit
- Requires "code equivalent performance"...
- Inherent uncertainties when interpreting code



Analysis Methods

- Equivalent lateral force method
  - Manual calculations
  - Etabs
- Modal response (dynamic) analysis
  - Etabs

Spectral Response Parameters

- S_{DS}=0.97
- S_{D1}=0.53
- S.D.C.= D
- S.C. = C
- O.C.=II
- R=5.0
- C_D=4.5

ETABS CASES & COMBINATIONS

- STATIC ANALYSIS (ACCIDENTAL TORSION)
  - EXZ1- ECC IN X, CW MOMENT
  - EXZ2- ECC. IN –X, CCW MOMENT
  - EYZ1
  - EYZ2
- DYNAMIC ANALYSIS (MEMBER FORCES)
  - XSPECF
  - YSPECF
- DYNAMIC ANALYSIS (DISPLACEMENTS)
  - XSPECD
  - YSPECD

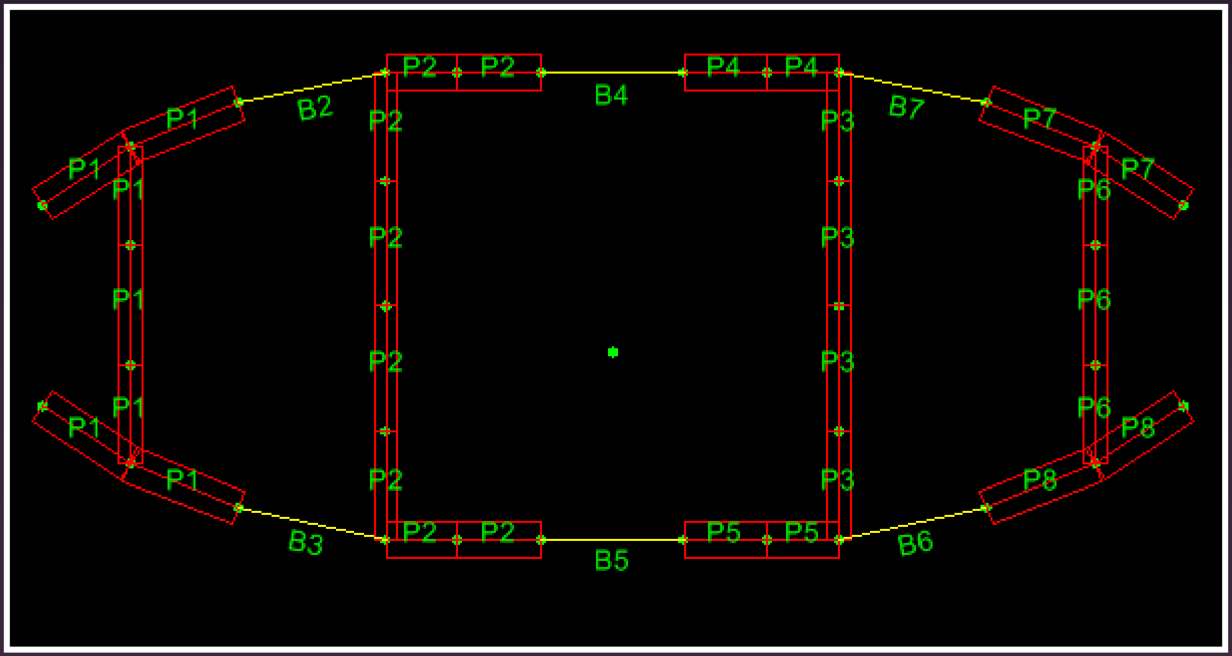
SCALE FACTORS

$$Ecc.\,Ratio = 0.05 \times A_x$$

$$\text{Scale Factor} = (\text{S.F.}_{\text{DYN}}) \times \left(\frac{V_{b\,\text{ELF}}}{V_{b\,\text{DYN}}} \right) \times 0.85$$

$$\text{Scale Factor} = \frac{386 \times C_d}{R}$$

Pier and Spandrel Labeling



Coupling Beams

Influence...

- Period
- Shear (in walls)
- displacements

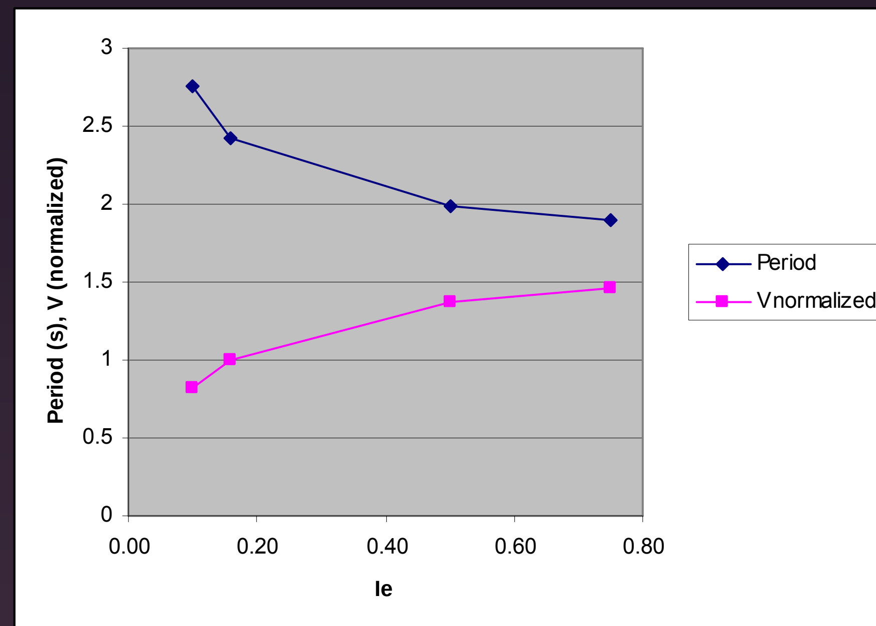
Cracked section

$$I_{effective} \geq \frac{0.2}{\left(1+3(h/l_n)^2\right)} \times I_{gross}$$

Ultimate shear

$$V_u \leq \phi \times 8.0\sqrt{f'_c} \times bd$$

Interpreting the output



Varying I_{eff}			
I_e	V_{max}	Vnorm	Period
0.10	189	0.814655	2.76
0.16	232	1	2.425
0.5	317	1.366379	1.99
0.75	340	1.465517	1.90

ULTIMATE SHEAR

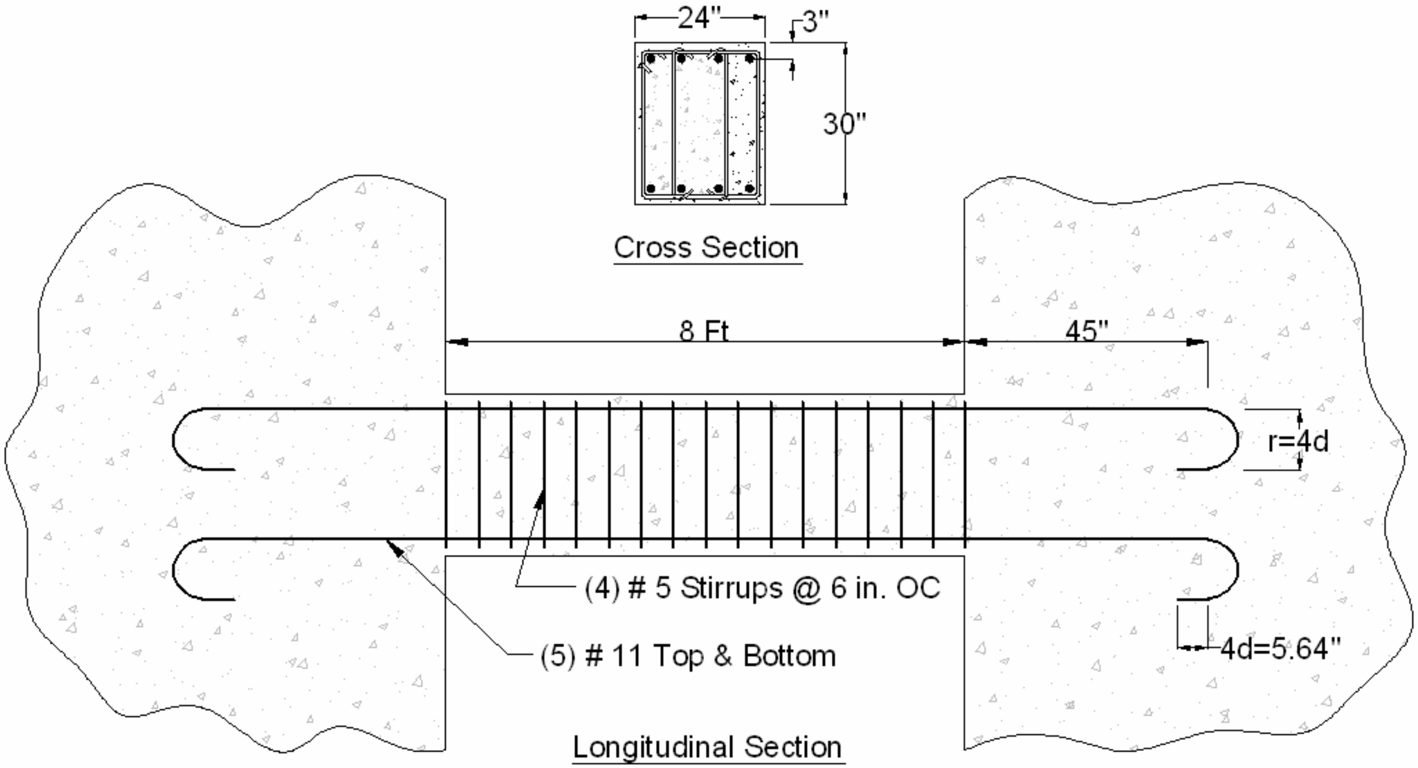
- DETERMINED GROUP, AND WILL BE THE MAXIMUM OF
  - $0.8V_{MAX}$
  - $V_{AVERAGE}$

DETAILING

- REINFORCING MUST ENSURE
  - PROPER DUCTILITY
  - FAILURE IN MOMENT, NOT SHEAR

Coupling Beam Ultimate Shear

Level	Shear (K)	Shears		Design Group Shears	
		$0.8\ V_{max}$ (K)	$V_{average}$ (K)	$0.8\ V_{max}$ (K)	$V_{average}$ (K)
Roof	90	**122**	122	**122**	122
24	111				
23	113				
22	121				
21	131				
20	142				
19	152				
18	162	161	**182**	161	**182**
17	171				
16	179				
15	187				
14	194				
13	201				
12	208	186	**221**	186	**213**
11	214				
10	220				
9	225				
8	229				
7	232				
6	231	186	**205**		
5	228				
4	220				
3	205				
2 Mezz	181				
2	163				


24"
3"
30"
Cross Section
8 Ft
45"
r=4d
(4) # 5 Stirrups @ 6 in. OC
(5) # 11 Top & Bottom
4d=5.64"
Longitudinal Section

Beam B1

Lateral System

Displacement

<2.0% Height (code)

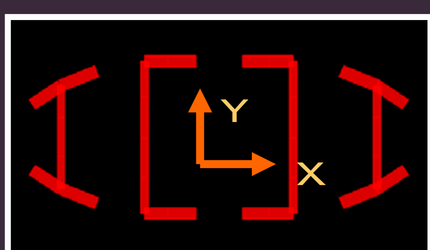
<1.0% Height (imposed)

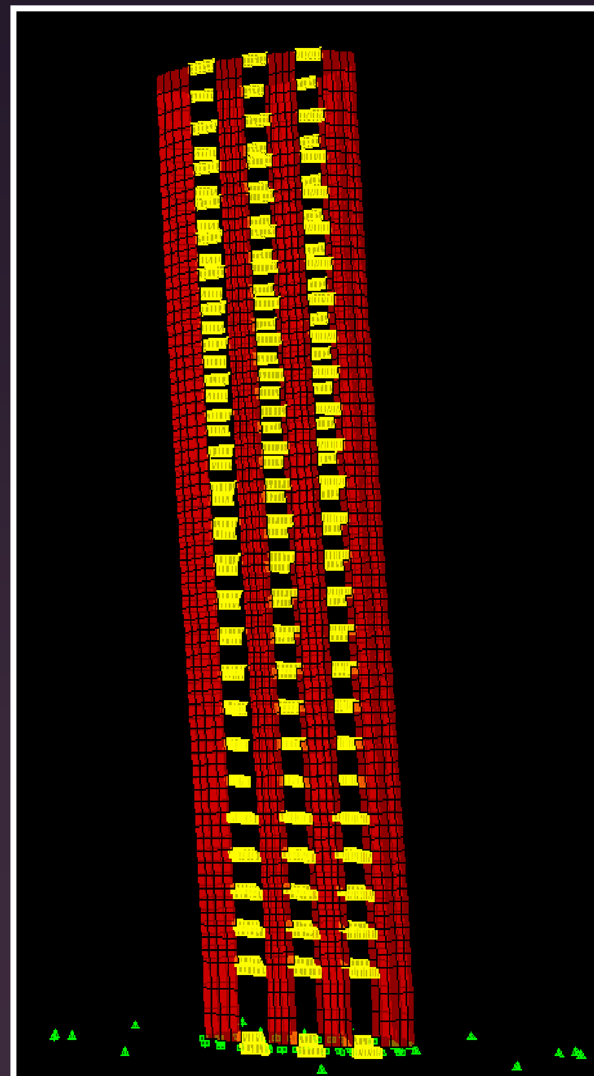
0.01H = 30 in.

Max Displacement

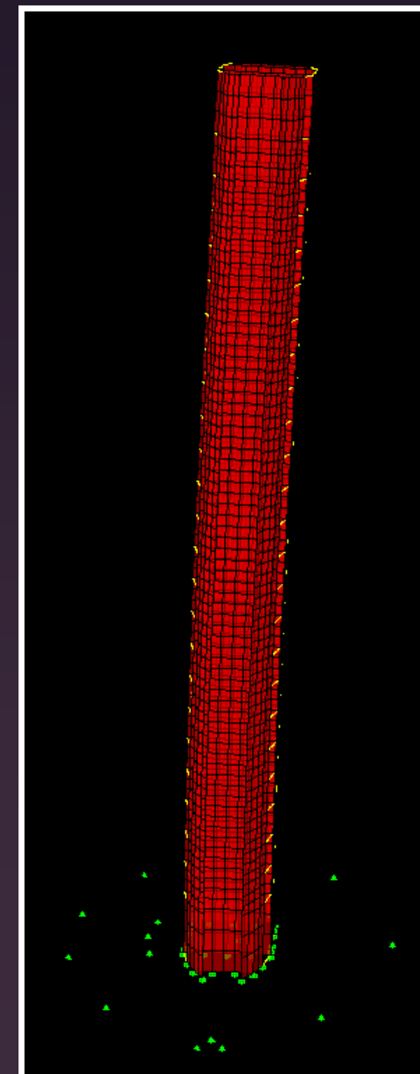
16.6 in. (x)

21.4 in. (y)

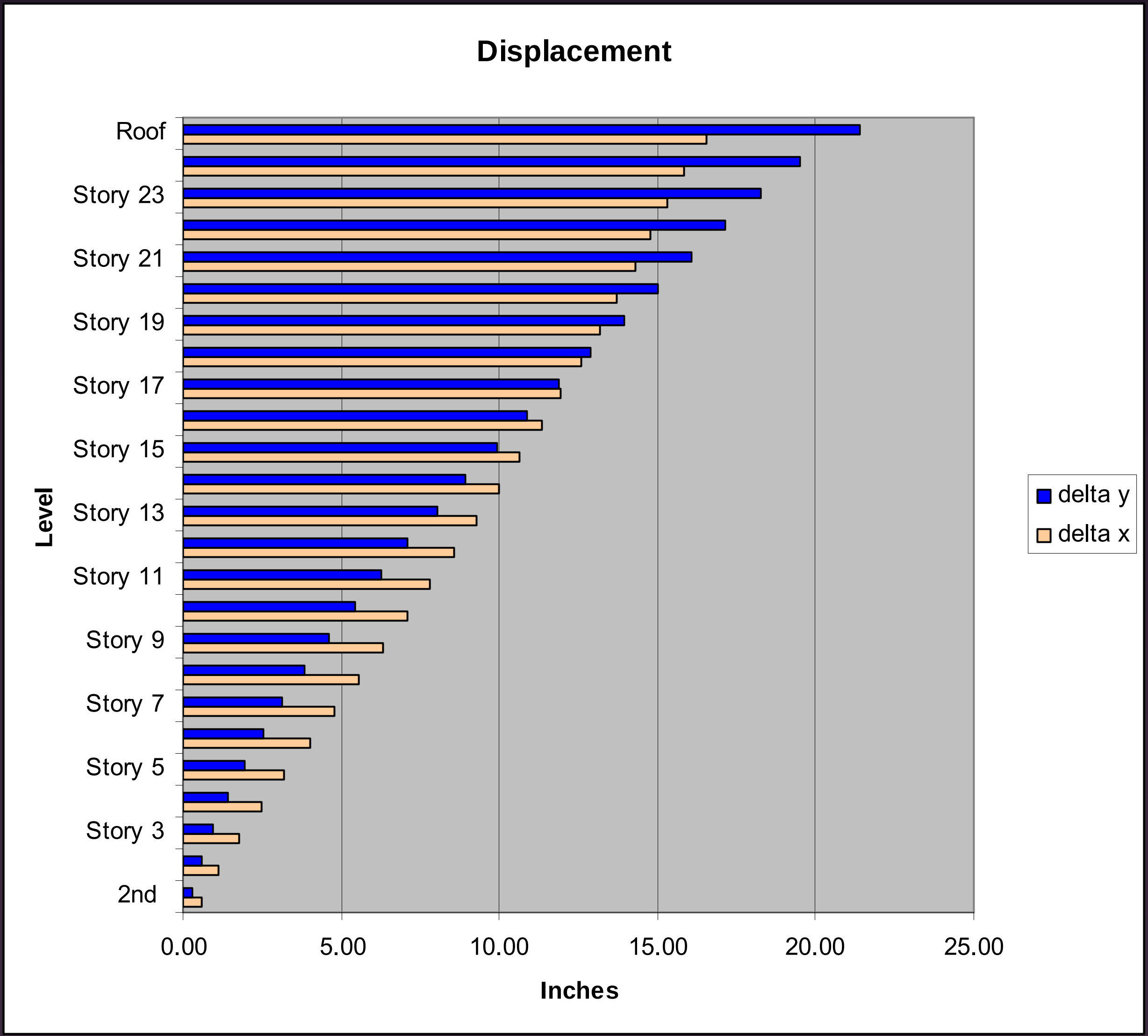




X direction



Y direction



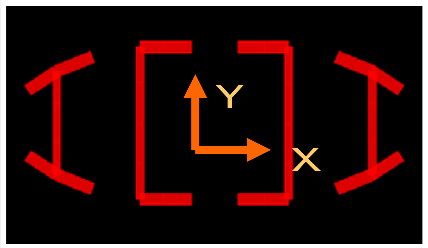
Max Displacement

16.6 in. (x)

21.4 in. (y)

Interpreting output

- Beam action in Y
- Frame action in X



Shear Walls

Design Criteria

Direct Shear

- Distributes by area
- Limit shear to:

$$V_u \leq \phi \times 4.0\sqrt{f'_c} \times t \times l$$

Flexure

- Distributes by inertia
- Reinforce to resist tension

Direct Shear

$$V_u \leq \phi \times 4.0\sqrt{f'_c} \times t \times l$$

Pier 3: $1100\ \text{k} = \phi \times 3.59\sqrt{f'_c} \times A_v,$ where $A_{v3} = 37.33\ \text{ft}^2$

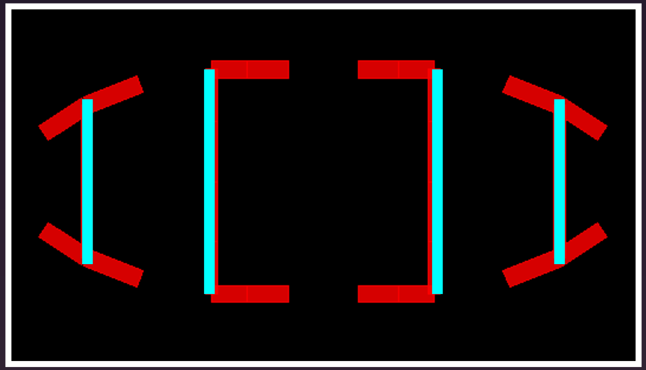
Pier 4 & 5: $343\ \text{k} = \phi \times 2.24\sqrt{f'_c} \times A_v,$ where $A_{v4/5} = 18.67\ \text{ft}^2$

Pier 6: $876\ \text{k} = \phi \times 4.11\sqrt{f'_c} \times A_v,$ where $A_{v6} = 26.0\ \text{ft}^2$

Pier 7 & 8: $350\ \text{k} = \phi \times 3.78\sqrt{f'_c} \times A_v,$ where $A_{v7/8} = {*}19.5\ \text{ft}^2$

$${*}A_{v7/8} = 9.77\ \text{ft}^2 \times \cos(33°) + 12.2\ \text{ft}^2 \times \cos(22°)$$

Interpreting the Output



A_v shown in blue

Theoretical

A_v (ft^2)	26	37.3	37.3	26
K_v	0.7	1.0	1.0	0.7
DF_v	0.21	0.29	0.29	0.21

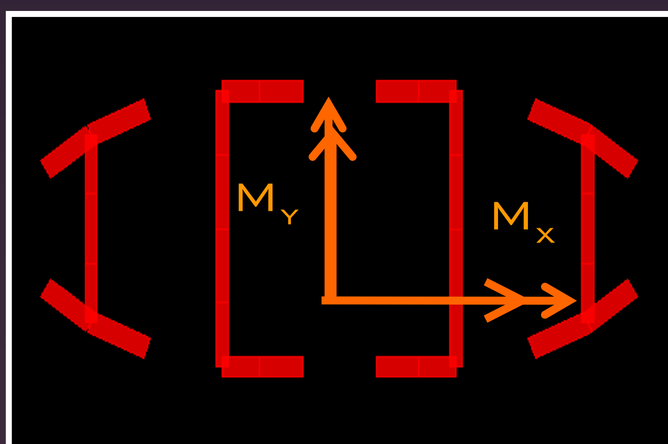
Etabs Output (YSPECF)

V_{OP}	876	1100	1100	876
DF_{OP}	0.22	0.28	0.28	0.22

Flexure

Reinforce Tension Areas

- PCA column
- Load cases derived from ASCE7



Moment sign convention

ASCE7 : $0.9D + 0.5L \pm 1.0E + 1.0E_v$

where $E_v = 0.2S_{DS}D$, $S_{DS} = 0.97$, and $L = 0$

ASCE7 then becomes :

(1) $0.7D + 1.0E_x + 0.3E_y$

(2) $0.7D + 1.0E_x - 0.3E_y$

(3) $0.7D - 1.0E_x + 0.3E_y$

(4) $0.7D - 1.0E_x - 0.3E_y$

(5) $0.7D + 0.3E_x + 1.0E_y$

(6) $0.7D - 0.3E_x + 1.0E_y$

(7) $0.7D + 0.3E_x - 1.0E_y$

(8) $0.7D - 0.3E_x - 1.0E_y$

Where $E_x = M_x$ due to Earthquake in Y

$E_y = M_y$ due to Earthquake in X

$D = P_{SELF\ WT} + P_{GRAVITY}$

Reinforcing

Trends:

- Heavy reinforcing in outer areas of flanges
- Light reinforcing in webs

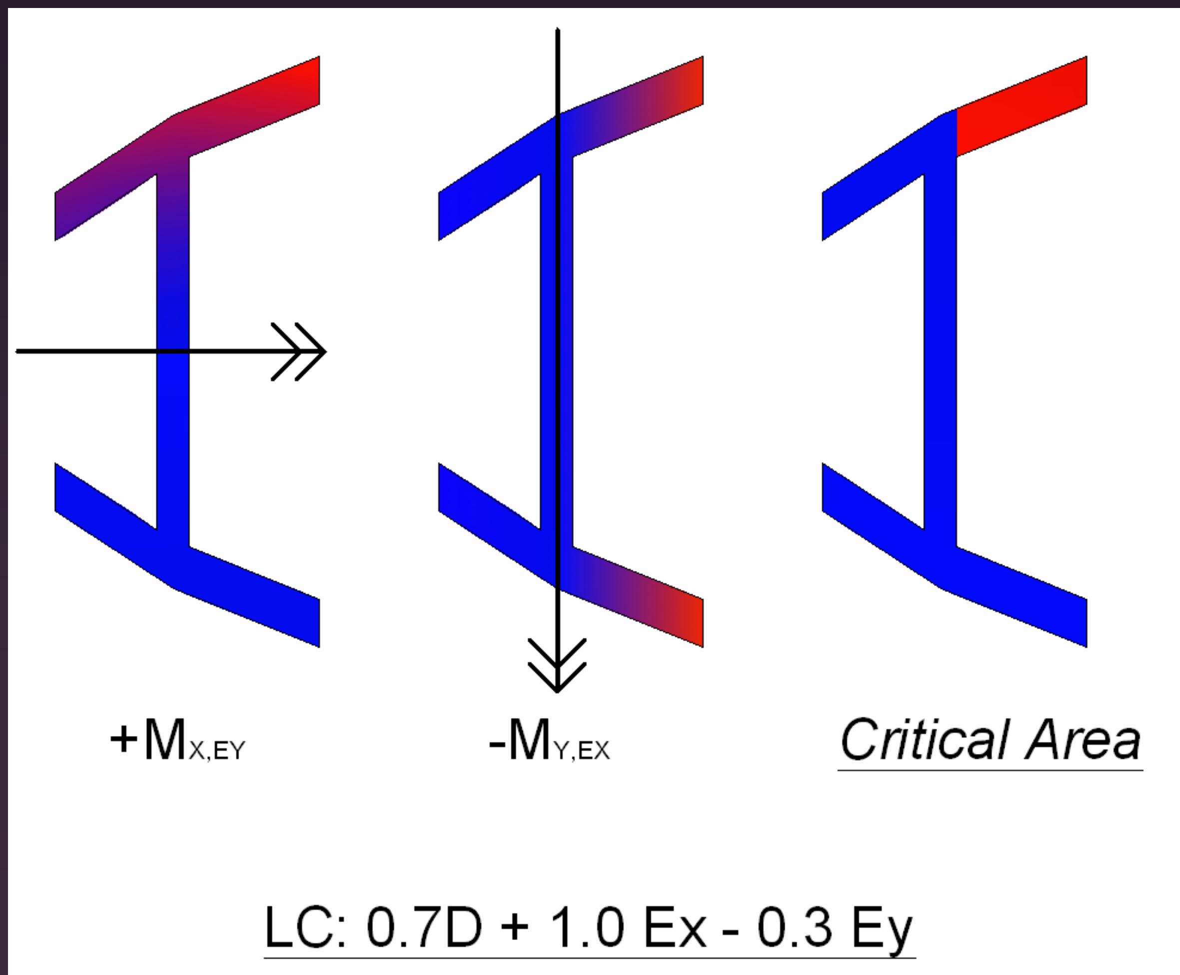
Pier Vertical Reinforcing Schedule

Pier	Rebar #	Rows	Spacing (in)	As (sq. in.)	ρ, per Pier (%)	ρ, per section (%)
3	9	1	16	18	0.26	0.94
4	9	2	6	38	1.41	
5	9	2	6	38	1.41	
6	9	1	11	15	0.40	1.16
7 outer	9	3	3.5	30	1.13	
7 inner	9	2	6.5	24	1.70	
8 outer	9	3	3.5	30	1.13	
8 inner	9	2	6.5	24	1.70	

Pier Horizontal Reinforcing Schedule

Pier	Rebar #	Rows	Spacing (in)	As (in^2/ft)	ρ, per Pier (%)
3	4	2	10	0.48	0.25
4	5	2	10	0.74	0.26
5	5	2	10	0.74	0.26
6	4	2	10	0.48	0.25
7	5	2	10	0.74	0.26
8	5	2	10	0.74	0.26

VERIFYING THE RESULTS



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Architectural Redesign

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Conclusions/Recommendations

Affected Areas

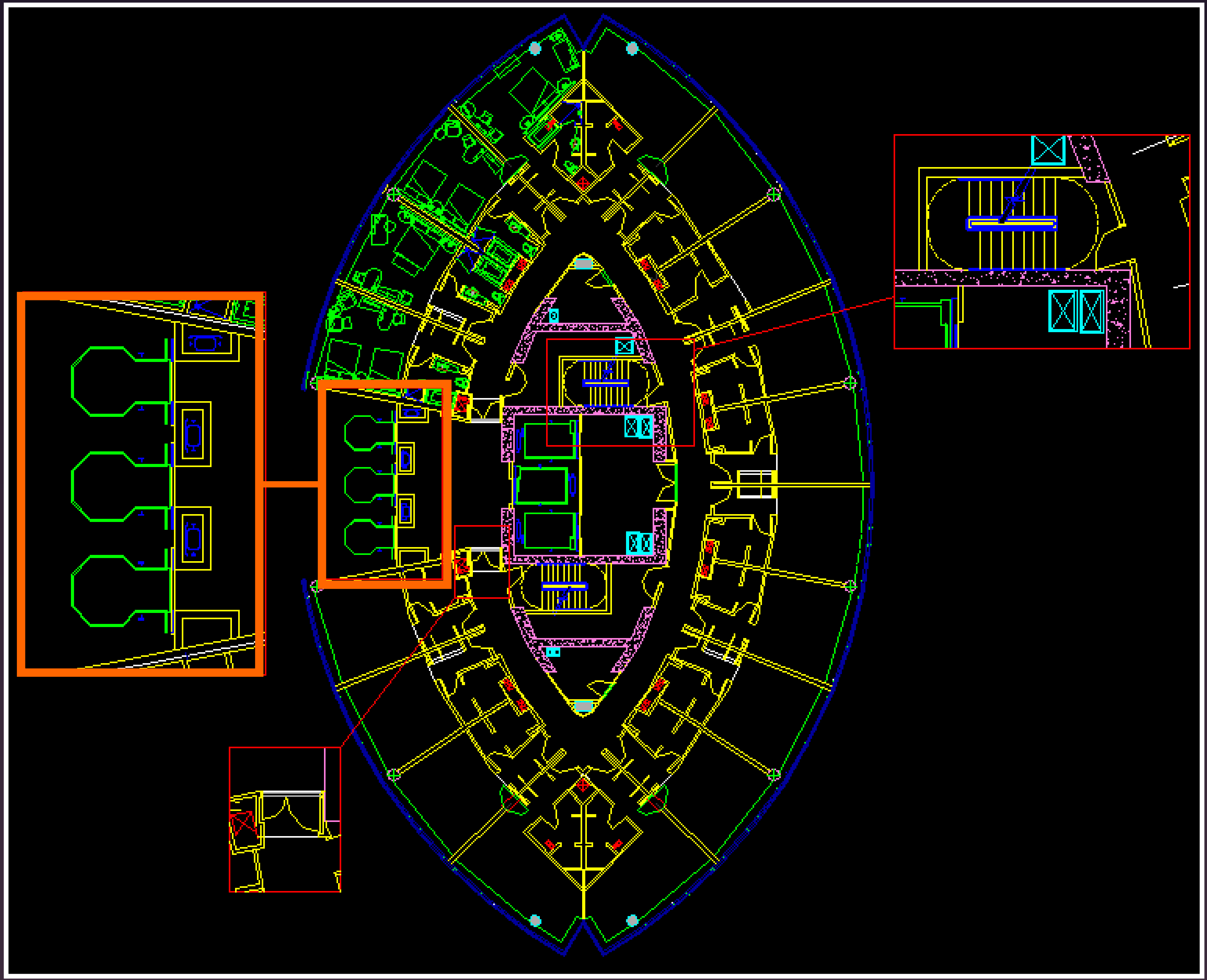
- Stairwells
- Patron elevators
- First floor service corridor and restrooms
- Second floor fire corridor

The atrium is a large focal point of the architecture

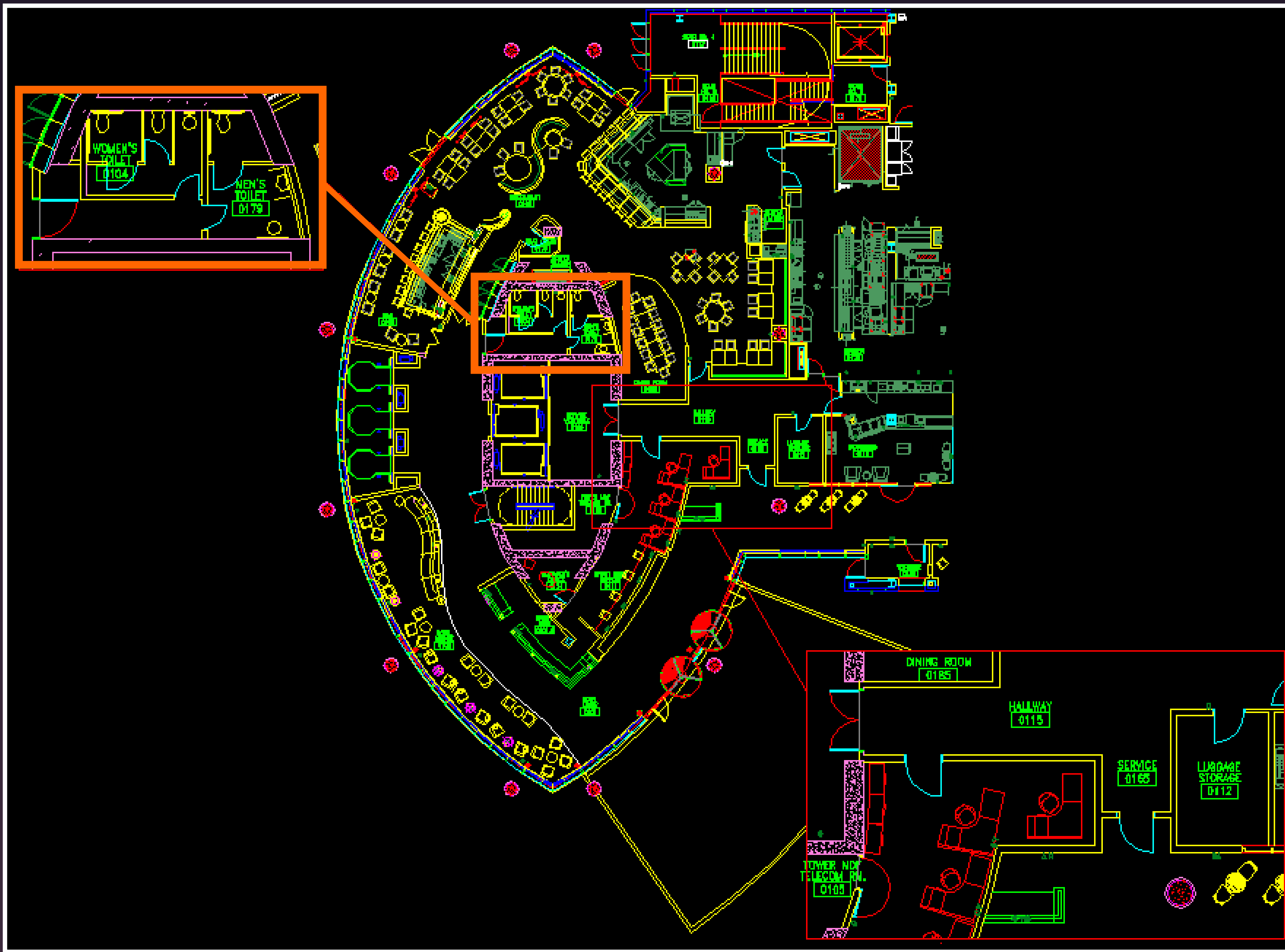
Notable IBC codes

1019.1: *"exit enclosure shall not be used for other than egress…"*
1019.1.2: *"no penetrations shall be allowed except those related to exit egress or systems directly related to the function of the exit way…"*

Typical Floor



Ground floor



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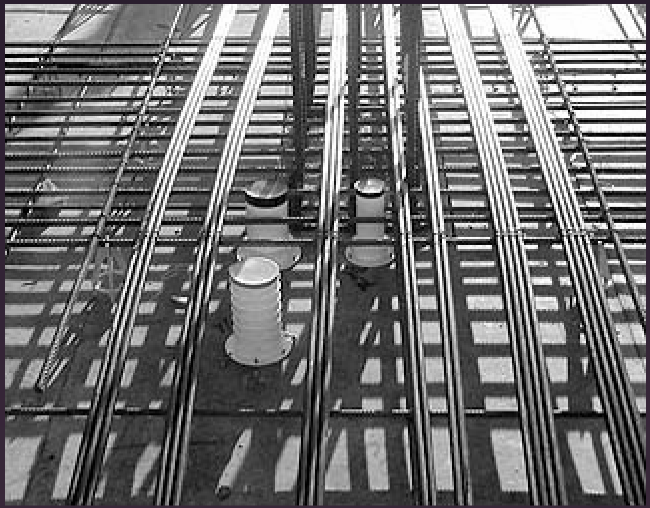
Primary Losses

- PT system more skill intensive
- Lower daily production
- Thicker slab



Post tension system require longer durations and more expensive labor

Secondary Losses

- Duration increase
- Interest earnings

Direct Loss Comparison

Flat Plate	
Location	Grand Rapids
Crew	C-17B
Daily Output (cy)	30.24
Labor Hours (cy)	6.878
Material ($)	242
Labor ($)	253
Equipment ($)	24
Total ($)	519
Concrete (cy)	5707
Material ($)	1,381,094
Labor ($)	1,443,871
Equipment ($)	136,968
Total ($)	**2,961,933**
Incl. O&P ($)	**3,909,752**
Duration (weeks)	**38**

*Actual duration of 47 weeks due to weather

Post Tension (x2.0)	
Location	Monterey
Crew	(2) C-17B
Daily Output (cy)	20
Labor Hours (cy)	8.2
Material ($)	475
Labor ($)	630
Equipment ($)	31
Total ($)	1136
Concrete (cy)	7228
Material ($)	3,433,300
Labor ($)	4,553,640
Equipment ($)	224,068
Total ($)	**8,211,008**
Incl. O&P ($)	**10,427,980**
Duration (weeks)	**72**

Post Tension (x3.0)	
Location	Monterey
Crew	(3) C-17B
Daily Output (cy)	30
Labor Hours (cy)	8.2
Material ($)	475
Labor ($)	945
Equipment ($)	31
Total ($)	1451
Concrete (cy)	7228
Material ($)	3,433,300
Labor ($)	6,830,460
Equipment ($)	224,068
Total ($)	**10,487,828**
Incl. O&P ($)	**13,319,542**
Duration (weeks)	**48**

Secondary Losses

- $230/night average room price
- 60% occupancy expected
- $8 million lost in 25 week delay

OUTLINE

Non-linear response

- Plastic hinging mechanism in beams
- Shear walls well below yield, system deforms evenly

Floor System

- Post Tension system viable alternative
- Costs of PT are staggering, use original flat plate system

Architecture

- Atrium remains focal point
- Original spaces accounted for

Acknowledgements

Bert Crandell	Ben Kochalski
Pete Jackson	Jeff Styles
Erika Johnson	Dr. Boothby
Dr. Lepage	All AE Faculty
Mom and Dad	My Friends

And Everyone Else that Made
Thesis a Reality

Questions?