Erie on the Park

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Architectural Engineering
Structural Emphasis
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Thesis Presentation - Spring 2006

PENNSTATE

Introduction

- Building
- Professionals

Existing Structure

- Columns
- Floor System
- Lateral System

Proposal

Structural Redesign

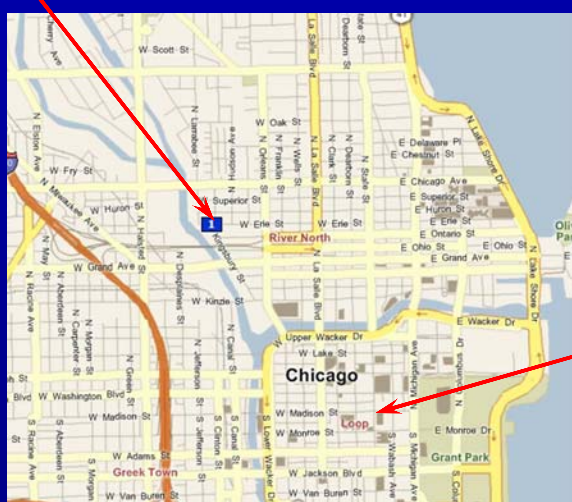
- Gravity System
- Lateral System
- Cost & Schedule

LEED Design

Recommendation

- 25 Story condominium complex
  - 30’ high lobby entrance
  - Floor 2-4: parking for 186 cars
  - Floor 5-24: 128 residential units
    - 310 ft^2 Studios
    - 1650 ft^2 3 bedroom suites
  - 25th Floor: Mechanical floor
  - Fitness Center on the 6th floor

Building



Loop

- Located in the River North district of Chicago, IL
- Less than a mile from the Loop

Owner/Developer

smithfield

Structural Engineer

Thornton-Tomasetti Group

Elevator Design

Lighting Design

LIGHTING DESIGNERS Schuler Shook

DRAPER AND KRAMER
Established 1893

Property Manager

Innovative Building Concepts

Electrical Engineer

Steel Fabricator

ZALK JOSEPHS FABRICATORS L.L.C.

Window Supplier

TRAINOR GLASS COMPANY

advance MECHANICAL SYSTEMS, INC.

HVAC Design

Architects

LUCIEN LAGRANGE AND ASSOCIATES
605 N MICHIGAN AVE
CHICAGO
ILLINOIS 60611
USA
T 312 751 7400
F 312 751 7460
E MAIL@LLARCH.COM
WWW.LLARCH.COM
ARCHITECTS

Fire Protection

GLOBAL
GLOBAL FIRE PROTECTION COMPANY

Geotech

STS CONSULTANTS

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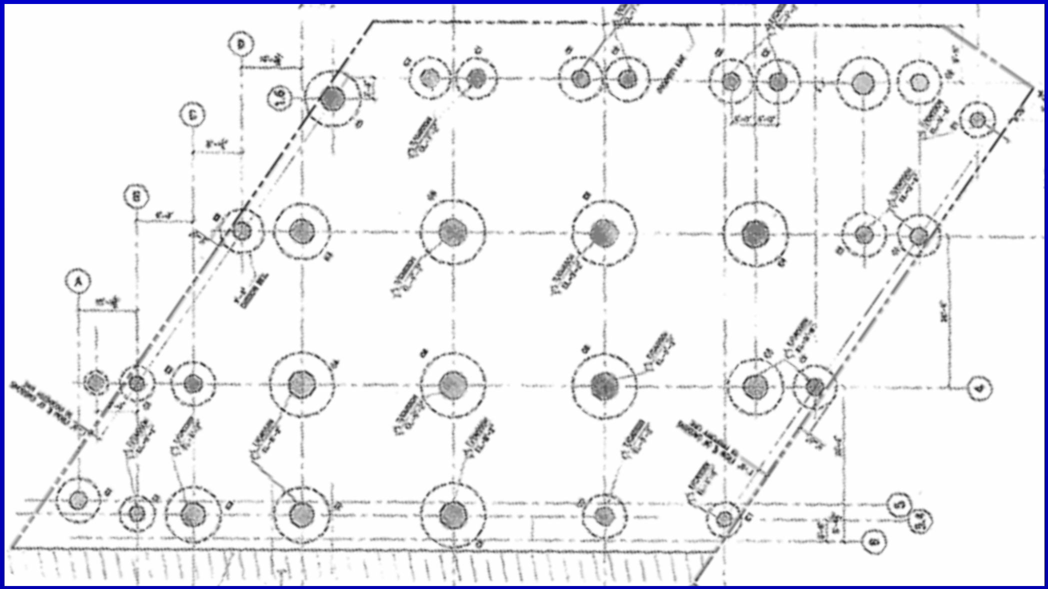
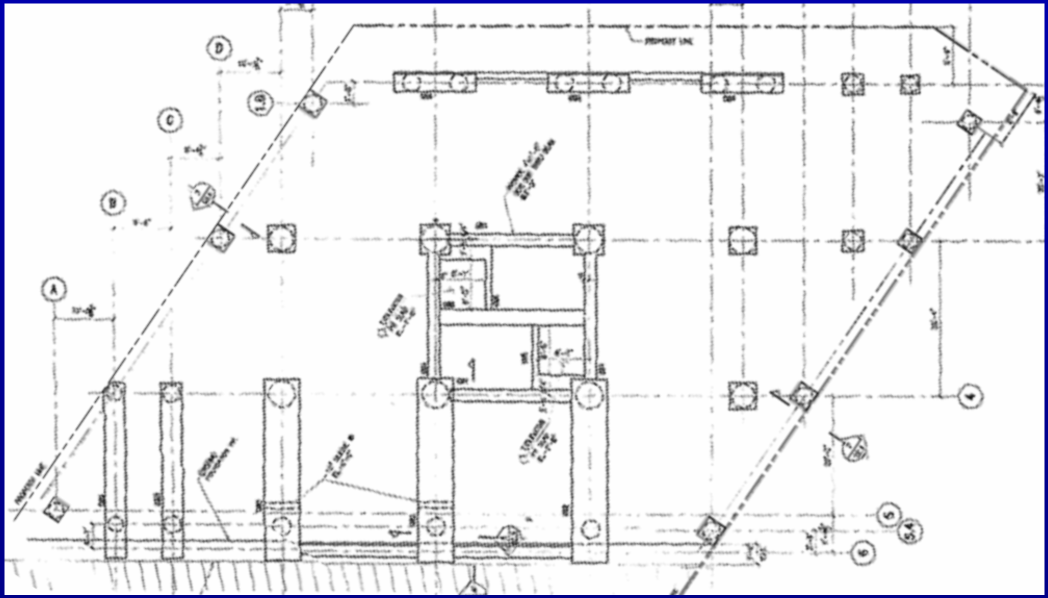
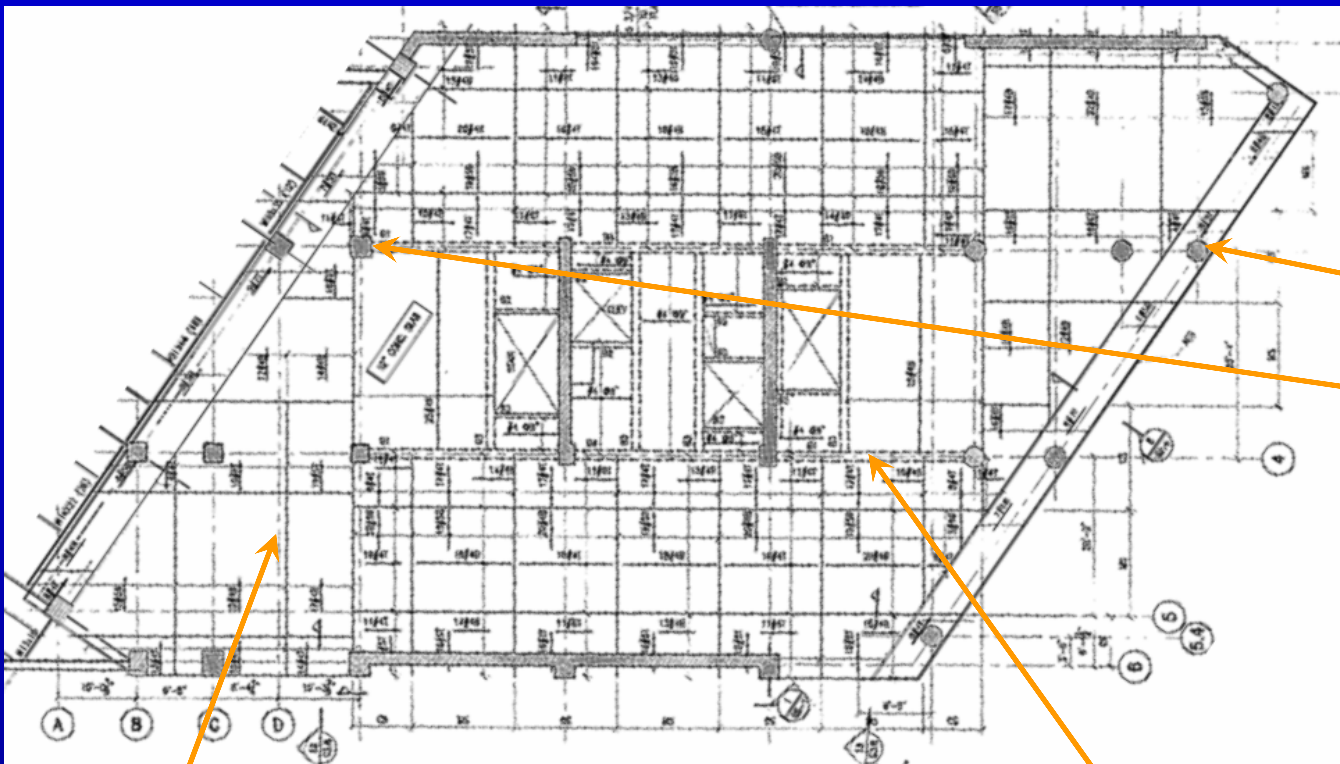


Foundation

- 85’ Drilled hardpan caissons
- Allowable soil bearing pressure of 30,000 psf
- Shaft diameter: 30”-54”
- Bell diameter: 4’-11’
- f'_c = 6,000 psi



- Caisson caps are 3’ deep and 6” longer and wider than their respective caisson
- Grade beams connect caisson caps to provide greater stiffness and resistance against overturning
- Grade beam depth: 52”-100”
- Grade beam width: 24”-72”



Floors 2, & 3

Columns:

- 30” Diameter east of column line G
- Rectilinear columns west of column line F

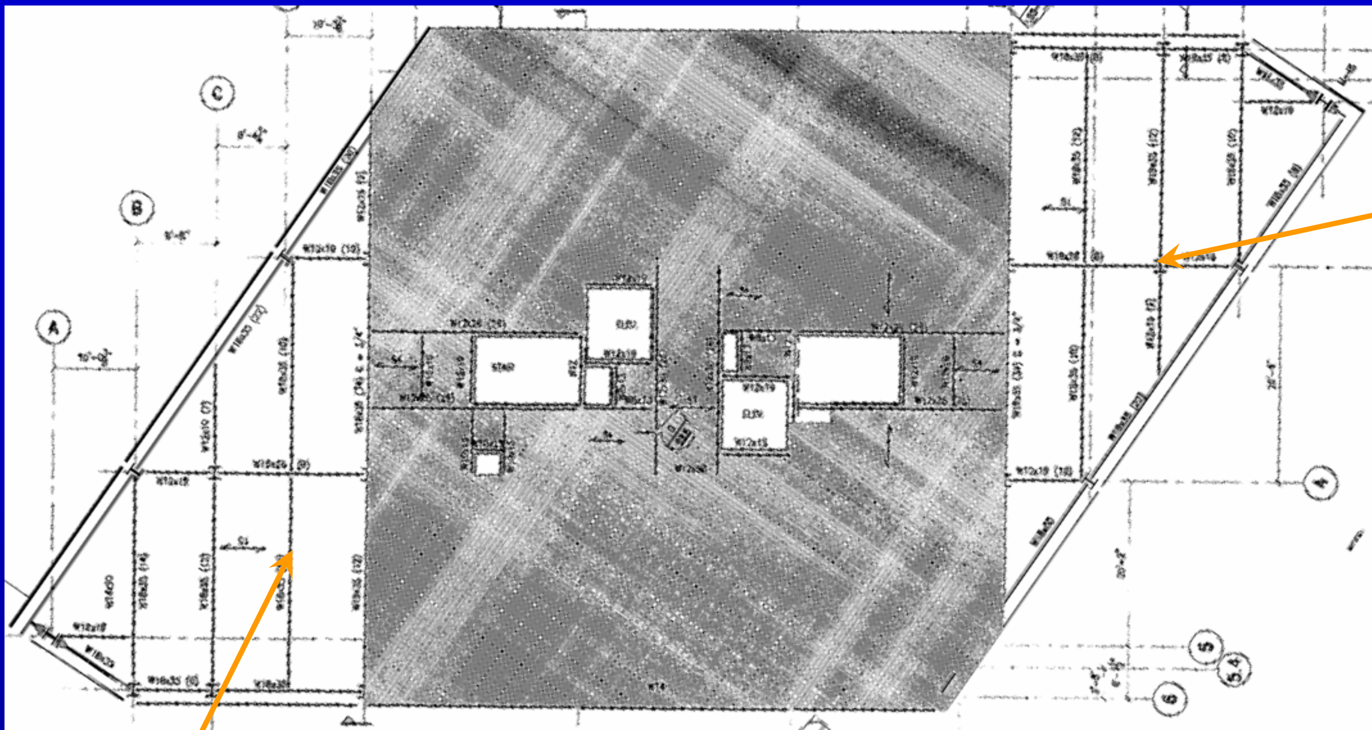
Flat-plate Floor Slab:

- 12” thick slab
- Grade 60 deformed rebar – epoxy coated
- f'_c = 6,000 psi

Concrete Beams:

- 12”x24” beams
- Provide added strength around elevator and stairwell openings

Floors 4-6



Steel Columns:

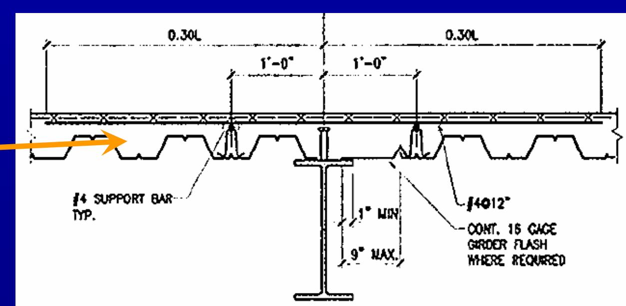
- W14 shapes
- Typical splice height of 4’
- f_y = 50 ksi

Steel Beams:

- Fully composite system
- Girders: W18x55
- Beams: W18x35

Slab-on-Deck:

- 4.5” thick slab
- 3” composite steel deck



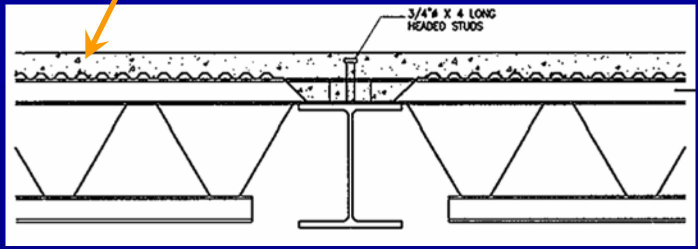
Floors 7-24

Steel Columns:

- W14 shapes
- Typical splice height of 4’
- f_y = 50 ksi

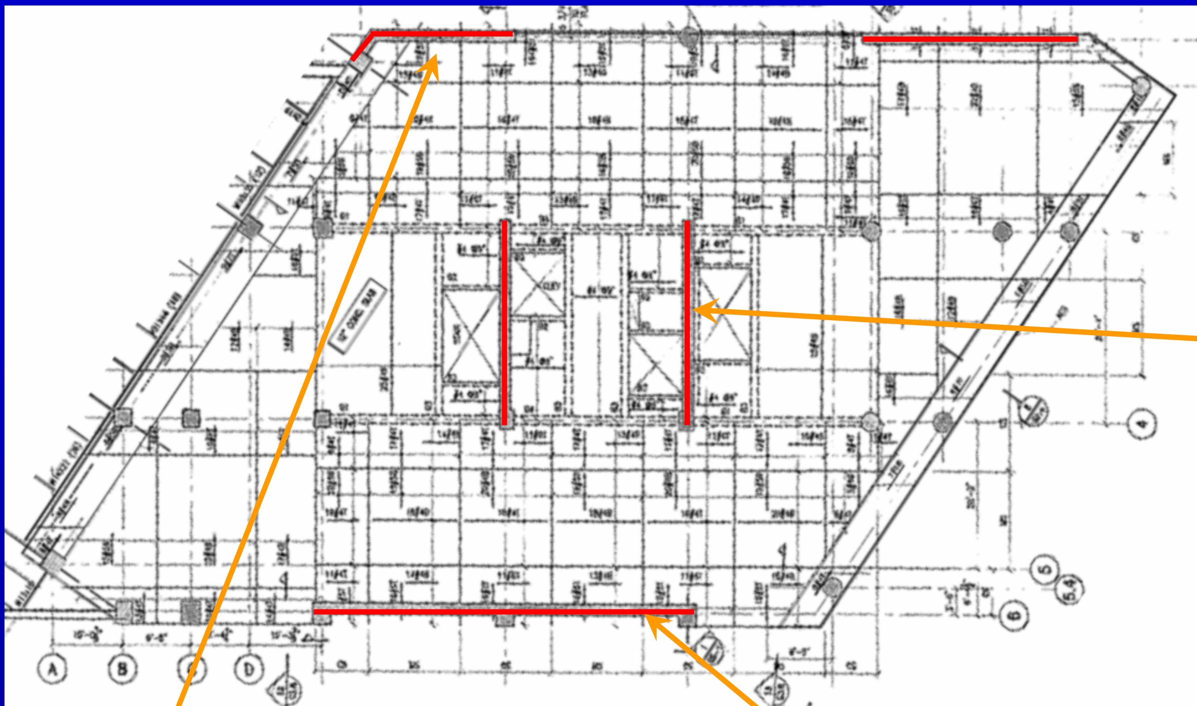
Slab-on-Deck:

- 2” thick slab
- 5/8” formed steel deck



Steel Beams:

- Open web steel joists span E-W
- Partially composite with girders
- Girders: W12x96

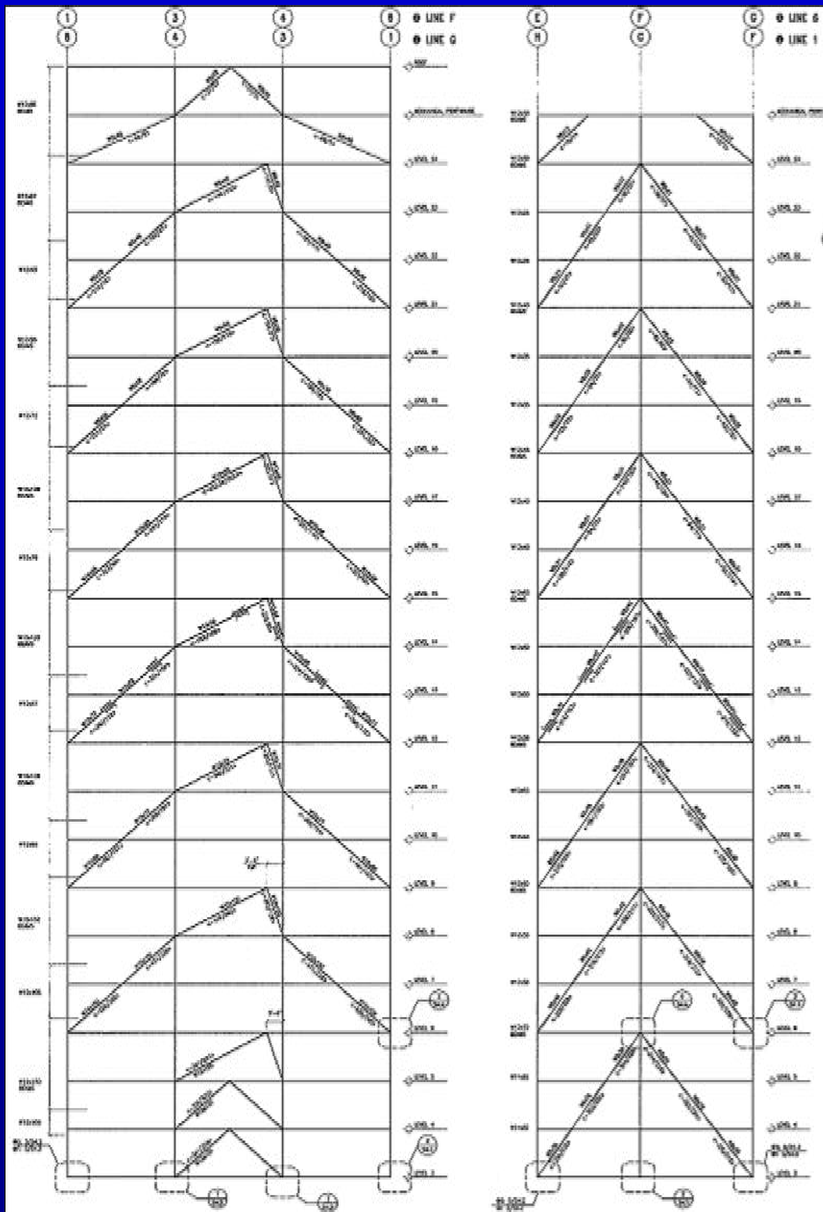


Lateral System
Floors G-3

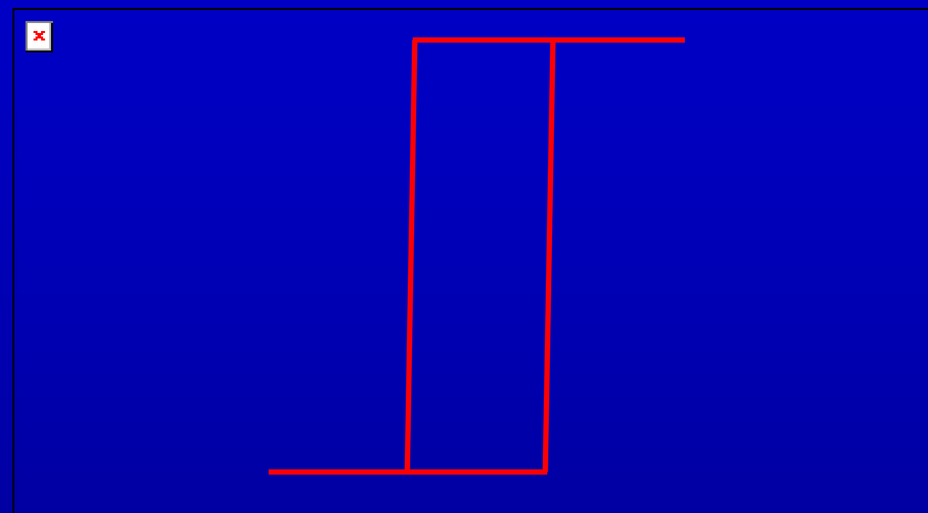
N-S Shear Walls:
- 18”x28’
- Rebar increased at ends to take axial loads
- f'_c = 8000 psi

E-W Walls (column line 1):
- 18” thick
- f'_c = 8000 psi

E-W Wall (column line 6):
- 18” thick
- f'_c = 6000 psi
- 8 ksi pilasters take gravity loads



Lateral System
Floors 4-24



Steel Braces:

- Columns are W14 shapes
- Beams are W12 shapes
- Braces are W8 & W10 shapes

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Floor System

Flat-Plate System
- Comparable Costs
- Less Vibration
- Easy Formwork
- Inherent Fireproofing

Post-tensioning
- Reduce floor depth
- Stiffer against lateral loads
- Helps resist punching shear

	Steel Joists	Concrete Joists	Flat Plate	Flat Slab	Precast Double-Tees	Composite Steel Beams
Weight (psf)	30	85	112.5	123	54	40
Depth (in)	16	18.5	9	9 +7	14	14
Vibration	Maybe	No	No	No	No	Maybe
Column Size	W14	20x20	31x31	15x15	20x20	W14
Constructability	Easy	Hard	Medium	Medium - Hard	Easy	Medium
Long Lead	Y	N	N	N	Y	Y
Formwork	N	Y	Y	Y	N	N
Fire Rating (hr)	1.5-2	>2	>2	>2	1.5-2	1-2
Cost (USD)						
Materials	7.85	6.85	5.20	5.80	6.35	8.65
Installation	4.28	9.40	7.05	7.50	1.30	4.49
Total	12.13	16.25	12.25	13.30	7.65	13.14
Viable Alternative	XXX	No	Yes	No	Yes	Yes

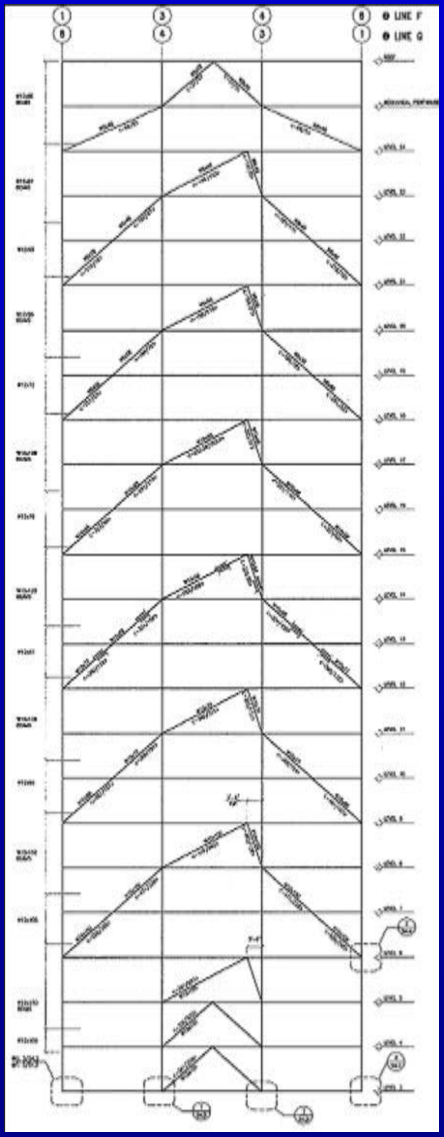
Lateral System

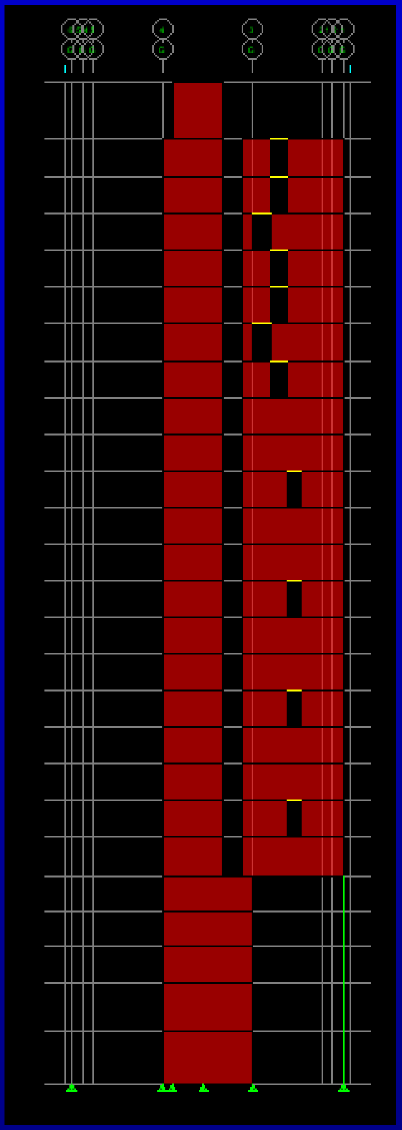
Shear Walls

- Lateral Force Resisting System
- Stiffer than moment frame system

Slab-Frame System

- Integrate with shear walls
- Creates double curvature response





Design Codes:

- IBC 2003
- ASCE 7 - 02
- ACI 318 - 05

Criteria:

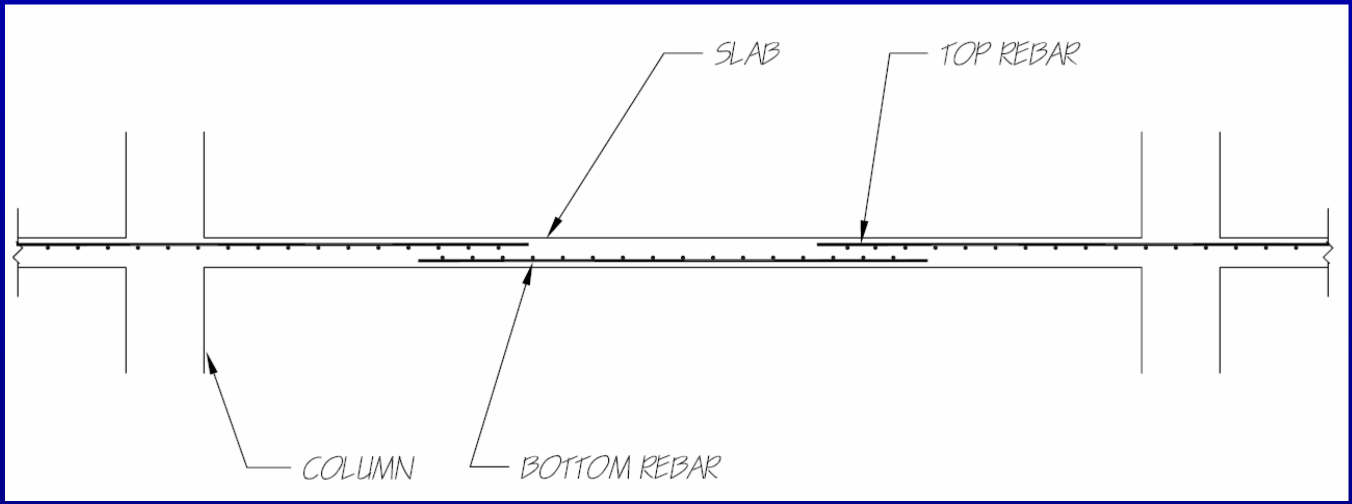
- Cost
- Construction Schedule
- Ease of Construction
- Susceptibility to Vibration
- Building Weight
- Coordination with other Trades
- Maintain Architecture Scheme
    - Flexible Floor Plans
    - Floor to Ceiling Windows
    - Dynamic Façade

Flat-Plate System

- Shear Design
  - Punching Shear
  - Wide Beam Shear
- Flexural Design
  - Direct Design
  - Equivalent Lateral Frame
- Lateral Frame
  - Portal Frame Analysis

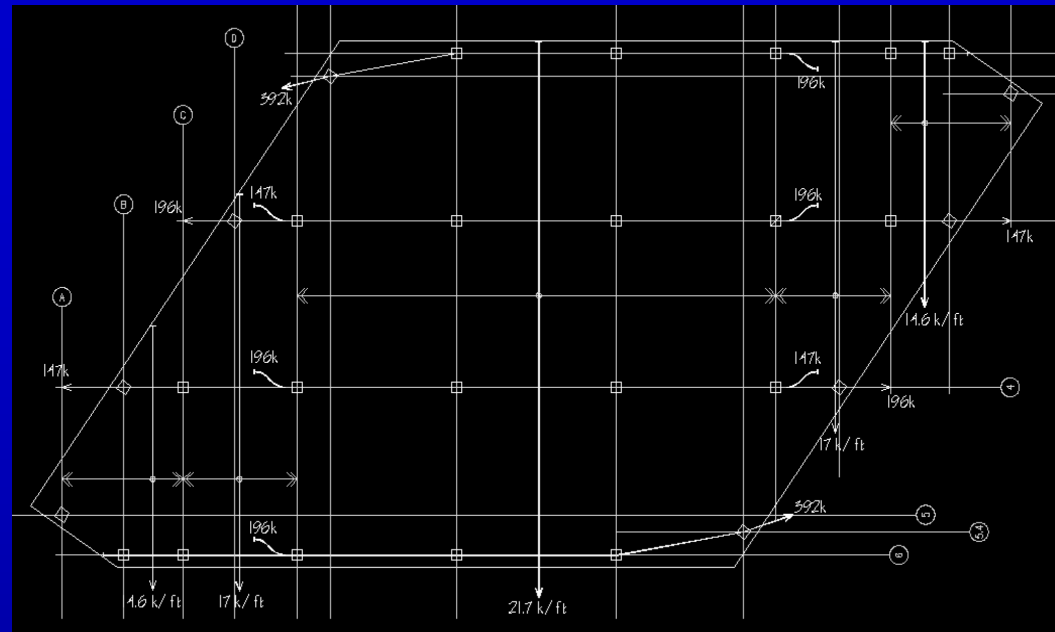
Final Design

- 10” Slab
  - 22 #6 bars in CS negative moment area
  - 20 #4 bars in CS positive moment area
  - 20 #4 bars in MS negative moment area
  - 15 #4 bars in MS positive moment area
- 15”x15” columns increasing to 30”x30”



PT Flat-Plate System

- Shear Design
  - Punching Shear
  - Wide Beam Shear
- Flexural Design
  - Load Balancing
  - Equivalent Lateral Frame
  - Service and Ultimate Loads
- Lateral Frame
  - Portal Frame Analysis

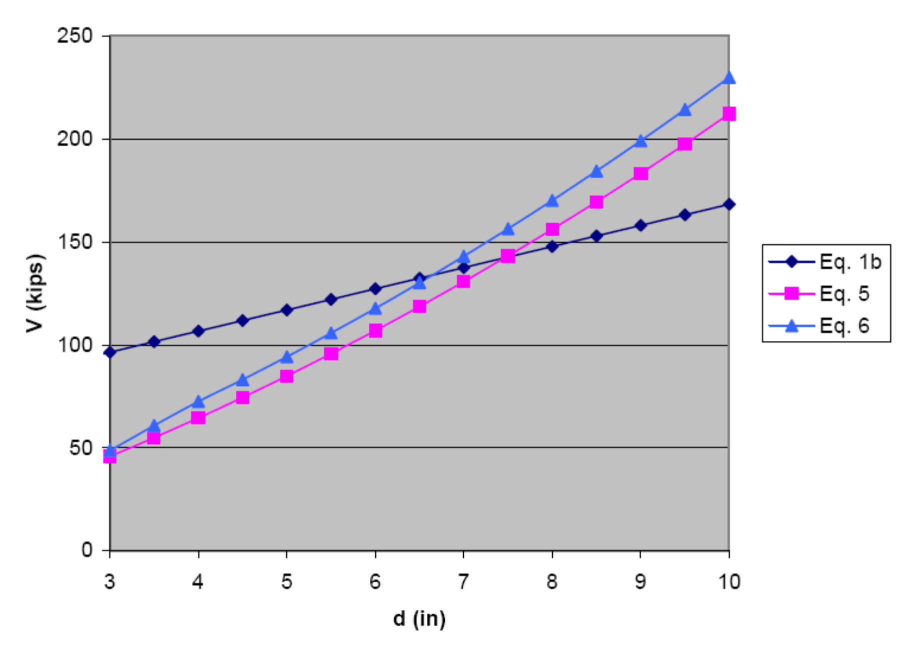


Final Design

- 8” Slab
- Tendons banded in E-W direction
- Uniform tendons in N-S direction
- 15”x15” columns increasing to 30”x30”

PT Flat-Plate System

- Shear Design
  - Punching Shear

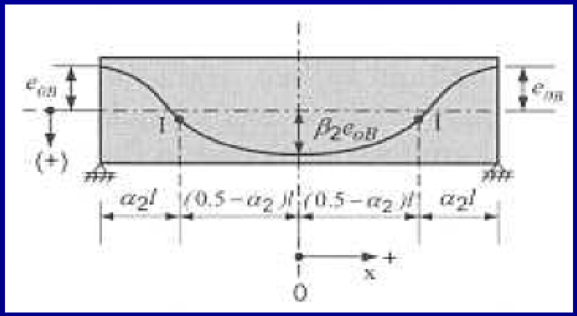


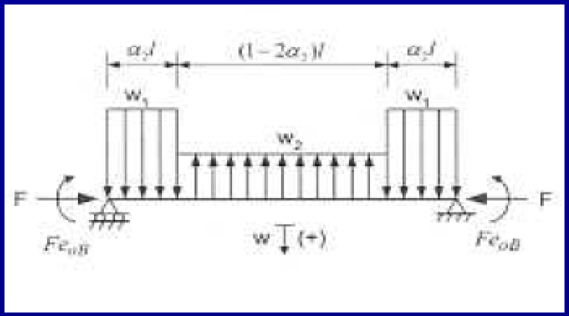
$V_c = \Phi*4*\sqrt{(f'_c)}*b_o*d$

d = 7.5” → Slab depth of 9”

$V_c = \Phi*(\beta_p*\sqrt{(f'_c)} + 0.3*f_{pc})*b_o*d + V_p$

d = 6.75” → Slab depth of 8”





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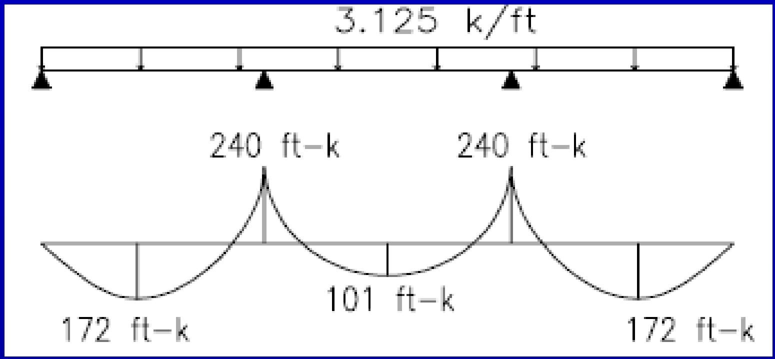
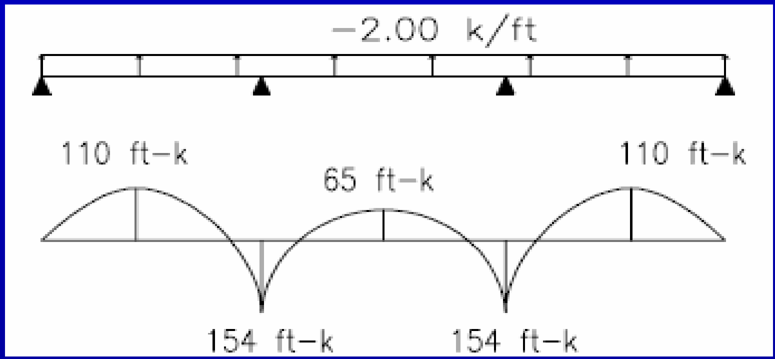
PT Flat-Plate System

- Flexural Design
  - Load Balancing
  - Equivalent Lateral Frame



Uniform unfactored dead load

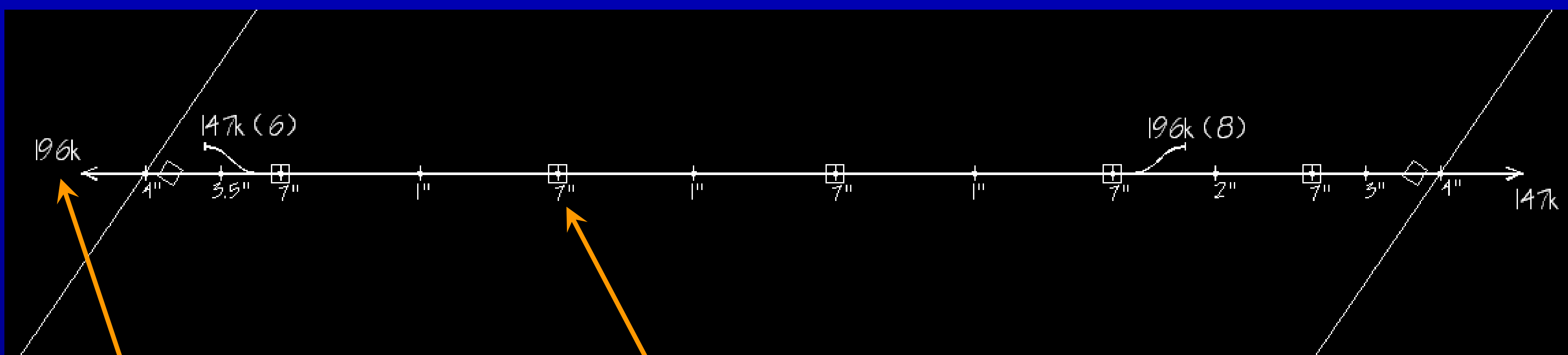


Equivalent load induced by tendons

Can increase/decrease induced load by:

- adjusting sag/drape of tendons
- adjusting force of tendons
- changing number of tendons

Example of an interior, banded tendon strip



Force from tendons

Tendon height from bottom of slab

	Wind								Seismic			
	Case 1		Case 2		Case 3		Case 4		10" Slab		8" PT Slab	
Story	N-S	E-W	N-S	E-W	N-S	E-W	N-S	E-W	Shear Walls	Frame	Shear Walls	Frame
Roof	22.05	11.55	16.54	8.66	16.54	8.66	12.41	6.50	14.80	16.44	12.08	13.43
Mechanical	36.39	34.62	27.29	25.96	27.29	25.96	20.49	19.49	41.60	46.23	37.49	41.66
24	39.60	26.87	29.70	20.15	29.70	20.15	22.29	15.13	29.82	33.13	24.76	27.51
23	38.58	26.22	28.93	19.66	28.93	19.66	21.72	14.76	27.45	30.50	22.79	25.33
22	37.75	25.75	28.32	19.31	28.32	19.31	21.26	14.50	25.19	27.98	20.91	23.24
21	43.85	25.75	32.89	19.31	32.89	19.31	24.69	14.50	25.47	28.30	21.15	23.50
20	43.85	25.75	32.89	19.31	32.89	19.31	24.69	14.50	23.18	25.76	19.25	21.39
19	43.85	25.75	32.89	19.31	32.89	19.31	24.69	14.50	21.00	23.33	17.43	19.37
18	42.86	25.26	32.15	18.95	32.15	18.95	24.13	14.22	20.74	23.05	17.22	19.14
17	41.88	24.77	31.41	18.58	31.41	18.58	23.58	13.95	18.58	20.65	15.43	17.15
16	41.39	24.53	31.04	18.40	31.04	18.40	23.30	13.81	16.55	18.38	13.74	15.26
15	41.14	24.41	30.85	18.31	30.85	18.31	23.16	13.74	14.62	16.25	12.14	13.49
14	40.15	23.92	30.12	17.94	30.12	17.94	22.61	13.47	12.82	14.25	10.65	11.83
13	40.15	23.92	30.12	17.94	30.12	17.94	22.61	13.47	10.99	12.21	9.12	10.14
12	39.17	23.44	29.38	17.58	29.38	17.58	22.05	13.19	9.57	10.64	7.95	8.83
11	39.17	23.44	29.38	17.58	29.38	17.58	22.05	13.19	8.13	9.03	6.75	7.50
10	37.94	22.83	28.45	17.12	28.45	17.12	21.36	12.85	6.80	7.55	5.64	6.27
9	37.53	22.62	28.14	16.97	28.14	16.97	21.13	12.74	5.59	6.21	4.64	5.15
8	36.34	22.04	27.25	16.53	27.25	16.53	20.46	12.41	4.50	5.00	3.73	4.15
7	35.60	21.67	26.70	16.25	26.70	16.25	20.04	12.20	3.52	3.91	2.93	3.25
6	36.23	22.16	27.17	16.62	27.17	16.62	20.40	12.48	2.60	2.89	2.15	2.39
5	34.14	21.00	25.61	15.75	25.61	15.75	19.22	11.82	1.83	2.03	1.51	1.68
4	30.71	19.01	23.04	14.25	23.04	14.25	17.29	10.70	1.14	1.27	0.92	1.02
3	30.05	18.72	22.53	14.04	22.53	14.04	16.92	10.54	0.73	0.81	0.59	0.66
2	35.51	22.33	26.63	16.75	26.63	16.75	19.99	12.57	0.40	0.45	0.33	0.36
Mezzanine	39.85	25.39	29.89	19.04	29.89	19.04	22.43	14.29	0.03	0.04	0.03	0.03
Ground	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

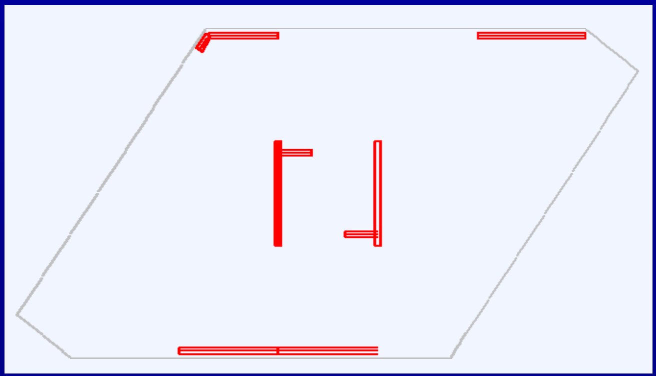
Lateral system design wind and seismic loads from ASCE 7 - 02

	Base Shear	Overturning Moment
Wind Case 1: N-S	986 k	151,500 ft-k
E-W	615 k	95,800 ft-k
Wind Case 2: N-S	740 k	113,600 ft-k
E-W	460 k	71,850 ft-k
Wind Case 3: N-S	740 k	113,600 ft-k
E-W	460 k	71,850 ft-k
Wind Case 4: N-S	555 k	85,300 ft-k
E-W	345 k	54,000 ft-k
Seismic – Walls:	350 k	73,500 ft-k
Seismic - Frame:	386 k	81,700 ft-k

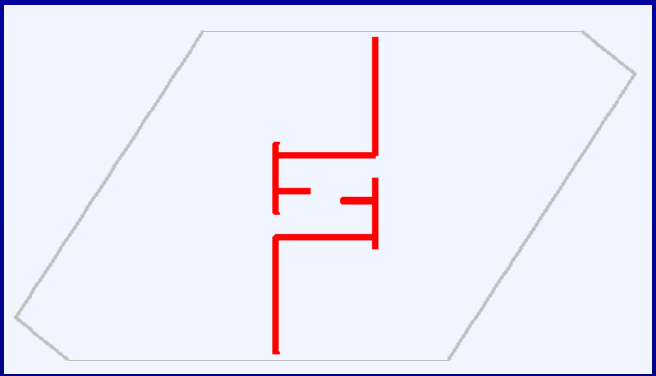
Shear Wall System

- Shear walls resist all of the lateral forces
- Openings allowed in shear walls for door openings
- Lower floor wall layout due to parking garage
- Upper floor wall layout around elevators and along column lines of initial brace system
- Walls checked for shear, flexure, and overturning

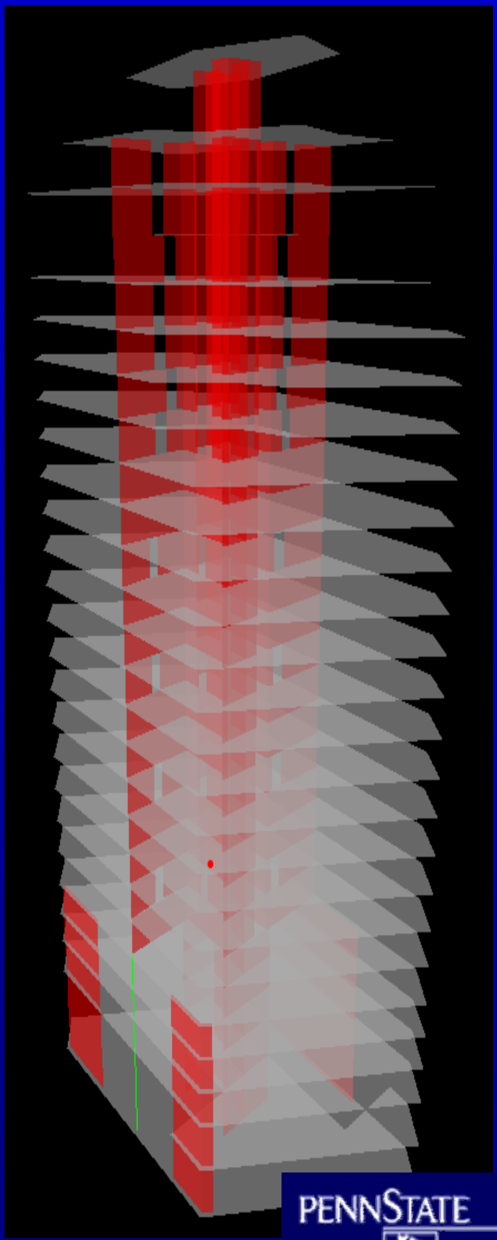
Designed for L/400 drift limit
Roof CM displacement = 6.35" ~ L/550



Wall layout FL 1-5



Wall layout FL 5-24

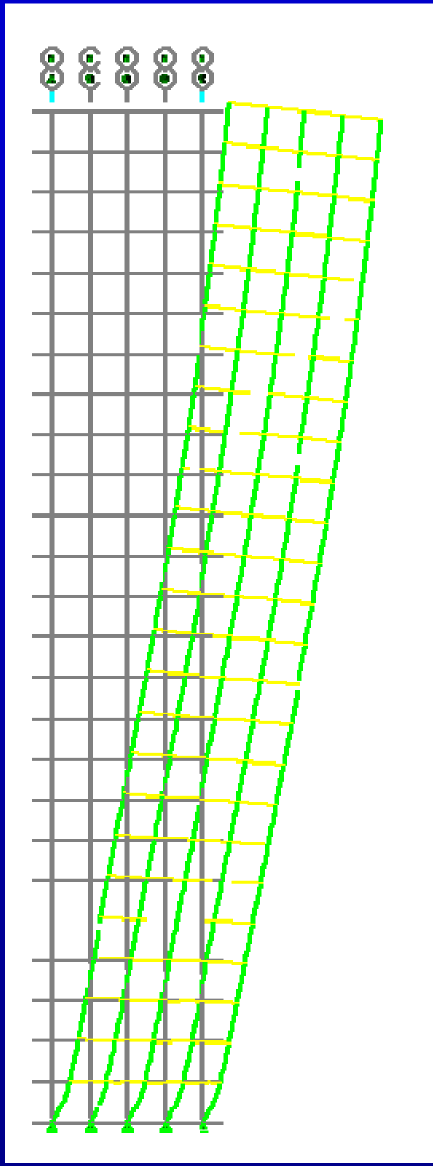


Combination System

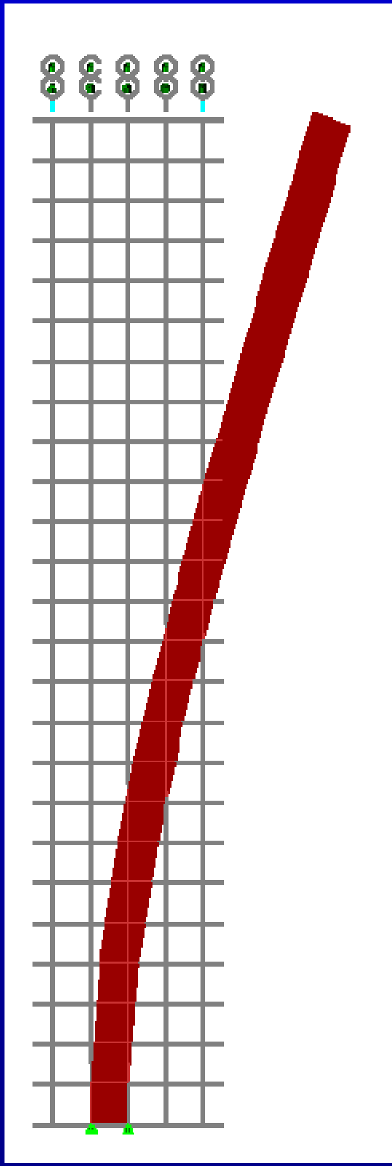
- Shear Walls
  - Deflect in bending
- Moment Frame System
  - Deflects in Shear
- Integrated system
  - Double curvature due to interaction between walls and frame

Reasons for a Combination System

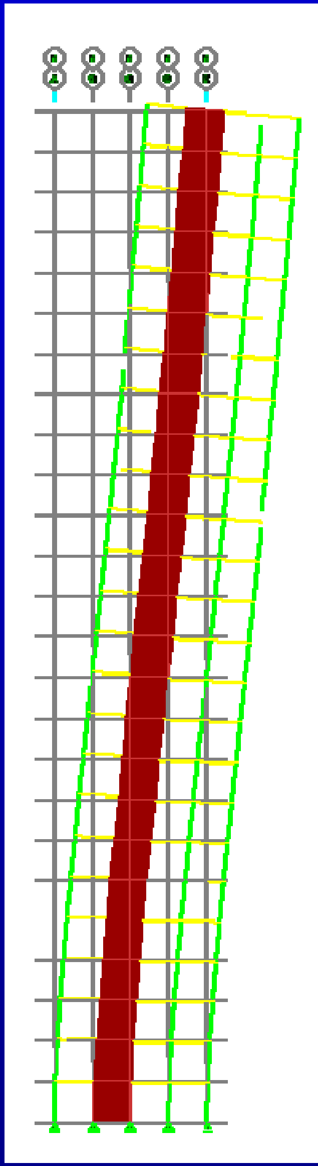
- Reduce the number of Shear Walls
- Moment Frame already exist because columns and slab poured integrally – minimal additional cost



Frame action



Shear Wall action



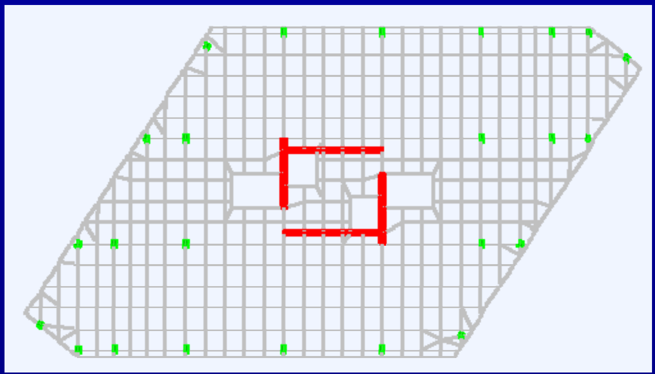
Combo System

Shear Wall/Slab-Frame System

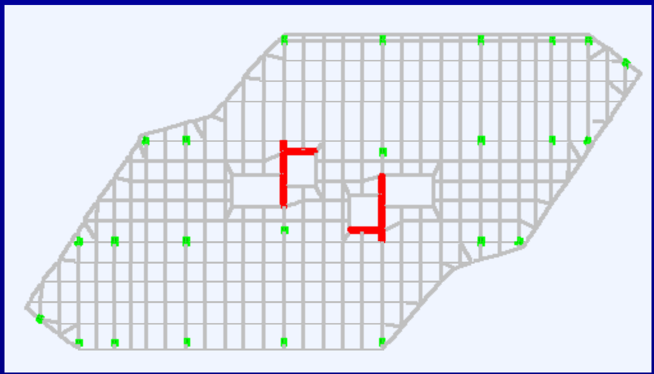
- Shear walls and slab-frame work together to resist the lateral forces
- Openings allowed in shear walls for door openings
- Lower floor wall layout still due to parking garage
- Upper floor wall layout around elevator core
- Walls checked for shear, flexure, and overturning

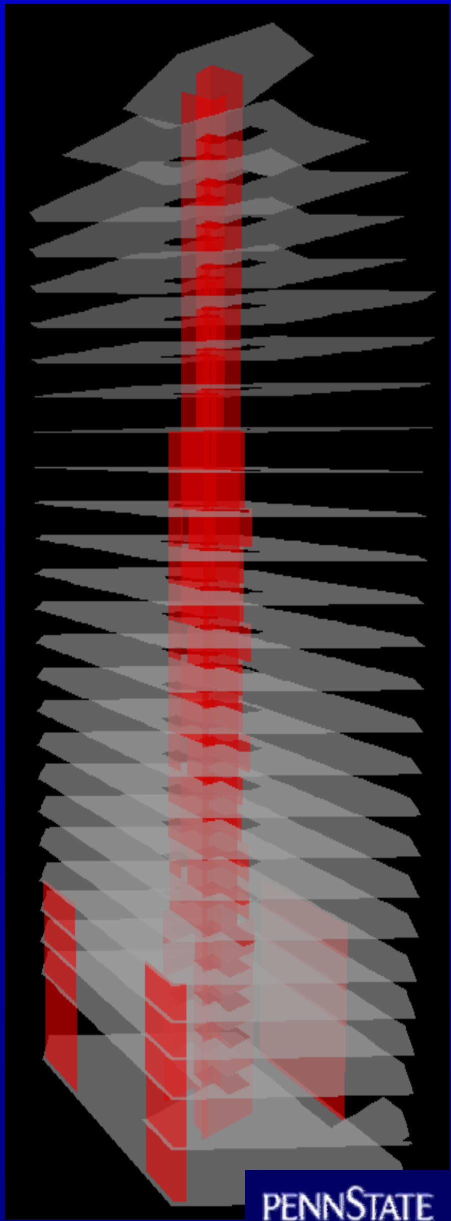
Designed for L/400 drift limit
Roof CM displacement = 6.85” ~ L/510

Wall layout FL 5-15



Wall layout FL 15-24





<u>Original Steel System</u> – Braced Frames

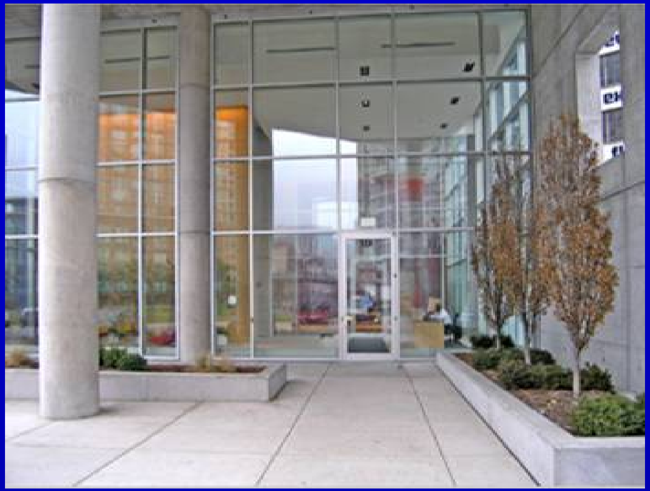
Cost:

Total (Incl. O&P) - $5,370,000

Per Square Foot - $25.21

Schedule:

28 Weeks (~7 months)



<u>PT Floor system</u> – Slab-Frame/Shear Walls

Cost:

Total (Incl. O&P) - $4,390,000

Per Square Foot - $20.60

Schedule:

40 Weeks (~10 months)

Cost Savings - $1,000,000 (18.25%)

Construction Duration – 12 week increase!

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- Building
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Existing Structure
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Proposal

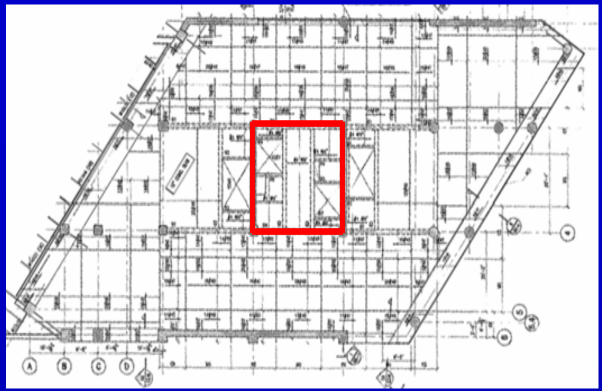
Structural Redesign
- Gravity System
- Lateral System
- Cost & Schedule

LEED Design

Recommendation

System Components

(2) 10,000 gal Cisterns
(1) 400 gal Compression Tank
(2) 5 HP Water pumps w/ controls
2500' Piping



Cost & Savings

Cost:
- Total - $55,700
- Including O&P - $64,000 (0.125%)

Savings:
- 416,360 gal H_2O/yr (4.43%)
- 4.43% Water Utility Cost

LEED Points

SS Credit 6.1 – Stormwater Quantity Control
WE Credit 3.1 – Reduce H_2O Usage by 20%
- high efficiency fixtures
- reuse of greywater

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    - Cost & Schedule
- LEED Design
- Recommendation

	Original Design	PT – Slab Frame
Walking Vibration:	Yes	No
Cost (per sqft):	$25.21	$20.60
Construction Duration:	7 Months	10 Months
Weight of Structure:	19700 kips	27560 kips
Ceiling Mechanical Space:	12"	8"
Ease of Construction:	Easy	Moderate
Maintain Architecture:	Yes	Yes
Recommendation:	NO	YES

Why?!?

- Already a deep foundation
  - Less $ to increase caisson diameters than switching from a shallow foundation
- No exterior bracing
  - Save $ on buying and installing custom cut windows
  - Save $ on maintaining exposed steel members
- Architecture
  - Near complete freedom with floor plans
  - Shear walls confined to elevator core
  - Unhindered views of Chicago skyline
  - Exterior braces not part of the original design
- LEED
  - Only 1/8th % of overall cost
  - Charge more for rooms
  - Better for the environment!

Questions?

PENNSTATE 1855

Design Professionals for your time and patience.

AE Professors for your wisdom and guidance.

Thank You!!

My family for their support.

My friends for keeping me sane.