Fairfield Inn and Suites

Pittsburgh, PA

Amanda Smith

AE Senior Thesis 2010

Structural Option

Advisor: Dr. Ali Memari

- Existing Building Information
- Project Goals
- Structural Depth Study
  - Gravity System
  - Lateral Resisting System
  - Foundation Impact

Presentation Outline

- Façade Breadth Study
- Construction Management Breadth Study
- Conclusions and Recommendations
- Acknowledgements

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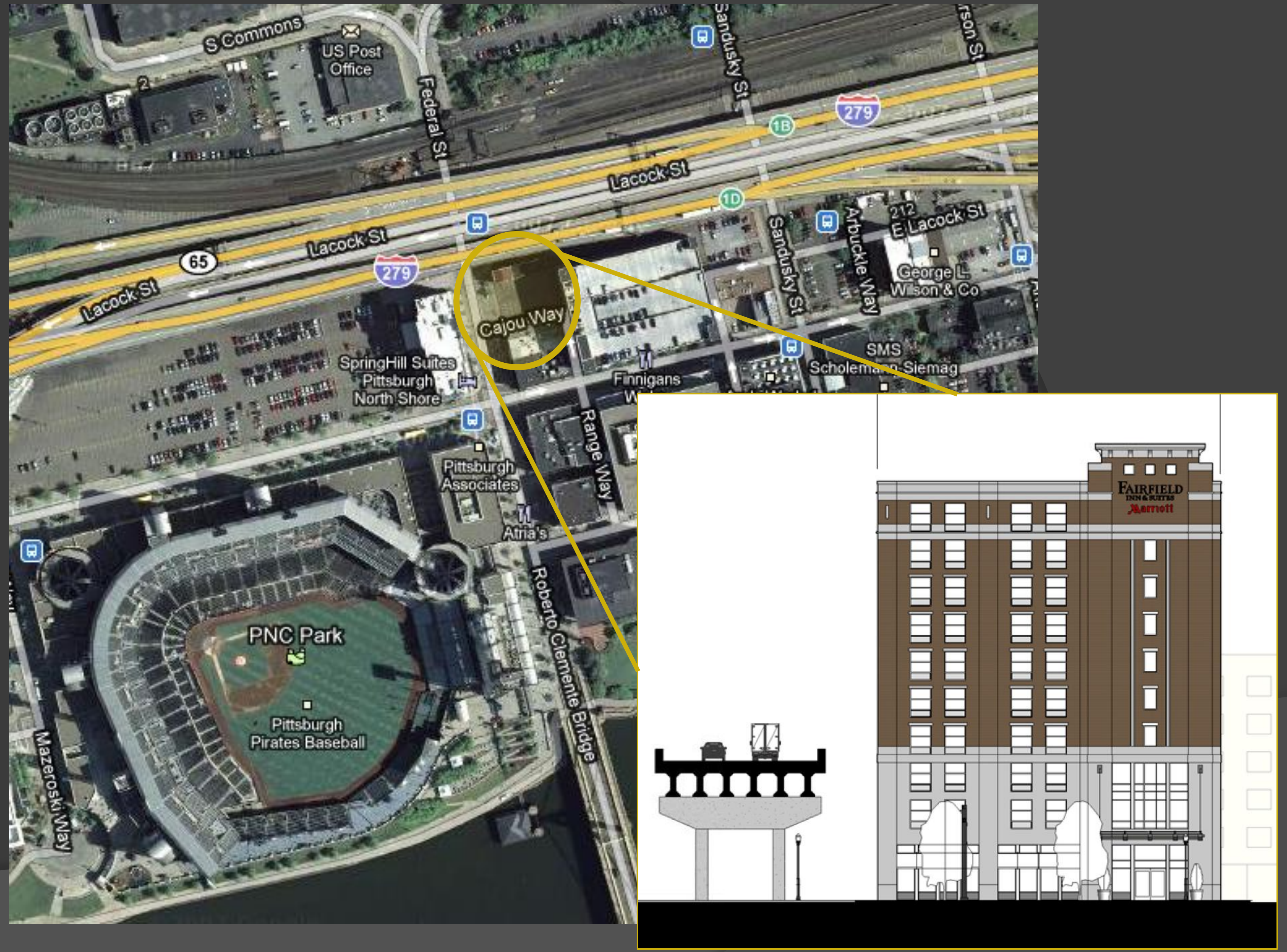
Location:
- Downtown Pittsburgh
- 228 Federal St, Pittsburgh, PA

Building Statistics:
- Occupancy - Hotel
- Size – 80,000 SF
- Stories – 10 stories above grade + 1 story below grade

Project Cost:
- $19 million



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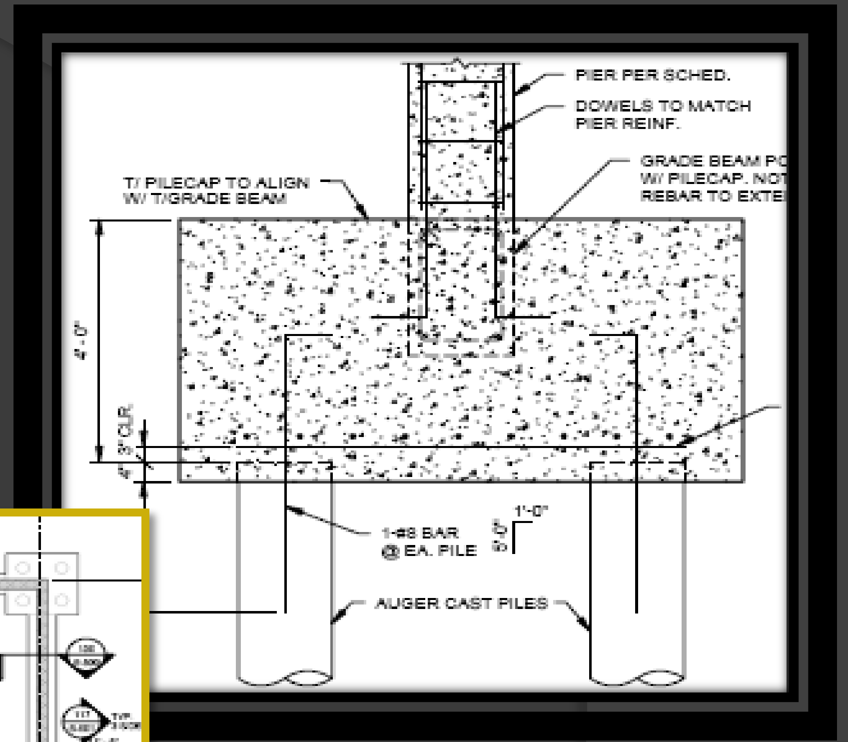
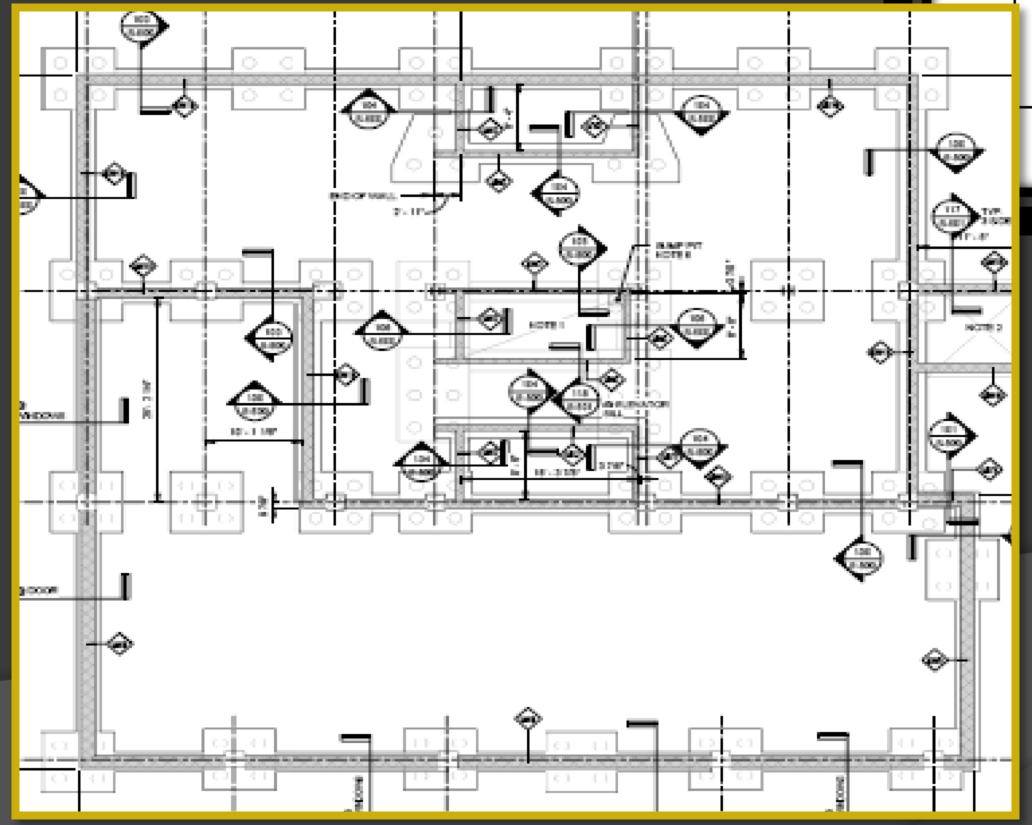
Existing Structural System

Foundation:

- Auger Cast Piles
  - 16" diameter
  - Topped by concrete pilecaps
  - Support 24"x24" reinforced concrete piers
- Grade Beams
  - 36" to 48" depth
  - Run between pilecaps





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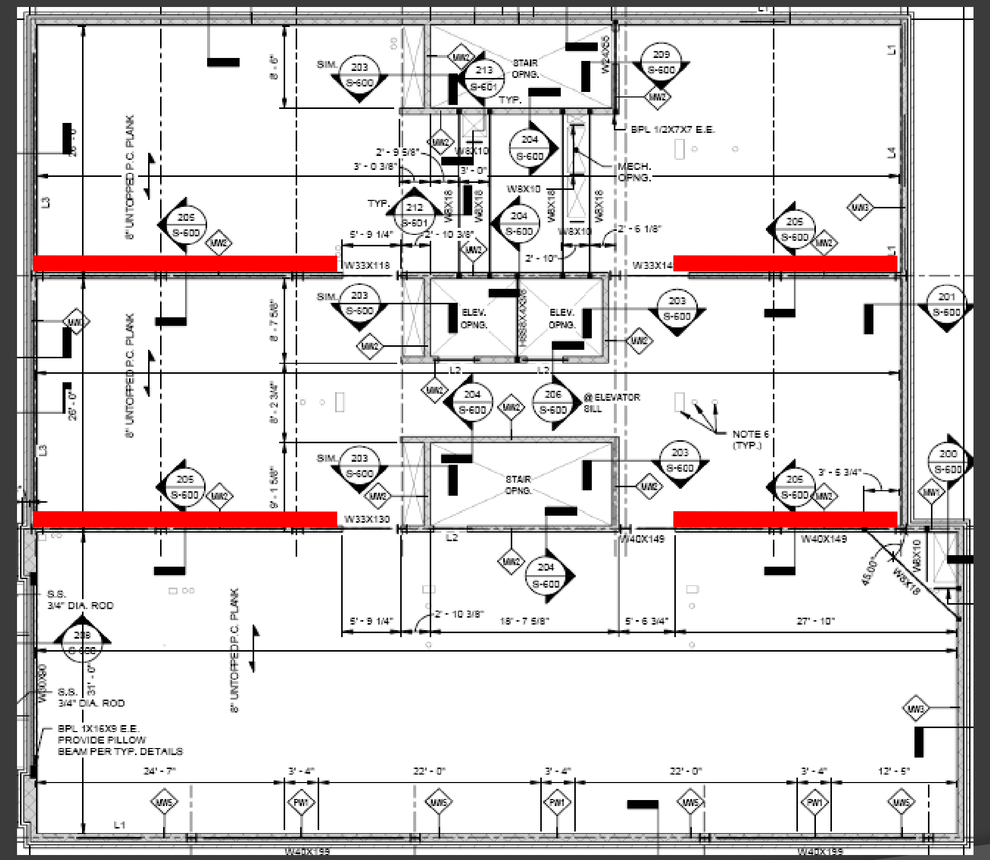
Existing Structural System

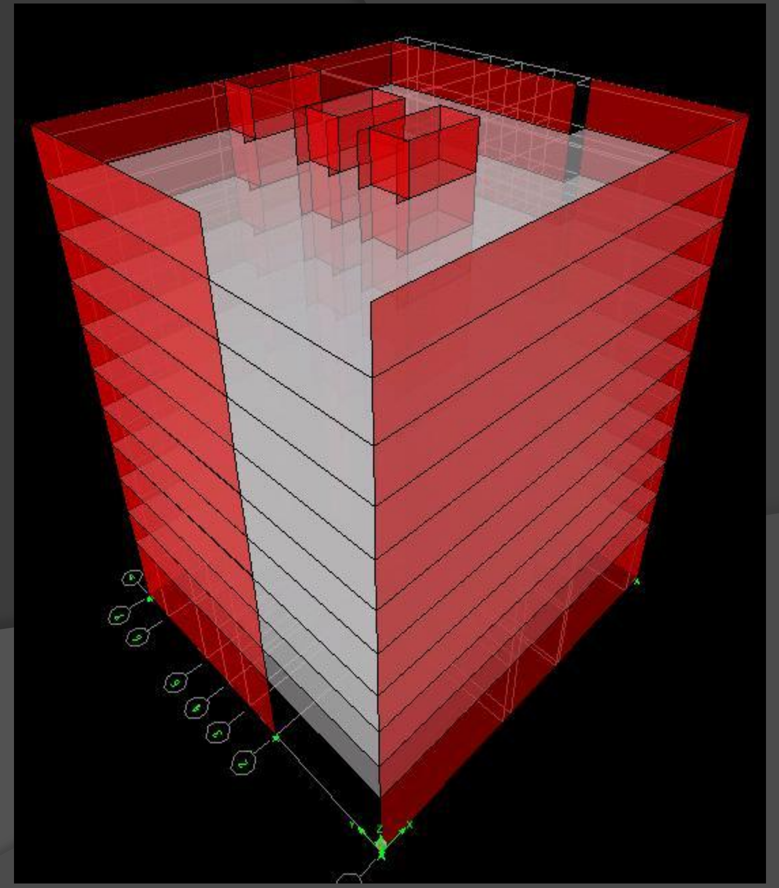
Gravity System:

- Typically 8" precast concrete plank floor
- Concrete masonry load bearing walls
- Transfer Beams
- Columns supporting lobby

Lateral Force Resisting System:

- Concrete masonry shear walls
  - 10" thick walls around perimeter
  - 8" thick walls in core





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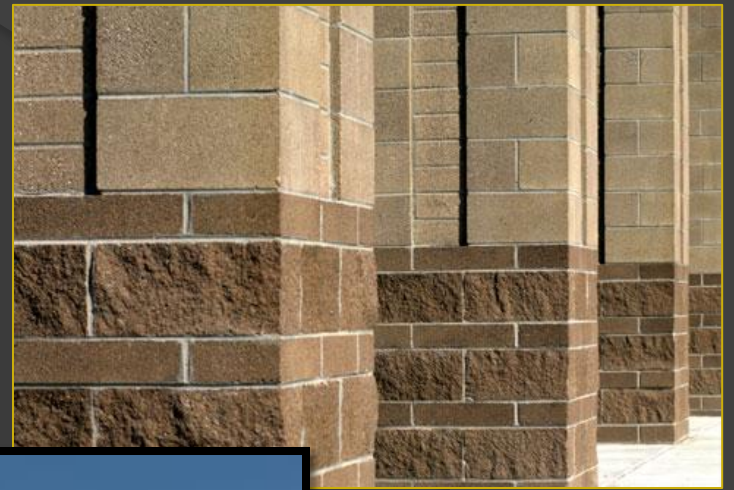
Problem Statement

- Building Weight
    - Poor Soil Site
    - Load bearing walls
    - High base shear value

Problem Solution

- Design lighter structural system
    - Steel Moment Frames
    - Core CMU shear walls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Project Goals

Structural Depth Study:
- Reduce overall building weight by redesigning gravity system
- Optimize the lateral force resisting system
- Foundation check

Façade Breadth Study:
- Effect of steel frame on façade

Construction Management Breadth Study:
- Impact on construction schedule and cost

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Structural Depth Study

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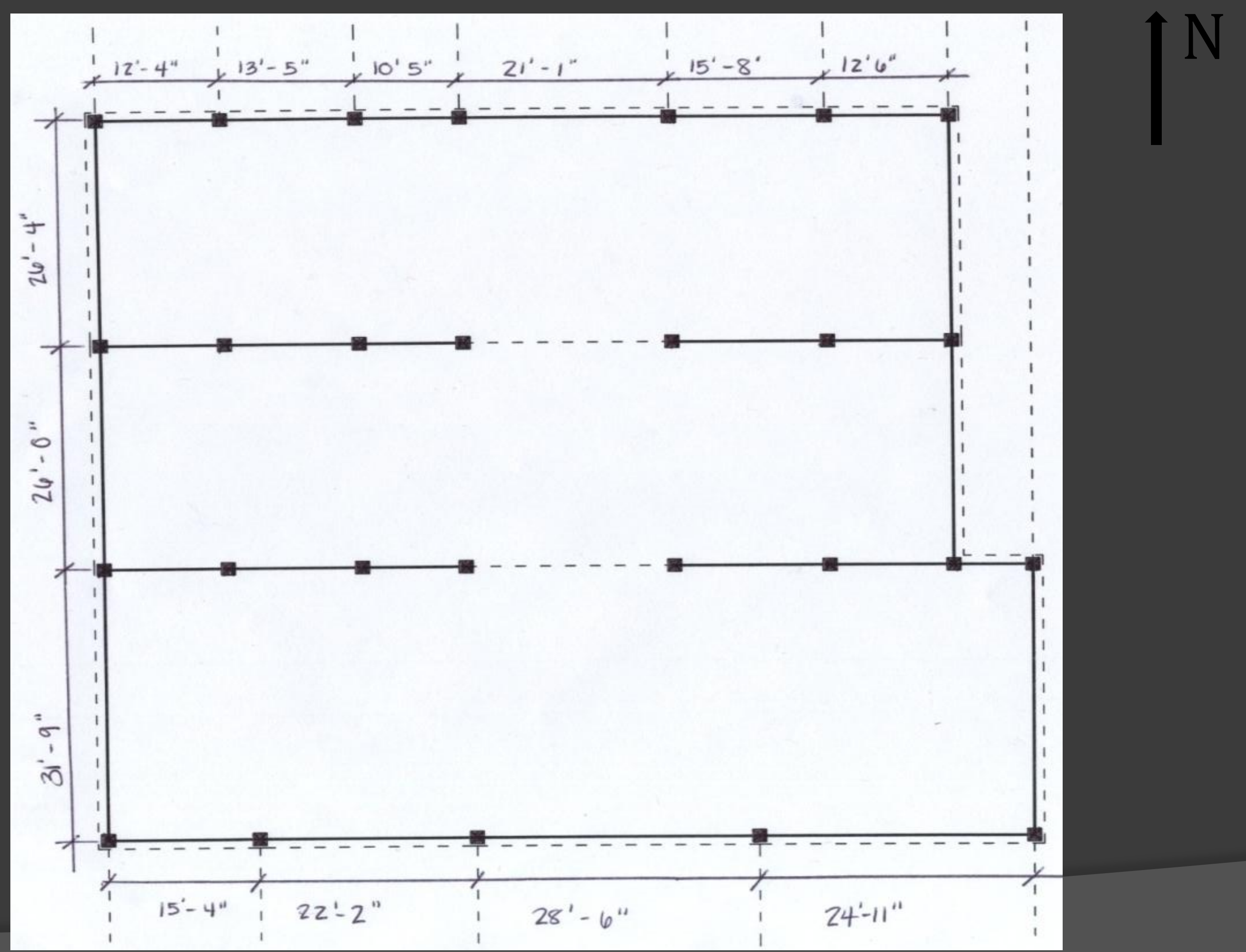

Framing Plan

- Moment frames span E-W
- Frames spaced at 26’ and 31’
- Columns kept at existing locations
- Columns added around the perimeter

Design Loads

ASCE 7-05

Live load values

Superimposed load values

Snow loads

Controlling Load Combination: 1.2D + 1.6L + 0.5Lr

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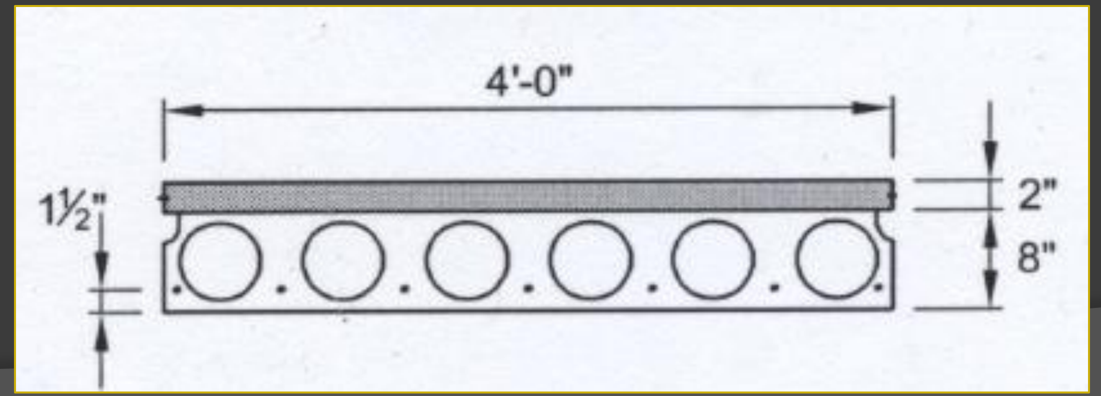
Hollow Core Plank Design

- Live Load = 80 psf
- Dead Load = 10 psf
- SDL = 25 psf

- Max Span = 31’-8”
- Normal weight concrete

Results using PCI Design Handbook:

- 78 –S
  - 7 strands at 8/16” dia.



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Beam/Girder Design Criteria

Strength Design Criteria: ASCE 7-05 LRFD Load Combinations
1.4D
1.2D + 1.6L + 0.5(L_r or S)
1.2D + 1.6L_r + 0.5L

Serviceability Criteria: Deflection
Non-Composite:
Dead Load ………………………….l/360
Live Load ……………………………l/360
Total Load …………………………l/240

Economy Criteria: Camber
do NOT camber: Beams that are less than 25ft
Beams that requires less that ¾" of camber

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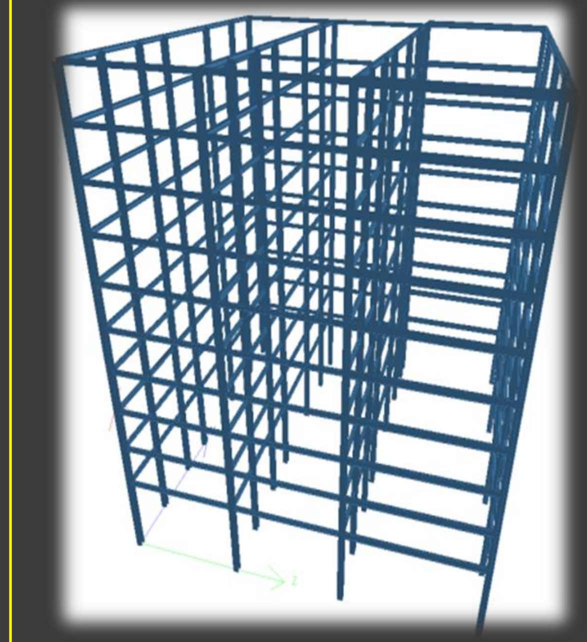
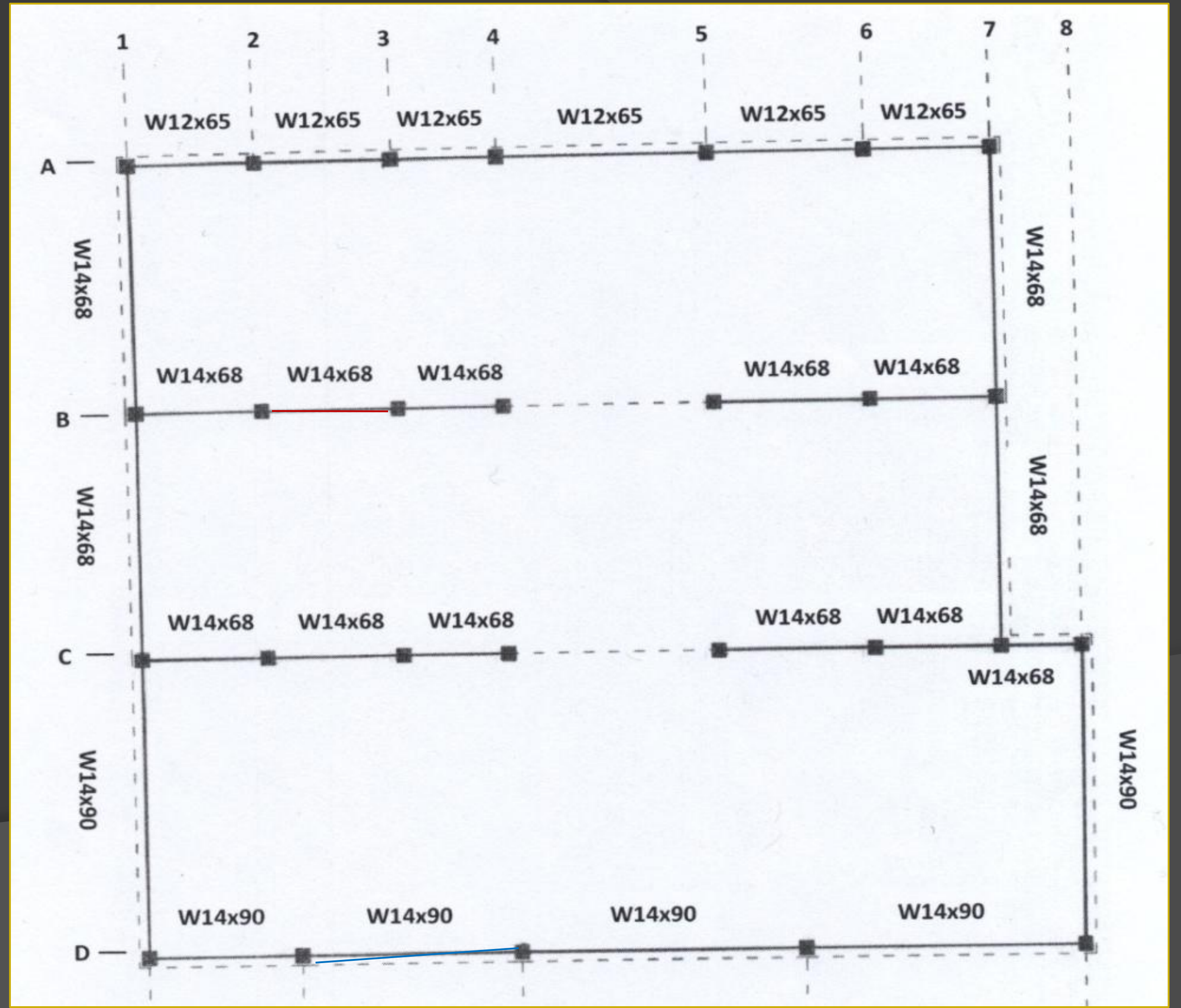
Beam/Girder Design

Optimal members were designed with Staad and checked by hand calculations

Example: Typical Girders

Member	Size	Length (ft.)	Hand Calc. M_u (ft-k)	Staad M_u (ft-k)	ϕM_n (ft-k)
Interior Girder	W 14x68	13.42	180	187	390
Exterior Girder	W 14x90	15.83	271	302	520





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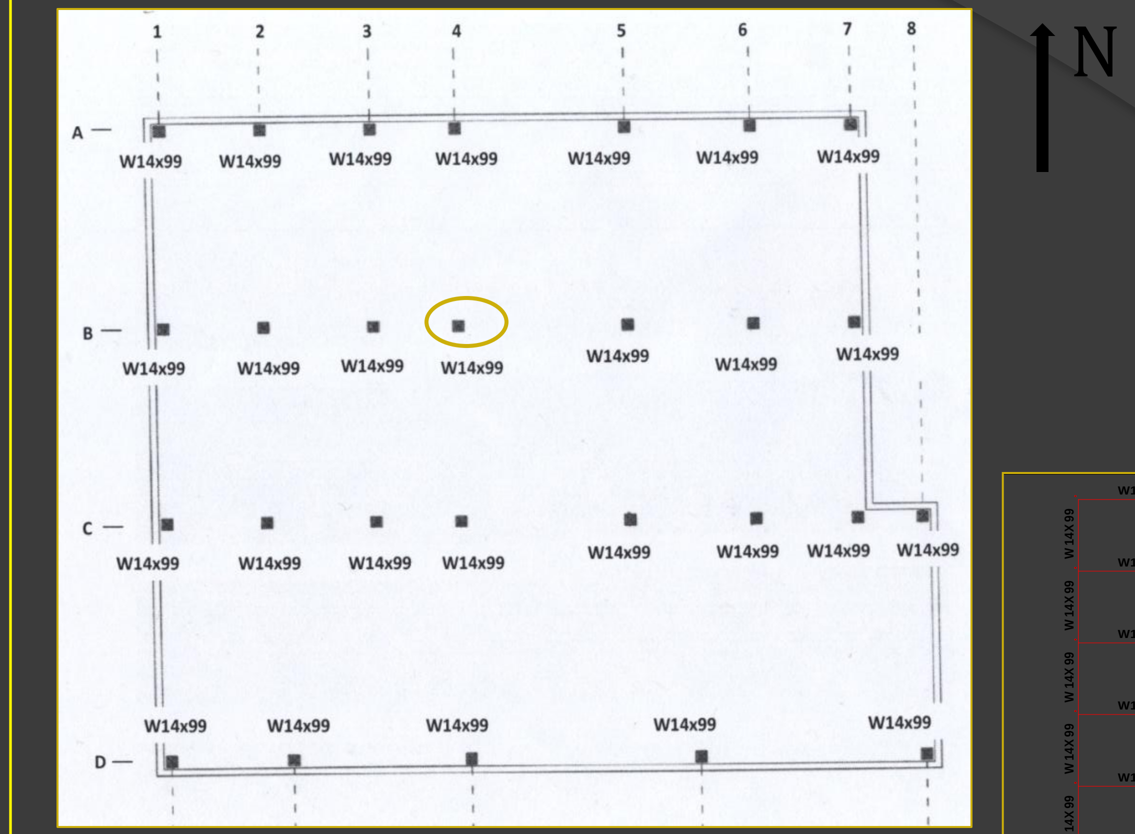
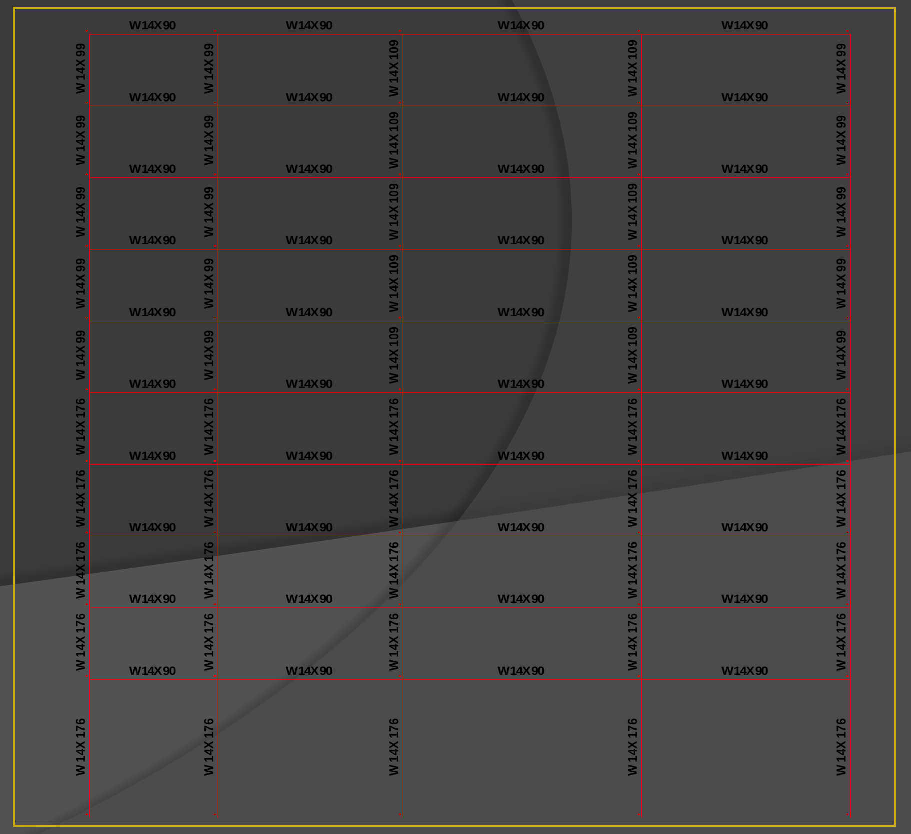
Column Design

- Columns resist gravity loads only
  - Levels 1 - 5: W14x176
  - Levels 6-10: W14x99
- Columns spliced at 5th story

Floor	Size	KL (ft)	Hand Calc. P_u (k)	Staad P_u (k)	ϕP_n (k)
1	W14x176	18	753	780	1890
6	W14x99	12	367	380	1210

Optimal members were determined by Staad and checked with hand calculations





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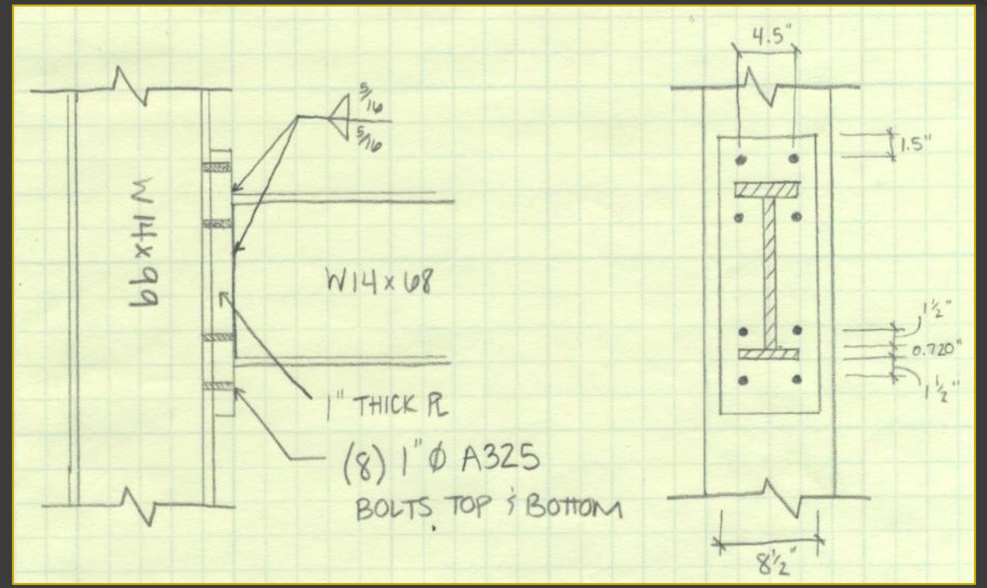
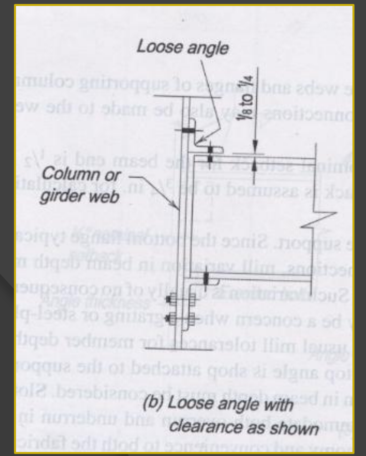
Connection Design

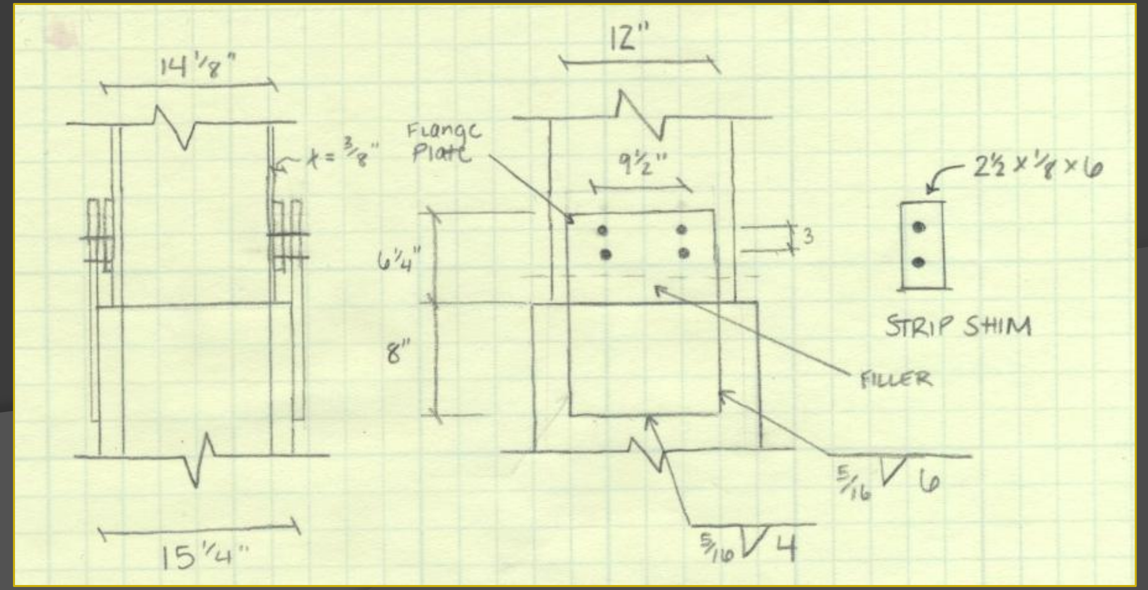
- Moment Frame Connection
  - 4 bolt unstiffened extended end plate
  - beam – column flange
- Seated Connection
  - all bolt unstiffened
  - beam – column web
- Column Splice Connection
  - bolted and welded
- Column base plate



Moment Connection



Seated Connection
L 4x4x1/4 w/ 7/8" bolts



Column Splice Connection

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Impact on Lateral Loads

- Seismic Loads control both directions
  - 31% decrease

	Original Building Design	New Building Design
Building Weight	16679 lbs	11359 lbs
Base Shear	583.5 kips	397.6 kips
Total Moment	40116 ft-kips	27962 ft-kips

- Controlling Load Combination
  - 0.9D + 1.0E

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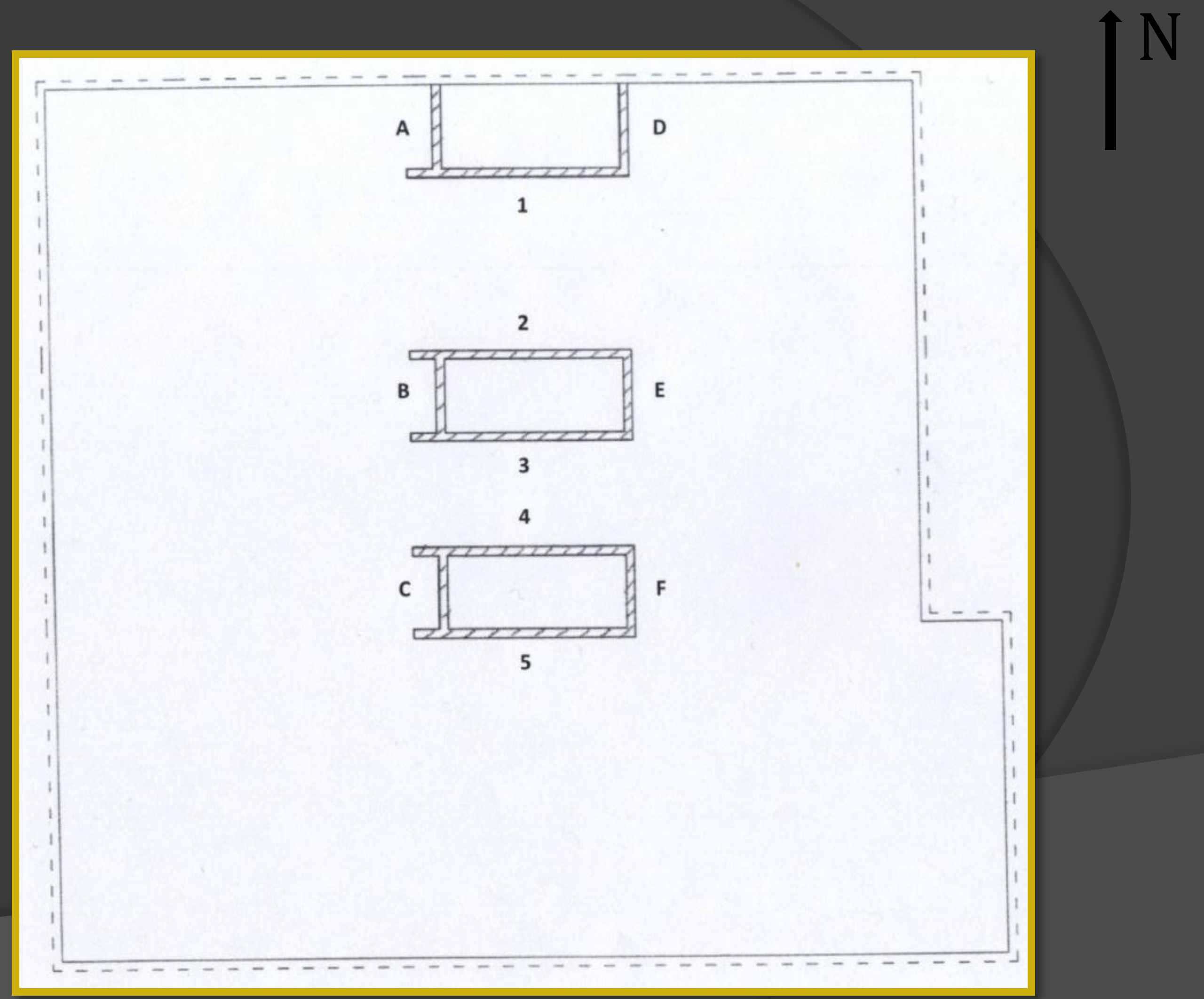
Shear Wall Design

- Shear wall layout
- Preliminary shear wall thickness = 10”

Wall A	Wall B	Wall C	Wall D	Wall E	Wall F
0.000	0.111	0.097	0.000	0.111	0.097
0.965	1.537	1.341	0.965	1.537	1.341
1.842	2.936	2.562	1.842	2.936	2.562
2.604	4.150	3.622	2.604	4.150	3.622
3.255	5.186	4.526	3.255	5.186	4.526
3.798	6.051	5.281	3.798	6.051	5.281
4.239	6.754	5.895	4.239	6.754	5.895
4.584	7.304	6.374	4.584	7.304	6.374
3.827	6.098	5.322	3.827	6.098	5.322
3.963	6.315	5.511	3.963	6.315	5.511
4.041	**6.439**	5.620	4.041	**6.439**	5.620



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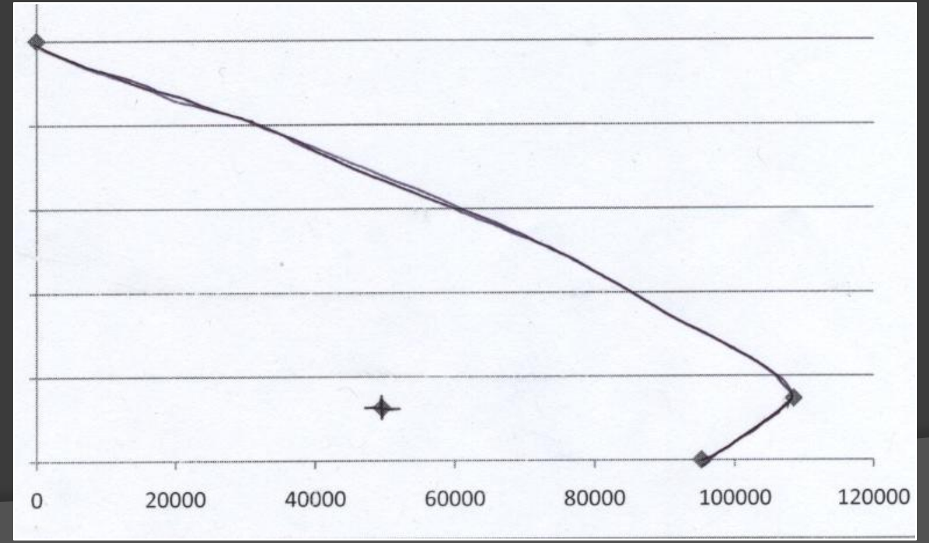
Shear Wall Design

- Reinforcing:
  - axial + flexural strength
  - No horizontal shear reinforcement
  - Vertical: #5 bars @ 8”, 16” & 32” O.C
- Interaction Diagram



Shear Wall Design: Wall 2

Bar Size	Area
3	0.11
4	0.2
5	0.31
6	0.44
7	0.6
8	0.79

Required Vertical Shear Reinforcing

$\rho_{t\,min} = A_v / (s*h) = 0.0025$

$A_{v\,req'd} =$ 0.40 in^2

$A_v =$ 0.62 > 0.40 OKAY

Flexural	Axial+Flexural Strength		Vertical Reinforcement							
ΦM_n (k-ft)	ΦP_n (k)	ΦM_n (k-ft)	M_n (k-ft)	V_u (k)	< V_n (k)	A_s/s	Spacing	$A_{v,req'd}$	Design Reinf.	A_v
6	42	22	26	3	296	0.000	16	0.00	(2) #5 bars	0.62
88	124	306	333	41	296	0.004	16	0.06	(2) #5 bars	0.62
243	202	850	908	78	296	0.007	16	0.11	(2) #5 bars	0.62
462	279	1618	1724	110	296	0.009	16	0.15	(2) #5 bars	0.62
736	355	2577	2753	137	296	0.012	16	0.19	(2) #5 bars	0.62
1056	430	3696	3965	161	296	0.014	16	0.22	(2) #5 bars	0.62
1413	502	4947	5334	181	296	0.015	16	0.24	(2) #5 bars	0.62
1799	573	6298	6831	196	296	0.017	16	0.27	(2) #5 bars	0.62
2207	643	7726	8433	209	296	0.018	16	0.28	(2) #5 bars	0.62
2641	711	9242	10151	217	296	0.018	16	0.29	(2) #5 bars	0.62
3459	**801**	**12107**	**13413**	**224**	**296**	**0.019**	**16**	**0.30**	**(2) #5 bars**	0.62

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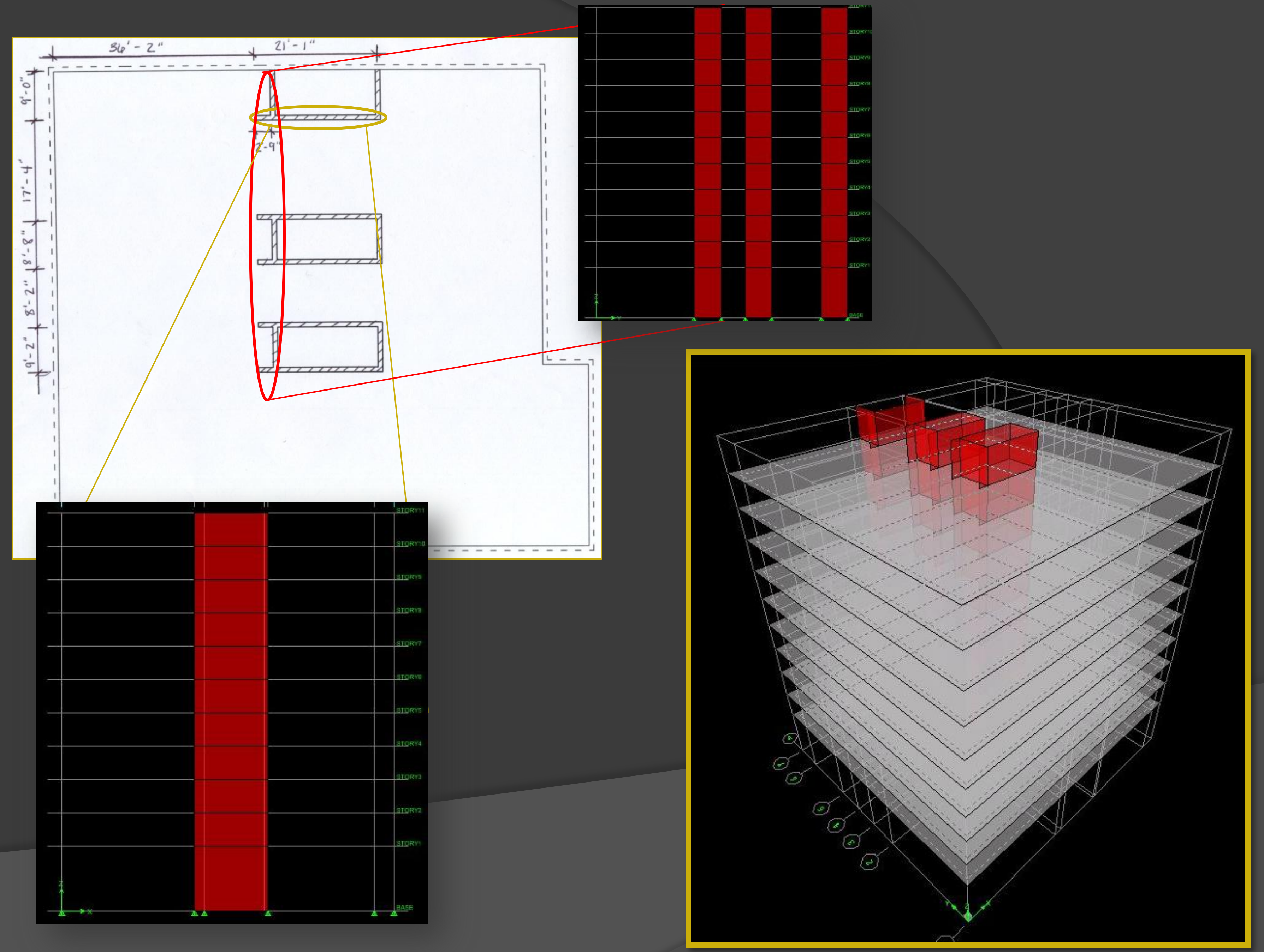
Optimization Study

- Modified shear walls
    - Thicker walls
    - Additional reinforcement

ETABS Model

- Assumptions:
    - Shear wall take full lateral loads
    - Floors modeled as rigid diaphragms
    - Lateral loads distributed based on relative stiffness of each wall
    - Gravity loads as additional area mass to the diaphragms



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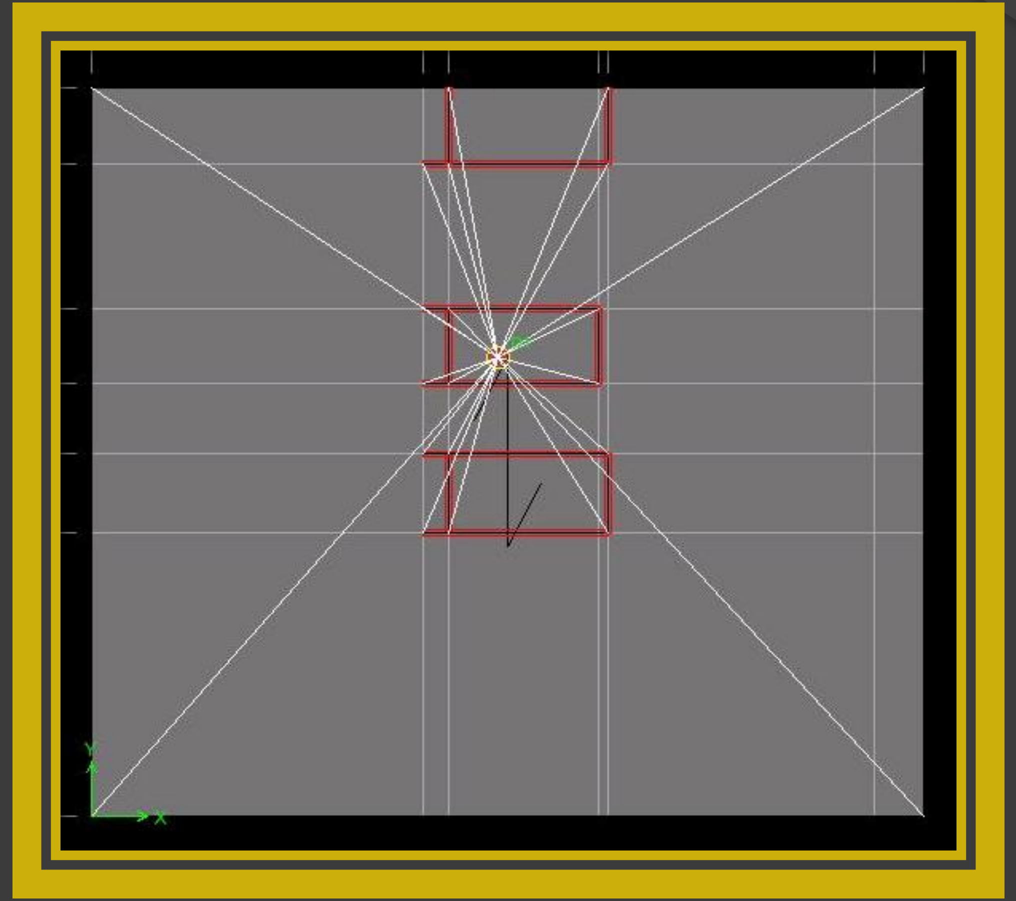
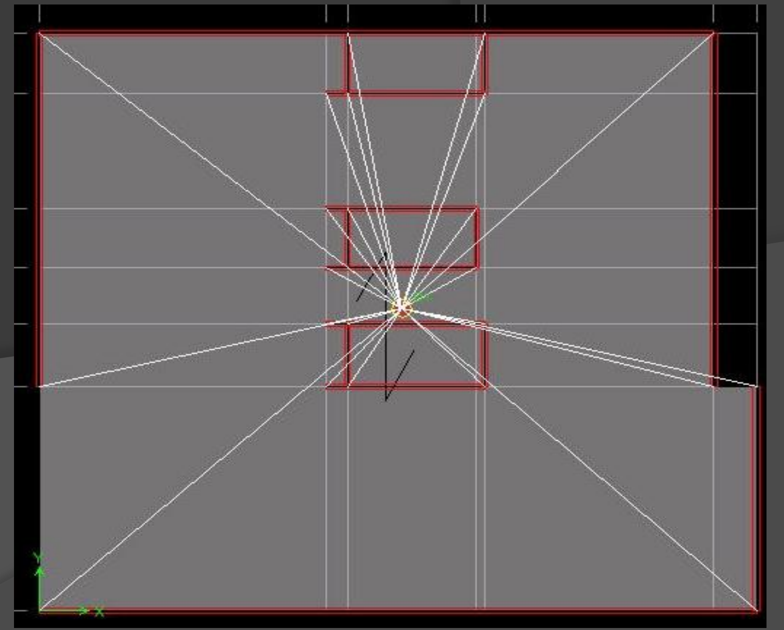
Optimization Study

- Shift in center of rigidities
- Increased stiffness to each shear wall
- Decreased in Overall Building Torsion

Overall Building Torsion		
	Modified Design	Original Design
N/S Direction	1519 ft-k	3346 ft-k
E/W Direction	1928 ft-k	2678 ft-k





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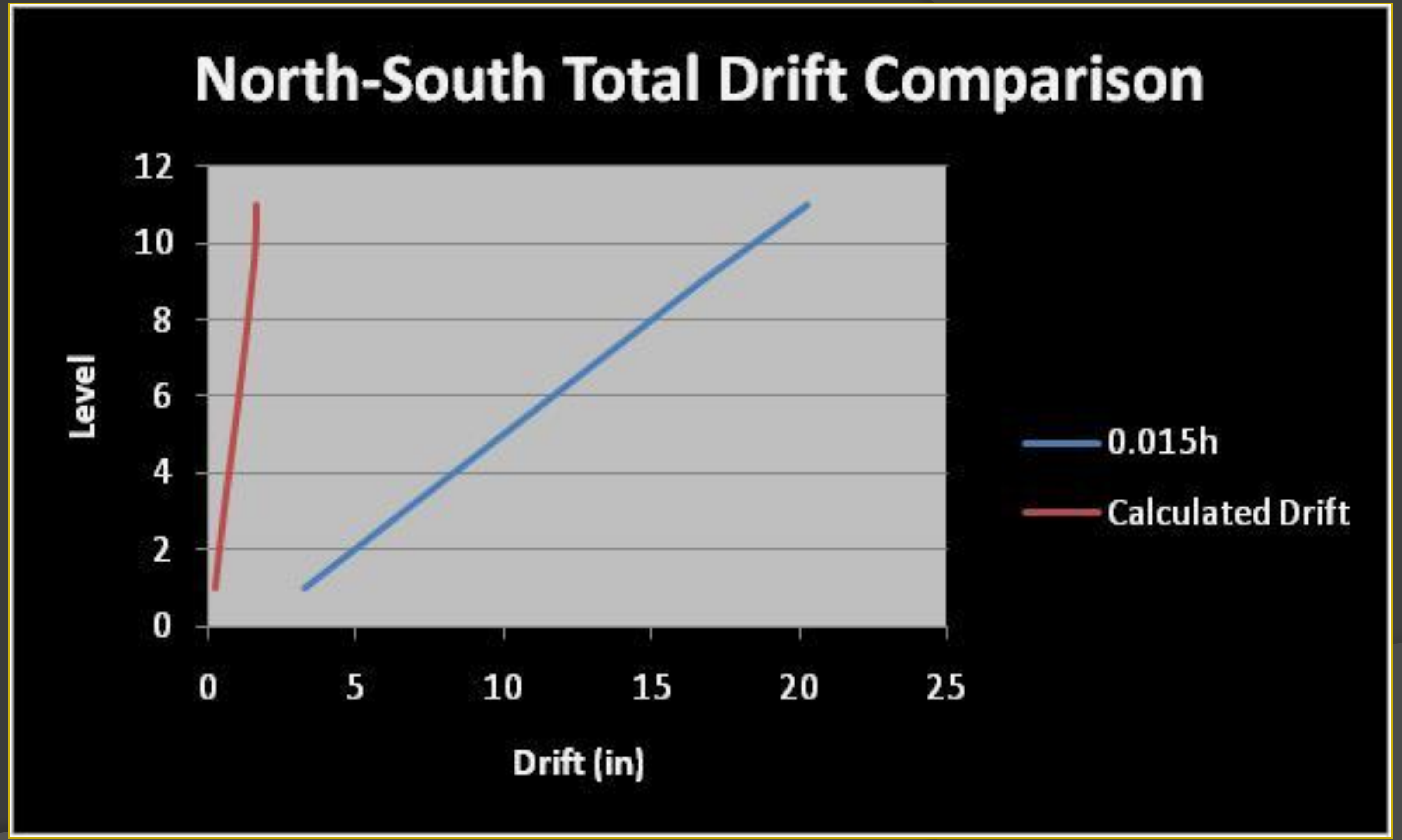
Optimization Study

Lateral Drifts

- ASCE 7-05 calculated drifts
- Drift Limitations:
  - Wind - H/400
  - Seismic - $0.015h_{sx}$
- Lateral drifts due to seismic loads governed
  - Max. drift in N-S direction



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Impact on Foundation

- Modified lateral resisting system
- New material for altered gravity load system
  - Decrease in overall building weight
  - Greater resistance to overturning

Overturning		
	Modified Design	Original Design
N/S Direction	27962 ft-k	40116 ft-k
E/W Direction	27962 ft-k	40116 ft-k

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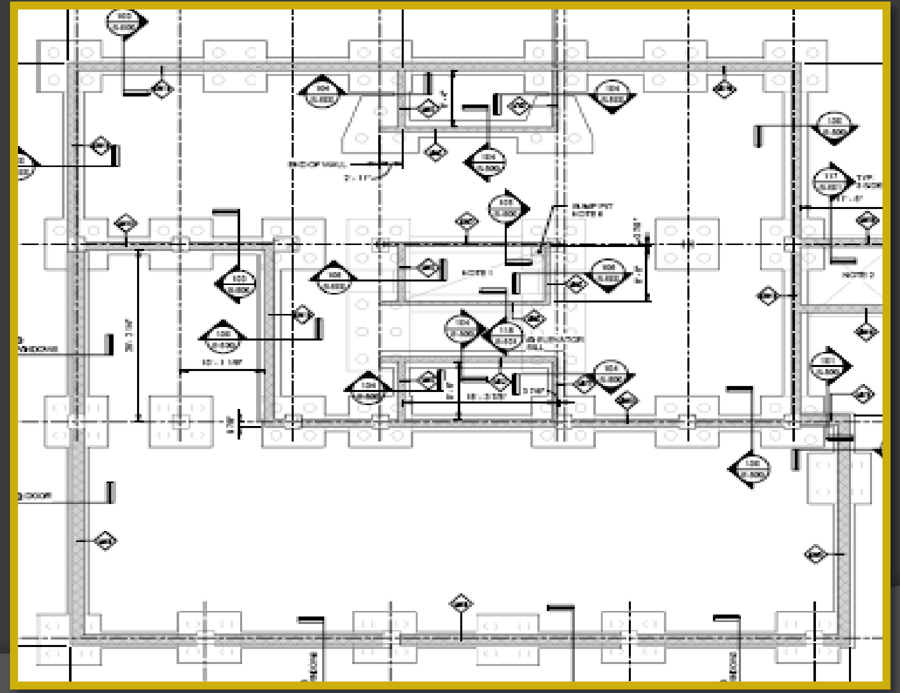
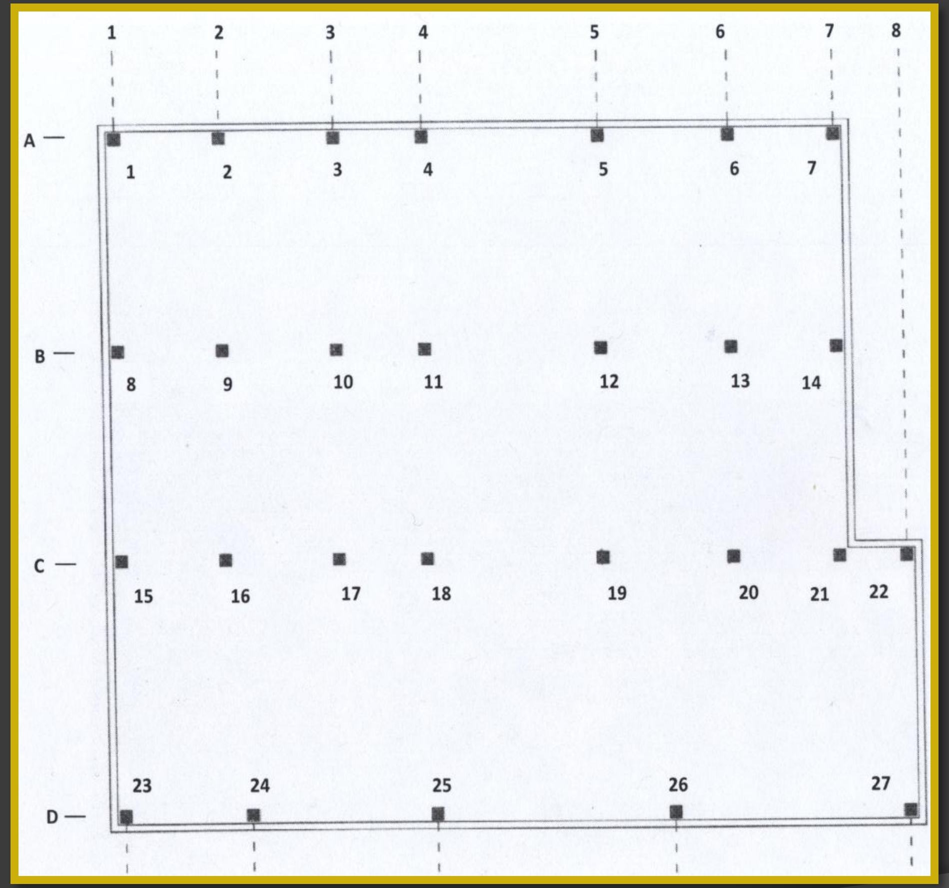
Impact on Foundation

- Auger cast Piles
  - 16” diameter

Structural System	Number of Required Piles
Redesigned Steel System	68
Original Concrete/Masonry System	104





Comparison of the number of piles to support the new design vs. the original design				
Column No.	Total Load on Each Column (k)	# of piles required to support Steel System	# of piles used in Original Design	% Decrease in required # of piles
1	132	1	4	75
2	265	2	4	50
3	246	2	Not in original	0
4	330	2	4	50
5	390	2	4	50
6	300	2	4	50
7	135	1	4	75
8	262	2	4	50
9	547	3	4	25
10	505	3	4	25
11	664	3	4	25
12	774	4	4	0
13	580	3	4	25
14	266	2	4	50
15	286	2	4	50
16	597	3	4	25
17	553	3	4	25
18	732	4	4	0
19	853	4	4	0
20	653	3	4	26
21	392	2	4	50
22	102	1	4	75
23	195	1	4	75
24	478	3	4	25
25	643	4	4	0
26	680	4	4	0
27	318	2	4	50
Average % Decrease in # Piles Required =				**35**

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Conclusions

- **Gravity System Redesign**
  - Strength ☑
  - Serviceability ☑
  - Reduction load bearing walls ☑
  - Reduced building weight ☑
- **Modified Lateral Resisting System**
  - Reduced overall building torsion ☑
  - Within drift limits ☑
- **Foundation**
  - Overturning resistance ☑
  - Reduced number of piles ☑

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Façade Breadth Study

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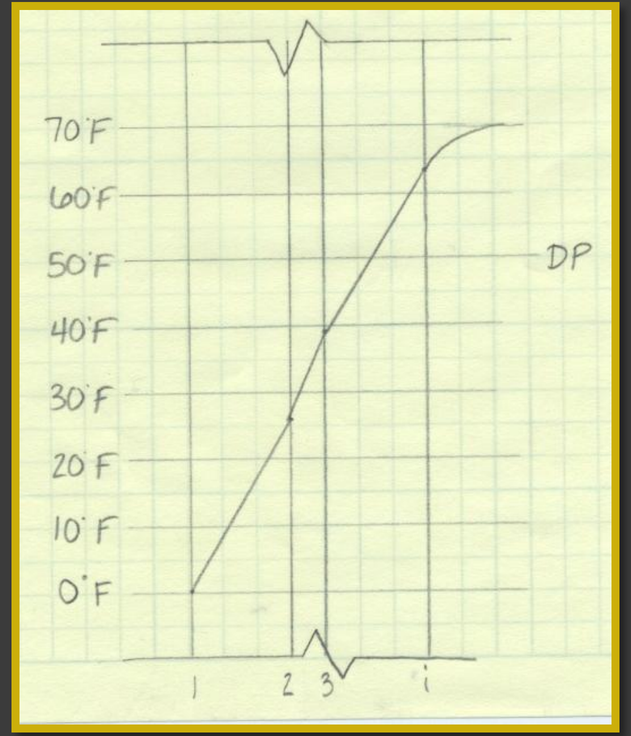
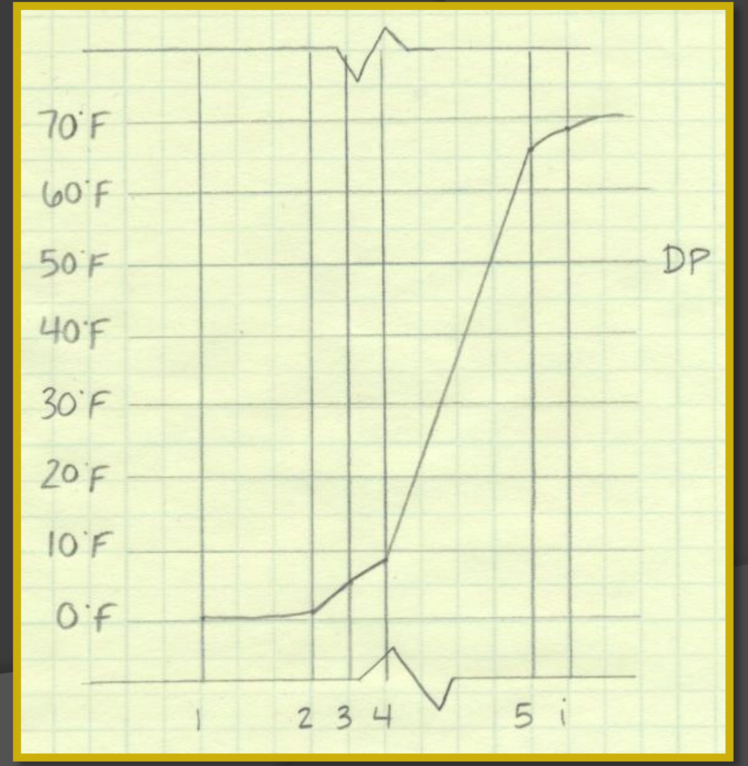
Thermal Gradients

Curtain Wall System		
Between Material	**$\Sigma R_{o\text{-}x}$ (°F ft² h/BTU)**	**Temperature (°F)**
o - 1	0.17	0
1 - 2	2.34	25.84
2 - 3	3.49	38.53
3 - i	5.66	62.49
	6.34	**70**
U = 0.158 (BTU/°F ft² h)		



Brick Venner System		
Between Material	**$\Sigma R_{o\text{-}x}$ (°F ft² h/BTU)**	**Temperature (°F)**
o - 1	0.17	0
1 - 2	0.28	0.848
2 - 3	1.54	4.67
3 - 4	2.86	8.67
4 - 5	21.86	66.2
5 - i	22.54	68.3
	23.10	**70**
U = 0.0433 (BTU/°F ft² h)		



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Cost Comparison

Façade Systems with Redesigned Structural System							
Wall System	S.F.	Crew Size	Material Cost/SF	Labor Cost/SF	Total Cost	Daily Output	Construction Time
Curtain Wall System	5734	2 Glaziers	$30.49	$6.94	$214,624	410	14 days
Brick Veneer System	5734	3 Brick Layers	$6.95	$8.94	$91,113	660	7 days

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Conclusions

- Research façade options on steel framing ☑
- Determined brick veneer is the most efficient facade thru heat transfer ☑
- Determined brick veneer is the cost efficient facade ☑

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Construction Management Breadth Study

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Construction Schedule

- **Redesigned Structural System**
  - Start Date: February 26, 2009
  - Finish Date: April 24, 2009
- **Original Structural System**
  - Start Date: February 26, 2009
  - Finish Date: August 13, 2009

Construction Time Comparison			
Component	Existing System (days)	Redesigned System (days)	Savings (+)
Shear Walls	150	21	129
Steel Frame	15	45	-30
Total			99

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Amanda Smith
AE Senior Thesis 2010

Structural Option
Advisor: Dr. Ali Memari

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Cost Impact of Redesigned System

- **Costs unaccounted for:**
  - Precast Plank floors
  - Foundation costs
  - Additional member connections

- **Example Detailed Cost Breakdown:**
  - Shear walls and reinforcement
  - Steel members, base plates, fireproofing
  - Crane

Shearwalls	Amt.	Unit	Mat'l Cost/Unit	Labor Cost/Unit	Equip Cost/Unit	Total Cost/Unit	Total Cost w/ O&P	TOTAL COST
10" CMU Block	18473	SF	3.06	4.47	0	7.53	10.15	$187,500.95
Reinforce.	7	Ton	810	420	0	1230	---	$ 8,610.00

Steel	Amt.	Unit	Mat'l Cost/Unit	Labor Cost/Unit	Equip Cost/Unit	Total Cost/Unit	Total Cost w/ O&P	TOTAL COST
Columns	2753	LF	145	3.26	2.18	150.44	168	$462,504.00
Baseplates	108	SF	45		0	45		$ 5,172.18
Beams	4807	LF	89.5	3.13	2.09	94.72	106	$509,542.00
Fireproofing	7559	SF	1	1	1.2	3.2		$ 24,188.80
Crane	76					300		$ 22,800.00

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Cost Impact

Overall Cost Comparison			
Component	**Existing System**	**Redesigned System**	**Additional Cost**
Shear Walls	$519,680	$196,111	-$323,569
Steel Framing	$171,660	$1,001,407	$829,747
Crane	$10,977	$22,822	$11,845
TOTAL	**$702,317**	**$1,220,340**	**$518,023**

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Conclusions

	Thesis Structural System	Existing Structural System
Crane Cost due to Steel	$22,822.00	$10,977.00
Total System Cost	$1,220,340.00	$702,317.00
Steel Erection Schedule (days)	45	15
Entire Structural System Schedule (days)	66	165

- Steel erection tops out 30 days earlier than the new structural system
- Structural system construction tops out 99 days earlier than existing structural system

Conclusions & Recommendations

Gravity System Redesign
- Steel Moment Frames
  - Reasonable design for gravity loads
  - Meets strength and serviceability requirements
  - Reduced overall building weight

Lateral Resisting System Redesign
- Modified Shear wall design is optimal

Foundation
- No alteration needed

Façade
- Brick veneer is most efficient

Construction Management
- Reduce schedule
- Increase cost

Acknowledgements

Atlantic Engineering Services:
- Tim Jones
- Robert Bertocchi

Massaro Corporation:
- Brian Miller

G.M.McCrossin Contracting:
- Shawn Steward

SNC-Lavalin America:
- Jeremy Coulombe

The Pennsylvania State University:
- Dr. Ali Memari
- Prof. M Kevin Parfitt
- Prof. Robert Holland
- The entire AE faculty and staff

My friends and family for all their continued support.

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Questions & Comments