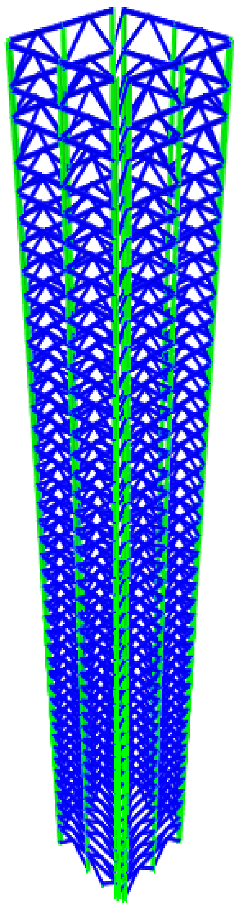


AE Senior Thesis 2008

Trump Taj Mahal Hotel

Atlantic City, New Jersey

Analysis and Design of a Steel Braced Frame Core

An Investigation of the Design of High Rise Steel Structures

Stephen Reichwein

Structural Emphasis

Presentation Outline

- Project Information
- Existing Structural System
- Problem Statement and Solution
- Structural Redesign
- Architectural Studies
- Construction Studies
- Conclusions

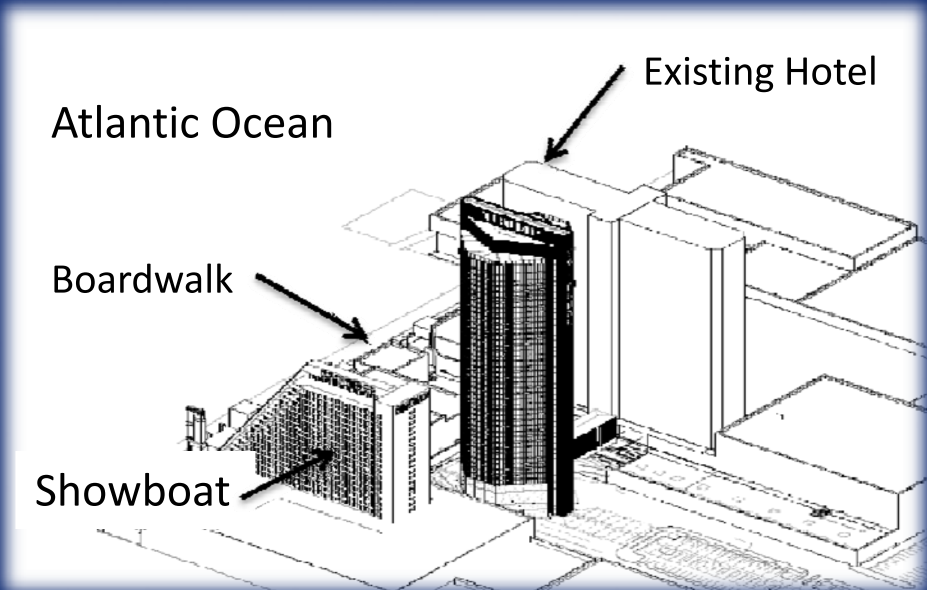
Project Information

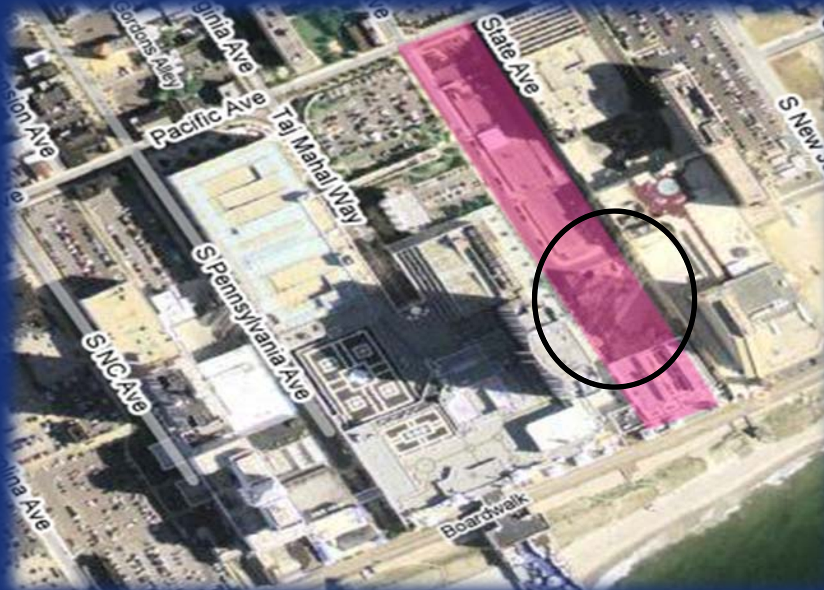
General Information

- 40 Story Hotel Tower
- Expansion to Existing Hotel
- Project Cost = $200 Million
- Project Size = 730,000 G.S.F
- Owner – Trump Hotels and Casino Resorts
- Project Delivery Method – Design Build
- Groundbreaking: July 2006
- Completion: August 2008

Project Information

Project Location

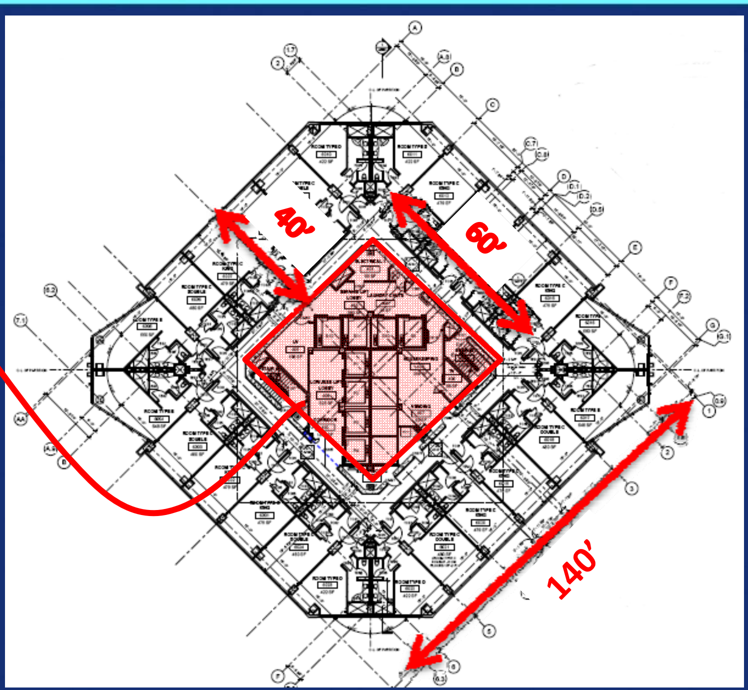




Project Information

Building Architecture

- Diamond Footprint
- Services in Central Core
- Reflective Glass Curtainwall (Shaft)
- Stainless Steel Capital
- Precast Concrete (Base)



MATERIAL KEY

GLASS TYPE	COLOR CODE	DESCRIPTION
A	(cyan)	1" IGU VISION GLASS
B	(orange)	1" IGU SPANDREL
C	(teal)	1" IGU SPANDREL W/OPACIFIER
METAL PANEL	(white)	
ARCH. PRECAST CONCRETE	(stippled)	

Presentation Outline

- Project Information
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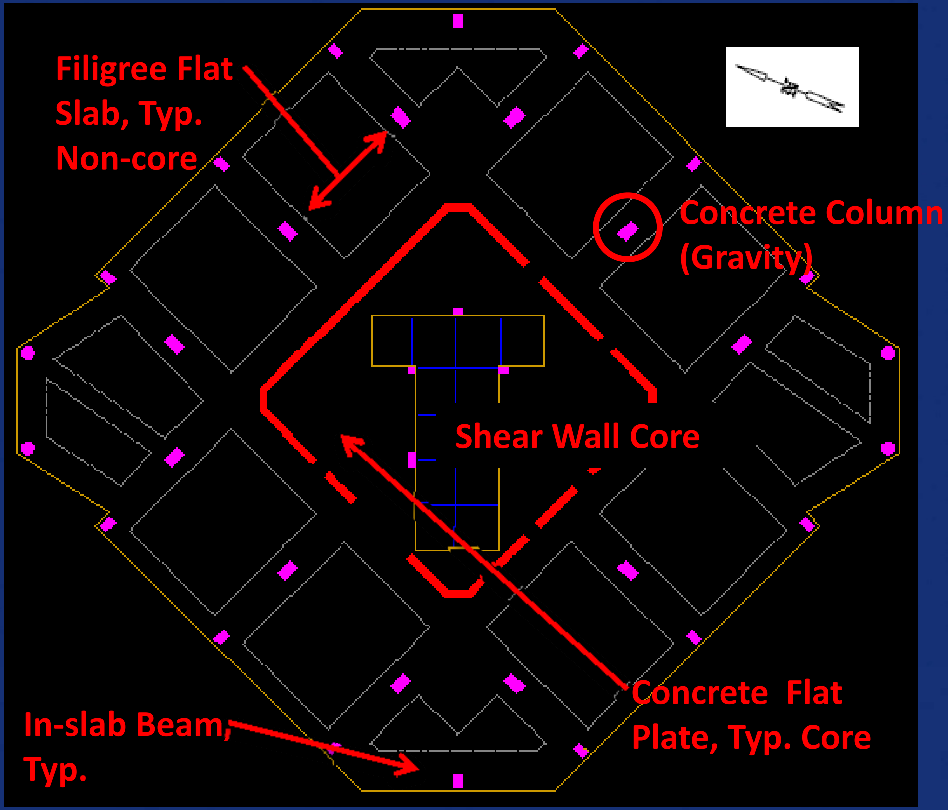
Existing Structural System

Gravity System

- Filigree Flat Plate (Non-core)
- Reinforced Flat Plate (Core)
- Concrete Columns (100% Gravity)

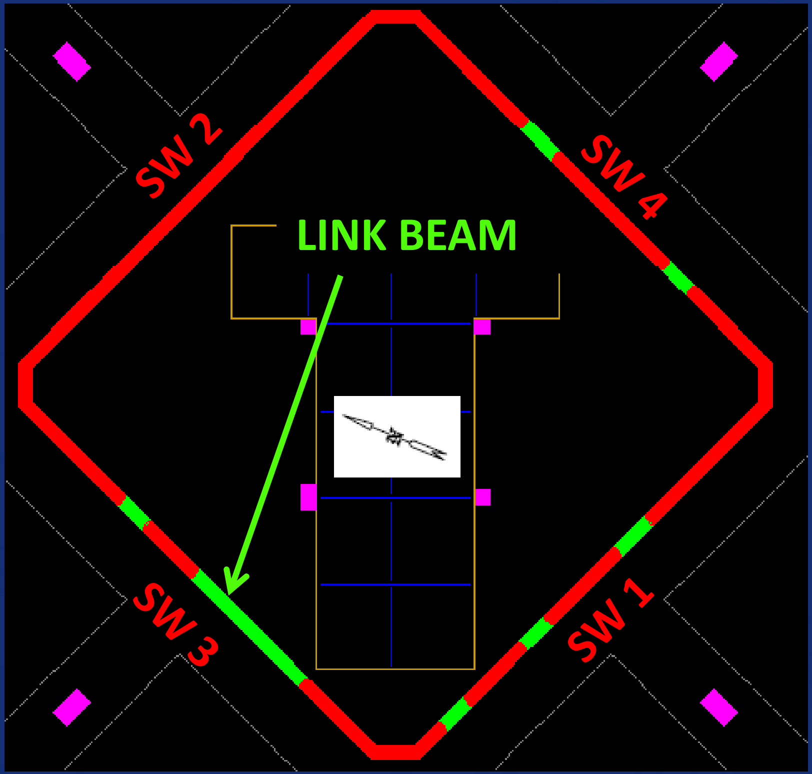


Existing Structural System

Lateral Force Resisting System

Reinforced Concrete Shear Wall Core

Levels	f'c	Thickness
1 thru 3	9000psi	24"
4 thru 15	9000psi	16"
16 thru 22	7000psi	16"
23 thru 41	5000psi	16"



Presentation Outline

- Project Information
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Problem Statement

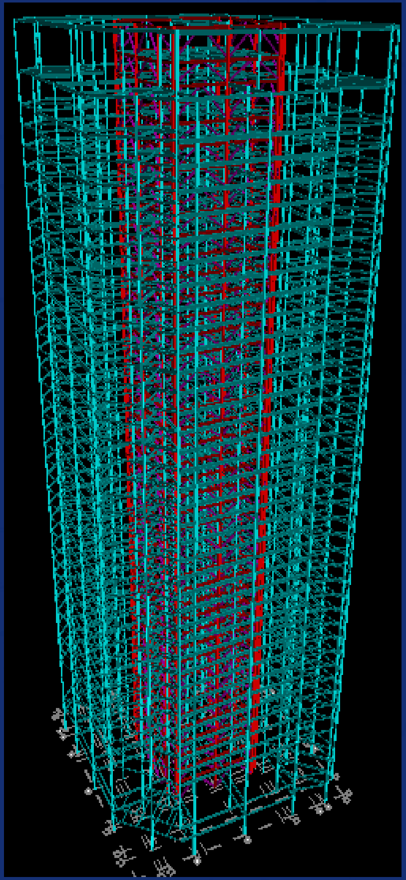
- Key design consideration: opening the hotel as soon as possible
  - Erection of concrete system slow and labor intensive

- Swallower mat foundation will provide cost and schedule savings
  - Extremely heavy concrete core requires a 9’-0” thick mat foundation

Why was a concrete structure the system of choice?

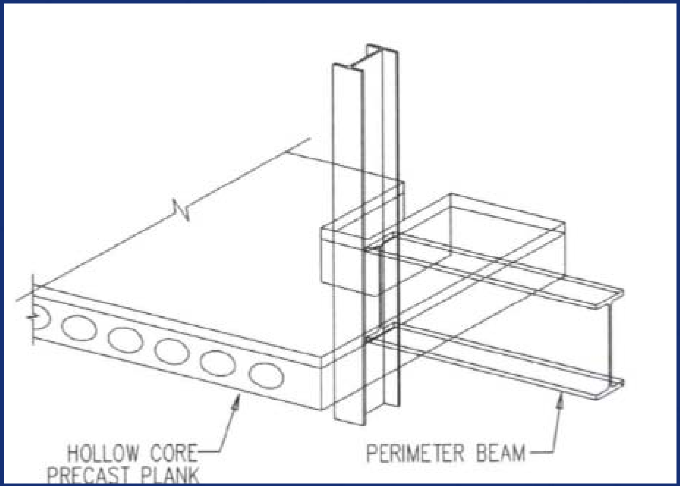
Design Goals

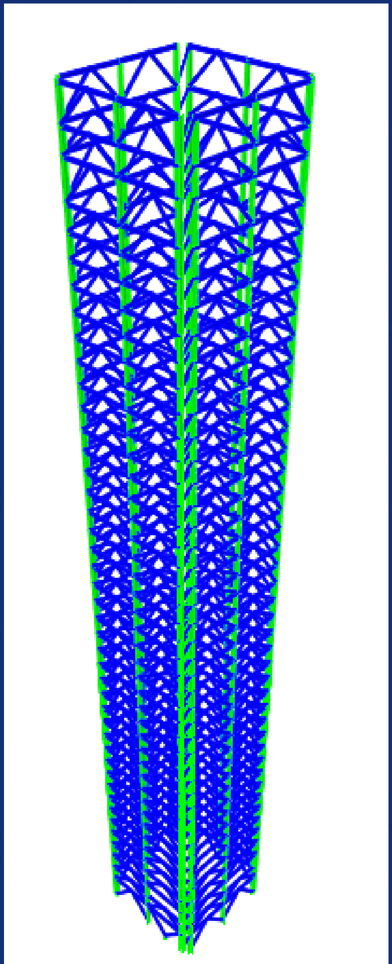
- Reduce structure dead weight using an all steel system
  - Premium 1: 10" floor to floor height increase
  - Premium 2: Architectural Impacts
- Eliminate costly concrete construction with faster steel erection
- Utilize a "core only" lateral force resisting system
- Determine why a concrete framing system was chosen over a steel framing system?



Solution Overview

- Lateral System Redesign
  - Steel Braced Frame Core
- Gravity System Redesign
  - Steel Non-Composite Frame with Precast Concrete Planks





Presentation Outline

- Project Information
- Existing Structural System
- Problem Statement and Solution
- Structural Redesign
- Architectural Studies
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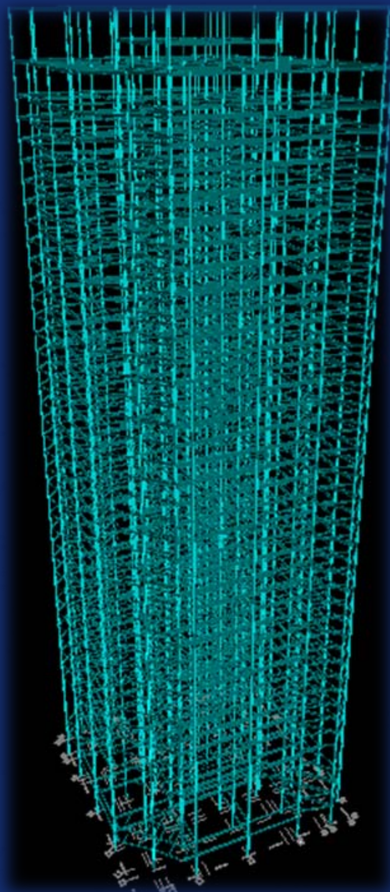
Structural Redesign

Non-Composite Steel Frame with Precast Planks

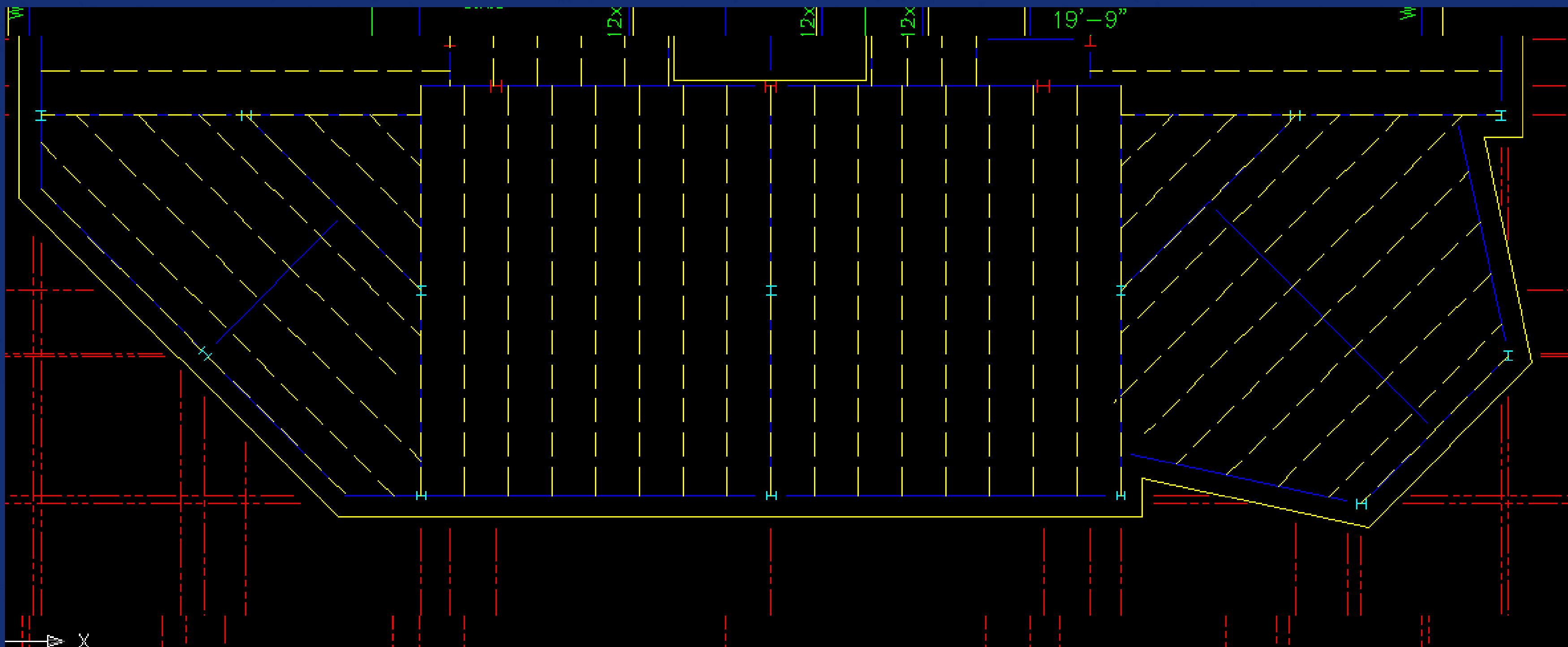
- Analysis and Design
    - RAM Steel – LRFD
    - Typical Dead Load = 98 psf
    - Typical Live Load = 40 psf

- System Takeoff
    - Girders and Beams: 1000 tons
    - Gravity Columns: 900 tons
    - 10” Precast Planks with 2” Topping: 683,000 S.F.
        - Nitterhouse



Structural Redesign

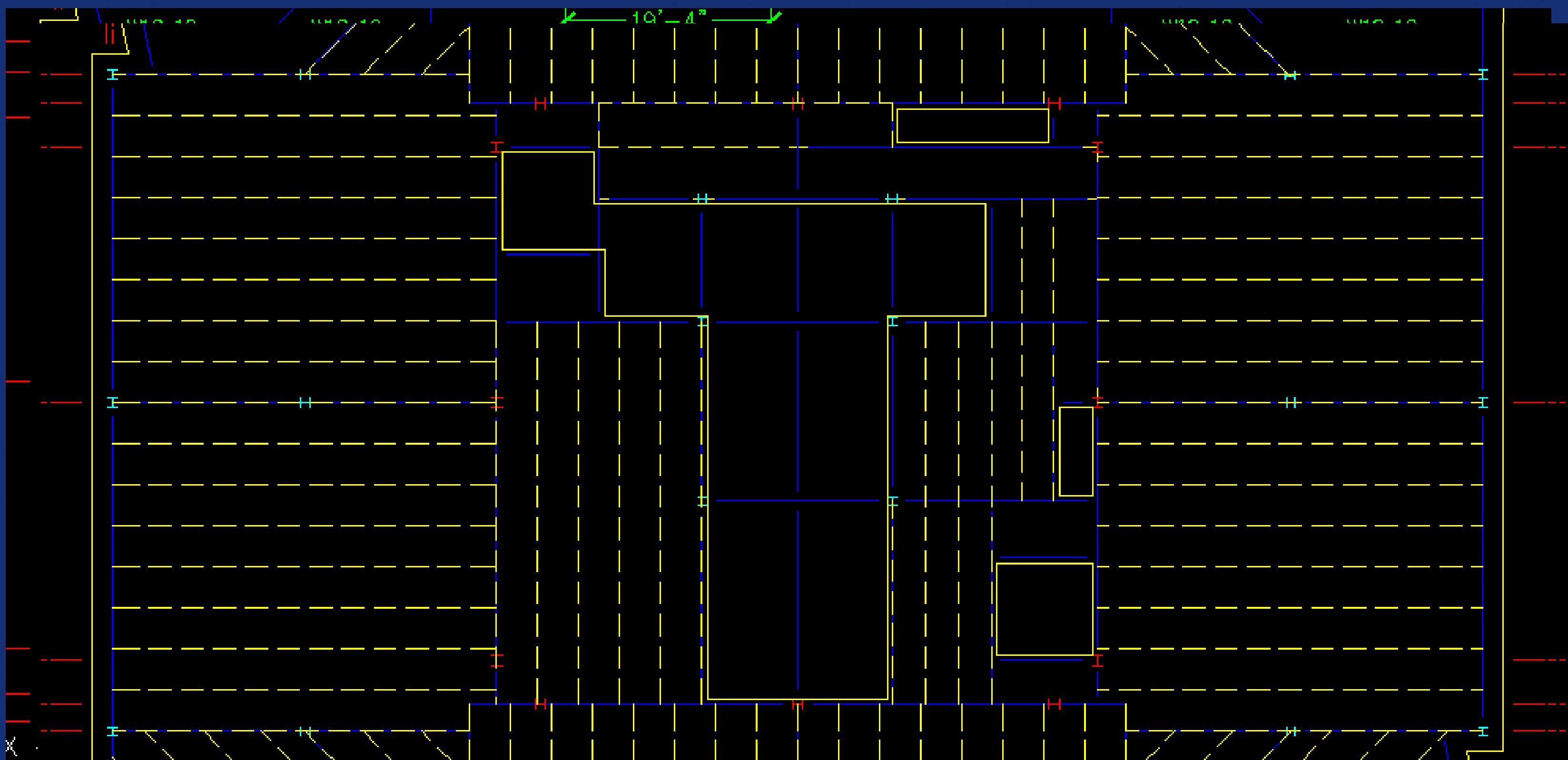
Non-Composite Steel Frame with Precast Planks



Typical Bay Framing

Structural Redesign

Non-Composite Steel Frame with Precast Planks

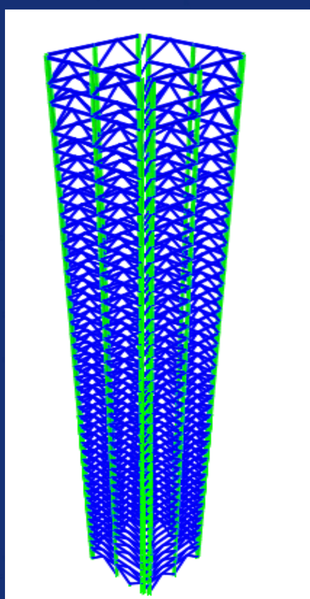


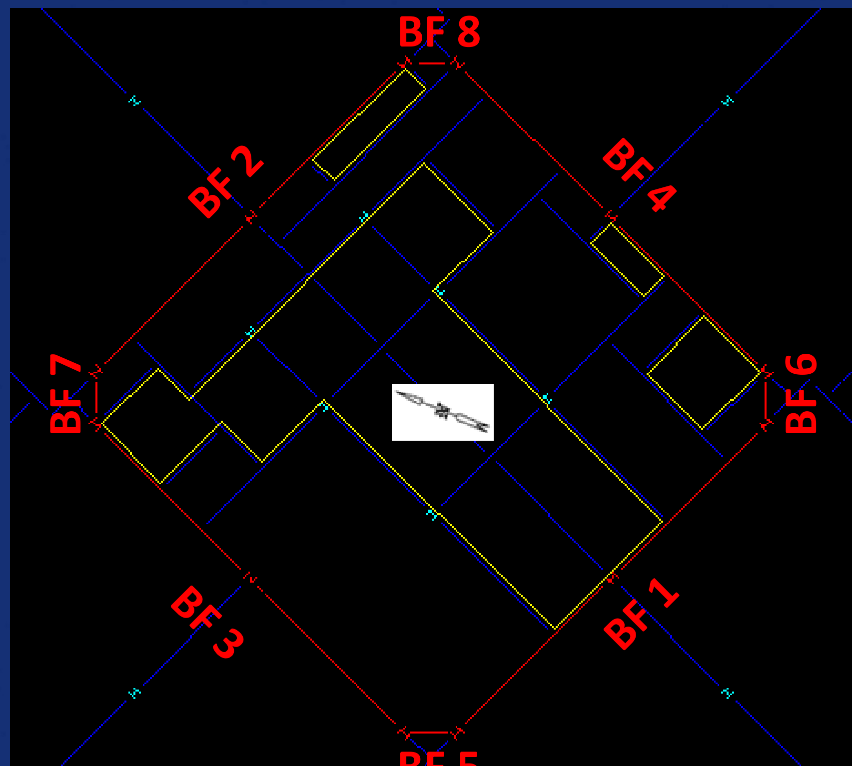
Typical Bay Framing

Structural Redesign

Steel Braced Frame Core

Redesigned Core



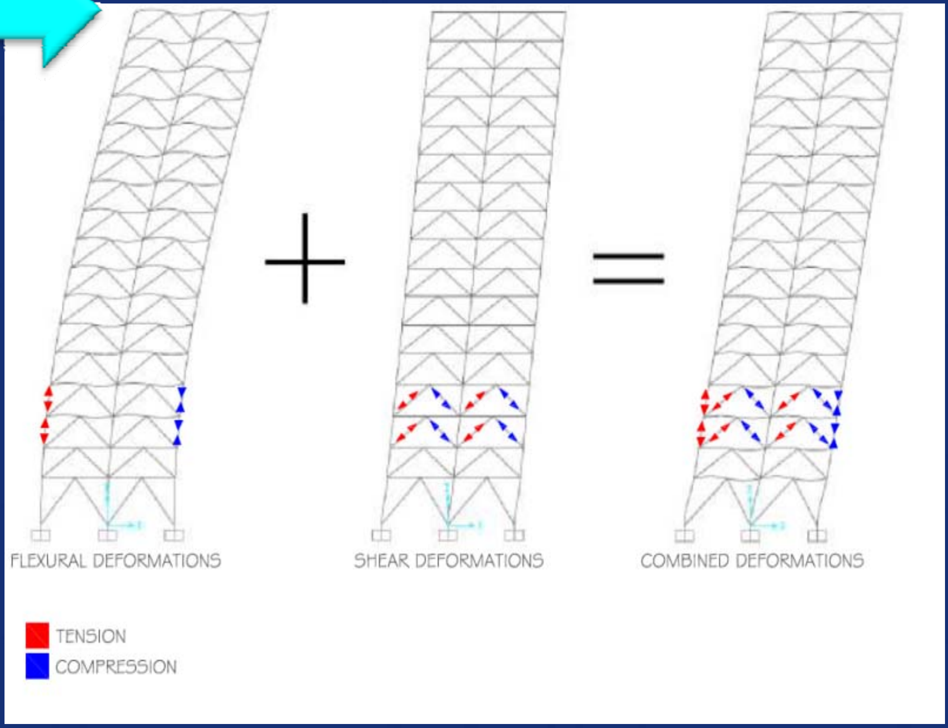


Wind tunnel loads provided by DFA

Structural Redesign

Steel Braced Frame Core

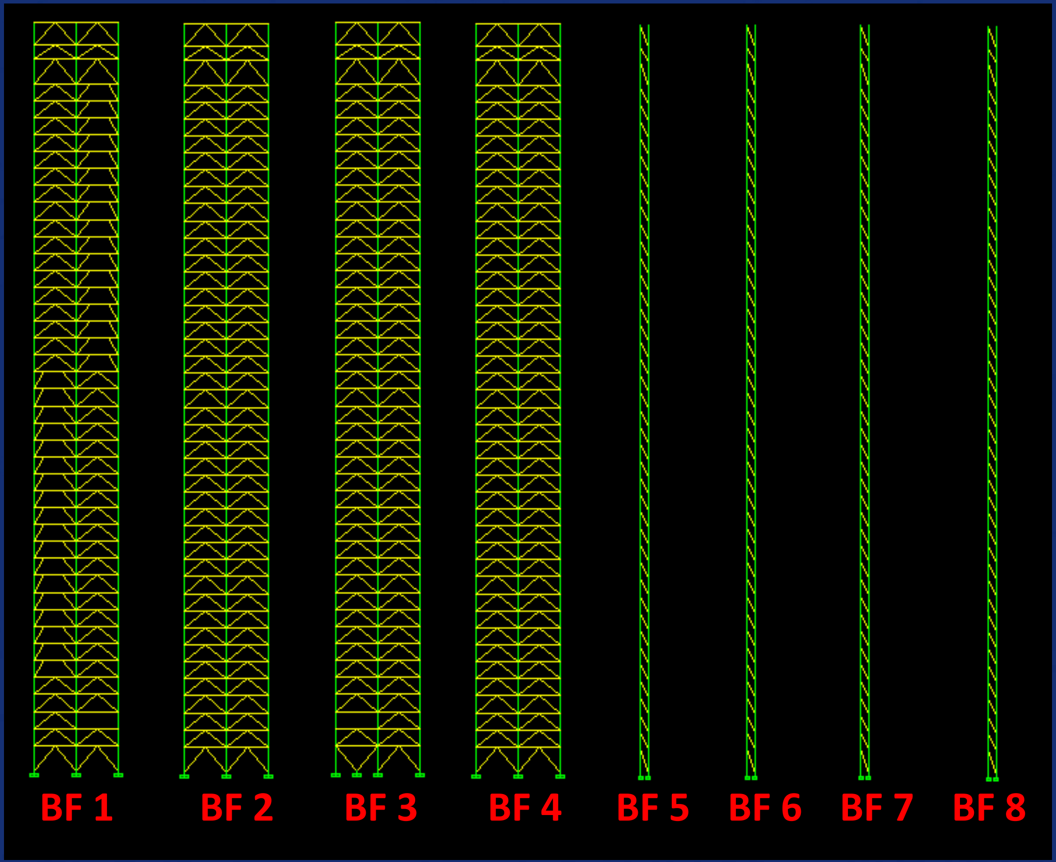
- Behavior
  - Cantilevered vertical truss
  - Columns resist moment with axial deformations
  - Braces resist shear
- Primary Drift Components
  - “Chord Drift” from axial shortening of columns
  - “Shear Racking” of braces
- Strength Design
  - Slenderness (KL/r)
  - H1-1a and H1-1b



Structural Redesign

Steel Braced Frame Core

Bracing Configurations



Frame	Direction
1	E/W
2	E/W
3	N/S
4	N/S
5-8	Both

BF 1 (E/W): Eccentric Braces 8'-0" Link

Structural Redesign

Steel Braced Frame Core

Classical Design Methods – Preliminary Analysis and Design

- Moment Area Method
- Classical Virtual Work

	Classical Virtual Work			Moment Area Method	
	A_{col}	A_{brace}	A_{girder}	Ovt. Mom	A_{col}
Group 5	76.23	9.33	11.76	1542667.14	22.44
Group 4	178.99	11.95	15.05	3585799.97	68.58
Group 3	288.65	13.53	17.05	5985908.32	143.53
Group 2	380.55	14.39	18.13	8762778.83	252.78
Group 1	498.74	14.88	24.17	12955479.37	424.18

W14x808 ($A_s = 237\ in^2$) << 424 in^2

Built-up Sections Required

Structural Redesign

Steel Braced Frame Core

Braced Frame Schedule

Concentrically Braced Frames (BF 1, 2, 3, 4)			
Levels	**Column**	**Brace**	**Girder**
1 - 4	1430plf Built-up	W12x210	W14x132
5 - 8	1113plf Built-up	W12x170	W14x132
9 - 16	910plf Built-up	W12x136	W14x109
17 - 24	W14x550	W12x106	W16x89
25 - 32	W14x311	W12x87	W16x77
33 - Roof	W14x257	W12x53	W16x77

Eccentrically Braced Frames (BF 1 Only)			
Levels	**Column**	**Brace**	**Girder**
1 - 4	1430plf Built-up	W12x210	W14x145
5 - 8	1113plf Built-up	W12x170	W14x145
9 - 16	910plf Built-up	W12x136	W14x145
17 - 24	W14x550	W12x106	W14x120
25 - 32	W14x311	W12x87	W16x77
33 - Roof	W14x257	W12x53	W16x77

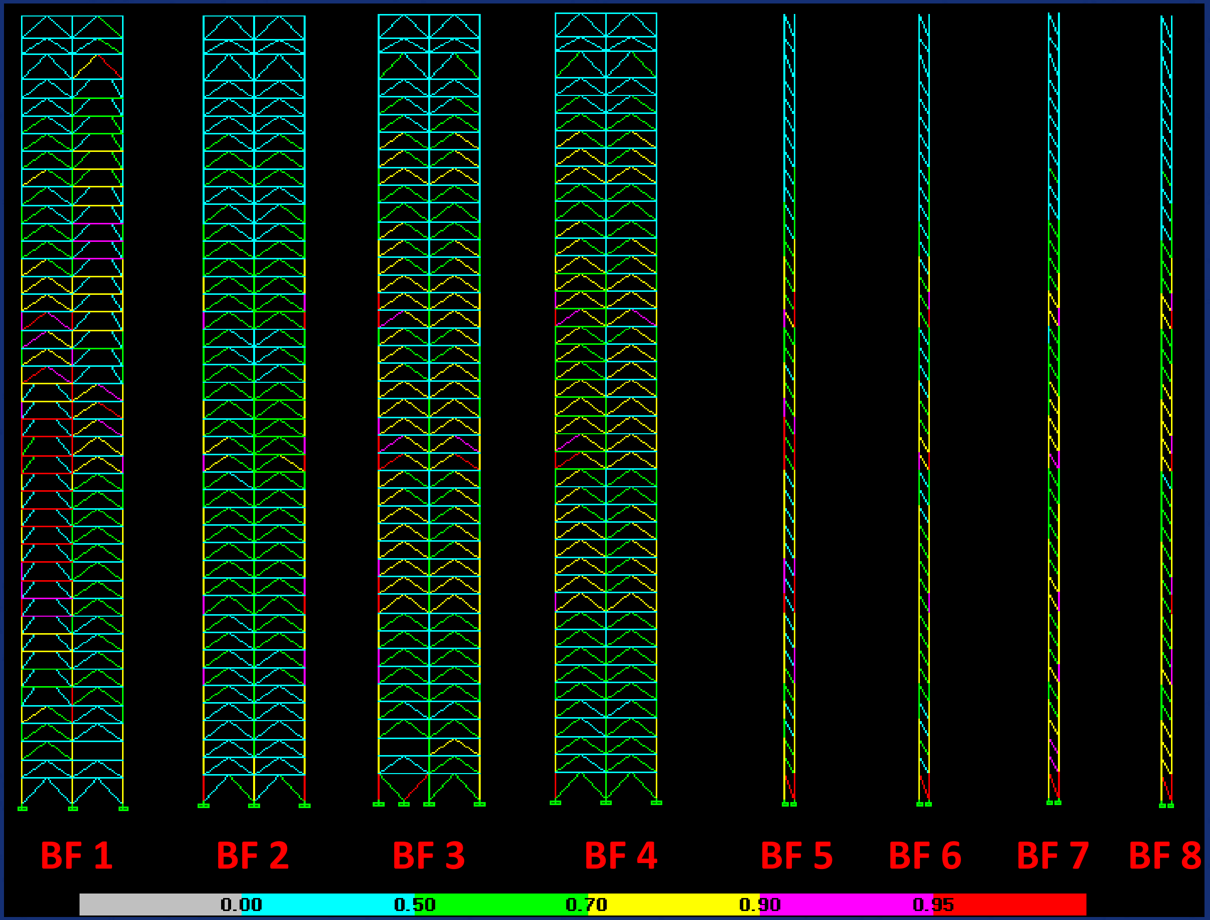
BF 5, 6, 7, 8	
Levels	**Brace**
1 - 16	2L8x8x1
16 - Roof	2L6x6x1

Structural Redesign

Steel Braced Frame Core

Strength Check

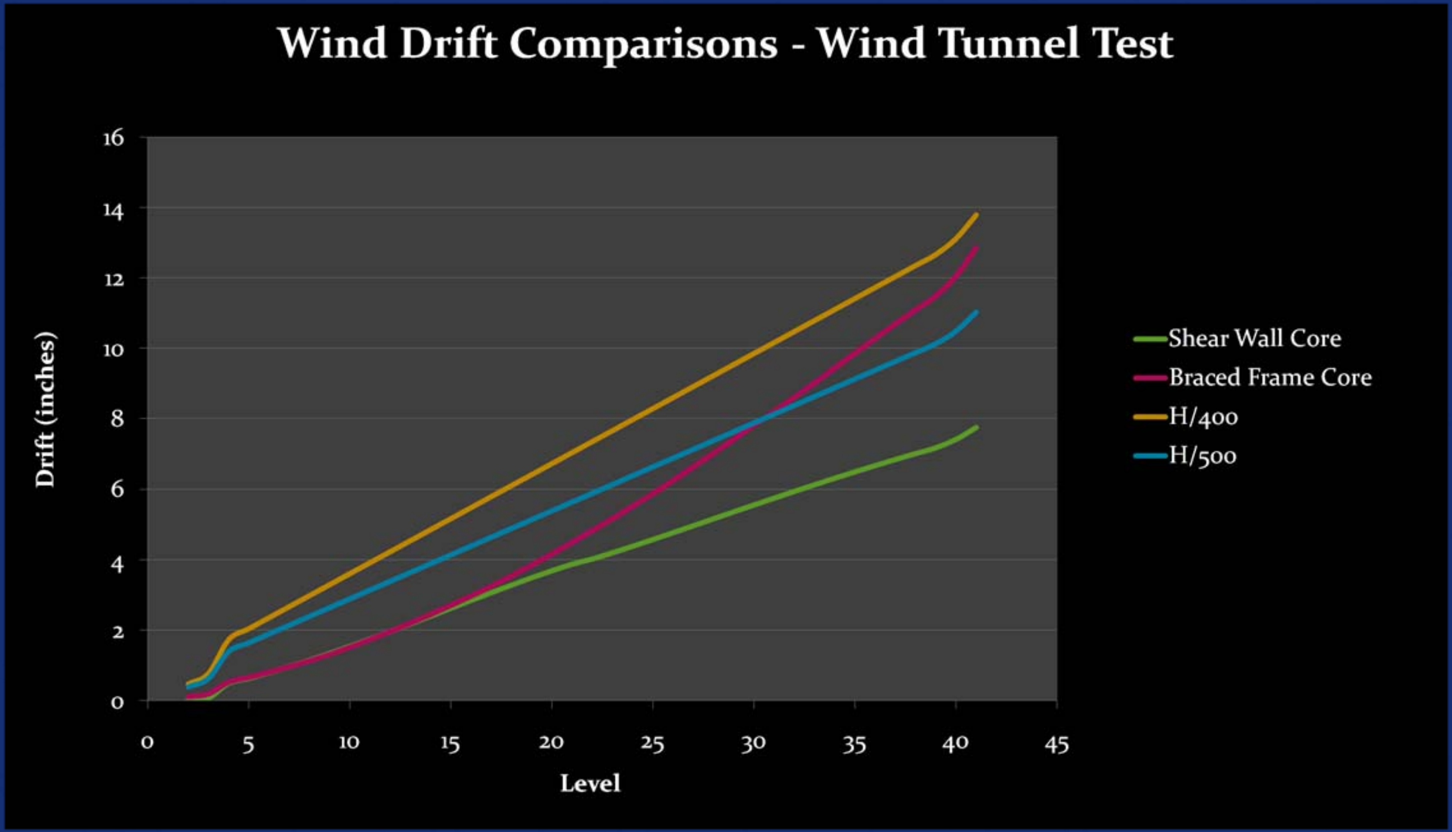
- H1-1a and H1-1b
- P-delta effects



Structural Redesign

Steel Braced Frame Core

Drift Results and Comparison – Wind Tunnel Loads (75%)



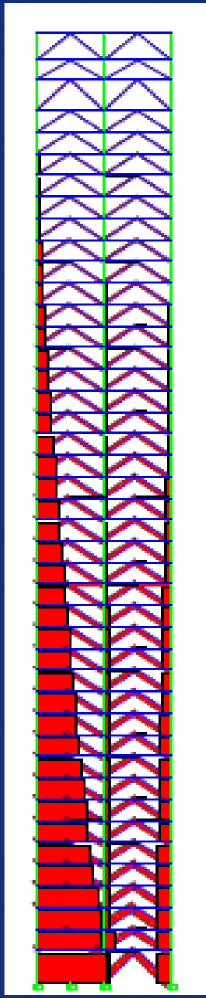
Structural Redesign

Steel Braced Frame Core

- Braced Frame Column Base Plate
  - A36 PL 65” x 55” x 10-1/2” with (32) 2-3/4” A449 Grade 120 Anchor Bolts

- Punching Shear
  - P_u = 15,910 kips
  - Mat Thickness Required = 110” ≈ 108”

9’-0” Thick Mat Foundation Still Required!!!!



Structural Redesign

Steel Braced Frame Core

Structural Dynamics – Fundamental Periods

- Translation X – East/West
- Translation Y – North/South
- Torsional - Rotation about Z

Direction	Shear Wall Core		Braced Frame Core	
	Period (s)	Frequency (1/s)	Period (s)	Frequency (1/s)
X (E/W)	3.13	0.32	3.78	0.26
Y (N/S)	2.75	0.36	4.28	0.23
Rz	1.77	0.56	2.9	0.34

Structural Redesign

Steel Braced Frame Core

Parametric RMS Acceleration Study

Parametric RMS Acceleration	Concrete Shear Wall Core	Steel Braced Frame Core
	4.4	9.4

Table 5.
Traditional Motion Perception (Acceleration) Guidelines (Note 1)
10-year Mean Recurrence Interval

Commercial	15–27 Target 21	3.75–6.75 Target 5.25	4.00–7.20 Target 5.60	4.29–7.71 Target 6.00
Residential	10–20 Target 15	2.50–5.00 Target 3.75	2.67–5.33 Target 4.00	2.86–5.71 Target 4.29

Notation:
T = period (seconds)
f = frequency (hertz)
g_p = peak factor

NOTE:
1. RMS and peak accelerations listed in this table are the traditional "unofficial" standard applied in U.S. practice based on the author's experience.

Concrete shear wall core is within target range; however, the steel braced frame core is not!!!!

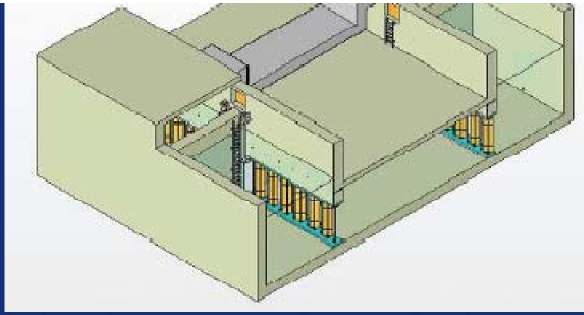
Structural Redesign

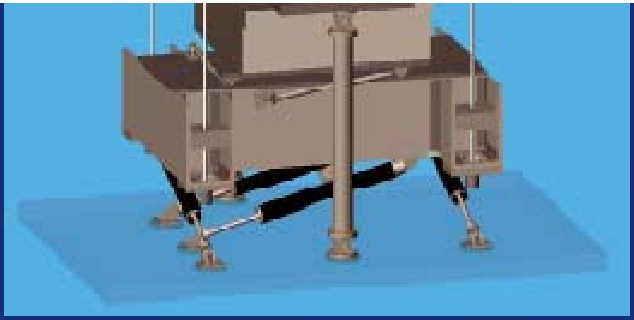
Steel Braced Frame Core

Solution to RMS Acceleration Issue

- Already sufficiently large braced frame members require supplemental mass and damping
- Building motion can be alleviated by additional mass and damping

Tuned mass dampers will add approximately $2 to $3 Million to overall project cost





Presentation Outline

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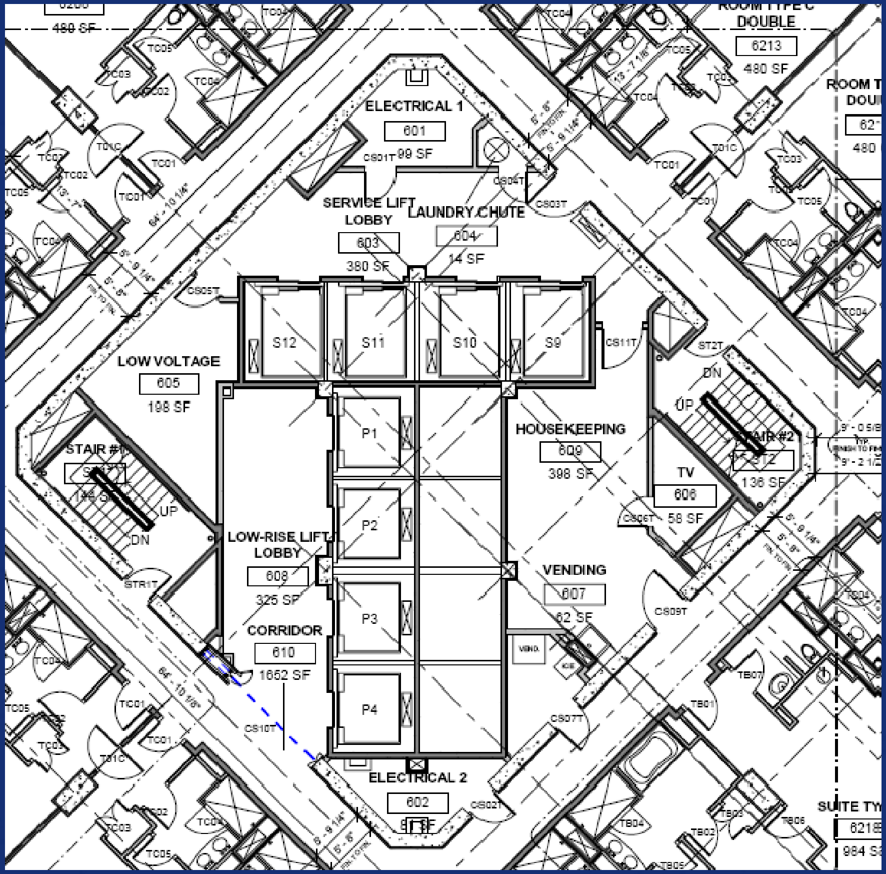
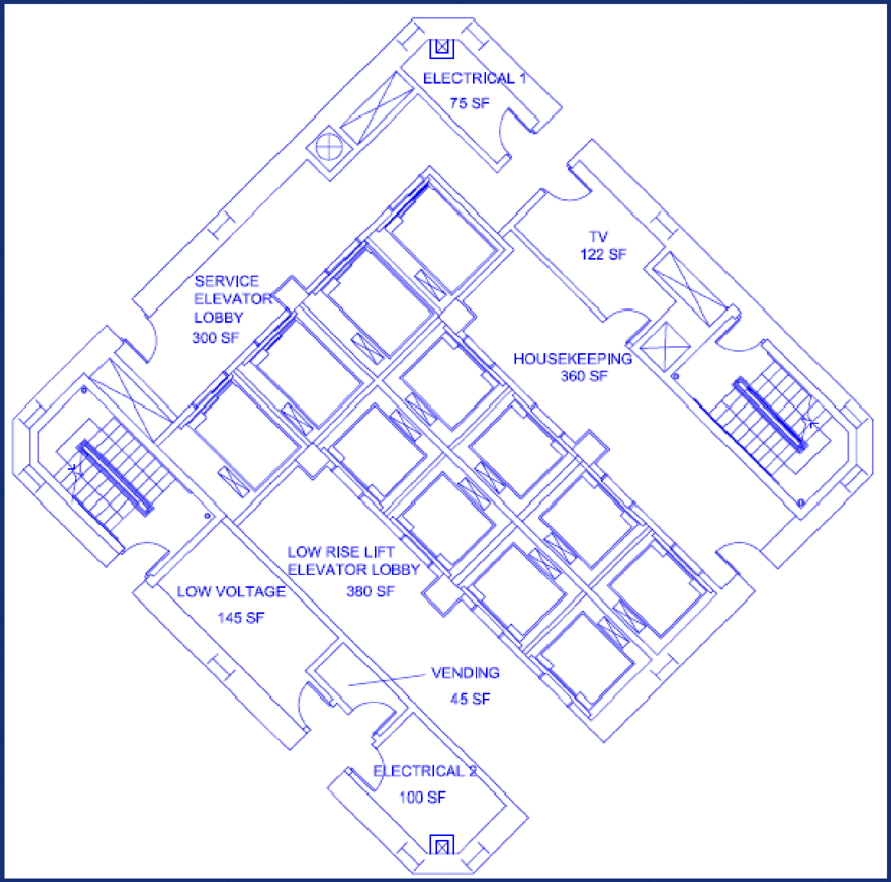
Architectural Studies

Redesigned Service Core



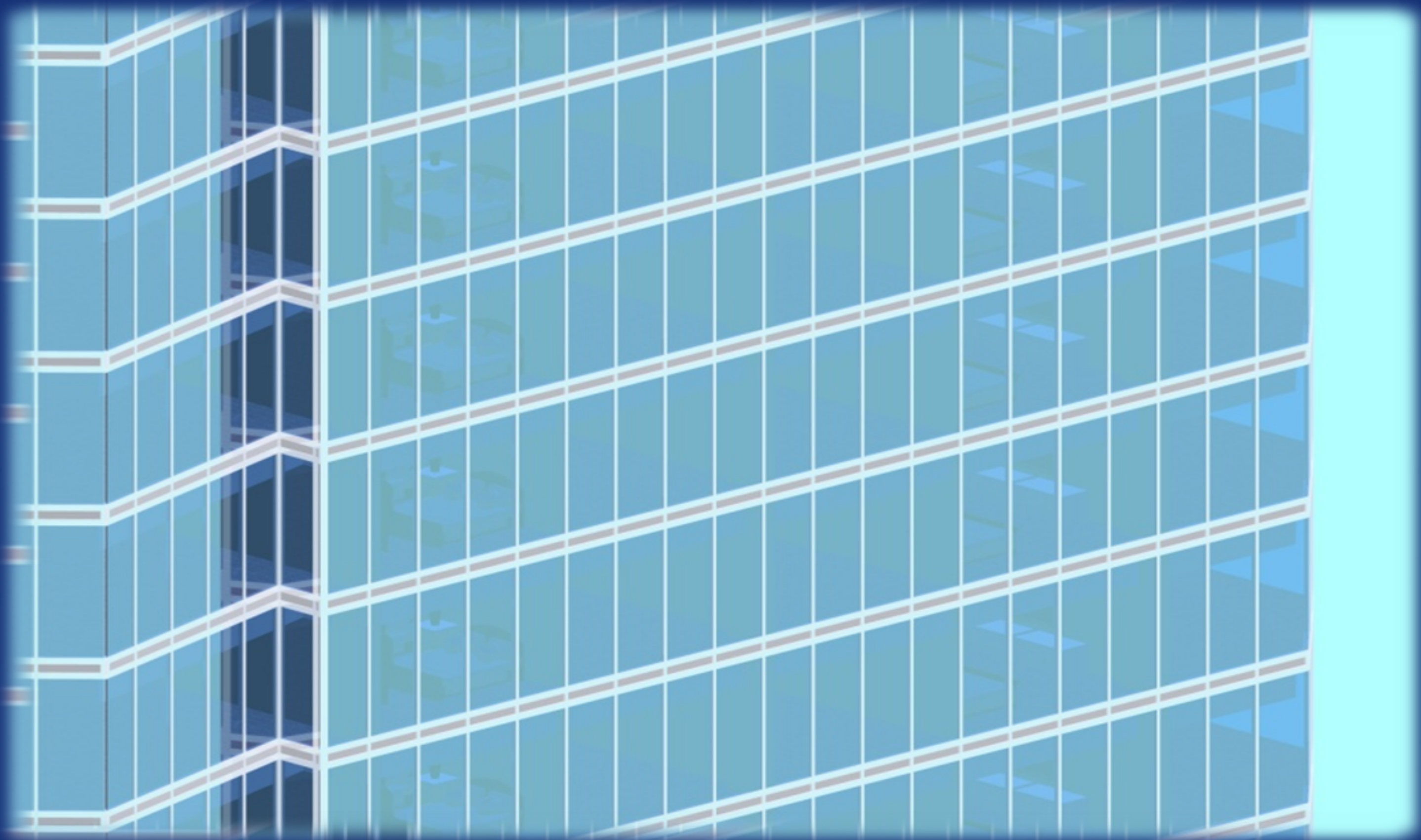


Architectural Studies

Interior Architectural Impacts

Architectural Studies

Exterior Architectural Impacts



Presentation Outline

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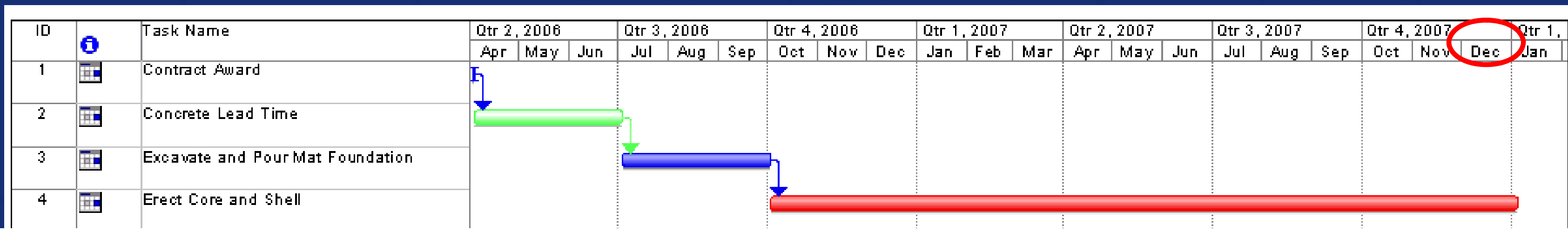
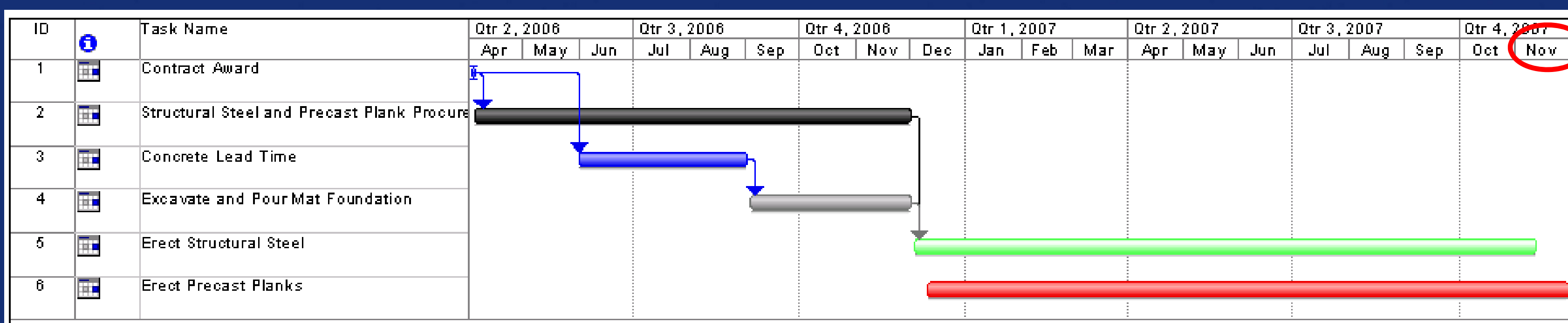
Construction Management Studies

Scheduling Comparison



Steel structure will top out a month earlier than concrete



Steel Structural System

Construction Management Studies

Cost Comparison

Line Item	Concrete Option	Steel Option
Foundation Cost	$3.3 million	$3.3 million
Superstructure Cost	$41.5 million	$39.2 million
Miscellaneous Cost		$5.9 million
Tuned Mass Damper Cost		$2 to $3 million
Misc. Structural Steel	$3.5 million	$3.5 million
Stair Cost	$1.4 million	$1.4 million
Total Cost	**$49.7 million**	**$55.3 to $56.3 million**

Presentation Outline

- Project Information
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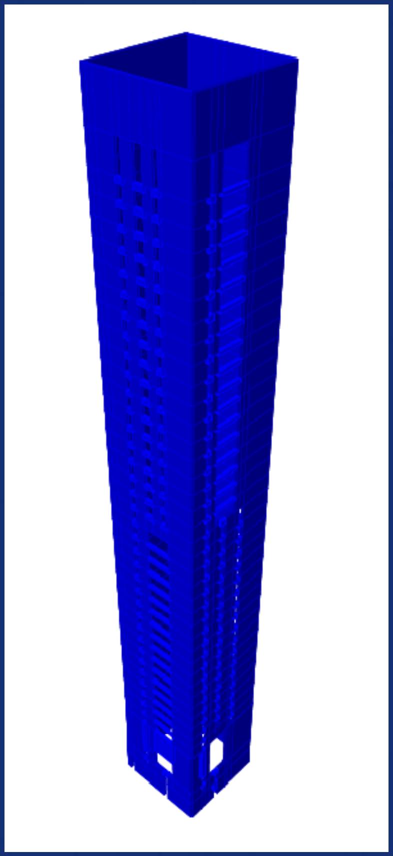
Conclusions

- Long lead time for steel and precast planks offers little schedule advantage (approximately 1 month less than concrete)
- Braced frame core performs adequately against strength and drift
- Lighter steel frame still requires 9'-0" thick mat foundation
- Building accelerations may be perceived by occupants because braced frame core is too flexible
- Steel structure will cost approximately $5.5 million more than concrete structure if mass damper is found to be required

Recommendation



- Because it is stiffer, the concrete shear wall core limits the dynamic movement of the building better than the steel braced frame core
- Filigree flat plate system erects much faster than a typical concrete floor system, giving the steel little schedule advantage
- With supplemental damping taken into consideration, the concrete system will cost less than steel structure

Acknowledgements

I would like to thank those individuals who have either indirectly or directly helped in making this project possible, taking time out of their busy schedules to answer my questions….

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KPFF
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Professor M. Kevin Parfitt
Professor Robert Holland

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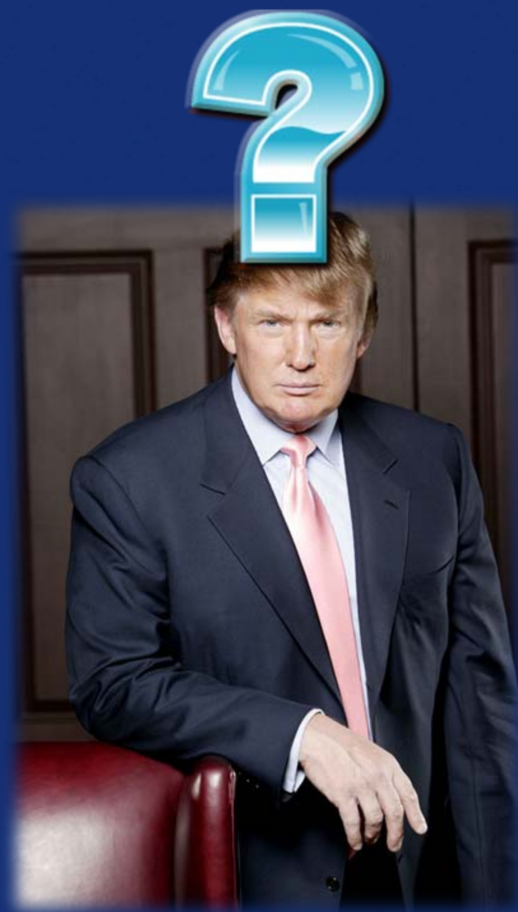
Charlie Carter
Benjamin M. Kovach

AE Students
Sam Jannotti
Jason Sambolt

Friends and Family
Parents
Brothers and Sisters
Penn State AE Class of 2008

Questions



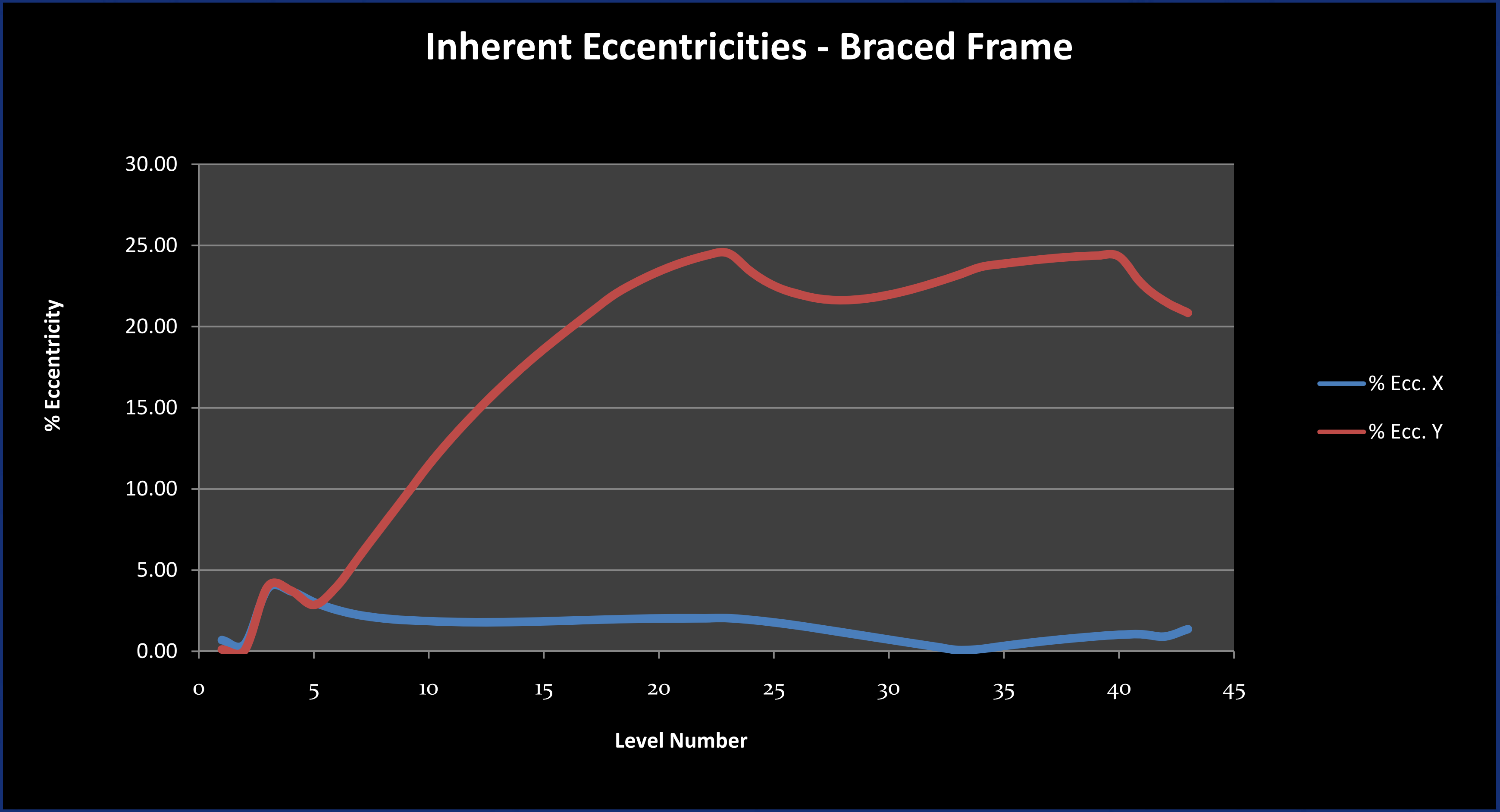
Wind Tunnel Test

Floor	Height ft	Fx kip	Fy kip	Mz kip-ft x10^3
Roof	437.22	139.0	191.4	1.71
40	414.72	169.3	233.3	2.66
39	399.72	103.2	142.1	1.66
38	387.72	96.3	132.7	1.58
37	378.14	100.2	138.0	1.67
36	368.56	97.6	134.5	1.63
35	358.98	95.1	131.0	1.59
34	349.40	92.5	127.5	1.54
33	339.82	90.0	124.0	1.50
32	330.24	87.4	120.5	1.46
31	320.66	84.9	116.9	1.42
30	311.08	82.3	113.4	1.37
29	301.50	79.9	110.1	1.33
28	291.92	77.4	106.6	1.29
27	282.34	74.8	103.1	1.25
26	272.76	72.3	99.6	1.21
25	263.18	69.7	96.0	1.16
24	253.60	65.8	90.6	1.12
23	244.02	63.3	87.2	1.08
22	234.44	60.8	83.7	1.03

Floor	Height ft	Fx kip	Fy kip	Mz kip-ft x10^3
21	224.86	58.3	80.3	0.99
20	215.28	55.8	76.9	0.95
19	205.70	53.3	73.4	0.91
18	196.12	50.9	70.1	0.87
17	186.54	48.4	66.7	0.82
16	176.96	45.9	63.3	0.78
15	167.38	43.4	59.8	0.74
14	157.80	40.9	56.4	0.70
13	148.22	38.4	53.0	0.65
12	138.64	35.9	49.5	0.61
11	129.06	33.4	46.1	0.57
10	119.48	31.0	42.6	0.53
9	109.90	28.5	39.2	0.48
8	100.32	26.0	35.8	0.44
7	90.74	23.6	32.5	0.40
6	81.16	21.1	29.1	0.36
5	71.58	18.6	25.6	0.32
4	62.00	29.8	41.1	0.39
3	26.00	9.2	12.6	0.15
2	16.00	6.4	8.8	0.10
Σ		2500.7	3444.9	41.0

Load Case	Y-Axis (%)	X-Axis (%)	Z-Axis (%)
1	+100	+50	+50
2	+100	+50	-50
3	+100	-50	+50
4	+100	-50	-50
5	-100	+50	+50
6	-100	+50	-50
7	-100	-50	+50
8	-100	-50	-50
9	+65	+100	+60
10	+65	+100	-60
11	-65	+100	+60
12	-65	+100	-60
13	+65	-100	+60
14	+65	-100	-60
15	-65	-100	+60
16	-65	-100	-60
17	+65	+50	+60
18	+65	-50	+60
19	-65	+50	-60
20	-65	-50	-60

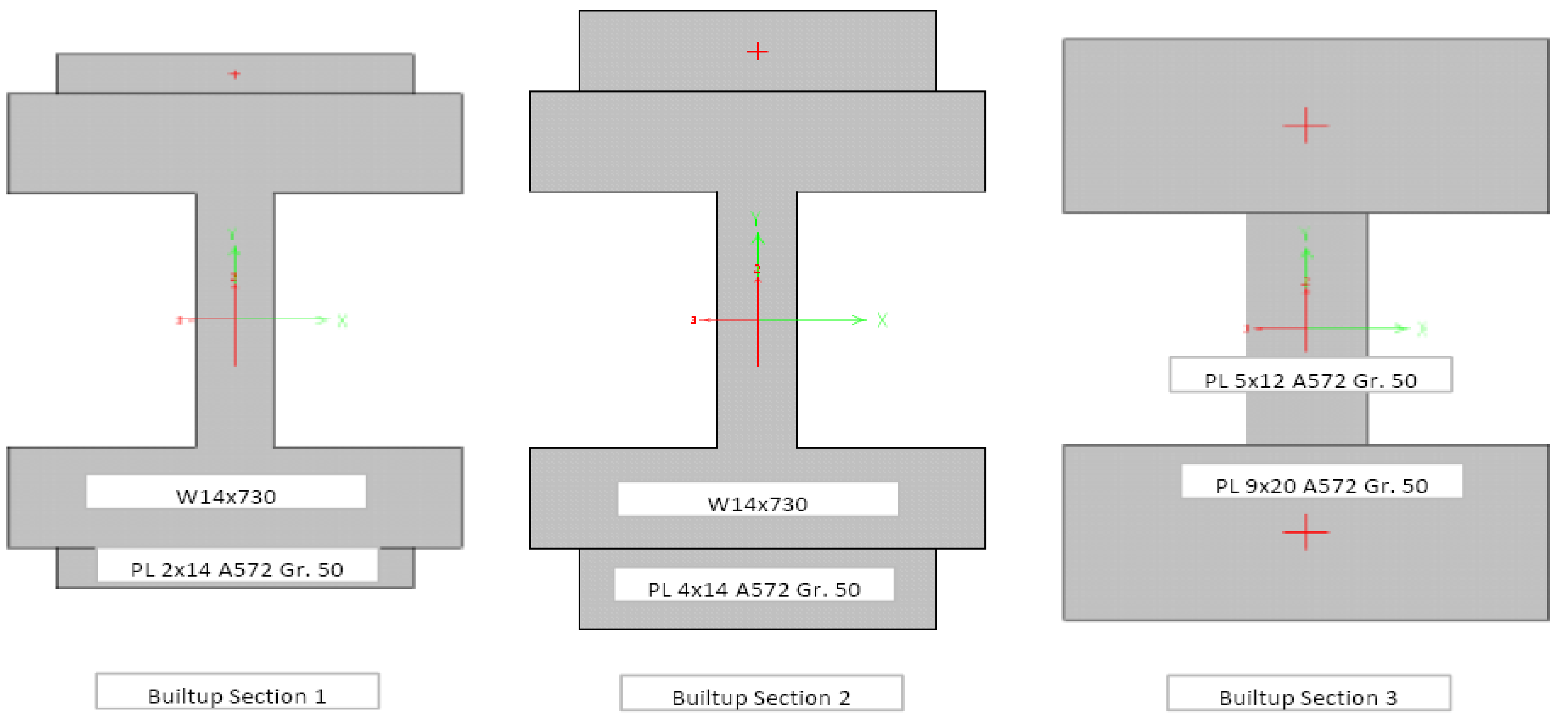
Inherent Eccentricity



Built-up Column Sections

Built-up Column Section Properties

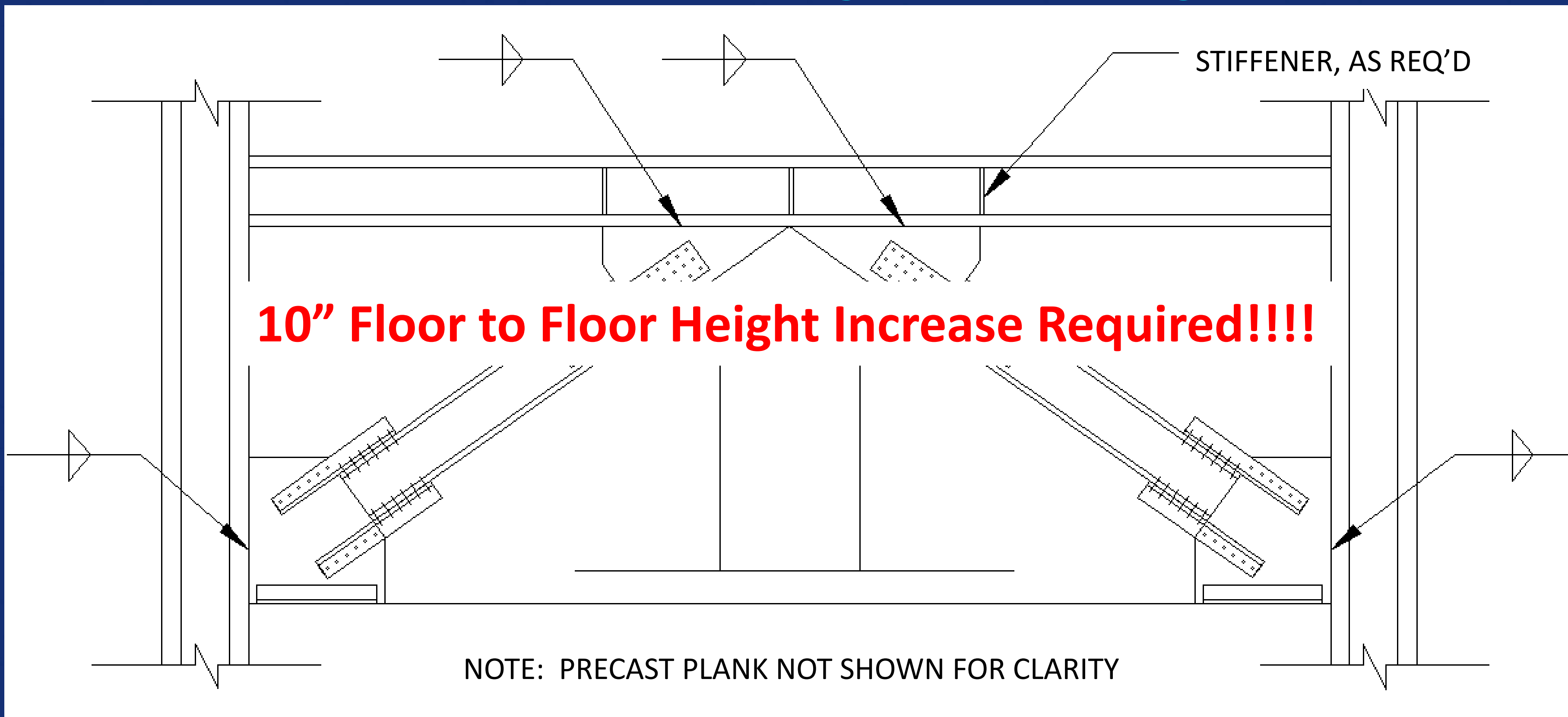
Section	Wt (plf)	A (in^2)	I_{33} (in^4)	I_{22} (in^4)	S_{33} (in^3)	S_{22} (in^3)	Z_{33} (in^3)	Z_{22} (in^3)	r_{33} (in)	r_{22} (in)
Builtup 1	908.54	267	22048	5465	1694	611	2292	986	9	4.5
Builtup 2	1112.71	327	33964	6550	2235	732	3137	1208	10.2	4.5
Builtup 3	1429.17	420	42840	12125	2856	1212	3960	1875	10.1	5.3



Structural Redesign

Steel Braced Frame Core

Connection Design and Detailing



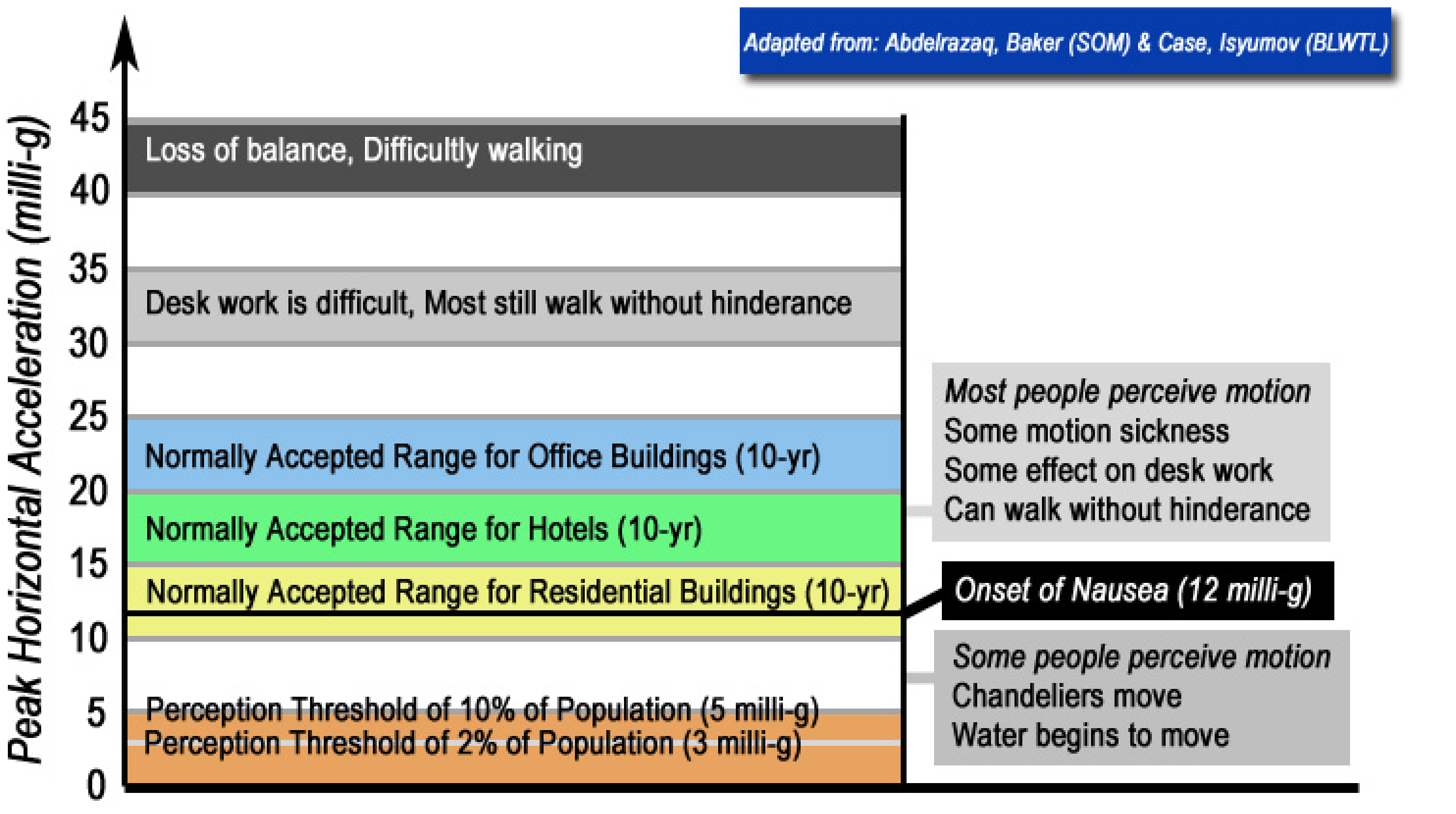
10” Floor to Floor Height Increase Required!!!!

25% Wind Force Reduction

> interval winds that strength design wind loads are based upon are special events. In lieu of using the precision of a map with ten-year wind speed isobars, the authors recommend using 75 percent of 50-year wind pressure as a reasonable (plus or minus 5 percent) approximation of the ten-year wind pressures. The Commentary to Appendix B of ASCE 7-02 recommends 70 percent.

From AISC Design Guide 3: Serviceability Design Considerations for Steel Buildings

Peak Acceleration



....Can only truly be determined utilizing wind tunnel studies

Structural Redesign

Steel Braced Frame Core

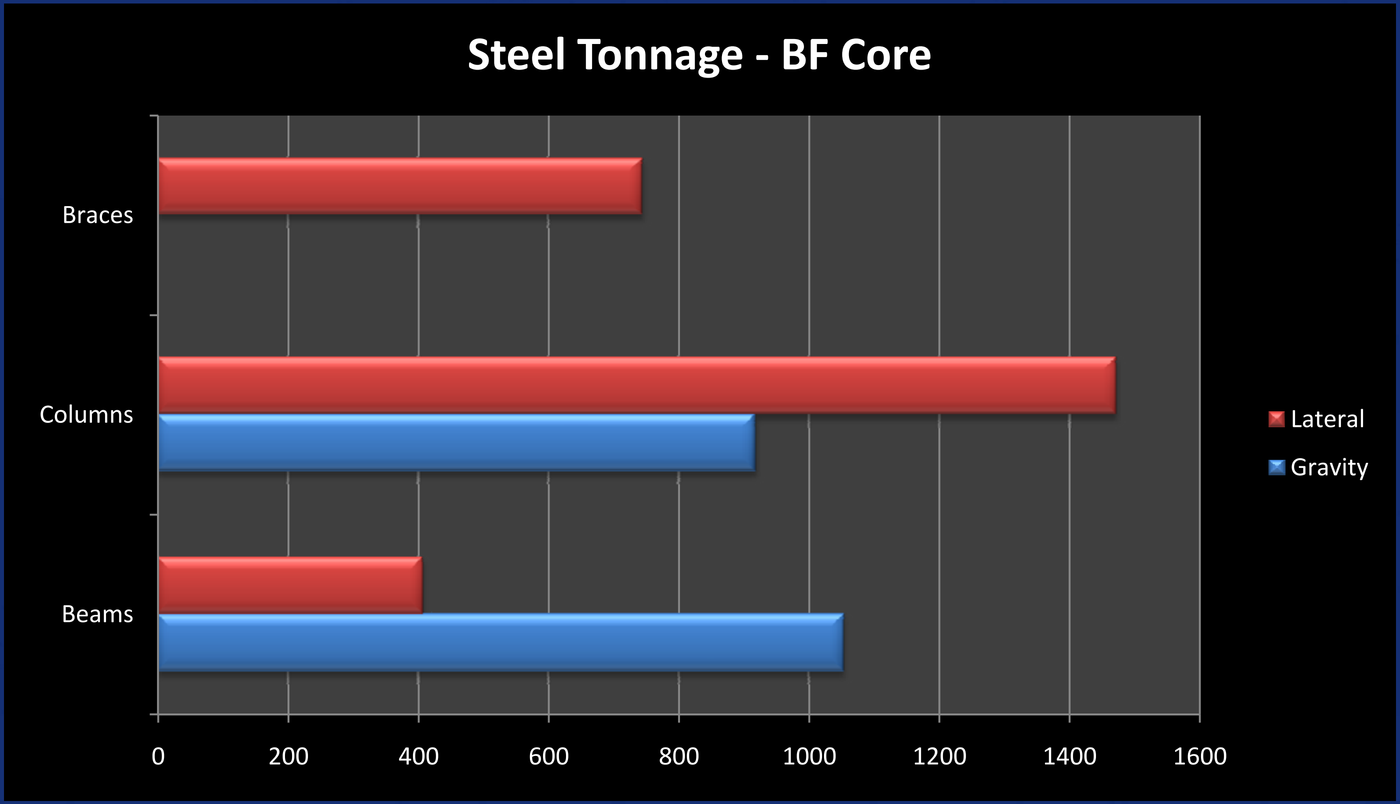
Braced Frame Schedule

Concentrically Braced Frames (BF 1, 2, 3, 4)			
Levels	**Column**	**Brace**	**Girder**
1 - 4	1430plf Built-up	W12x210	W14x132
5 - 8	1113plf Built-up	W12x170	W14x132
9 - 16	910plf Built-up	W12x136	W14x109
17 - 24	W14x550	W12x106	W16x89
25 - 32	W14x311	W12x87	W16x77
33 - Roof	W14x257	W12x53	W16x77

Eccentrically Braced Frames (BF 1 Only)			
Levels	**Column**	**Brace**	**Girder**
1 - 4	1430plf Built-up	W12x210	W14x145
5 - 8	1113plf Built-up	W12x170	W14x145
9 - 16	910plf Built-up	W12x136	W14x145
17 - 24	W14x550	W12x106	W14x120
25 - 32	W14x311	W12x87	W16x77
33 - Roof	W14x257	W12x53	W16x77

BF 5, 6, 7, 8	
Levels	**Brace**
1 - 16	2L8x8x1
16 - Roof	2L6x6x1

Steel Tonnage



Steel Cost Breakdown