PAUL PARFITT

BAE/MAE
Structural Option
Senior Thesis
Tower 333
May 4th 2007

Tower 333

- Introduction
- Proposal
- Lateral System Redesign
  - Elimination of Moment Frames
  - Core-Only Solution
- Cost Analysis & Schedule Reduction
- Building Envelope Performance & Quality Control
- Conclusion/Recomendation

TOWER 333

Tower 333

- Owner: Hines Development
- Structural: Magnusson Klemencic Associates
- Architect: LMN Architects
- Location: Bellevue Washington
- Height: 267 feet
- # Of Stories: 18 above grade, 8 below grade
- Floor height : 13'-10"
  Parking levels: 9'-10"
- Floor Plate: 22,000 ft^2
- Building Area: 594,000 ft^2

- Tower crane collapsed Nov. 16th with one fatality
- Uses existing foundation from previously abandoned project
  - Previous owner went bankrupt

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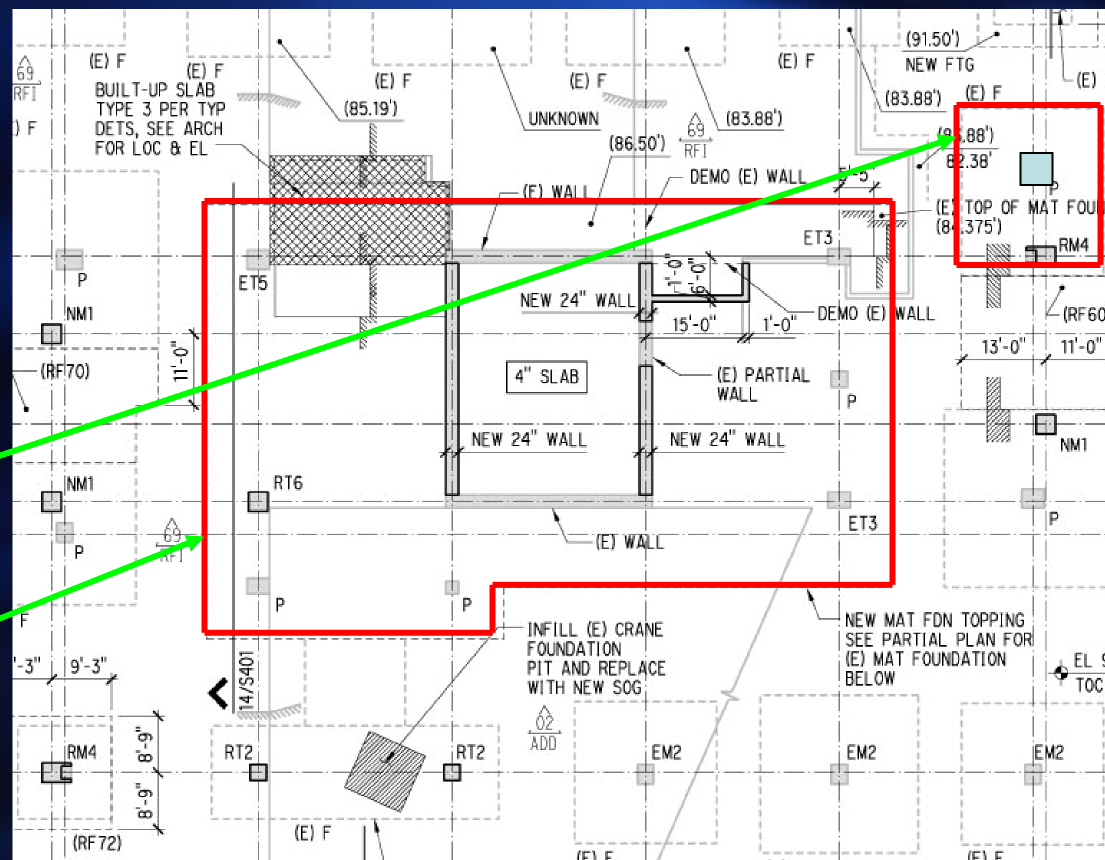
Existing Structure

Pre-existing Foundation:

- Columns: spread footings
- Core: mat slab
- Sub levels 8-5 previously finished when owner went bankrupt

Foundation Designed by MKA:

- Sits on existing foundation from previously abandoned project
- Columns sit on spread footings (reinforced where needed)
- Core sits on mat foundation additional 24" concrete added to mat slab.



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Existing Structure

Gravity System:

- Typical bay of upper office floors supported by 42' long W18x40 composite beams and 30' long W18x97 composite girders

- 2-1/2" concrete slab on a 3" deep composite metal deck f'c=4,000psi.

Superimposed Dead Loads:

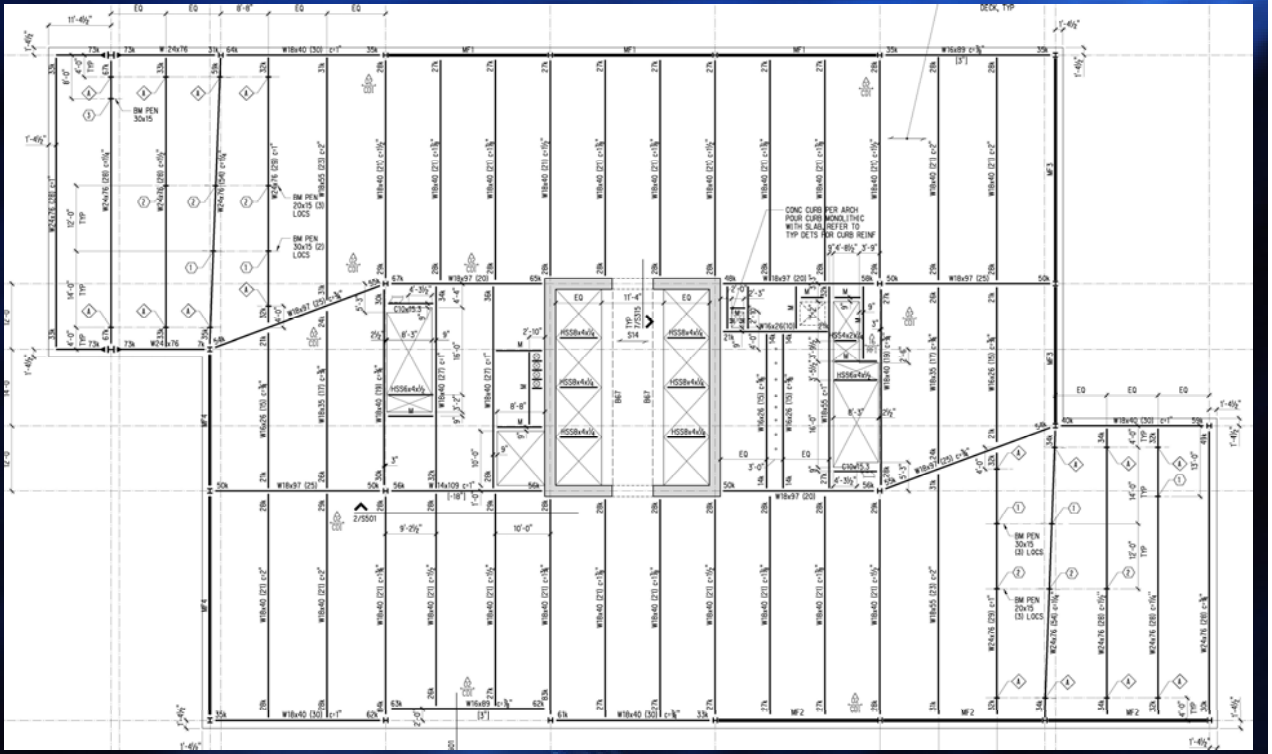
Mechanical/Electrical:
5 PSF

Partitions:
20 PSF

Misc. :
5 PSF

Live Loads:

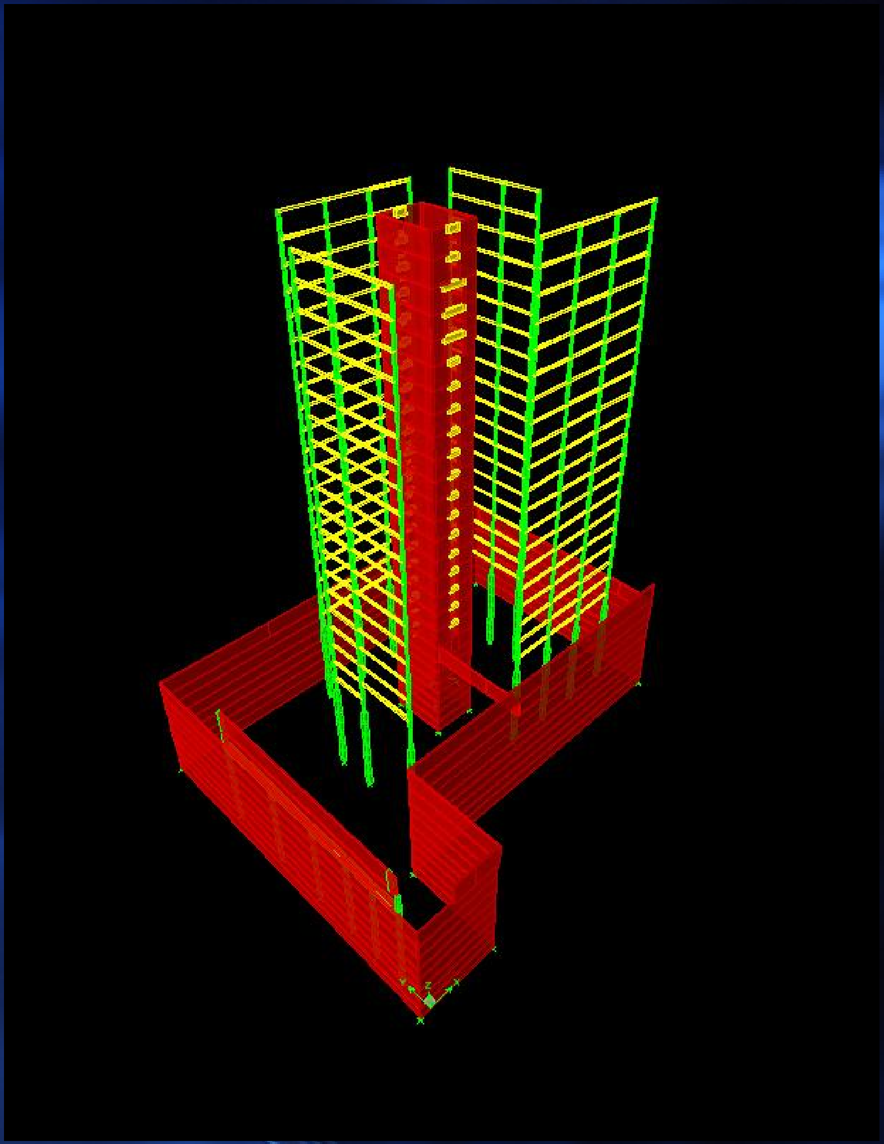
50psf



Existing Structure

Lateral System:

- Dual, concrete core & special perimeter steel moment frames
- Concrete Core: f'c=9,000psi
- By ASCE7-05, steel moment frames are designed for 25% of base shear
- MKA design modeled in ETABS. Due to relative stiffness of moment frames, only 10% of base shear resisted in frames



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Proposal

Goals:

- Eliminate special moment frames
- Utilize pre-existing core
  - Develop into core-only lateral force resisting system
- Reduce erection time
- Save money in material costs
- Reduce labor costs
- Determine if proposed design is viable economic alternative

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Proposal

Things to Consider:

- Peer Review criteria due to core-only system
- Undersized core due to utilization of previous foundation
- Torsion imposed on building
- Story drift
- Maximum building displacement
- Shear capacity of coupling beams
- Bending & shear capacity of piers

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Lateral System Redesign

Peer Review:

- Peer review required by IBC 2003 for buildings 160 feet or higher without dual lateral system

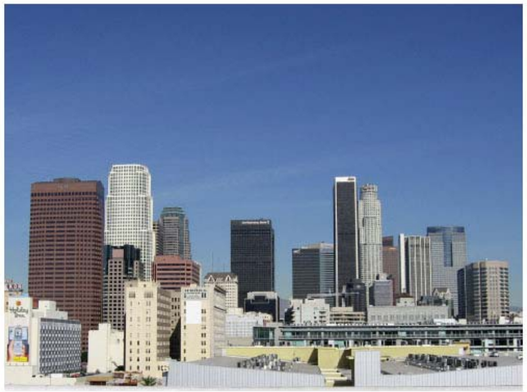
- Peer review provides an objective and technical review of the structure under seismic conditions

Lateral System Redesign

Los Angeles Tall Buildings Structural Design Council

AN ALTERNATIVE PROCEDURE FOR SEISMIC ANALYSIS AND DESIGN OF TALL BUILDINGS LOCATED IN THE LOS ANGELES REGION

A CONSENSUS DOCUMENT



2005 EDITION

DEPARTMENT OF BUILDING INSPECTION
City & County of San Francisco
1660 Mission Street, 2nd Floor, San Francisco, California 94103-2414

ADMINISTRATIVE BULLETIN

NO. AB-083

DATE : DRAFT 6 February 2007

SUBJECT : **Seismic Design and Review Procedures for New Tall Buildings**

TITLE : **Requirements and Guidelines for the Seismic Design and Review of New Tall Buildings using Non-Prescriptive Seismic-Design Procedures**

PURPOSE : The purpose of this Administrative Bulletin (AB) is to present requirements and guidelines for the seismic structural design, Seismic Peer Review, and building permit submittals for new tall buildings in San Francisco that use non-prescriptive seismic design procedures.

REFERENCES : 2001 *San Francisco Building Code (SFBC)*
- Section 104.2.5 alternate materials, alternate design and methods of construction
- Section 1605.2 Rationality
- Section 1629.10 Alternative procedures

ASCE/SEI 7-05, *Minimum Design Loads for Buildings and Other Structures*
Structural Engineers Association of California, *Recommended Lateral Force Requirements and Commentary (SEAOC Blue Book)*, 1999
Structural Engineers Association of California, "Seismology Committee Background and Position Regarding 1997 UBC Eq. 30-7 and Drift," September 2001 (http://www.seaoc.org/Pages/committees/seismpdfs/UBC/30_7.pdf)

DISCUSSION :

The Director has established these guidelines to help Project Sponsors and Engineers of Record (EOR) understand the Department of Building Inspection's expectations with regard to structural/seismic design, project submittals, seismic peer review, and structural plan review for tall buildings designed using non-prescriptive seismic design procedures.

1. SCOPE

This Administrative Bulletin presents requirements and guidelines for Seismic Peer Review, building permit submittals, and seismic structural design for new tall buildings in San Francisco that use non-prescriptive seismic design procedures.

Redesign takes into account procedures set by LA's & San Francisco's Tall Buildings Code

Tower 333 is Performance Based Design

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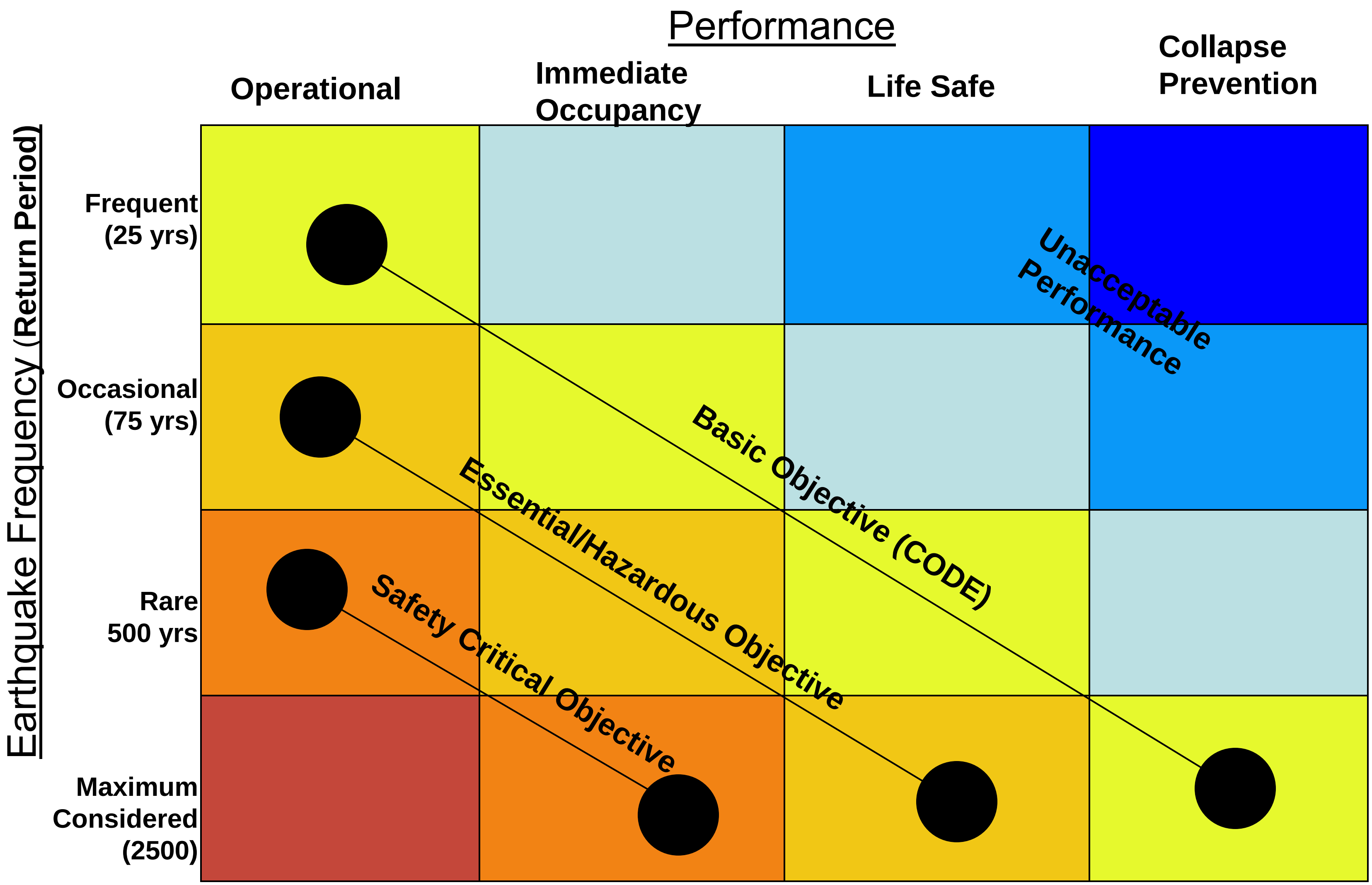
Lateral System Redesign



Source: Vision 2000, FEMA-349

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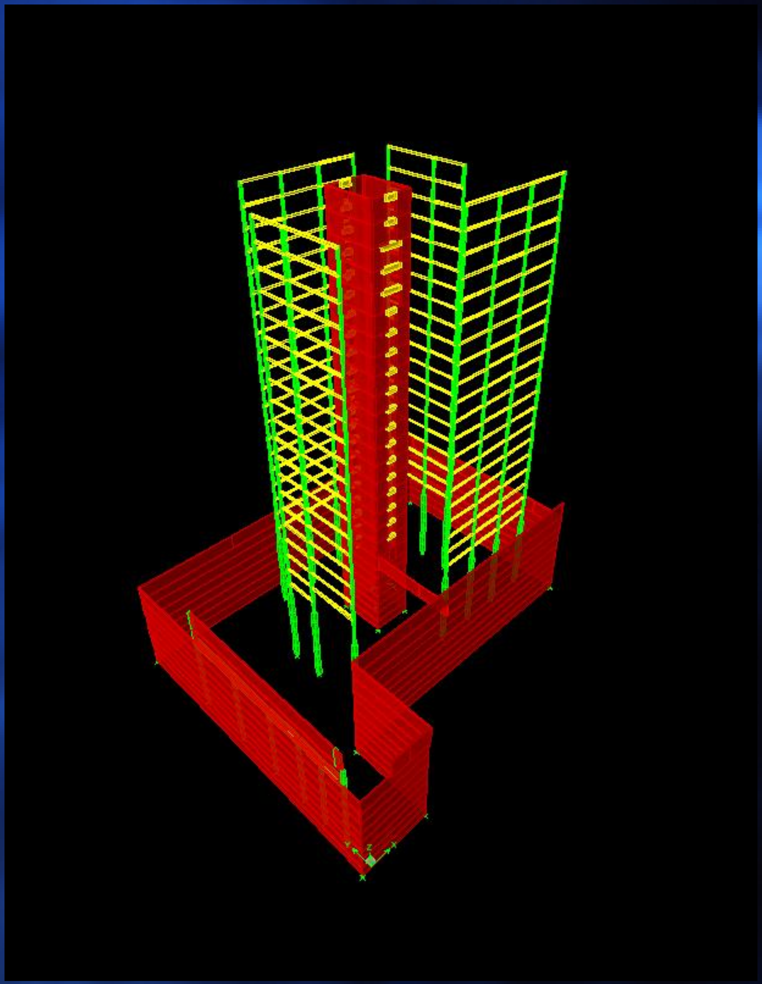
Lateral System Redesign

<u>Key Concepts:</u>

- Stringent peer review criteria
- Eliminate moment frames.
- Core-only alternative.
- Plastic hinges at coupling beam connections critical to design.
  - Protects piers at base from significant yielding
- Design coupling beams as flexure critical not shear critical



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Lateral System Redesign

Typical Floor Framing Plan

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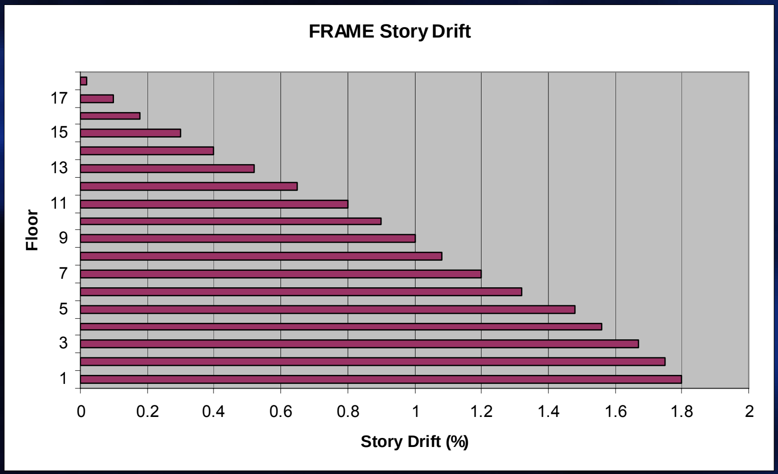
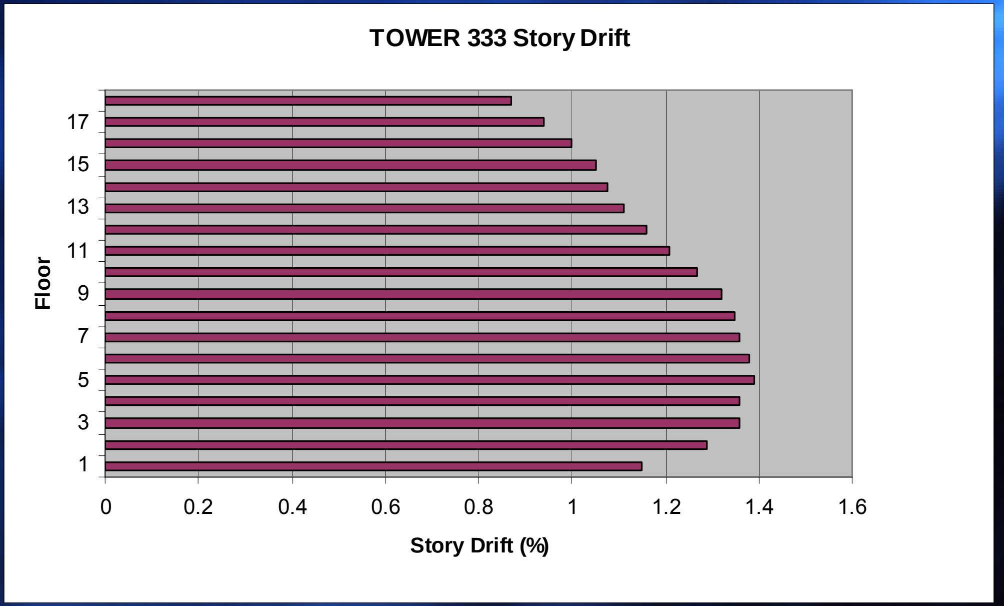
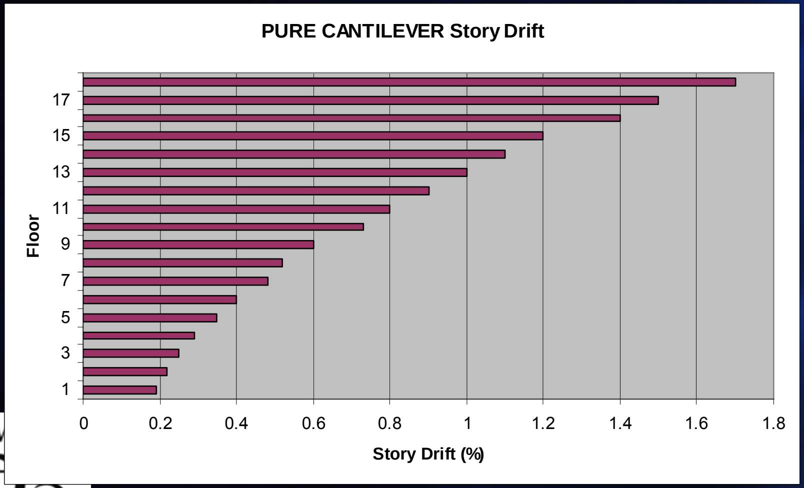
Lateral System Redesign







Lateral System Redesign

- Trial size of 30” thick walls determined
- Controlling case: Spectral Force in Y-direction (North-South)
- ETABS analysis run on multiple design alterations

					Max Edge Point Disp. (in.)		
	Trial	Description	T_x (sec.)	T_y (sec.)	X	Y	Max Story Drift
30" Thick Walls All Floors	1	All Coupling Beams 30"x45"	3.46	2.9	22	56	2.40%
36" Thick Walls All Floors All Coupling Beams 36 x 45"	2a.	All Coupling Beams 36"x45"	3.13	2.58	22.3	54.4	1.85%
	2b.	Add Flange in Basement Levels	2.98	2.3	17.6	44.8	1.70%
	2c.	Add Flange to All Levels	2.17	1.8	17.3	41	1.50%
	2d.	Close Web In Basement	3.07	2.34	17.36	44.9	1.70%
	2e.	Close Web & Use 12ksi Concrete In Basement Levels	3.26	2.4	18	46	1.70%

Core Design Analysis Results From Critical (N-S) Directional Dynamic Loading

Lateral System Redesign

					Max Edge Point Disp. (in.)		
	Trial	Description	T_x (sec.)	T_y (sec.)	X	Y	Max Story Drift
36" Walls B-8 through FL. 6 30" Walls FL. 7-13 24" Walls FL. 14-Roof	3a.	45" Deep CB's 7' long (E-W) , 54" Deep CB's 6' long (N-S)	2.97	2.15	13.4	36.8	1.46%
	3b.	45" Deep CB's 7' long (E-W), 60" Deep CB's 6' long (N-S)	2.97	2.13	11.75	33.8	1.33%
	3c.	45" Deep CB's 7' long (E-W), 66" Deep CB's 6' long (N-S)	2.97	2.1	11.5	33	1.30%
	3d.	45" Deep CB's 7' long (E-W), 72" Deep CB's 6' long (N-S)	2.98	2.1	12.89	35.8	1.40%

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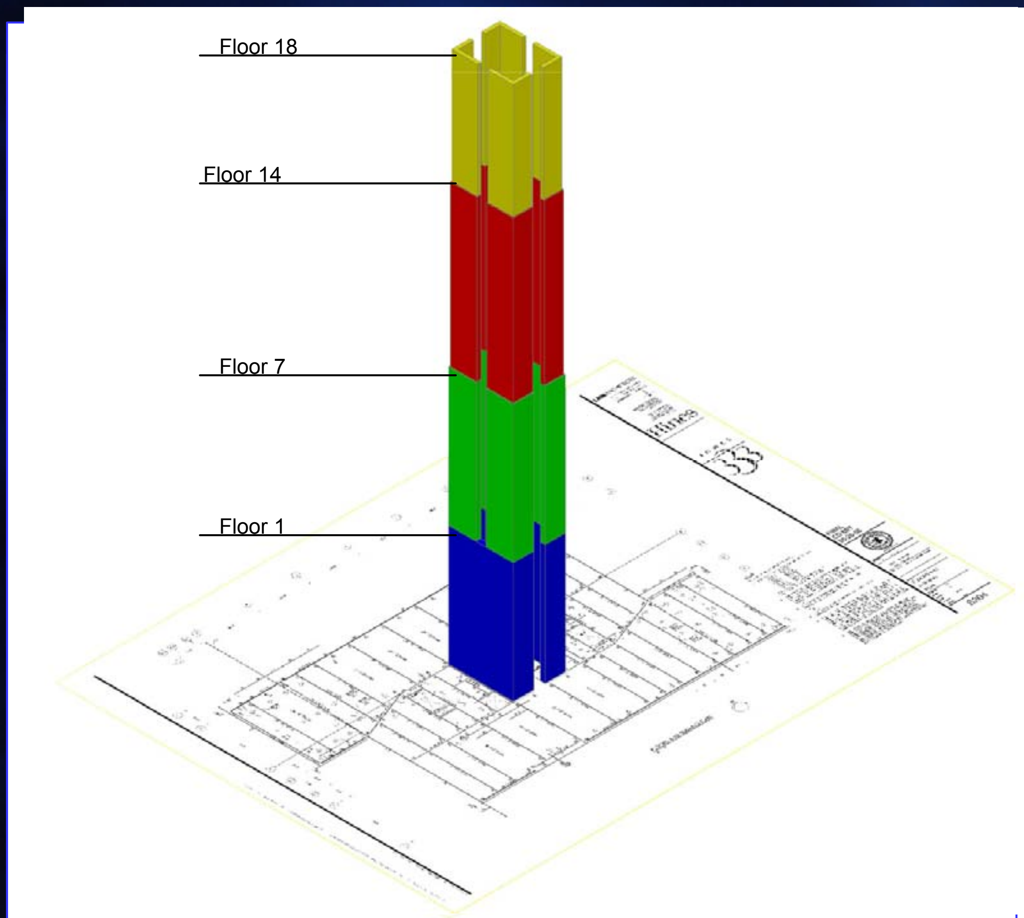
Lateral System Redesign

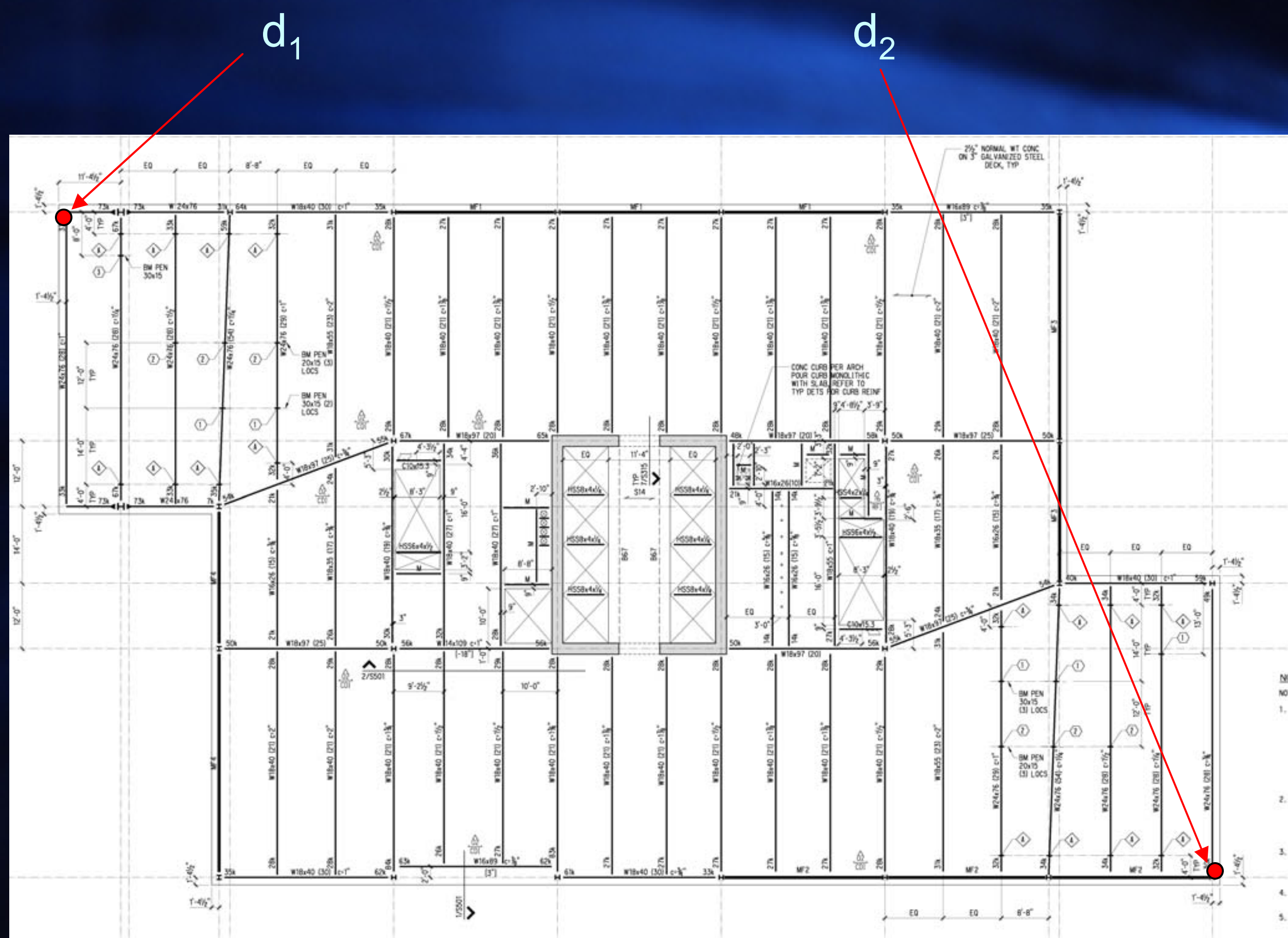


Lateral System Redesign

Torsion Multiplier & Eccentricity Ratio

A_x Max = 1.71

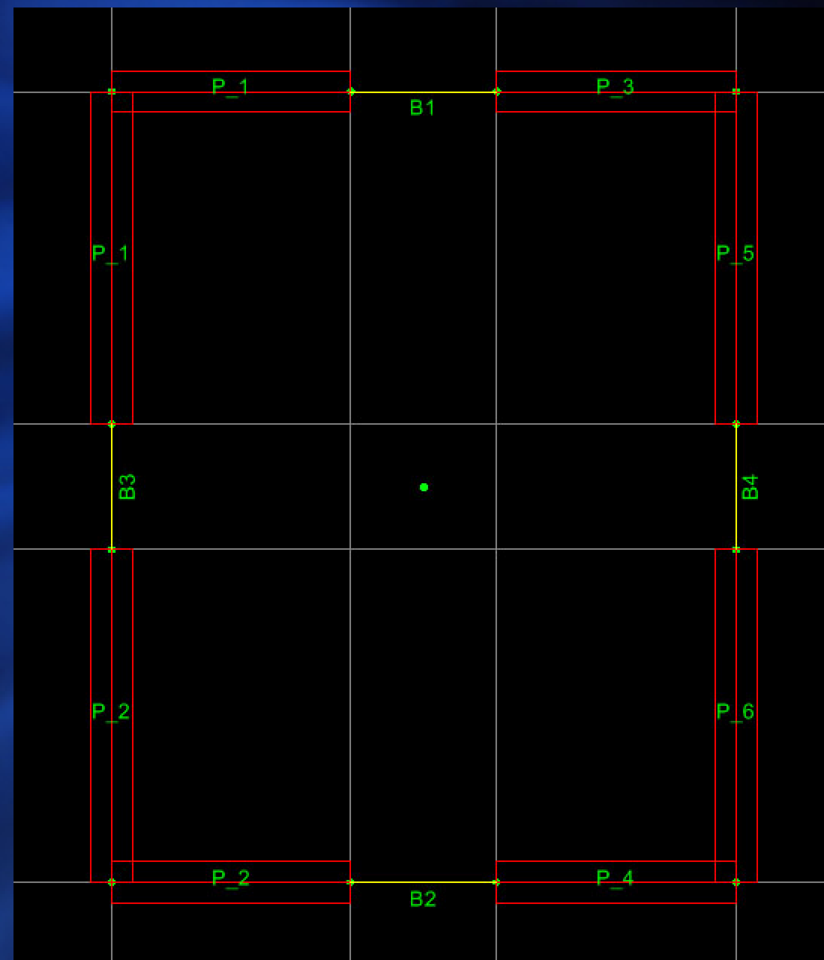
Ecc. Ratio = .086



Lateral System Redesign

Coupling Beams

	Group	Floors	80% Max Shear (kips)	Average Shear (kips)	$V_{u\ (kips)}$
Beam 1	1	1 through 6	793	714	793
	2	7 through 13	696	535	
	3	14 through 18	493	313	
Beam 2	1	1 through 6	793	714	793
	2	7 through 13	696	535	
	3	14 through 18	343	313	
Beam 3	1	1 through 6	990	789	990
	2	7 through 13	784	511	
	3	14 through 18	496	262	
Beam 4	1	1 through 6	990	767	990
	2	7 through 13	784	524	
	3	14 through 18	449	272	



Concrete Piers

		Max Moment (ft-k)	
	Max Shear (kips)	About Y-Axis	About X-Axis
Pier 1		41878	51477
Pier 2		41878	51477
Pier 3	1454.8		
Pier 4	1454.8		
Pier 5	1984.36		
Pier 6	1984.37		

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Lateral System Redesign

Design of coupling beams:

Beams in East-West direction utilize horizontal reinforcing

Group	Stories	bxh (in^2)	Flex Reinf.	Shear Reinf.
3	1 through 6	1620	14 - #11	7-#6 @ 4"
2	7 through 13	1350	12-#11	6-#6 @ 4"
1	14 through 18	1080	10-#11	5-#6 @ 4"

Beams in North-South direction utilize diagonal reinforcing

	V_u (kips)	h (in.)	d (in.)	V_u/bwdsqrt(f'c)	Diag Bars	A_d (in^2.)	α (degrees)	$øV_n$ (kips)	$øV_n/V_u$
Zone 3 (FL. 14-18)	421	60	48	3.9	6-#11	9.36	33.7	530	1.26
Zone 2 (FL. 7-13)	667	60	48	6.5	8-#11	12.48	33.7	706	1.06
Zone 1 (FL. 1-6)	841	60	48	5.1	10-#11	15.6	33.7	883	1.05

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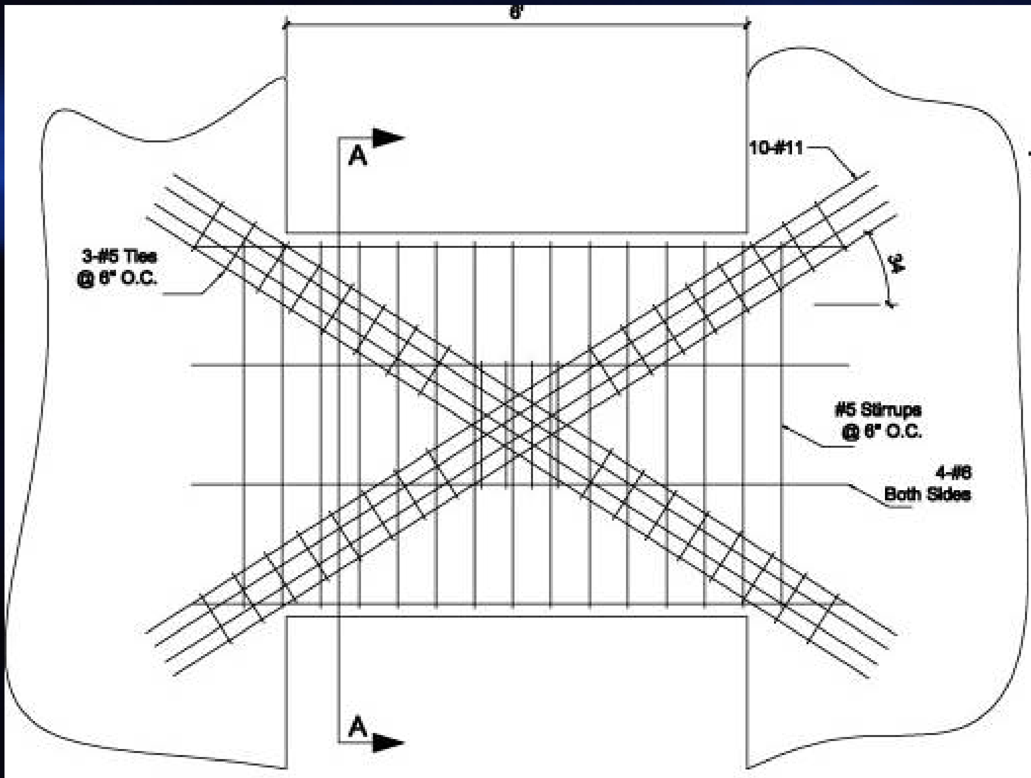
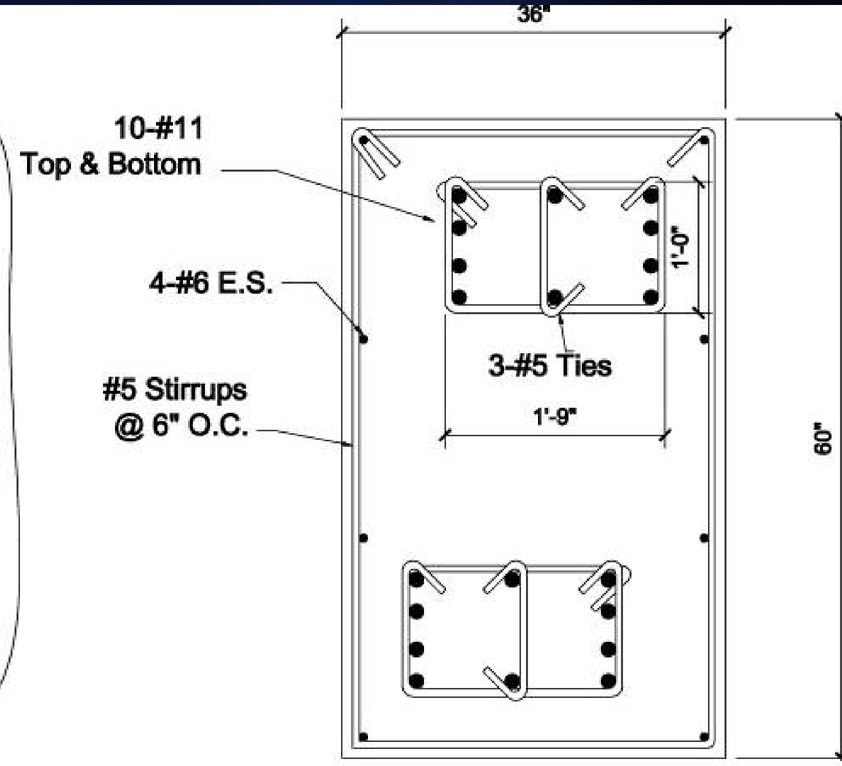
Lateral System Redesign



60" Coupling Beam Reinforcing



Section A
60" Coupling Beam Reinforcing

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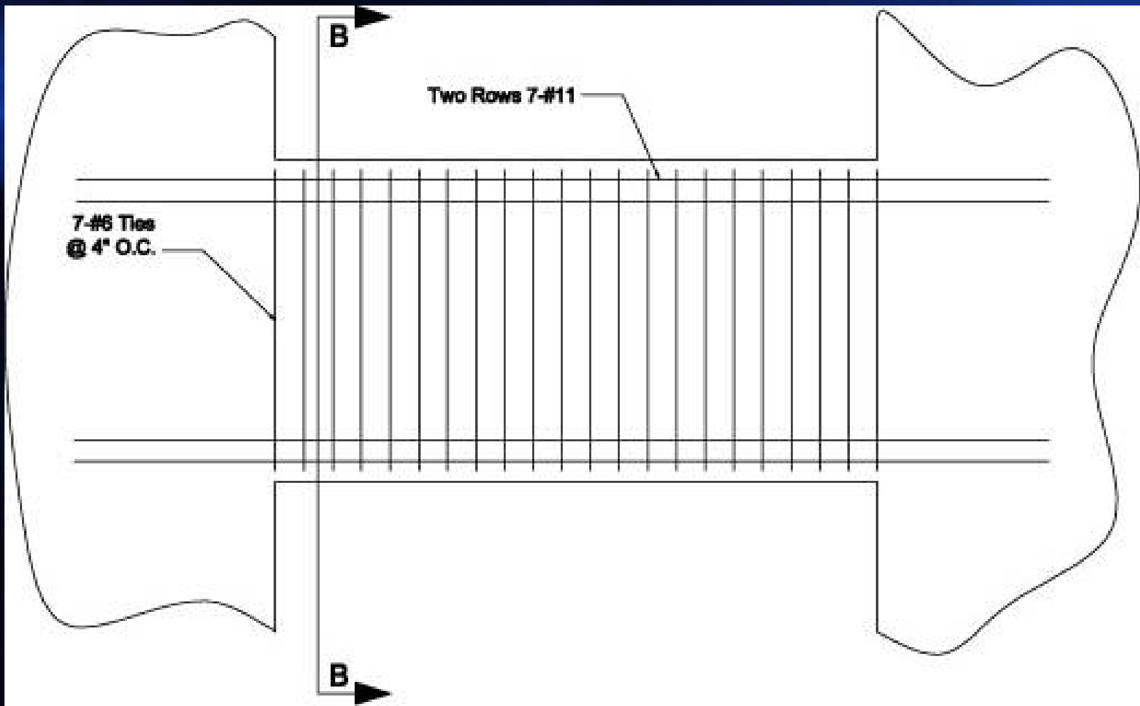
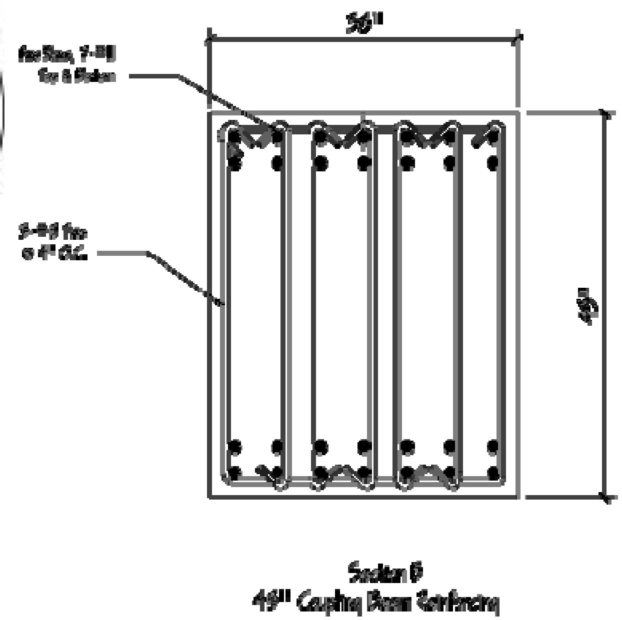
Lateral System Redesign



45" Coupling Beam Reinforcing



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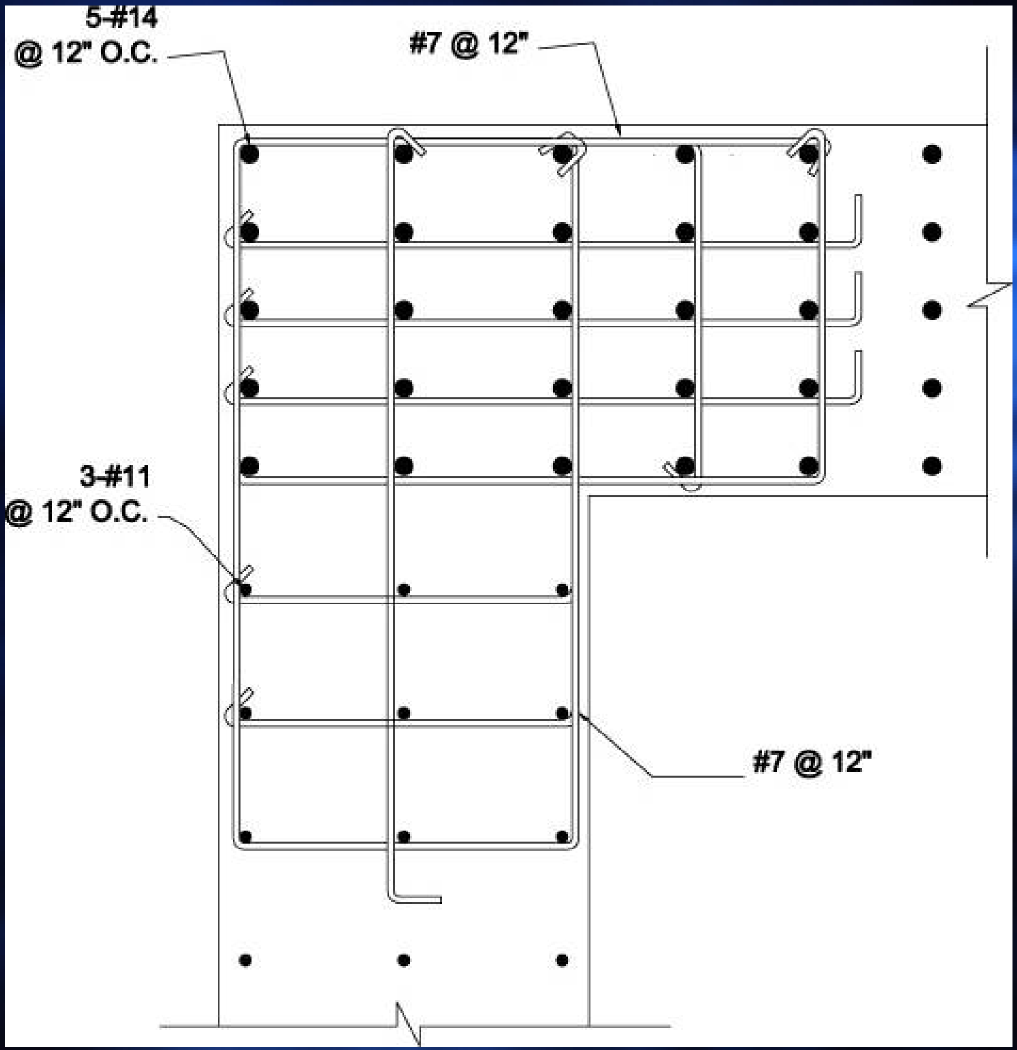
Lateral System Redesign

Pier Design: @ Floor 1

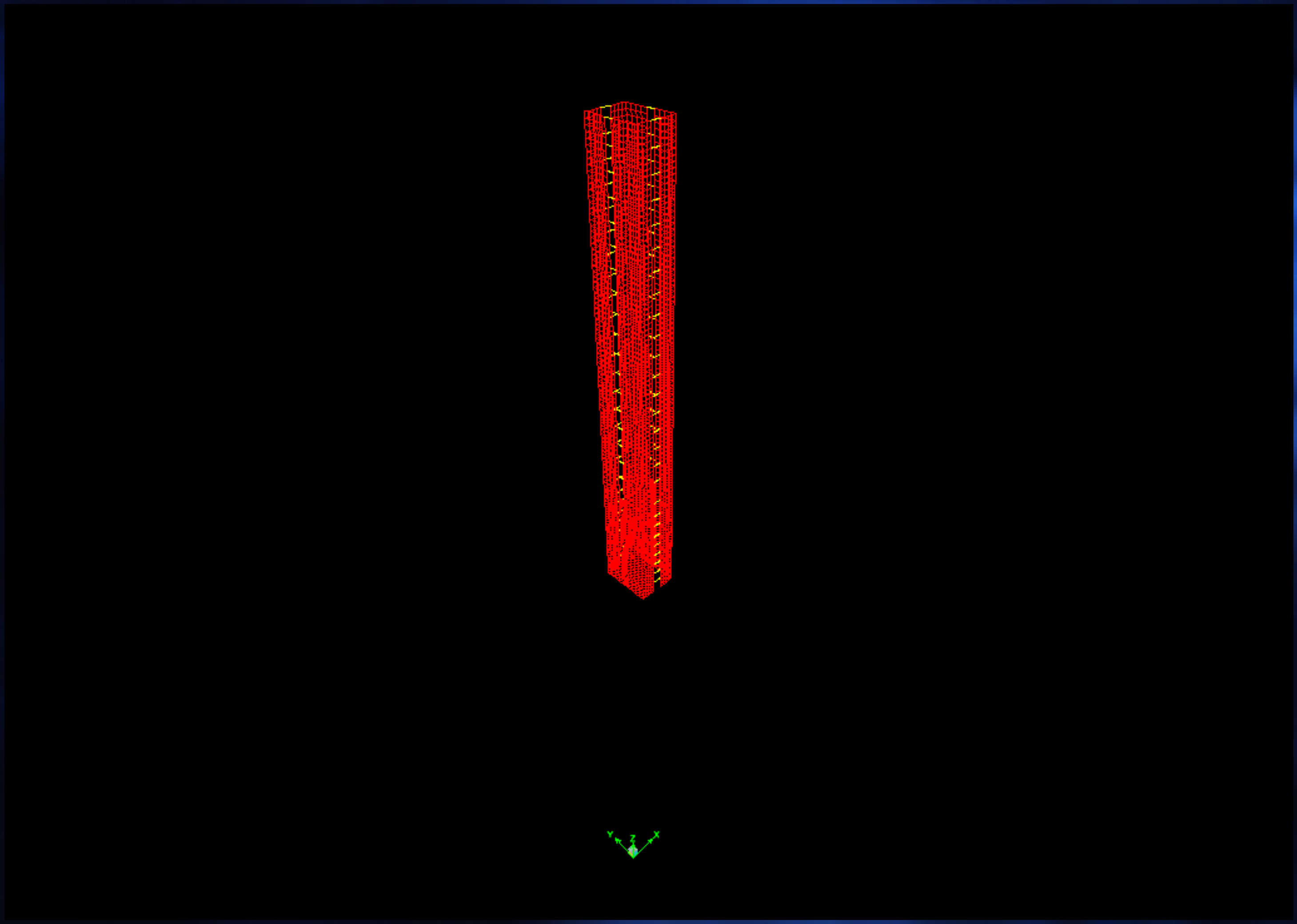
ρ_g = 1.6%

Pier Design: @ Floor 9

ρ_g = 0.3%



Lateral System Redesign



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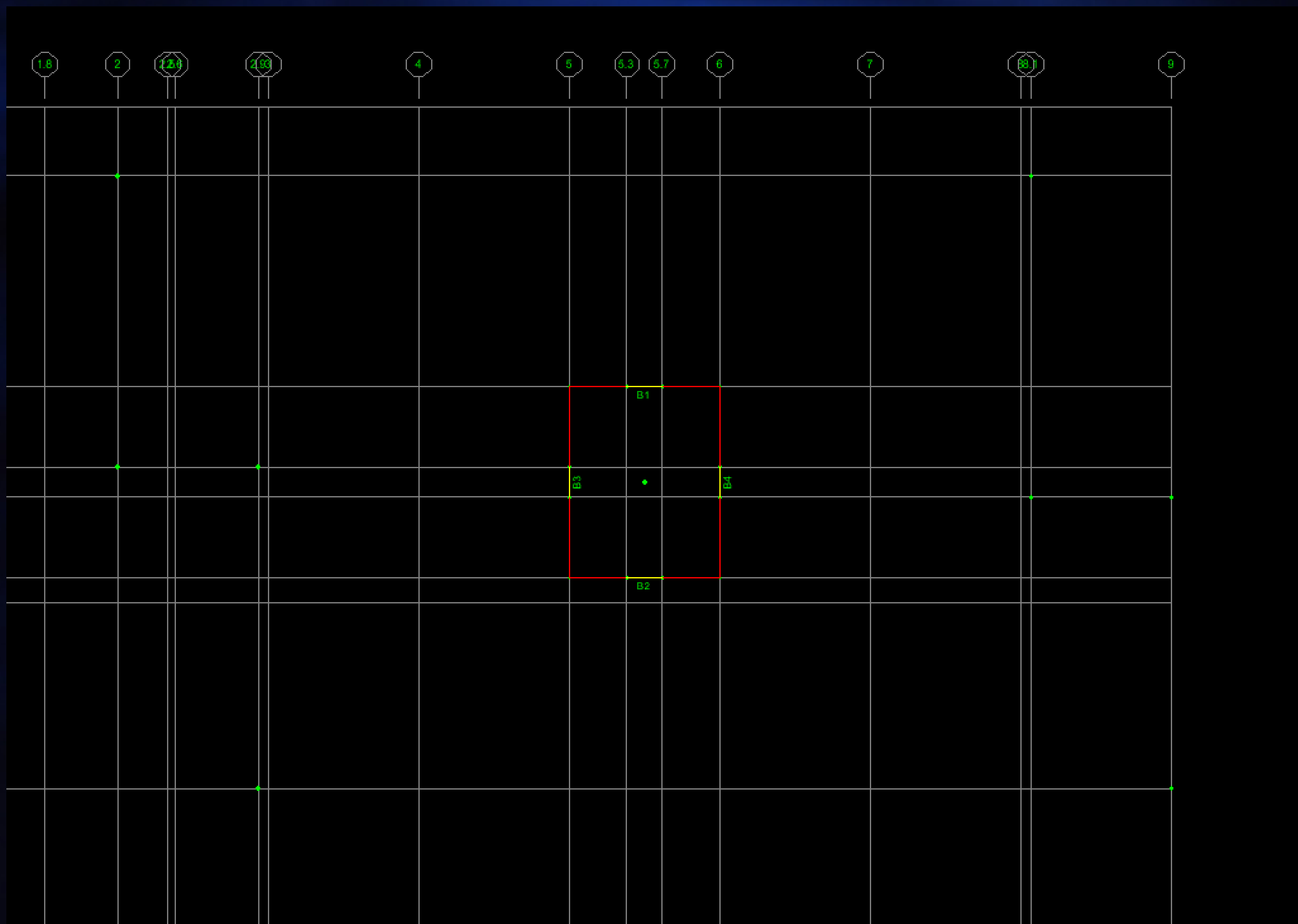
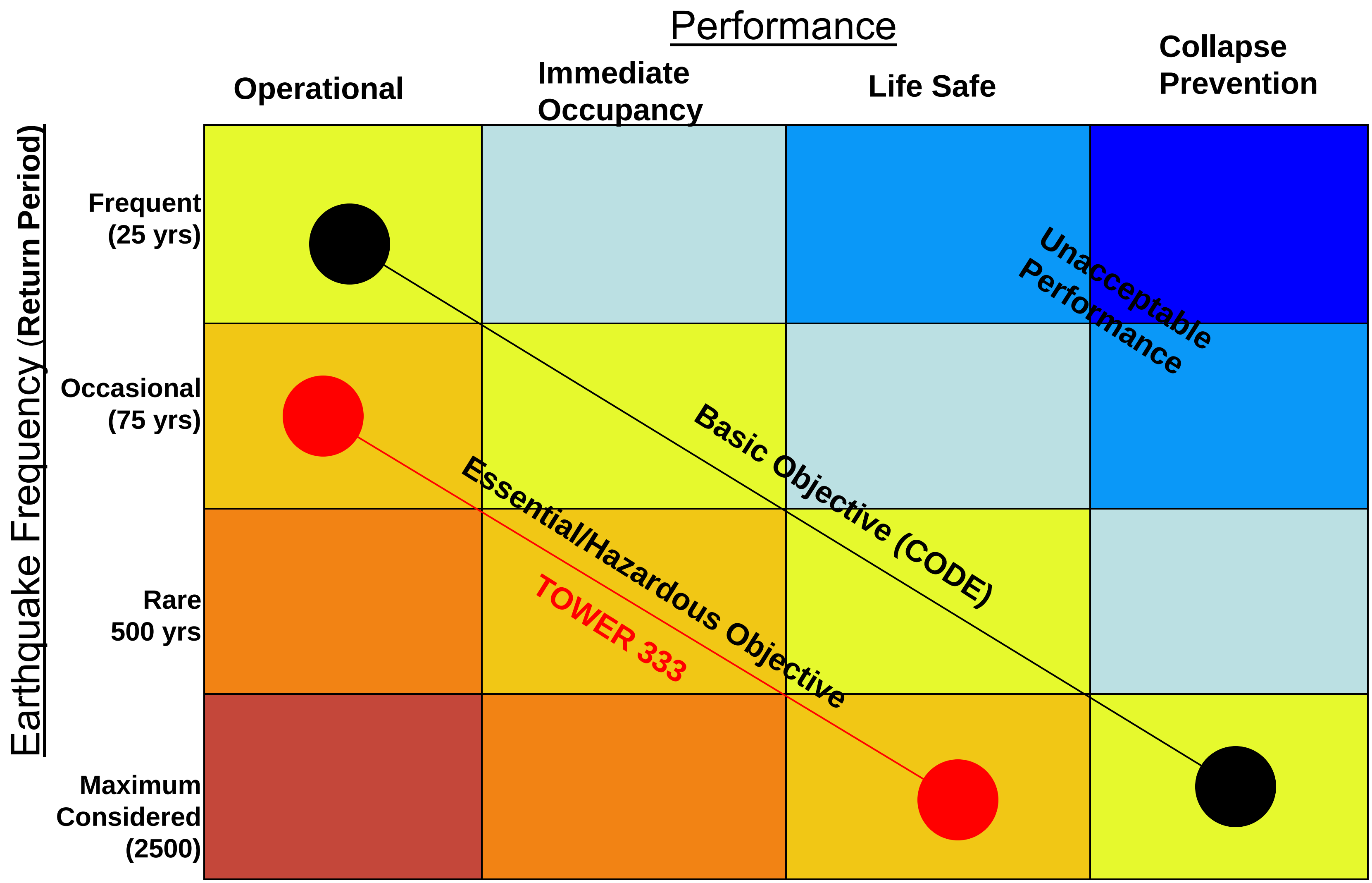
Lateral System Redesign



Lateral System Redesign



Source: Vision 2000, FEMA-349

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Lateral System Redesign

Proposed New Lateral System:

Floors P-8 through Mezzanine: Two symmetrical "C" shaped core walls
36" thick all levels

Floors 1 through 18: Four symmetrical "L" shaped core walls
36" thick @ fl. 1-6
30" thick @ fl. 7-13
24" thick @ fl. 14-18

60" deep coupling beams in (North-South) direction
45" deep coupling beams in (East-West) direction

Max building disp.: 33" = 1.03% of building height
Max story drift: 1.3% < 1.5%

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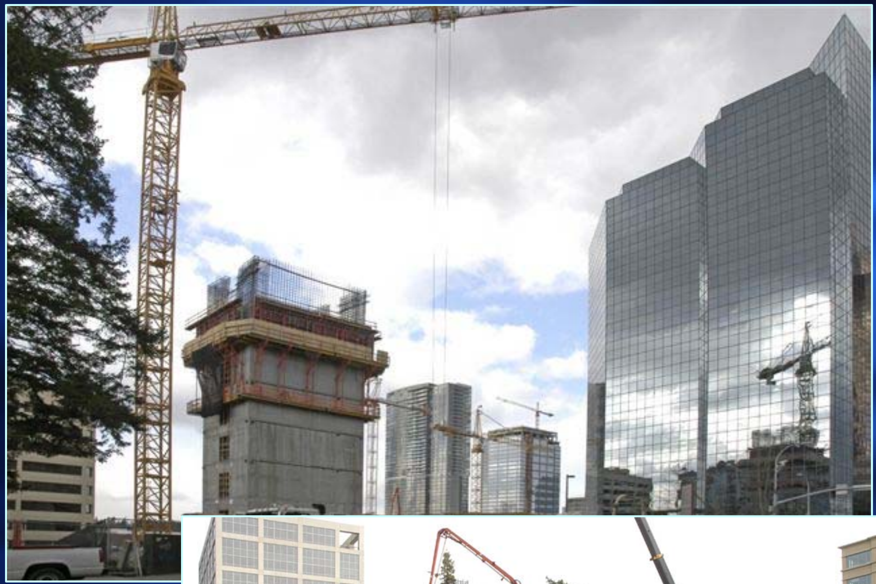
Cost Analysis & Schedule Reduction

Goals :

- Core-only lateral system that performs well under seismic conditions
- Provide a system that is cheaper
- Reduce building erection time

Considerations:

- Cost of shop labor/materials
- Reduced erection time
- Revenue from early finish date



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Cost Analysis & Schedule Reduction

<u>Material Cost:</u>

- Eliminated two sets of 2’ thick x 6’ x 13’-10” volume of concrete from each upper floor

  Savings of 234 CY concrete = $152,000

- Concrete added to thickened core:
  - Sublevel 8 through Mezzanine: 36.4 CY/floor
  - Floor 1 through Floor 6: 50.4 CY/floor
  - Floor 7 through Floor 13: 25 CY/floor

  Total cost of additional concrete: $523,000

- Fire rated drywall for exposed core:
  - Amount of drywall needed: 6,408 ft2
  - Cost of added fire rated drywall: $23,700

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Cost Analysis & Schedule Reduction

Moment Frames:

Contacted Steel Fabricator for representative costs for Seattle Area

- Shop costs of creating a moment connection end was $910/end.
  - Approximately 400 ends in perimeter moment frames
    - savings of these connections totaled $364,000.

- Cost of doubler-plate $380
  - 280 doubler-plate/stiffeners locations located in the moment frames
    - savings of $106,400

- Saving 682,000 lbs of steel = $785,156

- Total cost savings in elimination of moment frames:
  $1,255,155

(This figured does not include savings in erection labor which equated to 4,000 hours of field labor.)

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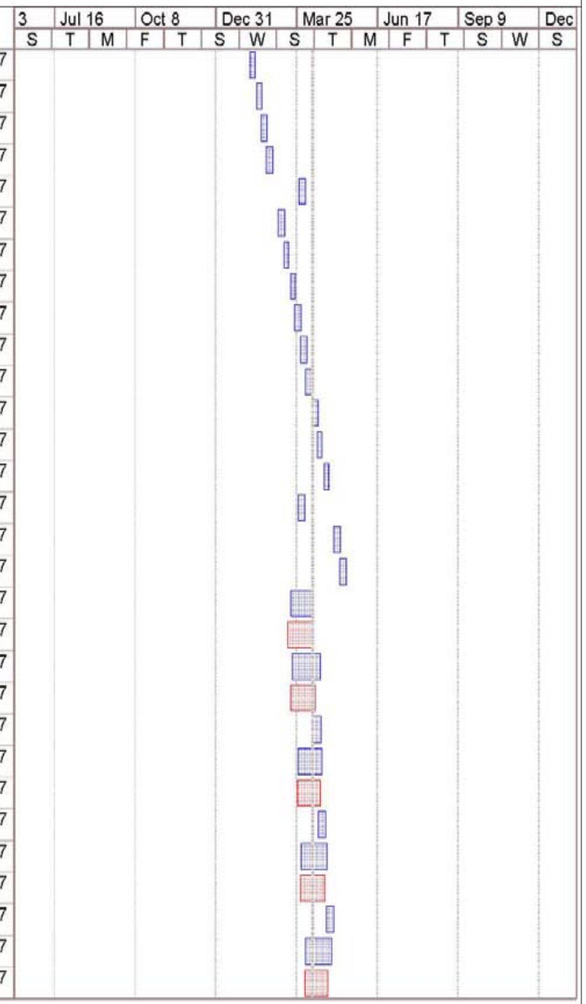
Cost Analysis & Schedule Reduction

Erection Time:

- One E-6 crew of 16 workers
- One E-9 crew of 16 workers
- 256 man hours per day
- 4,000 labor hrs/256 hrs/day = 16 days saved in labor
- 7.6% reduction over 210 day steel erection schedule

PAUL PARFITT — TOWER 333 — 3-14-07

ID	Task Name	Duration	Start	Finish
31	CONCRETE CORE LVL 3	5 days	Mon 2/5/07	Fri 2/9/07
32	CONCRETE CORE LVL 4	5 days	Mon 2/12/07	Fri 2/16/07
33	CONCRETE CORE LVL 5	5 days	Fri 2/16/07	Thu 2/22/07
34	CONCRETE CORE LVL 6	5 days	Thu 2/22/07	Wed 2/28/07
35	CONCRETE CORE LVL 7	5 days	Wed 3/28/07	Tue 4/3/07
36	CONCRETE CORE LVL 8	5 days	Tue 3/6/07	Mon 3/12/07
37	CONCRETE CORE LVL 9	5 days	Mon 3/12/07	Fri 3/16/07
38	CONCRETE CORE LVL 10	5 days	Mon 3/19/07	Fri 3/23/07
39	CONCRETE CORE LVL 11	5 days	Fri 3/23/07	Thu 3/29/07
40	CONCRETE CORE LVL 12	5 days	Thu 3/29/07	Wed 4/4/07
41	CONCRETE CORE LVL 13	5 days	Wed 4/4/07	Tue 4/10/07
42	CONCRETE CORE LVL 14	5 days	Tue 4/10/07	Mon 4/16/07
43	CONCRETE CORE LVL 15	5 days	Mon 4/16/07	Fri 4/20/07
44	CONCRETE CORE LVL 16	5 days	Mon 4/23/07	Fri 4/27/07
45	CONCRETE CORE LVL 17	5 days	Tue 3/27/07	Mon 4/2/07
46	CONCRETE CORE LVL 18	5 days	Thu 5/3/07	Wed 5/9/07
47	CONCRETE CORE PENTHOUSE	5 days	Wed 5/9/07	Tue 5/15/07
48	ERECT ZONES 3&4 @ MEZZANINE	18 days	Mon 3/19/07	Wed 4/11/07
49	ERECT ZONES 3&4 @ MEZZANINE MODIFIED	17 days	Fri 3/16/07	Mon 4/9/07
50	ERECT ZONES 5,6,7 LVL 1 & 2	21 days	Wed 3/21/07	Wed 4/18/07
51	ERECT ZONES 5,6,7 LVL 1 & 2 MODIFIED	20 days	Mon 3/19/07	Fri 4/13/07
52	SOMD @ LVL 1 & 2	6 days	Thu 4/12/07	Thu 4/19/07
53	ERECT ZONES 8 & 9 @ LVL 3 & 4	19 days	Tue 3/27/07	Fri 4/20/07
54	ERECT ZONES 8 & 9 @ LVL 3 & 4 MODIFIED	18 days	Mon 3/26/07	Wed 4/18/07
55	SOMD @ LVL 3 & 4	6 days	Tue 4/17/07	Tue 4/24/07
56	ERECT ZONES 10 & 11 @ LVL 5 & 6	19 days	Fri 3/30/07	Wed 4/25/07
57	ERECT ZONES 10 & 11 @ LVL 5 & 6 MODIFIED	18 days	Thu 3/29/07	Mon 4/23/07
58	SOMD @ LVL 5 & 6	6 days	Wed 4/25/07	Wed 5/2/07
59	ERECT ZONES 12,13,14 @ LVL 7 & 8	19 days	Wed 4/4/07	Mon 4/30/07
60	ERECT ZONES 12,13,14 @ LVL 7 & 8 MODIFIED	18 days	Tue 4/3/07	Thu 4/26/07



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Cost Analysis & Schedule Reduction

11 days saved in erection schedule

- E-6 crew costing $8,277/day
- E-9 crew costing $8,468/day
- Over 11 days = $221,581

Steel Erection Sequence	Erection Days	Erection Days With 7.6% Reduction	Days Saved Per Sequence
1 & 2	16	15	1
3 & 4	18	17	1
5, 6, 7	21	20	1
8 & 9	19	18	1
10 & 11	19	18	1
12, 13, 14	19	18	1
15 & 16	19	18	1
17 & 18	19	18	1
19 & 20	19	18	1
21 & 22	19	18	1
23, 24, 25	21	20	1
26	1	1	0

Total Days Saved
11

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Cost Analysis & Schedule Reduction

- Modified building schedule
- Turn over building 1 week early
- Rent: $25/ft = $190,400 revenue
- 951 parking stalls @ $47/week = $44,700
- Total rental revenue $235,100

(Does not include additional savings in administrative and finance costs)

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Cost Analysis & Schedule Reduction

Summary of Building Cost for Core-Only Lateral System:

- Concrete saved: --- (+) $152,000
- Concrete added: -- (-) $523,000
- Fire Rated Walls: --- (-) $23,700
- Steel shop production: ----------------------------------- (+) $470,400
- Steel material: --- (+) $785,156
- Labor/Erection: --- (+) $221,900
- Rent Revenue: --- (+) $190,400
- Parking Revenue: -- (+) $44,700

- Total dollars saved with proposed core-only design: (+) $1,318,156

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Building Envelope Performance & Quality Control

Purpose of Building Envelope:

- Prevent air & water leakage into building

Poor performance:

- Deterioration of polymer sealants
- Deterioration of metals
- Potential mold growth
- Very costly to repair post construction

Common Industry Assumption:

Better design of specifications & design of building envelope = better performance

Reality:

Communication & Implementation is the primary problem

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Building Envelope Performance & Quality Control

Solution:

Incorporate 3rd party building envelope consultant early in design phase

- •Continuous involvement good communication and implementation
- •Provides field tests & inspections

Two Kinds of Tests:

- •Mock-up test
- •In field test

Both follow:

- •ASTM E331
- •AAMA 501.1-05

Static Pressure Field Test
Photo courtesy of SGH

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Building Envelope Performance & Quality Control

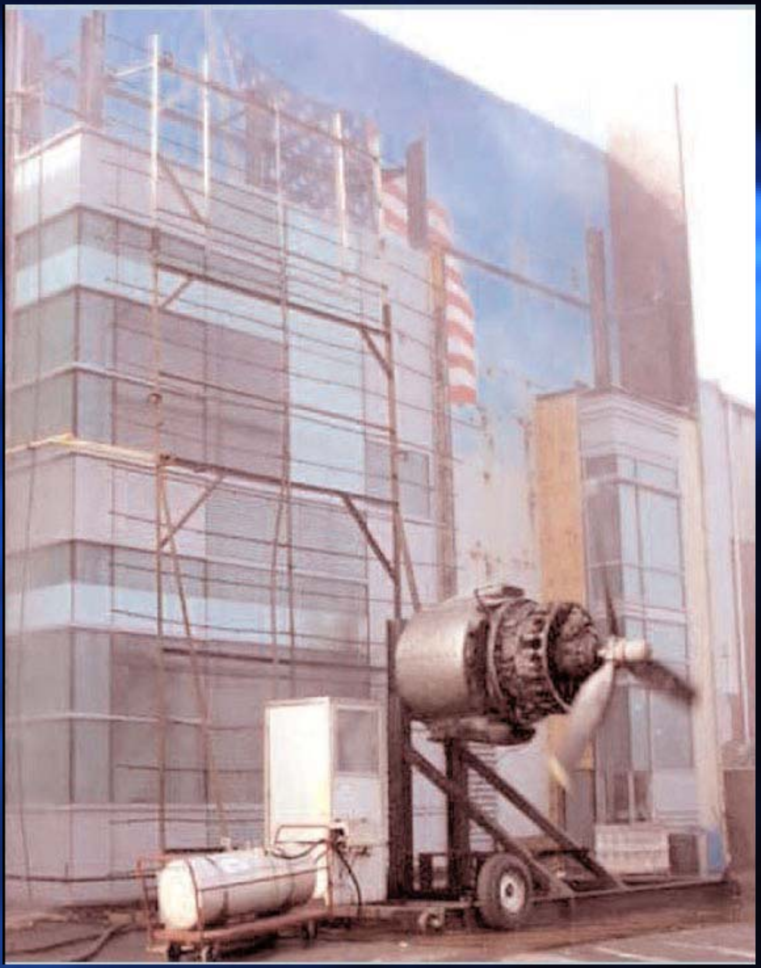
ASTM 331"Uniform Static Air Pressure Difference":

- •2.86 lbs/ft2
- •5 gal/ft2/hr
- •Not accurate for wind driven rain

AAMA 501.1-05 "Dynamic Pressure" :

- •Mechanical wind machine
- •5gal/ft2/hr
- •Test to run no less than 15 mins

Water penetration: ½ oz. or more through envelope in 15 minutes intervals



Dynamic Pressure Test With Turbo Prop Engine

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Building Envelope Performance & Quality Control

Quality assurance summary:

- Quality is not just in specs and design
- Communication & implementation is key
- Hire 3rd party building technology consultant
    - Allows for better communication and implementation
    - Provide random field tests & inspections to ensure quality product.

Static Pressure Field Test
Photo Courtesy of SGH

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Conclusion

- Was proposed design feasible?
  - Met all performance criteria
    - Max story drift 1.3%
    - Developed plastic hinges in coupling beams
    - Limit yielding in piers
- Was proposed design economical?
  - Cheaper structure to build
  - Quicker erection time
  - Increased revenue due to early finish date

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Conclusion

Findings:

- Proposed core-only design feasible & economical alternative to existing structure
- Proper specs and design of envelope will not always prevent curtain wall problems

Recommendation:

- Recommend that proposed design be implemented
- Recommend that 3rd party consultant be hired for quality assurance of building envelope erection

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Acknowledgments

Thanks to all the organizations that assisted:

Hines Development
Magnusson Klemencic Associates
LMN Architects
Simpson Gumpertz & Heger
Wiss Janney Elstner Associates

Penn State University:

Dr. Andres Lepage
Andreas Phelps
The rest of the AE faculty & staff

Special thanks to my family & fellow 5th year AE's

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Questions?

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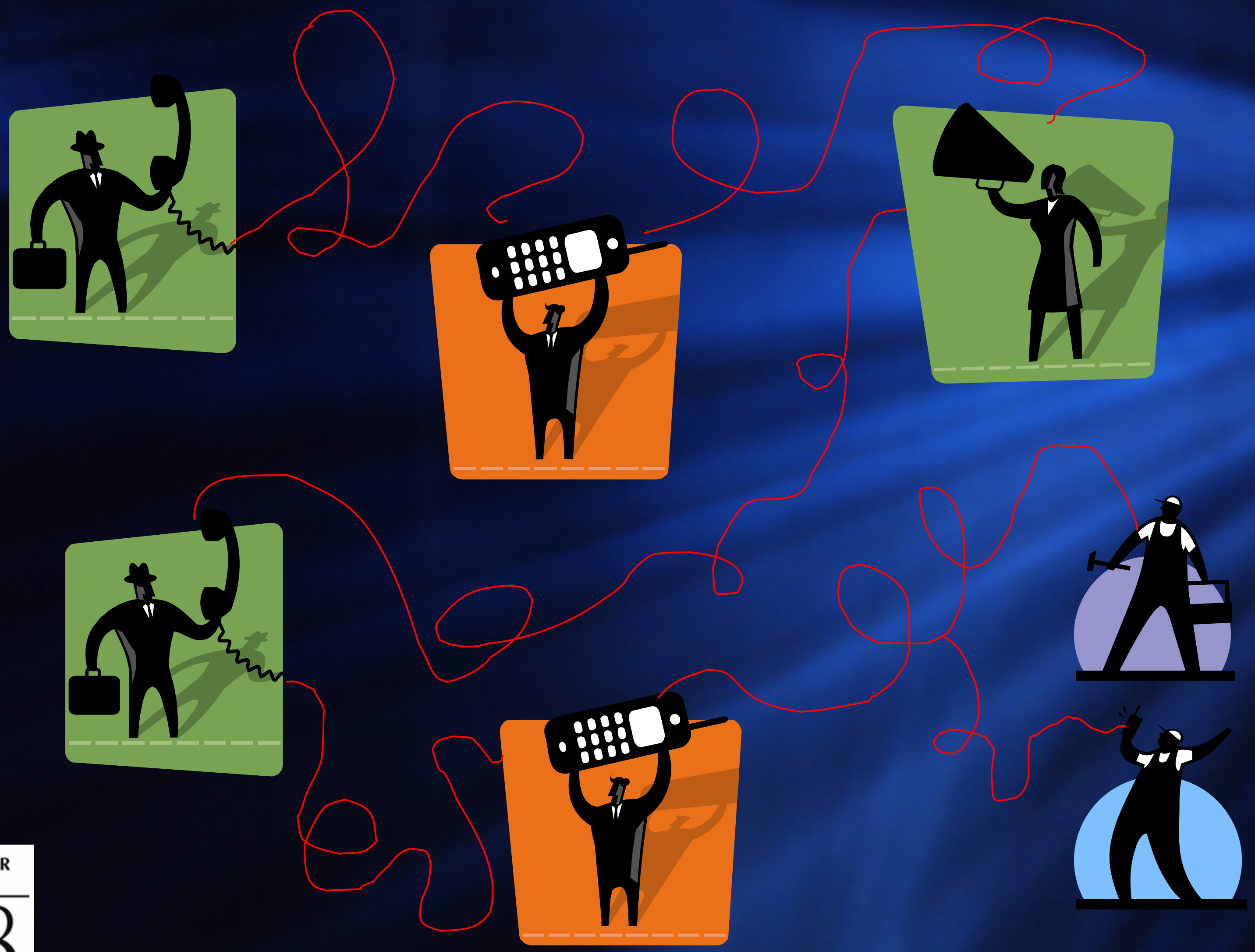
Building Envelope Performance & Quality Control



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