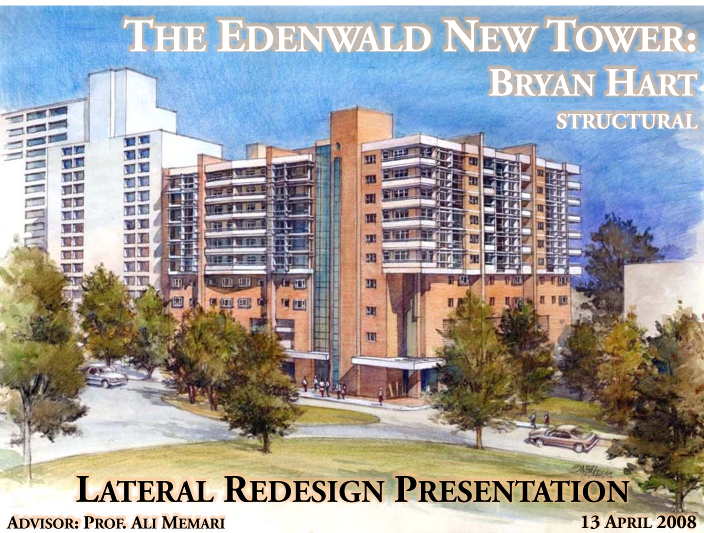
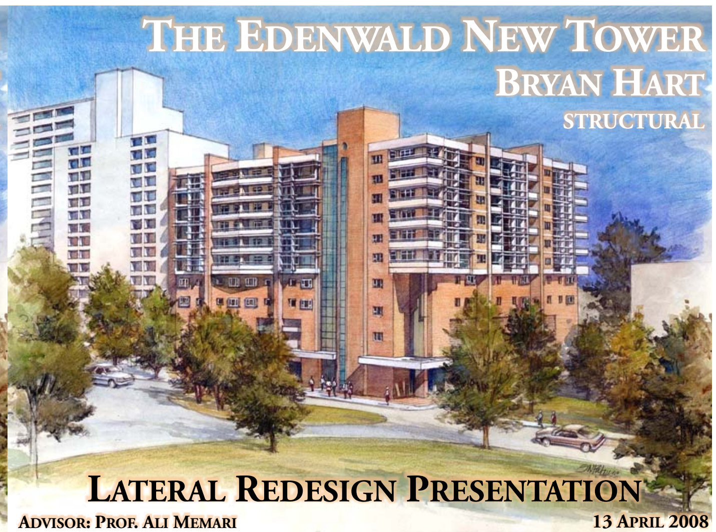

THE EDENWALD NEW TOWER:
BRYAN HART
STRUCTURAL
LATERAL REDESIGN PRESENTATION
ADVISOR: PROF. ALI MEMARI
13 APRIL 2008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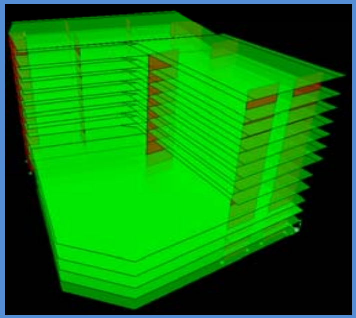
BUILDING SCHEMATIC



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OVERVIEW

BUILDING STATISTICS

- General Description:
  - 12 Story Retirement Community Addition
  - 60 Independent Living Apartments
  - 32 Assisted Living Apartments
  - Amenities

- Size: 253,000 sq. ft.

- Overall Project Cost: $52 million

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Edenwald New Tower

Recent History of Seismic Code Changes

1997 NEHRP PROVISIONS → IBC 2000

2000 NEHRP PROVISIONS → ASCE 7-02 → IBC 2003/ NFPA 5000 2002

ASCE 7 Seismic Task Group → ASCE 7-05 → IBC 2006

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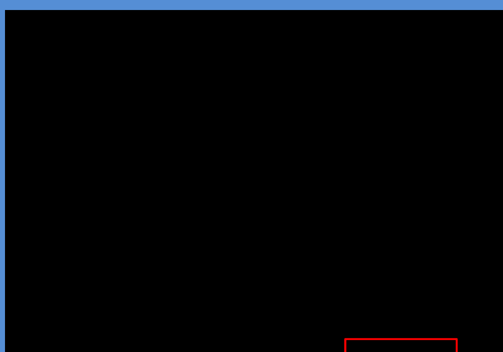
Overview

Background

- Original lateral system designed according to IBC 2000
- ASCE 7-05 is current governing code for seismic
- Result?
  - Decrease in spectral response acceleration parameters

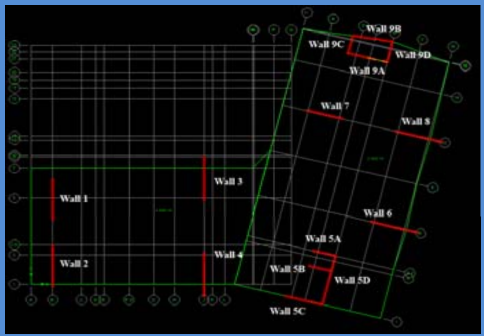


OVERVIEW

PROPOSAL/GOALS

- Redesign and optimize main lateral force resisting system (MLFSR) for updated code
- Configure new shear wall design to reduce torsion as much as possible
- Use coupling beams at shear wall openings
- Lighting Breadth: Analyze 6th floor corridor (assisted living)

WALL LOCATIONS

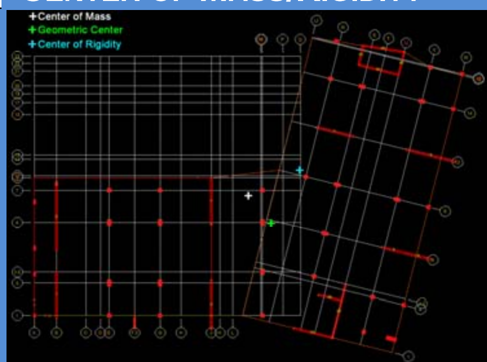


EXISTING CONDITIONS

LATERAL SYSTEM

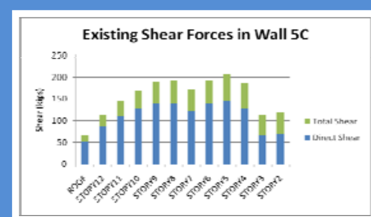
- (5) 14” simply reinforced shear walls
- (10) 12” simply reinforced shear walls

Center of Mass/Rigidity



Torsion

- **Eccentricity of 25 to 30 feet, dependent on floor**
- **How much of total shear does torsion account for?**



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LATERAL REDESIGN

ETABS ANALYSIS OVERVIEW

- Method
  - Input:
    - Static load cases, load combinations
  - Dynamic Analysis Output:
    - 12 modes of vibration (building period)
    - Member forces & reactions
  - Serviceability design
    - Sizes & Locations
  - Strength design
    - Reinforcement

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LATERAL REDESIGN

ETABS ANALYSIS OVERVIEW

- Elements modeled:
  - Rigid Diaphragms
  - Shear Walls
  - Coupling Beams
- P Delta Effects
  - Non-iterative method
- Cracked section properties

Distribution of Seismic Forces per Floor

Level	w_x	h_x	$w_x h_x^k$	C_{vx}	F_x	M
*Roof	4301	119.33	12802763957	0.2520	200	23849
12						13919
11						10264
10						7780
9						5716
8						4042
7						2815
6						1549
5						1438
4						447
3	4960	18.67	617893065.2	0.0122	10	180
2	3642	9.33	104778906.3	0.0021	2	15
*Includes weight of Penthouse					Overturning Moment	72014 ft-kips
					Base Shear	793 kips

Basic Wind Speed	90 mph
Occupancy Category	III
Importance Factor	1.15
Exposure	B
Topographic Factor (K_{zt})	1.0
Wind Directionality Factor (K_d)	0.85
Gust Factor (both directions)	0.83
Internal Pressure Coefficient	± 0.18

LATERAL REDESIGN

STATIC LOAD CASES

- **Seismic**
  - **Equivalent Lateral Force Procedure**
    - **ASCE 7-05 Chapter 12**
- **Wind**
  - **Wind load criteria established**
    - **Method 2, ASCE 7-05 Chapter 6**
  - **Forces calculated by ETABS**

Load Combo Reference #	ASCE 7-05 Combination	Load Combination as Entered in ETABS	Load Combo Reference #	ASCE 7-05 Combination	Load Combination as Entered in ETABS
1 1	Combination 1	1.4D	5 1	Combination 6	0.9D + 1.6W1
2 1	Combination 2	1.2D + 1.6L + 0.5S	5 2		0.9D + 1.6W2
3 1	Combination 4	1.2D + 1.6W1 + L + 0.5S	5 3		0.9D + 1.6W3
3 2		1.2D + 1.6W2 + L + 0.5S	5 4		0.9D + 1.6W4
3 3		1.2D + 1.6W3 + L + 0.5S	5 5		0.9D + 1.6W5
3 4		1.2D + 1.6W4 + L + 0.5S	5 6		0.9D + 1.6W6
3 5		1.2D + 1.6W5 + L + 0.5S	5 7		0.9D + 1.6W7
3 6		1.2D + 1.6W6 + L + 0.5S	5 8		0.9D + 1.6W8
3 7		1.2D + 1.6W7 + L + 0.5S	5 9		0.9D + 1.6W9
3 8		1.2D + 1.6W8 + L + 0.5S	5 10		0.9D + 1.6W10
3 9		1.2D + 1.6W9 + L + 0.5S	5 11		0.9D + 1.6W11
3 10		1.2D + 1.6W10 + L + 0.5S	5 12		0.9D + 1.6W12
3 11		1.2D + 1.6W11 + L + 0.5S	5 13		0.9D - 1.6W1
3 12		1.2D + 1.6W12 + L + 0.5S	5 14		0.9D - 1.6W2
3 13		1.2D - 1.6W1 + L + 0.5S	5 15		0.9D - 1.6W3
3 14		1.2D - 1.6W2 + L + 0.5S	5 16		0.9D - 1.6W4
3 15		1.2D - 1.6W3 + L + 0.5S	5 17		0.9D - 1.6W5
3 16		1.2D - 1.6W4 + L + 0.5S	5 18		0.9D - 1.6W6
3 17		1.2D - 1.6W5 + L + 0.5S	5 19		0.9D - 1.6W7
3 18		1.2D - 1.6W6 + L + 0.5S	5 20		0.9D - 1.6W8
3 19		1.2D - 1.6W7 + L + 0.5S	5 21		0.9D - 1.6W9
3 20		1.2D - 1.6W8 + L + 0.5S	5 22		0.9D - 1.6W10
3 21		1.2D - 1.6W9 + L + 0.5S	5 23		0.9D - 1.6W11
3 22		1.2D - 1.6W10 + L + 0.5S	5 24		0.9D - 1.6W12
3 23		1.2D - 1.6W11 + L + 0.5S	6 1	Combination 7	0.86D + Ex
3 24		1.2D - 1.6W12 + L + 0.5S	6 2		0.86D - Ex
4 1	Combination 5	1.24D + Ex + L + 0.2S	6 3		0.86D + Ey
4 2		1.24D - Ex + L + 0.2S	6 4		0.86D - Ey
4 3		1.24D + Ey + L + 0.2S			
4 4		1.24D - Ey + L + 0.2S			

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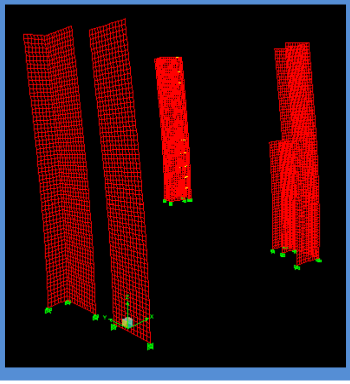
LATERAL REDESIGN

LOAD COMBINATIONS

- Based on basic combinations from ASCE 7-05 Chapter 2
- Wind combinations include 4 cases described in Chapter 6
- Total of 64 Combinations used

WALL DEFLECTION



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LATERAL REDESIGN

SERVICEABILITY

- Iterative Process:
  - Multiple solutions Considered
- Drift/Displacement limits
  - Seismic Drift: according to ASCE 7-05 12.12.1
  - Displacement: H/400

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DRIFT/DISPLACEMENT VALUES

Wind X

Story	Story drift (in)	Allowable (in)		Displacement (in)	Allowable (in)	
Roof	0.13527	0.36	ok	0.971	3.6	ok
12	0.10518	0.28	ok			
11	0.1046	0.28	ok			
10	0.10188	0.28	ok			
9	0.10032	0.28	ok			
8	0.09632	0.28	ok			
7	0.10165	0.32	ok			
6	0.09348	0.32	ok			
5	0.08677	0.34	ok			
4	0.05945	0.28	ok			
3	0.04716	0.28	ok			
2	0.0303	0.28	ok			
1	0.01232	0.28	ok			

Wind Y

Story	Story drift (in)	Allowable (in)		Displacement (in)	Allowable (in)	
Roof	0.16802	0.36	ok	0.994671428	3.6	ok
12	0.13029	0.28	ok			
11	0.12957	0.28	ok			
10	0.12709	0.28	ok			
9	0.12354	0.28	ok			
8	0.11868	0.28	ok			
7	0.12626	0.32	ok			
6	0.11652	0.32	ok			
5	0.10782	0.34	ok			
4	0.07389	0.28	ok			
3	0.05751	0.28	ok			
2	0.04082	0.28	ok			
1	0.01775	0.28	ok			

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LATERAL REDESIGN

DRIFT/DISPLACEMENT VALUES

Seismic X

Story	Story drift (in)	Amplified Story Drift (in)	Allowable (in)		Displacement (in)	Allowable (in)	
Roof	0.387	1.684	2.160	ok	2.660	3.600	ok
12	0.300	1.305	1.679	ok			
11	0.298	1.295	1.679	ok			
10	0.290	1.261	1.679	ok			
9	0.281	1.222	1.679	ok			
8	0.266	1.159	1.679	ok			
7	0.279	1.214	1.921	ok			
6	0.250	1.086	1.921	ok			
5	0.230	0.998	2.039	ok			
4	0.152	0.662	1.679	ok			
3	0.118	0.511	1.679	ok			
2	0.074	0.321	1.679	ok			
1	0.029	0.125	1.679	ok			

Seismic Y

Story	Story drift (in)	Amplified Story Drift (in)	Allowable (in)		Displacement (in)	Allowable (in)	
Roof	0.279	1.215	2.160	ok	1.930	3.600	ok
12	0.216	0.939	1.679	ok			
11	0.213	0.925	1.679	ok			
10	0.208	0.905	1.679	ok			
9	0.200	0.871	1.679	ok			
8	0.190	0.828	1.679	ok			
7	0.200	0.868	1.921	ok			
6	0.181	0.785	1.921	ok			
5	0.165	0.715	2.039	ok			
4	0.111	0.482	1.679	ok			
3	0.083	0.360	1.679	ok			
2	0.057	0.249	1.679	ok			
1	0.027	0.117	1.679	ok			

THESIS DESIGN

LATERAL REDESIGN

SERVICEABILITY SUMMARY

- Removed Walls
  - Walls 3, 4, 6, 7, 8
- Added Walls
  - 1B
  - Used to induce core-like behavior
- Coupling beams used in Core 9
- Core 9 made 16” thick
- Center of rigidity not relocated
  - *Torsion not resolved*

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Lateral Redesign

Wall Strength Design

- Flexural Reinforcement
  - ETABS calculated
- Shear Reinforcement
  - Hand Calculated
- Boundary Elements
  - Hand Calculated

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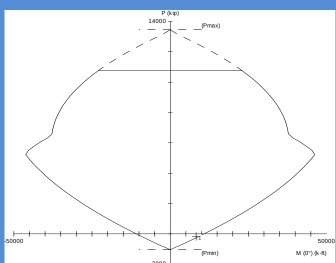
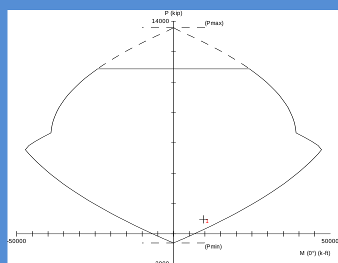
Lateral Redesign

Strength Design: Flexure

- Determined by ETABS according to ACI 318-02
  - Checked against P-M2-M3 interaction diagrams
  - Considers effective flange widths
- Walls 1, 2, 5D designed in PCAColumn to account for additional gravity load

P-M INTERACTION: WALL 1,2





LATERAL REDESIGN

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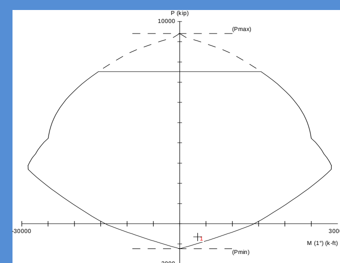
P-M INTERACTION WALL 5D



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LATERAL REDESIGN

STRENGTH DESIGN: SHEAR

- Design performed according to ACI Code 11.10
- Limitations
  - Minimum reinforcement ratio of 0.0025
  - Maximum spacing of 18”
  - Shear strength limited to

$$10\sqrt{f'_c}hd$$

- Factor of safety, ϕ, taken to be:
  - 0.75 for wind
  - 0.6 for seismic

STRENGTH DESIGN: BOUNDARY ELEMENT

- For sizing, calculated effective axial load from axial force and moment
  - Initially calculated according to

$$P_{u,BE} = \frac{P_{grav}}{2} + \frac{M_u}{l}$$

  - More accurately calculated as

$$P_{u,BE} = (\sigma_{grav} A_{BE}) + \frac{M_u}{l}$$

  - *Latter equation reduced load up to 50%*

LATERAL REDESIGN

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STRENGTH DESIGN: BOUNDARY ELEMENT

- Designed according to ACI Code Ch. 21
- Needed when maximum compressive stress exceeds 1 ksi

$$0.2\sqrt{f'_c}$$

Shear Wall Summary

Wall	Flexural Vertical Reinf*	Shear Horizontal Reinf*	Boundary Element Length (in)	Boundary Element Width (in)	Boundary Element Reinf
1	#7 @ 12"	#5 @ 18"	14	12	(10) #9
1B	#8 @ 12"	#5 @ 18"	8	12	(4) #9
2	#5 @ 16"	#5 @ 18"	15	12	(8) #10
5A	#8 @ 12"	#5 @ 18"	4	12	(2) #10
5B	#5 @ 12"	#5 @ 18"	--	--	--
5C	#9 @ 12"	#5 @ 18"	14	12	(10) #9
5D	#6 @ 12"	#4 @ 12"	14	12	(10) #9
9A	#7 @ 12"	#6 @ 18"	12	12	(6) #9
9A2	#9 @ 12"	#6 @ 18"	6	12	(2) #9
9B	#7 @ 12"	#6 @ 18"	15	12	(8) #10
9C	#9 @ 10"	#6 @ 18"	8	12	(4) #9
9D	#8 @ 8"	#6 @ 18"	6	12	(4) #9

*Placed in both faces

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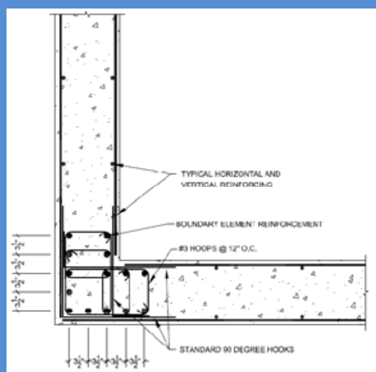
Lateral Redesign

Strength Design: Boundary Element

- **Element designed as short column**
- **Checked for adequate tensile strength using similar process**
- **Limitations:**
  - **Maximum reinforcement ratio of 0.06**
  - **Minimum dimensions as dictated by ACI Code 21.7.6.2**

Shear Wall Connection Detail



Lateral Redesign

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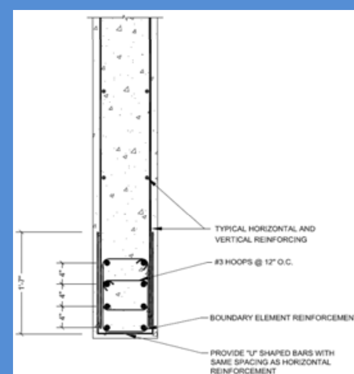
Shear Wall End Detail



Coupling Beam Design

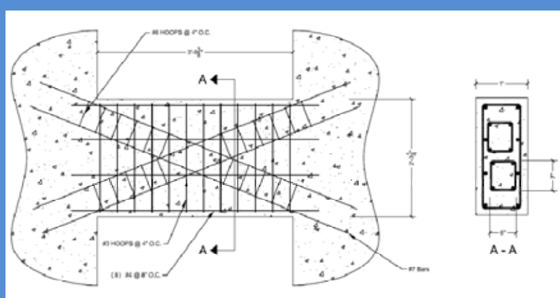
Beam	Location	V_u	Load Combo
B1	Roof	32.46	321
B2	Story 12	36.02	321
B2	story 11	38.17	321
B2	Story 10	39.08	321
B2	Story 9	39.36	321
B2	Story 8	41.25	42
B3	Story 7	54.45	42
B3	Story 6	55.15	42
B4	Story 5	64.53	42
B2	Story 4	48.31	42
B2	Story 3	53.39	42
B2	Story 2	51.5	42

Coupling Beam Design

Lateral Redesign

- **Used to:**
  - **Improve energy dissipation**
  - **Increase relative stiffness**
  - **Develop plastic hinges which allow 2 piers to bend as 1**
- **According to code, if aspect ratio < 4, diagonal reinforcement may be used**

COUPLING BEAM B2



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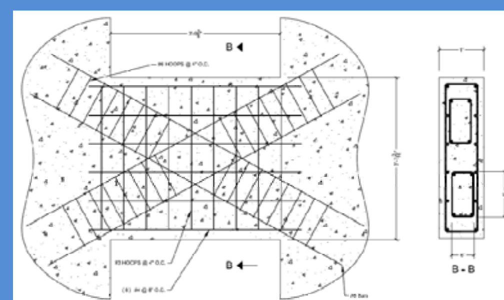
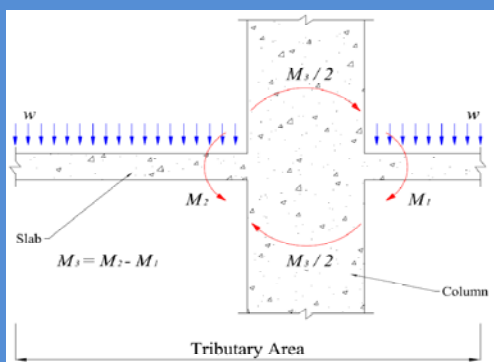
COUPLING BEAM B3



UNBALANCED MOMENT



LATERAL REDESIGN

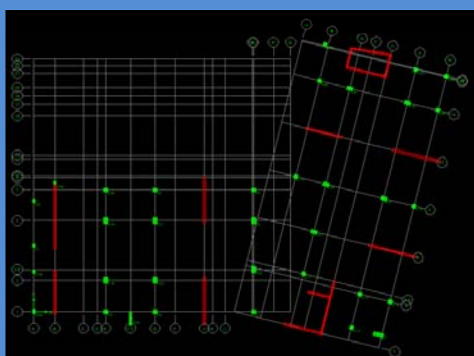
COLUMN DESIGNS

- Used to account for gravity load carried by removed shear walls
- Designed in PCAColumn to account for:
  - Dead Load
  - Live Load
  - Unbalanced Moments

Column Schedule

Column	J1, J7	J3, J5	S12, V6, V12	R12, W6, W12
Size	22"x22"	22"x36"	22"x36"	22"x22"
Rebar	(8) #11	(8) #10	(8) #10	(8) #11

Original Design



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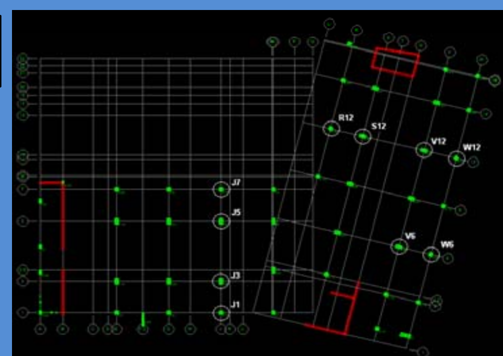
Lateral Redesign

Column Locations



SAVINGS

- Concrete (5000 psi) = $106,107
- Wall placement (crane & bucket) = $119,760
- Reinforcement (material & labor) = $88,036
- Spread Footings (material, placement, reinforcement) = 341,550
- Gross savings = *$655,453*

COSTS

- Concrete (5000/6000 psi) = $59,636
- Col. placement (crane & bucket) = $39,207
- Reinforcement (material & labor) = $41,409
- Spread Footings (material, placement, reinforcement) = $117,224
- Gross costs = *$140,252*

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COST ANALYSIS

- Estimate savings of removed walls
- Estimate cost of replacement columns

- <u>Net Savings: $515,201</u>
  - 0.96% of total project cost ($52 million)

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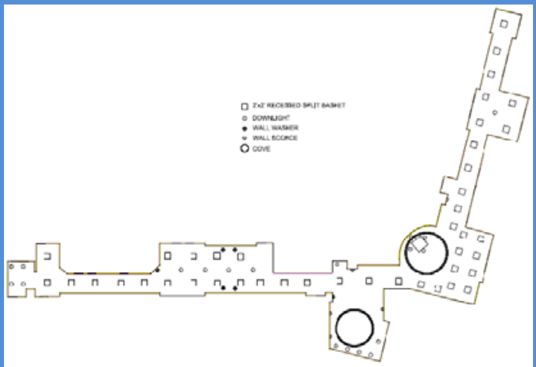
EXISTING LIGHTING PLAN



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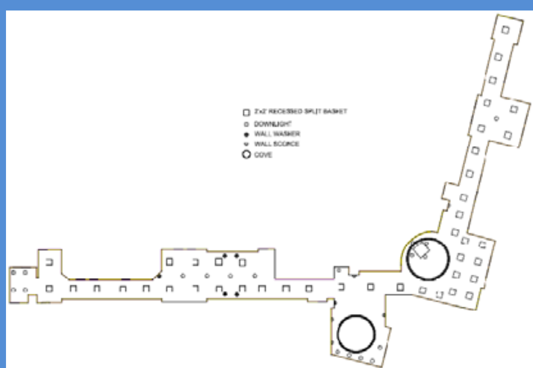
LIGHTING
REDESIGN

6TH FLOOR CORRIDOR

- Concerns for elderly lighting
  - Illumination (category D, 30 fc)
  - Glare
  - ADA compliance
  - Power Density
  - General Aesthetics
  - Traffic direction
- Existing Conditions
  - Coves
  - Recessed 2'x2' split baskets
  - Downlights & wall washers
  - Wall sconces

EXISTING LIGHTING PLAN



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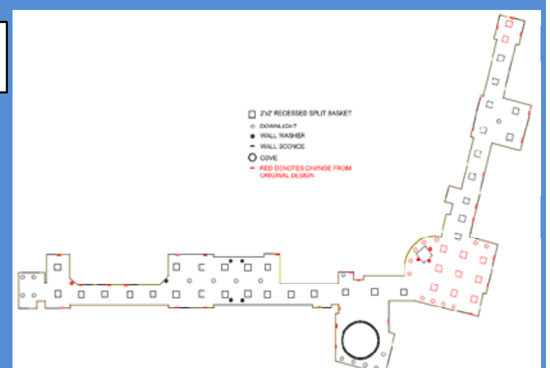
LIGHTING REDESIGN

6TH FLOOR CORRIDOR / REVISED LIGHTING PLAN



ORIGINAL COVE

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LIGHTING REDESIGN

REVISED LIGHTING

ORIGINAL NE CORNER

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REVISED NE CORNER

LIGHTING REDESIGN

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LIGHTING REDESIGN

SUMMARY

- Power Density
  - Originally: 1.7 watts/s.f.
  - Revised designed: 1.9 watts/s.f.
- Traffic direction
  - Wall sconces make apartment entrances more conspicuous
- Illumination
  - Originally: below 20 fc in limited areas
  - Revised design: uniform 30 fc minimum

- Were coupling beams feasible? ⊘
  - Reinforcing steel problematic
  - Entire core widened for beams
  - Deflection of core OK without beams

- Was lighting redesign feasible?
  - 30 fc illumination maintained ✓
  - Power density not improved ⊘
    - However, removal of cove allows for energy savings to offset power used by ADA sconces

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Conclusions

- Was proposed lateral redesign/optimization feasible?
  - Serviceability requirements ✓
  - Strength Requirements ✓
  - Economical?
    - Savings of $500,000 ✓

- Was torsion resolved?
  - Center of rigidity not influenced ⊘
  - Can it be resolved?
    - Architectural overhaul

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CONCLUSIONS

RECOMMENDATIONS

- Lateral Design
  - Implement proposed redesign of shear walls
  - Abandon coupling beams
- Lighting Design
  - Implement redesign of superfluous cove
  - Only replace existing sconces with ADA compliant sconces, but do not add additional ones to each entrance

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FOR THOSE STILL AWAKE…

…ARE THERE ANY QUESTIONS?

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Core 9 PCAColumn Output

	Pu	Mux	Muy	fMnx	fMny			Pu	Mux	Muy	fMnx	fMny	
No.	kip	k-ft	k-ft	k-ft	k-ft	fMn/Mu	No.	kip	k-ft	k-ft	k-ft	k-ft	fMn/Mu
1	-1437.9	-143.1	162.7	-21995.6	25014.7	153.738	30	-1012.1	-3728.2	2485	-24070.4	16043.5	6.456
2	-1231	-146.4	214.3	-21714.3	31795.5	148.351	31	-855	967.2	9448.9	4231.9	41342.8	4.375
3	-1162.2	921.7	9530.6	3702.7	38286	4.017	32	-1120.8	3067.9	-733.5	21984.9	-5256.3	7.166
4	-1428	3022.4	-651.8	20148.7	-4345.5	6.666	33	-898.5	815.7	6346.6	5246.8	40821	6.432
5	-1205.7	770.3	6428.3	4526.5	37777.1	5.877	34	-846.2	589.1	7879	3104.7	41525.8	5.27
6	-1153.4	543.6	7960.7	2626.5	38464.9	4.832	35	-1118.8	2480.9	-1903.8	21416	-16434.5	8.632
7	-1426	2435.4	-1822.1	19706.9	-14744.7	8.092	36	-1024.5	2075	855.9	21664.5	8935.9	10.441
8	-1331.7	2029.5	937.5	19904.5	9194.9	9.808	37	-725	-1667.5	7741.4	-9154.7	42501.2	5.49
9	-1032.2	-1713	7823	-8636.7	39443	5.042	38	-1019.7	3072.3	6484.3	16960.3	35795.7	5.52
10	-1326.8	3026.8	6565.9	15649.3	33947.4	5.17	39	-829.7	-1037.2	4226.3	-10151	41361.8	9.787
11	-1136.9	-1082.7	4308	-9625.6	38298.7	8.89	40	-719.7	-1512.1	7448.2	-8647.8	42597.2	5.719
12	-1027	-1557.6	7529.9	-8177.9	39534.9	5.25	41	-1050.9	2520.8	3282.7	20076.1	26143.9	7.964
13	-1358.1	2475.3	3364.3	18468.4	25101.6	7.461	42	-940.9	2045.9	6504.5	12416.9	39476.7	6.069
14	-1248.1	2000.4	6586.2	11121.5	36616.5	5.56	43	-993.7	-1151.2	-9239.7	-5337.2	-42839.1	4.636
15	-1300.9	-1196.6	-9158	-5212.2	-39889.5	4.356	44	-728	-3251.8	942.7	-24731.1	7169.4	7.605
16	-1035.2	-3297.3	1024.3	-23225.5	7215.2	7.044	45	-950.3	-999.7	-6137.4	-7021.3	-43106	7.023
17	-1257.5	-1045.2	-6055.8	-6930.1	-40152.6	6.63	46	-1002.5	-773	-7669.8	-4318.5	-42847.4	5.587
18	-1309.7	-818.5	-7588.2	-4302.5	-39887.3	5.257	47	-729.9	-2664.8	2113	-25829.2	20480.6	9.693
19	-1037.1	-2710.3	2194.7	-24244.3	19631.6	8.945	48	-824.2	-2258.9	-646.7	-23114	-6616.9	10.232
20	-1131.4	-2304.4	-565	-21713.9	-5323.9	9.423	49	-1123.7	1483.5	-7532.2	8193.9	-41601.9	5.523
21	-1430.9	1438	-7450.5	7461.4	-38657.5	5.189	50	-829.1	-3256.3	-6275.1	-18785	-36200.3	5.769
22	-1136.3	-3301.7	-6193.4	-17928.4	-33630.1	5.43	51	-1019	853.3	-4017.1	9037.8	-42548.9	10.592
23	-1326.2	807.8	-3935.5	8133	-39623.7	10.068	52	-1129	1328.1	-7239	7632.4	-41600.7	5.747
24	-1436.2	1282.6	-7157.4	6927	-38654	5.401	53	-797.8	-2704.7	-3073.5	-21740.1	-24703.9	8.038
25	-1105.1	-2750.2	-2991.8	-20443.1	-22238.9	7.433	54	-907.8	-2229.9	-6295.3	-14439.5	-40765.4	6.475
26	-1215.1	-2275.4	-6213.7	-13938.3	-38063.5	6.126	55	-758.4	1398	14189.8	4169.3	42319.7	2.982
27	-1148.7	1359.1	14234	3669.1	38425.6	2.7	56	-1006.3	-1603.4	-13896.4	-4933.2	-42754.9	3.077
28	-1396.6	-1642.2	-13852.2	-4625.8	-39018.3	2.817	57	-1142.9	3484	-2147.3	21446.1	-13218.1	6.156
29	-1533.2	3445.1	-2103.1	19230.8	-11739.9	5.582	58	-621.8	-3689.4	2440.8	-26092.9	17262.2	7.072

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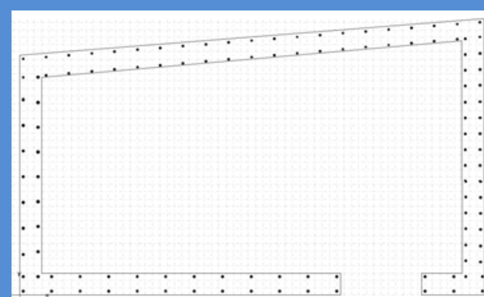
Core 9 Flexural Reinforcement



STRENGTH DESIGN: SHEAR

- Nominal Shear Strength of Wall

$$V_n = V_c + V_s$$

$$\phi V_n \leq V_u$$

STRENGTH DESIGN: SHEAR

- Design performed according to ACI Code 11.10
- Nominal Shear Strength of Concrete

$$V_c = \left[0.6\sqrt{f'c} + \frac{l_w\left(1.25\sqrt{f'c} + 0.2N_u/l_w h\right)}{M_u/V_u - l_w/2}\right]hd$$

$$V_c = 3.3\sqrt{f'_c}hd + \frac{N_u d}{4l_w}$$

- Required Horizontal Shear Reinforcement

$$A_v = \frac{(V_u - \phi V_c)s}{\phi f_y d}$$