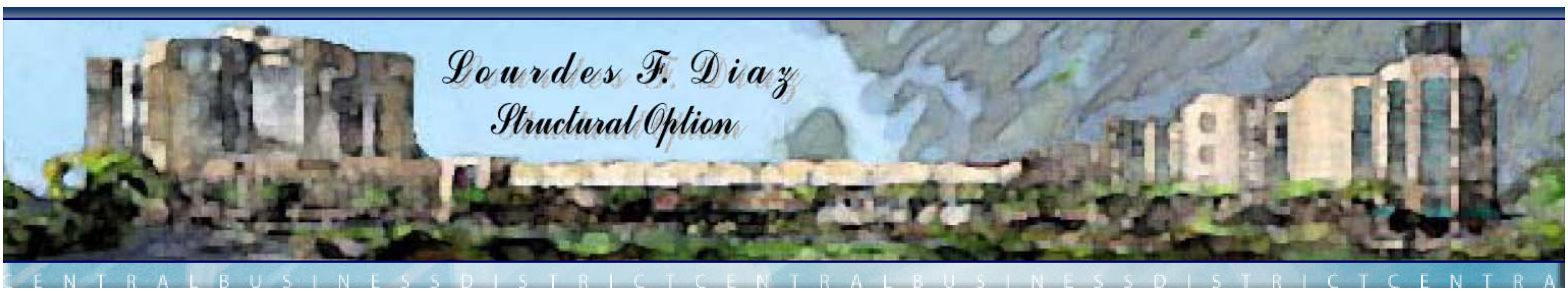
ARCHITECTURAL ENGINEERING
THE PENNSYLVANIA STATE UNIVERISITY
THESIS PROJECT

PASEO CARIBE

CONDOMINIUM TOWER & PARKING

Coupled Shear Wall Systems in High Seismic Zones

ARCHITECTURAL ENGINEERING
THE PENNSYLVANIA STATE UNIVERISITY
THESIS PROJECT

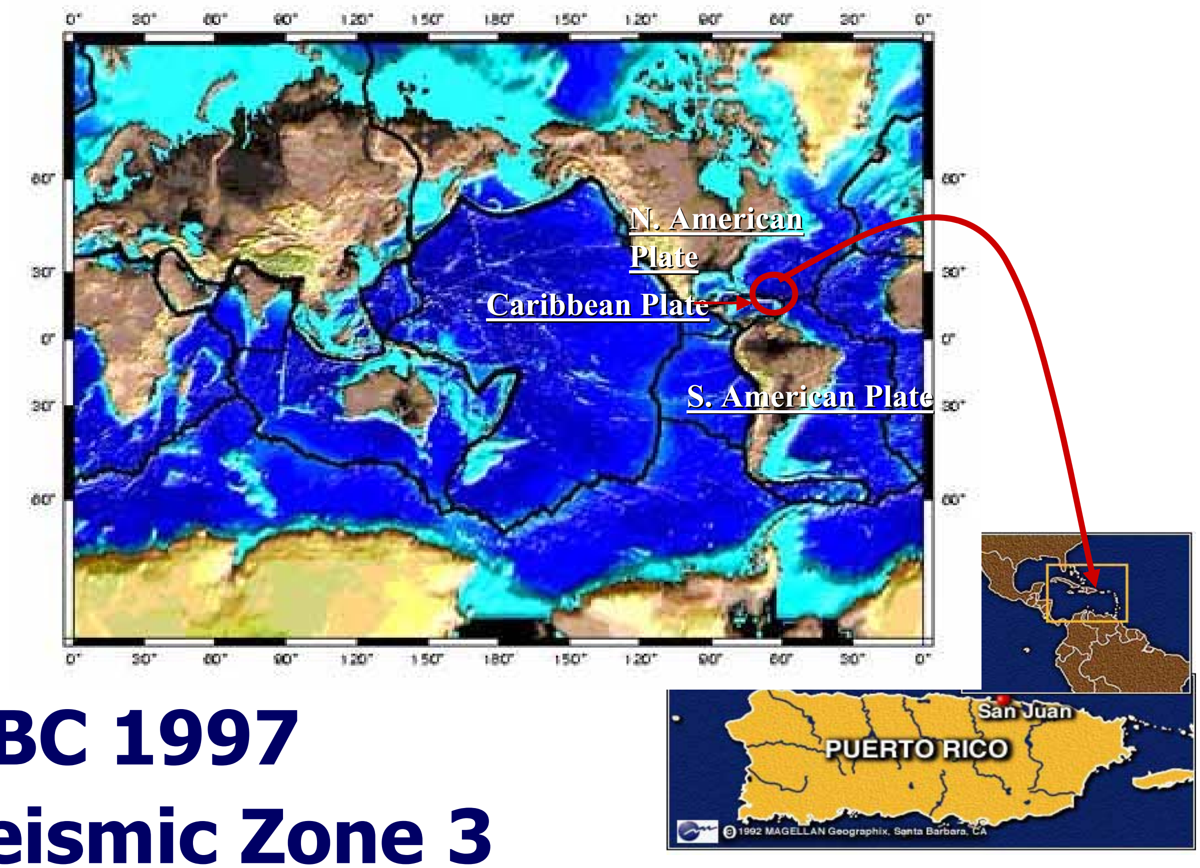


BACKGROUND

- **LOCATION**
  - **San Juan, Puerto Rico**
  - **Bordered by the Caribbean & South American Plates**

BACKGROUND

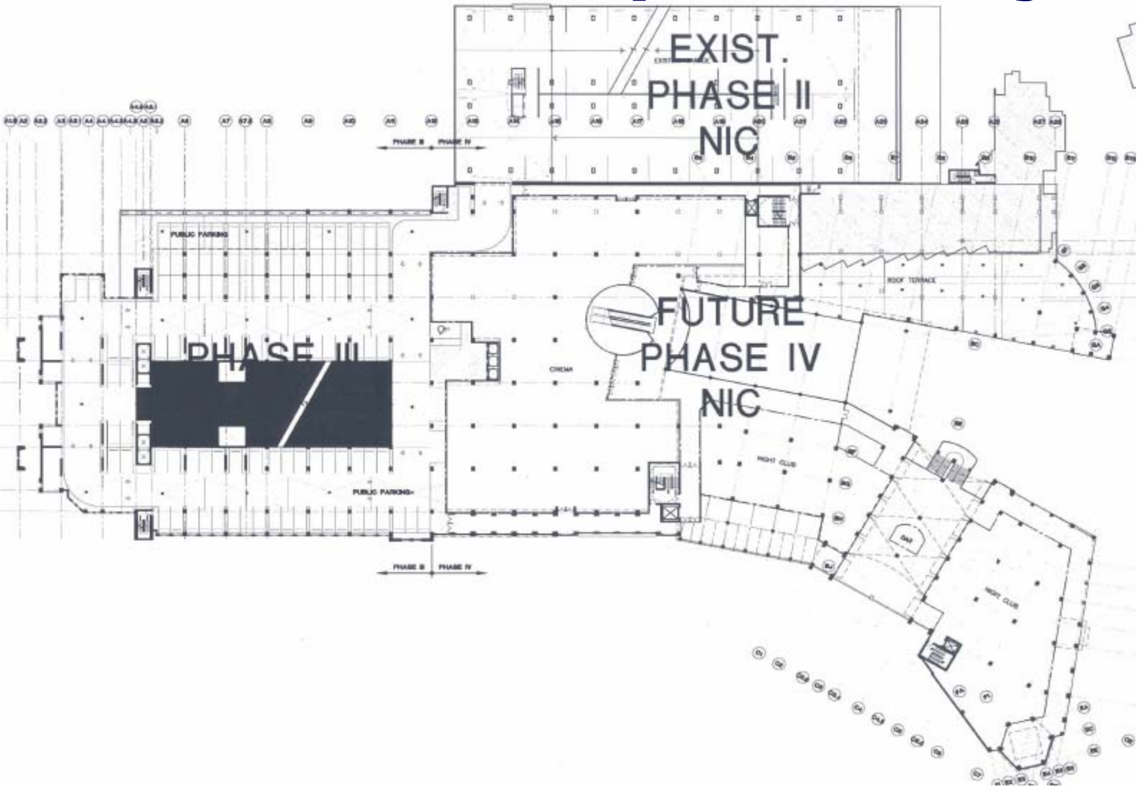
- **LOCATION**



- **UBC 1997**
- **Seismic Zone 3**

BACKGROUND

- **Project Overview**
  - **IV Phase Development Project**



BACKGROUND

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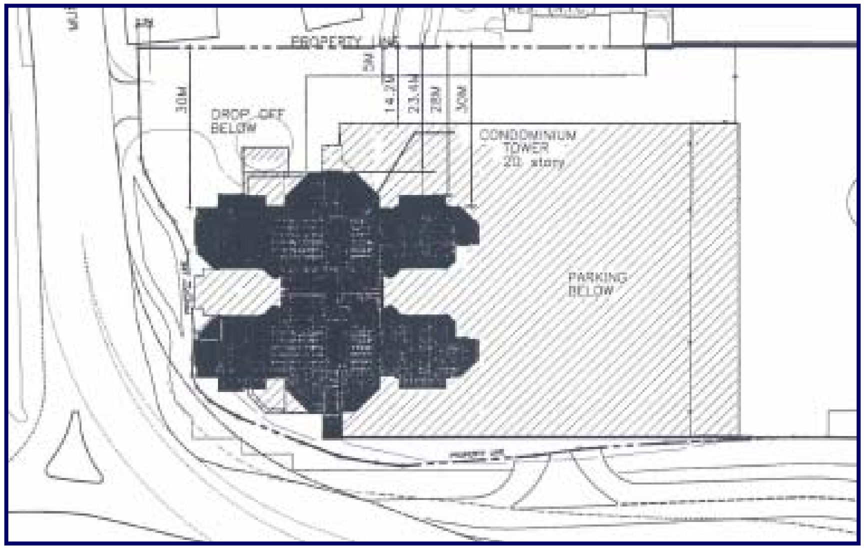
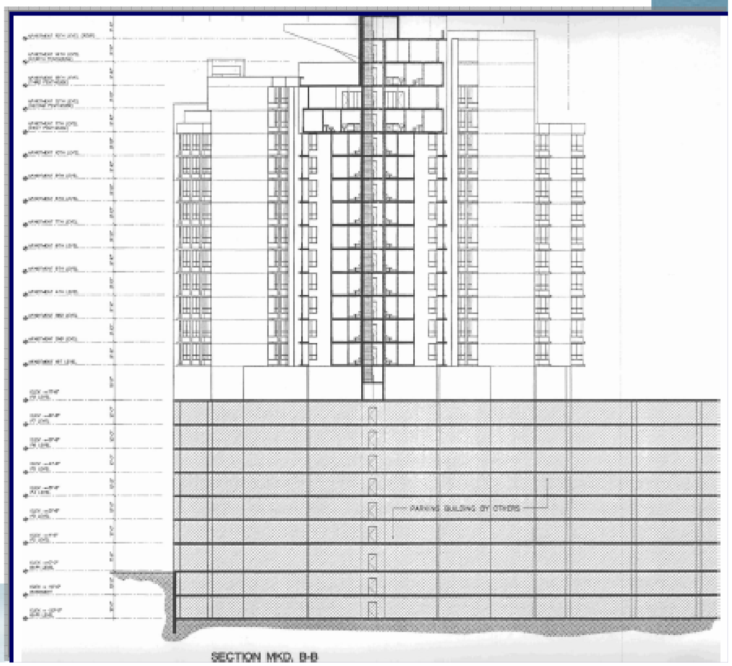
CONCLUSION

- **Project Overview**
  - **Parking Garage: Phase II**
    - **10 stories, 1700 parking spaces**



BACKGROUND

- **Project Overview**
  - **Parking Garage: Phase II**
    - **10 stories, 1700 parking spaces**
  - **Condominium Tower: Phase III**
    - **Add. 14 stories**
    - **4 – 3,500 ft^2 aparts / floor**



EXISTING STRUCTURE

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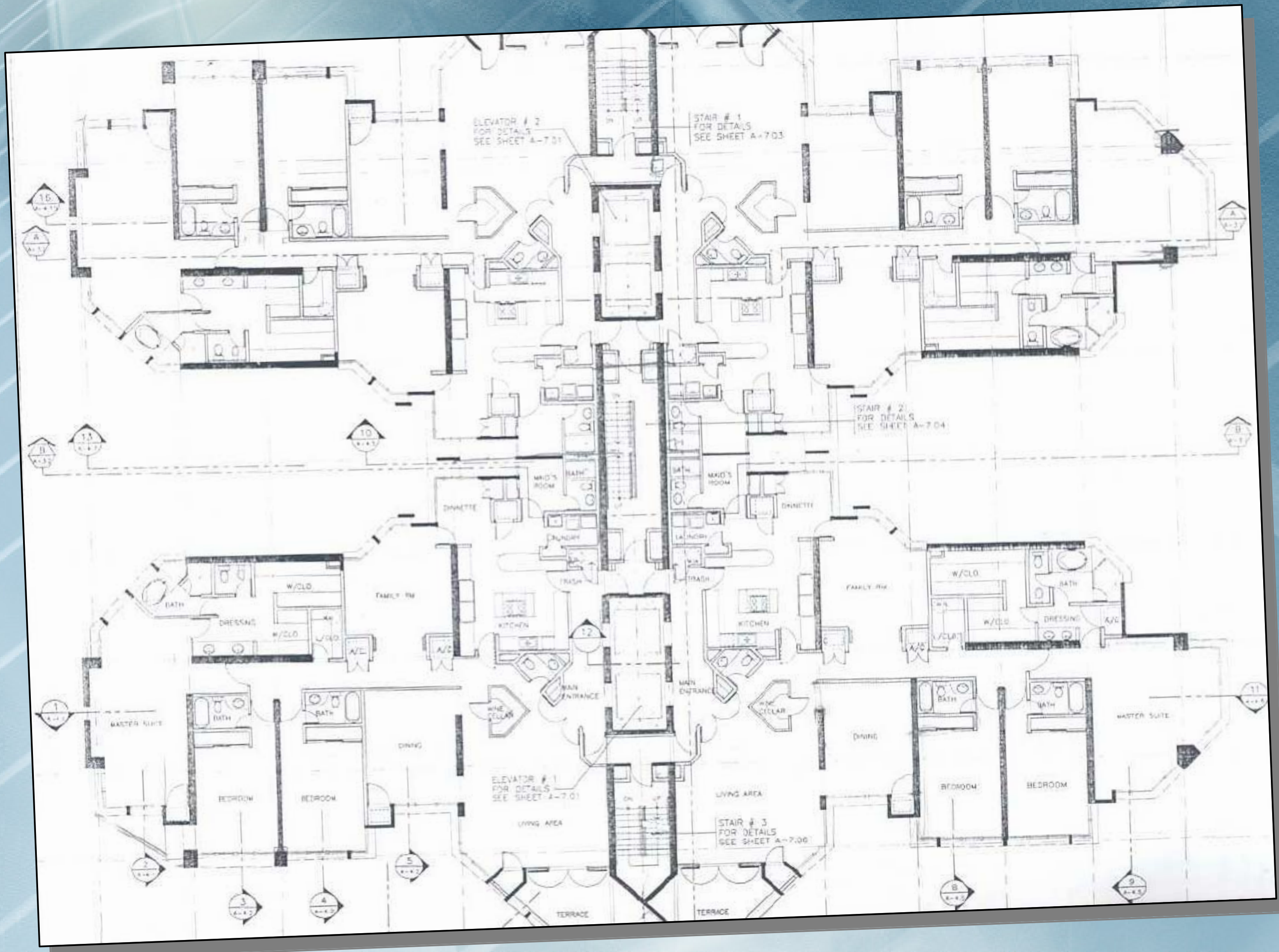

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- **Gravity System**
  - **Cast-in-Place Bearing Wall**
    - **9” Post-Tensioned Flat Slab**
    - **36 – 12” Walls: 620 LF / Floor**
    - **Typical Open Span: 17’ E-W**
- **Lateral System**
  - **Bearing Walls act as Shear Walls**
  - **Very Stiff 10’ x 160’ Core**
    - **4 Elevator Shafts**
    - **3 Sets of Stairs**

PROBLEM STATEMENT

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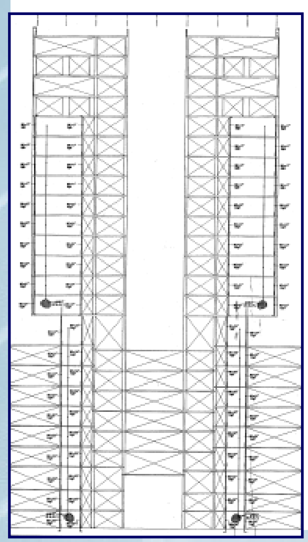
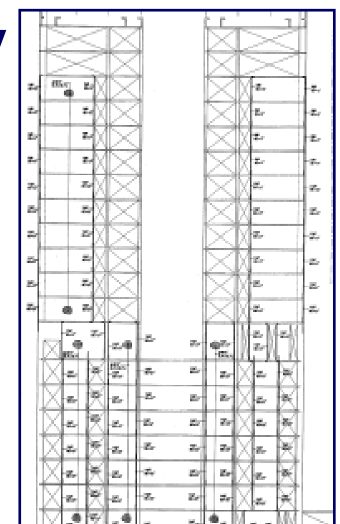
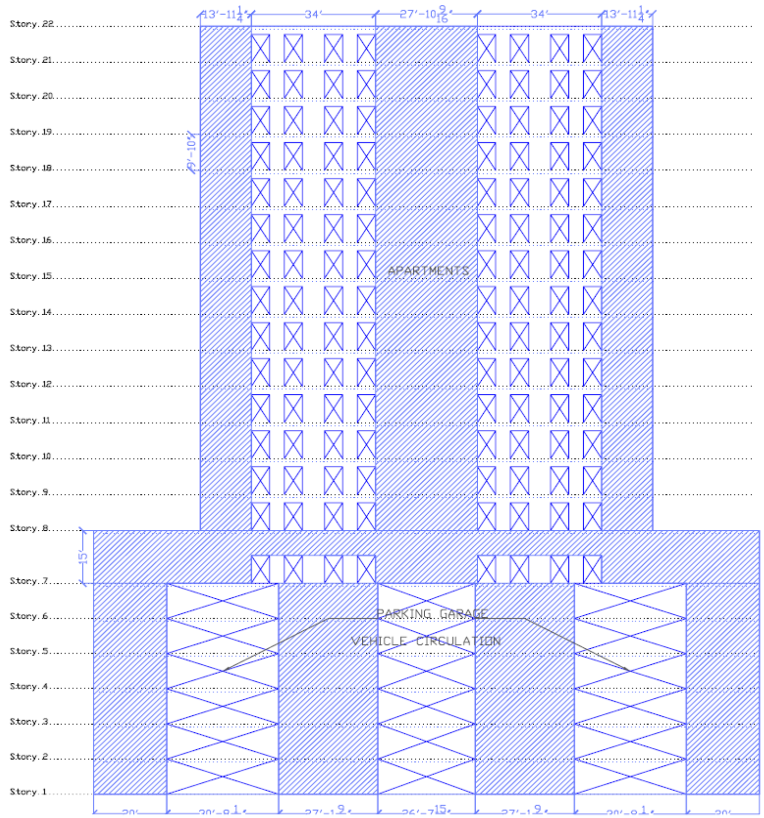
- **Lateral Discontinuity**
  - **Transition of Occupancy at 8th Floor**
  - **Vertical Irregularity: UBC Table 16L**
    - **Type 1: Soft Story – Transfer Girders**
    - **Type 2: Weight Mass – Doubled Slab Area**
    - **Type 3: Vertical Geometry > 1.3L**
    - **Type 4: In plane Discontinuity**





PROBLEM STATEMENT

- **Lateral Discontinuity**



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- **Multiple Lateral Discontinuities**
- **Large Self Weight = 92,000k**
- **Low $R_{\text{Bearing Wall}}$ Value = 4.5**

VERY LARGE SEISMIC FORCES

V = 8400 KIPS

PROBLEM STATEMENT

- **Non-Structural Issues**
  - **In plan, no open space > 22′ E-W**
  - **Material and Labor Intensive Design**
    - **Concrete:** **11200 cy**
    - **Formwork:** **520,000 ft^2**
    - **Rebar:** **560 tons**

DESIGN GOALS

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- **Efficient Lateral System:**
  - **Reduce No. Lateral Elements to 4 in each direction**
  - **Limit No. Irregularities**
  - **Has a Predictable and Clean Failure Mechanism**
  - **Does not interfere with the Architecture & Assigned Use of Space**

KEY ELELEMENTS

- **Reduce Vase Shear:**
  - **Use a frame gravity system with a higher R: 5.5**
  - **Reduce the Weight with a lighter Steel Frame**
- **Improved Capacity:**
  - **Higher f'c = 5ksi**
  - **Thicker 24" walls**
  - **Diagonally Reinforced Coupled Walls**
  - **Higher T to increase participation of coupled beam**
  - **Limit discontinuity and use symmetry to keep a low ρ factor**

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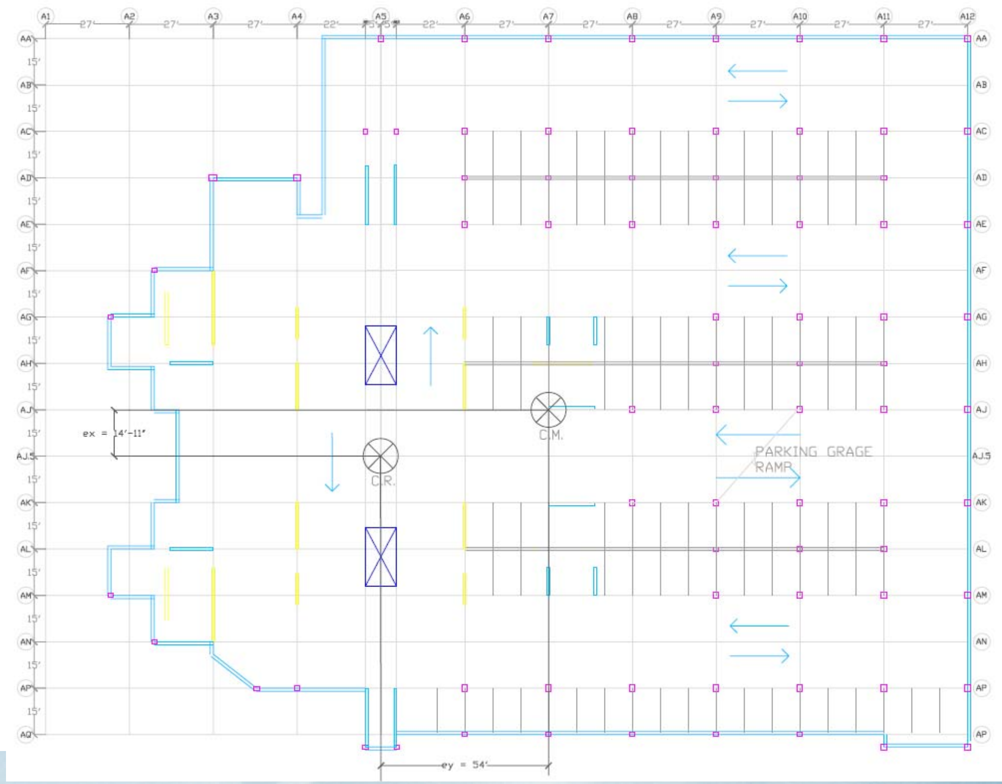
- **Method**
  - **Take advantage of the Existing 27'x30' Parking Grid**



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- **Method**
  - **Take advantage of the Existing 27'x30' Parking Grid**
- **Requirements**
  - **Existing Height w/ 9" P/T Slab: 230 ft**
  - **UBC Overall Height Restriction: 240 ft**
  - **Clear Story Height Required: 9 ft**
  - **Max Story Height Increase: 8 in**

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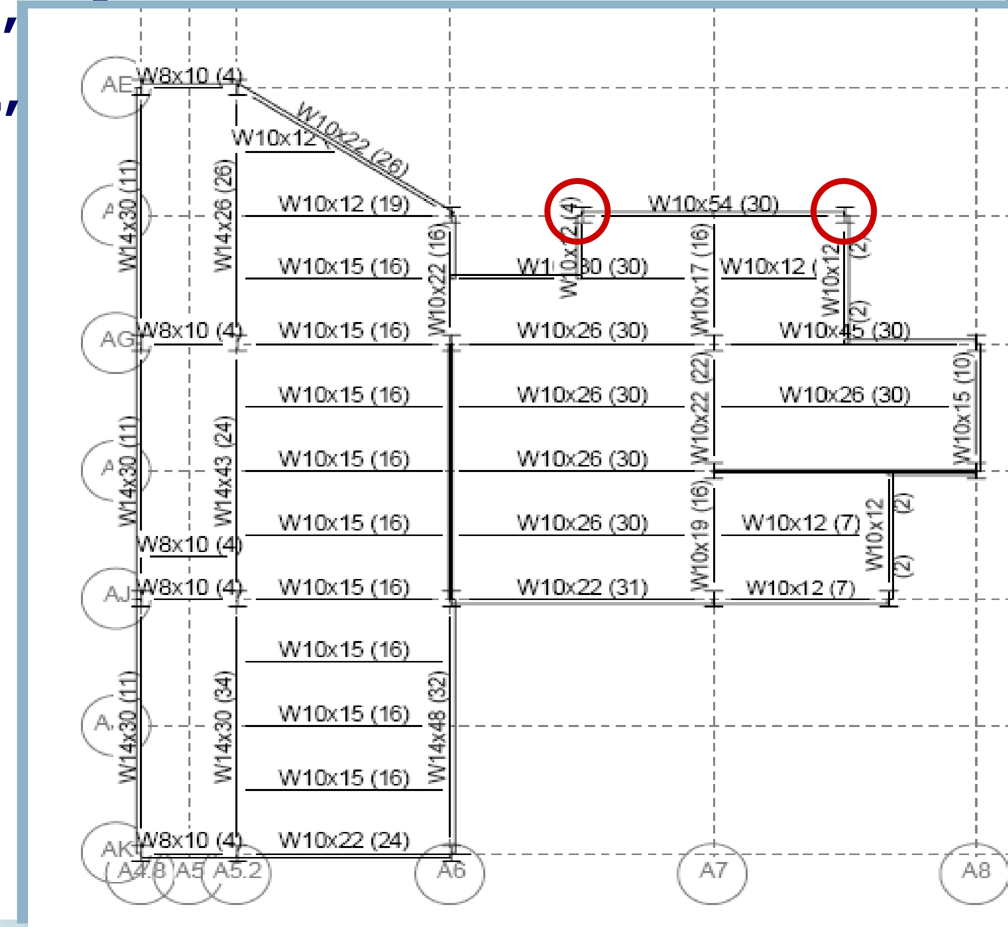
Results – Apartments

- **Spacing: 7.5′**
- **Max Span: 27′**
- **Apartments:**

  W10 x 26

  Corridor:

  W14 x 30



- **ΔH_{story} = 5″**
- **ΔH_{total} = 70″**

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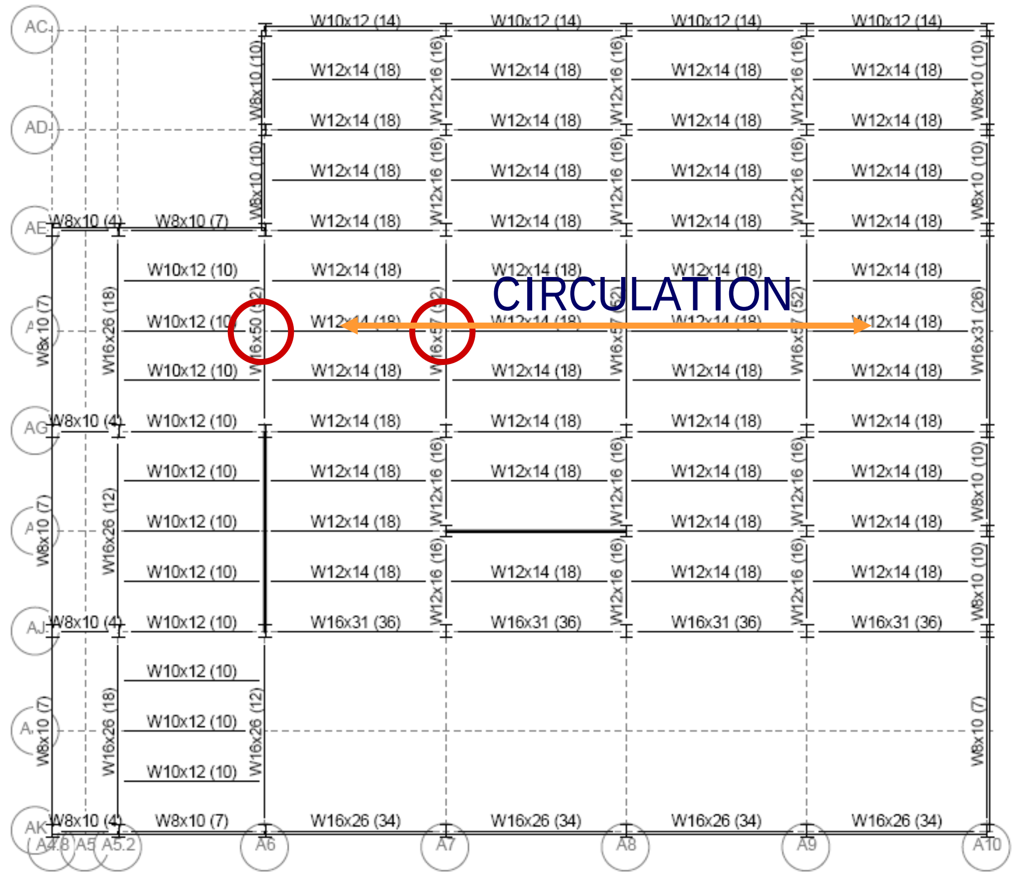
Results – Parking Garage

Floor Type: Parking Structure



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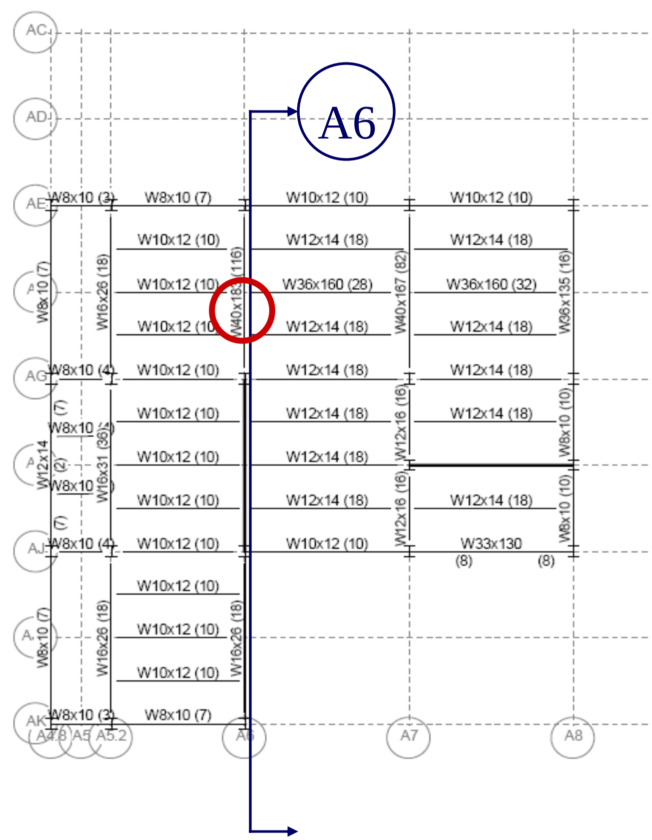
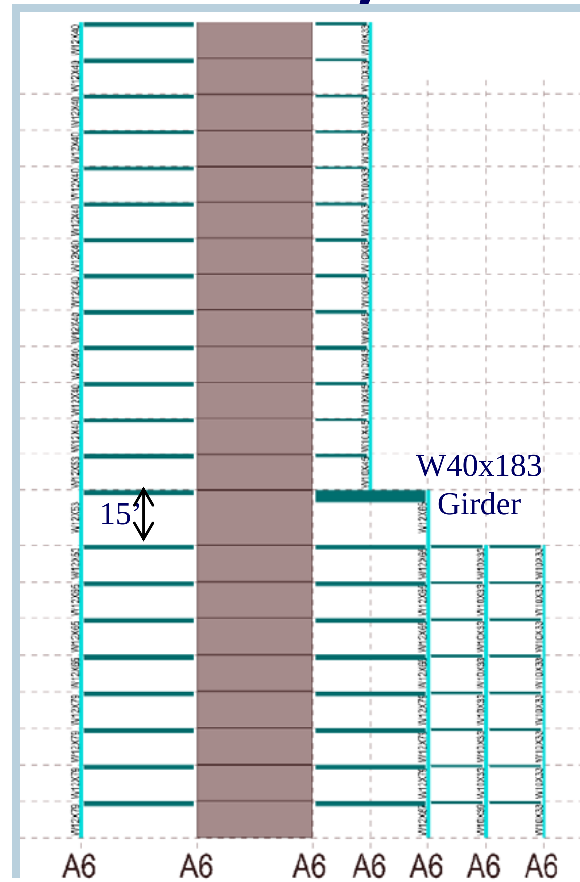
Results – Transition Level, 8th

Floor Type: Parking Structure 9

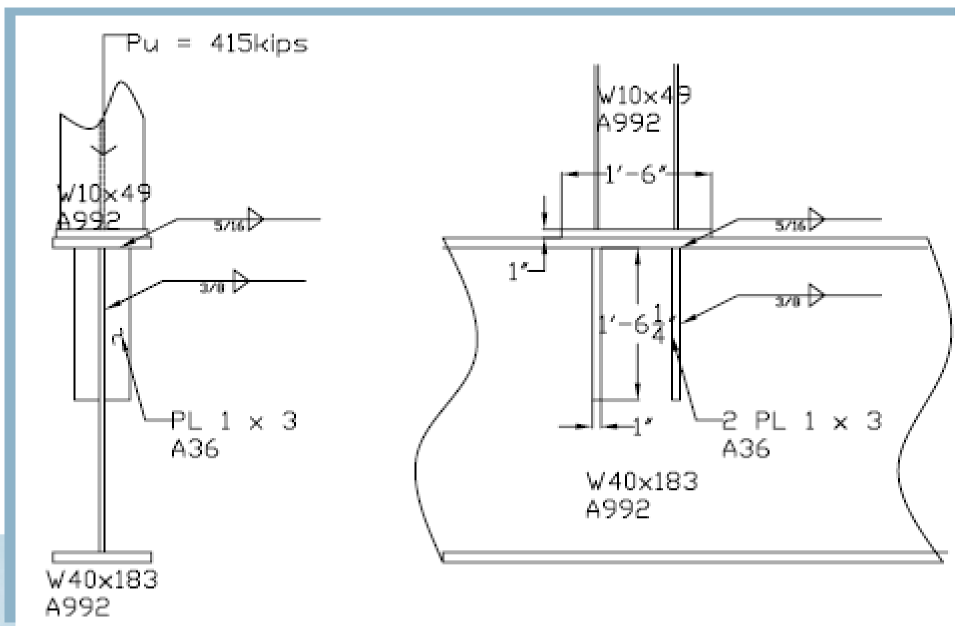




FRAME SYSTEM

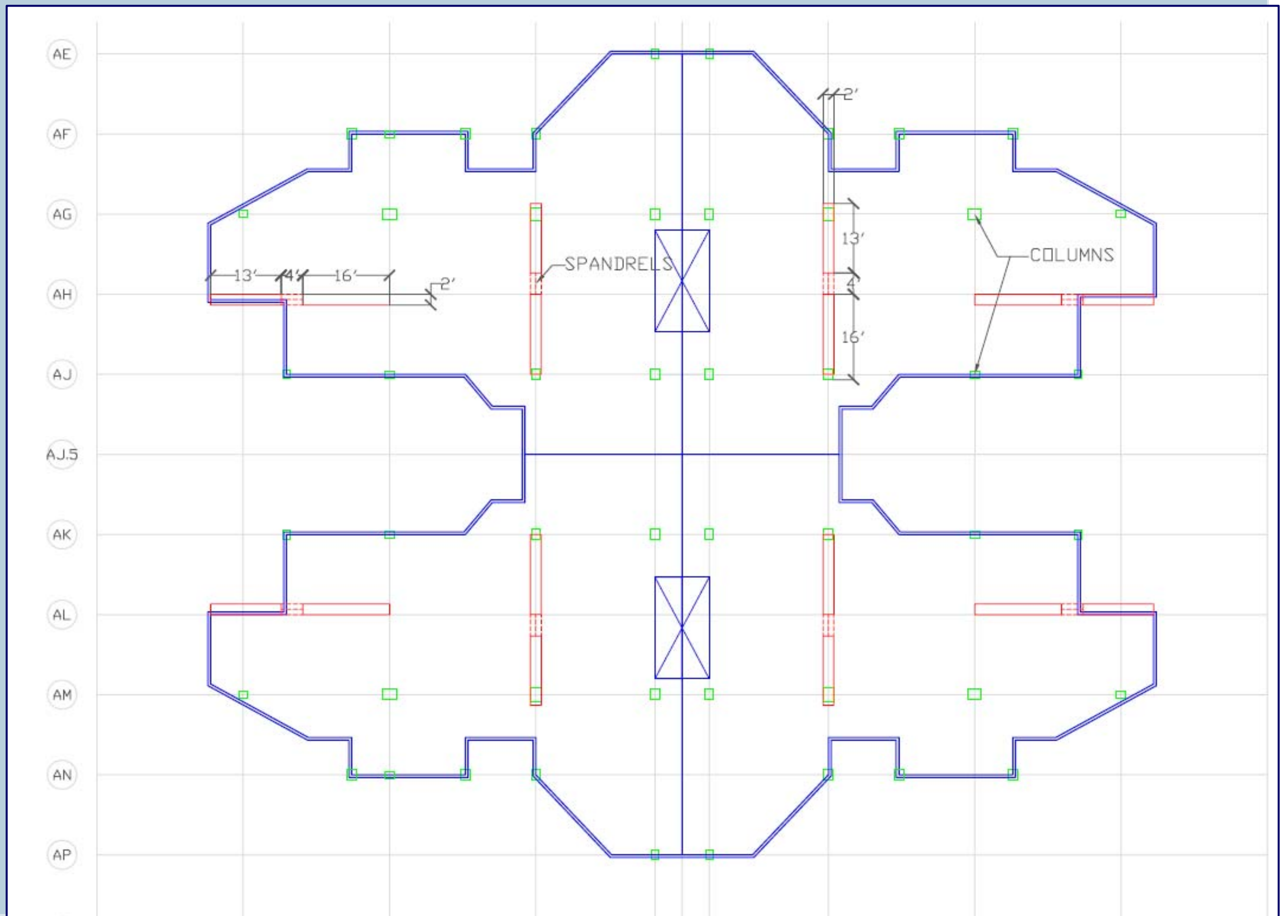
Results – Connection

Check	Rn, kips	Φ	ΦRn, k	Ru, kips
Lateral Flange Bending	465	0.9	419	415
Local Web Yielding	519	1	519	415
Local Web Crippling	724	0.75	543	415
Web Buckling	642	0.85	545	415



COUPLED WALLS

- **Proposed Layout**



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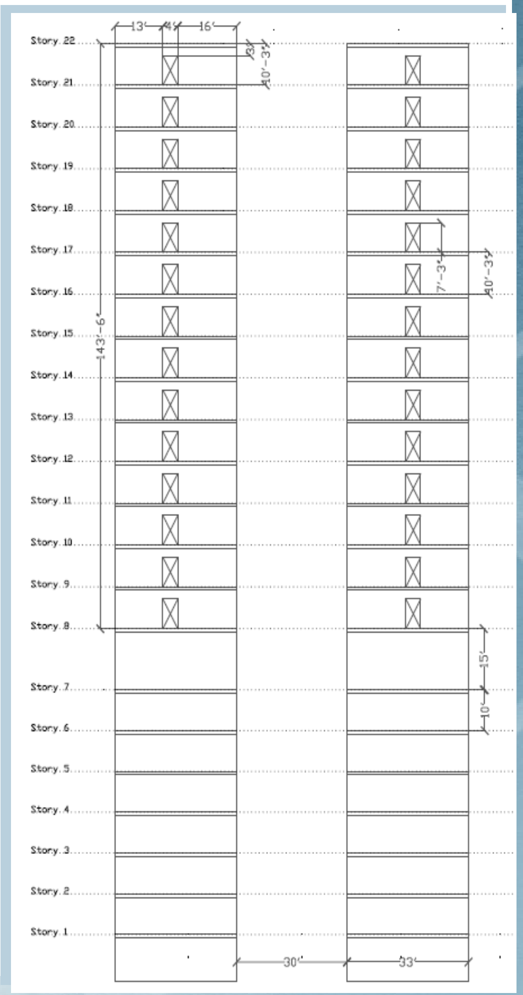
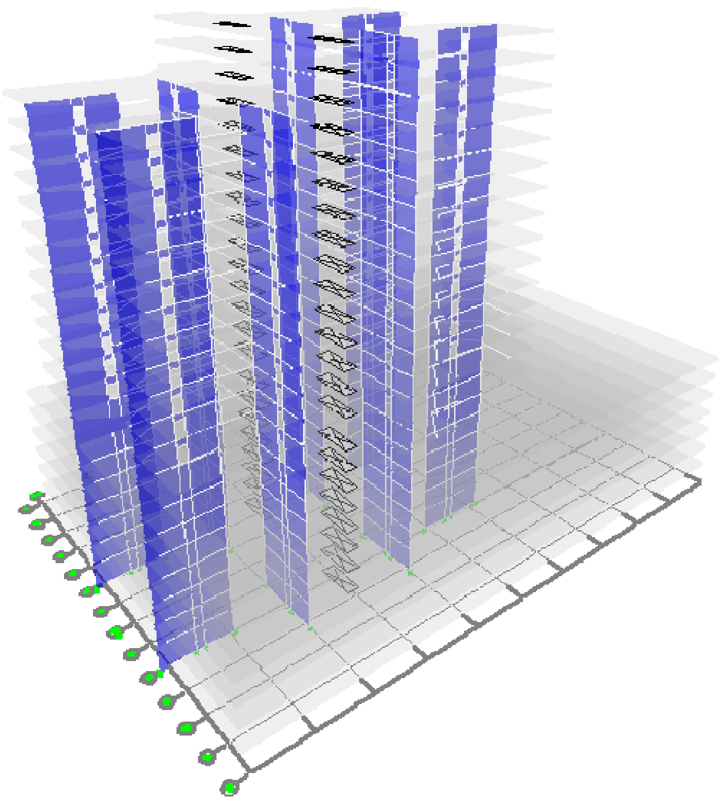
- **Proposed Layout**
- **Method**
  - **Direct Shear – ETABS**
  - **Axial Dead & Live – RAM**
    - **Steel System W = 62,000 ki**
    - **25% Reduction**
  - **Torsion**
    - **Eccentric Loading**
    - **Accidental Torsion, Ax = 2**
- **Load Combinations**
  - **$\rho = 1.1$**
  - **$C_a = 0.33$**
  - **0.8D + 1.2E**
  - **1.48D + 1.2E + 0.55L**



COUPLED WALLS

- **ETABS MODEL**



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Summary Results

Pier Forces AH | **Units** ft-kip

Load Case: EQ X

Load Combinations: 0.8*D + 1.2*E — Load Case 1; 1.48*D + 1.2*E + 1.1L — Load Case 2

Story	Pier	Load	Loc	P_D	P_L	P_E (±)	$V_{E\ Direct}$	$V_{E\ Torsion}$	$V_{E\ Total}$	M_E	Factored Loads: Pu_{CASE2}, k	Pu_{CASE1}, k	Vu, k	Mu, ft-k
STORY22	AHP3	EQY	Bottom	-96	-4	87	141	14	154	393	-251	27	185	472
STORY21	AHP3	EQY	Bottom	-144	-10	192	176	17	193	901	-456	115	232	1081
STORY20	AHP3	EQY	Bottom	-193	-16	280	36	22	58	467	-639	182	70	560
STORY19	AHP3	EQY	Bottom	-241	-22	368	114	28	142	678	-822	249	171	813
STORY18	AHP3	EQY	Bottom	-289	-26	484	156	34	189	946	-1038	349	227	1135
STORY17	AHP3	EQY	Bottom	-338	-30	627	189	39	228	1240	-1286	483	273	1488
STORY16	AHP3	EQY	Bottom	-386	-33	795	218	44	261	1556	-1563	646	313	1867
STORY15	AHP3	EQY	Bottom	-434	-36	986	244	48	292	1892	-1866	836	350	2270
STORY14	AHP3	EQY	Bottom	-483	-39	1197	267	52	319	2246	-2194	1050	383	2695
STORY13	AHP3	EQY	Bottom	-531	-42	1425	289	56	345	2620	-2543	1285	414	3144
STORY12	AHP3	EQY	Bottom	-580	-45	1668	309	60	369	3016	-2910	1538	443	3619
STORY11	AHP3	EQY	Bottom	-628	-48	1921	329	63	392	3450	-3288	1803	471	4140
STORY10	AHP3	EQY	Bottom	-677	-51	2167	350	66	416	4000	-3658	2059	500	4800
STORY9	**AHP3**	**EQY**	**Bottom**	-725	**-53**	2366	371	69	440	5008	**-3971**	**2258**	**528**	**6009**
STORY8	AHP3-4	EQY	Bottom	-1769	-113	0	665	98	763	67872	-2742	-1415	916	81446
STORY7	AHP3-4	EQY	Bottom	-1874	-143	0	699	146	844	74861	-2930	-1499	1013	89833
STORY6	AHP3-4	EQY	Bottom	-1979	-152	0	738	185	923	82238	-3095	-1583	1107	98686
STORY5	AHP3-4	EQY	Bottom	-2083	-161	0	765	218	983	89887	-3261	-1667	1180	107864
STORY4	AHP3-4	EQY	Bottom	-2188	-170	0	788	245	1033	97764	-3426	-1751	1239	117317
STORY3	AHP3-4	EQY	Bottom	-2293	-179	0	806	265	1071	105820	-3591	-1834	1285	126984
STORY2	AHP3-4	EQY	Bottom	-2398	-188	0	815	279	1094	113969	-3756	-1918	1313	136763
STORY1	**AHP3-4**	**EQY**	**Bottom**	-2518	**-197**	0	828	286	1115	120194	**-3944**	**-2015**	**1337**	**144233**

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- **Coupled Beams**
  - **CR Ratio = 27%**
  - **Results**

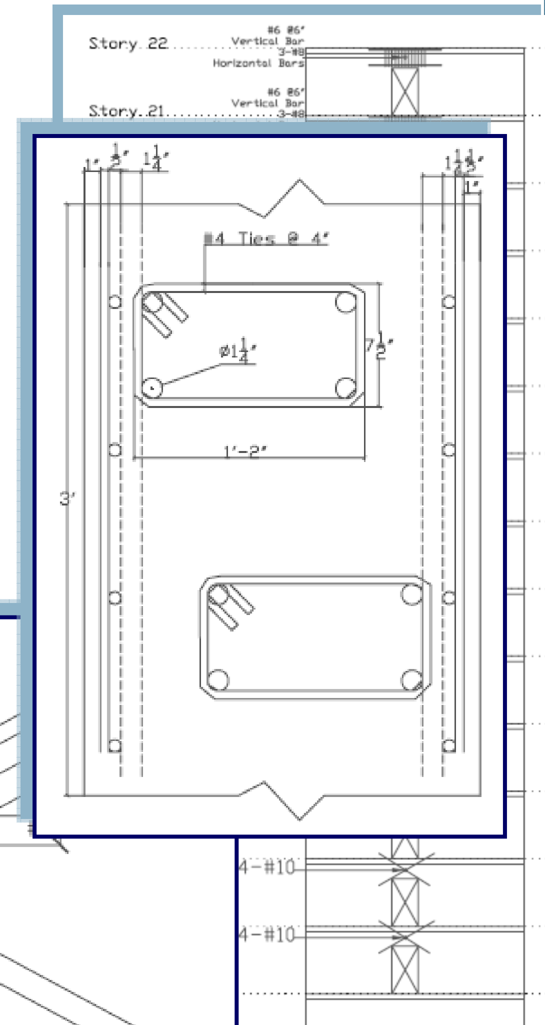
Spandrel Reinforcement

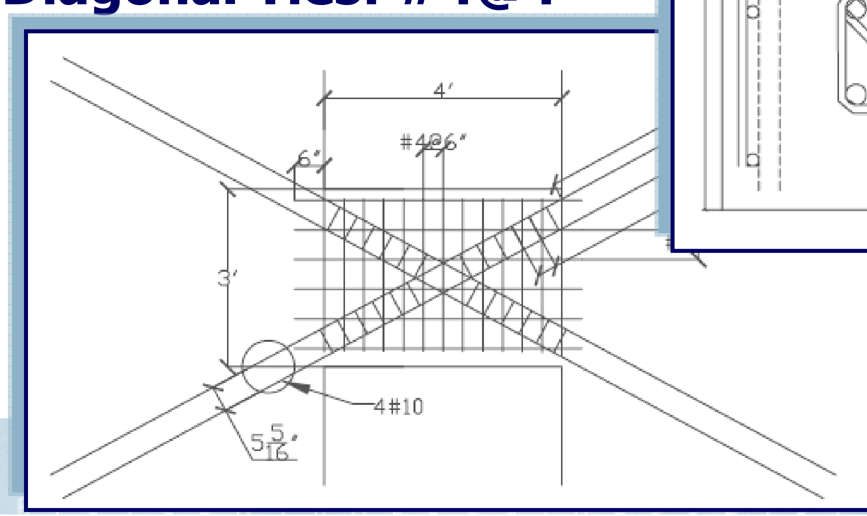
f'c =	5	ksi
b_w, in =	24	in
Φ =	0.85	
Vc =	97.75	kips
fy =	60	ksi
$ΦVn_{max}$ =	391	kips

Story	Spandrel	Load	V_E, kips	Vu, kips	h ,in	d,in	Vu/bwd√f'c	α, degı	$A_{s\text{-}v\ req}$, in²	Ad_{used}, in²	Diagonal Bars	Vertical Bars	ΦVn. Kips	ΦVn/Vu
STORY22	ALS3-4	EQX	85.34	**102.408**	36	28.8	2.1	0	0.19	0.59	0	#6 @ 9"	143.27	**1.40**
STORY21	ALS3-4	EQX	108.46	**130.152**	36	28.8	2.7	0	0.46	0.59	0	#6 @ 9"	143.27	**1.10**
STORY20	ALS3-4	EQX	86.85	**104.22**	36	28.8	2.1	0	0.21	0.59	0	#6 @ 9"	143.27	**1.37**
STORY19	ALS3-4	EQX	87.65	**105.18**	36	28.8	2.2	0	0.22	0.59	0	#6 @ 9"	143.27	**1.36**
STORY18	ALS3-4	EQX	115.8	**138.96**	36	28.8	2.8	0	0.55	0.88	0	#6 @ 6"	172.85	**1.24**
STORY17	ALS3-4	EQX	143.31	**171.972**	36	28.8	3.5	0	0.87	0.88	0	#6 @ 6"	172.85	**1.01**
STORY16	ALS3-4	EQX	168.18	**201.816**	36	28.8	**4.1**	30	3.96	5.08	4-#9	0	**259.08**	1.28
STORY15	ALS3-4	EQX	190.54	**228.648**	36	28.8	**4.7**	30	4.48	5.08	4-#9	0	**259.08**	1.13
STORY14	ALS3-4	EQX	210.62	**252.744**	36	28.8	**5.2**	30	4.96	5.08	4-#9	0	**259.08**	1.03
STORY13	ALS3-4	EQX	228.46	**274.152**	36	28.8	**5.6**	30	5.38	5.08	4-#9	0	**259.08**	0.95
STORY12	ALS3-4	EQX	243.29	**291.948**	36	28.8	**6.0**	30	5.72	6.24	4-#10	0	**318.24**	1.09
STORY11	ALS3-4	EQX	252.77	**303.324**	36	28.8	**6.2**	30	5.95	6.24	4-#10	0	**318.24**	1.05
STORY10	ALS3-4	EQX	245.7	**294.84**	36	28.8	**6.0**	30	5.78	6.24	4-#10	0	**318.24**	1.08
STORY9	ALS3-4	EQX	198.68	**238.416**	36	28.8	**4.9**	30	4.67	6.24	4-#10	0	**318.24**	1.33
													Avg =	1.12

COUPLED WALLS

- **Coupled Beams**
  - **CR Ratio = 27%**
  - **Results**
  - **Details**
    - **Vertical: #4@6"**
    - **Horizontal: #6@9"**
    - **Diagonal Ties: #4@4"**





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- **Flexure ΦMn**
  - **1st Level**
    - **L = 33 ft**
    - **B.Z: 39 #11**
    - **Web: #10@9"**
    - **ΦMn = 146337 ft-k > 144233 ft-k**

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Strain Compatibility for Shear Walls
Limiting Concrete Strain
Rectangular Stress Block (ultimate)

Job: EQX (E-W)
Location: 1st Level
Pier: AH
Length: 33'
Date: Feb, 06
Engineer: Lourdes Diaz

General Information

f'c = 5.00 ksi
fy = 60.00 ksi
l = 396.00 in
b = 24.00 in
Ag = 9504.00 in^2
x = 75.00 in Compression Zone Boundary Element Length
y = 24.00 in Compression Zone Boundary Element Width
cg = 198.00 in from extreme compression fiber
Strain = -0.0030 Ultimate concrete strain (- compression)
c = 83.50 in
β = 0.80
ρ total = 0.0195
Po= 43127 kips

Governing Equation: 0.8D + 1.2E
Pu, kips = 2015.00
Mu, ft-kips = 144233.00
phi = 0.82

Reinforcement		cover	3.00			#/row	Area / Bar	X
Boundary rows	13	spacing	6.00	Bar Size	11	3	1.56	75.00
Internal rows	26	spacing	9.00	Bar Size	10	2	1.27	196.50
Total Rows	52							393.00

Layer	y,in	Strain	c or fs, ksi	As, in^2	Ts, kips	Cc or Cs, kips	Moment Calculations	
Compression Zone	83.50	-0.00300	5.00		0.00	6813.60	0.00	1121518.56
As 1	3.00	-0.00289	60.00	4.68	0.00	280.80	0.00	54756.00
As 2	9.00	-0.00268	60.00	4.68	0.00	280.80	0.00	53071.20
As 3	15.00	-0.00246	60.00	4.68	0.00	280.80	0.00	51386.40
As 4	21.00	-0.00225	60.00	4.68	0.00	280.80	0.00	49701.60
As 5	27.00	-0.00203	60.00	4.68	0.00	280.80	0.00	48016.80
As 6	33.00	-0.00181	52.62	4.68	0.00	246.25	0.00	40630.67
As 7	39.00	-0.00160	46.37	4.68	0.00	216.99	0.00	34501.32
As 8	45.00	-0.00138	40.11	4.68	0.00	187.73	0.00	28723.07
As 9	51.00	-0.00117	33.86	4.68	0.00	158.48	0.00	23295.89
As 10	57.00	-0.00095	27.61	4.68	0.00	129.22	0.00	18219.80
As 11	63.00	-0.00074	21.36	4.68	0.00	99.96	0.00	13494.79
As 12	69.00	-0.00052	15.11	4.68	0.00	70.70	0.00	9120.87
As 13	75.00	-0.00031	8.86	4.68	0.00	41.45	0.00	5098.03
As 14	84.00	0.00002	0.52	2.54	1.32	0.00	-150.85	0.00
As 15	93.00	0.00034	9.90	2.54	25.14	0.00	-2639.85	0.00
As 16	102.00	0.00066	19.28	2.54	48.96	0.00	-4700.13	0.00
As 17	111.00	0.00099	28.65	2.54	72.78	0.00	-6331.67	0.00
As 18	120.00	0.00131	38.03	2.54	96.60	0.00	-7534.49	0.00
As 19	129.00	0.00163	47.41	2.54	120.41	0.00	-8308.58	0.00
					6927.04	9368.38	602602.88	1551535.01
			Pn =		2471.81			
					9398.85	9368.38		

Mn = 179511.49 ft-kip

phi M =	**146336.62 ft-kips**	>	**144233.00**
phi P =	**2015.00 kips**	>	**2015.00**

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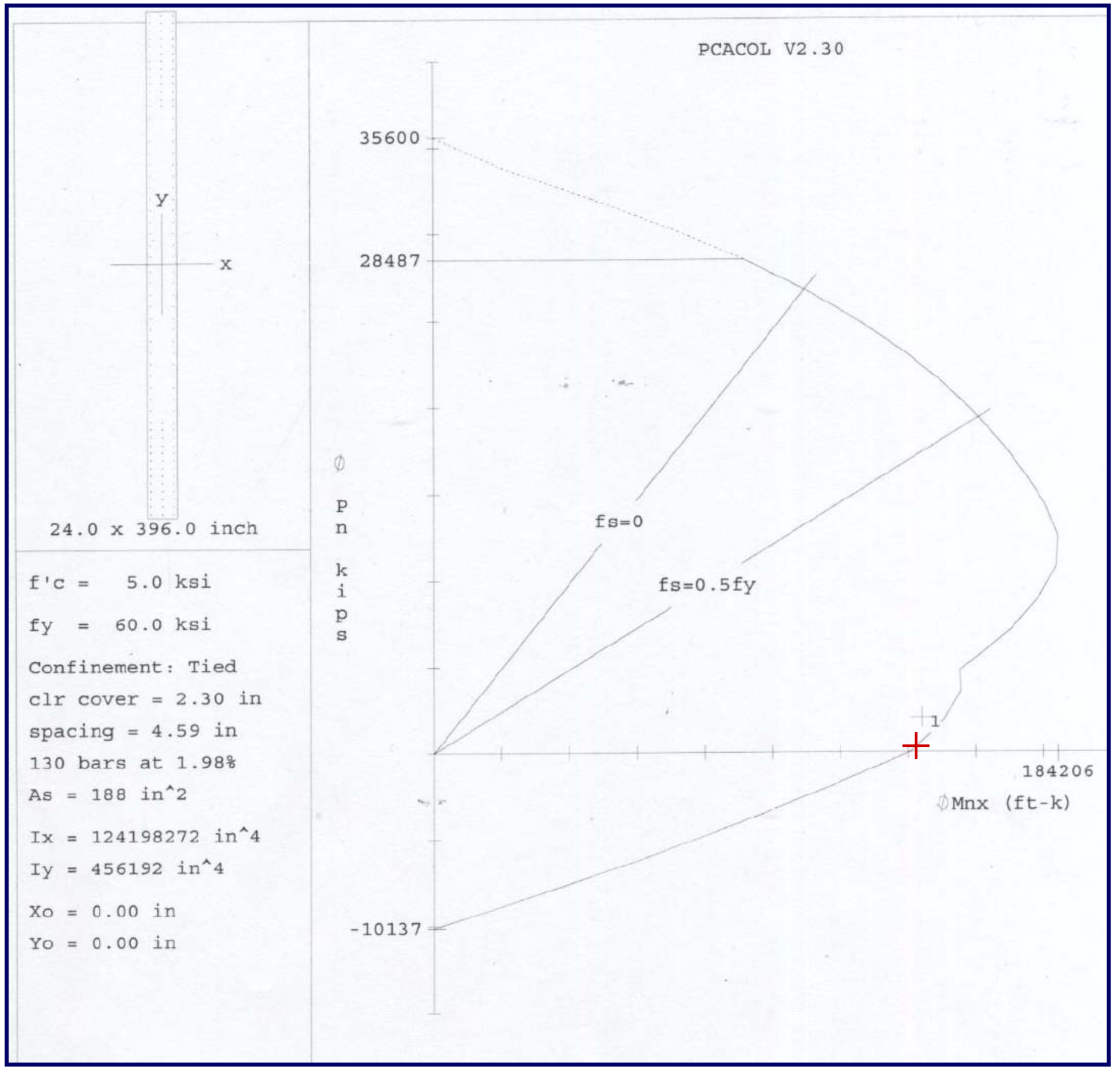
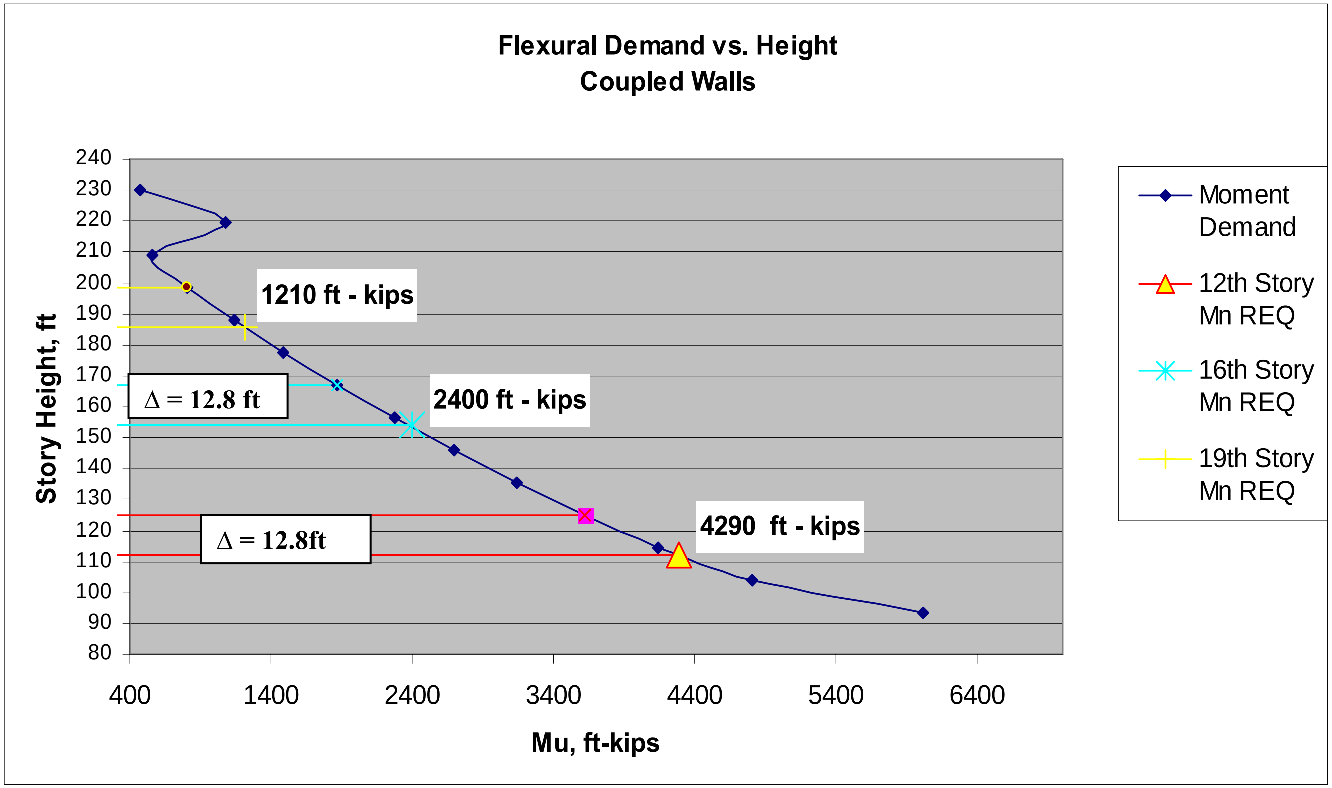


COUPLED WALLS

- **Flexure, ΦMn**
  - **Cut-Off Requirements – 0.8*L**



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- **Flexure, ΦMn**
  - **Cut-Off Requirements – 0.8*L**
  - **Vertical Reinforcement**

Summary Flexural Strenght: Preliminary Design

					Boundary End Zone				Wall Web						
Story Level	L, ft	Pu	$Mu_{,SEISMIC}$	$Mu_{, CUTOFF}$	# Layers	# Rows	Bar Size	Spacing	# Layers	# Rows	Bar Size	Spacing	ΦMn	Mpr	P_o
1st - 4th	33	-2015	144233	144233	3	13	11	6	2	26	10	9	146337	224387	43127
5th - 8th	33	-1583	98686	123500	3	7	11	6	2	34	9	9	132047	195107	41429
9th - 12th	16	2258	6009	8056	2	6	10	6	2	13	9	9	7320.87	48408	19500
13th - 16th	16	1285	3144	4290	2	4	9	6	2	11	9	9	5668	38695	18701
17th - 22th	16	483	1488	2400	2	0	8	6	2	16	8	12	6578	24746	17919

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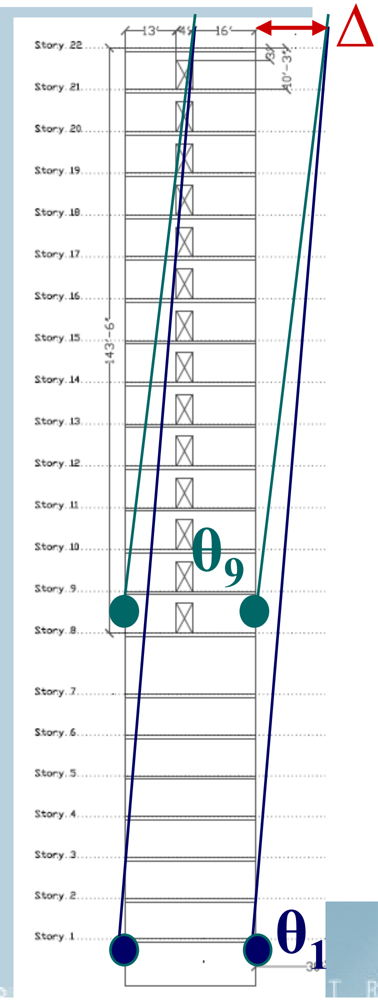
- **Ductility & Plastic Hinge Development**

Preferred Plastic Hinge at Base:

Minimize Impact on Non-Structural Systems

$$\Theta_1 < \theta_9$$



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■ Ductility & Plastic Hinge Development

Required Shear Strenght to Develop Plastic Hinge at 1st Story Level

Ip = 16.5 ft
Pier: AH
V = 1026 kips

Story Level	hi	hi - Ip/2	Δi, ft	ƒi / V_{BASE}	Work / V
22	230	221.75	1	0.271	0.2710
21	219.75	211.5	0.954	0.067	0.0641
20	209.5	201.25	0.908	-0.230	-0.2088
19	199.25	191	0.861	0.149	0.1284
18	189	180.75	0.815	0.079	0.0644
17	178.75	170.5	0.769	0.068	0.0525
16	168.5	160.25	0.723	0.058	0.0423
15	158.25	150	0.676	0.056	0.0376
14	148	139.75	0.630	0.048	0.0301
13	137.75	129.5	0.584	0.046	0.0268
12	127.5	119.25	0.538	0.042	0.0225
11	117.25	109	0.492	0.037	0.0182
10	107	98.75	0.445	0.067	0.0299
9	96.75	88.5	0.399	0.032	0.0128
8	86.5	78.25	0.353	0.031	0.0110
7	71.5	63.25	0.285	0.038	0.0108
6	61.5	53.25	0.240	0.042	0.0101
5	51.5	43.25	0.195	0.029	0.0057
4	41.5	33.25	0.150	0.025	0.0038
3	31.5	23.25	0.105	0.019	0.0020
2	21.5	13.25	0.060	0.010	0.0006
1	11.5	3.25	0.015	0.015	0.0002
				1	**0.6361**

Required Shear Strenght to Develop Plastic Hinge at 9 th Story Level

Ip = 8 ft
Pier: AH
V = 811 kips

Story Leve	hi	hi - Ip/2	Δi, ft	ƒi / VBASE	Work / V
22	143.45	139.45	1.0000	0.3428	0.3428
21	133.2	129.2	0.9265	0.0851	0.0788
20	122.95	118.95	0.8530	-0.2910	-0.2482
19	112.7	108.7	0.7795	0.1887	0.1471
18	102.45	98.45	0.7060	0.0999	0.0705
17	92.2	88.2	0.6325	0.0863	0.0546
16	81.95	77.95	0.5590	0.0740	0.0414
15	71.7	67.7	0.4855	0.0703	0.0341
14	61.45	57.45	0.4120	0.0604	0.0249
13	51.2	47.2	0.3385	0.0580	0.0196
12	40.95	36.95	0.2650	0.0530	0.0140
11	30.7	26.7	0.1915	0.0469	0.0090
10	20.45	16.45	0.1180	0.0851	0.0100
9	10.2	6.2	0.0445	0.0407	0.0018
				1.0000	**0.6004**

Virtual Work

θ = 1.0 / 221.75 = 0.00450958

Internal Work , Coupling Beams

Story	1.25V_n	l_c, ft	Work (ft-kip)
22	210.69	18.5	17.58
21	210.69	18.5	17.58
20	210.69	18.5	17.58
19	210.69	18.5	17.58
18	254.19	18.5	21.21
17	254.19	18.5	21.21
16	381	18.5	31.79
15	381	18.5	31.79
14	381	18.5	31.79
13	381	18.5	31.79
12	468	18.5	39.04
11	468	18.5	39.04
10	468	18.5	39.04
9	468	18.5	39.04
			396.04

Internal Work, Piers

Base	Mpr, (k -ft)		Work,(k -ft)
AH	224387		**1011.89**

θ = 1.0 / 139.45 = 0.00717103

Internal Work , Coupling Beams

Story	1.25Vn	lc, ft	Work (ft-kip)
22	210.69	18.5	27.95
21	210.69	18.5	27.95
20	210.69	18.5	27.95
19	210.69	18.5	27.95
18	254.19	18.5	33.72
17	254.19	18.5	33.72
16	381.00	18.5	50.54
15	381.00	18.5	50.54
14	381.00	18.5	50.54
13	381.00	18.5	50.54
12	468.00	18.5	62.09
11	468.00	18.5	62.09
10	468.00	18.5	62.09
9	468.00	18.5	62.09
			629.77

Internal Work, Piers

Level	Mpr, (k -ft)		Work,(k -ft)
9th A1	56800		407.31
9th A2	40780		292.43
			699.75

V = (1066.90 + 396.04)/.6361 = **2213** kips < V = (585.94 + 629.77)/.6004 = **2214** kips

COUPLED WALLS

▪ Minimum Shear and Magnified Shear Demand

Minimum Reinforcement for Shear Strenght

Units: Kips-ft
Direction: EQ X
Pier Label: AH
ρmin = 0.0025
hw = 230 ft
lw = 33 ft
hw/lw = 6.97
Φ = 0.85
Vn < 5376 (33' length)
Vn < 2606 (16' length)

$$V_u* = \varpi_v (M_{pr} / M_u) * V_u$$

							Dynamic Amplification Factor	3.45					
							Ductile Behavior						
Level	Vu, kips	Length, ft	ρ_{REQ}	ρ_{USED}	Horizontal Reinforcement	ΦVn, kips	Vu, kips	Vu*, kips	ρ_n	ρ_{USED}	Horizontal Reinforcemetn	ΦVn, kips	ΦVn/Vu
22	185	16	-0.0012	0.00305	#6 @ 12" E.F.	897	185	638	0.0004	0.00305	#6 @ 12" E.F.	1271	1.99
21	232	16	-0.0010	0.00305	#6 @ 12" E.F.	897	232	799	0.0010	0.00305	#6 @ 12" E.F.	1271	1.59
20	70	16	-0.0019	0.00305	#6 @ 12" E.F.	897	70	242	-0.0013	0.00305	#6 @ 12" E.F.	1271	5.26
19	171	16	-0.0013	0.00305	#6 @ 12" E.F.	897	171	588	0.0001	0.00305	#6 @ 12" E.F.	1271	2.16
18	227	16	-0.0010	0.00305	#6 @ 12" E.F.	897	227	783	0.0010	0.00305	#6 @ 12" E.F.	1271	1.62
17	273	16	-0.0007	0.00305	#6 @ 12" E.F.	897	273	943	0.0017	0.00305	#6 @ 12" E.F.	1271	1.35
16	313	16	-0.0005	0.00305	#6 @ 12" E.F.	897	313	1081	0.0022	0.00305	#6 @ 12" E.F.	1271	1.18
15	350	16	-0.0002	0.00305	#6 @ 12" E.F.	897	350	1207	0.0028	0.00305	#6 @ 12" E.F.	1271	1.05
14	383	16	0.0000	0.00305	#6 @ 12" E.F.	897	383	1322	0.0033	0.00550	#8 @ 12" E.F.	1847	1.40
13	414	16	0.0001	0.00305	#6 @ 12" E.F.	897	414	1429	0.0037	0.00550	#8 @ 12" E.F.	1847	1.29
12	443	16	0.0003	0.00305	#6 @ 12" E.F.	897	443	1527	0.0041	0.00550	#8 @ 12" E.F.	1847	1.21
11	471	16	0.0005	0.00305	#6 @ 12" E.F.	897	471	1625	0.0046	0.00550	#8 @ 12" E.F.	1847	1.14
10	500	16	0.0007	0.00305	#6 @ 12" E.F.	897	500	1724	0.0050	0.00550	#8 @ 12" E.F.	1847	1.07
9	**528**	**16**	**0.0008**	**0.00305**	**#6 @ 12" E.F.**	**897**	528	1822	0.0054	0.00550	#8 @ 12" E.F.	1847	1.01
8	885	33	0.0002	0.00305	#6 @ 12" E.F.	1850	885	3053	0.0039	0.00550	#8 @ 12" E.F.	3808	1.25
7	931	33	0.0004	0.00305	#6 @ 12" E.F.	1850	931	3212	0.0043	0.00550	#8 @ 12" E.F.	3808	1.19
6	983	33	0.0005	0.00305	#6 @ 12" E.F.	1850	983	3390	0.0046	0.00550	#8 @ 12" E.F.	3808	1.12
5	1019	33	0.0006	0.00305	#6 @ 12" E.F.	1850	1019	3516	0.0049	0.00550	#8 @ 12" E.F.	3808	1.08
4	1050	33	0.0007	0.00305	#6 @ 12" E.F.	1850	1050	3622	0.0051	0.00550	#8 @ 12" E.F.	3808	1.05
3	1074	33	0.0008	0.00305	#6 @ 12" E.F.	1850	1074	3705	0.0053	0.00550	#8 @ 12" E.F.	3808	1.03
2	1087	33	0.0008	0.00305	#6 @ 12" E.F.	1850	1087	3749	0.0054	0.00550	#8 @ 12" E.F.	3808	1.02
1	**1104**	**33**	**0.0009**	**0.00305**	**#6 @ 12" E.F.**	**1850**	1104	3808	0.0055	0.00550	#8 @ 12" E.F.	3808	1.00

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- **Boundary Zones**
  - **Requirements**

$$P_u < 0.10 A_g f'c$$

$$\frac{M_u}{l_u V_u} < 1.0$$

$$V_u < 3A_{cv}\sqrt{f'_c}, \quad \frac{M_u}{l_u V_u} < 3$$

  - **Length**

$$\frac{B.Z(ft)}{l_w} = \frac{0.1P_u}{0.2P_o}$$

Required Bondary Zones Accordng to UBC Simplied Procedure

f'c = 5 ksi
t = 24 in
$B.Z._{min}$ = 0.15Lw

Story	Lw, ft	P_{uCASE2}	>0.10f'cAg	Vu, k	Vu > 3Acv√f'c	Mu, ft-kip	Mu/(luVu) > 3	Po	0.35Po	0.15Po	B.Z./Lw	B.Z., in
1st	33	3944	4752	1104	2016	144233	3.96	43127	15094	6469	0.046	60
5th	33	3261	4752	1019	2016	107864	3.21	41429	14500	6214	0.039	60
9th	16	3971	2304	528	978	6009	0.71	203413	71195	30512	0.010	30
12th	16	2910	2304	443	978	3619	0.51	18701	6545	2805	0.078	30
16th	16	1866	2304	313	978	2270	0.45	17919	6272	2688	N.R	N.R.

Ties: #5@6”

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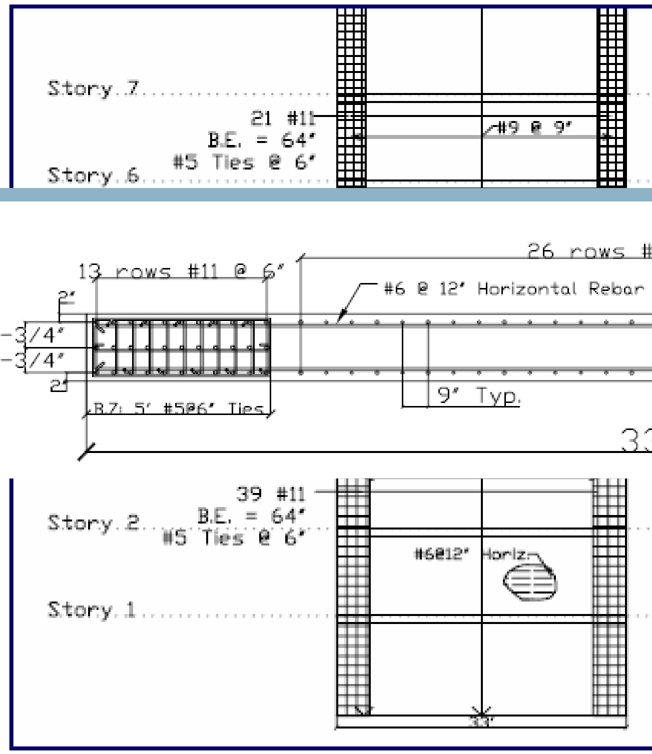
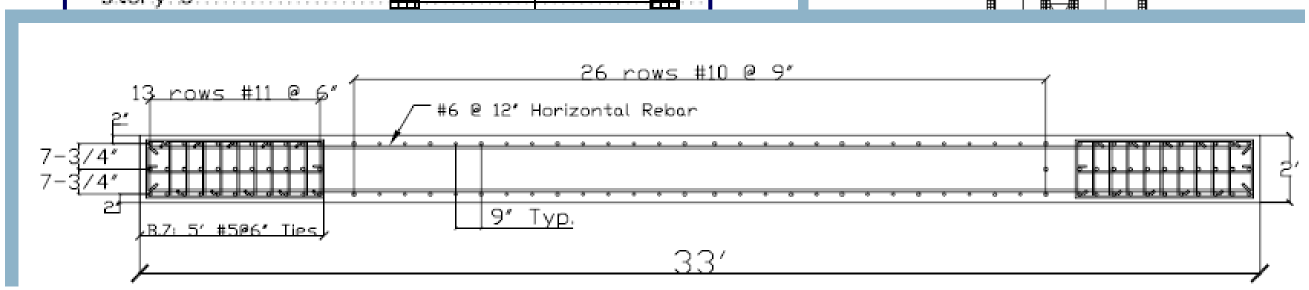
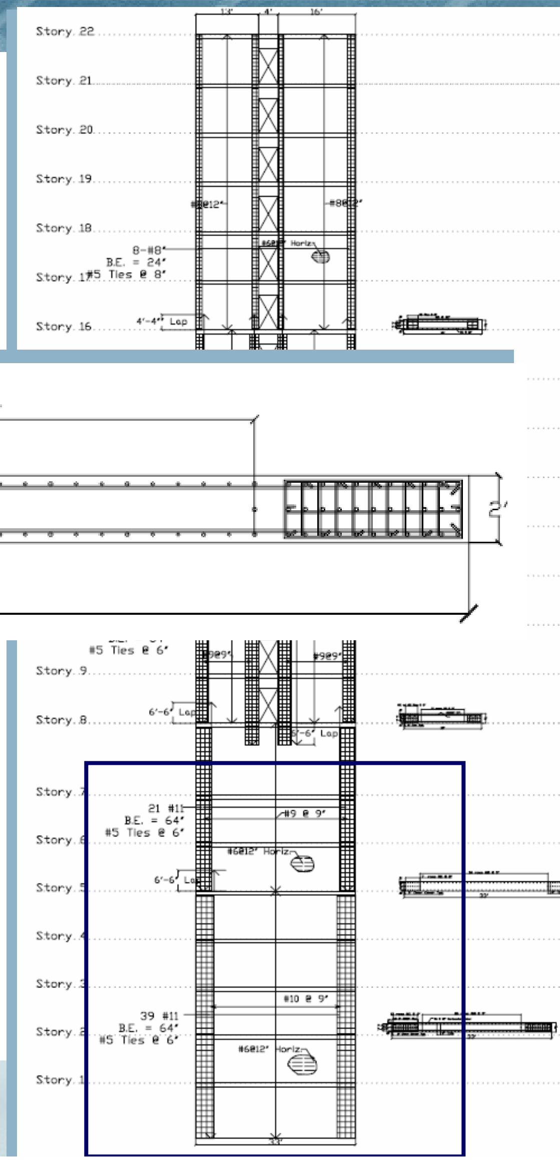
- **Final Design**







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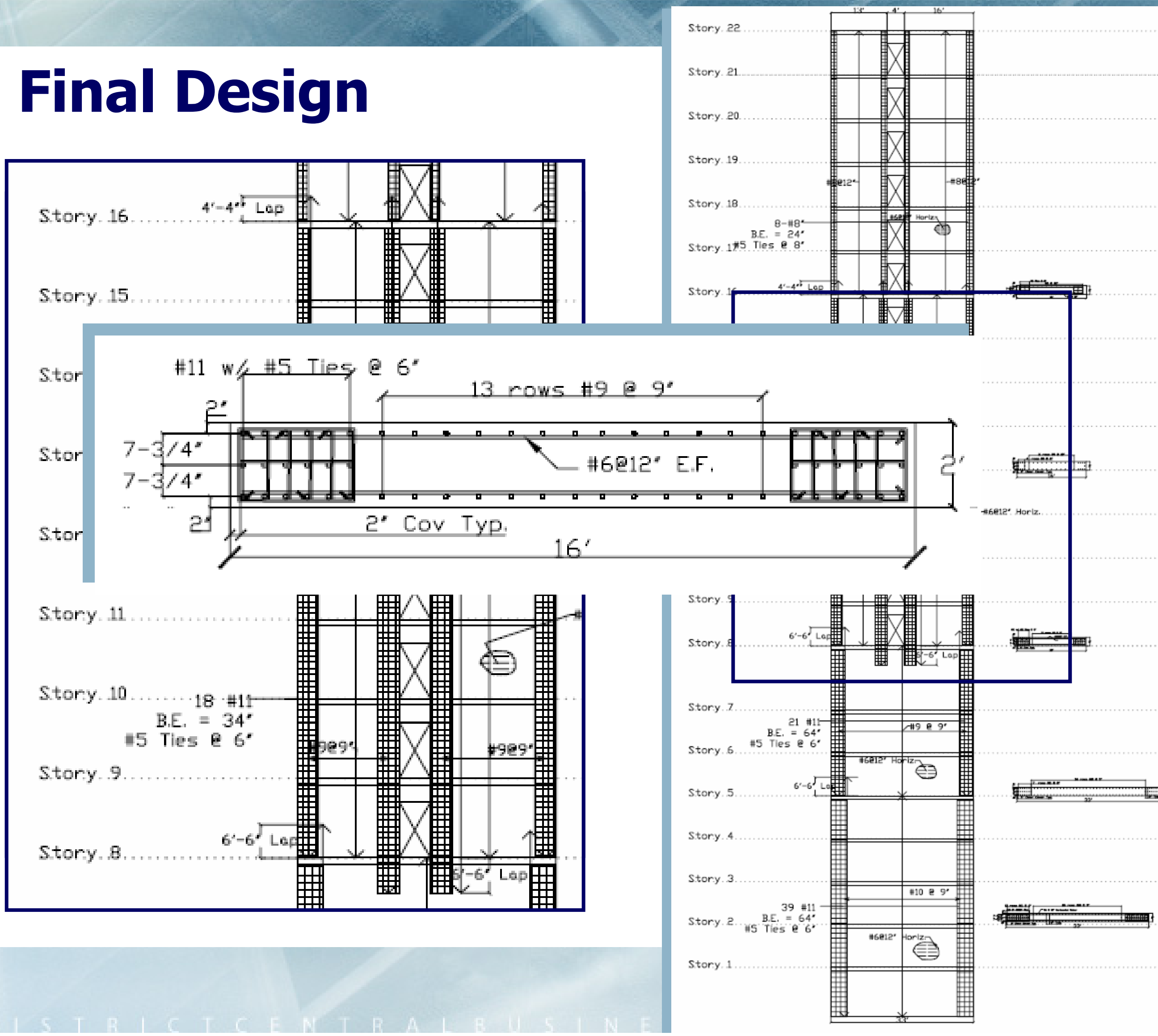
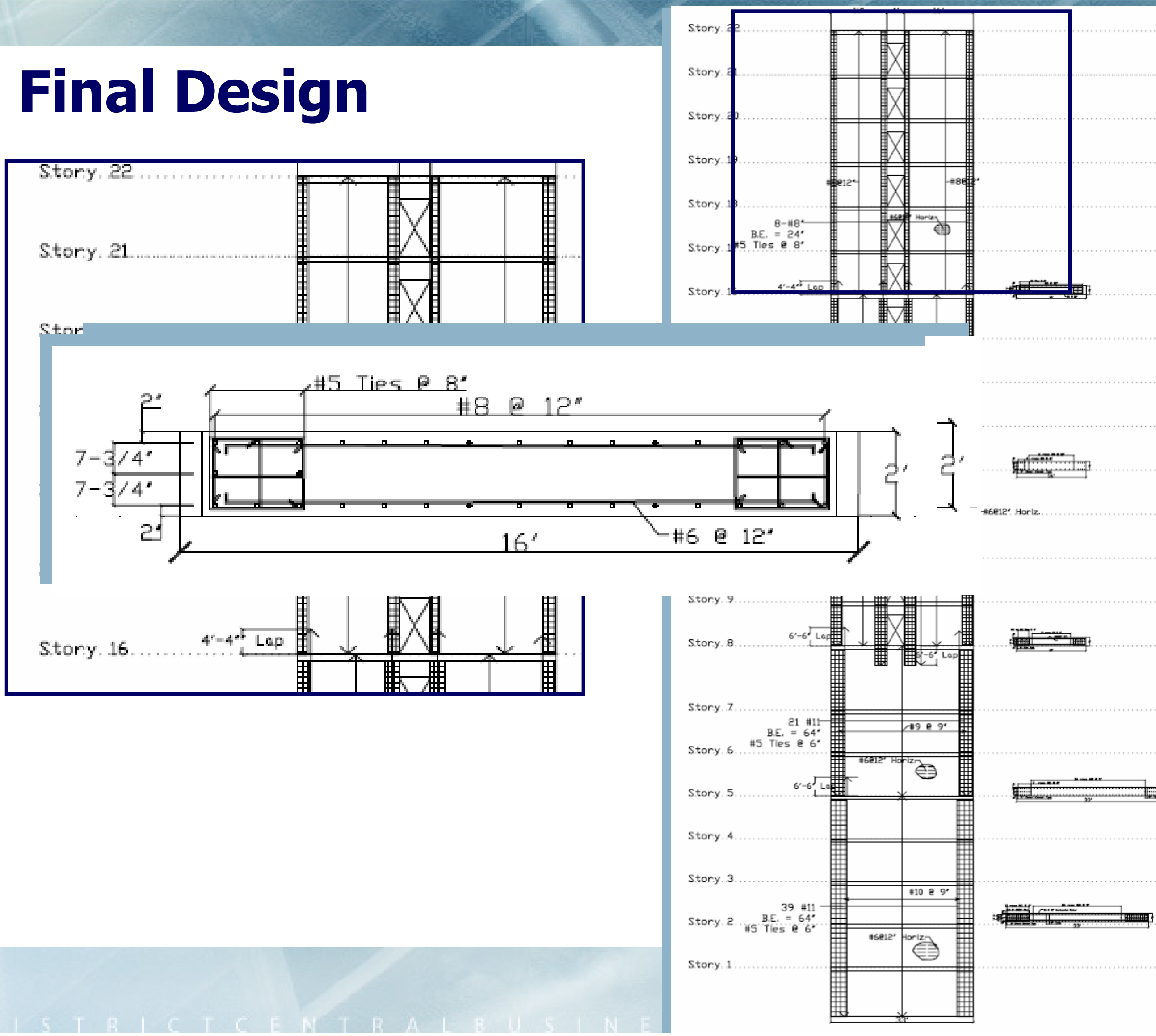
- **Final Design**



COUPLED WALLS

- **Final Design**



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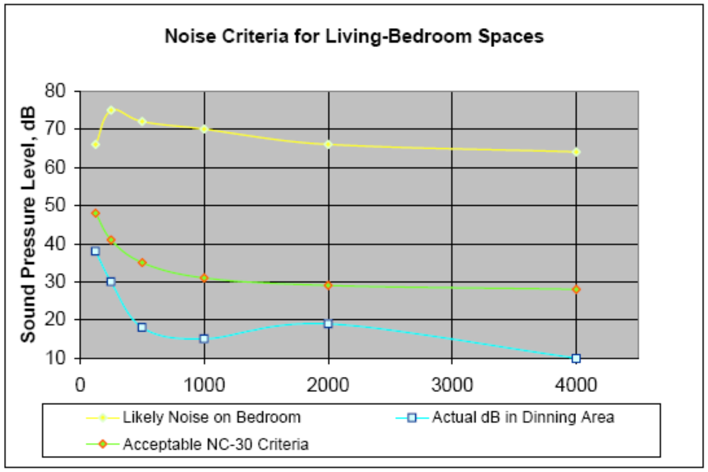
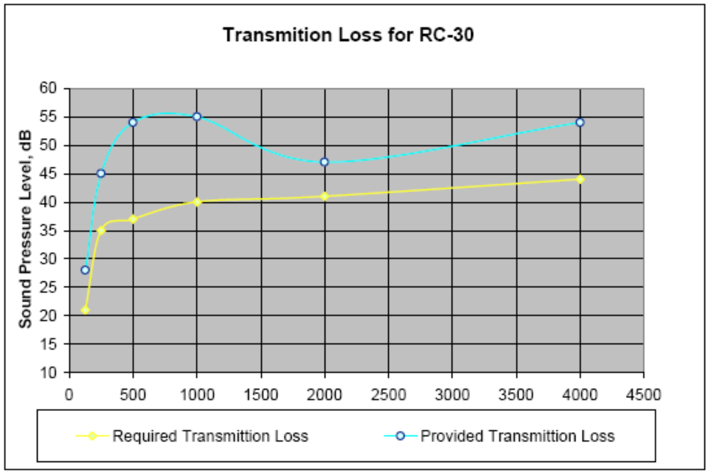
- **Architecture**
  - **Saved 160 ft^2 / Floor**
  - **Flexible and Open Plan for:**
    - **Architect**
    - **Owner**
    - **Future Tenants**
  - **Larger Open Areas of up to 50’**

COMMODITIES

- **Acoustics**





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- **Acoustics**
- **Vibrations**

Living Areas:
W10X15

↑TO

W10X26

Floor Vibration Summary

Slab			
	f'c, ksi	5	
	t, in	2.5	
	deck, in	1.5	
	n	6.15	
Beam			
	Size	W10x26	
	w, klf	0.59	
	Area, in^2	7.61	
	d, in	10.2	
	I, in^4	144	
	L, ft	27	
	Tributary Width, ft	7.5	
	d_{eff},in	90	
	$I_{transformed}$, in4	551	
	Δ, in	0.442	
	f_{beam}, Hz	5.32	
	B_b, ft	28.35	Effective Width
	W_b, kips	90.32	Effective Weight
Girder			
	Size	W10x22	
	w, klf	2.15	
	Area, in^2	6.49	
	d, in	10.2	
	I, in^4	188	
	L, ft	15	
	Tributary Width, ft	27	
	d_{eff},in	45	
	$I_{transformed}$, in4	597	
	Δ, in	0.141	
	f_{beam}, Hz	9.42	
	B_g, ft	19.58	Effective Width
	W_g, kips	23.39	Effective Weight
Combined Floor System			
	W, kips	81.1	
	f_n, Hz	4.92	
	a_p/g, %	0.48	> 0.5
			Acceptable

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- **U.S Cost**
  - **$1,000,000 Savings**
  - **Formwork ↓ 450,000 sfca**
  - **Rebar Placement ↓ 100 tons**
- **Puerto Rico**
  - **$400,000 Deficit**
  - **Concrete Labor Market → 12%**
  - **Finishes & Partitions → 323%**

CONSTRUCTION

Existing Building

											Adjusted Values	
Lateral System												
Walls				Quantity	Daily Output	Material	Labor	Equipm.	Total	**Total**	**City Index - PR**	
	Concrete	4,000 psi	cy	4661		91			91	**$424,151.00**	0.761	$322,778.91
	Form	4 uses	sfca	281740	235	2.42	7.05		9.47	**$2,668,077.80**	0.299	$797,755.26
	Placing	w/ Crane and Bucket	cy	4661	95		22.5	10.65	33.15	**$154,512.15**	0.761	$117,583.75
	Finishes	Break ties/ patch voids	sfca	126297	540	0.03	0.51	0.54	0.78	**$136,400.76**	0.761	$103,800.98
	Rebar	#8-18 over 100 tons	tons	530	3.2	855	418.5	7.05	1280.55	**$678,691.50**	1.01	$685,478.42
	Unloading and Sorting		tons	530	100		21.5	6.5	28	**$14,840.00**	1.01	$14,988.40
									Total	**$4,076,673.21**		**$2,042,385.71**
Floor System/ Floor Cost												
Number Floors		14		Quantity	Daily Output	Material	Labor	Equipm.	Total	**Total**		
Floor Slab												
	Concrete	4,500psi	cy	467		93			93	**$608,034.00**	0.761	$462,713.87
	Form	Flat Plate - 4 Uses	sf	16813	560	1.4	2.96	0	4.36	**$1,026,265.52**	0.299	$306,853.39
	Placing	9" thick elvated	cy	467	160		11.9	4.65	16.55	**$108,203.90**	0.761	$82,343.17
	Finishing	Screen, Float, Hand Tr	sf	16813	600		0.46	0.46	0.68		0.761	$0.00
	Rebar	Elevated Slab #4-#7	tons	8.8	2.9	905	435		1340	**$165,088.00**	1.01	$166,738.88
	P/T Tendons	Ungrouted 100' span	lbs	11200	1500	0.47	0.85	0.02	1.34	**$210,112.00**	1.01	$212,213.12
	Unloading and Sorting		tons	8.8	100		21.5	6.5	28	**$246.40**	1.01	$248.86
									Total	**$2,117,703.42**		**$1,231,111.30**
									Total	$6,194,376.63		$3,273,497.01

Steel Frame & Coupled Walls

				Quantity	Daily Output	Material	Labor	Equipm.	Total	**Total**	**Adjusted Values**	
Lateral System											**City Index**	
Walls	Concrete	5,000 psi	cy	3960		96			96	**$380,160.00**	0.761	$289,301.76
	Form	4 uses	sfca	81760	235	2.42	7.05		9.47	**$774,267.20**	0.299	$231,505.89
	Placing	w/ Crane and Bucket	cy	3960	95		22.5	10.65	33.15	**$131,274.00**	0.761	$99,899.51
	Finishes	Break ties/ patch voids	sfca	496	540	0.03	0.51	0.54	0.78	**$386.88**	0.761	$294.42
	Rebar	#8-18 over 100 tons	tons	477	3.2	855	418.5	7.05	1280.55	**$610,822.35**	1.01	$616,930.57
	Unloading and Sorting		tons	477	100		21.5	6.5	28	**$13,356.00**	1.01	$13,489.56
	Coupling Beams			23.85	3.2				5% Rebar	**$31,208.92**	1.01	$31,521.01
								Total		**$1,941,475.35**		**$1,282,942.72**
Frame System/ Floor Cost												
Number of Floors			14									
	Steel	Apartments>15 story	tons	735	13.9	2050	365	118	2533	**$1,861,755.00**	0.878	$1,634,620.89
	Deck	20 gage, 1.5"	sf	16813	4300	1.24	0.3	0.02	1.56	**$367,195.92**	0.878	$322,398.02
	Concrete	4500psi	cy	182		93			93	**$236,964.00**	0.761	$180,329.60
	Placing	<6" Pumped	cy	182	140		13.55	5.3	18.85	**$48,029.80**	0.761	$36,550.68
	Finishes	Screen, Float, Hand Tr	sf	16813	600		0.46	0.46	0.68	**$160,059.76**	0.761	$121,805.48
	Studs	3/4" dia 3-3/8" long	ea	2700	950	0.43	0.69	0.28	1.4	**$52,920.00**	0.878	$46,463.76
									Total	**$2,726,924.48**		**$2,342,168.43**
Additional Cost												
	Exterior Shell	6" thick, 4000psi, with	sf	4225					12.2	**$51,545.00**	0.868	**$44,741.06**
									Total	$4,719,944.83		$3,669,852.21
								Difference		**$1,474,431.80**		**-$396,355.20**

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- **Current design reflects the labor practices and situation of the country**
- **Designers applied the best and most economical design to a complicated structure**
- **Coupled wall systems proved to be an effective resisting system, allowed for increased floor area and architectural freedom**
- **Reduced the amount of material and labor required for the project**
- **Overall: Good design when the resources are available**

THANK YOU

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