Largo Medical Office Building

Presented by Thaison Nguyen

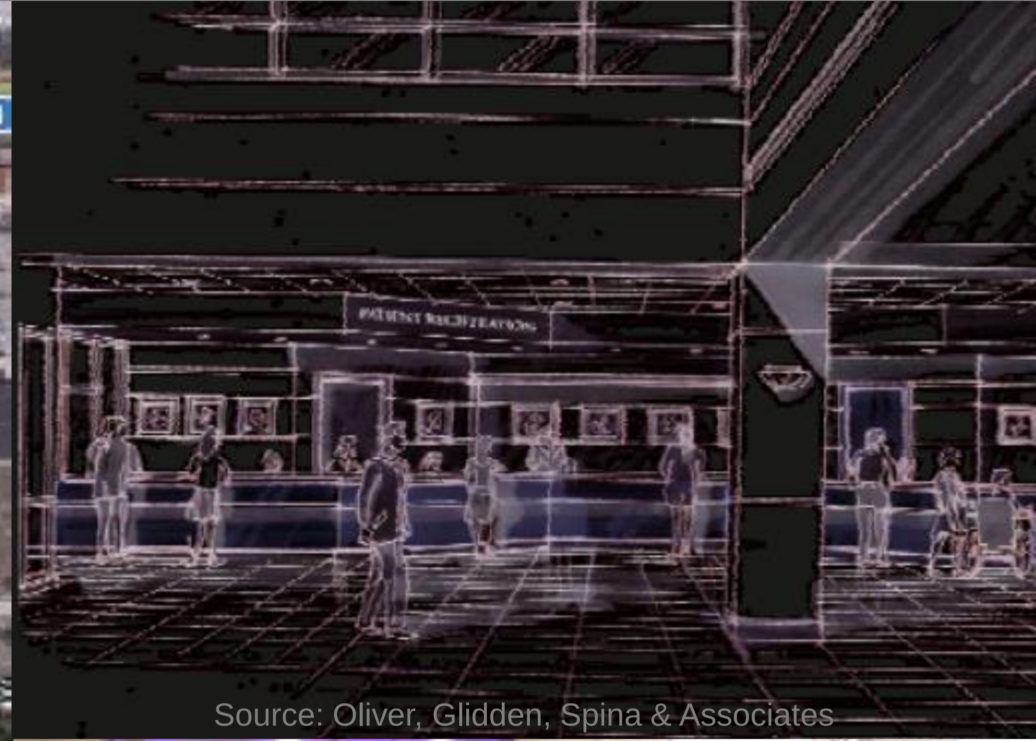
General

Gross Area: 154,240 sq. ft.
As-Built Cost: $12.6 Million (not including equipment)
Dates of Construction: August 2008 — November 2009
Project Delivery Method: Design-Bid-Build

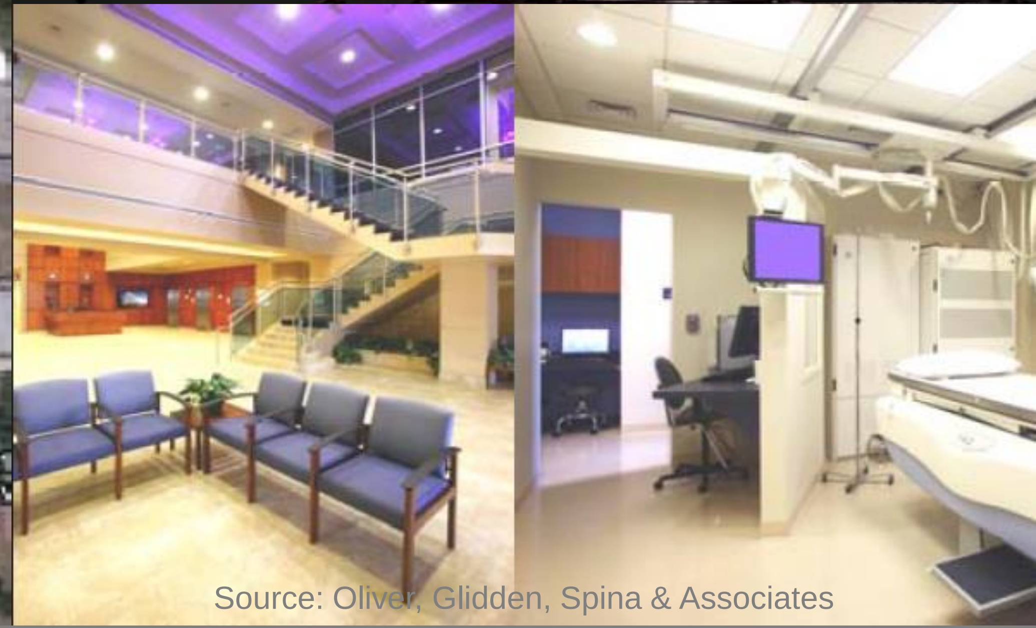
MEP Systems

Primary Cooling: DX with (2) Cooling Towers
Heating: Resistant Heating Elements located at each floor
Electrical: 480/277V 3 phase - High Voltage
208/120V 3 phase - Low Voltage
Lighting: LED and Fluorescent Lighting with occupancy and photo-sensors

Source: Oliver, Glidden, Spina & Associates



Source: Oliver, Glidden, Spina & Associates



Source: Oliver, Glidden, Spina & Associates

Project Intent

Tame torsional and soft-story effects

Project Scope

Evaluate redesigns of LMOB’s lateral system

Façade redesign

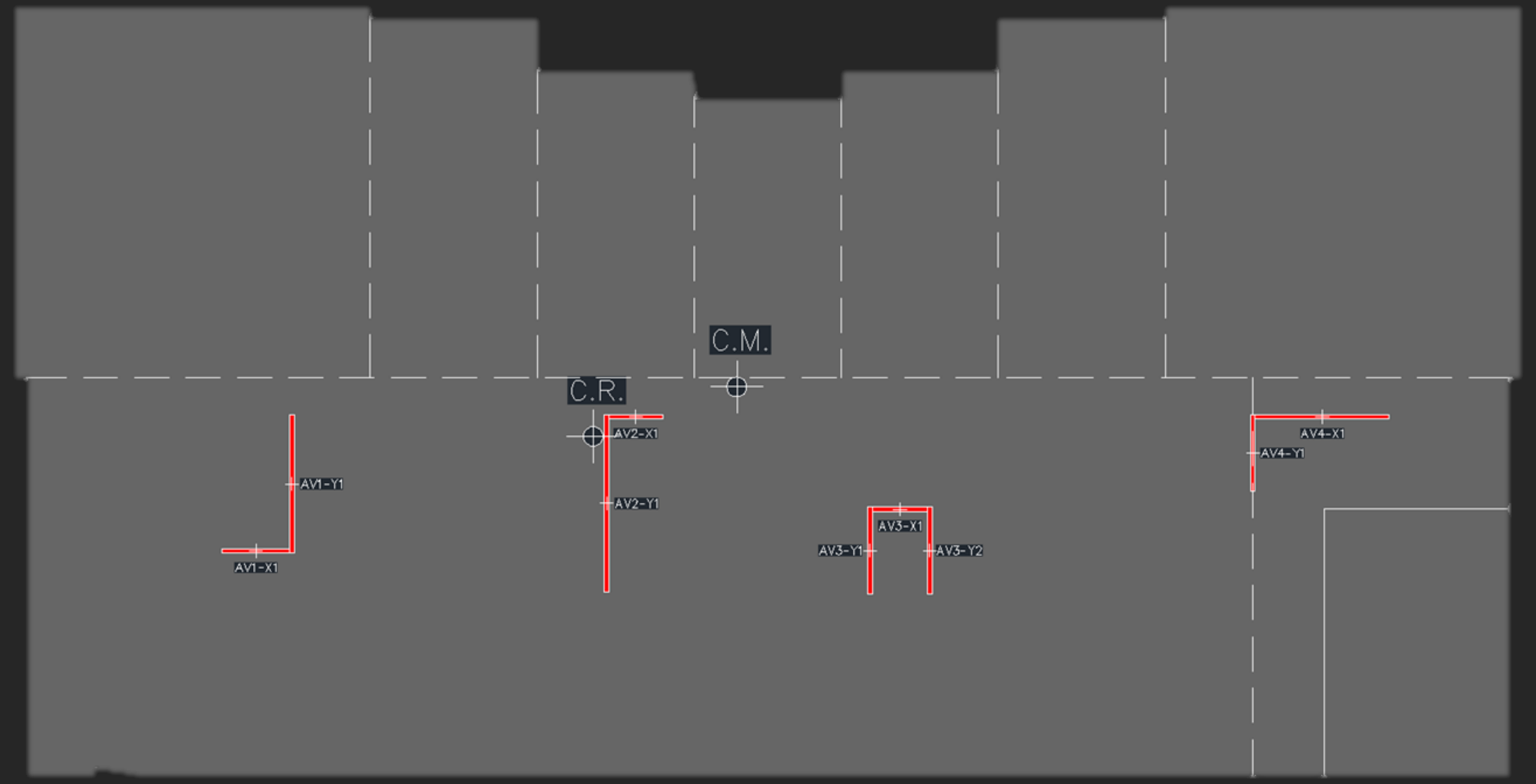


Table P1.1, Design Guides

Use	Codes and Standards
General Building Code	IBC 2009
General Load Determination	ASCE 7-05
Structural Steel Design	AISC Steel Design and Construction Manual 14th Edition
Steel Reinforcement Parameters	ASTM A615
Reinforced Concrete Design	ACI 318-11
Tilt-Up Wall Design	TCA Tilt-Up Construction and Design Manual 2006
Cold Formed Steel (CFS) Design	AISI Manual 2008
Other	ACI 201.2R-08
	ASHRAE Standard 170

Design I

Supplement existing lateral force resisting elements

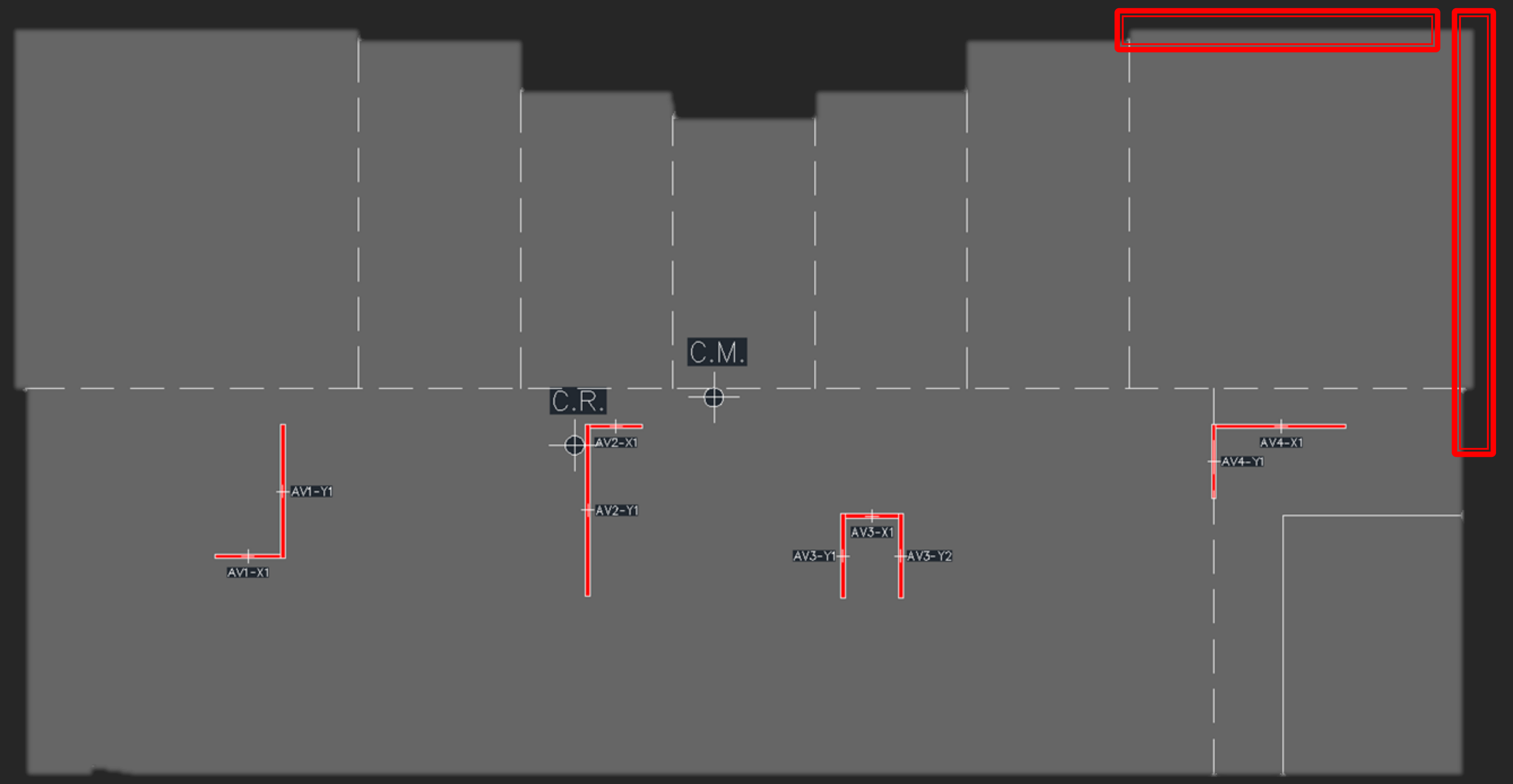
General Design Process

1. Required perimeter lateral force resisting elements' stiffness to reduce eccentricity between C.M. and C.R.

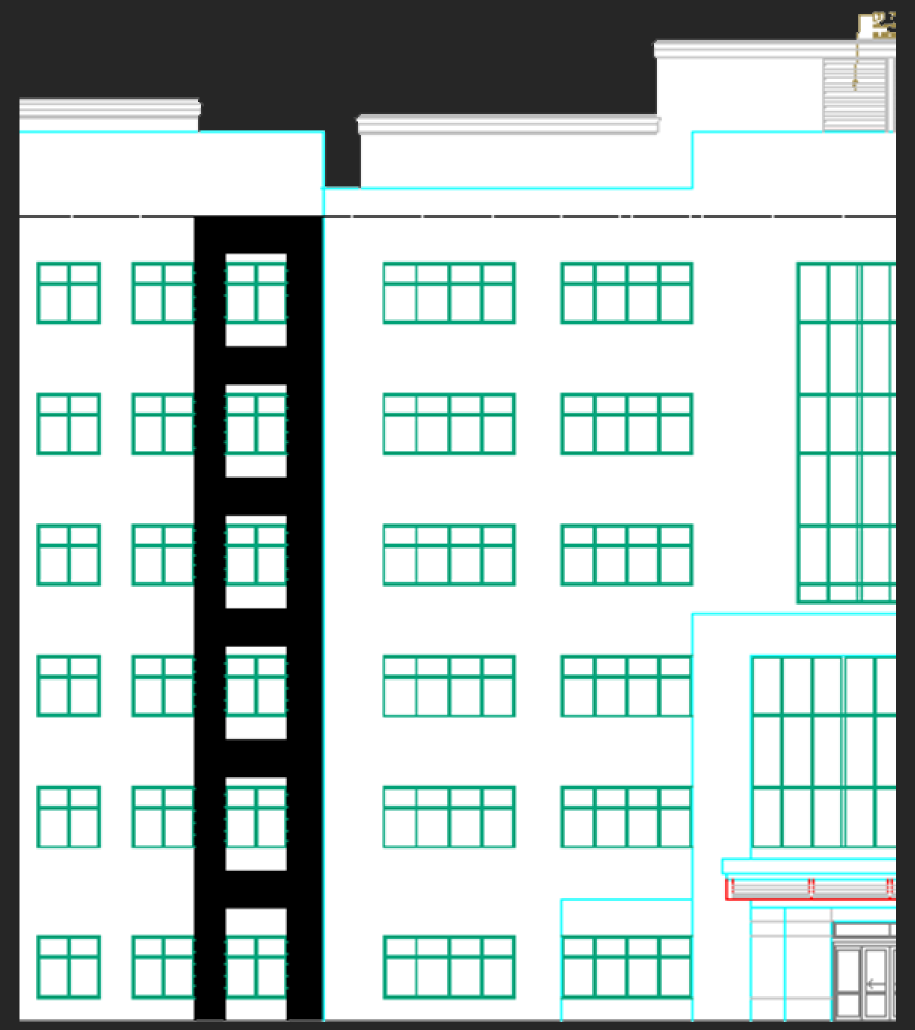
$$K_x = \frac{K_1L_1 - K_1C_r + ... + K_{n-1}L_{n-1} - K_{n-1}C_r}{C_r - L_x}$$

2. Check if there is enough free space between openings

3. Design individual components



East Façade



North Façade

Table P1.2, Comparison of Center of Mass and Center of Rigidity Outputs

Story	ETABS				Hand Calculations			
	X_{CM}	Y_{CM}	X_{CR}	Y_{CR}	X_{CM}	Y_{CM}	X_{CR}	Y_{CR}
STORY6	114.75	58.44	120.61	64.29	114.79	58.90	117.18	63.61
STORY5	114.79	58.9	121.34	64.13	114.69	58.72		
STORY4	114.79	58.9	121.78	63.52	114.69	58.72		
STORY3	114.79	58.9	121.71	62.23	114.69	58.72		
STORY2	114.79	58.9	118.51	59.14	114.69	58.72		
STORY1	114.69	58.72	112.77	54.76	110.07	59.34		

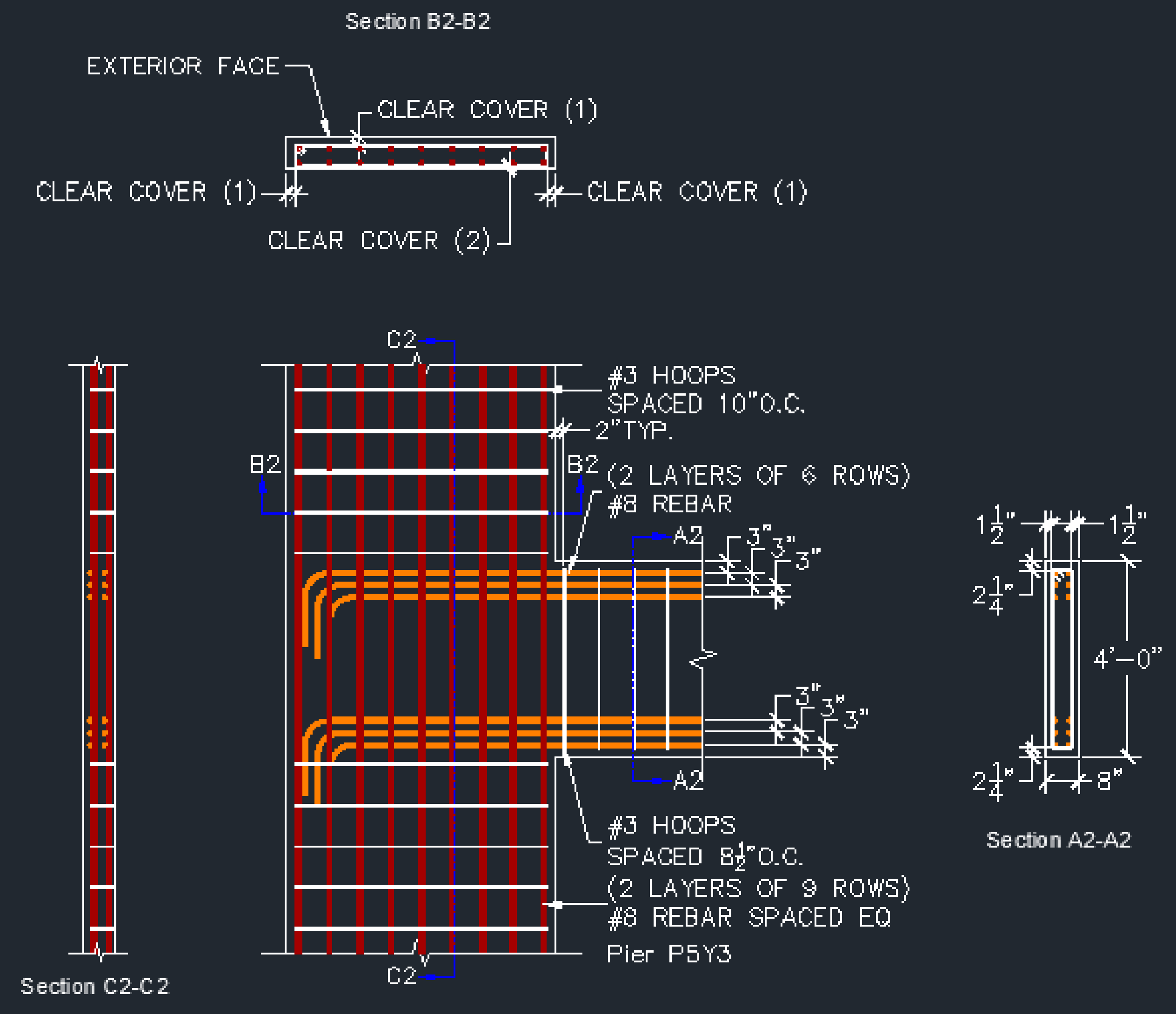


Table P1.3, Base Shear of Lateral Force Resisting Elements

Element	V_{base} (Kip)	
	Original	Design I
AV1-X1	76.5	62
AV1-Y1	325	229.1
AV2-Y1	304.4	335.4
AV2-X1	63.9	43.7
AV3-Y1	126.6	102
AV3-X1	121.7	33.4
AV3-Y2	121.7	102
AV4-Y1	84	89.5
AV4-X1	159.6	187.4
AV5-X1	N/A	14.8
AV5-Y1	N/A	145.9
AV5-Y2	N/A	23.8

Design II

Move lateral force resisting elements to the perimeter

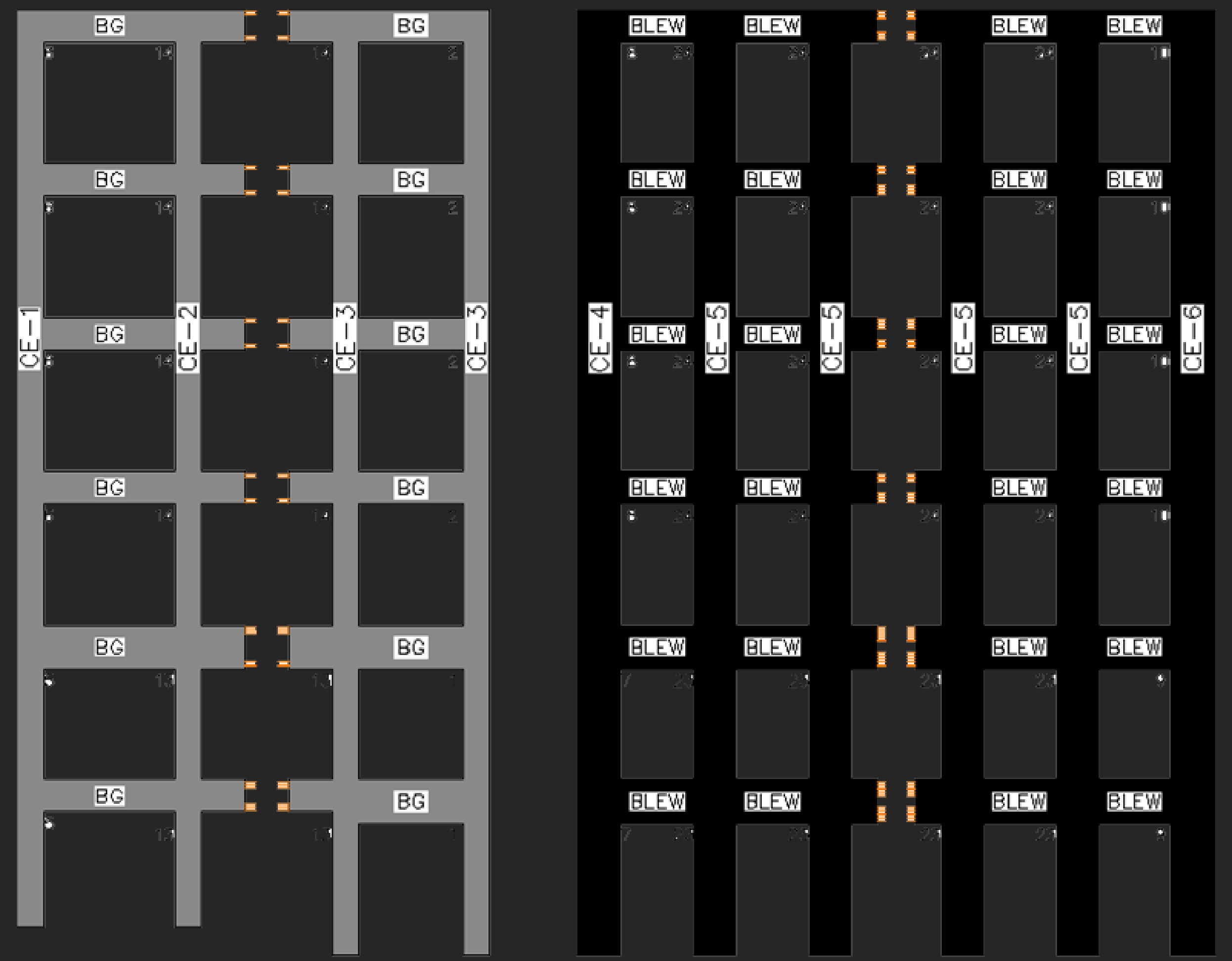
General Design Process

1. Based on building symmetry and openings in façade, select locations for lateral force resisting elements

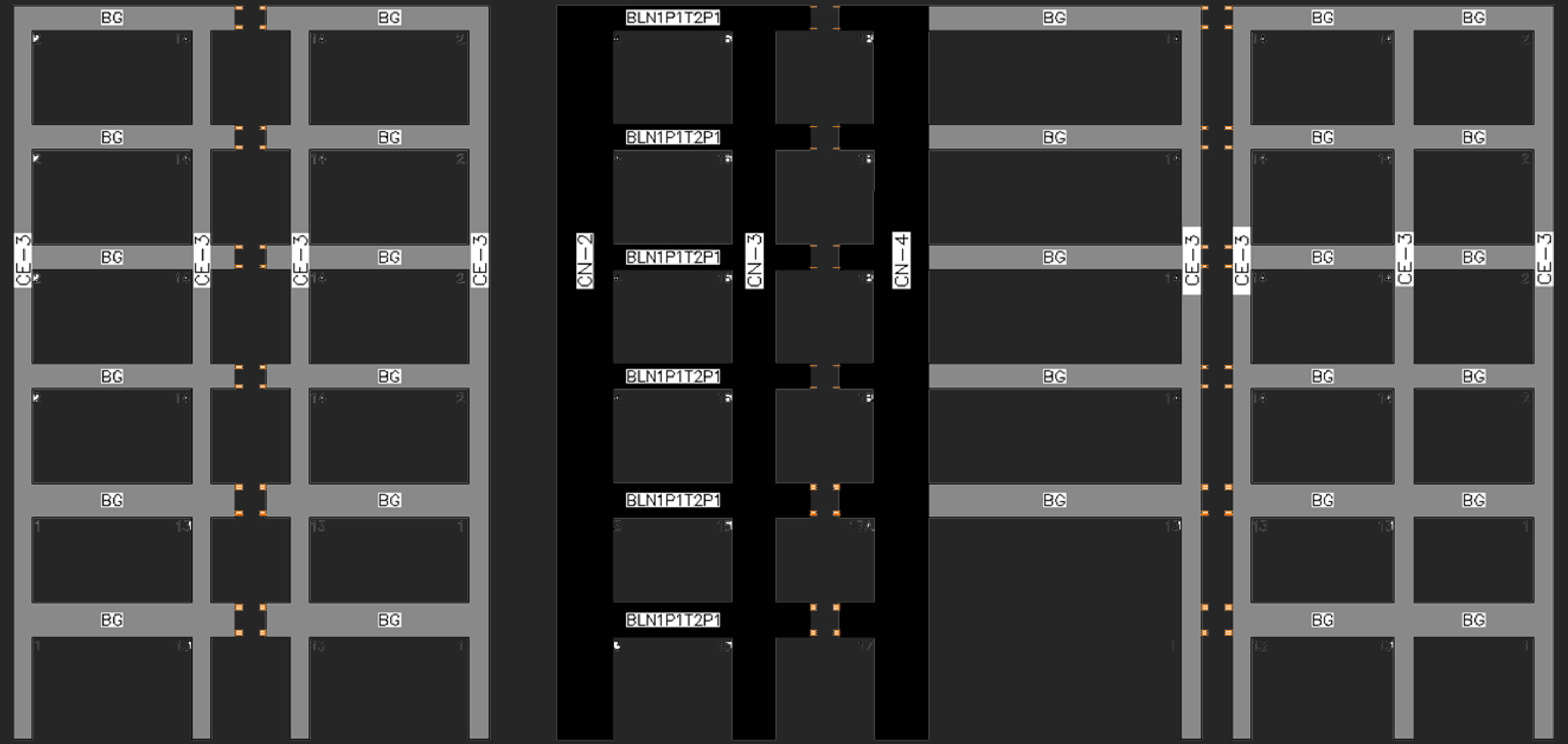
2. Determine stiffness of preliminary lateral force resisting elements

3. Access torsional effects

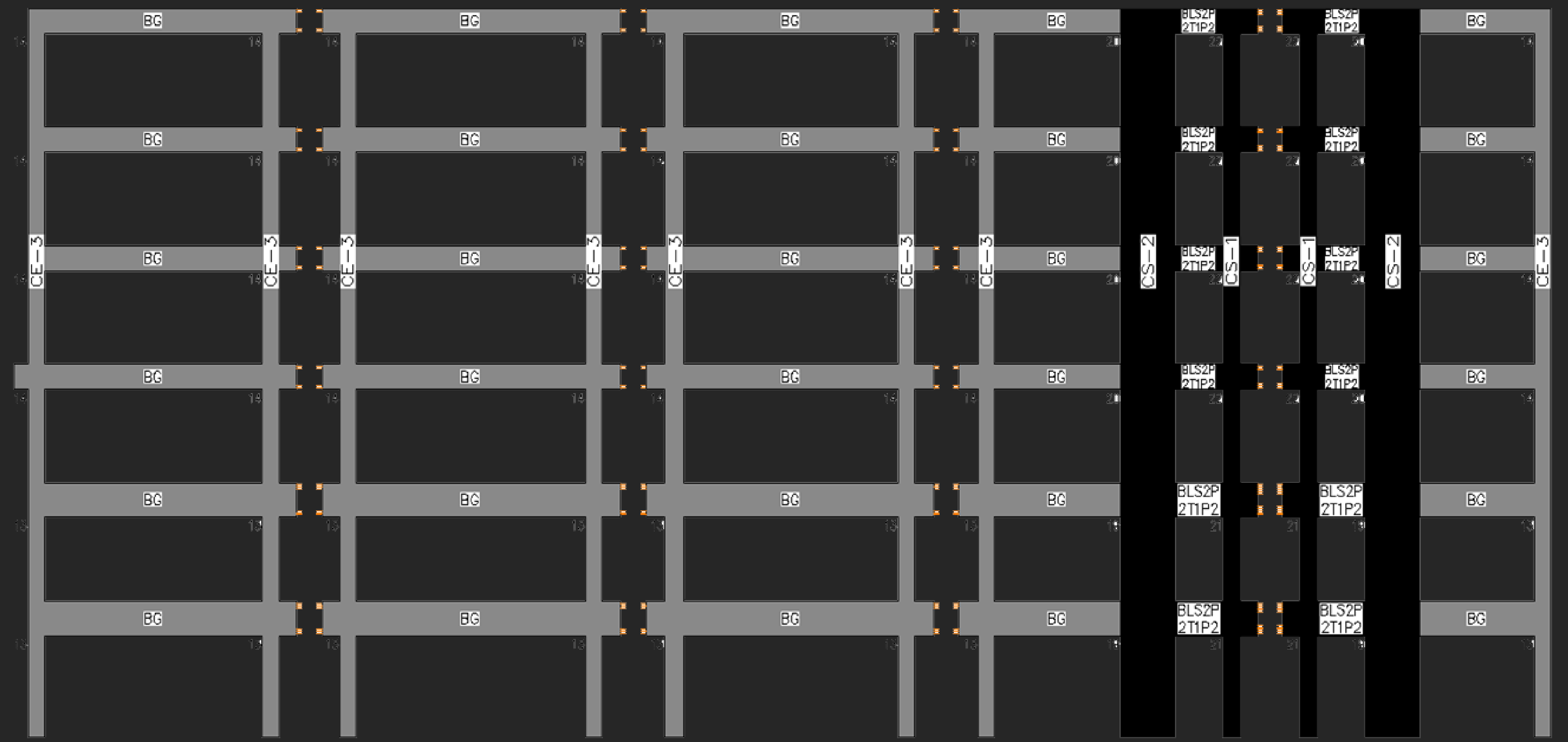
4. Design individual components



East Façade Tilt-Up Wall Panels



North Façade Tilt-Up Wall Panels



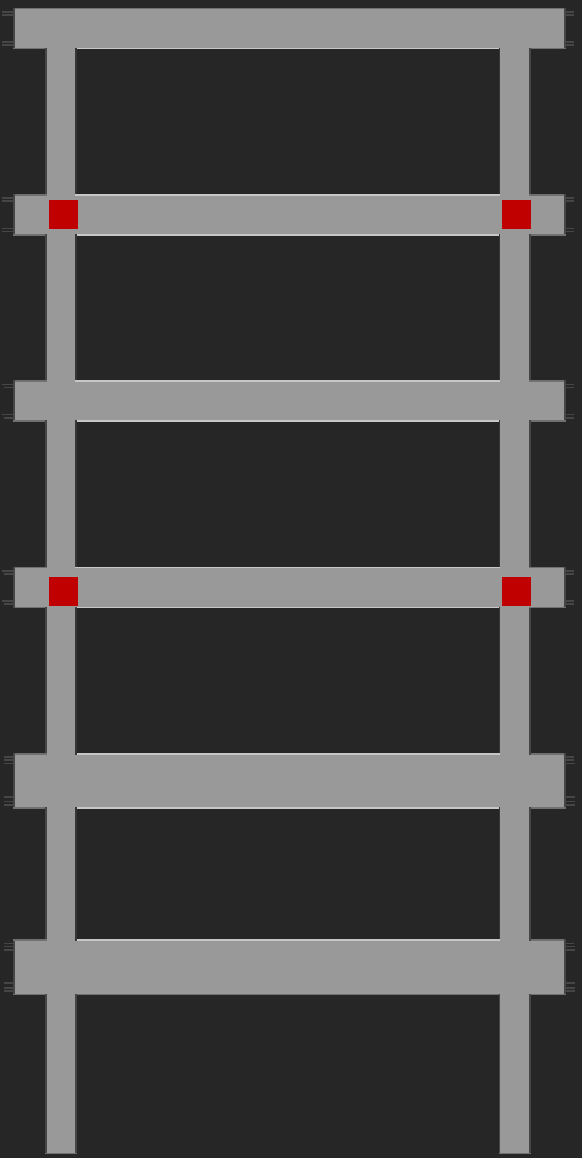
South Façade Tilt-Up Wall Panels

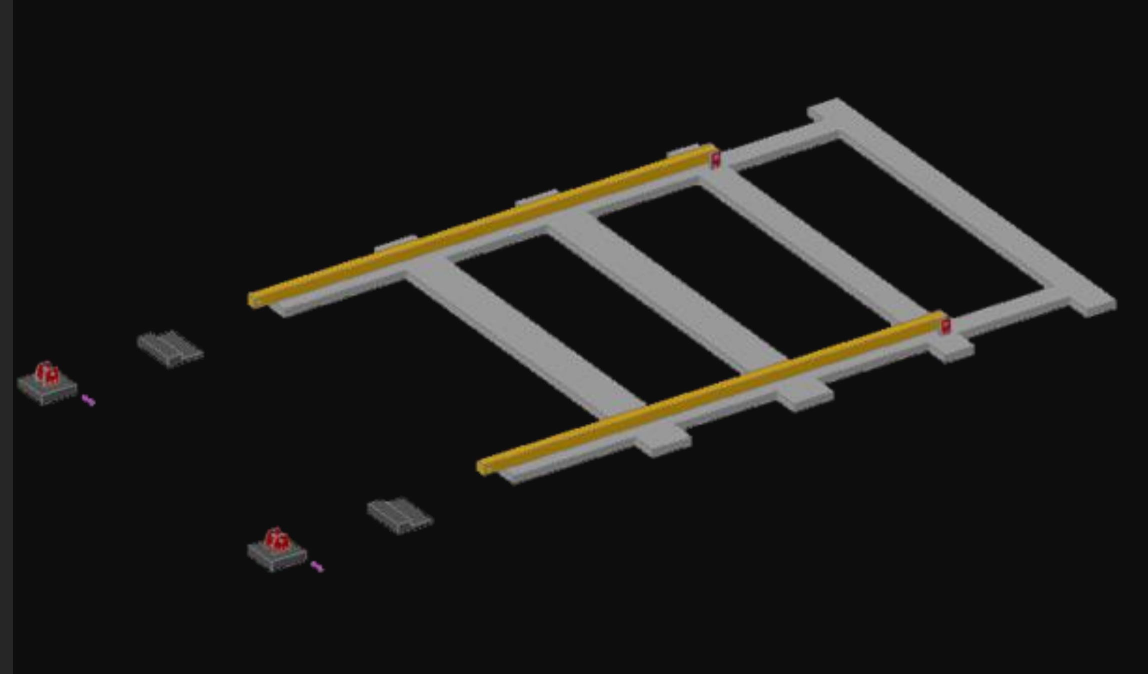
Table P1.4, Maximum Factored Loads on Structural Tilt-Up Walls

Loading Condition	Maximum Loads	
	Moment (Kip-ft)	Shear (Kip)
Two Level Brace Points	84.2	12.9
Wind MWFRS (Constr.)	40.5	4.8
Wind MWFRS	15.6	5.9

Table P1.5, Slenderness Magnification Factor and Loads Incorporating Factor

Panel Angle (°)	δ	$M_{u,p\Delta\text{-max}}$ (kip-ft)		$P_{u,p\Delta\text{-max}}$ (kip)		$V_{u,p\Delta\text{-max}}$ (kip)	
		1.2D + 1.6W	1.4D	1.2D + 1.6W	1.4D	1.2D + 1.6W	1.4D
0	1.00		83.5				12.9
10	1.05		84.2		0.0		12.7
20	1.10		80.4		3.8		12.2
30	1.15		74.3		0.0		0.0
40	1.21		65.7		7.1		0.0
50	1.26		55.1		0.0		0.0
60	1.30		42.8		0.0		0.0
90	1.37	44.4		9.5	11.0	4.9	





Source: TCA, 2006

Figure P1.1, Unit Strip Tilt-Up Wall Interaction

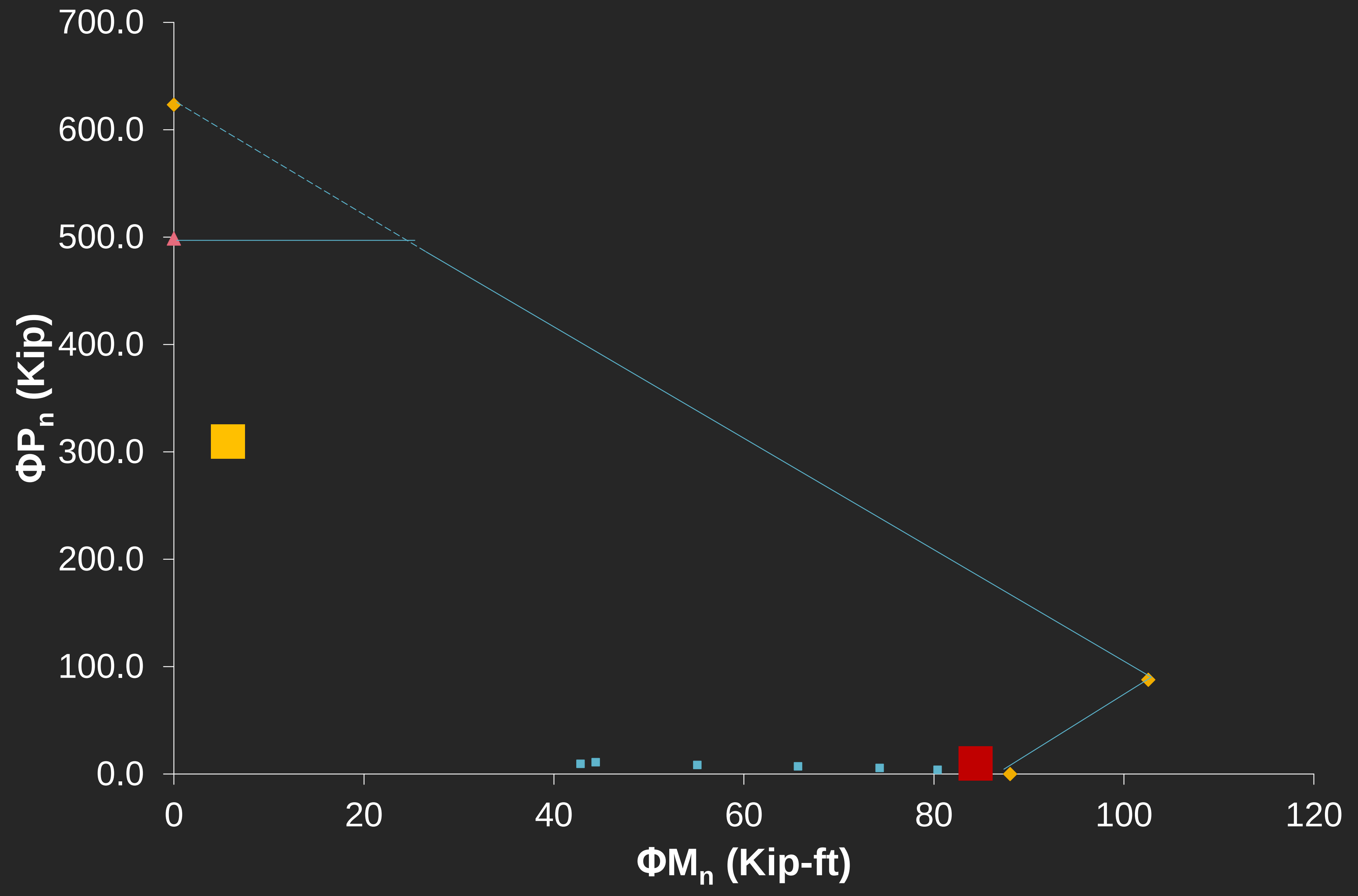
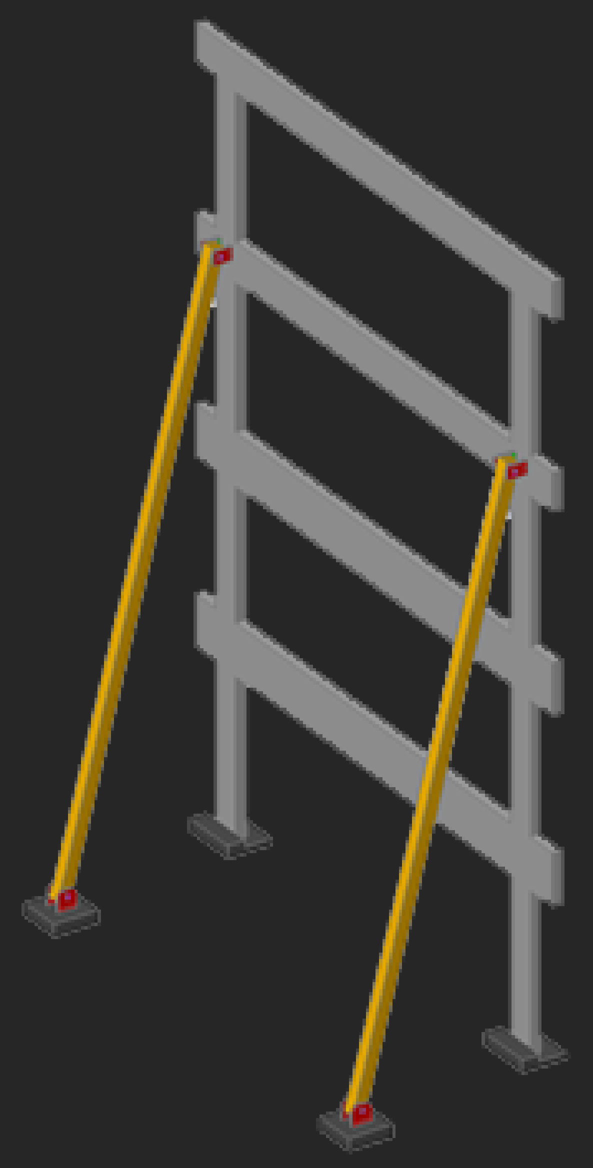


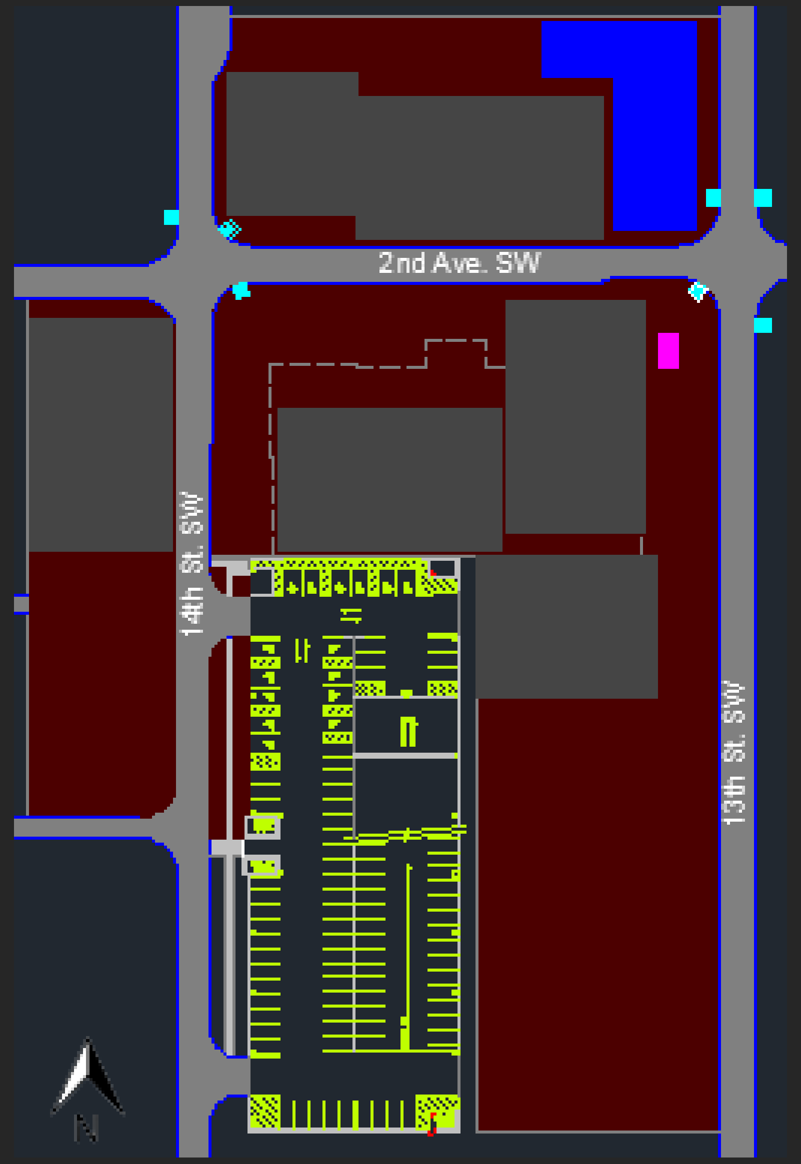
Table P1.6, Initial Design Parameters		
Factored Axial Load (Kip)	L (in)	I_{req} (in^4)
29.8	894	105.5
97.9	547	129.5
235.3	547	311.2

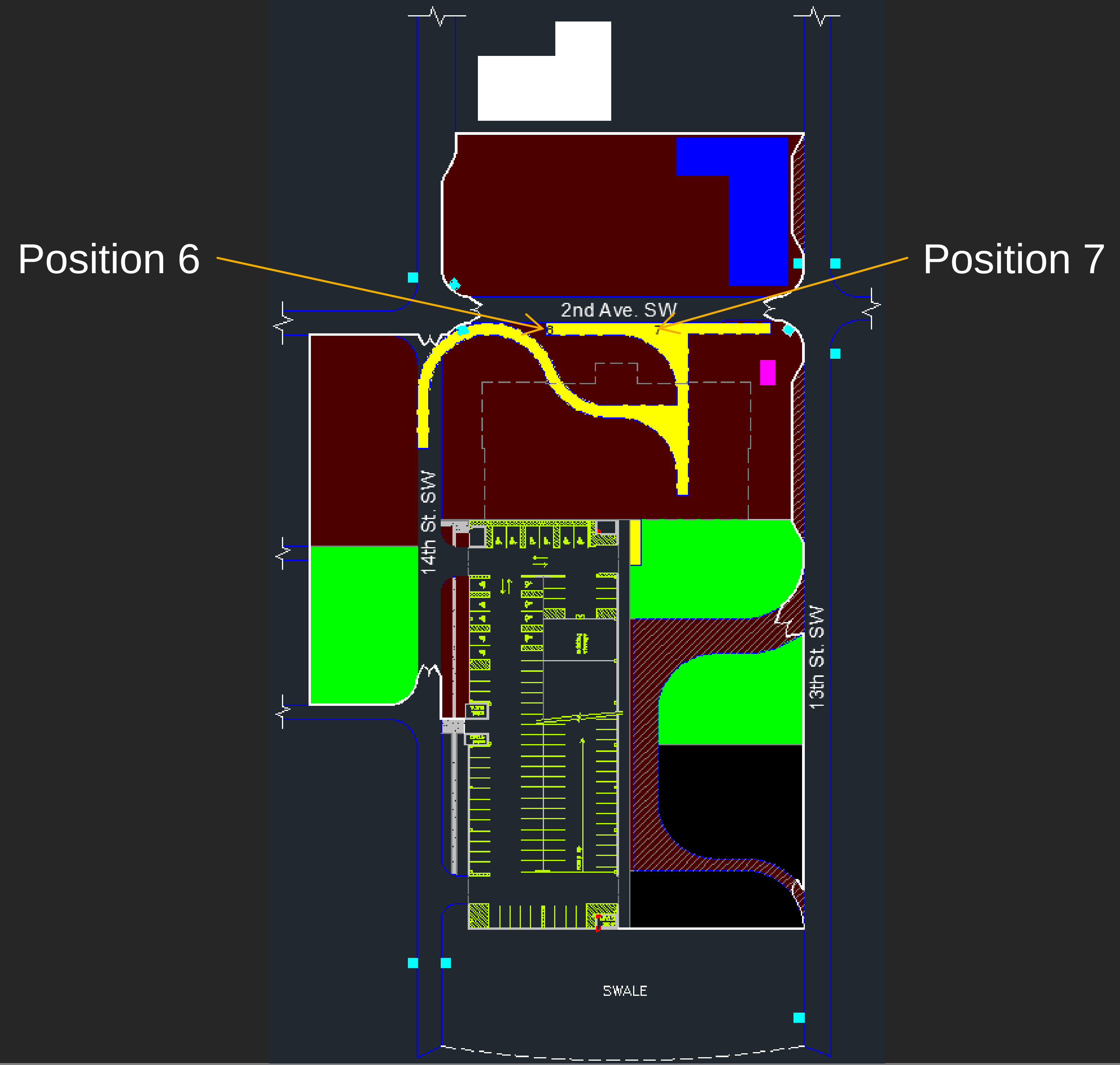
Table P1.7, Magnification Factors								
Member	H (Kip)	Δ_H (in)	P_e (Kip)	P_r/P_y	EI*	P_{e1} (Kip)	B_2	B_1
HSS10x10x3/8	2.14	0.000		0.049	4686400	57.8	0	2.1
HSS10x10x3/8	1.31	0.000		0.161	4686400	154.8	0	2.7
HSS12x12x1/2	2.08	0.000		0.245	10602400	350.2	0	3.0

Table P1.8, Temporary Bracing Combined Loading				
Bracing Member	P_r (Kip)	M_r (Kip-ft)	P_r/P_c	$P_r/P_c + 8/9(M_r/M_c)$
HSS10x10x3/8	29.8	82.4	0.52	0.97
HSS10x10x3/8	97.9	40.6	0.64	0.86
HSS12x12x1/2	235.3	72.2	0.68	0.89



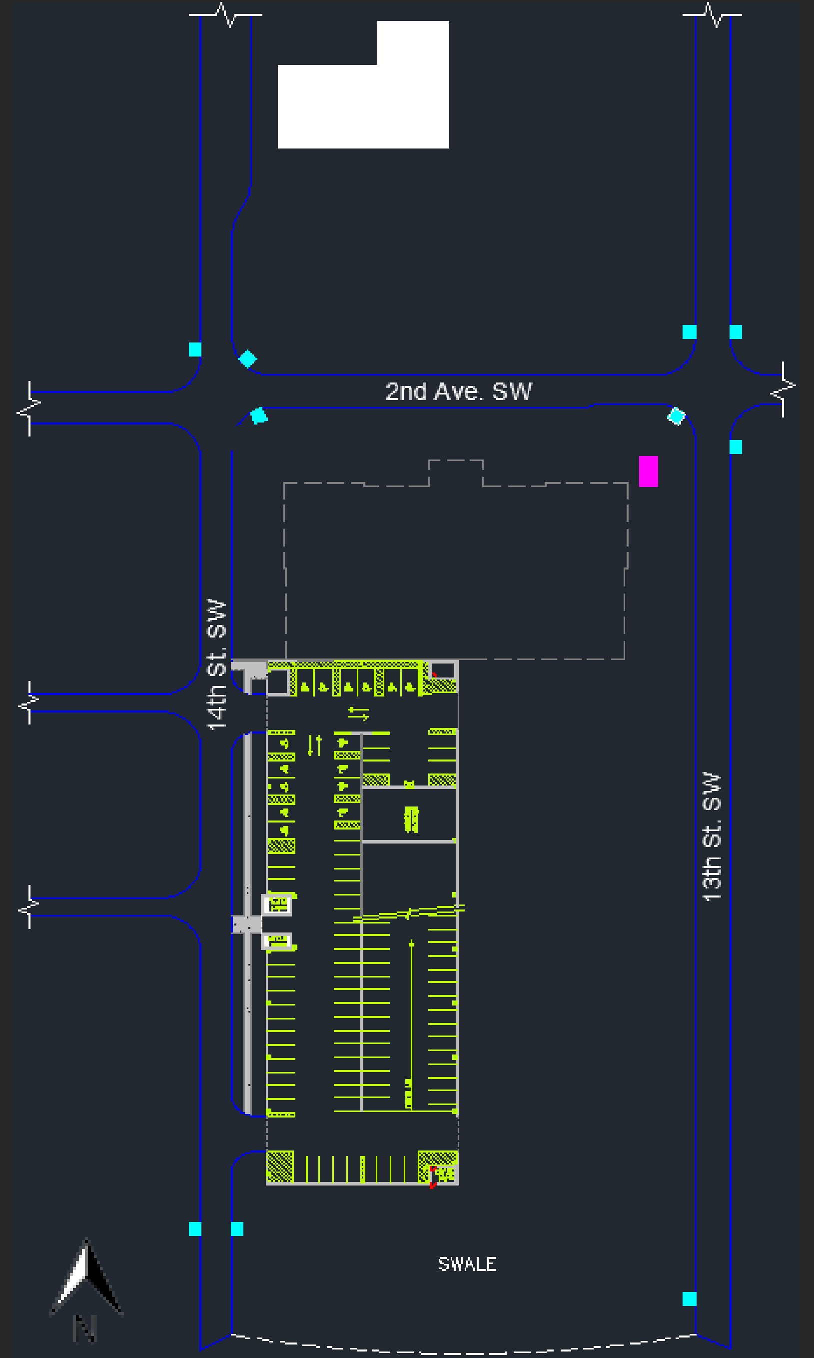
- 🟥 Active Construction Site
- 🟦 Construction and Management Infrastructure
- ⬛ Construction Parking
- ⬜ Existing Buildings
- 🟪 Existing Site Electric and Water Utilities
- 🟦 Existing Stormwater Drains
- 🟩 Material and Equipment Storage Areas
- ▨ Material Delivery Area and Temporary Construction Roads
- 🟨 Path of Heavy Lift Crane



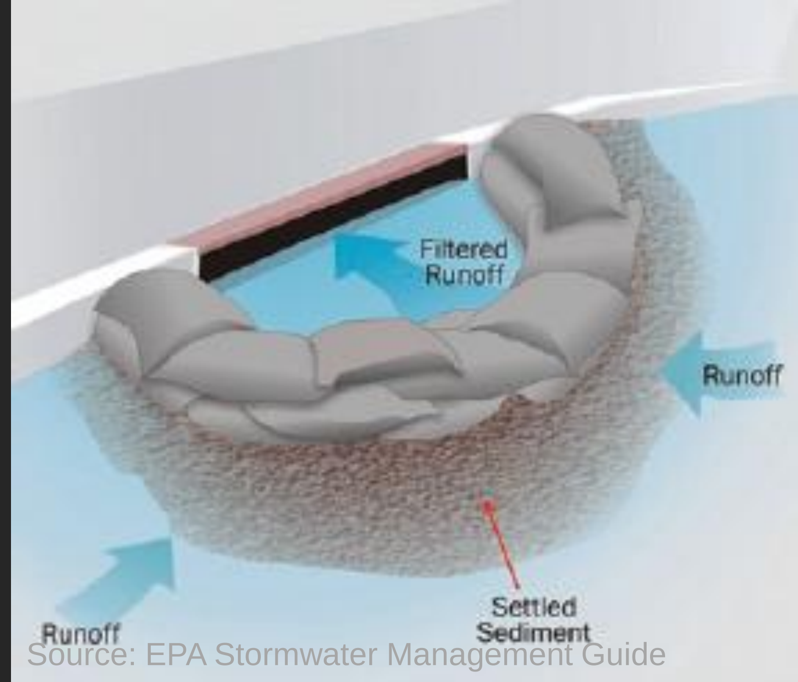


Construction Logistics

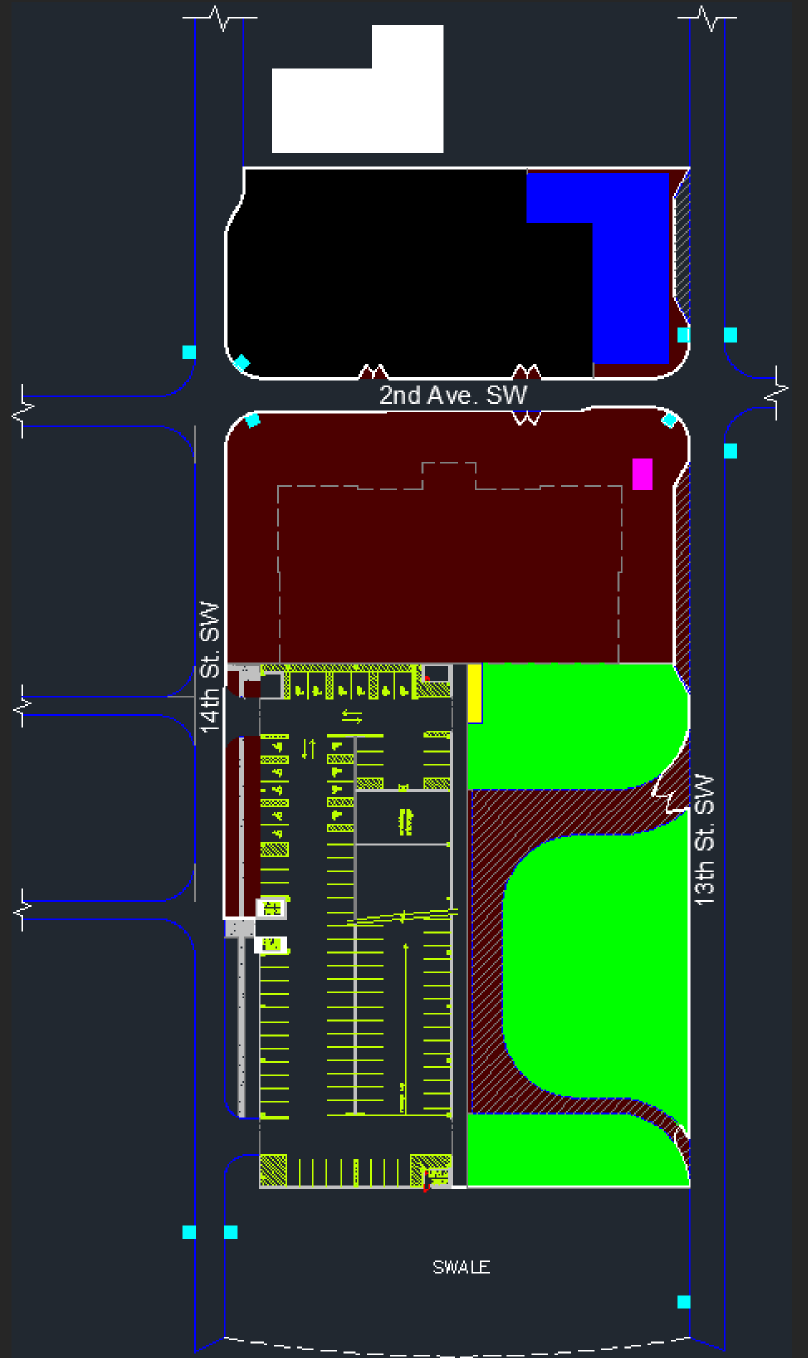
1. No weather related or safety violations that will cause delays
2. Reduce impact on surrounding facilities
3. Prevent contaminants from leaving site
4. Keep track of all equipment and materials on the site
5. Maximum equipment and material dimensions are bounded




Source: EPA Stormwater Management Guide



Source: EPA Stormwater Management Guide



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- 🟨 Path of Heavy Lift Crane

Table P1.9, Cargo Capacity and Turning Radius of Various Truck Types

Source: Texas Department of Transportation Roadway Design Manual

Truck Type	Maximum Cargo Length	Turning Radius for 90° Turn
Single Unit – 20’-0” Wheelbase	22’-0”	42’-0”
Semi-Truck – 23’-6” Wheelbase	30’-0”	40’-0”
Semi-Truck – 31’-4” Wheelbase	37’-4”	45’-0”
Semi-Truck – 42’-0” Wheelbase	42’-0”	45’-0”

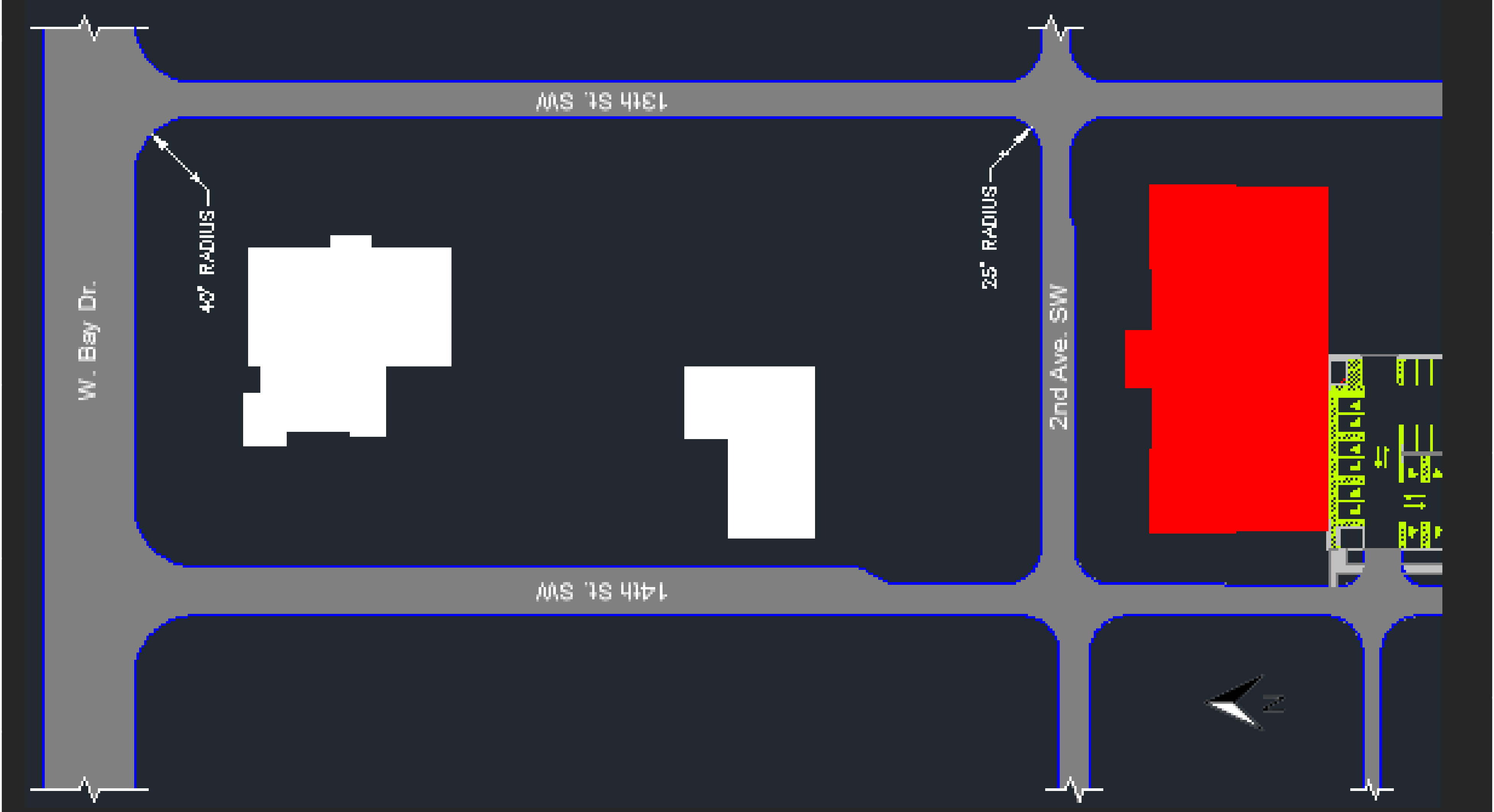


Table P1.10, Total and Select Itemized Cost of Each Design

Design	Itemized Cost			Total Cost
	Necessary Infrastructure	Structural	Façade	
Original	$293,658	$3,710,785	$869,748	$12,600,000
Design I	$307,176	$3,776,745	$858,413	$12,668,143
Design II	$576,009	$3,546,273	$1,799,585	$13,647,676

Table P1.11, Displacement at Roof Corners

Story	Corner	Load	Design I		Design II	
			X	Y	X	Y
6	**NW**	WINDDX	0.69	-0.15	0.56	0
	NW	WINDDY	-0.24	0.82	0.01	0.84
	NW	WINDT1DX	0.49	-0.17	0.41	-0.03
	NW	WINDT1DY	-0.33	0.28	-0.06	0.5
	NW	WINDT2	0.07	-0.02	0.25	0.32
	NW	WINDDXY	0.33	0.51	0.43	0.63
	NW	WINDT1DNX	0.54	-0.04	0.44	0.02
	NW	WINDT1DNY	-0.03	0.95	0.07	0.75
	NE	WINDDX	0.69	-0.08	0.56	0
	NE	WINDDY	-0.24	0.62	0.01	0.81
	NE	WINDT1DX	0.49	0	0.41	0.02
	NE	WINDT1DY	-0.33	0.77	-0.06	0.73
	NE	WINDT2	0.07	0.67	0.25	0.6
	NE	WINDDXY	0.33	0.4	0.43	0.61
	NE	WINDT1DNX	0.54	-0.12	0.44	-0.02
	NE	WINDT1DNY	-0.03	0.16	0.07	0.49

Original = 0.72, Design I = 0.62, Design II = 0.65

Table P1.12, Total and Select Itemized Cost of Each Design

Design	Itemized Cost			Total Cost
	Necessary Infrastructure	Structural	Façade	
Original	$293,658	$3,710,785	$869,748	$12,600,000
Design I	$307,176	$3,776,745	$858,413	$12,668,143
Design II	$576,009	$3,546,273	$1,799,585	$13,647,676

Table P1.13, Estimated Acoustical Performance of Wall

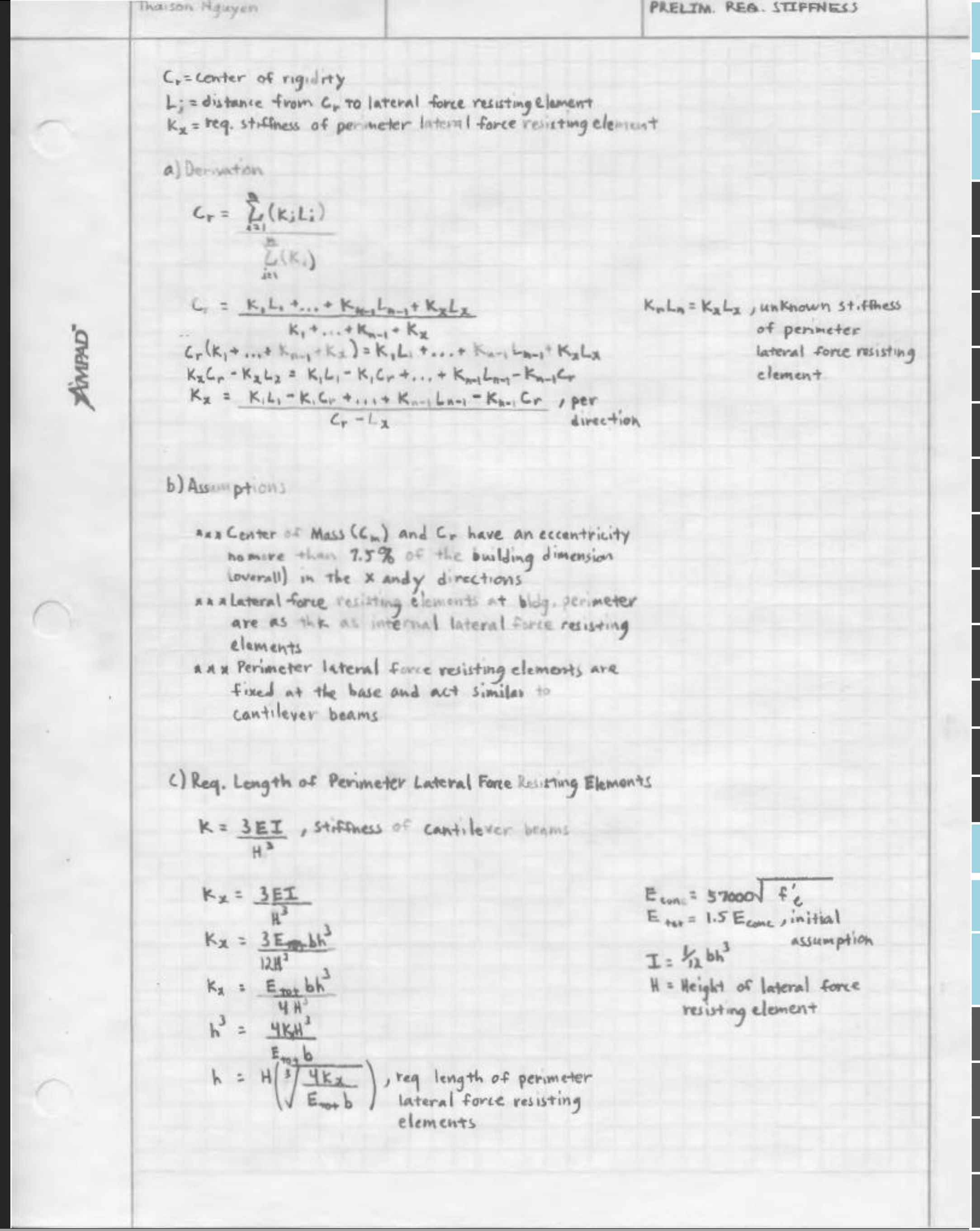
Wall Type	STC
Façade Wall Redesign	54
Original and Retrofit Wall Design	57

Table P1.14, Condensation Drying Rate for 3/8” Weep Hole

Head Height		Max Wall Area Served		Exit Flow Rate $((2\rho gh/m)^{1/2})$		Drainage Time (s)
in	mm	m^2	ft^2	m/s	ft/s	
0.1875	4.7625	64	689	1.2	4.0	0.02

Carry on the struggle

Appendix



Thaison Nguyen

PRELIM. REQ. STIFFNESS

C_r = center of rigidity
L_i = distance from C_r to lateral force resisting element
K_x = req. stiffness of perimeter lateral force resisting element

a) Derivation

$$C_r = \frac{\sum_{i=1}^{n}(K_i L_i)}{\sum_{i=1}^{n}(K_i)}$$

$$C_r = \frac{K_1L_1 + \dots + K_{n-1}L_{n-1} + K_xL_x}{K_1 + \dots + K_{n-1} + K_x}$$

$$C_r(K_1 + \dots + K_{n-1} + K_x) = K_1L_1 + \dots + K_{n-1}L_{n-1} + K_xL_x$$

$$K_xC_r - K_xL_x = K_1L_1 - K_1C_r + \dots + K_{n-1}L_{n-1} - K_{n-1}C_r$$

$$K_x = \frac{K_1L_1 - K_1C_r + \dots + K_{n-1}L_{n-1} - K_{n-1}C_r}{C_r - L_x}$$, per direction

$K_nL_n = K_xL_x$, unknown stiffness of perimeter lateral force resisting element

b) Assumptions

- *** Center of Mass (C_m) and C_r have an eccentricity no more than 7.5% of the building dimension (overall) in the x and y directions
- *** Lateral force resisting elements at bldg. perimeter are as thk as internal lateral force resisting elements
- *** Perimeter lateral force resisting elements are fixed at the base and act similar to cantilever beams

c) Req. Length of Perimeter Lateral Force Resisting Elements

$K = \frac{3EI}{H^3}$, stiffness of cantilever beams

$$K_x = \frac{3EI}{H^3}$$

$$K_x = \frac{3E_{tot}bh^3}{12H^3}$$

$$K_x = \frac{E_{tot}bh^3}{4H^3}$$

$$h^3 = \frac{4K_xH^3}{E_{tot}b}$$

$$h = H\left(\sqrt[3]{\frac{4K_x}{E_{tot}b}}\right)$$, req length of perimeter lateral force resisting elements

$E_{conc} = 57000\sqrt{f'_c}$
$E_{tot} = 1.5E_{conc}$, initial assumption
$I = \frac{1}{12}bh^3$
H = Height of lateral force resisting element

Table AP1.1, Calculated Design I Center of Rigidity

Lateral Resisting Element		Stiffness	Element C.R.		Global C.R.	
Designation	Resisting Direction		x (ft)	y (ft)	x (ft)	y (ft)
AV1-X1	X	15.18	36.84	34.33	117.18	63.61
AV1-Y1	Y	122.10	42.34	44.54		
AV2-Y1	Y	248.14	90.26	41.59		
AV2-X1	X	7.53	94.68	54.76		
AV3-Y1	Y	31.20	130.34	34.42		
AV3-X1	X	8.23	134.88	40.67		
AV3-Y2	Y	31.20	139.42	34.42		
AV4-Y1	Y	21.79	188.63	49.26		
AV4-X1	X	112.61	199.17	54.76		
AV5-Y1	Y	31.716	229.17			
AV5-Y2	Y	91.324	226.83			
AV5-X1	X	31.726		117.08		

Table AP1.2, Calculated Design II Center of Rigidity

Lateral Resisting Element		Stiffness	Element C.R.		Global C.R.	
Designation	Resisting Direction		x (ft)	y (ft)	x (ft)	y (ft)
A1-Y1	Y	291.715	0.42	88.75	114.80	61.30
A2-Y1	Y	291.715	229.08	88.75		
A5-X1	X	215.657	152.38	115.00		
A6-X1	X	190.186	179.00	0.42		

Table AP1.3, Formatted ETABS Center of Mass and Center of Rigidity Output for Design I

Story	XCM (ft)	YCM (ft)	XCR (ft)	YCR (ft)
STORY6	114.75	58.44	120.61	64.29
STORY5	114.79	58.9	121.34	64.13
STORY4	114.79	58.9	121.78	63.52
STORY3	114.79	58.9	121.71	62.23
STORY2	114.79	58.9	118.51	59.14
STORY1	114.69	58.72	112.77	54.76

Table AP1.4, Formatted ETABS Center of Mass and Center of Rigidity Output for Design II

Story	XCM (ft)	YCM (ft)	XCR (ft)	YCR (ft)
STORY6	114.77	58.42	116.8	59.52
STORY5	114.83	58.89	117.01	59.08
STORY4	114.83	58.89	117.23	58.76
STORY3	114.83	58.89	117.4	58.6
STORY2	114.83	58.89	117.47	58.77
STORY1	114.74	58.71	116.62	59.1

Building Overview
Scope and Intent
Solving Torsional Irregularity
Construction Management
Lessons Learned

Table AP 1.5, Case I MWFRS Applied Loads

Floor Level	Wind Perpendicular to Long Side	Wind Perpendicular to Short Side
	Kip	Kip
0	62.76	25.43
1	121.12	49.43
2	124.09	51.79
3	131.29	55.47
4	137.03	58.41
5	141.78	60.84
Roof 1	168.50	47.45
Top	29.61	14.47

Table AP 1.6, Calculations: Wind Perpendicular to Long Side (Part 2)

Floor Level	Wind Load Direct Component in Lateral Resisting Elements (Kip)										
	AV1-X1	AV1-Y1	AV2-Y1	AV2-X1	AV3-X1	AV3-Y2	AV4-Y1	AV4-X1	AV5-Y1	AV5-Y2	AV5-X1
0	0.00	14.03	28.51	0.00	0.00	3.58	2.50	0.00	3.64	10.49	0.00
1	0.00	27.07	55.02	0.00	0.00	6.92	4.83	0.00	7.03	20.25	0.00
2	0.00	27.74	56.37	0.00	0.00	7.09	4.95	0.00	7.20	20.75	0.00
3	0.00	29.35	59.64	0.00	0.00	7.50	5.24	0.00	7.62	21.95	0.00
4	0.00	30.63	62.24	0.00	0.00	7.83	5.47	0.00	7.96	22.91	0.00
5	0.00	31.69	64.40	0.00	0.00	8.10	5.66	0.00	8.23	23.70	0.00
Roof 1	0.00	37.66	76.54	0.00	0.00	9.62	6.72	0.00	9.78	28.17	0.00
Top	0.00	6.62	13.45	0.00	0.00	1.69	1.18	0.00	1.72	4.95	0.00

Table AP 1.7, Calculations: Wind Perpendicular to Long Side (Part 2)

Floor Level	Wind Load Torsion Component in Lateral Resisting Elements (Kip)										
	AV1-X1	AV1-Y1	AV2-Y1	AV2-X1	AV3-X1	AV3-Y2	AV4-Y1	AV4-X1	AV5-Y1	AV5-Y2	AV5-X1
0	0.046	1.57	3.18	0.0068	0.019	0.12	0.16	0.10	0.61	1.72	0.17
1	0.10	1.06	2.15	0.015	0.043	0.080	0.35	0.23	0.41	1.16	0.39
2	0.10	1.04	2.11	0.015	0.042	0.079	0.35	0.22	0.40	1.14	0.38
3	0.11	1.10	2.24	0.016	0.045	0.084	0.37	0.24	0.43	1.21	0.40
4	0.11	1.15	2.33	0.017	0.047	0.087	0.39	0.25	0.45	1.26	0.42
5	0.11	1.19	2.42	0.017	0.048	0.090	0.40	0.26	0.46	1.30	0.44
Roof 1	0.14	1.41	2.87	0.020	0.058	0.11	0.47	0.30	0.55	1.55	0.52
Top	0.024	0.25	0.50	0.0036	0.010	0.02	0.083	0.053	0.10	0.27	0.091

Table AP 1.8, Calculations: Wind Perpendicular to Long Side (Part 3)

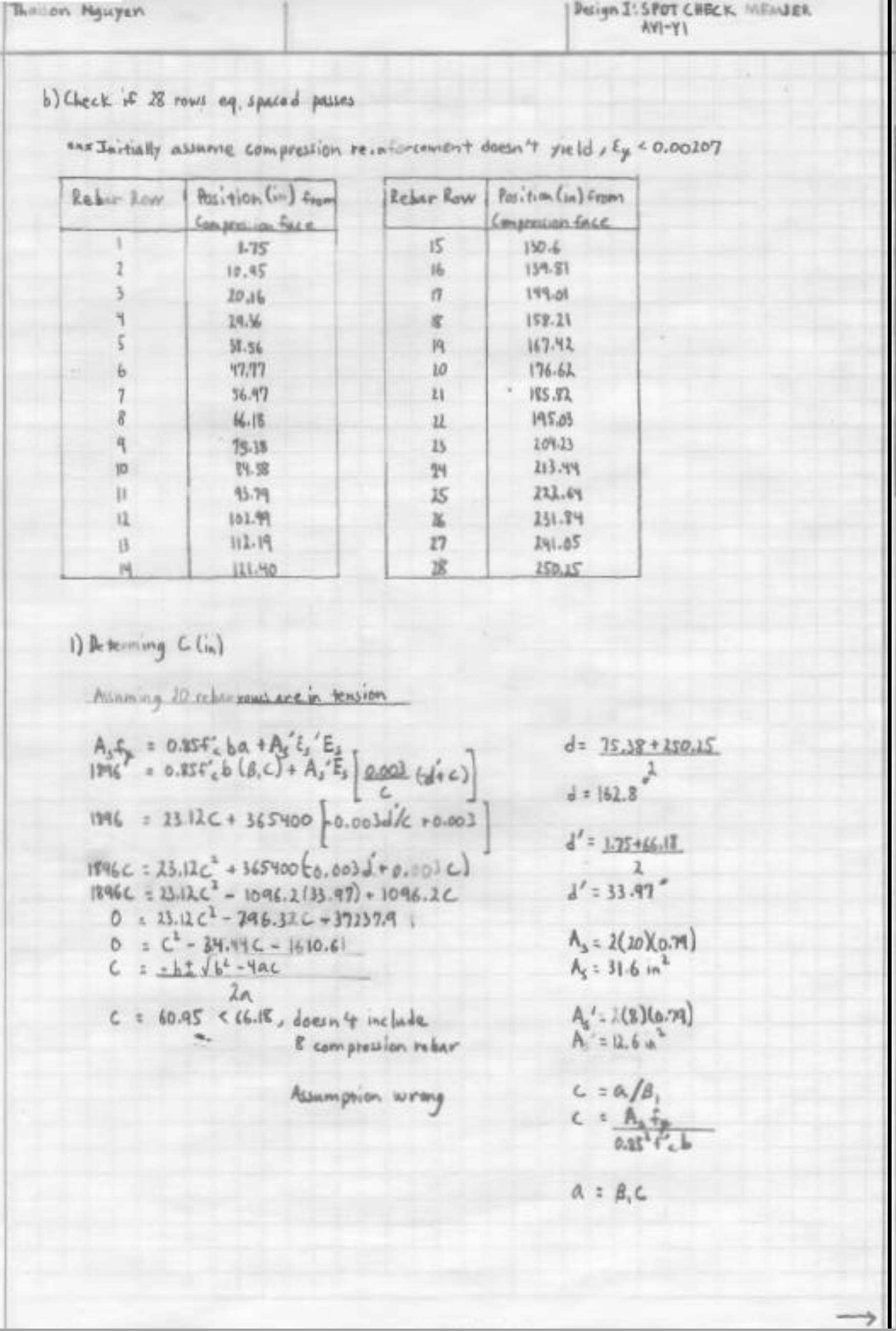
Floor Level	Total Wind Load in Lateral Resisting Elements (Kip)										
	AV1-X1	AV1-Y1	AV2-Y1	AV2-X1	AV3-X1	AV3-Y2	AV4-Y1	AV4-X1	AV5-Y1	AV5-Y2	AV5-X1
0	-0.046	15.59	31.69	-0.0068	-0.019	3.47	2.34	-0.10	3.04	8.78	0.174
1	-0.101	28.13	57.16	-0.015	-0.043	6.84	4.48	-0.23	6.62	19.09	0.386
2	-0.100	28.78	58.48	-0.015	-0.042	7.01	4.60	-0.22	6.80	19.61	0.381
3	-0.106	30.45	61.87	-0.016	-0.045	7.41	4.87	-0.24	7.19	20.74	0.403
4	-0.110	31.78	64.58	-0.017	-0.047	7.74	5.08	-0.25	7.51	21.65	0.421
5	-0.114	32.88	66.82	-0.017	-0.048	8.01	5.26	-0.26	7.77	22.40	0.435
Roof 1	-0.135	39.07	79.41	-0.020	-0.058	9.52	6.25	-0.30	9.23	26.62	0.517
Top	-0.024	6.87	13.95	-0.0036	-0.010	1.67	1.10	-0.053	1.62	4.68	0.091

Table AP 1.9, Calculations: Wind Perpendicular to Long Side (Part 4)

	AV1-X1	AV1-Y1	AV2-Y1	AV2-X1	AV3-X1	AV3-Y2	AV4-Y1	AV4-X1	AV5-Y1	AV5-Y2	AV5-X1
V_{base} (Kip)	0.7	213.5	433.9	0.1	0.3	51.6	33.9	1.6	49.7	143.5	2.8
$M_{ov,base}$ (Kip-ft)	38.0	10945	22243	5.6	16.1	2665.3	1749.4	85.2	2585.9	7455.3	145.0

Table AP 1.10, Comparison between Calculations and Computer Output

Computer Output for Base Shear Experienced by AV1-Y1 (Kip)	209.30			
Difference w/ Calculations (%)	2.03	<	10.00	√



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Design I: SPOT CHECK MEMBER AV1-Y1

b) Check if 28 rows eq. spaced passes

*** Initially assume compression reinforcement doesn't yield, $\varepsilon_y < 0.00207$

Rebar Row	Position (in) from Compression face
1	1.75
2	10.95
3	20.16
4	29.36
5	38.56
6	47.77
7	56.97
8	66.18
9	75.38
10	84.58
11	93.79
12	102.99
13	112.19
14	121.40

Rebar Row	Position (in) from Compression face
15	130.6
16	139.81
17	149.01
18	158.21
19	167.42
20	176.62
21	185.82
22	195.03
23	204.23
24	213.44
25	222.64
26	231.84
27	241.05
28	250.25

1) Determining C (in)

Assuming 20 rebar rows are in tension

$A_s f_y = 0.85 f'_c ba + A_s' \varepsilon_s' E_s$

$1896 = 0.85 f'_c b(\beta_1 c) + A_s' E_s \left[\frac{0.003}{c}(-d' + c)\right]$

$1896 = 23.12c + 365400\left[-0.003d'/c + 0.003\right]$

$1896c = 23.12c^2 + 365400(-0.003d' + 0.003c)$

$1896c = 23.12c^2 - 1096.2(33.97) + 1096.2c$

$0 = 23.12c^2 - 796.32c + 37237.9$

$0 = c^2 - 34.44c - 1610.61$

$c = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$c = 60.95 < 66.18$, doesn't include 8 compression rebar

Assumption wrong

$d = \frac{75.38 + 250.25}{2}$

$d = 162.8$"

$d' = \frac{1.75 + 66.18}{2}$

$d' = 33.97$"

$A_s = 2(20)(0.79)$

$A_s = 31.6\ in^2$

$A_s' = 2(8)(0.79)$

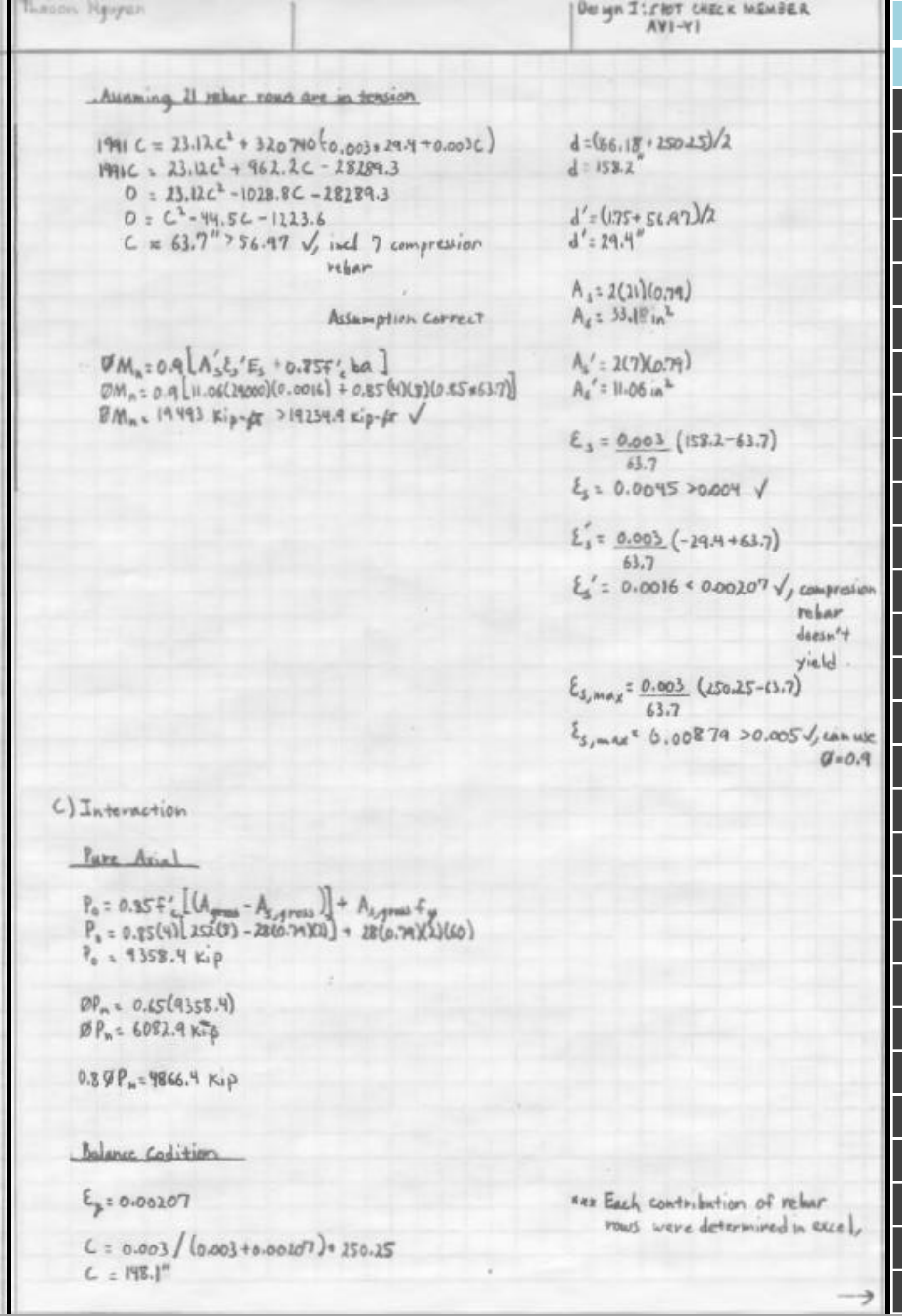
$A_s' = 12.6\ in^2$

$c = a/\beta_1$

$c = \frac{A_s f_y}{0.85 f'_c b}$

$a = \beta_1 c$

→



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Design I: SPOT CHECK MEMBER AV1-Y1

Assuming 21 rebar rows are in tension

$1991c = 23.12c^2 + 320740(-0.003 \cdot 29.4 + 0.003c)$

$1991c = 23.12c^2 + 962.2c - 28289.3$

$0 = 23.12c^2 - 1028.8c - 28289.3$

$0 = c^2 - 44.5c - 1223.6$

$c = 63.7" > 56.97$ ✓, incl 7 compression rebar

Assumption correct

$\phi M_n = 0.9\left[A_s' \varepsilon_s' E_s + 0.85 f'_c ba\right]$

$\phi M_n = 0.9\left[11.06(29000)(0.0016) + 0.85(4)(8)(0.85 \cdot 63.7)\right]$

$\phi M_n = 19493$ kip-ft > 19234.9 kip-ft ✓

$d = (66.18 + 250.25)/2$

$d = 158.2$"

$d' = (1.75 + 56.97)/2$

$d' = 29.4$"

$A_s = 2(21)(0.79)$

$A_s = 33.18\ in^2$

$A_s' = 2(7)(0.79)$

$A_s' = 11.06\ in^2$

$\varepsilon_s = \frac{0.003}{63.7}(158.2 - 63.7)$

$\varepsilon_s = 0.0045 > 0.004$ ✓

$\varepsilon_s' = \frac{0.003}{63.7}(-29.4 + 63.7)$

$\varepsilon_s' = 0.0016 < 0.00207$ ✓, compression rebar doesn't yield

$\varepsilon_{s,max} = \frac{0.003}{63.7}(250.25 - 63.7)$

$\varepsilon_{s,max} = 0.00879 > 0.005$ ✓, can use $\phi = 0.9$

C) Interaction

Pure Axial

$P_o = 0.85 f'_c\left[(A_{gross} - A_{s,gross})\right] + A_{s,gross} f_y$

$P_o = 0.85(4)\left[252(8) - 28(0.79)(2)\right] + 28(0.79)(2)(60)$

$P_o = 9358.4$ kip

$\phi P_n = 0.65(9358.4)$

$\phi P_n = 6082.9$ kip

$0.8\phi P_n = 4866.4$ kip

Balance Condition

$\varepsilon_y = 0.00207$

$c = 0.003/(0.003 + 0.00207) \cdot 250.25$

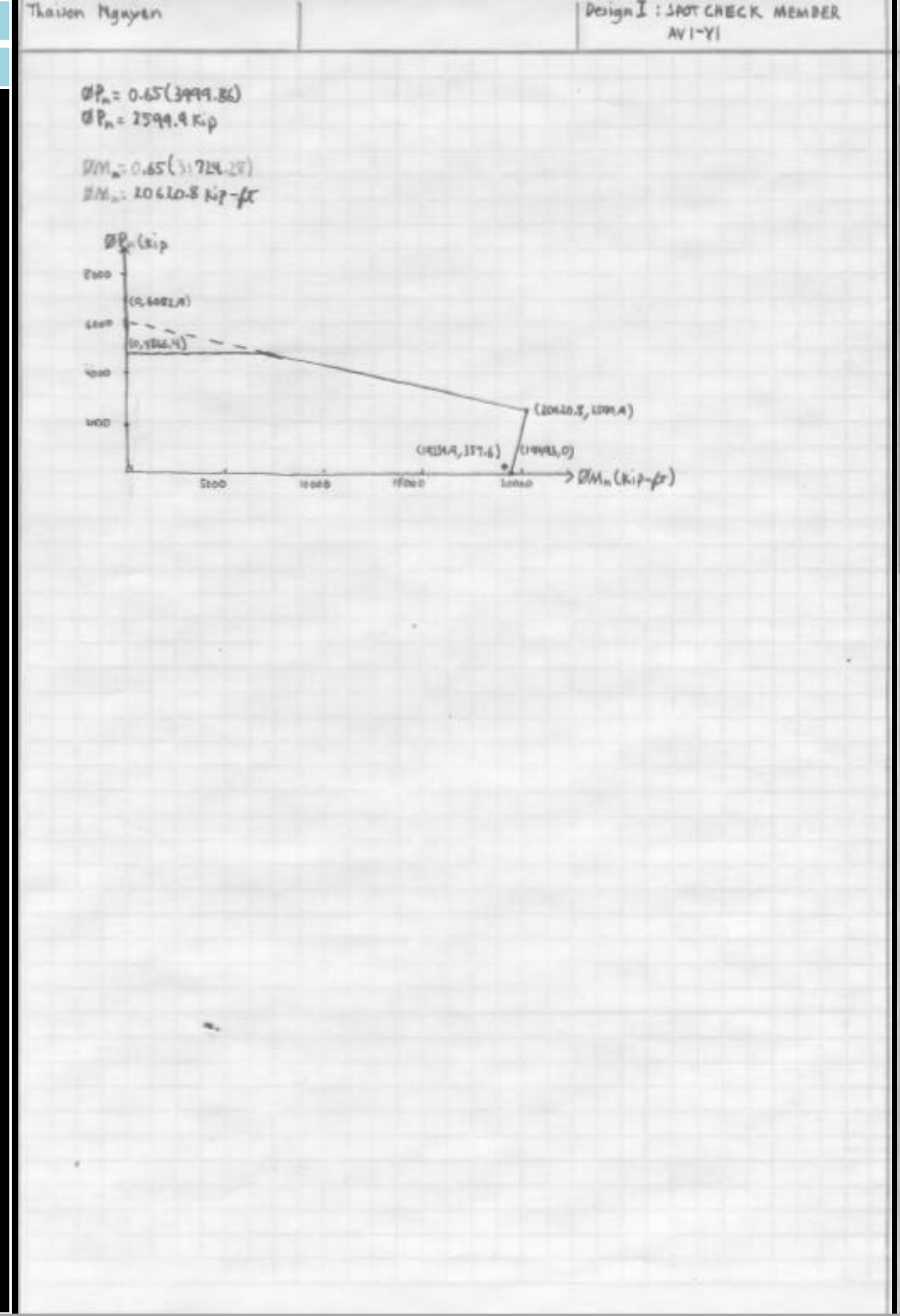
$c = 148.1$"

*** Each contribution of rebar rows were determined in excel.

→

Table AP 1.11. Reinforcement Contribution to Axial and Bending Capacity

Row	Position (in)	ε_{si}	f_{si} (Ksi)	M_{bi} (Kip-in)	M_b (Kip-ft)	P_b (Kip)
1	1.75	0.00296	60	14910.0	31724.28	3999.86
2	10.95	0.00278	60	13805.6		
3	20.16	0.00259	60	12701.1		
4	29.36	0.00241	60	11596.7		
5	38.56	0.00222	60	10492.2		
6	47.77	0.00203	58.94	9222.0		
7	56.97	0.00185	53.53	7390.6		
8	66.18	0.00166	48.13	5758.4		
9	75.38	0.00147	42.72	4325.1		
10	84.58	0.00129	37.31	3090.9		
11	93.79	0.00110	31.91	2055.7		
12	102.99	0.00091	26.50	1219.6		
13	112.19	0.00073	21.10	582.5		
14	121.40	0.00054	15.69	144.4		
15	130.60	0.00035	10.28	-94.6		
16	139.81	0.00017	4.88	-134.6		
17	149.01	-0.00002	-0.53	24.4		
18	158.21	-0.00020	-5.94	382.5		
19	167.42	-0.00039	-11.34	939.6		
20	176.62	-0.00058	-16.75	1695.7		
21	185.82	-0.00076	-22.16	2650.9		
22	195.03	-0.00095	-27.56	3805.1		
23	204.23	-0.00114	-32.97	5158.3		
24	213.44	-0.00132	-38.37	6710.6		
25	222.64	-0.00151	-43.78	8461.9		
26	231.84	-0.00170	-49.19	10412.2		
27	241.05	-0.00188	-54.59	12561.6		
28	250.25	-0.00207	-60	14910.0		



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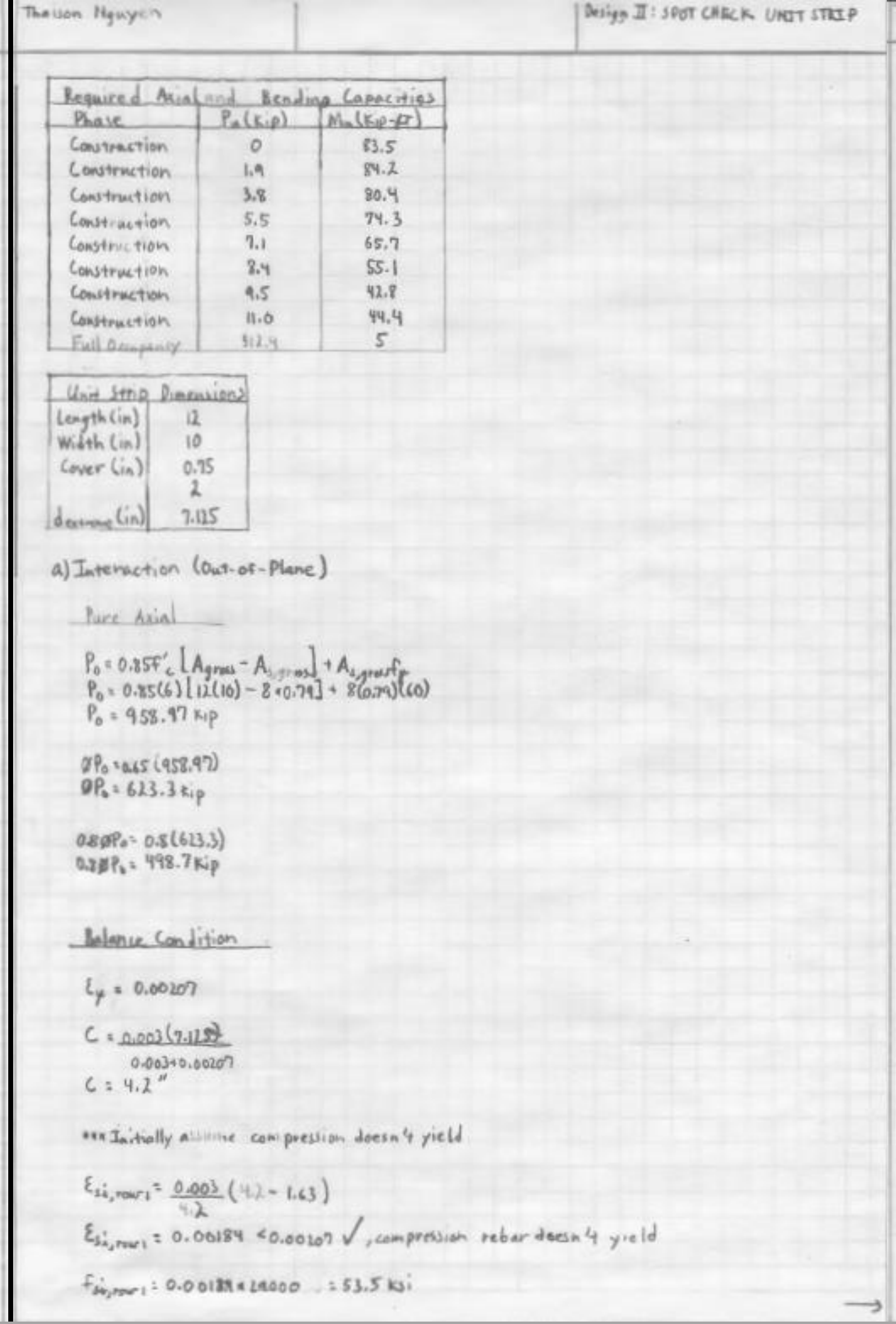
Design I: SPOT CHECK MEMBER AV1-Y1

$\phi P_n = 0.65(3999.86)$

$\phi P_n = 2599.9$ Kip

$\phi M_n = 0.65(31724.28)$

$\phi M_n = 20620.8$ kip-ft



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Design II: SPOT CHECK UNIT STRIP

Required Axial and Bending Capacities		
Phase	P_u (Kip)	M_u (Kip-ft)
Construction	0	83.5
Construction	1.9	84.2
Construction	3.8	80.4
Construction	5.5	74.3
Construction	7.1	65.7
Construction	8.4	55.1
Construction	9.5	42.8
Construction	11.0	44.4
Full Occupancy	312.4	5

Unit Strip Dimensions	
Length (in)	12
Width (in)	10
Cover (in)	0.75 2
$d_{extreme}$ (in)	7.125

a) Interaction (Out-of-Plane)

Pure Axial

$P_o = 0.85 f'_c\left[A_{gross} - A_{s,gross}\right] + A_{s,gross} f_y$

$P_o = 0.85(6)\left[12(10) - 8 \cdot 0.79\right] + 8(0.79)(60)$

$P_o = 958.97$ kip

$\phi P_o = 0.65(958.97)$

$\phi P_o = 623.3$ kip

$0.8\phi P_o = 0.8(623.3)$

$0.8\phi P_o = 498.7$ Kip

Balance Condition

$\varepsilon_y = 0.00207$

$c = \frac{0.003(7.125)}{0.003 + 0.00207}$

$c = 4.2$"

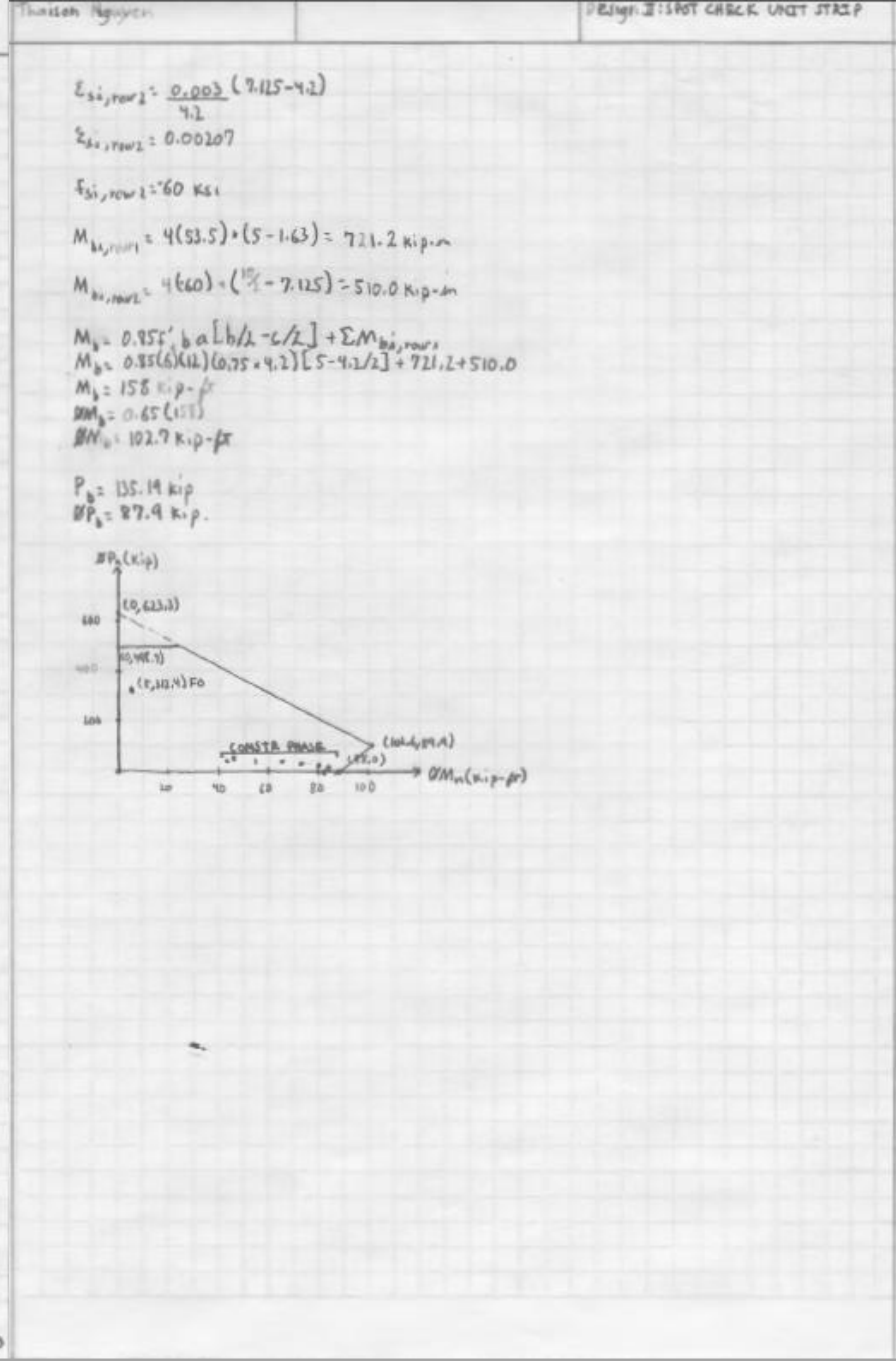
*** Initially assume compression doesn't yield

$\varepsilon_{si,row1} = \frac{0.003}{4.2}(4.2 - 1.63)$

$\varepsilon_{si,row1} = 0.00184 < 0.00207$ ✓, compression rebar doesn't yield

$f_{si,row1} = 0.00184 \cdot 29000 = 53.5$ ksi

→



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Design II: SPOT CHECK UNIT STRIP

$\varepsilon_{si,row2} = \frac{0.003}{4.2}(7.125 - 4.2)$

$\varepsilon_{si,row2} = 0.00207$

$f_{si,row2} = 60$ ksi

$M_{bi,row1} = 4(53.5) \cdot (5 - 1.63) = 721.2$ kip-in

$M_{bi,row2} = 4(60) \cdot (10/2 - 7.125) = 510.0$ kip-in

$M_b = 0.85 f'_c ba\left[h/2 - c/2\right] + \Sigma M_{bi,rows}$

$M_b = 0.85(6)(12)(0.75 \cdot 4.2)\left[5 - 4.2/2\right] + 721.2 + 510.0$

$M_b = 158$ kip-ft

$\phi M_b = 0.65(158)$

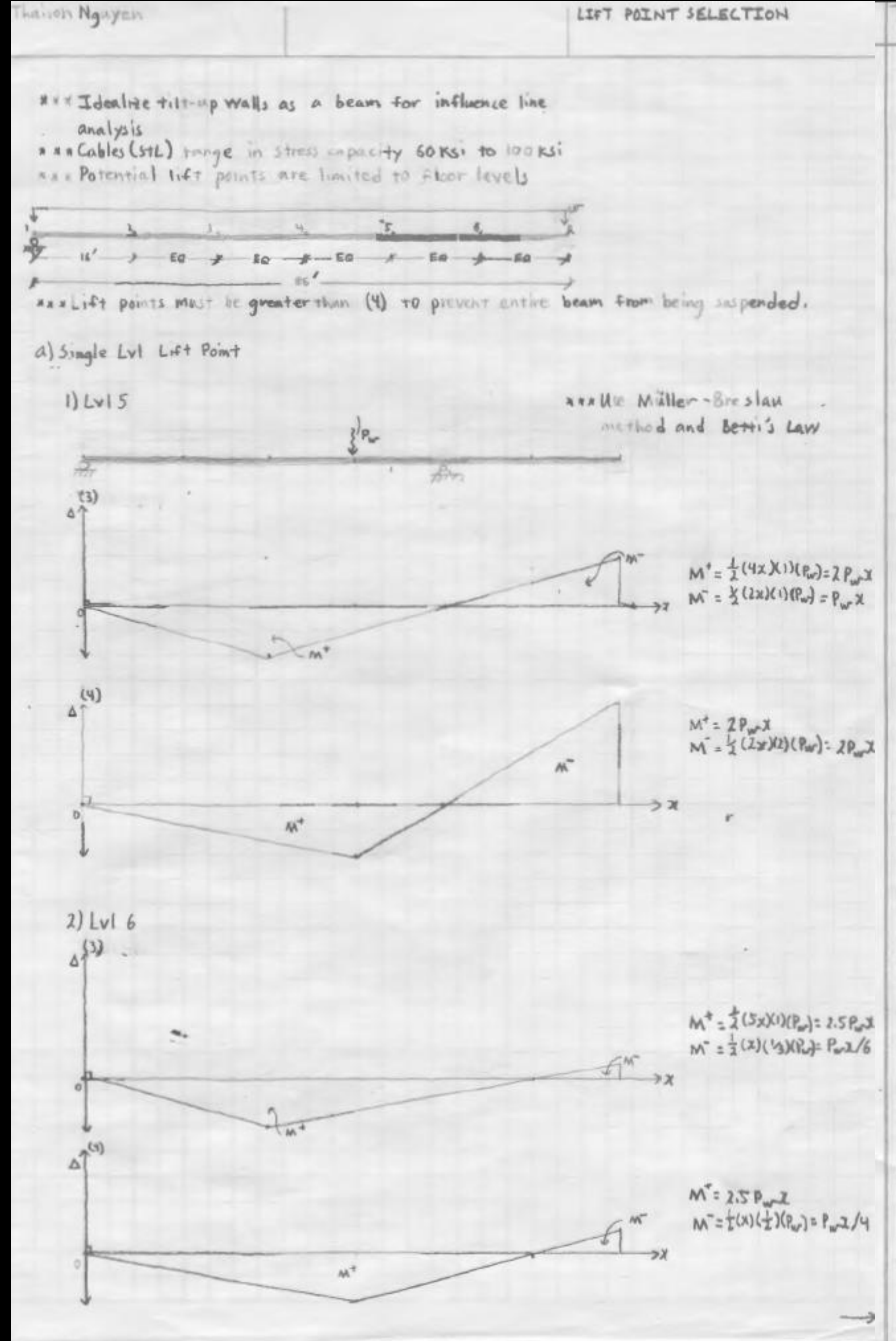
$\phi M_b = 102.7$ kip-ft

$P_b = 135.19$ kip

$\phi P_b = 87.9$ kip.

Gen. Modeling Assumptions

1. All concrete lateral force resisting elements act as if they're are monolithically cast
2. Effective concrete cross-sections is 35% of gross cross-sectional area
3. Rigid panel zone factor 1.0
4. Considered P-Δ effects for drift analysis
5. Seismic importance factor is 1.25
6. All pin connections are perfectly frictionless
7. Non lateral force resisting elements carry no lateral load to the ground
8. Beam end offsets to the pier face
9. Floor diaphragms are considered rigid
10. MEP openings are ignored
11. All material weights are zero
12. Use ACI 318-08 and occasionally ACI 318-05 design criteria



Thaison Nguyen | LIFT POINT SELECTION

*** Idealize tilt-up walls as a beam for influence line analysis

*** Cables (STL) range in stress capacity 60 ksi to 100 ksi

*** Potential lift points are limited to floor levels

*** Lift points must be greater than (4) to prevent entire beam from being suspended.

a) Single Lvl Lift Point

1) Lvl 5

*** Use Müller-Breslau method and Betti's Law

$M^+ = \frac{1}{2}(4x)(1)(P_w) = 2P_w x$

$M^- = \frac{1}{2}(2x)(1)(P_w) = P_w x$

$M^+ = 2P_w x$

$M^- = \frac{1}{2}(2x)(2)(P_w) = 2P_w x$

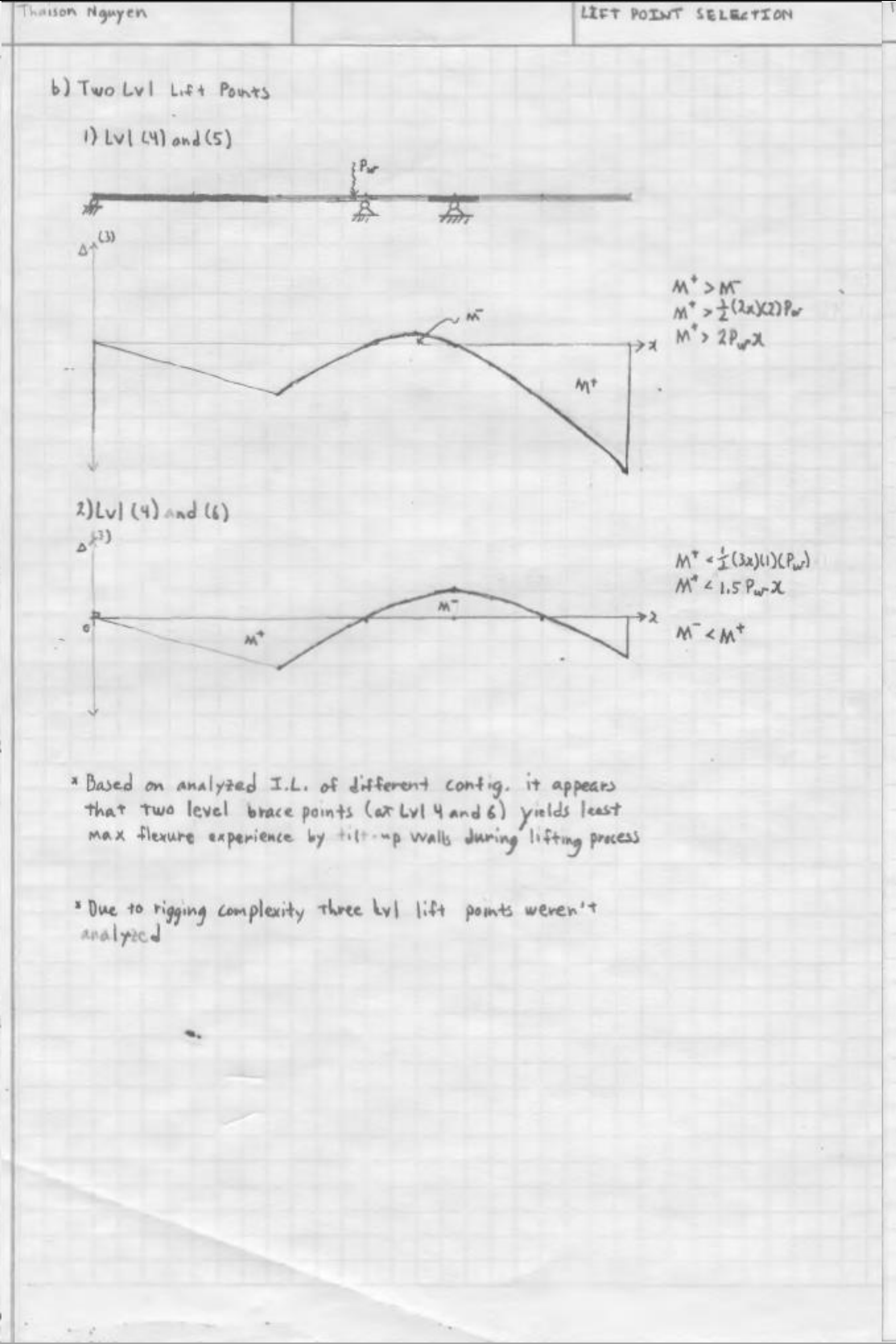
2) Lvl 6

$M^+ = \frac{1}{2}(5x)(1)(P_w) = 2.5P_w x$

$M^- = \frac{1}{2}(x)(\frac{1}{3})(P_w) = P_w x/6$

$M^+ = 2.5P_w x$

$M^- = \frac{1}{2}(x)(\frac{1}{2})(P_w) = P_w x/4$



Thaison Nguyen | LIFT POINT SELECTION

b) Two Lvl Lift Points

1) Lvl (4) and (5)

$M^+ > M^-$

$M^+ > \frac{1}{2}(2x)(2)P_w$

$M^+ > 2P_w x$

2) Lvl (4) and (6)

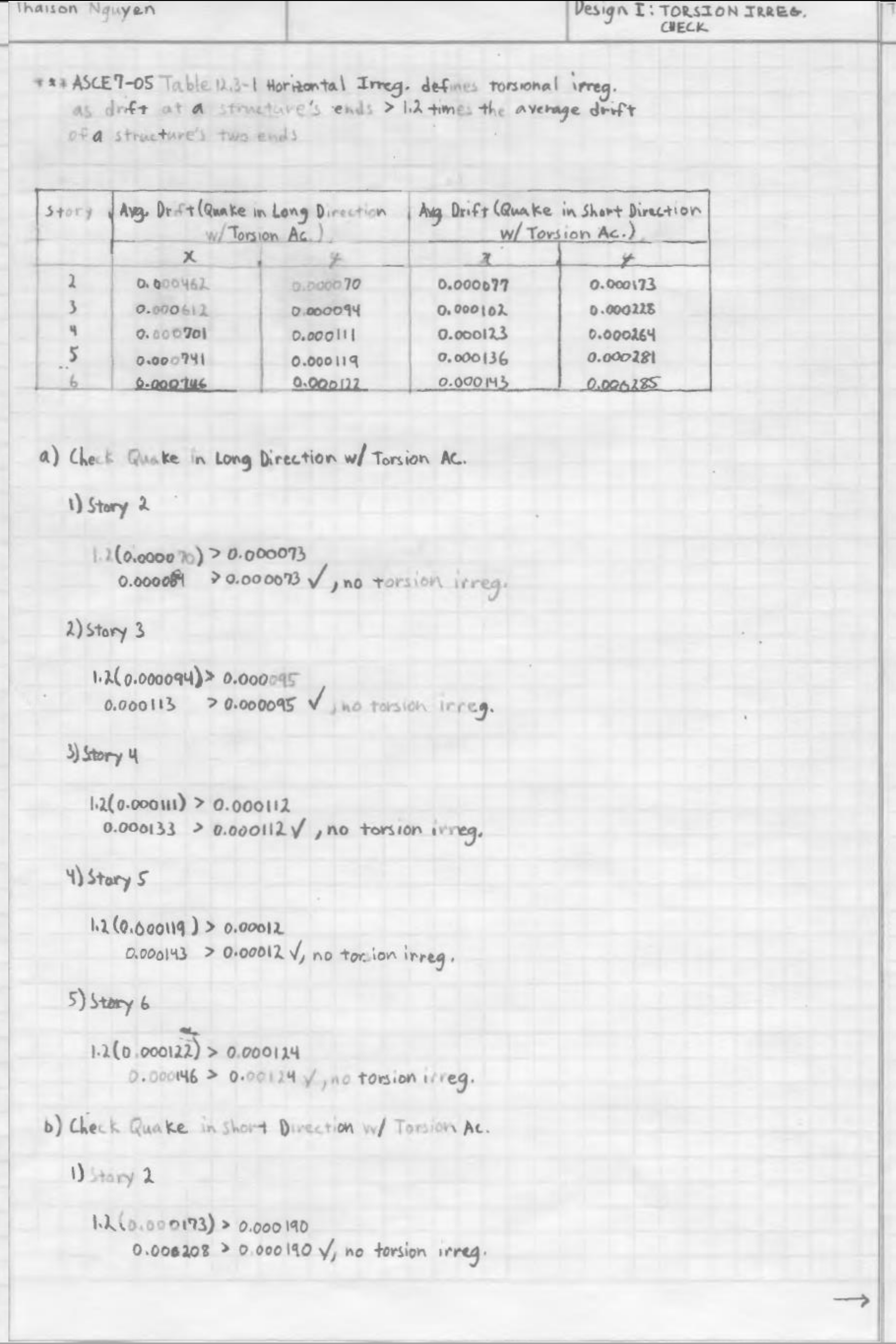
$M^+ < \frac{1}{2}(3x)(1)(P_w)$

$M^+ < 1.5P_w x$

$M^- < M^+$

* Based on analyzed I.L. of different config. it appears that two level brace points (at Lvl 4 and 6) yields least max flexure experience by tilt-up walls during lifting process

* Due to rigging complexity three lvl lift points weren't analyzed



Thaison Nguyen | Design I: TORSION IRREG. CHECK

*** ASCE7-05 Table 12.3-1 Horizontal Irreg. defines torsional irreg. as drift at a structure's ends > 1.2 times the average drift of a structure's two ends

Story	Avg. Drift (Quake in Long Direction w/ Torsion Ac.)		Avg Drift (Quake in Short Direction w/ Torsion Ac.)	
	x	y	x	y
2	0.000462	0.000070	0.000077	0.000173
3	0.000612	0.000094	0.000102	0.000228
4	0.000701	0.000111	0.000123	0.000264
5	0.000741	0.000119	0.000136	0.000281
6	0.000746	0.000122	0.000143	0.000285

a) Check Quake in Long Direction w/ Torsion AC.

1) Story 2

1.2(0.000070) > 0.000073
0.000084 > 0.000073 ✓, no torsion irreg.

2) Story 3

1.2(0.000094) > 0.000095
0.000113 > 0.000095 ✓, no torsion irreg.

3) Story 4

1.2(0.000111) > 0.000112
0.000133 > 0.000112 ✓, no torsion irreg.

4) Story 5

1.2(0.000119) > 0.00012
0.000143 > 0.00012 ✓, no torsion irreg.

5) Story 6

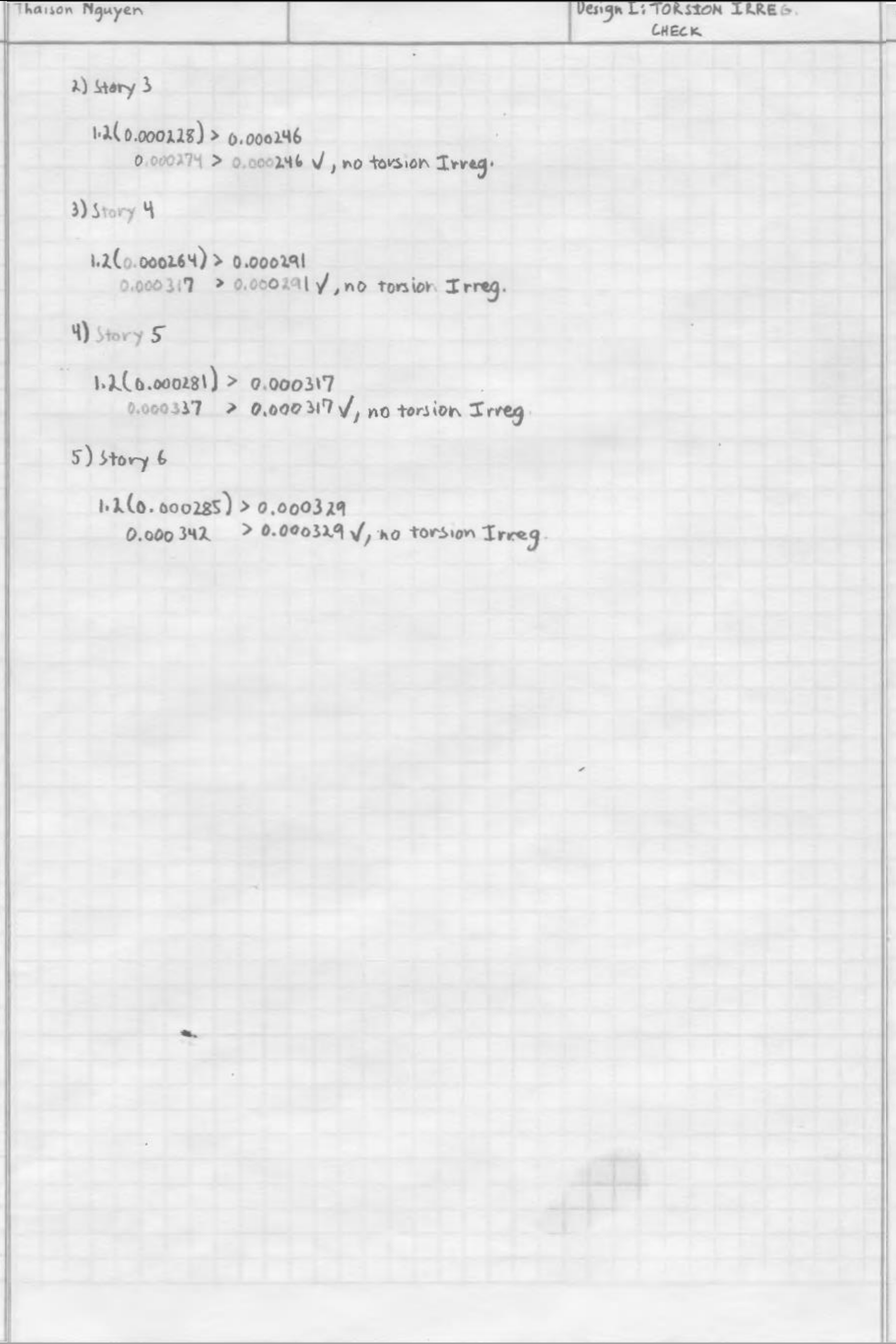
1.2(0.000122) > 0.000124
0.000146 > 0.00124 ✓, no torsion irreg.

b) Check Quake in Short Direction w/ Torsion Ac.

1) Story 2

1.2(0.000173) > 0.000190
0.000208 > 0.000190 ✓, no torsion irreg.

→



Thaison Nguyen | Design I: TORSION IRREG. CHECK

2) Story 3

1.2(0.000228) > 0.000246
0.000274 > 0.000246 ✓, no torsion Irreg.

3) Story 4

1.2(0.000264) > 0.000291
0.000317 > 0.000291 ✓, no torsion Irreg.

4) Story 5

1.2(0.000281) > 0.000317
0.000337 > 0.000317 ✓, no torsion Irreg

5) Story 6

1.2(0.000285) > 0.000329
0.000342 > 0.000329 ✓, no torsion Irreg.

Thaison Nguyen | Design II: TORSION IRREG. CHECK

*** ASCE 7-05 Table 12.3-1 Horizontal Irreg. defines torsional irreg. as drift at a structure's ends > 1.2 times the average drift of a structure's two ends.

Story	Average Drift (Quake in Long Direction w/ Torsion Ac.)		Average Drift (Quake in Short Direction w/ Torsion Ac.)	
	x	y	x	y
2	0.000621	0.000015	0.000012	0.000340
3	0.000652	0.000015	0.000012	0.000331
4	0.000595	0.000012	0.000011	0.000296
5	0.000495	0.000008	0.000009	0.000242
6	0.000395	0.000004	0.000007	0.000177

a) Check Quake in Long Direction w/ Torsion AC.

*** By visual inspection there is no torsion irreg. at any story when bldg. is exposed to quake in long bldg. direction (w/ torsion AC.)

b) Check Quake in Short Direction w/ Torsion Ac.

1) Story 2

1.2(0.00034) > 0.000363
0.000408 > 0.000363 ✓, no torsion irreg.

2) Story 3

1.2(0.000331) > 0.000354
0.000397 > 0.000354 ✓, no torsion irreg.

3) Story 4

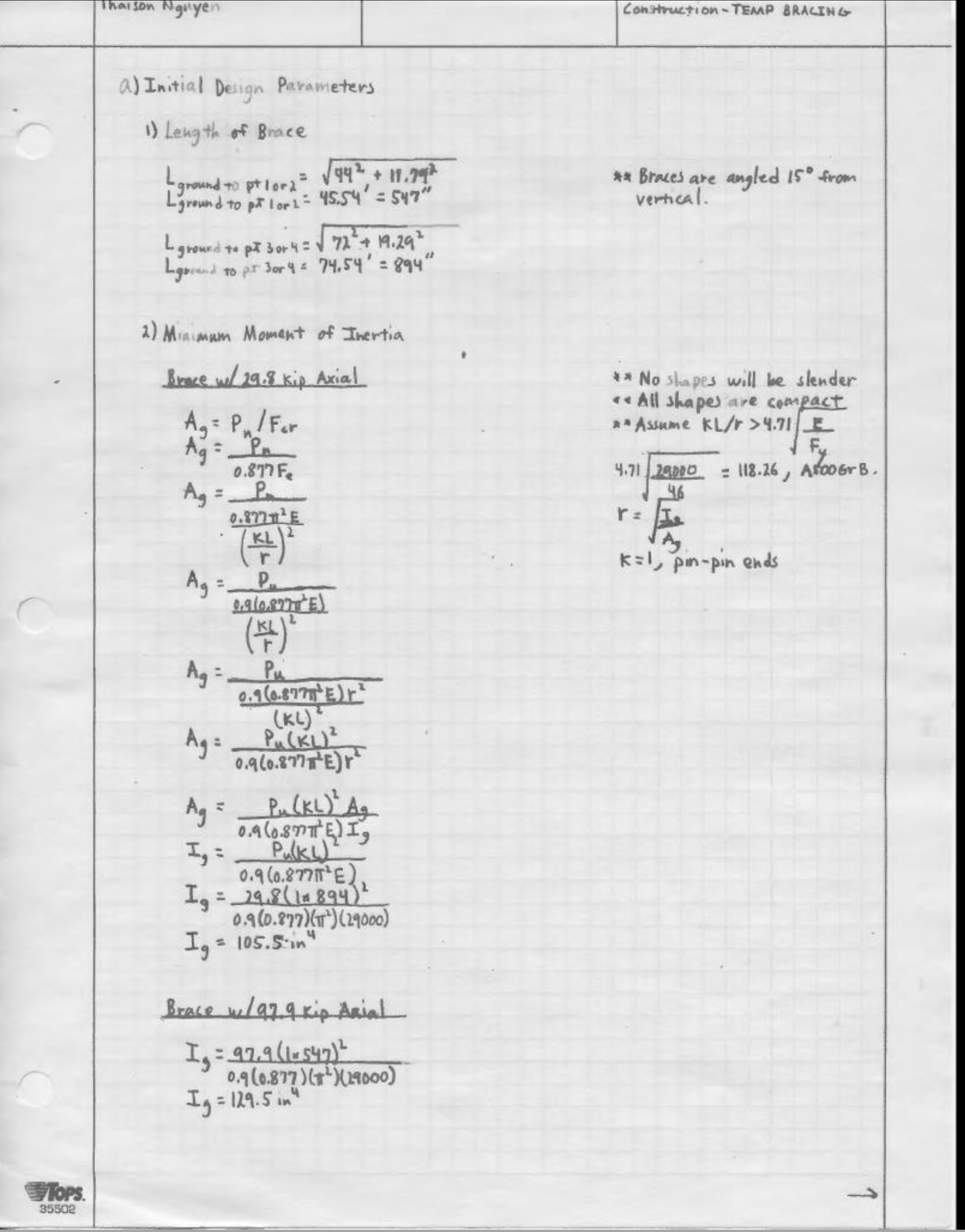
1.2(0.000296) > 0.000318
0.000355 > 0.000318 ✓, no torsion irreg.

4) Story 5

1.2(0.000242) > 0.000260
0.000290 > 0.000260 ✓, no torsion irreg.

5) Story 6

1.2(0.000177) > 0.000191
0.000212 > 0.000191 ✓, no torsion irreg.



Thaison Nguyen | Construction - TEMP BRACING

a) Initial Design Parameters

1) Length of Brace

$L_{ground\ to\ pt\ 1\ or\ 2} = \sqrt{44^2 + 11.79^2}$
$L_{ground\ to\ pt\ 1\ or\ 2} = 45.54' = 547''$

$L_{ground\ to\ pt\ 3\ or\ 4} = \sqrt{72^2 + 19.29^2}$
$L_{ground\ to\ pt\ 3\ or\ 4} = 74.54' = 894''$

** Braces are angled 15° from vertical.

2) Minimum Moment of Inertia

<u>Brace w/ 29.8 Kip Axial</u>

$A_g = P_n / F_{cr}$
$A_g = \frac{P_n}{0.877 F_e}$
$A_g = \frac{P_n}{\frac{0.877\pi^2 E}{\left(\frac{KL}{r}\right)^2}}$
$A_g = \frac{P_u}{\frac{0.9(0.877\pi^2 E)}{\left(\frac{KL}{r}\right)^2}}$
$A_g = \frac{P_u}{\frac{0.9(0.877\pi^2 E) r^2}{(KL)^2}}$
$A_g = \frac{P_u (KL)^2}{0.9(0.877\pi^2 E) r^2}$

$A_g = \frac{P_u (KL)^2 A_g}{0.9(0.877\pi^2 E) I_g}$
$I_g = \frac{P_u (KL)^2}{0.9(0.877\pi^2 E)}$
$I_g = \frac{29.8(1 * 894)^2}{0.9(0.877)(\pi^2)(29000)}$
$I_g = 105.5\ in^4$

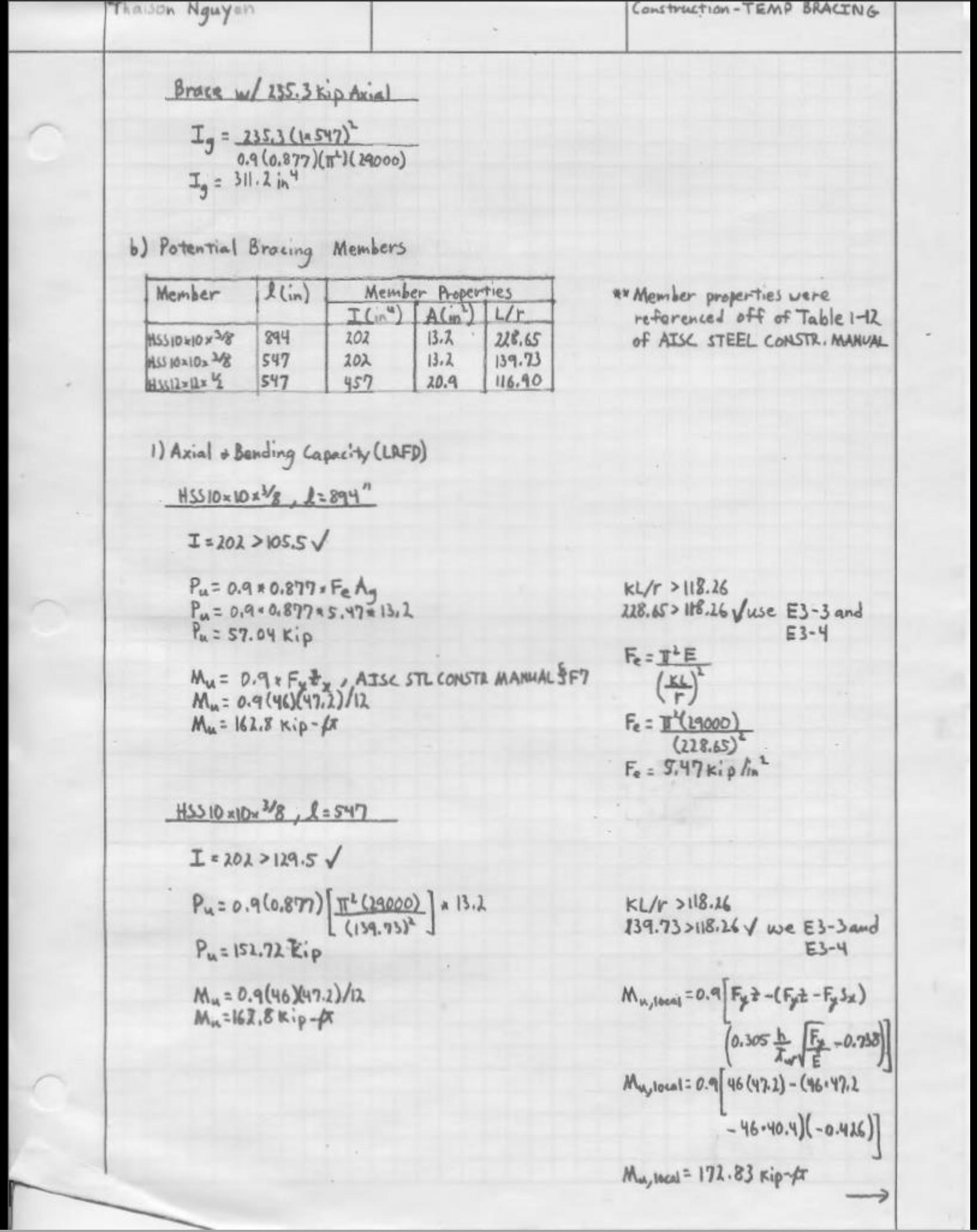
** No shapes will be slender
** All shapes are compact
** Assume $KL/r > 4.71\sqrt{\frac{E}{F_y}}$

$4.71\sqrt{\frac{29000}{46}} = 118.26$, A500 Gr B.
$r = \sqrt{\frac{I_g}{A_g}}$
K=1, pin-pin ends

<u>Brace w/ 97.9 Kip Axial</u>

$I_g = \frac{97.9(1 * 547)^2}{0.9(0.877)(\pi^2)(29000)}$
$I_g = 129.5\ in^4$

→



Thaison Nguyen | Construction - TEMP BRACING

<u>Brace w/ 235.3 Kip Axial</u>

$I_g = \frac{235.3(1 * 547)^2}{0.9(0.877)(\pi^2)(29000)}$
$I_g = 311.2\ in^4$

b) Potential Bracing Members

Member	ℓ (in)	Member Properties		
		I (in^4)	A (in^2)	L/r
HSS10x10x3/8	894	202	13.2	228.65
HSS10x10x3/8	547	202	13.2	139.73
HSS12x12x1/2	547	457	20.9	116.90

** Member properties were referenced off of Table 1-12 of AISC STEEL CONSTR. MANUAL

1) Axial & Bending Capacity (LRFD)

<u>HSS10x10x3/8, ℓ=894"</u>

$I = 202 > 105.5$ ✓

$P_u = 0.9 * 0.877 * F_e A_g$
$P_u = 0.9 * 0.877 * 5.47 * 13.2$
$P_u = 57.04$ Kip

$M_u = 0.9 * F_y Z_x$, AISC STL CONSTR MANUAL §F7
$M_u = 0.9(46)(47.2)/12$
$M_u = 162.8$ Kip-ft

$KL/r > 118.26$
$228.65 > 118.26$ ✓ use E3-3 and E3-4

$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$
$F_e = \frac{\pi^2(29000)}{(228.65)^2}$
$F_e = 5.47\ kip/in^2$

<u>HSS10x10x3/8, ℓ=547</u>

$I = 202 > 129.5$ ✓

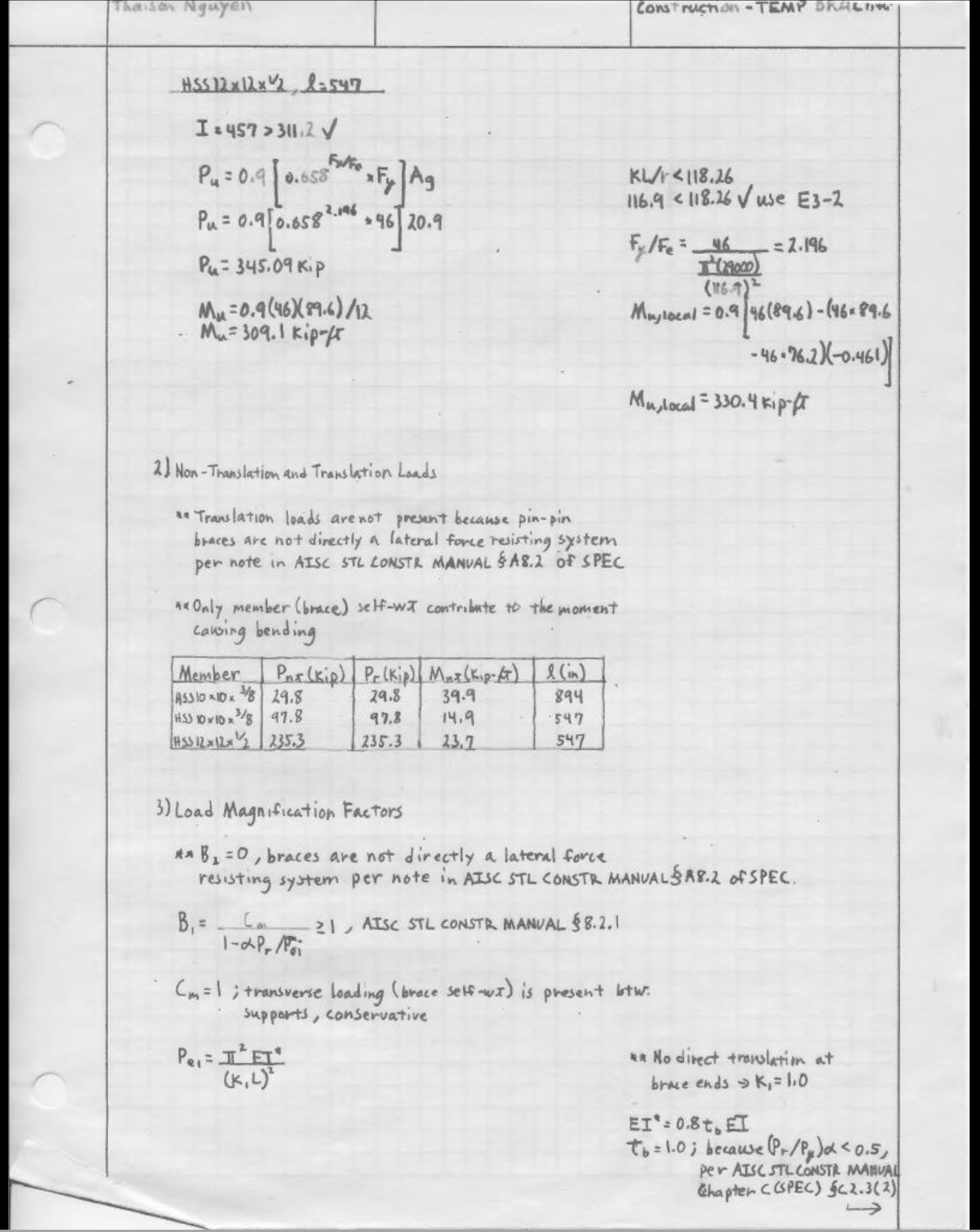
$P_u = 0.9(0.877)\left[\frac{\pi^2(29000)}{(139.73)^2}\right] * 13.2$
$P_u = 152.72$ Kip

$M_u = 0.9(46)(47.2)/12$
$M_u = 162.8$ Kip-ft

$KL/r > 118.26$
$139.73 > 118.26$ ✓ use E3-3 and E3-4

$M_{u,local} = 0.9\left[F_y Z - (F_y Z - F_y S_x)\left(0.305\frac{h}{t_w}\sqrt{\frac{F_y}{E}} - 0.738\right)\right]$
$M_{u,local} = 0.9\left[46(47.2) - (46 * 47.2 - 46 * 40.4)(-0.426)\right]$
$M_{u,local} = 172.83$ Kip-ft

→



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<u>HSS12x12x1/2, ℓ=547</u>

$I = 457 > 311.2$ ✓

$P_u = 0.9\left[0.658^{F_y/F_e} * F_y\right] A_g$
$P_u = 0.9\left[0.658^{2.196} * 46\right] 20.9$
$P_u = 345.09$ Kip

$M_u = 0.9(46)(89.6)/12$
$M_u = 309.1$ Kip-ft

$KL/r < 118.26$
$116.9 < 118.26$ ✓ use E3-2

$F_y/F_e = \frac{46}{\frac{\pi^2(29000)}{(116.9)^2}} = 2.196$

$M_{u,local} = 0.9\left[46(89.6) - (46 * 89.6 - 46 * 76.2)(-0.461)\right]$

$M_{u,local} = 330.4$ Kip-ft

2) Non-Translation and Translation Loads

** Translation loads are not present because pin-pin braces are not directly a lateral force resisting system per note in AISC STL CONSTR MANUAL §A8.2 of SPEC

** Only member (brace) self-wt contribute to the moment causing bending

Member	P_{nt} (Kip)	P_r (Kip)	M_{nt} (Kip-ft)	ℓ (in)
HSS10x10x3/8	29.8	29.8	39.9	894
HSS10x10x3/8	97.8	97.8	14.9	547
HSS12x12x1/2	235.3	235.3	23.7	547

3) Load Magnification Factors

** $B_2 = 0$, braces are not directly a lateral force resisting system per note in AISC STL CONSTR MANUAL §A8.2 of SPEC.

$B_1 = \frac{C_m}{1 - \alpha P_r / P_{e1}} \geq 1$, AISC STL CONSTR MANUAL §8.2.1

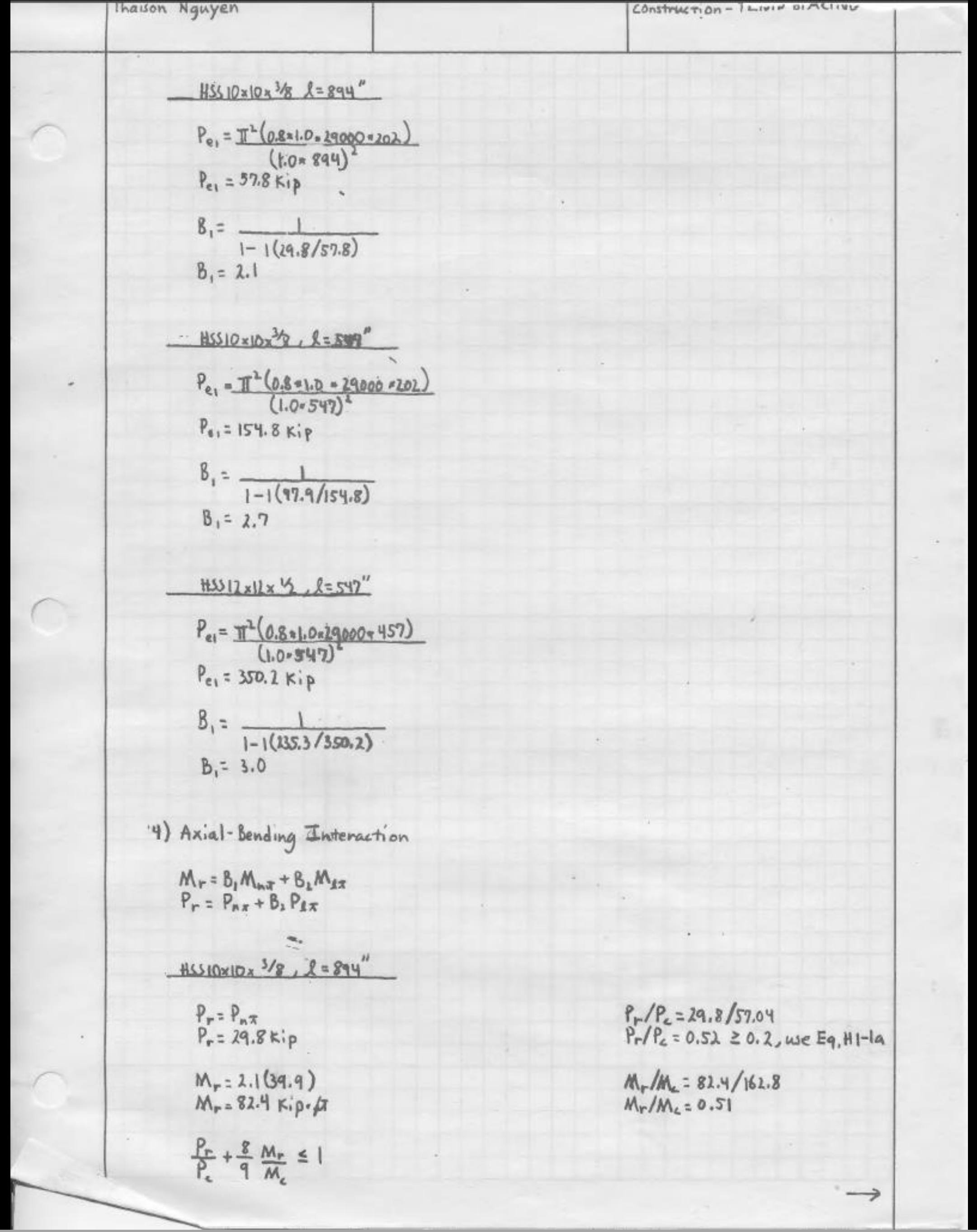
$C_m = 1$; transverse loading (brace self-wt) is present btw. supports, conservative

$P_{e1} = \frac{\pi^2 EI^*}{(K_1 L)^2}$

** No direct translation at brace ends ⇒ $K_1 = 1.0$

$EI^* = 0.8\tau_b EI$
$\tau_b = 1.0$; because $(P_r/P_y)\alpha < 0.5$, per AISC STL CONSTR MANUAL Chapter C (SPEC) §C2.3(2)

→



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<u>HSS10x10x3/8 ℓ=894"</u>

$P_{e1} = \frac{\pi^2(0.8 * 1.0 * 29000 * 202)}{(1.0 * 894)^2}$
$P_{e1} = 57.8$ Kip

$B_1 = \frac{1}{1 - 1(29.8/57.8)}$
$B_1 = 2.1$

<u>HSS10x10x3/8, ℓ=547"</u>

$P_{e1} = \frac{\pi^2(0.8 * 1.0 * 29000 * 202)}{(1.0 * 547)^2}$
$P_{e1} = 154.8$ Kip

$B_1 = \frac{1}{1 - 1(97.9/154.8)}$
$B_1 = 2.7$

<u>HSS12x12x1/2, ℓ=547"</u>

$P_{e1} = \frac{\pi^2(0.8 * 1.0 * 29000 * 457)}{(1.0 * 547)^2}$
$P_{e1} = 350.2$ Kip

$B_1 = \frac{1}{1 - 1(235.3/350.2)}$
$B_1 = 3.0$

4) Axial-Bending Interaction

$M_r = B_1 M_{nt} + B_2 M_{\ell t}$
$P_r = P_{nt} + B_2 P_{\ell t}$

<u>HSS10x10x3/8, ℓ=894"</u>

$P_r = P_{nt}$
$P_r = 29.8$ Kip

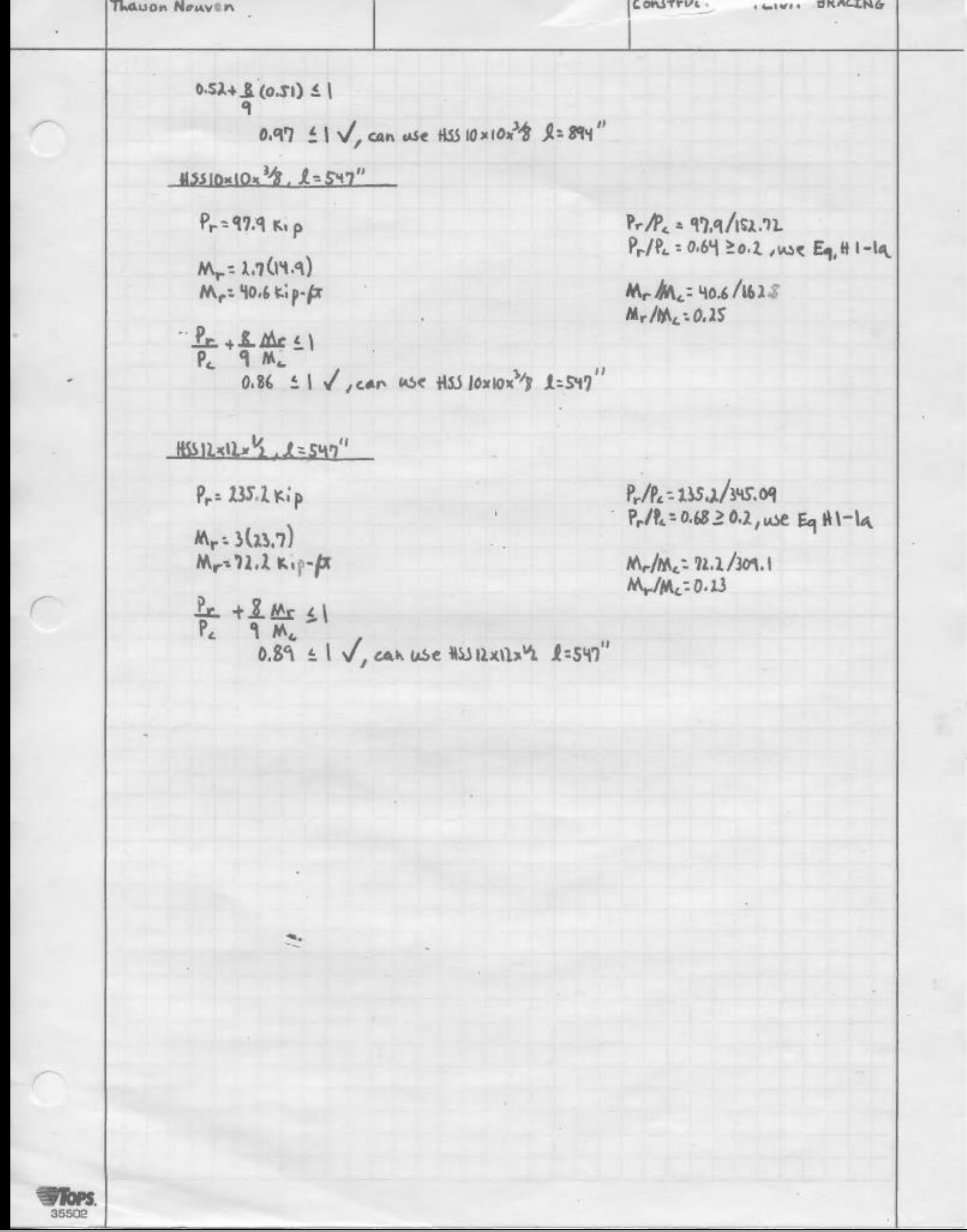
$M_r = 2.1(39.9)$
$M_r = 82.4$ Kip-ft

$\frac{P_r}{P_c} + \frac{8}{9}\frac{M_r}{M_c} \leq 1$

$P_r/P_c = 29.8/57.04$
$P_r/P_c = 0.52 \geq 0.2$, use Eq. H1-1a

$M_r/M_c = 82.4/162.8$
$M_r/M_c = 0.51$

→



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$0.52 + \frac{8}{9}(0.51) \leq 1$
$0.97 \leq 1$ ✓, can use HSS 10x10x3/8 ℓ= 894"

<u>HSS10x10x3/8, ℓ=547"</u>

$P_r = 97.9$ Kip

$M_r = 2.7(14.9)$
$M_r = 40.6$ Kip-ft

$\frac{P_r}{P_c} + \frac{8}{9}\frac{M_r}{M_c} \leq 1$
$0.86 \leq 1$ ✓, can use HSS 10x10x3/8 ℓ=547"

$P_r/P_c = 97.9/152.72$
$P_r/P_c = 0.64 \geq 0.2$, use Eq. H1-1a

$M_r/M_c = 40.6/162.8$
$M_r/M_c = 0.25$

<u>HSS12x12x1/2, ℓ=547"</u>

$P_r = 235.2$ Kip

$M_r = 3(23.7)$
$M_r = 72.2$ Kip-ft

$\frac{P_r}{P_c} + \frac{8}{9}\frac{M_r}{M_c} \leq 1$
$0.89 \leq 1$ ✓, can use HSS12x12x1/2 ℓ=547"

$P_r/P_c = 235.2/345.09$
$P_r/P_c = 0.68 \geq 0.2$, use Eq H1-1a

$M_r/M_c = 72.2/309.1$
$M_r/M_c = 0.23$

Building Overview
Scope and Intent
Solving Torsional Irregularity
Construction Management
Lessons Learned

Original Structural System

Cost Code	Item	Units	Required	Material Unit	Material Cost	Labor Unit	Daily Output	Unit Crew	Number of	Labor Cost	Equipment Unit	Equipment	Total w/ Waste	Notes
	Reinforcement													
032110600700	#3 to #7 Rebar (60 Ksi)	Ton	4	$953.00	$4,089.32	$392.80	3.00	4	2	$1,685.50			$6,183.76	10% Waste Factor
032110600750	#8 to #18 Rebar (60 Ksi)	Ton	22	$953.00	$20,758.25	$293.62	4.00	4	2	$6,395.63			$29,229.70	10% Waste Factor
032116100100	Epoxy Coating	Ton	26	$443.15	$11,554.25								$11,554.25	
	Concrete													
033105350300	4000 psi	Yd^3	255	$104.75	$26,728.58								$29,401.44	10% Waste Factor
033105351420	Superplasticizer	Yd^3	255	$6.26	$1,597.34								$1,757.07	10% Waste Factor
033105705000	Crane and Bucket for Walls	Yd^3	255			$19.58	80.00	13	1	$4,996.14	$15.00	$3,827.48	$8,823.62	
031113852800	Job Built Formwork Over 16' High, 3 Use	ft^2	20668	$0.92	$19,014.93	$3.76	315.00	6	4	$77,713.18			$98,629.60	10% Waste Factor
	Structural Steel													
051223177400	W14x120	ft.	3526	$154.63	$545,225.38	$1.90	960.00	7	1	$6,699.40	$1.57	$5,535.82	$557,460.60	
051223753140	W16x67	ft.	15132	$86.30	$1,305,891.60	$2.40	760.00	7	1	$36,316.80	$1.99	$30,112.68	$1,372,321.08	
051223755500	W24x76	ft.	6768	$97.99	$663,196.32	$2.46	1110.00	11	1	$16,649.28	$1.48	$10,016.64	$689,862.24	
	Fireproofing													
078116100700	Sprayed Cemtitious	ft^2	25799	$0.61	$15,737.39	$0.67	1100.00	4	4	$17,285.33	$0.12	$3,095.88	$37,692.34	10% Waste Factor
	Misc.													
321123230050	Base Course Crushed Graded Stone	Yd^2	4994	$3.09	$15,431.46	$0.23	5200.00	10	1	$1,148.62	$0.77	$3,845.38	$21,968.61	10% Waste Factor
320610100100	2-1/2" Asphalt Road Topping	Yd^2	4994	$10.21	$50,988.74	$0.07	660.00	7	1	$364.56	$0.23	$1,148.62	$55,051.36	[4]
015433203320	Sheepsfoot Drum Vibratory Roller/Compactor	Per Day	18			$1,621.96				$29,195.28	$1,532.95	$27,593.10	$56,788.38	
015433602800	Self-Propelled 5 Ton Crane w/ Telesc. Boom	Per Day	80			$271.18				$21,694.40	$225.49	$18,039.20	$39,733.60	
	Subtotals				$2,680,213.55					$220,144.13		$103,214.80	$3,016,457.65	
	Sales Tax (6%)				$160,812.81									[8]
	Overhead & Profit (10%)				$284,102.64					$22,014.41				[9]
	Subtotal				$3,125,129.00					$242,158.54		$103,214.80		
	Contingency (10%)				$312,512.90					$24,215.85		$10,321.48		
	Adjustments				-$3,419.18					-$264.94		-$112.93		[10]
	Total				$3,434,222.72					$266,109.45		$113,423.36	$4,004,443.31	

Original Façade Wall System

Cost Code	Item	Units	Required Quantity	Material Unit Cost [1] [2]	Material Cost	Labor Unit Cost [1] [2]	Daily Output per Crew [1] [2]	Unit Crew Size	Number of Crews	Labor Cost	Equipment Unit Cost [1] [2]	Equipment Cost	Total w/ Waste Factor	Notes
	CMU													
042210141150	8"	ft^2	44587	$2.33	$103,888.64	$2.56	395.00	5	4	$114,143.74			$223,226.82	[3] [4]
015423751510	Scaffolding	ft.	3486	$5.60	$19,521.60	$18.48	45.00	3	5	$64,421.28			$84,918.96	[4]
040516300700	Grout	ft^2	44587	$2.19	$97,646.41	$1.17	800.00	6	2	$52,167.26	$0.16	$7,133.98	$181,359.25	[5]
	Bond Beams													
042210162100	8"	ft.	7663	$4.31	$33,027.53	$3.37	300.00	5	1	$25,824.31			$60,503.22	[4]
	Lintels													
051223451000	Relieving Angles	lb.	883	$0.23	$203.09								$213.24	[4] [6]
	Reinforcement													
032110600700	#3 to #7 Rebar (60 Ksi)	Ton	25	$953.00	$23,976.91	$392.80	3.00	4	2	$9,882.61			$36,257.21	10% Waste Factor
032116100100	Epoxy Coating	Ton	25	$443.15	$11,149.39								$12,264.33	10% Waste Factor
	Barriers to Moisture Infiltration													
076510100020	Aluminum Flashing	ft^2	7117	$0.72	$5,124.24	$1.20	145.00	1	7	$8,540.40			$13,920.85	[4] [7]
076513100750	Laminated Sheet Flashing, Self Adhered	ft^2	2815	$3.46	$9,739.90	$0.38	460.00	1	1	$1,069.70			$11,296.60	[4] [7]
075113400900	Vapor Retarder/Waterproofing	100 ft^2	446	$4.90	$2,185.03	$3.24	58.00	1	2	$1,444.80			$3,848.33	10% Waste Factor
	Misc.													
092213130030	Furring Strips/Resilient Channels	ft^2	44587	$0.40	$17,834.96	$1.29	155.00	1	10	$57,517.75			$76,244.45	[4]
	Subtotals				$324,297.70					$335,011.85		$7,133.98	$704,053.26	
	Sales Tax (6%)				$19,457.86									[8]
	Overhead & Profit (10%)				$34,375.56					$33,501.18				[9]
	Subtotal				$378,131.11					$368,513.03		$7,133.98		
	Contingency (10%)				$37,813.11					$36,851.30		$713.40		
	Adjustments				-$413.71					-$403.19		-$7.81		[10]
	Total				$415,530.51					$404,961.15		$7,839.58	$869,747.80	

Structural Solution (1)

Cost Code	Item	Units	Required	Material Unit	Material Cost	Labor Unit	Daily Output	Unit Crew	Number of	Labor Cost	Equipment Unit	Equipment	Total w/ Waste	Notes
	Reinforcement													
032110600700	#3 to #7 Rebar (60 Ksi)	Ton	6	$953.00	$5,260.56	$392.80	3.00	4	2	$2,168.26			$7,954.87	10% Waste Factor
032110600750	#8 to #18 Rebar (60 Ksi)	Ton	34	$953.00	$32,021.28	$293.62	4.00	4	2	$9,865.78			$45,089.18	10% Waste Factor
032116100100	Epoxy Coating	Ton	39	$443.15	$17,336.25								$17,336.25	
	Concrete													
033105350300	4000 psi	Yd^3	255	$104.75	$26,728.58								$29,401.44	10% Waste Factor
033105350411	6000 psi	Yd^3	71	$126.32	$8,920.69								$9,812.76	10% Waste Factor
033105351420	Superplasticizer	Yd^3	326	$6.26	$2,039.42								$2,243.36	10% Waste Factor
033105705000	Crane and Bucket for Walls	Yd^3	326			$19.58	80.00	13	1	$6,378.87	$15.00	$4,886.78	$11,265.65	
031113852800	Job Built Formwork Over 16' High, 3 Use	ft^2	26389	$0.92	$24,277.51	$3.76	315.00	6	4	$99,221.14			$125,926.40	10% Waste Factor
	Structural Steel													
051223177400	W14x120	ft.	3526	$154.63	$545,225.38	$1.90	960.00	7	1	$6,699.40	$1.57	$5,535.82	$557,460.60	
051223753140	W16x67	ft.	15132	$86.30	$1,305,891.60	$2.40	760.00	7	1	$36,316.80	$1.99	$30,112.68	$1,372,321.08	
051223755500	W24x76	ft.	6768	$97.99	$663,196.32	$2.46	1110.00	11	1	$16,649.28	$1.48	$10,016.64	$689,862.24	
	Fireproofing													
078116100700	Sprayed Cemtitious	ft^2	25799	$0.61	$15,737.39	$0.67	1100.00	4	4	$17,285.33	$0.12	$3,095.88	$37,692.34	10% Waste Factor
	Misc.													
321123230050	Base Course Crushed Graded Stone	Yd^2	4994	$3.09	$15,431.46	$0.23	5200.00	10	1	$1,148.62	$0.77	$3,845.38	$21,968.61	10% Waste Factor
320610100100	2-1/2" Asphalt Road Topping	Yd^2	4994	$10.21	$50,988.74	$0.07	660.00	7	1	$364.56	$0.23	$1,148.62	$55,051.36	[4]
015433203320	Sheepsfoot Drum Vibratory Roller/Compactor	Per Day	18			$1,621.96				$29,195.28	$1,532.95	$27,593.10	$56,788.38	
015433602800	Self-Propelled 5 Ton Crane w/ Telesc. Boom	Per Day	80			$271.18				$21,694.40	$225.49	$18,039.20	$39,733.60	
	Subtotals				$2,713,055.17					$246,987.72		$104,274.10	$3,079,908.11	
	Sales Tax (6%)				$162,783.31									[8]
	Overhead & Profit (10%)				$287,583.85					$24,698.77				[9]
	Subtotal				$3,163,422.33					$271,686.49		$104,274.10		
	Contingency (10%)				$316,342.23					$27,168.65		$10,427.41		
	Adjustments				-$3,461.07					-$297.25		-$114.09		[10]
	Total				$3,476,303.49					$298,557.89		$114,587.42	$4,083,921.23	

Revised Original Façade Wall System

Cost Code	Item	Units	Required Quantity	Material Unit Cost [1] [2]	Material Cost	Labor Unit Cost [1] [2]	Daily Output per Crew [1] [2]	Unit Crew Size	Number of Crews	Labor Cost	Equipment Unit Cost [1] [2]	Equipment Cost	Total w/ Waste Factor	Notes
	CMU													
042210141150	8"	ft^2	41727	$2.33	$97,224.61	$2.56	395.00	5	4	$106,821.89			$208,907.73	[3] [4]
015423751510	Scaffolding	ft.	3486	$5.60	$19,521.60	$18.48	45.00	3	5	$64,421.28			$84,918.96	[4]
040516300700	Grout	ft^2	41727	$2.19	$91,382.79	$1.17	800.00	6	2	$48,820.94	$0.16	$6,676.37	$169,725.79	[5]
	Bond Beams													
042210162100	8"	ft.	7519	$4.31	$32,406.89	$3.37	300.00	5	1	$25,339.03			$59,366.26	[4]
	Lintels													
051223451000	Relieving Angles	lb.	739	$0.23	$169.97								$178.47	[4] [6]
	Reinforcement													
032110600700	#3 to #7 Rebar (60 Ksi)	Ton	22	$953.00	$20,731.09	$392.80	3.00	4	2	$8,544.77			$31,348.97	10% Waste Factor
032116100100	Epoxy Coating	Ton	22	$443.15	$9,640.06								$10,604.07	10% Waste Factor
	Insulation													
072113102100	1" Expanded Polystyrene	ft^2	44593	$0.25	$11,148.13	$0.37	800.00	1	3	$16,499.23			$28,204.76	[4]
	Barriers to Moisture Infiltration													
076510100020	Aluminum Flashing	ft^2	7117	$0.72	$5,124.24	$1.20	145.00	1	7	$8,540.40			$13,920.85	[4] [7]
076510100020	Laminated Sheet Flashing, Self Adhered	ft^2	2815	$3.46	$9,739.90	$0.38	460.00	1	1	$1,069.70			$11,296.60	[4] [7]
075113400900	Vapor Retarder/Waterproofing	100 ft^2	446	$4.90	$2,185.03	$3.24	58.00	1	2	$1,444.80			$3,848.33	10% Waste Factor
	Misc.													
092213130030	Furring Strips/Resilient Channels	ft^2	41727	$0.40	$16,690.92	$1.29	155.00	1	10	$53,828.22			$71,353.68	[4]
	Subtotals				$315,965.22					$335,330.25		$6,676.37	$693,674.47	
	Sales Tax (6%)				$18,957.91									[8]
	Overhead & Profit (10%)				$33,492.31					$33,533.03				[9]
	Subtotal				$368,415.45					$368,863.28		$6,676.37		
	Contingency (10%)				$36,841.54					$36,886.33		$667.64		
	Adjustments				-$403.08					-$403.57		-$7.30		[10]
	Total				$404,853.91					$405,346.04		$7,336.70	$858,413.48	

Structural Solution (2)

Cost Code	Item	Units	Quantity	Material Unit Cost [1] [2]	Material Cost	Labor Unit Cost [1] [2]	Daily Output per Crew [1] [2]	Unit Crew Size	Number of Crews	Labor Cost	Equipment Unit Cost [1] [2]	Equipment Cost	Total w/ Waste Factor	Notes
	Reinforcement													
032110600700	#3 to #7 Rebar (60 Ksi)	Ton	37	$953.00	$35,577.40	$392.80	3.00	4	2	$14,664.01			$53,799.15	10% Waste Factor
032110600750	#8 to #18 Rebar (60 Ksi)	Ton	249	$953.00	$237,412.79	$293.62	4.00	4	4	$73,147.05			$334,301.12	10% Waste Factor
032110601200	Reinforcing in Place, A615 Gr. 75	Ton	33	$88.15	$2,869.50								$3,156.45	10% Waste Factor
032116100100	Epoxy Coating	Ton	286	$443.15	$126,941.87								$139,636.06	10% Waste Factor
031519100510	1-1/2" Anchor Bolts, 24" Long	Set	44	$52.75	$2,321.00	$13.85	32.00	2	1	$609.40			$3,046.45	[4]
	Concrete													
033105350411	6000 psi	Yd^3	655	$126.32	$82,711.14								$90,982.25	10% Waste Factor
033105351420	Superplasticizer	Yd^3	655	$6.26	$4,098.89								$4,508.78	10% Waste Factor
033105705000	Crane and Bucket for Walls	Yd^3	655			$19.58	80.00	13	2	$1,566.40	$15.00	$9,821.62	$11,388.02	
031113852800	Job Built Formwork Over 16' High, 3 Use	ft^2	21215	$0.92	$19,517.52	$3.75	315.00	6	6	$79,555.13			$101,024.40	10% Waste Factor
	Structural Steel													
051223177400	W14x120	ft.	1634	$154.63	$252,665.42	$1.90	960.00	7	1	$3,104.60	1.57	2565.38	$258,335.40	
051223753140	W16x67	ft.	13740	$86.30	$1,185,762.00	$2.40	760.00	7	1	$32,976.00	1.99	27342.6	$1,246,080.60	
051223755500	W24x76	ft.	4056	$97.99	$397,447.44	$2.46	1110.00	11	1	$9,977.76	1.48	6002.88	$413,428.08	
051223400400	Angles 4" and Larger	lb.	6024	$0.67	$4,036.08	$2.09	440.00	4	2	$12,590.16	$0.33	$1,987.92	$18,614.16	
	Fireproofing													
078116100700	Sprayed Cemtitious	ft^2	11955	$0.61	$7,292.55	$0.67	1100.00	4	2	$8,009.85	$0.12	$1,434.60	$17,466.26	10% Waste Factor
	Misc.													
321123230050	Base Course Crushed Graded Stone	Yd^2	4994	$3.09	$15,431.46	$0.23	5200.00	10	1	$1,148.62	$0.77	$3,845.38	$21,968.61	10% Waste Factor
320610100100	2-1/2" Asphalt Road Topping	Yd^2	4994	$10.21	$50,988.74	$0.07	660.00	7	1	$364.56	$0.23	$1,148.62	$55,051.36	[4]
015433203320	Sheepsfoot Drum Vibratory Roller/Compactor	Per Day	18			$1,621.96				$29,195.28	$1,532.95	$27,593.10	$27,593.10	
015433601400	200 Ton Crawler Crane	Week	4	$126.54	$506.16	$2,423.05				$9,692.20	$12,315.92	$49,263.68	$59,462.04	
015433602800	Self-Propelled 5 Ton Crane w/ Telesc. Boom	Per Day	45			$271.18				$12,203.10	$225.49	$10,147.05	$22,350.15	
034105101300	Pre-Cast Conc. Foundations	Each	22	$3,612.00	$79,464.00	$97.54	22.00	6	1	$2,145.88	$83.57	$1,838.54	$83,448.42	
051223770800	Tilt-Up Temporary Bracing	Ton	58	$2,382.35	$138,176.30	$316.58	14.40	15	1	$18,361.64	$127.58	$7,399.64	$163,937.58	
	Subtotals				$2,643,220.26					$309,311.64		$150,391.01	$3,129,578.43	
	Sales Tax (6%)				$158,593.22									[8]
	Overhead & Profit (10%)				$280,181.35					$30,931.16				[9]
	Subtotal				$3,081,994.82					$340,242.81		$150,391.01		
	Contingency (10%)				$308,199.48					$34,024.28		$15,039.10		
	Adjustments				-$3,371.99					-$372.26		-$164.54		[10]
	Total				$3,386,822.32					$373,894.83		$165,265.57	$4,122,281.85	

Redesigned Façade Wall System

Cost Code	Item	Units	Quantity	Material Unit Cost [1] [2]	Material Cost	Labor Unit Cost [1] [2]	Daily Output per Crew [1] [2]	Unit Crew Size	Number of Crews	Labor Cost	Equipment Unit Cost [1] [2]	Equipment Cost	Total w/ Waste Factor	Notes
	Sheathing and Framing													
092813100200	5/8" Fiber Cement Board	ft^2	23378	$9.37	$219,049.99	$8.58	66.00	2	12	$200,581.52			$430,584.01	[4]
015423751510	Scaffolding	ft.	3486	$5.60	$19,521.60	$18.48	45.00	3	5	$64,421.28			$84,918.96	[4]
054113305430	16 Gauge Mtl. Stud	ft.	26548	$18.15	$481,837.13	$8.98	63.00	2	15	$238,396.55			$744,325.53	[4]
	Insulation													
072113102100	1" Expanded Polystyrene	ft^2	44593	$0.25	$11,148.13	$0.37	800.00	1	2	$16,499.23			$28,204.76	[4]
098436100970	3-1/2" Acoustical Insulation	ft^2	23378	$0.35	$8,182.23	$0.16	1400.00	1	3	$3,740.45			$12,331.79	[4]
	Barriers to Moisture Infiltration													
076510100020	Aluminum Flashing	ft^2	7117	$0.72	$5,124.24	$1.20	145.00	1	6	$8,540.40			$13,920.85	[4] [7]
076510100020	Laminated Sheet Flashing, Self Adhered	ft^2	2815	$3.46	$9,739.90	$0.38	460.00	1	1	$1,069.70			$11,296.60	[4] [7]
072726100100	Vapor Retarder/Waterproofing (Fluid)	ft^2	44593	$0.10	$4,459.25	$0.19	1375.00	5	4	$8,472.58			$13,154.79	[4] [7]
	Misc.													
092213130030	Furring Strips/Resilient Channels	ft^2	41727	$0.40	$16,690.92	$1.29	155.00	1	10	$53,828.22			$71,353.68	[4]
	Subtotals				$775,753.38					$595,549.92		$0.00	$1,410,090.96	
	Sales Tax (6%)				$46,545.20									[8]
	Overhead & Profit (10%)				$82,229.86					$59,554.99				[9]
	Subtotal				$904,528.44					$655,104.91		$0.00		
	Contingency (10%)				$90,452.84					$65,510.49		$0.00		
	Adjustments				-$989.64					-$716.74		$0.00		[10]
	Total				$993,991.64					$719,898.66		$0.00	$1,799,584.81	

[1] Values referenced from R.S. Means 2013

[2] Open shop labor

[3] CMU laid in alternate courses

[4] Waste Factor is assumed to be 5%, unless noted

[5] Grout Waste factor is 25%, Provided by R.S. Means

[6] Wt. of relieving angles is based on stl. density of 490 lb/ft3

[7] All flashing are assumed to be 24" in height

[8] Sales tax is assumed to be 6%

[9] O+P is assumed to be 10%

[10] Location factor is 91.4 (total weighted average) for 2013 and 91.3 (total weighted average) for 2008, valuesfrom R.S. Means

Table P1.12, Thermal and Moisture Resistance of Retrofit and Original

Wall System	Total R-Value (h-ft^2-°F/Btu)	Total R_v-Value
Original	1.2	88.9
Retrofit	6.2	114.2

Table P1.13, Average Relative Humidity Across Retrofit Wall Assembly

Layer Inter-face	R_i/R	R_{vi}/R_v	Normal Conditions (%)				100% Exterior RH (%)			
			Winter		Summer		Winter		Summer	
			High	Low	High	Low	High	Low	High	Low
1			59.0	86.0	75.0	90.0	100.0	100.0	100.0	100.0
2	0.235	0.892	53.9	95.9	36.7	55.7	58.2	97.1	39.8	56.7
3	0.042	0.000	53.7	92.2	37.7	55.6	58.0	93.3	40.9	56.6
4	0.000	0.018	53.6	92.7	36.6	54.9	57.2	93.7	39.3	55.8
5	0.011	0.078	53.2	94.0	32.4	52.0	53.7	94.1	32.8	52.1
6	0.709	0.000	50.1	49.9	51.0	50.5	50.5	50.0	51.6	50.6
7	0.003	0.012	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0

Table P1.14, Average Relative Humidity Across Original Wall Assembly

Layer Inter-face	R_i/R	R_{vi}/R_v	Normal Conditions (%)				100% Exterior RH (%)			
			Winter		Summer		Winter		Summer	
			High	Low	High	Low	High	Low	High	Low
1			59.0	86.0	75.0	90.0	100.0	100.0	100.0	100.0
2	0.082	0.043	58.4	81.0	76.6	88.1	97.3	93.3	101.7	97.6
3	0.000	0.000	58.4	81.0	76.6	88.1	97.3	93.3	101.7	97.6
4	0.000	0.000	58.4	81.0	76.6	88.0	97.3	93.4	101.7	97.6
5	0.442	0.953	52.1	75.9	36.9	51.1	52.2	75.9	37.1	51.2
6	0.002	0.000	52.1	75.7	37.0	51.1	52.2	75.8	37.1	51.2
7	0.474	0.004	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0

Table P1.15, Average Relative Humidity Across Retrofit Wall Assembly

Layer Inter-face	R_i/R	R_{vi}/R_v	Normal Conditions (%)				100% Exterior RH (%)			
			Winter		Summer		Winter		Summer	
			High	Low	High	Low	High	Low	High	Low
1			59.0	86.0	75.0	90.0	100.0	100.0	100.0	100.0
2	0.016	0.034	58.8	86.0	74.1	88.7	98.3	99.3	98.5	98.3
3	0.710	0.222	54.4	48.9	98.3	77.9	83.0	54.2	127.6	85.1
4	0.098	0.000	53.9	44.9	104.8	77.6	82.3	49.7	135.9	84.8
5	0.000	0.000	53.9	44.9	104.8	77.6	82.3	49.7	135.9	84.8
6	0.085	0.741	50.4	54.0	47.3	50.3	50.5	54.1	47.4	50.3
7	0.000	0.000	50.4	54.0	47.3	50.3	50.5	54.0	47.4	50.3
8	0.091	0.003	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0

Building Overview Scope and Intent Solving Torsional Irregularity Construction Management Lessons Learned