Analysis And Design of Concrete Building

The Westinghouse Electric Company Corporate Headquarters

Cranberry, PA

Jessica L. Laurito
Structural Option

AE Senior Thesis
April 14, 2009
Penn State University

Topic Outline

The Westinghouse Electric Company Corporate Headquarters

- Building Background Information
- Existing Building Conditions
- Project Goals
- Design Process
- Design Implications and RAM Model
- Lateral Loads and Considerations
- Schedule Comparison
- Cost Analysis Study
- Sustainable Architecture Study
- Recommendations
- Acknowledgements
- Questions

Background Information

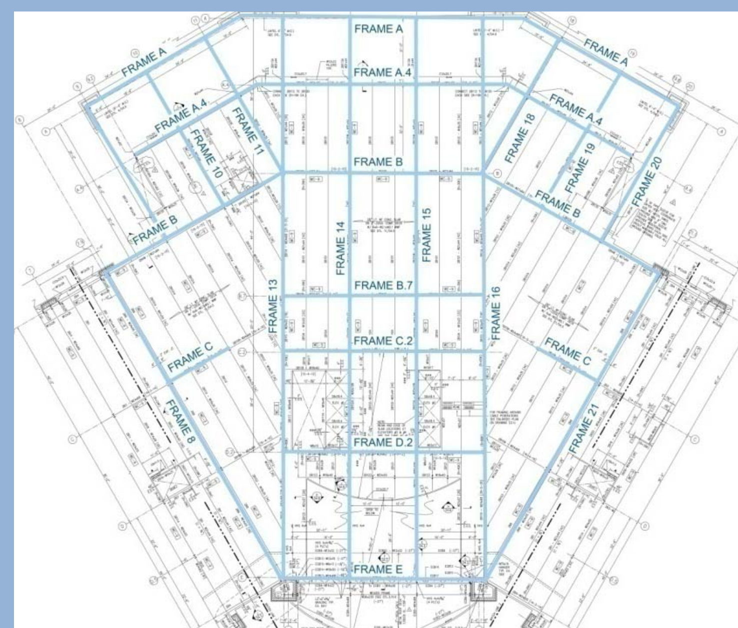
The Westinghouse Electric Company Corporate Headquarters

- Function: Corporate Headquarters and Office Space
- Project Size: 434,800 sq. ft.
- Stories: 5 above grade, 1 below grade
- Total Cost: $55,878,000
- Construction: February 2008 – May 2009
- Building Location: Cranberry, Pennsylvania

Existing Conditions

Existing Structural Steel Framing

- Steel framing
- Composite metal deck LWC topping
- Typical floor height 14’
- Foundation: Spread footings and caissons
- Moment connections at every column
- Typical bay size is 45’x24’



Existing Conditions

- 434,800 SF Building One
- Buildings Two And Three On Each Side To Start The Campus
- The Building Is Equipped With Amenities such as:
  - Cafeteria
  - Gym
  - Locker Rooms
  - Offices
  - Executive Conference Rooms
- LEED Certified Building Goal

Existing Conditions

Background Information

Existing Conditions

Project Goals

Design Process

Design Implications

Lateral Loads

Schedule Comparison

Cost Analysis

Sustainable Architecture

Recommendations

Acknowledgements

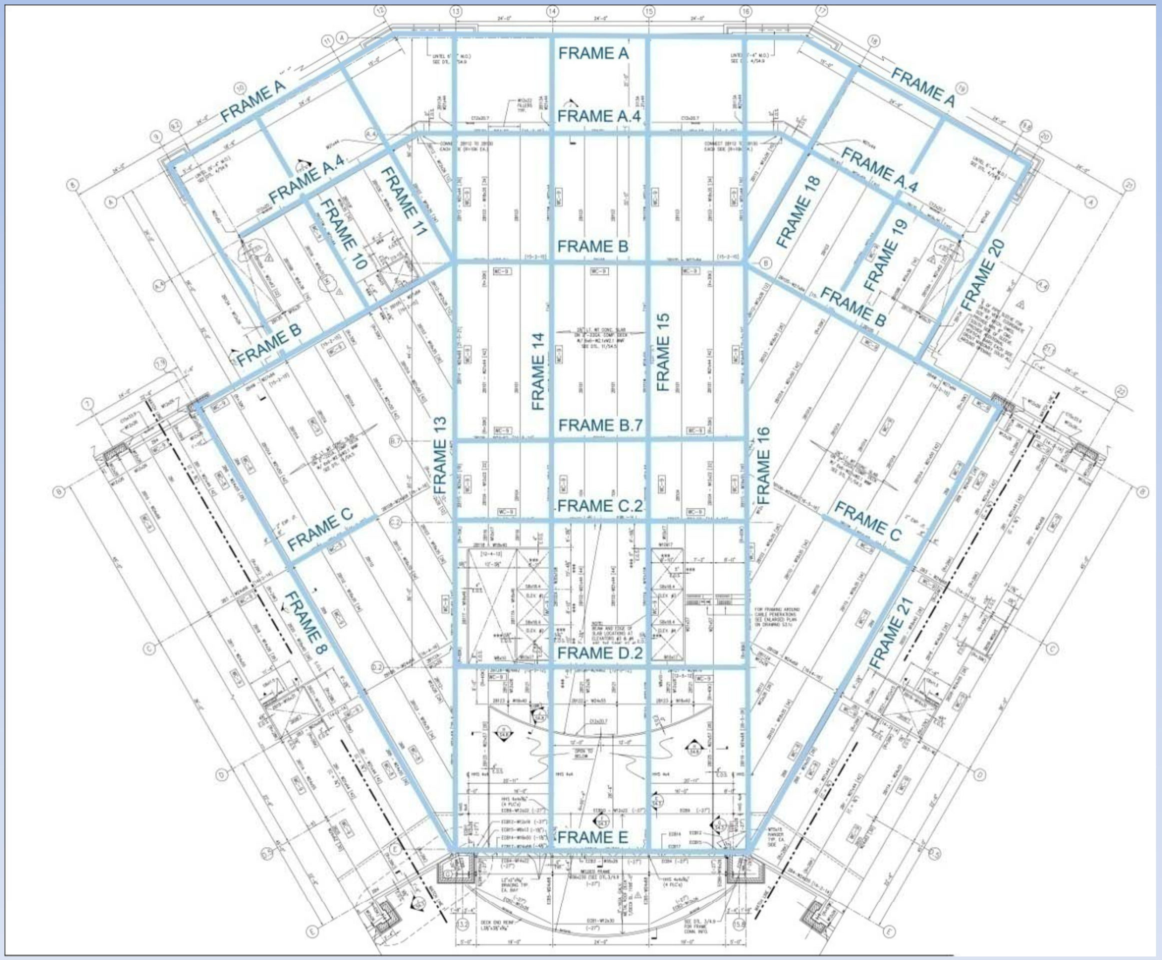
Questions

- 83 Acre Site in Butler County
- Easily Accessible From I-79, I-76, and PA-228

Site Map From www.google.com

Existing Conditions

Existing Conditions



Existing Conditions

Problem Statement

- Background Information
- Existing Conditions
- **Project Goals**
- Design Process
- Design Implications
- Lateral Loads
- Schedule Comparison
- Cost Analysis
- Sustainable Architecture
- Recommendations
- Acknowledgements
- Questions

Structural Depth

- The building has been shown to be effective with the existing system. However, the wind moment connections at every column could be more efficient.
- The typical bay size fits into the $L_1/L_2>2$ requirement, making it ideal for a one-way slab.

Construction Management Breadth

- Before a final decision can be made on the effectiveness of the new building structure, the systems must be compared for cost and construction time.

Sustainable Architecture Breadth

- As a corporate headquarters, the building should make a statement.
- LEED certification is a requirement to the owner.
- A campus of this magnitude needs to be integrated into the environment.

Project Goals

Structural Depth Goals

- Redesign the structural system using reinforced cast-in-place concrete and a one-way slab with beams floor system
- Implement the code effectively and efficiently
- Design a practical building

Construction Management Breadth Study Goals

- Calculate a cost estimate for redesigned building
- Generate a schedule for redesigned building
- Effectively compare the new cost and schedule with Turner Construction Company's actual cost and schedule

Sustainable Architecture Breadth Study Goals

- Incorporate the building into the environment
- Successfully implement a green roof
  - Detail, specify plants and materials, size drainage system pipes
- Determine number of LEED points possible for new design

Design Process

Design Codes Used:

- IBC 2006
- ACI 318-08
- ASCE 7-05
- AISC Steel Construction Manual 13th Ed.

Design Basis

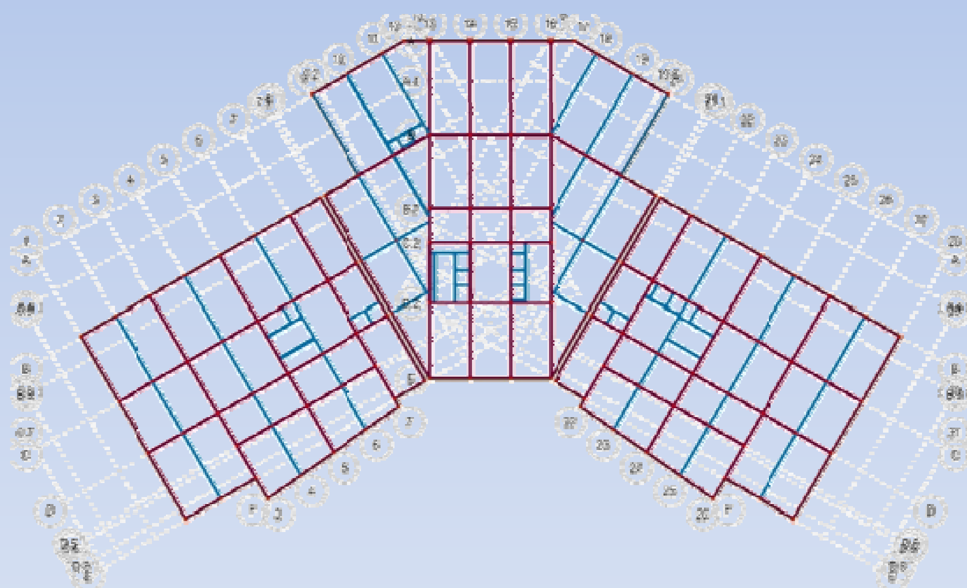
- Dead load= weight of concrete + superimposed loads
  Live load= 70 PSF (50 Office and 20 Partition)
- Same building as the steel, only concrete
  - No beams, just girders and slab
- Additional load for green roof =100 PSF dead and patio live load= 100 PSF
- Hand design checked in RAM Structural System and rechecked with lateral by hand
- Foundations resized for new building

Concrete Design Considerations

- One-way slab $L_1/L_2 > 2$
- Transverse reinforcement for shrinkage and temperature
- Moment transfer in concrete is different than in steel
- Foundation impact on spread footings and caissons
    - Resized for new dead load

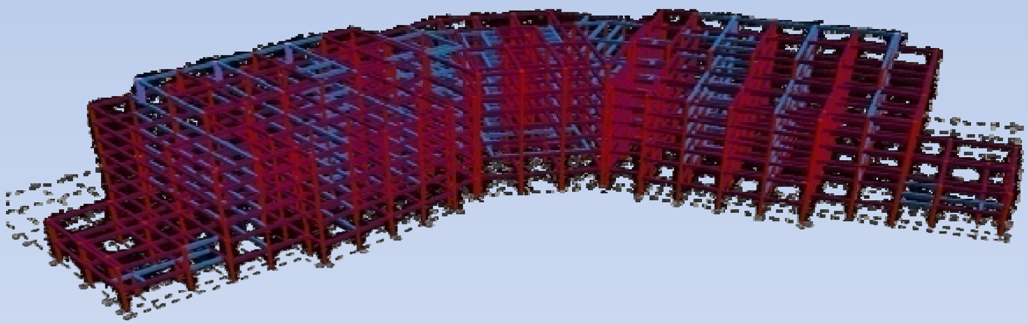
Design Process

- Determine superimposed loads from drawings and ASCE 7-05
- Perform a preliminary design of slabs, beams, and columns
- Determine location of CMRF's



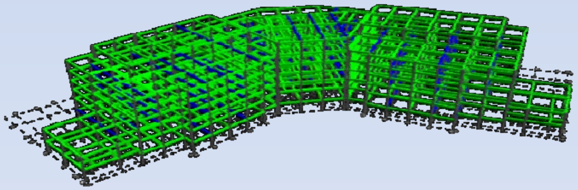
Design Process

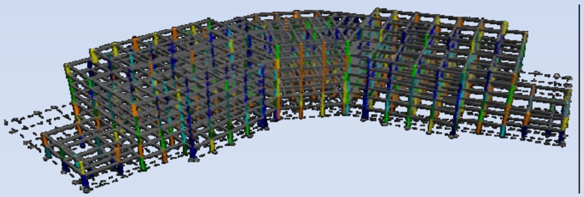
- Determine superimposed loads from drawings and ASCE 7-05
- Perform a preliminary design of slabs, beams, and columns
- Determine location of CMRF's
- Create a RAM Structural System Model



Design Process

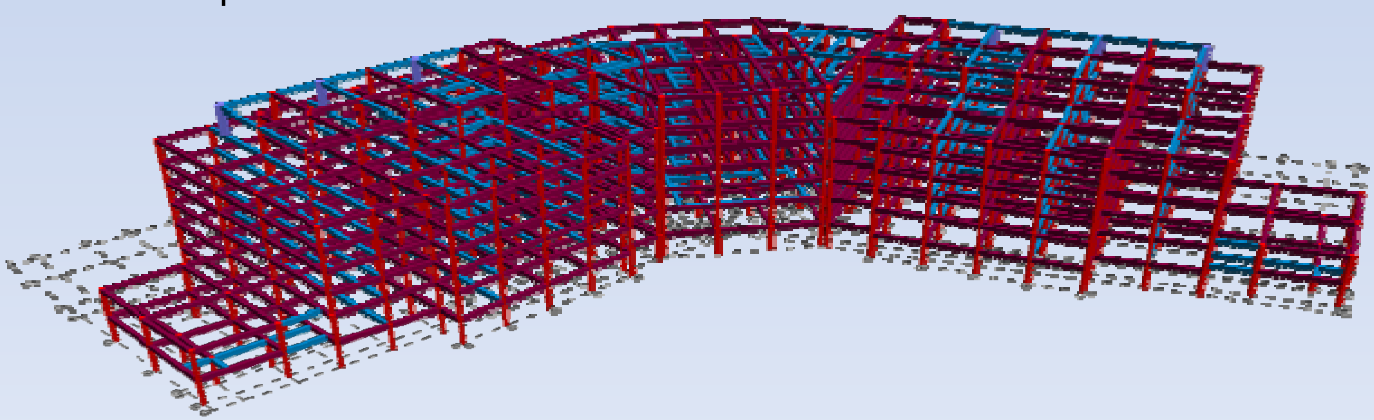
- Determine superimposed loads from drawings and ASCE 7-05
- Perform a preliminary design of slabs, beams, and columns
- Determine location of CMRF's
- Create a RAM Structural System Model
- Compare the preliminary sizes to the RAM generated model sizes
- Hand calculation of lateral loads
- Update beam and column sizes for lateral loads in RAM model





Design Process

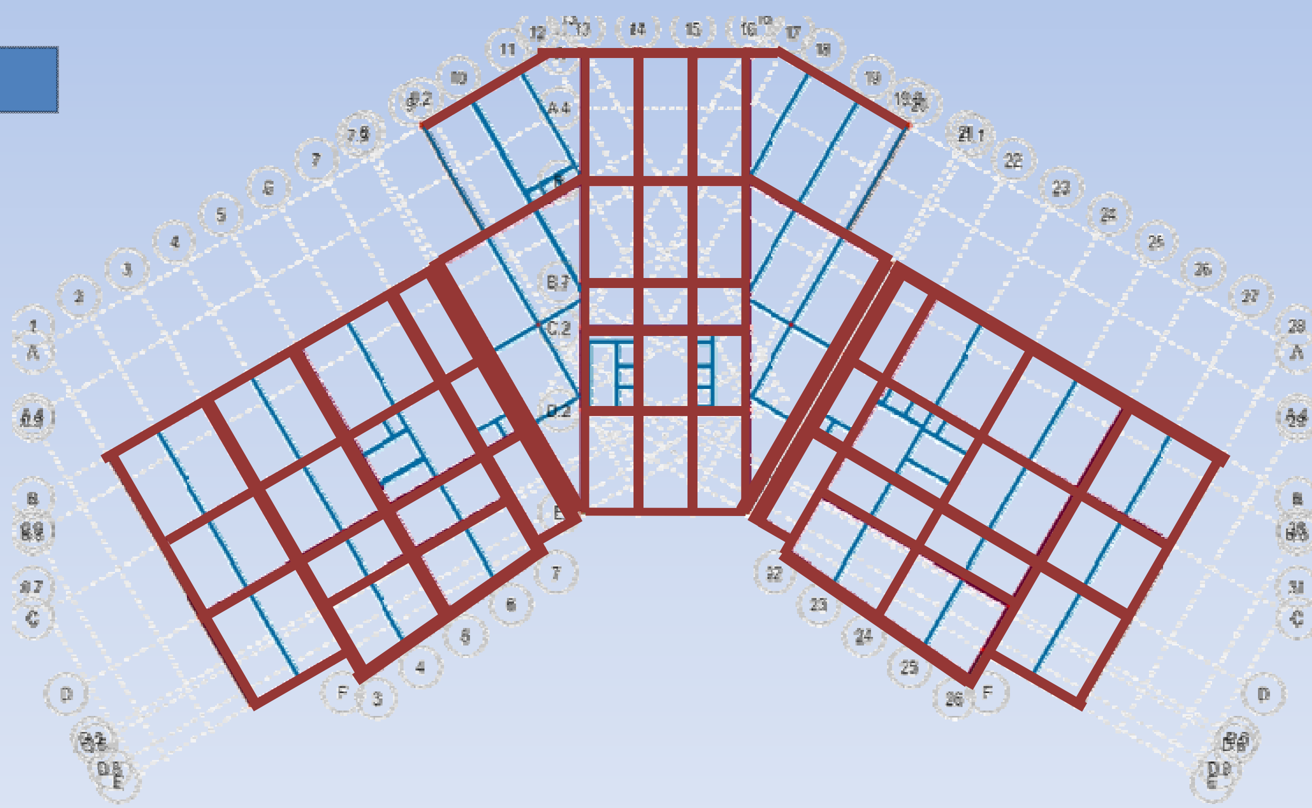
- Determine superimposed loads from drawings and ASCE 7-05
- Perform a preliminary design of slabs, beams, and columns
- Determine location of CMRF's
- Create a RAM Structural System Model
- Compare the preliminary sizes to the RAM generated model sizes
- Hand calculation of lateral loads
- Update beam and column sizes for lateral loads in RAM model
- Spot check column sizes with PCA Column
- Spot check lateral beam by hand
- Update RAM model



Design Assumptions

- The ideal condition for the gravity members was assumed to be a simply supported beam
- The lateral members were assumed to be the ideal fixed-fixed connection to the columns
- The column connection to the foundation was assumed to be pinned
- The seismic response coefficient was assumed to be R=3.0
- Model has ordinary moment frames in RAM Structural System
- Green roof and inclusive loads are present (separate analysis without performed for breadth)

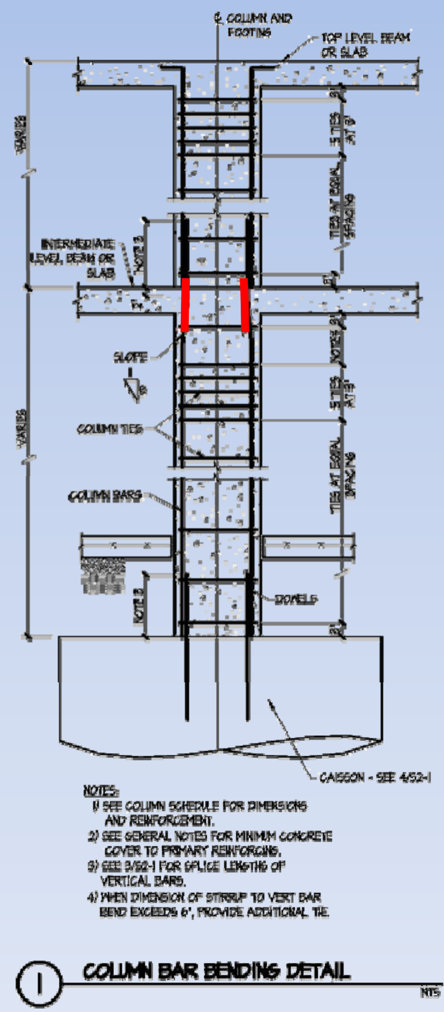
Design Process



DESIGN IMPLICATIONS

Design Process

Concrete Moment Resisting Frame Detail

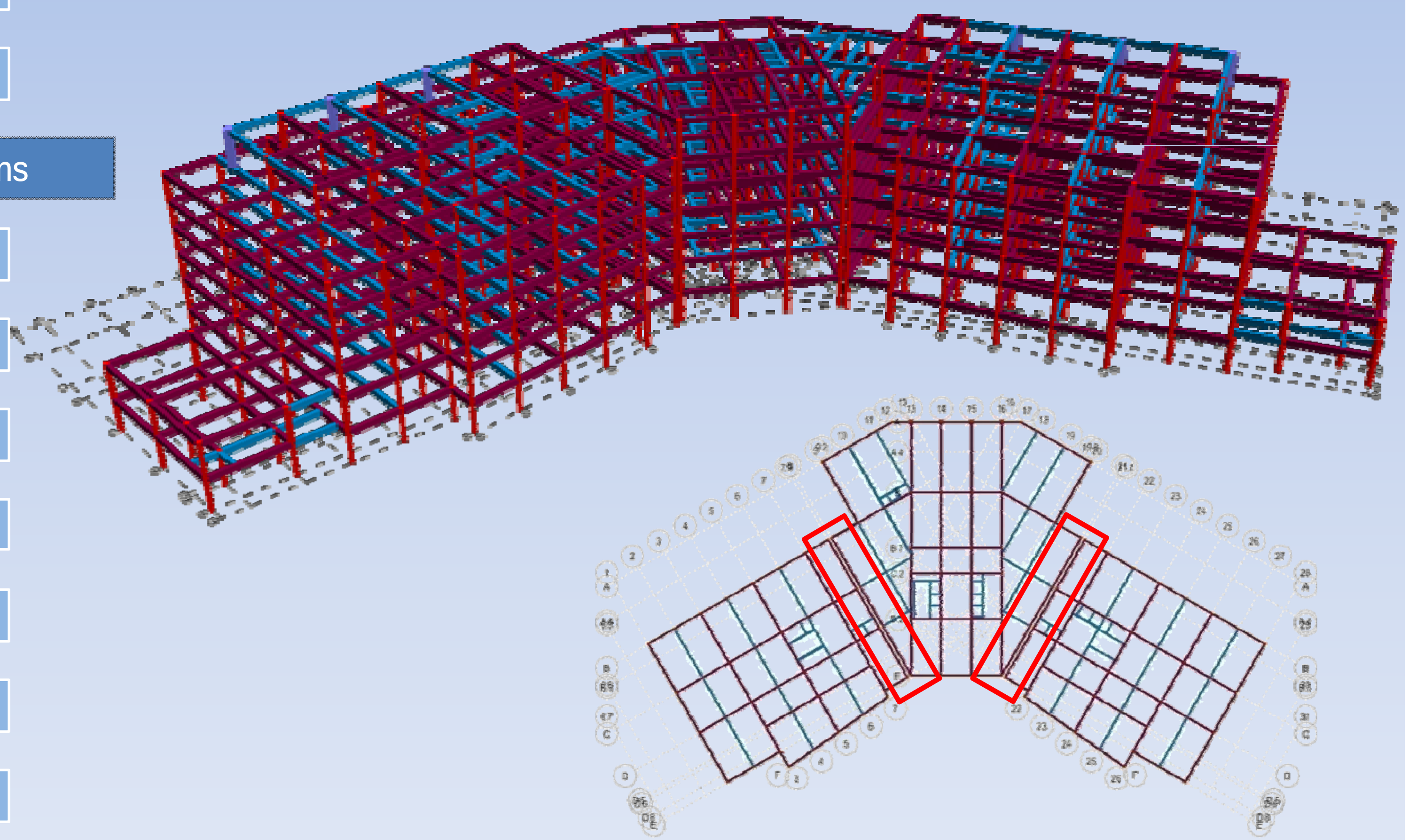


Design Implications

Background Information
Existing Conditions
Project Goals
Design Process
Design Implications
Lateral Loads
Schedule Comparison
Cost Analysis
Sustainable Architecture
Recommendations
Acknowledgements
Questions

RAM Structural System Model

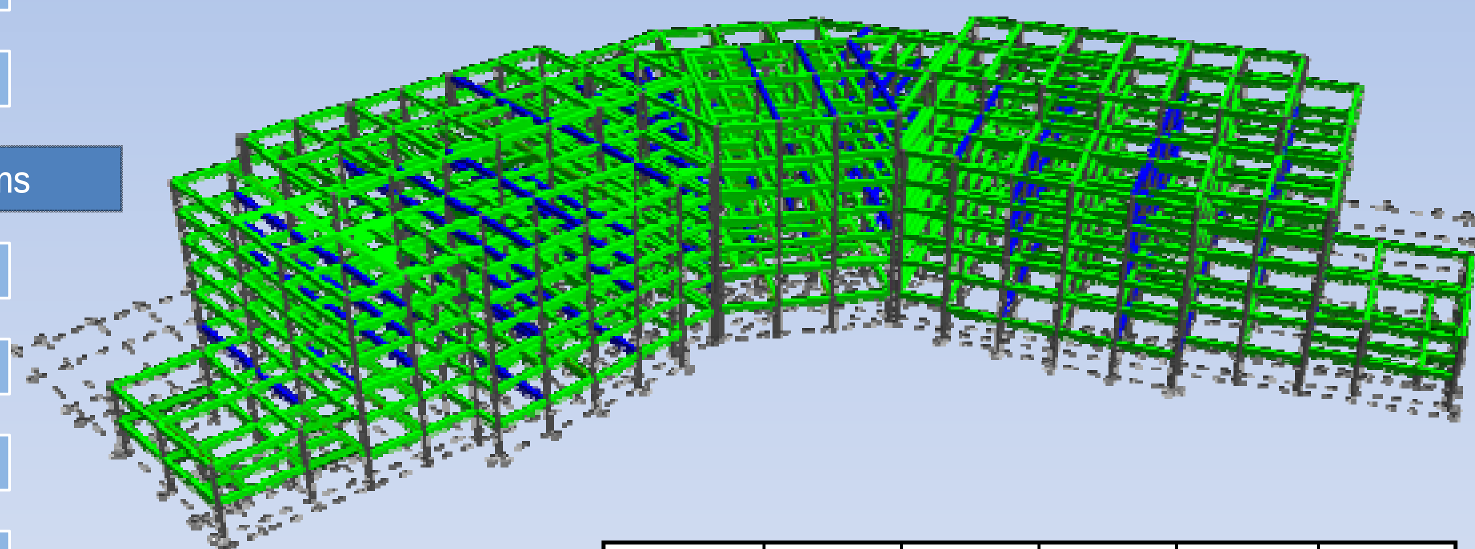
Whole building framing



Design Implications

RAM Structural System Model

Whole building framing beams

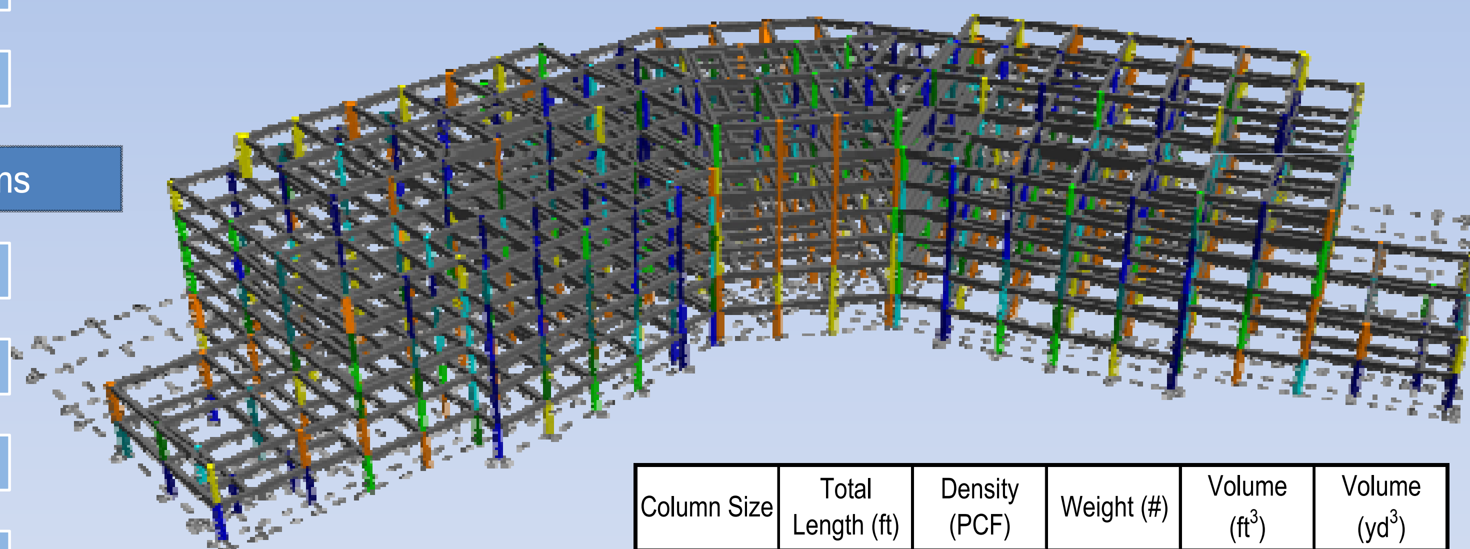


Beam Size	Total Length (ft)	Density (PCF)	Weight (#)	Volume (ft^3)	Volume (yd^3)
24x34	32000.00	145	26293333	181333.33	6716.05
30x34	96	145	98600	680	25.19
34x34	223.87	145	260594.78	1797.2054	66.56
28x34	71.01	145	68067.78	469.43296	17.39
32x34	102.88	145	112711	777.32	28.79
Total Beam volume				185057.	6854.0

Design Implications

RAM Structural System Model

Whole building framing columns



Column Size	Total Length (ft)	Density (PCF)	Weight (#)	Volume (ft^3)	Volume (yd^3)
24x24	8141.5	145	4722070	32566	1206.15
28x28	622	145	360760	2488	92.15
30x30	986.5	145	572170	3946	146.15
32x32	72	145	41760	288	10.67
34x34	18	145	10440	72	2.67
36x36	182	145	105560	728	26.96
48x48	220	145	127600	880	32.59
Total Column Volume				4096	1517.33

Foundation Implications

Old and New Foundation Sizes for spot checked columns

Size	Column	Type of Foundation	Size (ft)	Height (in)	Capacity (k)	Required (k)	Required Size	Required Height (in)	New Size (ft)	New Capacity (k)	Final Height (in)	RAM Size (ft)	RAM Height (in)
28	0.7-C	spread footing	5	18	200	384.844	6.936	18.273	7	392	22	8	24
24	1-B	spread footing	9.5	28	722	978.696	11.061	39.397	11.5	1058	44	11	36
24	1-C	spread footing	12	36	1152	1471.816	13.564	49.499	14	1568	54	13	42
24	1-D	spread footing	11	34	968	1606.032	14.169	51.518	14.5	1682	56	14	42
28	2-D	spread footing	12	36	1152	2179.108	16.504	56.044	17	2312	60	16	48
24	4-B	spread footing	10	32	800	1417.268	13.310	47.480	13.5	1458	52	13	42
30	1-E	caisson #48	5.5	146	712.749	957.832		146	7.00	1084.30	150		
28	6-B	spread footing	10	32	800	1454.464	13.484	42.858	13.5	1458	48	13	36
24	7.9-C	spread footing	13	40	1352	1342.364	12.954	45.460	13	1352	50	12	36
28	8-B	spread footing	11	34	968	922.328	10.737	33.426	11	968	38	11	30
24	8-C	spread footing	13	40	1352	1330.536	12.896	45.460	13	1352	50	12	36
48	13-A	spread footing	8	32	512	570.728	8.446	14.111	9	648	18	9	24
24	14-A.4	spread footing	8	32	512	418.416	7.232	25.211	8	512	30	7	18
24	15-B.7	spread footing	12	36	1152	1782.08	14.925	53.536	15	1800	58	14	48
28	16-E	caisson #53	4	306	376.991	1316.164		306	8.25	1399.22	310		

Background Information
Existing Conditions
Project Goals
Design Process
Design Implications
Lateral Loads
Schedule Comparison
Cost Analysis
Sustainable Architecture
Recommendations
Acknowledgements
Questions

Seismic Design Loads

Floor	w_x (k)	h_x (ft)	h_x^k (ft)	$w_x h_x^k$	C_{vx}	Story Force F_x (k)	Story Shear V_x (k)	Moment at Floor (ft-k)
Penthouse	6481.1	92.5	1115.41	7229044	0.179	293.33	0	27133.348
Roof	18245.1	74.5	797.56	14551503	0.361	590.46	293.33	43989.083
5	14162.0	60	570.24	8075727	0.200	327.69	883.79	19661.364
4	13922.9	46	377.75	5259370	0.130	213.41	1211.48	9816.8534
3	16960.3	32	215.24	3650482	0.091	148.13	1424.89	4740.0283
2	17785.3	18	88.23	1569200	0.039	63.67	1573.02	1146.1239
1	19178.2						1636.69	
Sum	106734.9	92.5	3164.42	40335326	1.000	1636.69	1636.69	106486.8

The seismic load for the redesigned concrete building is considerably larger than for the as-built steel building, which is to be expected since the new building is more massive.

Floor	w_x (k)	h_x (ft)	h_x^k (ft)	$w_x h_x^k$	C_{vx}	Story Force F_x (k)	Story Shear V_x (k)	Moment at Floor (ft-k)
Penthouse	4213	92.5	1678.33	7070795	0.347	136.16	0	12594.449
Roof	4240.5	74.5	1176.85	4990465	0.245	96.10	136.16	7159.2331
5	4713.6	60	825.15	3889471	0.191	74.90	232.25	4493.7722
4	4726.5	46	533.66	2522321	0.124	48.57	307.15	2234.2278
3	4724.0	32	294.28	1390147	0.068	26.77	355.72	856.60376
2	4653.4	18	114.53	532940	0.026	10.26	382.49	184.72265
1	5444.4						392.75	
Sum	28502.4	74.5	2944.46	20396140	1.000	392.75	392.75	14928.56

Lateral Loads

Wind Load For the Redesigned Concrete Building

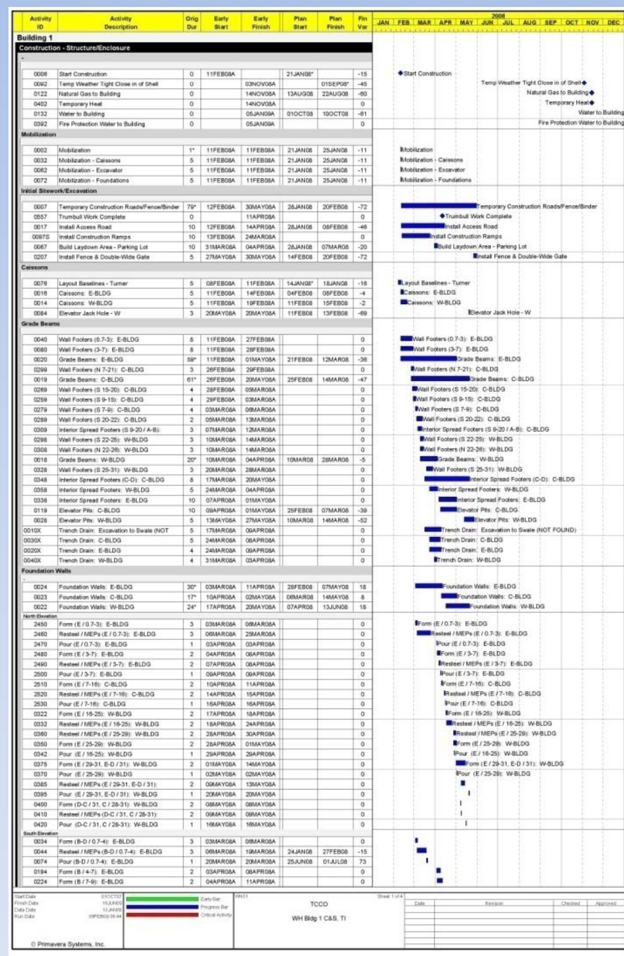
Level	Wind Design					
	Load (kips)		Shear (kips)		Moment (ft-k)	
	N-S	E-W	N-S	E-W	N-S	E-W
Pent	193.4	38.8	0	0	3481.3	698.2
Roof	151.5	30.2	193.4	38.8	2196.7	437.6
5	144.8	29.3	344.9	69.0	2026.7	410.7
4	138.0	28.1	489.7	98.3	1932.5	393.8
3	132.6	27.4	627.7	126.4	1856.3	384.1
2	140.2	31.0	760.3	153.9	2523.7	557.2
Total	900.5	184.8	900.5	184.8	10535.9	2183.4

Wind Load For the As-Built Steel Building

Level	Wind Design					
	Load (kips)		Shear (kips)		Moment (ft-k)	
	N-S	E-W	N-S	E-W	N-S	E-W
Pent	196.5	39.6	0	0	3536.7	712.1
Roof	152.9	30.5	196.5	39.6	2217.2	442.4
5	146.0	29.7	349.4	70.1	2044.3	415.2
4	139.1	28.4	495.4	99.7	1948.0	397.7
3	133.5	27.7	634.6	128.1	1869.4	387.5
2	140.9	31.2	768.1	155.8	2536.6	562.0
Total	909.0	187.0	909.0	187.0	14152.2	2916.9

SCHEDULE COMPARISON

TURNER CONSTRUCTION COMPANY

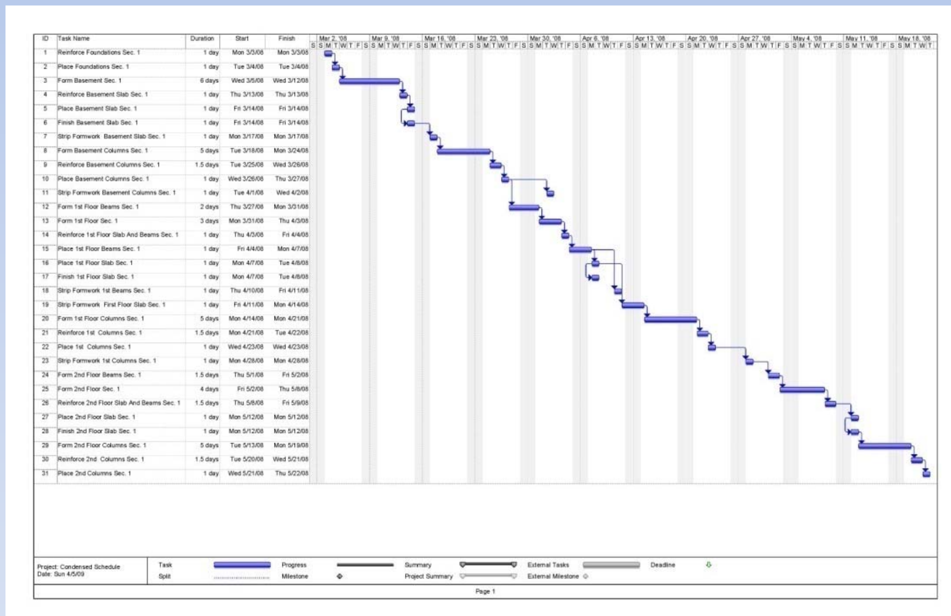


- Design- Bid-Build
- Started foundations March 3rd, 2008
- Finished construction October 17th, 2008

Schedule Comparison

Redesigned Building Schedule

- Start foundations on March 3rd, 2008
- Finish structure on December 9th, 2008
- Lead time for steel is insignificant -steel will be on site when foundations are finished



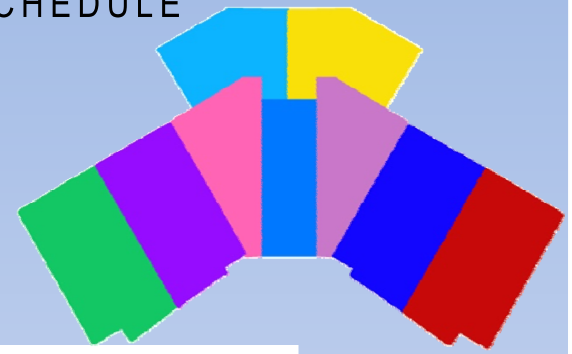
ID	Task Name	Duration	Start	Finish
1	Reinforce Foundations Sec. 1	1 day	Mon 3/3/08	Mon 3/3/08
2	Place Foundations Sec. 1	1 day	Tue 3/4/08	Tue 3/4/08
3	Form Basement Sec. 1	6 days	Wed 3/5/08	Wed 3/12/08
4	Reinforce Basement Slab Sec. 1	1 day	Thu 3/13/08	Thu 3/13/08
5	Place Basement Slab Sec. 1	1 day	Fri 3/14/08	Fri 3/14/08
6	Finish Basement Slab Sec. 1	1 day	Fri 3/14/08	Fri 3/14/08
7	Strip Formwork Basement Slab Sec. 1	1 day	Mon 3/17/08	Mon 3/17/08
8	Form Basement Columns Sec. 1	5 days	Tue 3/18/08	Mon 3/24/08
9	Reinforce Basement Columns Sec. 1	1.5 days	Tue 3/25/08	Wed 3/26/08
10	Place Basement Columns Sec. 1	1 day	Wed 3/26/08	Thu 3/27/08
11	Strip Formwork Basement Columns Sec. 1	1 day	Tue 4/1/08	Wed 4/2/08
12	Form 1st Floor Beams Sec. 1	2 days	Thu 3/27/08	Mon 3/31/08
13	Form 1st Floor Sec. 1	3 days	Mon 3/31/08	Thu 4/3/08
14	Reinforce 1st Floor Slab And Beams Sec. 1	1 day	Thu 4/3/08	Fri 4/4/08
15	Place 1st Floor Beams Sec. 1	1 day	Fri 4/4/08	Mon 4/7/08
16	Place 1st Floor Slab Sec. 1	1 day	Mon 4/7/08	Tue 4/8/08
17	Finish 1st Floor Slab Sec. 1	1 day	Mon 4/7/08	Tue 4/8/08
18	Strip Formwork 1st Beams Sec. 1	1 day	Thu 4/10/08	Fri 4/11/08
19	Strip Formwork First Floor Slab Sec. 1	1 day	Fri 4/11/08	Mon 4/14/08
20	Form 1st Floor Columns Sec. 1	5 days	Mon 4/14/08	Mon 4/21/08
21	Reinforce 1st Columns Sec. 1	1.5 days	Mon 4/21/08	Tue 4/22/08
22	Place 1st Columns Sec. 1	1 day	Wed 4/23/08	Wed 4/23/08
23	Strip Formwork 1st Columns Sec. 1	1 day	Mon 4/28/08	Mon 4/28/08
24	Form 2nd Floor Beams Sec. 1	1.5 days	Thu 5/1/08	Fri 5/2/08
25	Form 2nd Floor Sec. 1	4 days	Fri 5/2/08	Thu 5/8/08
26	Reinforce 2nd Floor Slab And Beams Sec. 1	1.5 days	Thu 5/8/08	Fri 5/9/08
27	Place 2nd Floor Slab Sec. 1	1 day	Mon 5/12/08	Mon 5/12/08
28	Finish 2nd Floor Slab Sec. 1	1 day	Mon 5/12/08	Mon 5/12/08
29	Form 2nd Floor Columns Sec. 1	5 days	Tue 5/13/08	Mon 5/19/08
30	Reinforce 2nd Columns Sec. 1	1.5 days	Tue 5/20/08	Wed 5/21/08
31	Place 2nd Columns Sec. 1	1 day	Wed 5/21/08	Thu 5/22/08

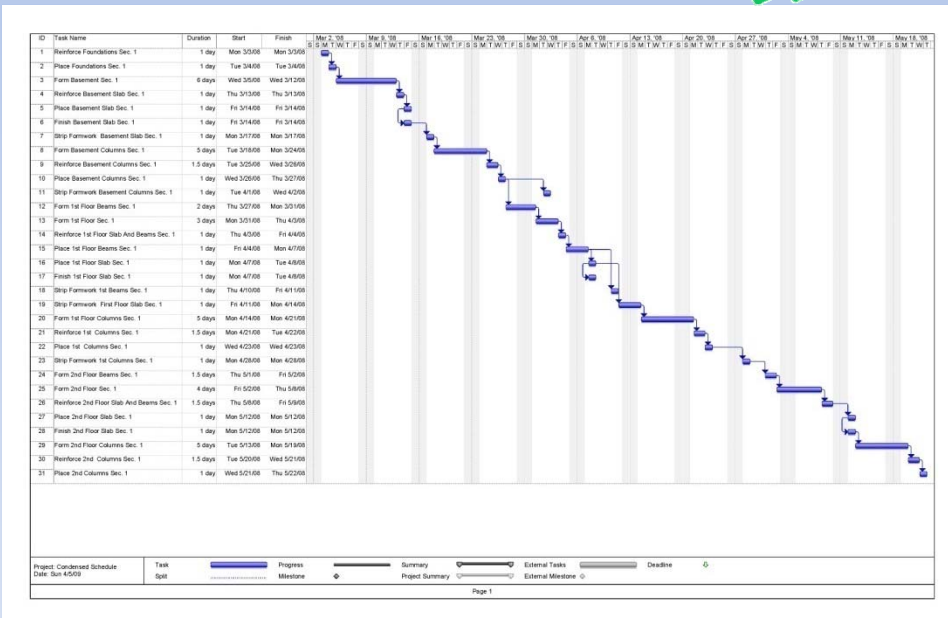
Project: Condensed Schedule
Date: Sun 4/5/09

- Time difference because of sequencing, could potentially be sequenced differently if more crews were on site
- Turner pushed ahead with the schedule finishing before their estimated date effectively

Schedule Comparison

Redesigned Building Schedule





ID	Task Name	Duration	Start	Finish
1	Reinforce Foundations Sec. 1	1 day	Mon 3/3/08	Mon 3/3/08
2	Place Foundations Sec. 1	1 day	Tue 3/4/08	Tue 3/4/08
3	Form Basement Sec. 1	6 days	Wed 3/5/08	Wed 3/12/08
4	Reinforce Basement Slab Sec. 1	1 day	Thu 3/13/08	Thu 3/13/08
5	Place Basement Slab Sec. 1	1 day	Fri 3/14/08	Fri 3/14/08
6	Finish Basement Slab Sec. 1	1 day	Fri 3/14/08	Fri 3/14/08
7	Strip Formwork Basement Slab Sec. 1	1 day	Mon 3/17/08	Mon 3/17/08
8	Form Basement Columns Sec. 1	5 days	Tue 3/18/08	Mon 3/24/08
9	Reinforce Basement Columns Sec. 1	1.5 days	Tue 3/25/08	Wed 3/26/08
10	Place Basement Columns Sec. 1	1 day	Wed 3/26/08	Thu 3/27/08
11	Strip Formwork Basement Columns Sec. 1	1 day	Tue 4/1/08	Wed 4/2/08
12	Form 1st Floor Beams Sec. 1	2 days	Thu 3/27/08	Mon 3/31/08
13	Form 1st Floor Sec. 1	3 days	Mon 3/31/08	Thu 4/3/08
14	Reinforce 1st Floor Slab And Beams Sec. 1	1 day	Thu 4/3/08	Fri 4/4/08
15	Place 1st Floor Beams Sec. 1	1 day	Fri 4/4/08	Mon 4/7/08
16	Place 1st Floor Slab Sec. 1	1 day	Mon 4/7/08	Tue 4/8/08
17	Finish 1st Floor Slab Sec. 1	1 day	Mon 4/7/08	Tue 4/8/08
18	Strip Formwork 1st Beams Sec. 1	1 day	Thu 4/10/08	Fri 4/11/08
19	Strip Formwork First Floor Slab Sec. 1	1 day	Fri 4/11/08	Mon 4/14/08
20	Form 1st Floor Columns Sec. 1	5 days	Mon 4/14/08	Mon 4/21/08
21	Reinforce 1st Columns Sec. 1	1.5 days	Mon 4/21/08	Tue 4/22/08
22	Place 1st Columns Sec. 1	1 day	Wed 4/23/08	Wed 4/23/08
23	Strip Formwork 1st Columns Sec. 1	1 day	Mon 4/28/08	Mon 4/28/08
24	Form 2nd Floor Beams Sec. 1	1.5 days	Thu 5/1/08	Fri 5/2/08
25	Form 2nd Floor Sec. 1	4 days	Fri 5/2/08	Thu 5/8/08
26	Reinforce 2nd Floor Slab And Beams Sec. 1	1.5 days	Thu 5/8/08	Fri 5/9/08
27	Place 2nd Floor Slab Sec. 1	1 day	Mon 5/12/08	Mon 5/12/08
28	Finish 2nd Floor Slab Sec. 1	1 day	Mon 5/12/08	Mon 5/12/08
29	Form 2nd Floor Columns Sec. 1	5 days	Tue 5/13/08	Mon 5/19/08
30	Reinforce 2nd Columns Sec. 1	1.5 days	Tue 5/20/08	Wed 5/21/08
31	Place 2nd Columns Sec. 1	1 day	Wed 5/21/08	Thu 5/22/08

- Time difference because of sequencing, could potentially be sequenced differently if more crews were on site
- Turner pushed ahead with the schedule finishing before their estimated date effectively

Cost Analysis Study

- Background Information
- Existing Conditions
- Project Goals
- Design Process
- Design Implications
- Lateral Loads
- Schedule Comparison
- **Cost Analysis**
- Sustainable Architecture
- Recommendations
- Acknowledgements
- Questions

Redesigned Building Estimate

Detailed Cost Analysis of the Structure-No Green Roof									
Level	Description	Amount	Material Price	Material Cost	Labor Price	Labor Cost	Equipment Price	Equipment Cost	Total Cost
Reinforcement	Foundation	58 Ton	$935.00	$54,230	$430.00	$24,940	$30.35	$1,760	$80,930
	Columns	156Ton	$935.00	$147,263	$430.00	$430.00	$30.35	$4,780	$152,473
	Beam/Slabs	504 Ton	$935.00	$470,642	$430.00	$216,445	$30.35	$15,277	$702,363
	SUB-TOTAL	719	$935.00	$672,134	$430.00	$241,815	$30.35	$21,817	$935,766
Cast in Place Concrete	Foundations	6100 CY	$109.00	$664,900	$14.90	$90,890	$5.55	$33,855	$789,645
	Columns	1443 CY	$109.00	$157,189	$34.00	$49,031	$16.95	$24,444	$230,664
	Slabs	14192 CY	$109.00	$1,546,928	$18.20	$258,294	$9.15	$129,857	$1,935,079
	Beams	6477 CY	$109.00	$706,026	$26.50	$171,648	$1,320.00	$8,550,036	$9,427,710
	SUB-TOTAL	28211	$109.00	$3,075,043	$20.20	$569,864	$1,352	$8,738,191	$12,383,098
Location Factor: 98.9%	Total Structure Estimate:		$13,173,000			Total Labor Cost:		$812,000	
	Total Material Cost:		$3,748,000			Total Equipment Cost:		$8,761,000	

Turner Construction Company

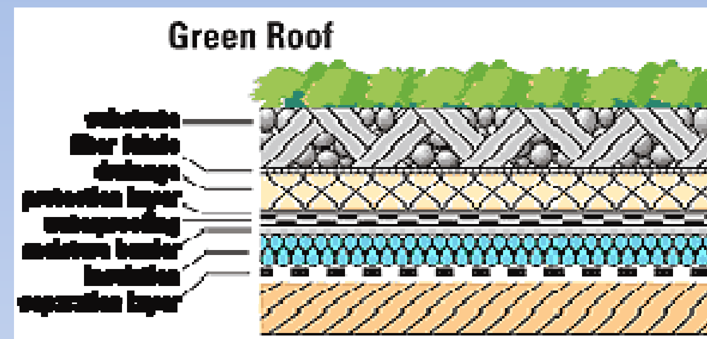
Turner Construction Company Budgets	
Deep foundations (caissons)	$215,000
Concrete (Spread ftgs, slabs)	$5,199,000
Structural Steel	$7,892,000
Total Structure	$13,306,000
Whole Building	$55,878,000

- $30.60/SF vs. $30.90/SF
- R.S. Means is not as accurate as real estimates
- Turner had contractors actually bid

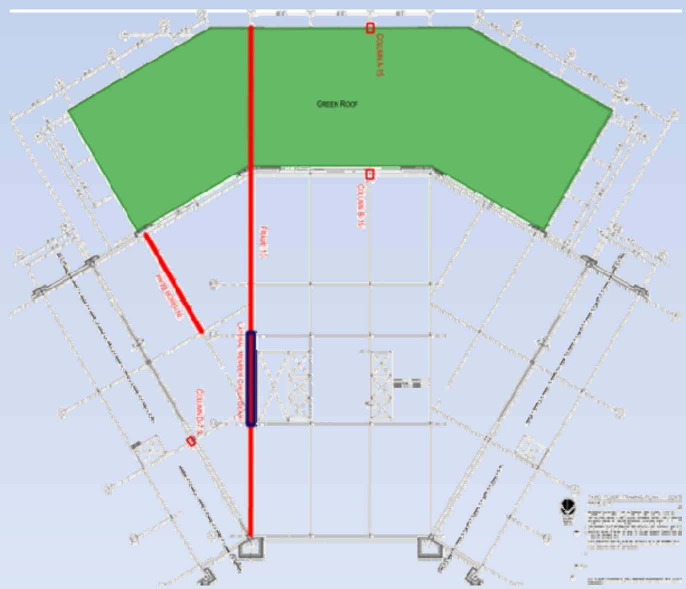
Sustainable Architecture Study

The Westinghouse Electric Company Corporate Headquarters

- Functions and benefits
  - Patio
  - Meeting area
  - Lunch area
  - Storm water collector
  - Reduces heat island effect



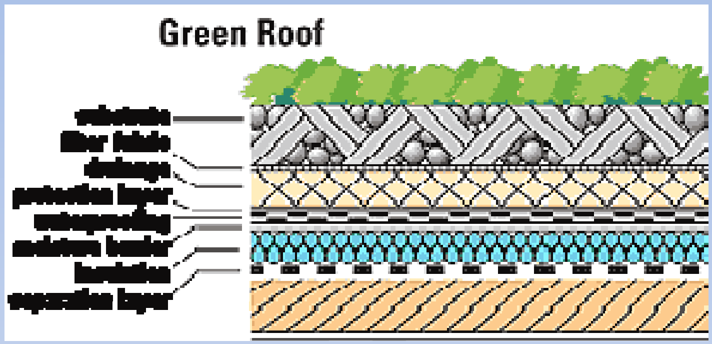
www.deq.state.mi.us/documents/deq-ess-p2-p2week-greenroofresources.doc



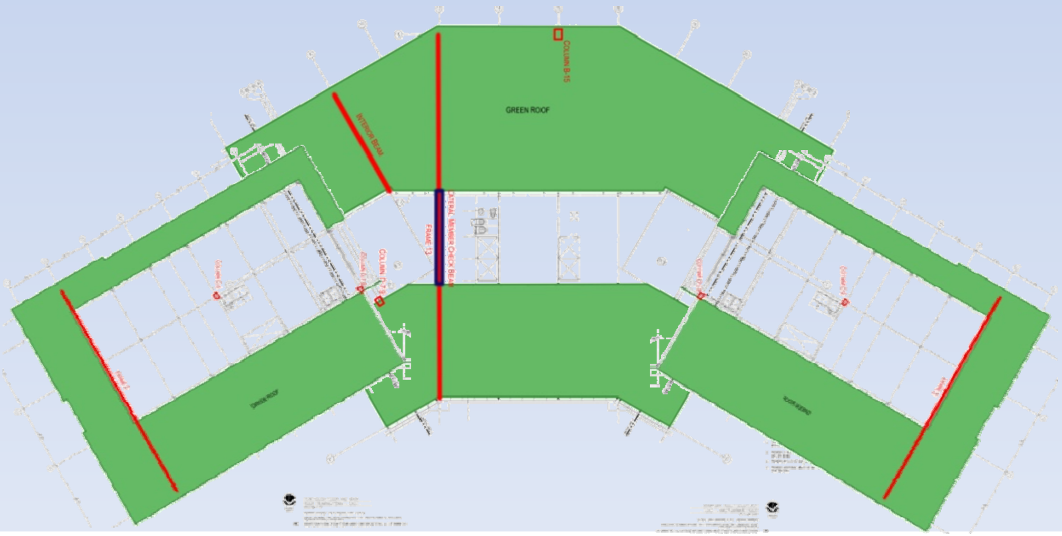
- Background Information
- Existing Conditions
- Project Goals
- Design Process
- Design Implications
- Lateral Loads
- Schedule Comparison
- Cost Analysis
- **Sustainable Architecture**
- Recommendations
- Acknowledgements
- Questions

THE WESTINGHOUSE ELECTRIC COMPANY CORPORATE HEADQUARTERS

- Functions and benefits
  - Patio
  - Meeting area
  - Lunch area
  - Storm water collector
  - Reduces heat island effect

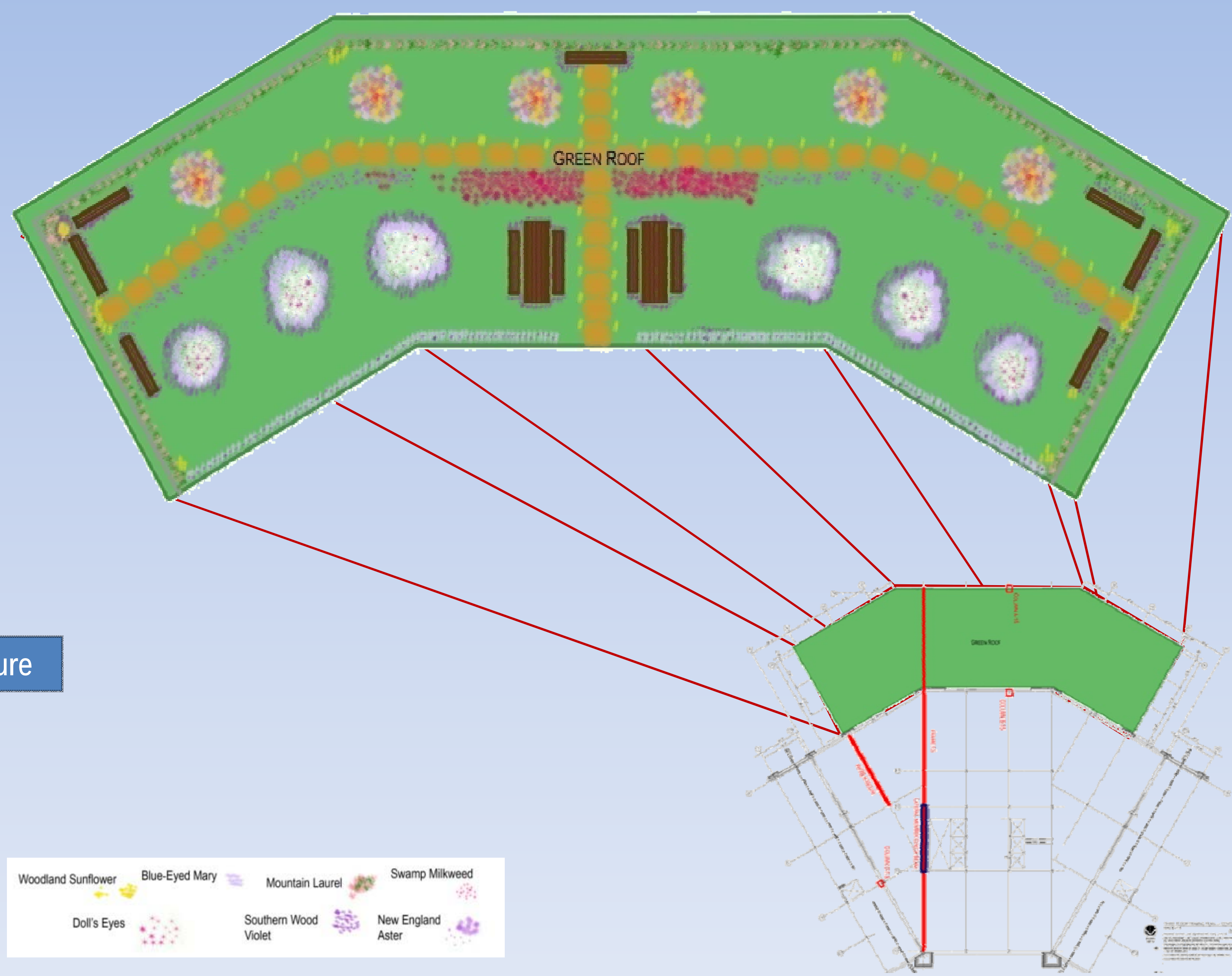


www.deq.state.mi.us/documents/deq-ess-p2-p2week-greenroofresources.doc



Sustainable Architecture Study

Plant Layout on accessible roof on 3rd floor



SUSTAINABLE ARCHITECTURE STUDY

Background Information
Existing Conditions
Project Goals
Design Process
Design Implications
Lateral Loads
Schedule Comparison
Cost Analysis
Sustainable Architecture
Recommendations
Acknowledgements
Questions

- No green roof structure costs $13,173,000 or $30.60/SF
- With green roof, structure costs $1,159,000 or $2.68/SF more
- Beam and columns needed to be resized, the slab was checked and found to be adequate
- Green roof adds 100 PSF dead and100 PSF live load to the accessible portion

Detailed Cost Analysis of the Structure

Level	Description	Amount	Material Price	Material Cost	Labor Price	Labor Cost	Equipment Price	Equipment Cost	Total Cost
Reinforcement	Foundation	58 Ton	$935.00	$54,230	$430.00	$24,940	$30.35	$1,760	$80,930
	Columns	175 Ton	$935.00	$163,625	$430.00	$430.00	$30.35	$5,311	$169,366
	Beam/Slabs	572 Ton	$935.00	$534,820	$430.00	$245,960	$30.35	$17,360	$798,140
	SUB-TOTAL	805	$935.00	$752,675	$430.00	$346,150.00	$30.35	$24,432	$1,123,257
Cast in Place Concrete	Foundations	6100 CY	$109.00	$664,900	$14.90	$90,890	$5.55	$33,855	$789,645
	Columns	1518 CY	$109.00	$165,462	$34.00	$51,612	$16.95	$25,730	$242,804
	Slabs	14192 CY	$109.00	$1,546,928	$18.20	$258,294	$9.15	$129,857	$1,935,079
	Beams	7197 CY	$109.00	$784,473	$26.50	$190,721	$1,320.00	$9,500,040	$10,475,234
	SUB-TOTAL	29007	$109.00	$3,161,763	$23.40	$271,330	$1,352	$9,689,482	$13,122,575
Location Factor: 98.9%	Total Structure Estimate:			$14,332,000		Total Labor Cost:		$863,000	
	Total Material Cost:			$3,915,000		Total Equipment Cost:		$9,714,000	

- An additional week is needed to erect the green roof building than without it

Recommendations

- The building was successfully redesigned and the code was correctly implemented
- It is possible to have a reinforced concrete building
- Based on cost and schedule, this system is not recommended
  - $30.90/SF vs. $30.60/SF
  - March-October vs. March-December
- The addition of a green roof however, is recommended.
  - If the building were in concrete the green roof structural cost would be $2.68/SF of building or $20.24/SF of green roof
  - One additional week construction for the additional structure

ACKNOWLEDGEMENTS

I would like to thank:

- Turner Construction Company
  - Bob Hennessey
- LLI Engineering
- Westinghouse Electric Company
- Wells Real Estate Funds
- Penn State University
  - Dr. Hanagan
  - Prof. Parfitt
  - Prof Holland
  - And the rest of the AE faculty and staff
- Family and friends

QUESTIONS

?

Floor Plans

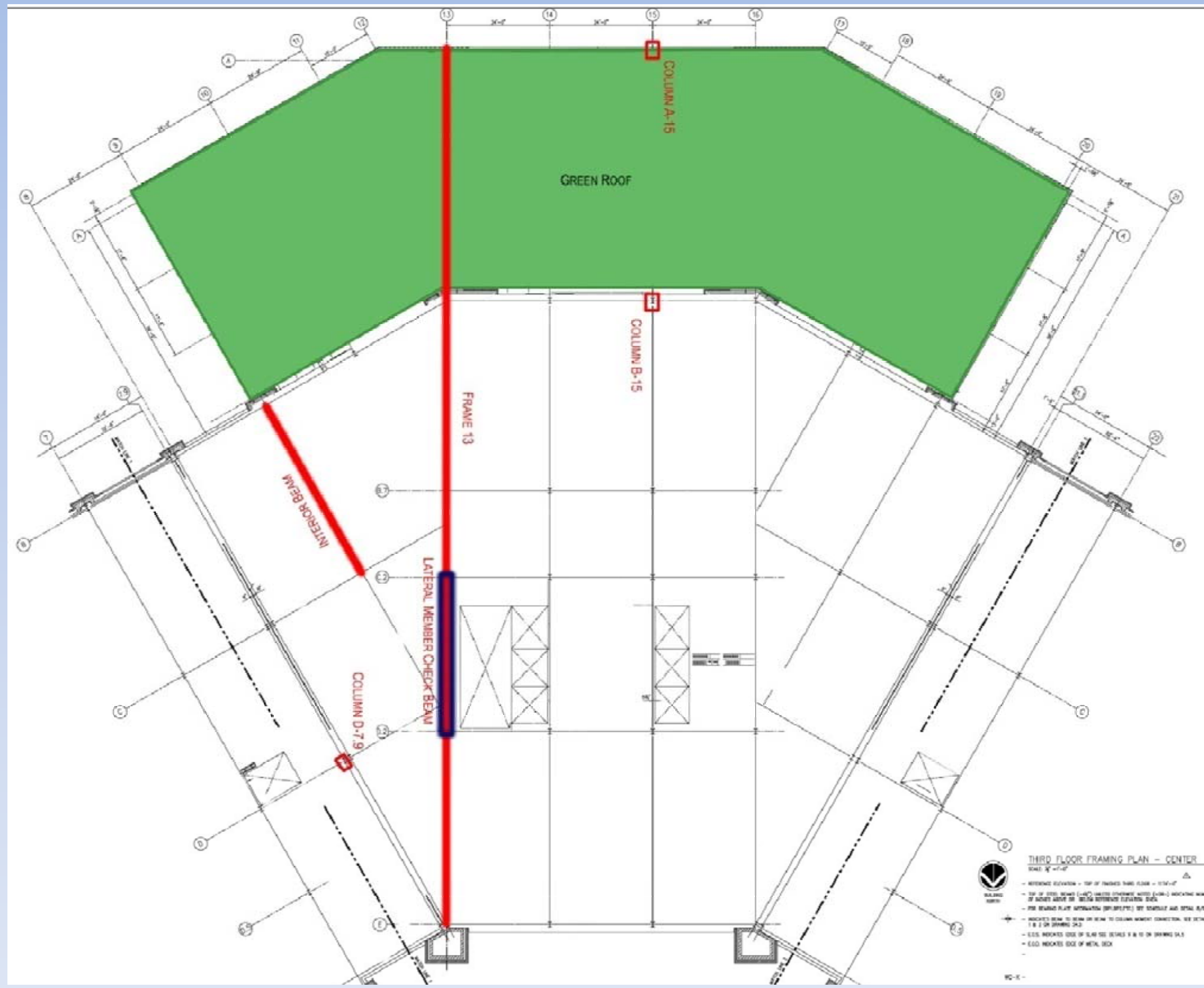
- **Background Information**
- Existing Conditions
- Project Goals
- Design Process
- Design Implications
- Lateral Loads
- Schedule Comparison
- Cost Analysis
- Sustainable Architecture
- Recommendations
- Acknowledgements
- Questions

Third Floor East

Floor Plans

- **Background Information**
- Existing Conditions
- Project Goals
- Design Process
- Design Implications
- Lateral Loads
- Schedule Comparison
- Cost Analysis
- Sustainable Architecture
- Recommendations
- Acknowledgements
- Questions

Third Floor Center



FLOOR PLANS

Background Information

Existing Conditions

Project Goals

Design Process

Design Implications

Lateral Loads

Schedule Comparison

Cost Analysis

Sustainable Architecture

Recommendations

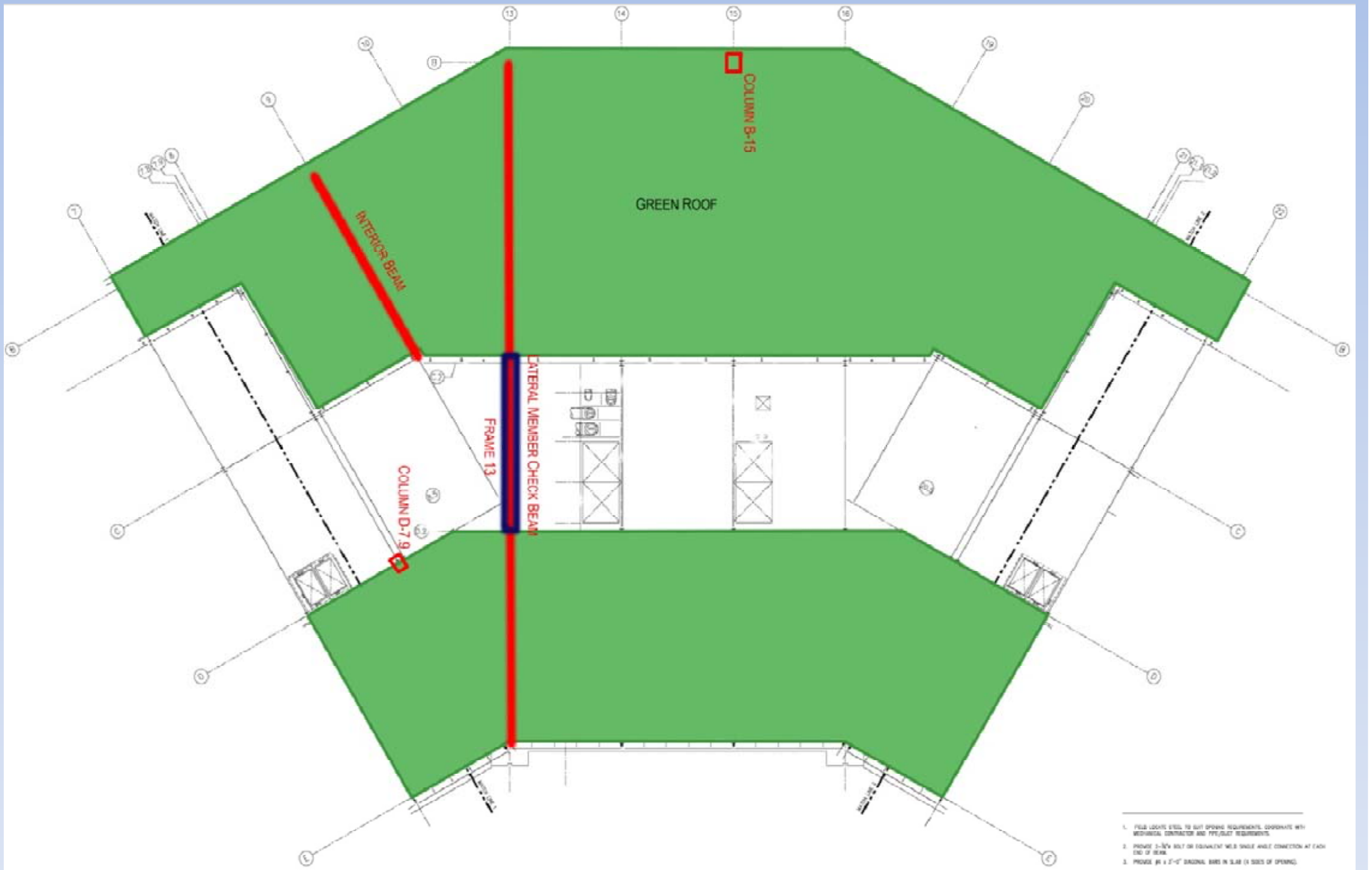
Acknowledgements

Questions

ROOF EAST

Floor Plans

Roof Center



Existing Conditions

Whole Building Steel

West Building Steel

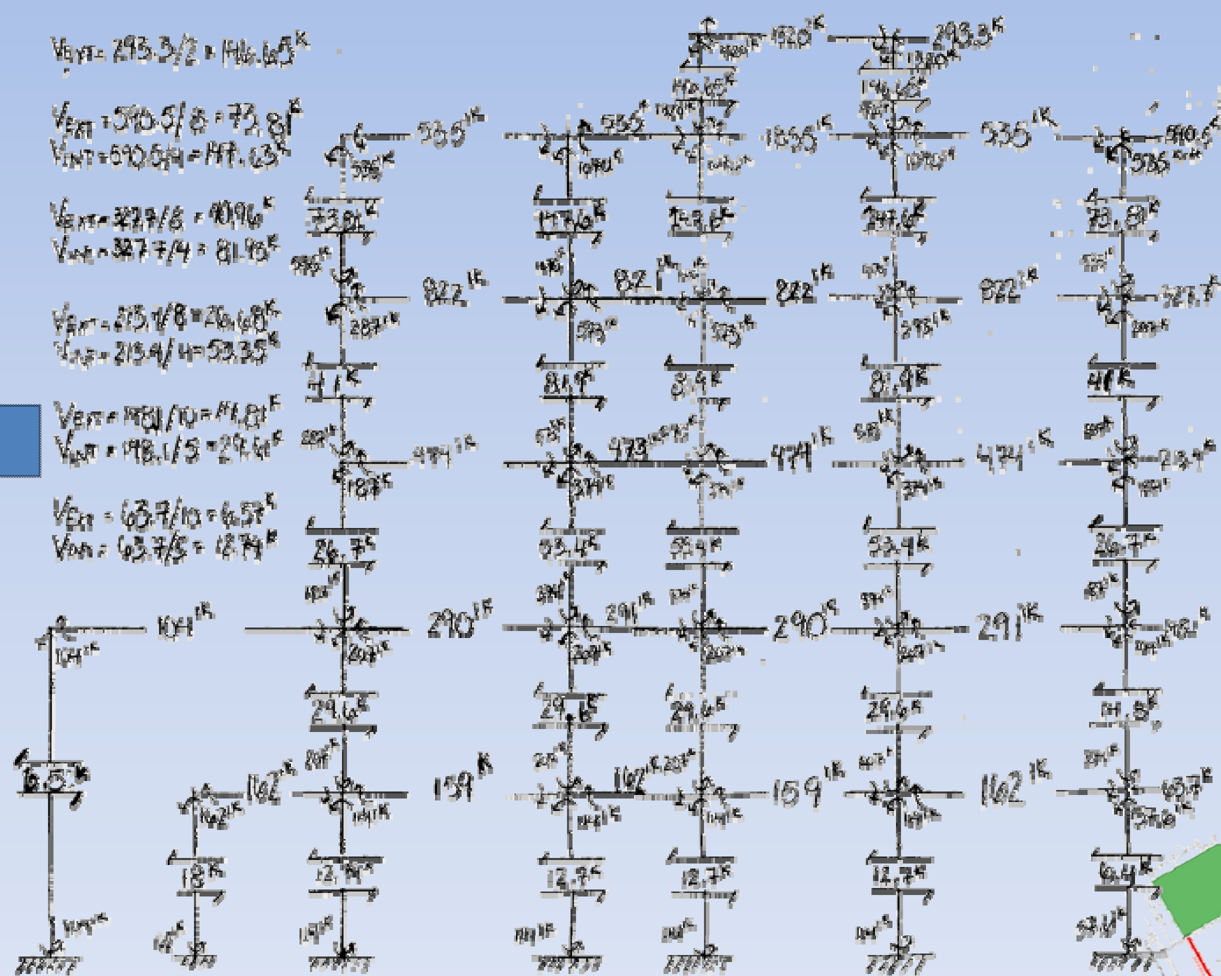
East Building Steel

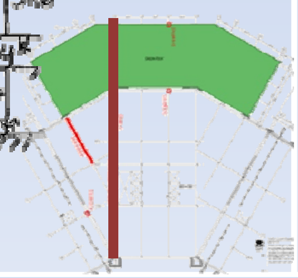
Pictures taken by Jessica L. Laurito on 8/19/2008

Reference Slide

- Background Information
- Existing Conditions
- Project Goals
- Design Process
- Design Implications
- **Lateral Loads**
- Schedule Comparison
- Cost Analysis
- Sustainable Architecture
- Recommendations
- Acknowledgements
- Questions

Portal Method Analysis For Redesigned

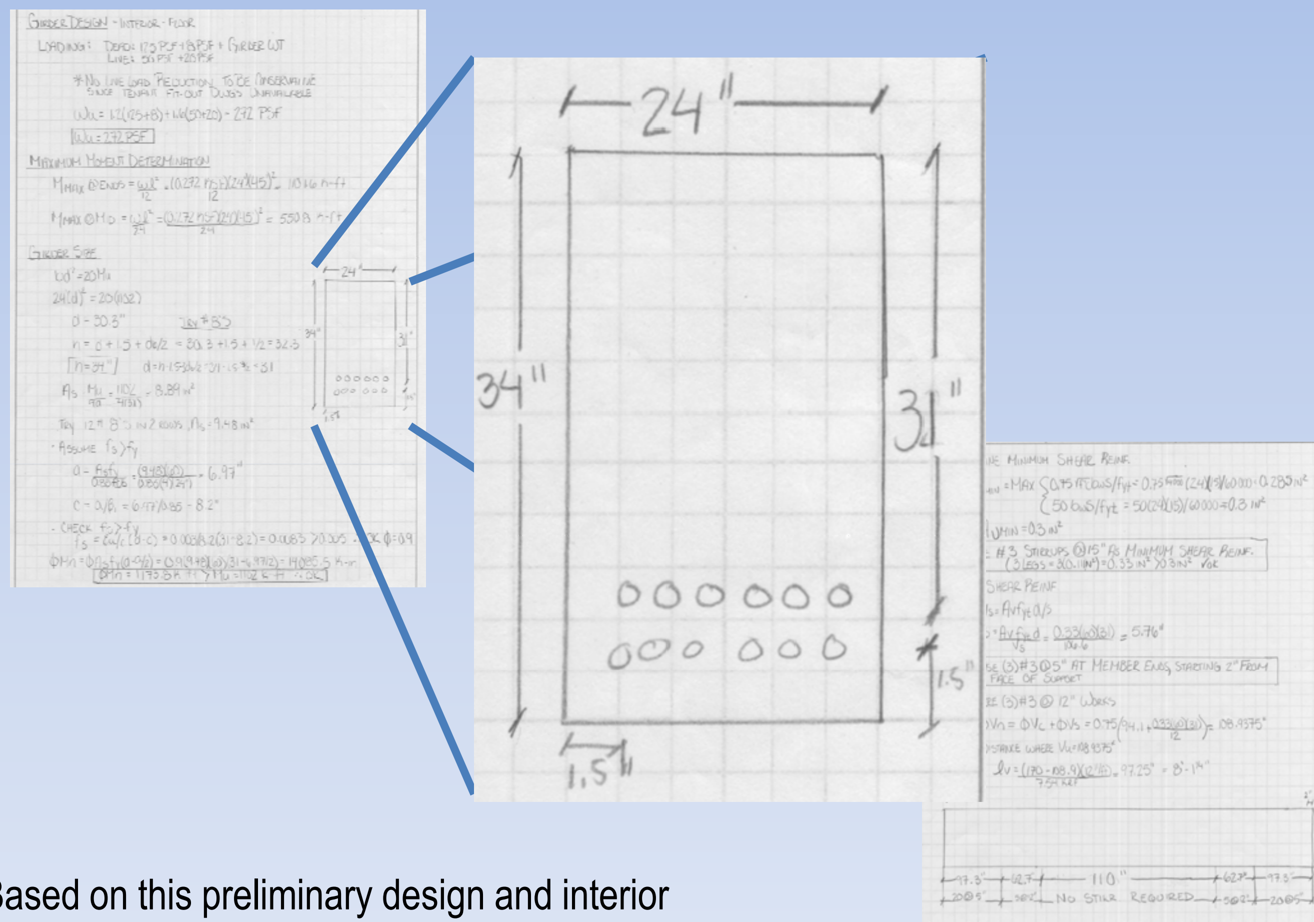




Reference Slide

Hand Calculated Beam

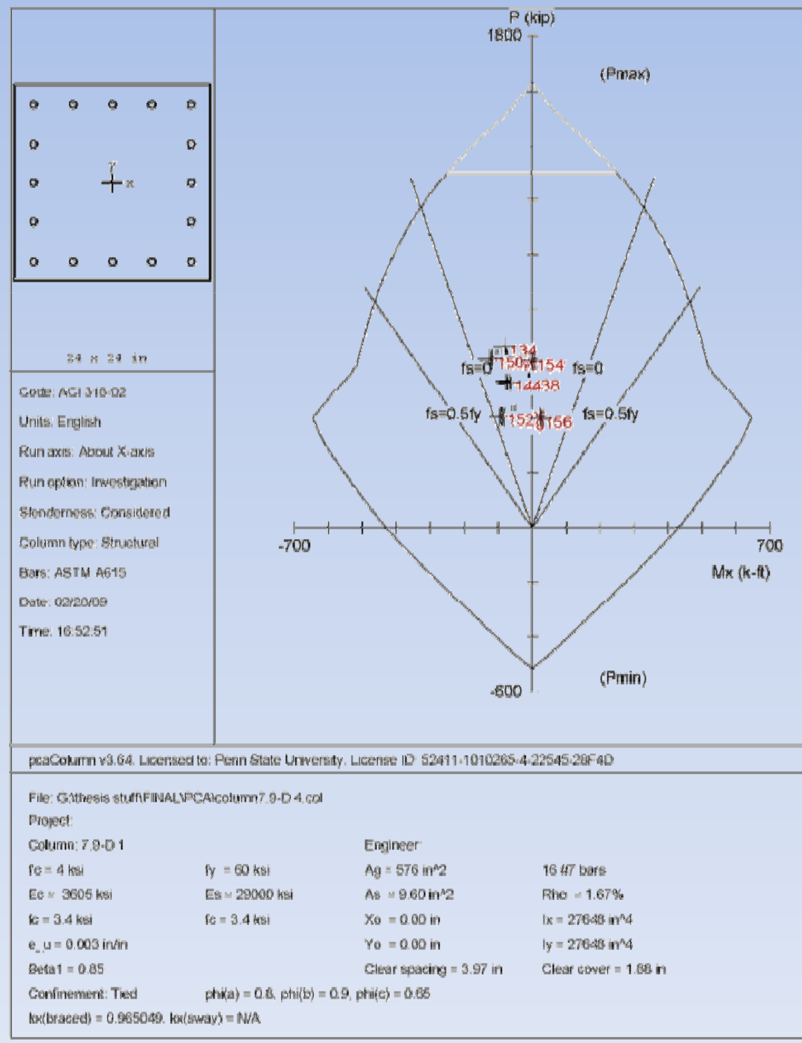
Preliminary Beam Design



Based on this preliminary design and interior gravity beam can be 24"x34"

PCA Column Check

Column D-7.9 Fourth Floor



Reference Slide

Torsion

Wind Frame 19

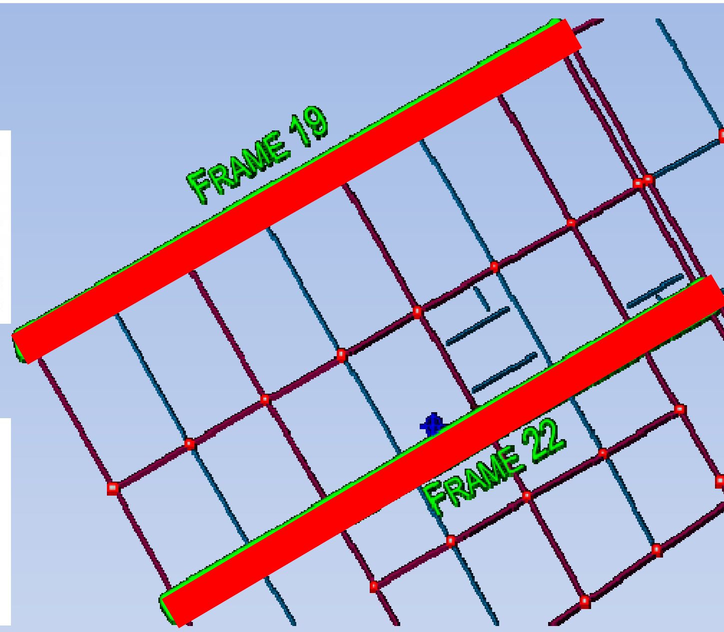
Load Case: W9 Wind Wind_IBC06_4_X+Y_CW

Level	Shear-X kips	Change-X kips	Shear-Y kips	Change-Y kips
Roof	24.27	24.27	17.43	17.43
Fifth	29.05	4.78	20.97	3.54
Fourth	43.42	14.37	31.90	10.93
Third	51.17	7.75	38.22	6.32
Second	46.66	-4.51	33.40	-4.82
First	-9.04	-55.70	-11.12	-44.52

Wind Frame 22

Load Case: W9 Wind Wind_IBC06_4_X+Y_CW

Level	Shear-X kips	Change-X kips	Shear-Y kips	Change-Y kips
Penthouse	3.26	3.26	3.47	3.47
Roof	3.71	0.45	7.56	4.10
Fifth	9.77	6.06	15.69	8.12
Fourth	12.68	2.91	20.61	4.92
Third	18.67	5.99	27.52	6.92
Second	19.37	0.70	35.57	8.05
First	-3.24	-22.62	-10.30	-45.87



Seismic Frame 19

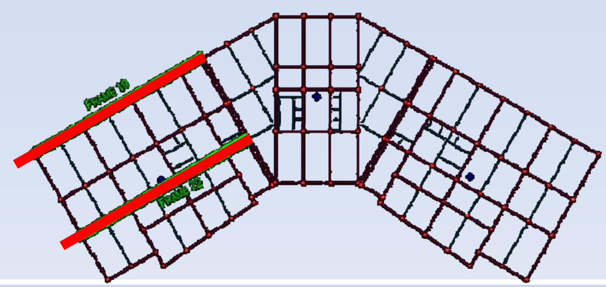
Load Case: E1 Seismic EQ_IBC06_X_+E_F

Level	Shear-X kips	Change-X kips	Shear-Y kips	Change-Y kips
Roof	50.00	50.00	15.85	15.85
Fifth	49.63	-0.37	14.53	-1.33
Fourth	64.72	15.09	19.06	4.54
Third	66.40	1.68	20.10	1.04
Second	73.12	6.72	15.00	-5.10
First	-23.19	-96.31	7.26	-7.74

Seismic Frame 22

Load Case: E1 Seismic EQ_IBC06_X_+E_F

Level	Shear-X kips	Change-X kips	Shear-Y kips	Change-Y kips
Penthouse	20.03	20.03	6.15	6.15
Roof	26.35	6.32	-6.05	-12.20
Fifth	47.99	21.64	-4.00	2.05
Fourth	56.10	8.12	-5.38	-1.38
Third	65.66	9.56	-5.03	0.35
Second	60.39	-5.28	-4.42	0.61
First	-17.19	-77.57	6.33	10.75



Reference Slide

- Background Information
- Existing Conditions
- Project Goals
- Design Process
- Design Implications
- **Lateral Loads**
- Schedule Comparison
- Cost Analysis
- Sustainable Architecture
- Recommendations
- Acknowledgements
- Questions

Drift For Redesigned Building

		Controlling Seismic						
Story	St heig	Story	Story height (ft)	Acutal Drift Ratio	Allowable Total Drift Ratio δ_{xe}/h_{sx}=).02*1.0/3		ble Total Drift (in) Δ_{Wind}=H/400	
Pent		Pent	92.5	0.0004	<	0.006667	75	Acceptable
Roof		Roof	74.5	0.0005	<	0.006667	35	Acceptable
5		5	60.0	0.0008	<	0.006667		Acceptable
4		4	46.0	0.0009	<	0.006667	8	Acceptable
3		3	32.0	0.001	<	0.006667	6	Acceptable
2		2	18.0	0.0009	<	0.006667	4	Acceptable

Drift For the As-Built Steel Building

		Controlling Wind							
Story	Story height (ft)	Story Drift (in)	Allowable Story Drift (in) Δ_{Wind}= H/400			Total Drift (in)	Allowable Total Drift (in) Δ_{Wind}=H/400		
Roof	74.5	0.127	<	0.435	Acceptable	1.02425	<	2.235	Acceptable
5	60.0	0.187	<	0.42	Acceptable	0.89767	<	1.8	Acceptable
4	46.0	0.247	<	0.42	Acceptable	0.71044	<	1.38	Acceptable
3	32.0	0.257	<	0.42	Acceptable	0.46336	<	0.96	Acceptable
2	18.0	0.207	<	0.54	Acceptable	0.20662	<	0.54	Acceptable

REFERENCE SLIDE

SEISMIC CALCULATIONS

Redesigned Values

Seismic Design Values, ASCE 7-05		
Response Modification Coefficient	R= 3	Table 12.2-1
Coefficient	C_U= 1.7	Table 12.8-1
Fundamental Period	T= 1.5999	Sec. 12.8.2
Seismic Response Coefficient	C_S= 0.015	Eq. 12.8-3
Building Height (above grade)	h= 92.5	

As-Built Values

Seismic Design Values, ASCE 7-05			
Response Modification Coefficient	R= 3	R= 3.5	Table 12.2-1
Coefficient	C_U= 1.7	C_U= 1.7	Table 12.8-1
Fundamental Period	T= 1.780	T= 1.780	Sec. 12.8.2
Seismic Response Coefficient	C_S= 0.014	C_S= 0.012	Eq. 12.8-3
Building Height (above grade)	h= 92.5	h= 92.5	

Seismic Calculations

Seismic Design Values, ASCE 7-05		
Occupancy	II	Table 1-1
Importance Factor	I= 1	Table 11.5-1
Site Class	D	Table 20.3-1
Spectral Response Acceleration, short	S_S= 0.12	Figure 22-1
Spectral Response Acceleration, 1 sec	S_1= 0.046	Figure 22-2
Site Coefficient F_a	F_a= 1.6	Table 11.4-1
Site Coefficient F_V	F_V= 2.4	Table 11.4-2
MCE Spectral Response Acceleration, short	S_{MS}= 0.192	Eq. 11.4-1
MCE Spectral Response Acceleration, 1 sec	S_{M1}= 0.1104	Eq. 11.4-2
Design Spectral Acceleration, short	S_{DS}= 0.128	Eq. 11.4-3
Design Spectral Acceleration, 1 sec	S_{D1}= 0.0736	Eq. 11.4-4
Seismic Design Category	B	Table 11.6-1

Seismic Calculations

Calculated Values				USGS Website Values
S_S= 0.12			(From Figure 22-1)	S_S= 0.125
S_1= 0.046			(From Figure 22-2)	S_1= 0.048
S_{MS}=	F_a*S_S =	0.192		S_{MS}= 0.2
S_{M1}=	F_V*S_1 =	0.1104		S_{M1}= 0.116
S_{DS}=	2S_{MS}/3=	0.128	A (Table 11.6-1)	S_{DS}= 0.133
S_{D1}=	2S_{M1}/3=	0.0736	B (Table 11.6-2)	S_{D1}= 0.077

F_a Values (Table 11.4-1 ASCE 7-05)					
	S_S≤0.25	S_S=0.5	S_S=0.75	S_S=1.0	S_S≥1.25
D	1.6	1.4	1.2	1.2	1

F_V Values (Table 11.4-2 ASCE 7-05)					
	S_1≤0.1	S_1=0.3	S_1=0.3	S_1=0.4	S_1≥0.5
D	2.4	2	1.8	1.6	1.5

SEISMIC CALCULATIONS

Redesigned Values

$C_T = 0.016$ (From Table 12.8-2)

$X = 0.9$ (From Table 12.8-2)

$T_a = C_t h_n^x = 0.9411255$

$T_s = S_{D1}/S_{DS} = 0.575$

$0.8T_s = 0.46$ $<T_a$ therefore must use Table 11.6-1,2

$T_L = 12$ (From Fig. 22-15 p. 228 ASCE 7-05)

$C_S =$ MAX for $T>T_L$

$S_{DS}/(R/I) =$	0.0427	(12.8-2)
$S_{D1}/(T^*R/I) =$	0.0153	(12.8-3)
$S_{D1}T_L/(T^2R/I) =$	0.3324	(12.8-4)
$\geq$	0.01	(12.8-5)

$C_S = 0.0153$

$T = C_U{}^*T_a = 1.5999134$

$V = C_s{}^*W$ 1636.69

- Background Information
- Existing Conditions
- Project Goals
- Design Process
- Design Implications
- **Lateral Loads**
- Schedule Comparison
- Cost Analysis
- Sustainable Architecture
- Recommendations
- Acknowledgements
- Questions

WIND CALCULATIONS

Basic Wind Speed (V) mph	90
Exposure Category	B
Importance Factor (I)	1
Wind Directionality Factor (Kd)	0.85
Topographic Factor (Kzt)	1

From Table 6-3

H (ft)	K_z	q_z
92.5	0.9675	14.354
74.5	0.908	13.471
60	0.85	12.611
46	0.79	11.720
32	0.712	10.563
18	0.59	8.902
0	0.57	8.456

From RAM

H (ft)	K_z	q_z
92.5	0.966	14.331
74.5	0.909	13.486
60	0.854	12.670
46	0.792	11.750
32	0.714	10.593
18	0.605	8.976
0	0.575	8.531

Floor Heights	Level	Total Height	K_Z	q_Z	Wind Pressures (psf)					
					N-S Windward	N-S Leeward	N-S Side Wall	E-W Windward	E-W Leeward	E-W Sidewall
18	Penthouse	92.5	0.9675	14.354	11.54	-8.21	-10.43	12.20	-4.91	-10.49
14.5	Roof	74.5	0.908	13.471	10.99	-8.21	-10.43	11.61	-4.91	-10.49
14	5	60	0.85	12.611	10.46	-8.21	-10.43	11.43	-4.91	-10.49
14	4	46	0.79	11.720	9.91	-8.21	-10.43	11.04	-4.91	-10.49
14	3	32	0.712	10.563	9.20	-8.21	-10.43	10.65	-4.91	-10.49
18	2	18	0.59	8.902	7.90	-8.21	-10.43	10.45	-4.91	-10.49

Reference Slide

Wind Calculations

Level	Wind Design					
	Load (kips)		Shear (kips)		Moment (ft-k)	
	N-S	E-W	N-S	E-W	N-S	E-W
Pent	193.4	38.8	0	0	3481.3	698.2
Roof	151.5	30.2	193.4	38.8	2196.7	437.6
5	144.8	29.3	344.9	69.0	2026.7	410.7
4	138.0	28.1	489.7	98.3	1932.5	393.8
3	132.6	27.4	627.7	126.4	1856.3	384.1
2	140.2	31.0	760.3	153.9	2523.7	557.2
Total	900.5	184.8	900.5	184.8	10535.9	2183.4

Level	Wind Design					
	Load (kips)		Shear (kips)		Moment (ft-k)	
	N-S	E-W	N-S	E-W	N-S	E-W
Roof	151.6	30.5	0	0	2198.6	442.4
5	144.8	29.7	151.6	30.5	2026.7	415.2
4	137.9	28.4	296.4	60.2	1930.7	397.7
3	132.3	27.7	434.3	88.6	1852.1	387.5
2	139.5	31.2	566.6	116.3	2511.1	562.0
Total	706.1	147.5	706.1	147.5	10519.2	2204.8

WIND CALCULATIONS

Basic Wind Speed (V) mph	90
Exposure Category	B
Importance Factor (I)	1
Wind Directionality Factor (Kd)	0.85
Topographic Factor (Kzt)	1

$q_p =$ $0.00256\, K_h K_{zt} K_d V^2 I =$ 14.836

GCpn= 1.5 -1

Pp = q_pGCpn = 22.254 -14.836

$n_1 = \frac{43.5}{H^{0.9}}$ 1.163 eq (C6-15) $n_1 > 1$ therefore Rigid structure

$g_Q =$ $g_V =$ 3.4

G= 0.85

z= 0.6h = 55.5

z_{min} = 30'

$I_z = c(33/z)^{1/6} =$ 0.275

$L_z = l(z/33)^{\epsilon} =$ 380.55

$Q_{N\text{-}S} =$ $\sqrt{(1/(1+0.63(B+h/L_z)^{0.63}))} =$ 0.731

$Q_{E\text{-}W} =$ $\sqrt{(1/(1+0.63(B+h/L_z)^{0.63}))} =$ 0.832

$G_{f\,N\text{-}S} = 0.925\,[(1+1.7 I_z g_Q Q)/(1+1.7 g_v I_z)] =$ 0.7722744

$G_{f\,E\text{-}W} = 0.925\,[(1+1.7 I_z g_Q Q)/(1+1.7 g_v I_z)] =$ 0.8296736

Foundation Implications

Caissons

Uncored Caisson

Axial capacity = area x allow bearing - weight of caisson
Uplift capacity NON-EMBEDDED CAISSON = Soli Friction + Weight of Caisson

0 ft Embedment					CAISSON	
Pile D [ft]	Area [sf]	Circumf. [ft]	Weight [kips]	Tu [kips] w/ SF	Uplift Capacity w/o Core [kips]	Axial Capacity w/o Core [kips]
5.00	19.63	15.71	35.83	12.04	47.87	553.21
5.50	23.76	17.28	43.36	13.24	56.60	669.39
6.00	28.27	18.85	51.60	14.44	66.04	796.63
6.50	33.18	20.42	60.56	15.65	76.21	934.93
7.00	38.48	21.99	70.23	16.85	87.08	1084.30
7.50	44.18	23.56	80.63	18.05	98.68	1244.73
Length = 12.17 ft						

FOUNDATION IMPLICATIONS

Spread footings

soil bearing	8 ksf
caisson bearing	30 ksf

$q_u = P_u/A$

d^2(4VC+q)+d(2VC+q)w=q(BL-w)

Punching Shear

$V_C \leq \phi(2+4\beta_C)\sqrt{(f'c)}b_O d$

$\phi 4\sqrt{(f'c)}b_O d$

$\phi(\alpha_s d/b_o+2)\sqrt{(f'c)}b_o d$

$\phi = 0.75$

$\beta_C = 1$

$f'c = 3000$

$\alpha =$	40	int
	30	edge
	20	corner