Penn State Hershey Medical Center
Children's Hospital

Hershey, Pennsylvania

Matthew Vandersall
Structural Option
AE Senior Thesis - 2011

Dr. Richard Behr – Thesis Advisor

Introduction

Location: Hershey, PA

Number of Stories: 5 Above Grade / 1 Below Grade

Size: ~263,000 SF

Height: 83.5 ft to top of the roof

Structural Engineer: Gannett Fleming

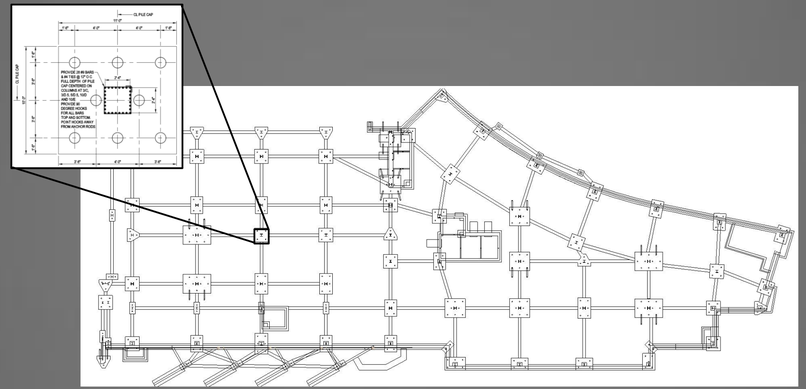
Construction: 3/17/2010 – 8/20/2012

Contracted Cost: $115,726,613

Delivery Method: Design-Bid-Build

(http//www.pennstatehershey.org)

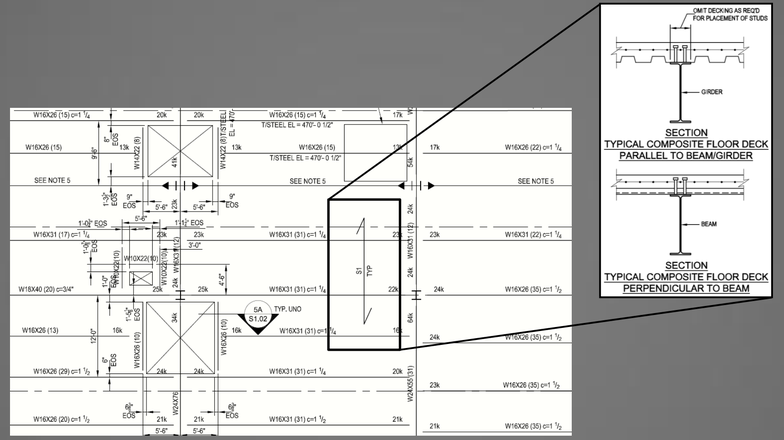
Existing Structural System



Foundation

- 600 micropiles
- 3’ x 3’ to 10’ x15’ pile caps
- Strut beams span between pile caps
- f’c = 4000 psi for all concrete elements

Existing Structural System



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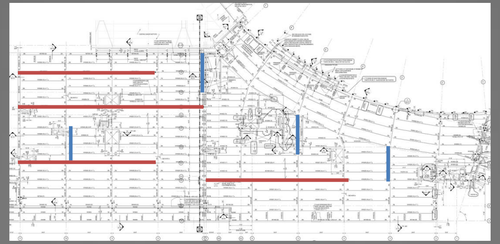
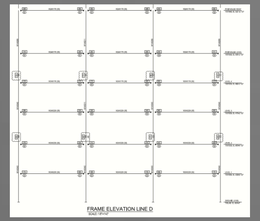
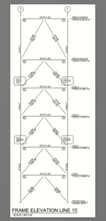
Gravity System

- Composite Floor System:
  - 2” deep, 20-gage composite metal deck with 4 ½” topping
  - ¾” Shear studs to wide flange beams
- All columns are W 14s
- Beams are typically W16s - W21s

Existing Structural System







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Lateral System

- 4 Moment Frames in East-West direction
- 4 Braced Frames in North-South direction

Children's Hospital – Hershey Medical Center

- Introduction
- Existing Structural System
- Thesis Proposal
- Structural Depth
  - Slab Design
  - Shear Wall Design
  - Column Design
- Construction Management Breadth
- Conclusion

Thesis Proposal

Structural Depth

- Redesign structure using reinforced concrete
- Minimize structural layout impact
- Design for future expansion

Construction Management Breadth

- Compare cost of existing versus proposed design
- Generate project schedules

Mechanical Breadth

- Analyze heat flow through the insulating glass curtain wall
- Propose an efficient curtain wall system to minimize heat transfer

MAE Coursework

- AE 597A – ETABS model
- AE 542 – heat transfer analysis for curtain wall systems

(Payette Associates)

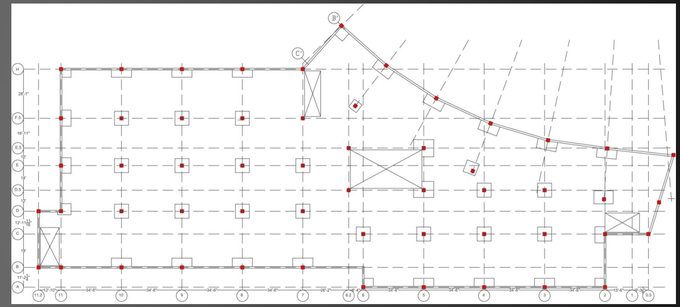
Structural Depth

Solution

- Gravity System:
  - Two-way reinforced flat slab system
  - Shear caps if necessary for punching shear
- Lateral System:
  - Reinforced concrete shear walls
- Two additional patient floors
  - Structural height = 113.5 ft

Proposed Column Layout

- Column line F and G eliminated
- Typical span: 30’ x 34.5’



Proposed Layout

Structural Depth

Two-Way Flat Slab Design

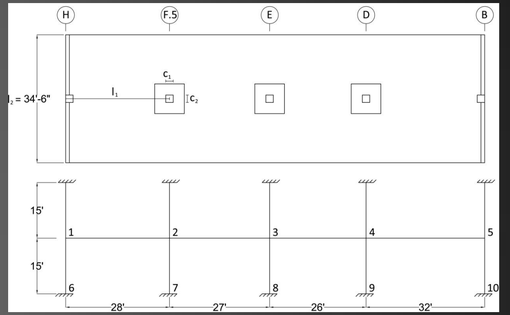
- Typical span considered for preliminary design
- Element stiffness determined
- Performed moment distribution
- Moments distributed to columns strips and middle strips
- Designed reinforcement

Assumptions:

- f'c = 5000 psi
- Slab thickness of 9"
- Shear cap depth of 4.5"

Final Design

Joint 1 Reinforcement	*Middle Strip*	*Column Strip*	*Middle Strip*
Strip Width, ft	8.625	17.25	8.625
Exterior Negative Moment (kip-ft)		-455.7	
Moment Coefficient	0.033	0.934	0.033
Distributed Moments	-15.0381	-425.6238	-15.0381
Required A_s (in^2)	0.49	13.96	0.49
Minimum A_s (in^2)	1.68	3.35	1.68
Selected Steel	6 #5 bars	24 #7 bars	6 #5 bars
Provided A_s (in^2)	1.86	14.4	1.86



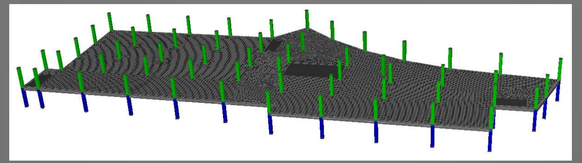
COF		0.5925		0.5926		0.5927		0.5921	
	Joint 1		Joint 2			Joint 3		Joint 4	Joint 5	
SPAN	1-6	1-2	2-1	2-7	2-3	3-2	3-8	3-4	4-3	4-9	4-5	5-4	5-10
k	468.1	443.3	443.3	452.2	459.9	459.9	452.2	477.9	477.9	452.2	387.1	387.1	468.1
DF	0.514	0.486	0.327	0.334	0.339	0.331	0.325	0.344	0.363	0.343	0.294	0.453	0.547
FEM		831.82	-831.82		773.55	-773.55		717.39	-717.39		1086.11	-1086.11	
DIST 1	-427.23	-404.59	19.06	19.44	19.77	18.58	18.27	19.31	-133.78	-126.58	-108.36	491.62	594.49
CO		11.29	-239.72		11.01	11.72		-79.29	11.44		291.09	-64.16	
DIST 2	-5.80	-5.49	74.80	76.30	77.60	22.36	21.98	23.23	-109.76	-103.86	-88.91	29.04	35.12
CO		44.32	-3.25		13.25	45.99		-65.06	13.77		17.20	-52.64	
DIST 3	-22.76	-21.56	-3.27	-3.33	-3.39	6.31	6.20	6.56	-11.23	-10.63	-9.10	23.83	28.81
CO		-1.94	-12.77		3.74	-2.01		-6.66	3.89		14.11	-5.39	
DIST 4	0.99	0.94	2.95	3.01	3.07	2.87	2.82	2.98	-6.53	-6.18	-5.29	2.44	2.95
CO		1.75	0.56		1.70	1.82		-3.87	1.77		1.44	-3.13	
DIST 5	-0.90	-0.85	-0.74	-0.75	-0.77	0.68	0.67	0.71	-1.16	-1.10	-0.94	1.42	1.71
SUM	-455.69	455.69	-994.20	94.67	899.53	-665.24	49.94	615.30	-948.99	-248.35	1197.35	-663.09	663.09
SUM JT	0.00		0.00			0.00			0.00			0.00	

Structural Depth

Ram Concept Model

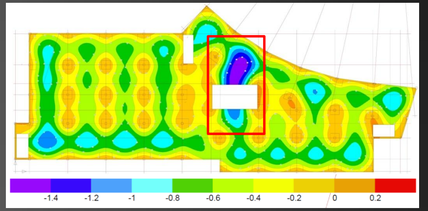
- Used to check all floor sections
- Live load patterns were considered
- Punching Shear checks performed
- Allowable deflection, $\Delta = \frac{L}{240} = 1.73''$

- Penthouse live load of 250 psf
- Slab thickness increased for penthouse level



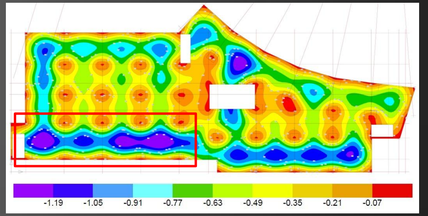
Typical Floor

Max Δ = 1.6"



Penthouse Level

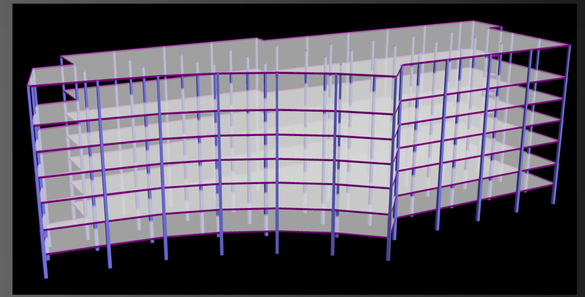
Max Δ = 1.4"



Structural Depth

Final Slab Design:

- Typical Floor
  - 9" two-way flat slab for typical floor
  - f'c = 5000 psi
  - 4.5" deep shear caps
- Penthouse Floor
  - 11" thick slab
  - f'c = 6000 psi
  - 9.5" deep shear caps
- #7 and #8 rebar for column strip
- #5 rebar for middle strip

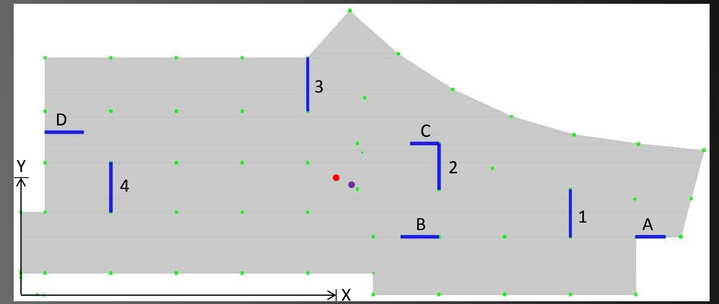


Structural Depth

Design of Shear Walls
- 4 in North-South direction
- 4 in East-West direction

Deflection/Story Drift Limitations
- Wind - H/400
- Seismic - $0.02*h_{sx}$

Assumptions
- f'c = 5000 psi
- Slab acts as a rigid diaphragm
- Cracked sections
  - Columns – $0.7I_g$
  - Shear Walls – $f_{22} = 0.5$
- Shear walls take no out-of-plane bending
- P-Δ effects considered within model

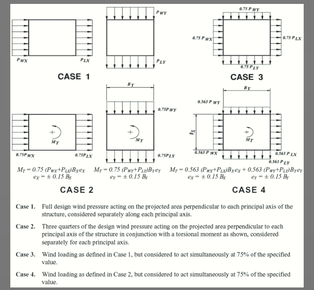


	X-Dir. (ft)	Y-Dir. (ft)
Center of Mass	166	61.4
Center of Rigidity	174.3	59.2
Eccentricity	8.3	-2.2

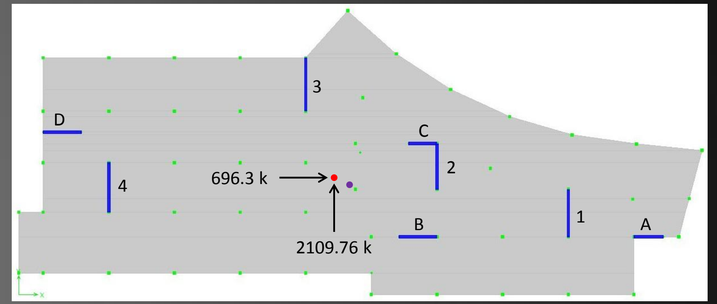
Structural Depth

Wind Loading

- Recalculation of base shear due to increased story height
- ASCE 7-10 wind load cases applied
- Load Case 1 controlled in both directions
- Serviceability checked for H/400



ASCE 7-10 Figure 27.4-8



Wind Base Shears

Level	Height	X-Disp.	Y-Disp.	Total Disp.	Story Drift	Drift Limit
	ft	*in*	*in*	*in*	*in*	*in*
Roof	22	0.62	0.60	0.86	0.20	0.66
Penthouse	15	0.47	0.45	0.65	0.14	0.45
6	15	0.38	0.35	0.52	0.14	0.45
5	15	0.28	0.26	0.38	0.13	0.45
4	16.5	0.18	0.17	0.25	0.11	0.49
3	15	0.10	0.09	0.13	0.09	0.45
2	15	0.03	0.03	0.04	0.04	0.45

Serviceability Check

Structural Depth

Seismic Loading

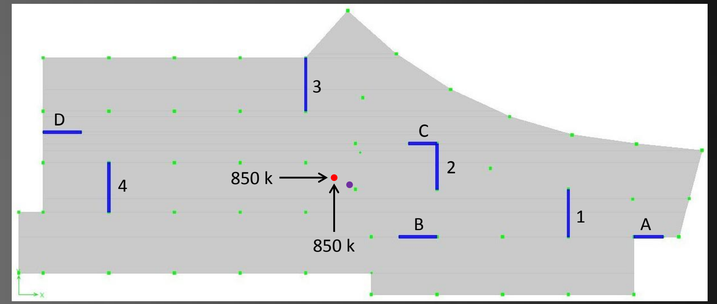
- Original response modification factor (R) = 3
- Ordinary reinforced concrete shear walls (R) = 5, Cd = 4.5
- Base shear calculated for additional weight of the structure
- Accidental torsional effects e = 0.05
- Drift checked against $0.02h_{sx}$

Load Cases:

ASCE 7-10 Section 12.5.3 (a) - "the requirement for considering the orthogonal combination is deemed satisfied if members are designed for 100% of the forces for one direction plus 30% of the forces for the perpendicular direction."

- **$30\%E_x + 100\%E_y$**
- **$30\%E_x - 100\%E_y$**
- **$100\%E_y + 30\%E_x$**
- **$100\%E_y - 30\%E_x$**

	Wall A	Wall B	Wall C	Wall D	Wall 1	Wall 2	Wall 3	Wall 4
Case 1	60.2	92.5	44.7	71.3	171.1	174.8	245.7	248
Case 2	52.3	79.4	79.5	54.4	165.3	211.4	226.8	231.7
Case 3	188.8	292.5	201.8	212.1	61.2	1.47	96.6	99.2
Case 4	186.3	285.7	209.1	207	41.3	118.7	46.1	44.7
Max Shear (kips)	188.8	292.5	209.1	212.1	171.1	211.4	245.7	248



Seismic Base Shears

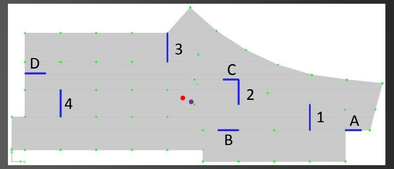
Level	Height	X-Disp.	Y-Disp.	Total Disp.	Story Drift	Drift Limit
	ft	*in*	*in*	*in*	*in*	*in*
Roof	22	1.2533	0.1996	1.27	0.94	5.28
Penthouse	15	0.9453	0.1483	0.96	0.63	3.6
6	15	0.7373	0.1141	0.75	0.62	3.6
5	15	0.533	0.0811	0.54	0.58	3.6
4	16.5	0.343	0.0515	0.35	0.50	3.96
3	15	0.1796	0.0265	0.18	0.39	3.6
2	15	0.0517	0.0075	0.05	0.16	3.6

Drift Limits

Structural Depth

Shear Wall Design

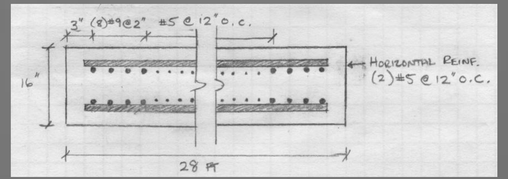
- Designed using ACI 318-08 Section 11.9 – "Provision for Walls"
- Design with controlling shear for each wall
- Wall 3 experienced greatest lateral force
- Load combination:
  - 1.2D + 1.6L + 1.0W

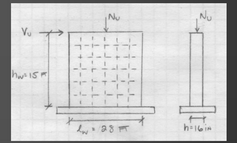


	Wall A	Wall B	Wall C	Wall D	Wall 1	Wall 2	Wall 3	Wall 4
Wind	145.4	223.0	165.1	170.36	521.6	524.9	560.1	481.8
Seismic	188.8	292.5	209.1	212.1	171.1	211.4	245.7	248
Controlling	188.8	292.5	209.1	212.1	521.6	524.9	560.1	481.8

Maximum Wall Shear Forces

Final Design

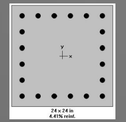


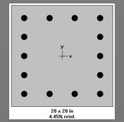


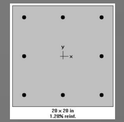
Structural Depth

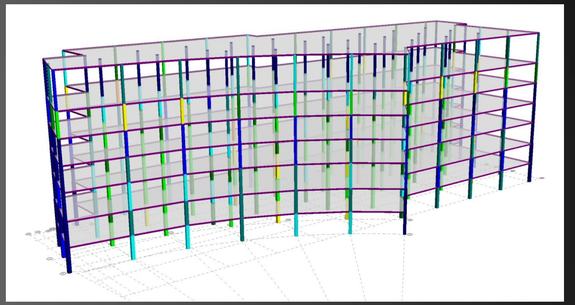
Column Design

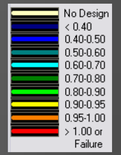
- Designed in RAM Structural System
- All columns are square geometry
- Three columns sizes
  - 24” x 24”
  - 20” x 20”
  - 18” x 18”
- Reinforcement pattern:
  - 14 bars, long. #6-#10 (four faces), transverse #3
  - 16 bars, long. #6-#10 (four faces), transverse #3
  - 20 bars, long. #6-#10 (four faces), transverse #3



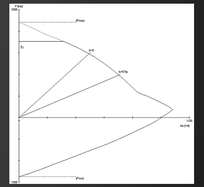








Load Capacity Ratios



Construction Management Breadth

Cost Analysis

- Costs determined from RS Means
- Accounts for material, labor, and equipment costs
- Equivalent structure difference = $256,000

Existing Structure	Total Cost
Structural Steel	$4,588,000
Reinforcement	$119,600
Metal Decking	$361,000
Concrete	$277,000
Floor Finishing	$122,200
Fireproofing	$376,000
	$5,843,800
5-Story Concrete Structure	
Concrete	$1,020,000
Reinforcement	$976,700
Formwork	$3,954,000
Floor Finishing	$149,000
	$6,100,000
7-Story Concrete Structure	
Concrete	$1,336,000
Reinforcement	$1,282,000
Formwork	$5,322,000
Floor Finishing	$198,000
	$8,138,000

Construction Management Breadth

Introduction

Existing Structural System

Thesis Proposal

Structural Depth

Slab Design

Shear Wall Design

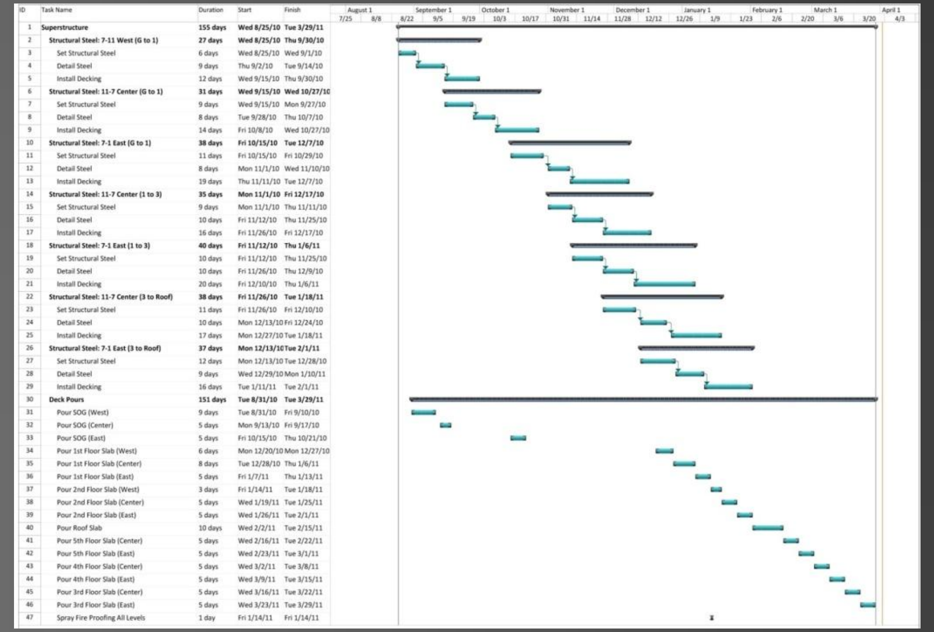
Column Design

Construction Management Breadth

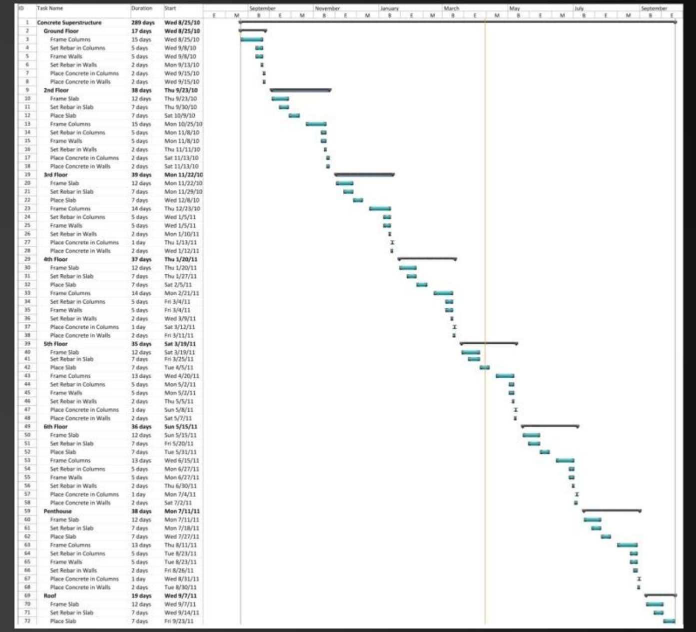
Conclusion

Schedule Impact

- Assumptions:
  - Multiple crews per task
  - For an ideal construction process
  - Based on RS Means output
- Existing Schedule
  - Projected 155 days
- Proposed Schedule
  - Completed 7-story design in 289 days
  - Equivalent 5-story design in 212 days



Existing Schedule



Proposed Schedule

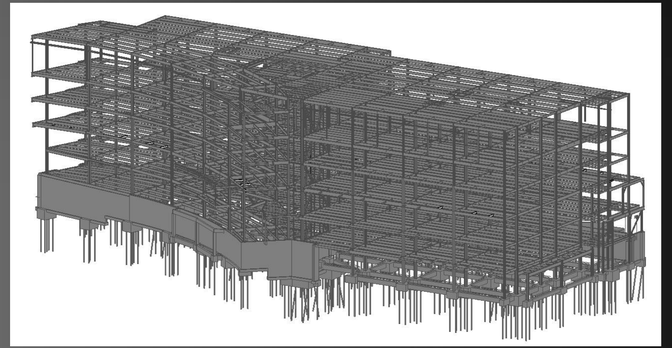
Conclusion

Goals:

- Structural layout impact minimized
- Floor depth was minimized
- Longer construction time frame

Recommendation:

- Concrete redesign can not be recommended
- Foundation would need to be checked and resized



Questions / Comments

(Payette Associates)

Acknowledgements:

- Earl Roberts (Owner Representative)
- PSU Architectural Engineering Faculty
- Payette Associates Inc.
- L.F. Driscoll Company, LLC
- Gannett Fleming Inc.