Penn State Hershey Medical Center Children's Hospital

Hershey, Pennsylvania



Matthew Vandersall Structural Option AE Senior Thesis - 2011

Dr. Richard Behr – Thesis Advisor

	Location: Hers
Introduction	Number of Sto
Existing Structural System	Size: ~263,000
Thesis Proposal	
Structural Depth	Height: 83.5 ft
Slab Design	Structural Eng
Shear Wall Design	Construction:
Column Design	Contracted Co
Construction Management Breadth	
Conclusion	Delivery Meth

Introduction

shey, PA

tories: 5 Above Grade / 1 Below Grade

) SF

t to top of the roof

gineer: Gannett Fleming

3/17/2010 - 8/20/2012

ost: \$115,726,613

hod: Design-Bid-Build



(http//www.pennstatehershey.org)

Introduction

Thesis Proposal

Structural Depth

Slab Design

Shear Wall Design

Column Design

Construction Management Breadth

Conclusion



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

Introduction

Thesis Proposal

Structural Depth

Slab Design

Shear Wall Design

Column Design

Construction Management Breadth

Conclusion



Existing Structural System

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

Gravity System

- Composite Floor System:
 - 2" deep, 20-gage composite metal deck with 4 ¹/₂" topping
 - ³/₄" Shear studs to wide flange beams
- All columns are W 14s
- Beams are typically W16s W21s

Introduction

Thesis Proposal

Structural Depth

Slab Design

Shear Wall Design

Column Design

Construction Management Breadth

Conclusion

Existing Structural System







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

- - 2" deep, 20-gage composite metal deck with 4 ½" topping
 - ³/₄" Shear studs to wide flange beams

Lateral System

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

	Structural Depth Redesigns Minimize
Introduction	Design for
Existing Structural System	Construction Mar • Compare
Structural Depth	• Generate
Slab Design	Mechanical Bread
Shear Wall Design	 Propose a
Column Design	MAE Coursework
Construction Management Breadth	• AE 597A -
Conclusion	• AE 542 - r

Thesis Proposal

- gn structure using reinforced concrete ze structural layout impact
- for future expansion

Aanagement Breadth

re cost of existing versus proposed design te project schedules

eadth

e heat flow through the insulating glass curtain wall e an efficient curtain wall system to minimize heat transfer

- ETABS model
- heat transfer analysis for curtain wall systems



(Payette Associates)

	Solution
	Gravity
	• Tw
Introduction	• She
Existing Structural System	• Lateral • Rei
Thesis Proposal	• Two ad
Structural Depth	• Str
Slab Design	Proposed Column
Shear Wall Design	• Column • Typical
Column Design	
Construction Management Breadth	
Conclusion	

Structural Depth

y System:

- wo-way reinforced flat slab system
- near caps if necessary for punching shear I System:
- einforced concrete shear walls
- ditional patient floors
- ructural height = 113.5 ft

ımn Layout

n line F and G eliminated l span: 30' x 34.5'



Proposed Layout

	Two-Way Flat	Slab Design				
	• Typical	 Typical span considered for preliminary design 			gn	
	• Flemer	ht stiffness determ	ined			
Introduction	Perforr	rformed moment distribution				
Existing Structural System	• Momel	nts distributed to c	columns s	trips and	middle s	
	• Design	ed reinforcement				
Thesis Proposal						
	Assumptions:	Assumptions: • $f'c = 5000 \text{ psi}$				
Structural Depth	• $f'c = 50$					
Slab Design	 Slab thickness of 9" 					
Shear Wall Design	• Shear o	 Slab thickness of 9" Shear cap depth of 4.5" 				
	Final Design	Joint 1 Reinforcement	Middle Strip	Column Strip	Middle Strip	
Column Design		Strip Width, ft	8.625	17.25	8.625	
		Moment Coefficient	0.033	0.934	0.033	
Construction Management Breadth		Distributed Moments	-15.0381	-425.6238	-15.0381	
		Required A _s (in ²) Minimum A. (in ²)	0.49	13.96	0.49	
		Selected Steel	6 #5 bars	24 #7 bars	6 #5 bars	
Conclusion		Provided A _s (in ²)	1.86	14.4	1.86	

Structural Depth

- trips



D B 0.5927 0.5921 Joint 5 3-8 3-4 4-3 4-5 5-4 5-10 2.95 1.42 663.09 0.00 0.00 0.00

	• Used
Introduction	Live IPunc
Existing Structural System	• Allow
Thesis Proposal	• Penth
Structural Depth	• Slab t
Slab Design	
Shear Wall Design	
Column Design	
Construction Management Breadth	
Conclusion	

Structural Depth

Ram Concept Model

- d to check all floor sections load patterns were considered ching Shear checks performed wable deflection, $\Delta = \frac{L}{240} = 1.73''$
- thouse live load of 250 psf thickness increased for penthouse level



Typical Floor Max ∆ = 1.6"



Penthouse Level

Max Δ = 1.4"



	Final Slab D
Introduction	• Typi
Existing Structural System	•
Thesis Proposal	• Doni
Structural Depth	• Pen •
Slab Design	•
Shear Wall Design	• #7 a
Column Design	• #5 r
Construction Management Breadth	
Conclusion	

Structural Depth

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



	• 4 in No
Introduction	- 4 III La
Existing Structural System	Deflection/Sto
Thesis Proposal	• Wind · • Seismi
Structural Depth	Assumptions
Slab Design	• f'c = 50
Shear Wall Design	Slab acCracke
Column Design	• Co
Construction Management Breadth	• Shear
Conclusion	• P-Δ ef

Structural Depth

ar Walls orth-South direction ast-West direction

> tory Drift Limitations - H/400 ic - 0.02*h_{sx}

6000 psi acts as a rigid diaphragm ed sections columns – 0.71_g hear Walls – $f_{22} = 0.5$ walls take no out-of-plane bending ffects considered within model



Dir. (ft)	Y-Dir. (ft)
166	61.4
174.3	59.2
8.3	-2.2

	Wind Loading • Recale
Introduction	 ASCE Load (Servic
Thesis Proposal	
Structural Depth	
Slab Design	
Shear Wall Design	
Column Design	
Construction Management Breadth	
Conclusion	

Structural Depth

- culation of base shear due to increased story height
- 7-10 wind load cases applied
- Case 1 controlled in both directions
- ceability 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
	<u>ft</u>	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

	Origina Ordina
Introduction	• Ordina • Base sł
Existing Structural System	Accide Drift ch
Thesis Proposal	
Structural Depth	ASCE 7-10 Section 12
Slab Design	satisfied if members perpendicular directi
Shear Wall Design	• 20% E
Column Design	• 30%Ex • 30%Ex
Construction Management Breadth	• 100%E • 100%F
Conclusion	

Structural Depth

Seismic Loading

hal response modification factor (R) = 3 hary reinforced concrete shear walls (R) = 5, Cd = 4.5 shear calculated for additional weight of the structure lental torsional effects e = 0.05 checked against 0.02h_{sx}

12.5.3 (a) - "the requirement for considering the orthogonal combination is deemed rs are designed for 100% of the forces for one direction plus 30% of the forces for the ction."

x + 100%Ey x - 100%Ey Ey + 30%Ex Ey - 30%Ex

	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

	Shear Wall De • Design
Introduction	• Wall 3
Existing Structural System	 Load c 1
Thesis Proposal	ــــــــــــــــــــــــــــــــــــــ
Structural Depth	Final Design
Slab Design	
Shear Wall Design	
Column Design	
Construction Management Breadth	
Conclusion	

Structural Depth

esign

- ned using ACI 318-08 Section 11.9 "Provision for Walls"
- n with controlling shear for each wall
- 3 experienced greatest lateral force
- combination:
- ..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



	Column Desig
	• Design
Introduction	All coleThree
Existing Structural System	• 24
Thesis Proposal	• 20 • 18
Structural Depth	Reinfo
Slab Design	• 12 • 16
Shear Wall Design	• 20
Column Design	
Construction Management Breadth	••••
Conclusion	24 4.4

Structural Depth

gn

- ned in RAM Structural System
- olumns are square geometry
- e columns sizes
- .4" x 24"
- 0″ x 20″
- .8" x 18"
- orcement pattern:
- 4 bars, long. #6-#10 (four faces), transverse #3 6 bars, long. #6-#10 (four faces), transverse #3 0 bars, long. #6-#10 (four faces), transverse #3







Load Capacity Ratios



	Cost Analysis
	• Costs d
Introduction	• Accour
Existing Structural System	
Thesis Proposal	• Equival
Structural Depth	
Slab Design	
Shear Wall Design	
Column Design	
Construction Management Breadth	
Conclusion	

Construction Management Breadth

- determined from RS Means
- unts for material, labor, and equipment costs
- alent structure difference = \$256,000

Existing Structure
StructuralSteel
Reinforcement
Metal Decking
Concrete
Floor Finishing
Fireproofing
5-Story Concrete Structu
Concrete
Reinforcement
Formwork
Floor Finishing
7-Story Concrete Structu
Concrete
Reinforcement
Formwork
Floor Finishing

	Total Cost
	\$4,588,000
	\$119,600
	\$361,000
	\$277,000
	\$122,200
	\$376,000
	\$5,843,800
e	
	\$1,020,000
	\$976,700
	\$3,954,000
	\$149,000
	\$6,100,000
e	
	\$1,336,000
	\$1,282,000
	\$5,322,000
	\$198,000
	\$8,138,000

	Schedule Imp
	• Assun
Introduction	• N • F
Existing Structural System	• B
Thesis Proposal	• Existin
Structural Depth	• P
Slab Design	• Propo
Shear Wall Design	• C • E
Column Design	

Conclusion

Construction Management Breadth

act

- nptions:
- Aultiple crews per task
- for an ideal construction process
- ased on RS Means output
- ng Schedule Projected 155 days
- osed Schedule Completed 7-story design in 289 days quivalent 5-story design in 212 days

ID	Task Name	Duration	Start	Finish	August 1	September 1	October 1	November 1	December 1	January 1	February 1	March 1	April
1	Superstructure	155 days	Wed 8/25/10	Tue 3/29/11	//15 8/8	6/22 9/5	alita 10/3 10/	17 10/31 11/14	11/28 12/12	14/29 1/9	1/23 2/6	2/20 3/6	3/20 4
2	Structural Steel: 7-11 West (G to 1)	27 days	Wed 8/25/10	Thu 9/30/10			-						
3	Set Structural Steel	6 days	Wed 8/25/10	Wed 9/1/10									
4	Detail Steel	9 days	Thu 9/2/10	Tue 9/14/10		č							
5	Install Decking	12 days	Wed 9/15/10	Thu 9/30/10		ž	2						
6	Structural Steel: 11-7 Center (G to 1)	31 days	Wed 9/15/10	Wed 10/27/10		-		-					
7	Set Structural Steel	9 days	Wed 9/15/10	Mon 9/27/10		E							
8	Detail Steel	8 days	Tue 9/28/10	Thu 10/7/10			200						
9	Install Decking	14 days	Fri 10/8/10	Wed 10/27/10			2						
10	Structural Steel: 7-1 East (G to 1)	38 days	Fri 10/15/10	Tue 12/7/10			-		-				
11	Set Structural Steel	11 days	Fri 10/15/10	Fri 10/29/10				-					
12	Detail Steel	8 days	Mon 11/1/10	Wed 11/10/10				1					
13	Install Decking	19 days	Thu 11/11/10	Tue 12/7/10				ž	-				
14	Structural Steel: 11-7 Center (1 to 3)	35 days	Mon 11/1/10	Fri 12/17/10				-					
15	Set Structural Steel	9 days	Mon 11/1/10	Thu 11/11/10									
16	Detail Steel	10 days	Fri 11/12/10	Thu 11/25/10				2	a)				
17	Install Decking	16 days	Fri 11/26/10	Fri 12/17/10					t				
18	Structural Steel: 7-1 East (1 to 3)	40 days	Fri 11/12/10	Thu 1/6/11				-					
19	Set Structural Steel	10 days	Fri 11/12/10	Thu 11/25/10				B	a)				
20	Detail Steel	10 days	Fri 11/26/10	Thu 12/9/10					č				
21	Install Decking	20 days	Fri 12/10/10	Thu 1/6/11					ż	2			
22	Structural Steel: 11-7 Center (3 to Roof)	38 days	Fri 11/26/10	Tue 1/18/11					-				
23	Set Structural Steel	11 days	Fri 11/26/10	Fri 12/10/10									
24	Detail Steel	10 days	Mon 12/13/10	Fri 12/24/10					1				
25	Install Decking	17 days	Mon 12/27/10	Tue 1/18/11						1 0			
26	Structural Steel: 7-1 East (3 to Roof)	37 days	Mon 12/13/10	Tue 2/1/11					-				
27	Set Structural Steel	12 days	Mon 12/13/10	Tue 12/28/10					5				
28	Detail Steel	9 days	Wed 12/29/10	Mon 1/10/11						č			
29	Install Decking	16 days	Tue 1/11/11	Tue 2/1/11						2	-		
30	Deck Pours	151 days	Tue 8/31/10	Tue 3/29/11		-							-
31	Pour SOG (West)	9 days	Tue 8/31/10	Fri 9/10/10		60							
32	Pour SOG (Center)	5 days	Mon 9/13/10	Fri 9/17/10		642							
33	Pour SOG (East)	5 days	Fri 10/15/10	Thu 10/21/10			Daniel H						
34	Pour 1st Floor Slab (West)	6 days	Mon 12/20/10	Mon 12/27/10					-				
35	Pour 1st Floor Slab (Center)	8 days	Tue 12/28/10	Thu 1/6/11						6B			
36	Pour 1st Floor Slab (East)	5 days	Fri 1/7/11	Thu 1/13/11						-			
37	Pour 2nd Floor Slab (West)	3 days	Fri 1/14/11	Tue 1/18/11						-			
38	Pour 2nd Floor Slab (Center)	5 days	Wed 1/19/11	Tue 1/25/11									
39	Pour 2nd Floor Slab (East)	5 days	Wed 1/26/11	Tue 2/1/11							Same S		
40	Pour Roof Slab	10 days	Wed 2/2/11	Tue 2/15/11									
41	Pour 5th Floor Slab (Center)	5 days	Wed 2/16/11	Tue 2/22/11									
42	Pour 5th Floor Slab (East)	5 days	Wed 2/23/11	Tue 3/1/11								0-0	
43	Pour 4th Floor Slab (Center)	5 days	Wed 3/2/11	Tue 3/8/11								Canada	
44	Pour 4th Floor Slab (East)	5 days	Wed 3/9/11	Tue 3/15/11								0000	
45	Pour 3rd Floor Slab (Center)	5 days	Wed 3/16/11	Tue 3/22/11									-
46	Pour 3rd Floor Slab (East)	5 days	Wed 3/23/11	Tue 3/29/11									-
47	Soray Fire Proofing All Levels	1 day	Fri 1/14/11	Fri 1/14/11						T			

Existing Schedule



Proposed Schedule

	Goals:
	• Structu
Introduction	• Floor o
Existing Structural System	
Thesis Proposal	• Longer
Structural Depth	Recommenda
	Concre
Slab Design	
Shear Wall Design	• Found
Column Design	
Construction Management Breadth	
Conclusion	

Conclusion

- tural layout impact minimized
- depth was minimized
- er construction time frame
- ation: rete redesign can not be recommended
- dation would need to be checked and resized





Questions / Comments

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(Payette Associates)