
A.E. SENIOR THESIS 2009
Daniel C. Myers
STRUCTURAL OPTION
A.E. Senior Thesis • April 13, 2009
Seismic Design: A Lateral Systems Investigation and Redesign
The University Hospitals Case Medical Center Cancer Hospital
Cleveland, Ohio
RESEARCH
INVESTIGATION
DESIGN


VISION 2010
Rainbow NICU
UHCMC Campus
UH Emergency Medicine
University Hospitals Vision 2010
• Cancer Hospital
• Neonatal Intensive Care Unit
• Center for Emergency Medicine
• Ahuja Medical Center
• Cardiovascular Facilities
Twinsburg
Ahuja MC
RESEARCH
INVESTIGATION
DESIGN


OVERVIEW
Problem:
• Current Vision 2010 plan provides service to primarily the east coast
Solution:
• Develop a design for west coast service while adhering to Vision 2010 restraints
• Gain an understanding of the seismic design of irregular shaped buildings
RESEARCH
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DESIGN


OVERVIEW
San Diego, CA
Seismic Controlled Category D
Cleveland, OH
Wind Controlled Category A
Goals:
• Investigate 3 seismic design solutions for the existing design in San Diego, CA
• Strengthening of Existing Structure
• Use of a seismic isolation joint
• Addition of concrete shear wall core
• Select and design the optimal system
• Adhere to Vision 2010 constraints
• Limit redesign
• Meet current time schedule
• Low cost increase
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OVERVIEW
Topics Presented
Building Background
Lateral Systems Investigation
Redesign of Existing System
Building Envelope Redesign
Schedule and Cost Analysis
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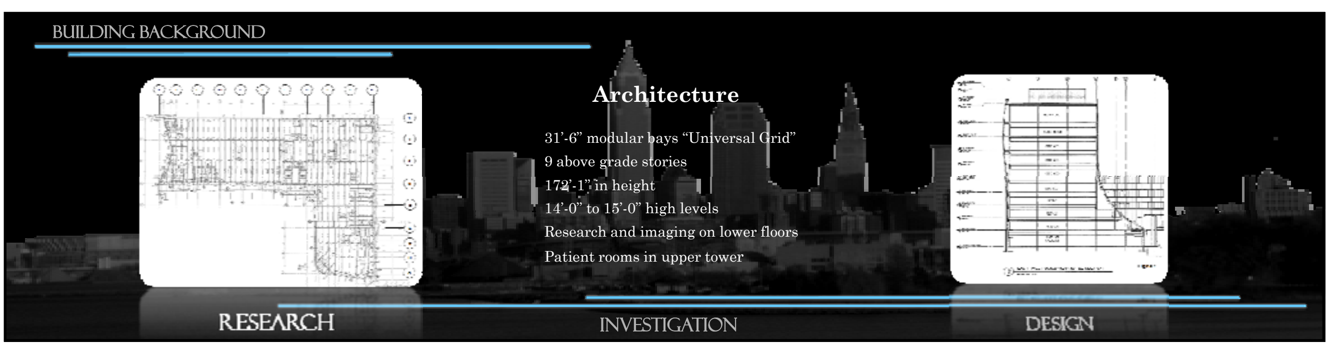
BUILDING BACKGROUND
Architecture
31'-6" modular bays "Universal Grid"
9 above grade stories
172'-1" in height
14'-0" to 15'-0" high levels
Research and imaging on lower floors
Patient rooms in upper tower
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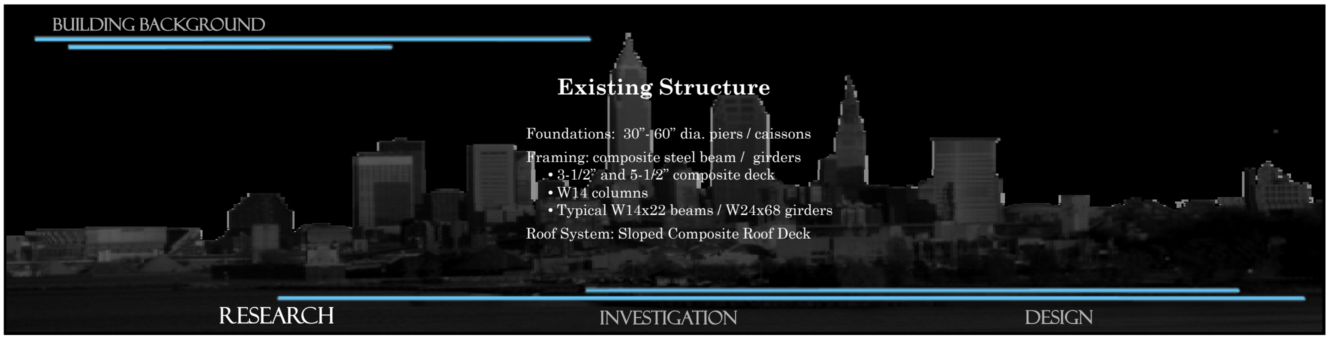
BUILDING BACKGROUND
Existing Structure
Foundations: 30"-60" dia. piers / caissons
Framing: composite steel beam / girders
• 3-1/2" and 5-1/2" composite deck
• W14 columns
• Typical W14x22 beams / W24x68 girders
Roof System: Sloped Composite Roof Deck
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BUILDING BACKGROUND
Existing Lateral System
6 Steel Braced Frames
Concentric and Eccentric Connections
HSS Diagonal Members
Near Elevator Core and Perimeter
Designed for Wind
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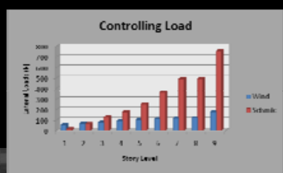
RELOCATION



New Lateral Loading

Wind and Seismic forces found under new parameters

Methods used:
- Main Wind-Force Resisting Systems Method 2
- Equivalent Lateral Force Procedure

Seismic forces exceeded Wind by 3 to 4 times

Wind effects will not be further investigated

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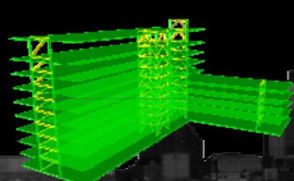
RELOCATION



ETABS Model

Existing lateral system modeled in *ETABS*

Loads manually calculated using ELF procedure

Manual and *ETABS* values compared

ETABS values found to be more conservative

ETABS vs. Manual (%Error)

Story	Strength	Deflection
Roof	17.81%	117.07%
8	24.68%	32.65%
7	24.17%	27.16%
6	24.02%	32.91%
5	24.11%	28.25%
4	24.20%	28.21%
3	24.81%	28.74%
2	25.32%	28.59%
1	25.86%	34.77%

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STRUCTURAL DEPTH

Lateral System Investigation

Strength and Serviceability:

- Period
- Deflection
- Story Shear
- Member Force
- Torsion

Structural Irregularity

Architectural Effect

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STRUCTURAL DEPTH

Strengthening Existing Structure

EXISTING STRUCTURE CRITICAL VALUES					
Level	Story Height (ft)	δ_{max} (in)	Δ_{max} (in)	V_{shear} (k)	Ax
Pent	162.58	0	0	0	0
Roof	137.75	25.81	9.16	-346.10	0.75
8th	117	21.57	6.33	-1843.36	0.76
7th	102	18.64	6.59	-2374.11	0.76
6th	87	15.59	7.69	-2795.55	0.77
5th	72	12.03	6.39	-3119.04	0.79
4th	57	9.07	6.22	-3270.11	1.03
3rd	42	6.19	5.40	-3514.24	1.05
2nd	28	3.69	4.62	-3721.45	1.10
1st	14	1.55	3.35	-3802.25	1.00
Ground	0	0	0	382.93	0

Positive:

- Strong resistance to torsion; Ax_{max} = 1.1
- Distributes forces well around inherent corner
- Fundamental period reasonable

Negative:

- Deflections @ critical points extremely large
- Floor to floor drift exceeds limit by approx. 3x
- Additional size and quantity of frames req'd
- All frames need to be designed as special

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STRUCTURAL DEPTH

Seismic Isolation Joint

SEISMIC ISOLATION JOINT CRITICAL VALUES					
Level	Story Height (ft)	δ_{max} (in)	Δ_{max} (in)	V_{shear} (k)	Ax
Pent	162.58	0	0	0	0
Roof	137.75	24.97	10.34	-312.27	0.69
8th	117	21.01	7.15	-1664.06	0.69
7th	102	18.27	7.41	-2127.06	0.69
6th	87	15.43	8.64	-2485.49	0.69
5th	72	12.12	7.20	-2767.78	0.80
4th	57	9.36	7.96	-2952.61	0.85
3rd	42	6.31	6.92	-3131.64	0.96
2nd	28	3.66	5.43	-3233.11	0.86
1st	14	1.58	4.12	-3261.01	0.80
Ground	0	0	0	154.88	0

Positive:
- Even stronger resistance to torsion; Ax_{max} = 1.0
- 10% reduction in drift and deflection
- No irregularity

Negative:
- Continues to greatly exceed drift limits by 2.5x
- Exhibits similar downfalls compared to existing
- Torsion decrease minimally affected lateral system
- Additional frames required in tower and extension

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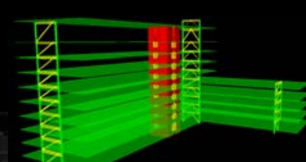
STRUCTURAL DEPTH

Concrete Shear Wall Core

CONCRETE CORE CRITICAL VALUES					
Level	Story Height (ft)	δ_{max} (in)	Δ_{max} (in)	V_{shear} (k)	Ax
Pent	162.58	0	0	-1.44	0
Roof	137.75	11.99	5.34	-350.26	3.00
8th	117	10.21	4.80	-2010.01	3.00
7th	102	8.61	4.89	-2734.33	3.00
6th	87	6.98	4.89	-3195.00	3.00
5th	72	5.35	4.50	-3661.29	3.00
4th	57	3.85	3.60	-3904.52	1.73
3rd	42	2.65	3.03	-4353.75	1.73
2nd	28	1.64	2.70	-4828.75	1.42
1st	14	0.74	2.22	-5058.78	1.70
Ground	0	0	0	1903.13	0

Positive:
- Dramatic decrease in drift, deflection, and period
- Shear walls effectively collect sizeable amount of load
- Loads within reasonable design values
- Works well with existing architecture

Negative:
- Significant torsion exists in building; Ax_{max} = 3.0
- Torsional irregularity type 1b
- Load collection by lateral elements not evenly distributed



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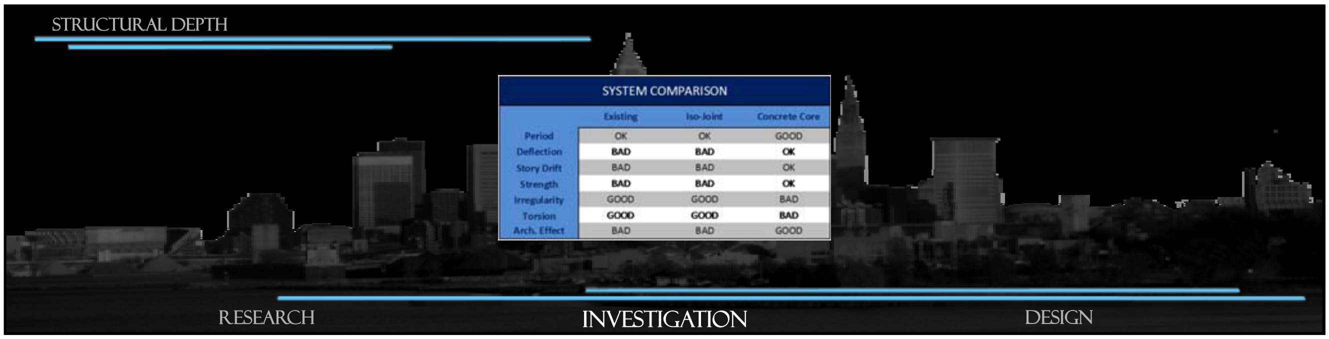

SYSTEM COMPARISON	Existing	Iso-Joint	Concrete Core
Period	OK	OK	GOOD
Deflection	BAD	BAD	OK
Story Drift	BAD	BAD	OK
Strength	BAD	BAD	OK
Irregularity	GOOD	GOOD	BAD
Torsion	GOOD	GOOD	BAD
Arch. Effect	BAD	BAD	GOOD


STRUCTURAL DEPTH
Symmetrical Perimeter
Added Moment Frame
Double Frame
Final Design
Steel Braced Frame Design
Designed in accordance with:
• ASCE 7-05
• AISC Steel Construction Manual, 2005
Initially designed based on deflection
• Critical point 51
• Deflection controlled
Used lower R value of 6 for special concrete shear walls
Accidental torsion factor of 1.0 assumed for design
CRITICAL DISPLACEMENT POINTS
Pt. 51
Pt. 61
Pt. 60
Pt. 53
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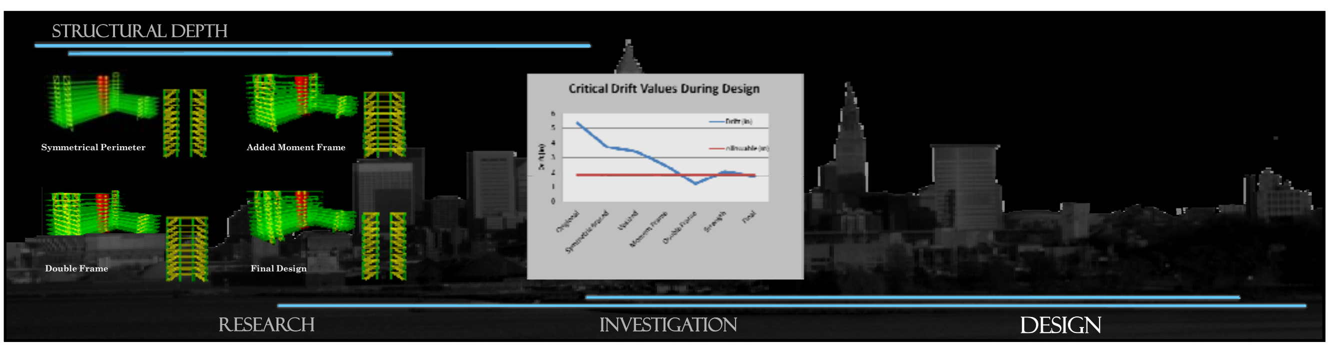
STRUCTURAL DEPTH
Symmetrical Perimeter
Added Moment Frame
Double Frame
Final Design
Critical Drift Values During Design
Original
Moment Frame
Double Frame
Final
RESEARCH
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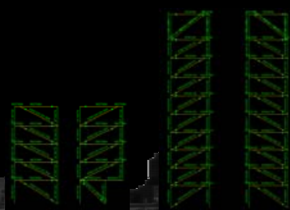
DESIGN

STRUCTURAL DEPTH

Final Braced Frame Design



Frames @ 7 Frames @ B and C

Frames @ B and C:
- Typical HSS16x16x1/2 braces on lower levels
- Typical HSS14x14x1/2 braces on upper levels
- W14 members preserved w/ W30 and W33 beams

Frames @ 7
- Typical HSS12x12x3/8 braces
- W14 member preserved w/ W27 beams

FINAL DESIGN CRITICAL VALUES				
Level	Story Height (ft)	Δ_{max} (in)	V_{shear} (k)	Ax
Pent	162.58	0	0	0
Roof	137.75	1.93	-354.55	0.97
8th	117	1.53	-2003.17	0.95
7th	102	1.63	-2638.32	0.96
6th	87	1.67	-3188.89	0.96
5th	72	1.67	-3655.56	0.97
4th	57	1.60	-3902.02	0.96
3rd	42	1.30	-4362.38	0.96
2nd	28	1.10	-4826.54	0.99
1st	14	0.73	-5053.11	0.91
Ground	0	0	1669.13	0

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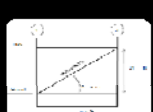
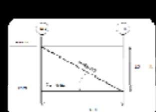
STRUCTURAL DEPTH

Strength Check



North/South Direction



East/West Direction

Strength:
- Redundancy Factor of 1.3 applied
- ASCE 7-05 Load Combination 5 controlled design

$$D+1.0E+L+.2S$$

Slenderness:

$$KL/r \leq 200$$

Width-to-Thickness:

$$b/t \leq 1.4\sqrt{E/Fy}$$

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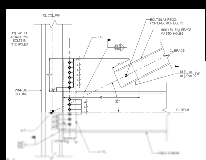
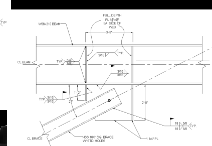
STRUCTURAL DEPTH

Critical Steel Connection Design

Master's Requirement



Ordinary Concentric Connection



Eccentric Connection

- Critical connections selected @ Frame C on Ground Floor
- Connection designed in accordance with:
  - ASCE 7-05
  - AISC Seismic Design Manual
- Ordinary Concentric Connection
- Special Eccentric Connection

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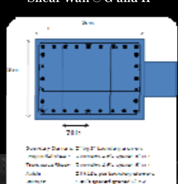
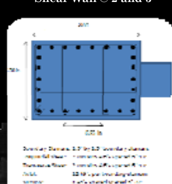
STRUCTURAL DEPTH

Concrete Shear Wall Design

Shear Wall @ G and H



Shear Wall @ 2 and 3



- Designed in accordance with:
  - ASCE 7-05
  - ACI 318-05
- Critical section selected at @ Shear Wall G and H
- Boundary Elements used to accommodate special seismic design provisions:
  - 2-1/2'x2-1/2' boundary element @ Shear Wall G and H
  - 3'x3' boundary element @ Shear Wall 2 and 3

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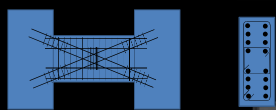
STRUCTURAL DEPTH



COUPLING BEAM DESIGN			
Level	Member	Sturrups	Diagonal Rebar
Roof	C130X18	9 #4 stirrups @ 4"oc	4 #5
8th	C94X18	7 #4 stirrups @ 4"oc	6 #9
7th	C94X18	7 #4 stirrups @ 4"oc	8 #11
6th	C94X18	7 #4 stirrups @ 4"oc	8 #14
5th	C94X18	7 #4 stirrups @ 4"oc	8 #14
4th	C94X18	7 #4 stirrups @ 4"oc	8 #14
3rd	C82X18	6 #4 stirrups @ 4"oc	8 #14
2nd	C82X18	6 #4 stirrups @ 4"oc	8 #11
1st	C82X18	6 #4 stirrups @ 4"oc	6 #9
Ground	C130X18	9 #4 stirrups @ 4"oc	6 #5

Coupling Beam Design

Located on all levels @ Shear Wall 2 and 3

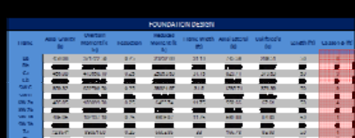
Sizes vary with story height between 82", 94", and 130"

Width of coupling beam 18" in accordance with walls

Diagonal reinforcement has been used on all coupling beams

RESEARCH INVESTIGATION DESIGN

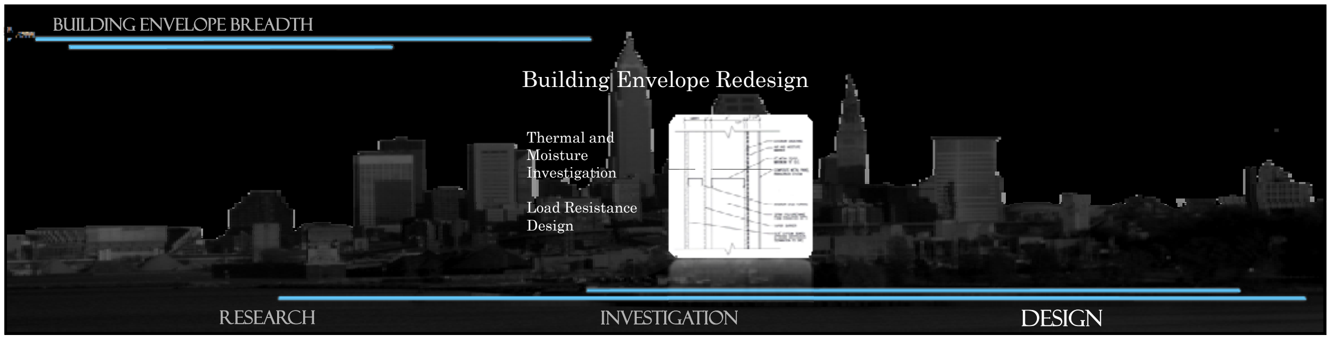
STRUCTURAL DEPTH



Foundations

- Gravity loads determined through column takedowns
- Maximum downward and uplift force calculated
- Uplift capacity assumed to be provided only by friction
- 50' caissons needed to gain req'd friction strength
- Caisson diameters range from 4' to 9'

RESEARCH INVESTIGATION DESIGN


BUILDING ENVELOPE BREADTH
Building Envelope Redesign
Thermal and Moisture Investigation
Load Resistance Design
RESEARCH
INVESTIGATION
DESIGN


BUILDING ENVELOPE BREADTH
Thermal and Moisture Analysis
Barrier Wall
Cavity Wall
EIFS System
Existing Wall System
• Works well with current architecture
• Slightly conservative
• Relies heavily on maintenance
Cavity Wall
• Adequate thermal resistance
• Most effective moisture penetration resistance
• Varies most from original architecture
EIFS
• Greatly reduces wall thickness
• More efficient thermal resistance value
• Not effective when penetrated
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BUILDING ENVELOPE BREADTH
5.25 ft
7.6 ft
0.375 in
0.375 in
Load Resistance Design
Lateral Force Resistance
• 2 plies of 1/4" Laminated Glass Units
• Fully tempered
Seismic Drift Resistance
• 3/8" clearance on all sides
Blast Resistance Capacity (increase to 5/16")
• 100lb explosive at 50'
• 500lb explosive at 100'
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SCHEDULE AND COST ANALYSIS BREADTH
Ground / Sub Floor
4 3 2 1
1st Level – 3rd Level
5 4 3 2 1
4th Level - Roof
3 2 1
Existing Schedule
July 2008 – December 2010
179 day estimated structure construction time
Use of single crane
Sequenced construction using 3 to 5 zones
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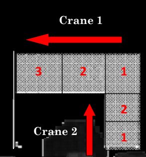
SCHEDULE AND COST ANALYSIS BREADTH

Revised Schedule



New schedule must accommodate 50 additional days for shear walls

Proposed use of 2nd crane for 17 days

Structural construction time decreased to 154 days

Adds additional time to meet Vision 2010 deadline

RESEARCH INVESTIGATION DESIGN

SCHEDULE AND COST ANALYSIS BREADTH

Cost Analysis

EXISTING LATERAL SYSTEM COST

Level	Steel Tonage	Steel Cost ($/ton)	CY of Concrete	Concrete Cost ($/CY)	Lateral Sys. Cost
Frame @Line B	79.44	$4,275.00	N/A	$139.50	$339,600.36
Frame @Line G	53.26	$4,275.00	N/A	$139.50	$227,698.17
Frame @Line K	101.65	$4,275.00	N/A	$139.50	$434,533.52
Frame @Line 2	53.68	$4,275.00	N/A	$139.50	$229,466.75
Frame @Line 3	52.79	$4,275.00	N/A	$139.50	$225,684.12
Frame @Line 7	22.57	$4,275.00	N/A	$139.50	$96,500.37
				Total:	$1,553,483.28

NEW LATERAL SYSTEM COST

Level	Steel Tonage	Steel Cost ($/ton)	CY of Concrete	Concrete Cost ($/CY)	Lateral Sys. Cost
Frames @Line B	176.41	$4,275.00	N/A	$139.50	$754,146.90
Frames @LineC	176.48	$4,275.00	N/A	$139.50	$754,432.26
Frames @Line 7	35.19	$4,275.00	N/A	$139.50	$150,436.69
SW G and H	98.18	$2,400.00	573.13	$139.50	$315,586.23
SW 2 and 3	129.33	$2,400.00	360.86	$139.50	$360,731.48
				Total:	$2,335,333.56

Estimated cost of existing lateral system:

$1,553,483.00

Estimated cost of new lateral system:

$2,335,333.00

Increase in cost compared to $1 billion Vision 2010 Budget

RESEARCH INVESTIGATION DESIGN


A.E. SENIOR THESIS 2009
Conclusion
•Seismic design solutions investigated
•Efficient new design for San Diego, CA developed
•Construction time decreased
•Low cost increase
•Vision 2010 constraints met
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A.E. SENIOR THESIS 2009
Acknowledgements
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Dr. Memari for being a great personal thesis mentor.
I would like to thank Cannon Design for supplying all plans and building information requested in a timely manner.
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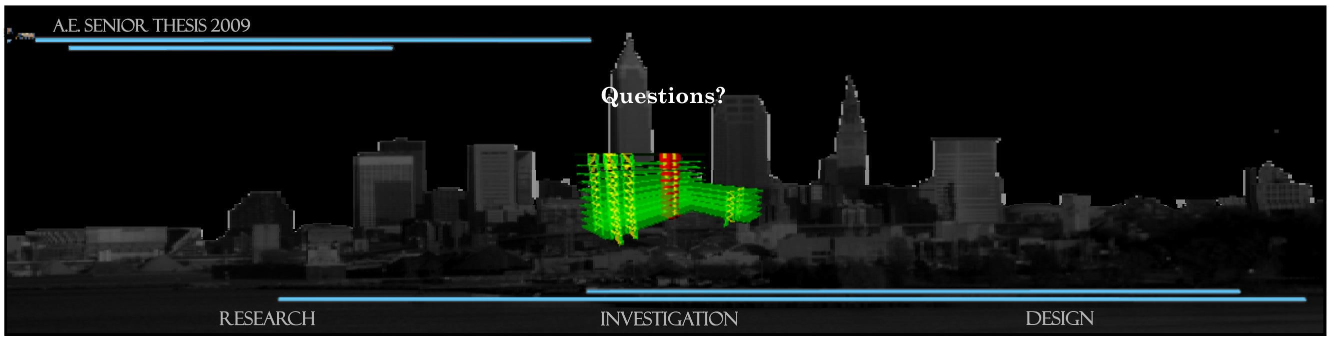
A.E. SENIOR THESIS 2009
Questions?
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