PricewaterhouseCoopers Building

Oslo, Norway

James Wilson

Structural Option

Senior Thesis Presentation 2009

The Pennsylvania State University

Presentation Outline

- Introduction
- Existing Structural System
- Proposal
- Redesign of Gravity System
- Redesign of Lateral System
- Breadth Study
- Conclusion

Location

Bjørvika B10 A
Oslo, Norway

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Building Data

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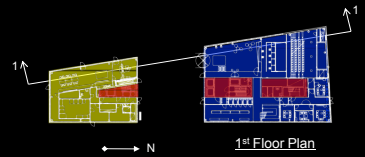
Spaces

Section 1-1



1st Floor Plan

Display Room / Shops
154 Person Auditorium / Lobby
Office / Conference Rooms
Cafeteria / Outdoor Patio
Vert. Transportation / Tech. Zone

9th Floor Plan

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Thesis Goals

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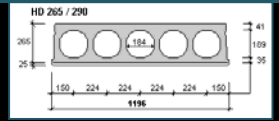
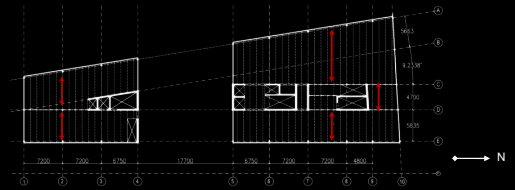


Precast Hollow Core Concrete Plank

4' wide
11" deep
+ 2" Topping



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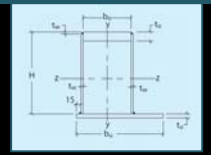
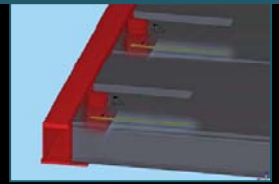
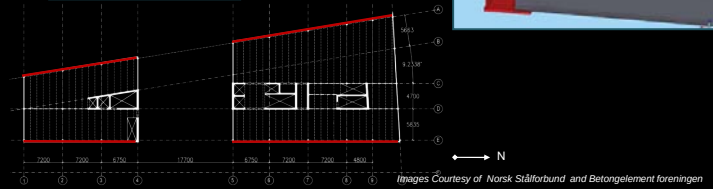
Floor System







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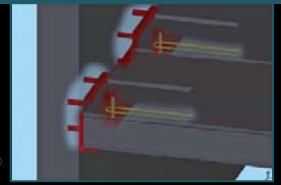

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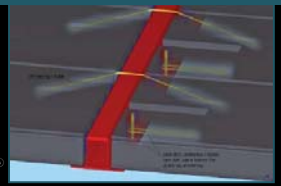

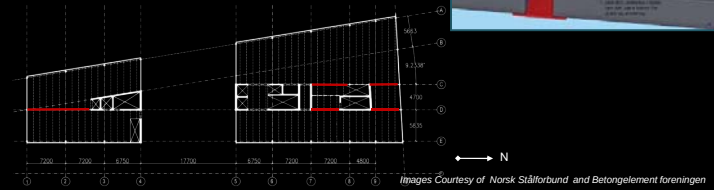

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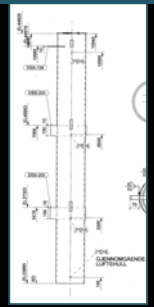
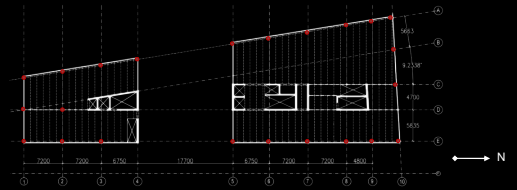
Columns





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LFRS - Cast in Place Concrete Shear Walls

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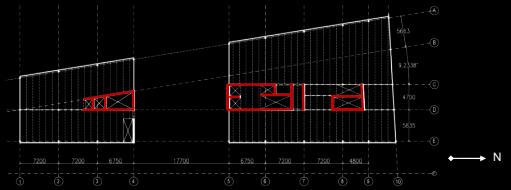

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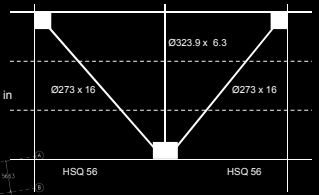
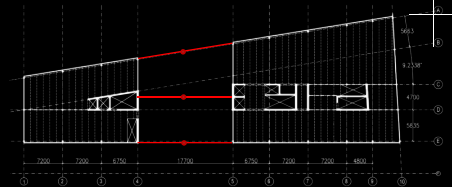
Transfer Truss

273 x 16mm = 10.7 x .63 in
323.9 x 6.3 mm = 12.75 x .63.25 in





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Materials

Steel:

Item	Euronorm	ASTM	Fy (ksi)	Fu (ksi)	Ea (ksi)	Va	Density (lb/ft^3)
Columns	S355	A572Gr50	51	74	30 500	.3	50
Beams	S355	A572Gr50	51	74	30 500	.3	50
Reinforcing	B500C	-	-	72	30 500	-	-

Concrete:

Item	Norwegian Standard	Eurocode CEN	f_{ck} (ksi)	f_{ctm} (ksi)	E_{cm} (ksi)
Cast in place	B35	C35/45	5	0.46	4 850
Prefabricated	B45	C45/55	6.5	0.55	5 222
Columns	B45	C45/55	6.5	0.55	5 222

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Redesign

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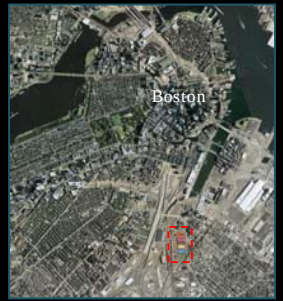
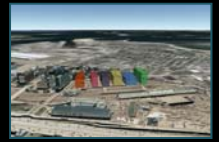
Relocation – Dorchester Ave. , Boston, MA





Arial images courtesy of Google Earth

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Framing Plan

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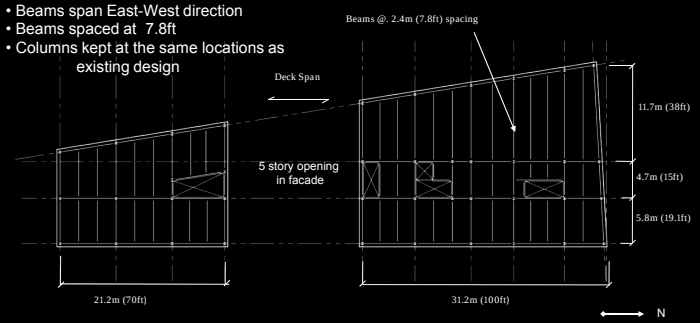

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Deck Design

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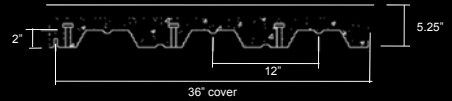
Live Load: 80 psf
SIMP Dead Load: 15psf
Span: 7.8ft

Results using United Steel Deck Manual:
20 gage 2" LOK– FLOOR composite deck
3.25" thk. Lightweight concrete slab
Provides 2hr fire rating without the need for fireproofing
WWF: 6 x 6 – W2.0 x2.0 reinforcing



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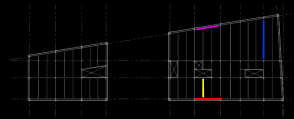
Beam / Girder Design

Composite or Non-composite?

Key	Member	Span (ft)	Composite			Non Composite		Most Economical by Equiv. Wt.
			Least Wt. Mem.	# Studs	Equivalent Wt.	Least Wt. Mem.	Wt	
	Typical Int. Beam	19.14	W12x14	8	**348**	W12x19	**364**	Composite
	Typical Ext. Girder	23.6	W14x22	12	**639**	W14x30	**708**	Composite
	Long span beam	38.5	W14x53	23	**2271**	W14x68	**2618**	Composite
	Long Span Ext. Girder	23.9	W14x30	22	**937**	W14x43	**1028**	Composite



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Beam / Girder Design Criteria

Strength – ASCE 7-05 sec2.3 LRFD load combinations:

1. 1.4 Dead
2. 1.2 Dead + 1.6Live + 0.5 Roof Live
3. 1.2 Dead + 1.6 Roof Live + 0.5 Live

Serviceability - Deflection:

Composite:

Construction Dead Load…….. l/360
Post Composite Live Load…….. l/360
Post Composite Superimposed .. l/240
Net Total Load…….. l/240

Economy – Camber

Do not camber: Beams less than 25ft
Beams that require less than 3/4" of camber
Beams in braced frames

No shoring

Member Depth limited to 14"

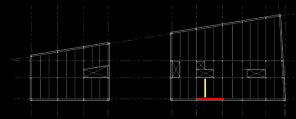
Image Courtesy of Oslo S Utvikling AS

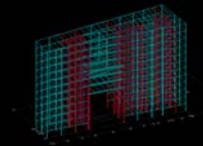
Beam / Girder Design

Optimal members were determined by RAM and checked with hand calculations

Example– Typical Beam and Girder

	Member	L (ft)	Mu	I Req Deflection (in⁴)			Least Wt. Member	I_{PC} (in⁴)	I_{LB} (in⁴)
				Δ_{LL}	Δ_T	Δ_{PC}			
Hand Calc	Beam	19.14	70.5	103	116.4	67.5	W12x14	88.6	101
	Girder	23.62	126.3	203	268.8	108.36	W14x22	199	424
RAM	Beam	19.14	72.4	-	-	-	W12x14	88.6	101
	Girder	23.62	154	-	-	-	W14x22	199	424





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Final Framing Plan

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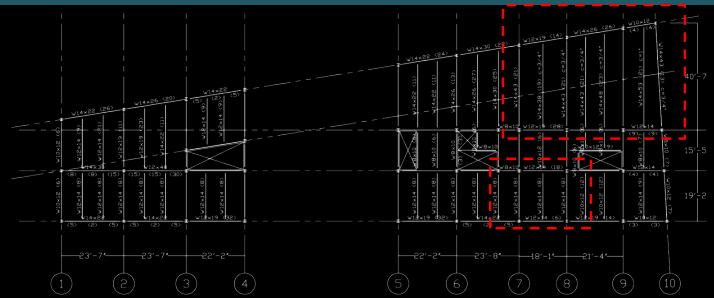
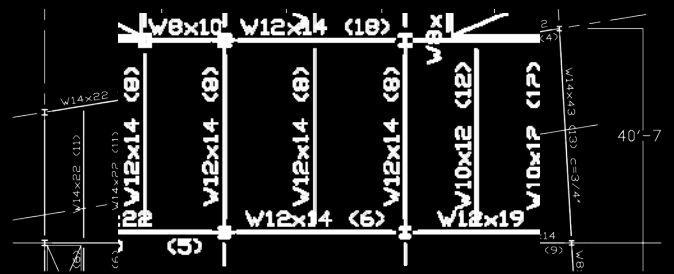


3rd Floor Framing Plan

**Members which are part of the lateral system are not labeled

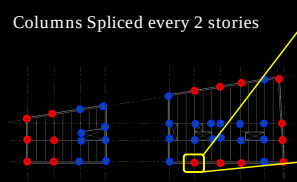


Column Design

Perimeter columns resisting gravity loads only:
Level 1-12: W10

Columns resisting gravity + lateral load:
Level 1-12: W14

Columns Spliced every 2 stories



Column E-6 Design Summary

	Floor	Pu (kips)	KL (ft)	Least Wt. Mem.	ΦPn (kips)	Pu < ΦPn
Hand Calc.	1	157	12	W10x33	292	OK
	5	293	12	W10x39	351	OK
	9	424	12	W10x49	513	OK
RAM	1	155	12	W10x33	292	OK
	5	287	12	W10x39	351	OK
	9	429	12	W10x49	513	OK

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Brace Location Study

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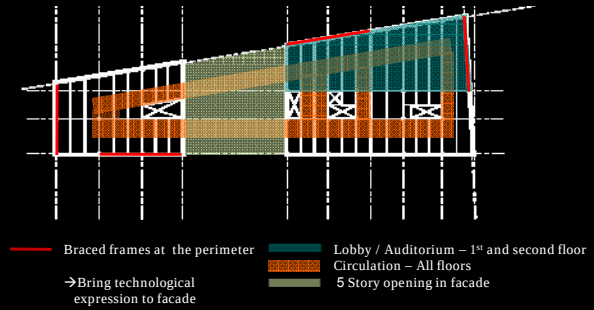

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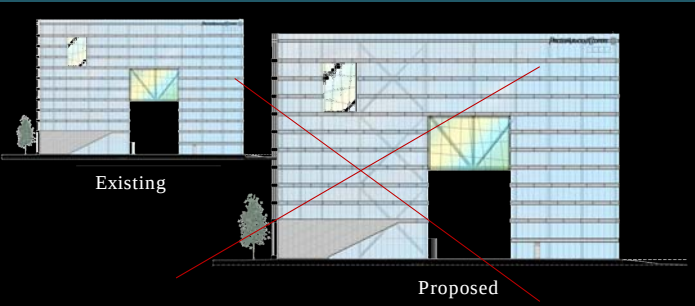
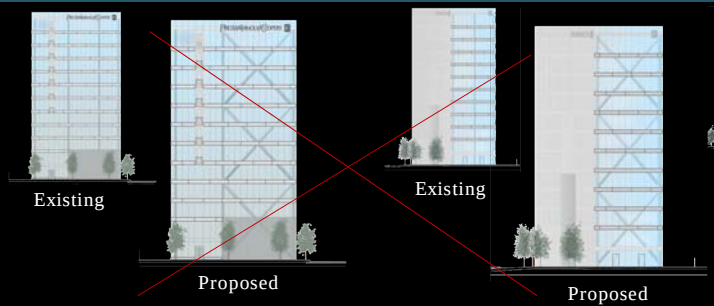
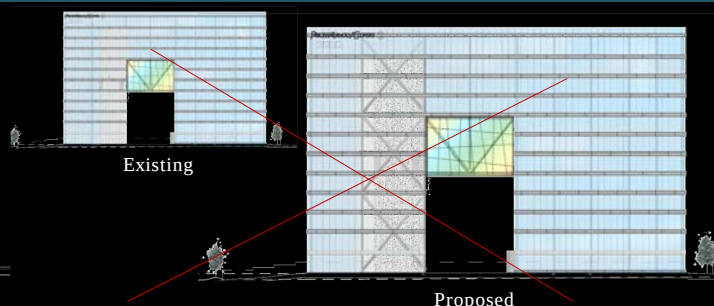
Architectural Study

Braced Frames at Perimeter







James Wilson

Structural Option

4/14/09

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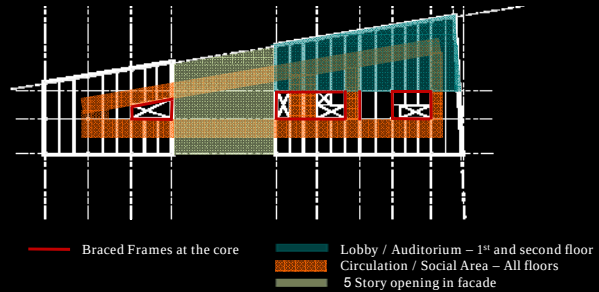

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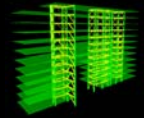
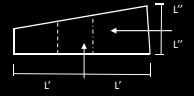
ETABS Model - Preliminary Design

Model of lateral system only was constructed in ETABS to determine optimal framing layout

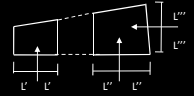
Wind load application:

- ASCE 7 – 05 – Analytical Procedure
- Wind loads applied at the center of pressure of diaphragm at each level





Levels 5-12



Level s 1-4

Image Courtesy of Oslo S Utvikling AS

ETABS Model - Preliminary Design

Seismic load application:

ASCE 7 – 05: Equivalent Lateral Force Procedure

Seismic loads applied at the center of mass at each level

= Center of Mass

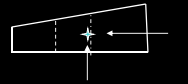


Image Courtesy of Oslo S Utvikling AS

Preliminary Design Results

Very large axial forces were induced in the columns towards the base of the structure due to the narrow shape of the core

Image Courtesy of Oslo S Utvikling AS

Outriggers

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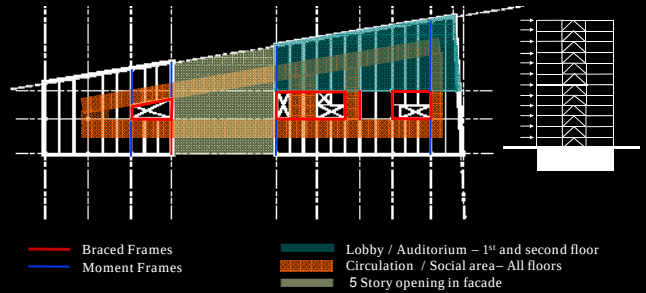

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RAM

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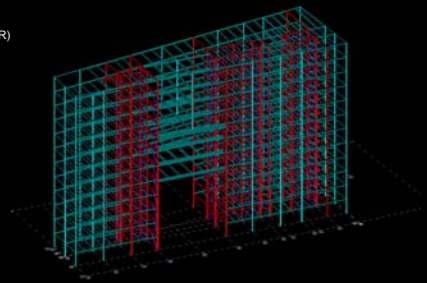
Members checked under combined loading in an integrated RAM model

1. 1.4(D + F)
2. 1.2(D + F + T) + 1.6(L + H) + 0.5(Lr or S or R)
3. 1.2D + 1.6(Lr or S or R) + (L or 0.8W)
4. **1.2D + 1.6W + L + 0.5(Lr or S or R)**
5. 1.2D + 1.0E + L + 0.2S
6. 0.9D + 1.6W + 1.6H
7. 0.9D + 1.0E + 1.6H



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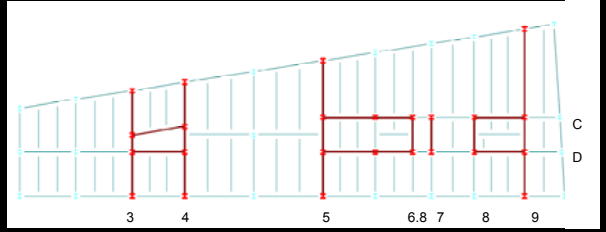
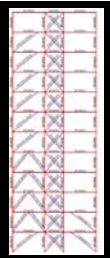


Elevation 3



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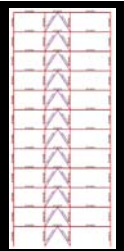
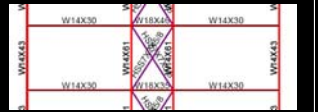
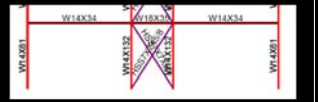


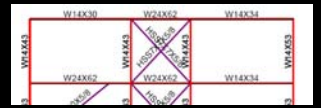
Elevation 5

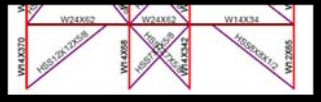
Elevation 6.8





Elevation 3





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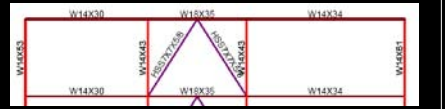

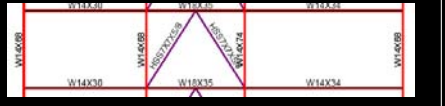

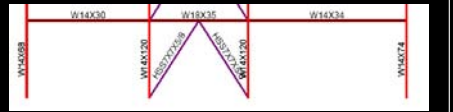

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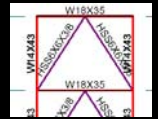
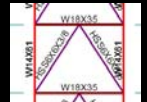
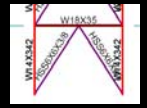
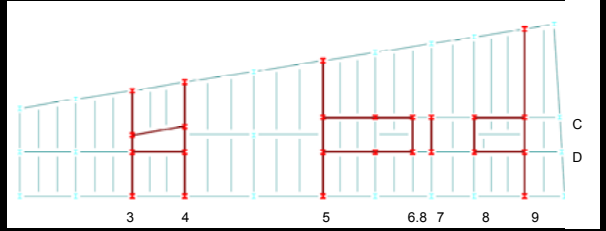




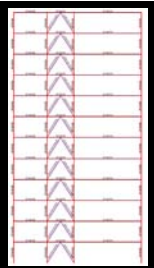


Elevation 6.8

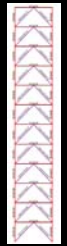


Elevation 7

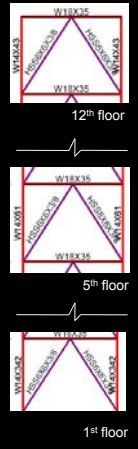
Elevation 8



Elevation 9



Elevation A



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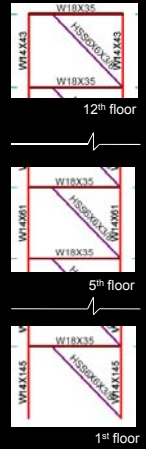

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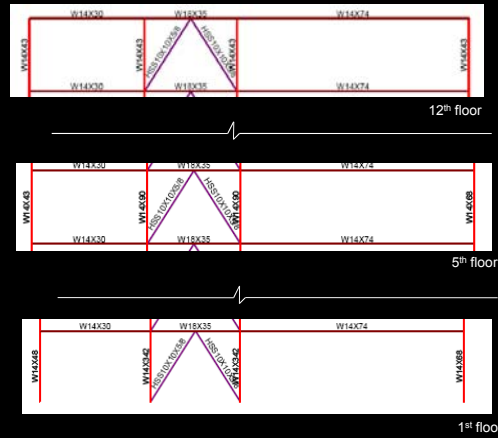
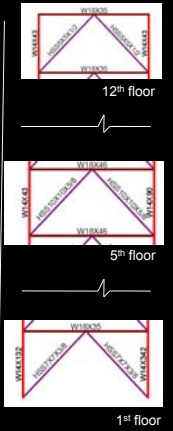
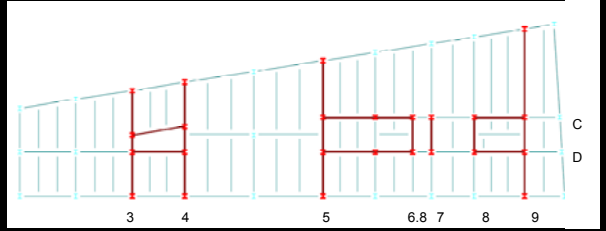


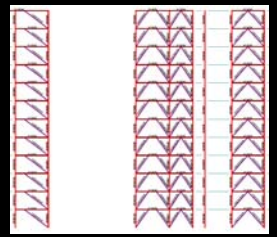
Elevation 9



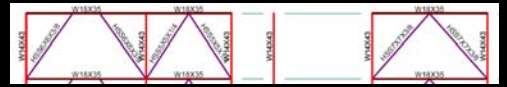
Elevation A



Elevation C



Elevation D

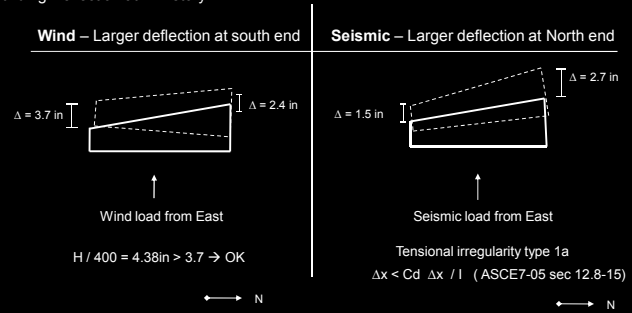


Elevation C

Elevation D

Drift and Torsion

Building Deflection at 12th story:



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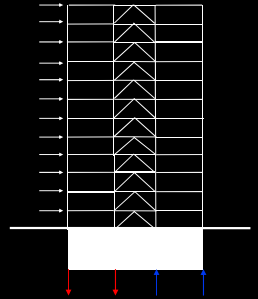
Foundations

- Introduction
- Existing Structural System
- Proposal
- Redesign of Gravity System
- **Redesign of Lateral System**
- Breadth Study
- Conclusion



Concrete substructure acts as a base to distribute loads to pile foundations

Outriggers help distribute loads to the perimeter

Image Courtesy of Oslo S Utvikling AS

Architecture

- Introduction
- Existing Structural System
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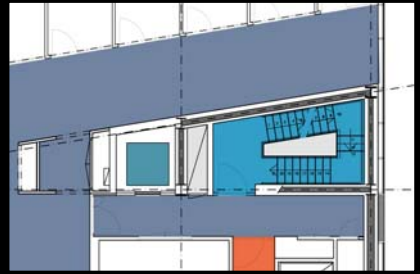
- Elevator relocated
- Duct shaft relocated
- Wall increase from 11.8" to 15"
- Elongated stairwell



Proposed Design

Existing Design

Presentation Outline

- Introduction
- Existing Structural System
- Proposal
- Redesign of Gravity System
- Redesign of Lateral System
- Breadth Study
- Conclusion

Cost comparison

Composite Concrete Deck vs. Precast Concrete Plank

Composite Concrete Deck on Composite Steel Frame					
Quantity	Description	Extended Cost ($)			
		Material	Labor	Equipment	Total
150000 S.F.	Metal Decking	279,000	69,000	6,000	354,000
660 Ton	Structural Steel	1,518,000	250,800	87,120	1,855,920
1500 C.S.F	WWF 6 x 6	23,475	33,000	-	56,475
1960 C.Y.	L.W. Concrete	286,160	-	-	286,160
14871 Ea.	Studs - 3/4"	8,030	11,153	5,651	24,835
150000 S.F.	Concrete Finish	-	73,500	3,000	76,500
				Total =	$ 2,653,889.57

Precast Concrete Plank on Steel Frame					
Quantity	Description	Extended Cost ($)			
		Material	Labor	Equipment	Total
430 Ton	Structural Steel	989,000	163,400	56,760	1,209,160
150000 S.F.	Precast Plank, 10" thick	1,147,500	126,000	78,000	1,351,500
923 C.Y.	2" Concrete Topping	97,838	-	-	97,838
150000 S.F.	Concrete Finish	-	52,500	6,000	58,500
2758 Ea.	Shear Stud - 3/4"	1,489	2,069	1,048	4,606
				Total =	$ 2,721,603.86

Image Courtesy of Oslo S Utvikling AS

Presentation Outline

- Introduction
- Existing Structural System
- Proposal
- Redesign of Gravity System
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- **Breadth Study**
- Conclusion

Schedule comparison

Construction schedule for composite concrete deck and precast concrete plank created in Microsoft Project

Results for Construction of structure :

+ Composite steel deck = 52 days
+ Precast Concrete Plank = 40 days

23% schedule reduction with use of precast plank

Image Courtesy of Oslo S Utvikling AS

Presentation Outline

- Introduction
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Conclusions – Gravity System

- Composite concrete deck on composite steel beams and girders is the most viable floor system for the PwC building if located in Boston
- However, precast concrete plank has potential to be more economical due to cost saving incurred by reduction of construction schedule

Image Courtesy of Oslo S Utvikling AS

Presentation Outline

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Conclusions – Lateral System

Image Courtesy of Oslo S Utvikling AS

Presentation Outline

- Introduction
- Existing Structural System
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- Redesign of Gravity System
- Redesign of Lateral System
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Acknowledgements

I would like to thank the following for their generous support and assistance on this senior thesis:

+ Prof. M. Kevin Parfitt - Thesis Consultant

+Pareto Investments - for granting me permission to use the PwC-building as the subject of this year long project.

+All the Professors at The Pennsylvania State University - for their assistance over the past five years.

+ Friends and family - for their patients and support

Image Courtesy of Oslo S Utvikling AS

Questions?

Image Courtesy of Oslo S Utvikling AS

	12.3-1 Horizontal Structural Irregularities	
	Irregularity	**Must Comply with Reference Section:**
1a	**Torsional Irregularity** Δ1 (in.) = 1.53 Δ2 (in.) = 2.67 → 1.2((Δ1 + Δ2)/2) = 2.52 < Δ2	12.7.3 16.2.2
3	**Diaphragm Discontinuity Irregularity** → Slit diaphragm at the bottom four stories	*12.7.3* *16.2.2*
5	**Nonparallel Systems-Irregularity** → Vertical lateral force resisting elements are not parallel or symmetric about major orthogonal axes.	*12.7.3* *16.2.2*

Outriggers

- Introduction
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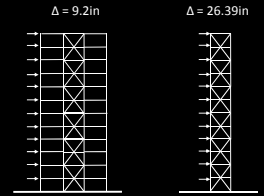
Members
Braces = HSS10x10x.5
Beams = W18x86
Columns = W14x132

→ 1/3 of deflection



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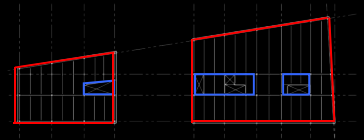
Next Step

- Introduction
- Existing Structural System
- Proposal
- Redesign of Gravity System
- **Redesign of Lateral System**
- Breadth Study
- Conclusion

Moment Frames at the perimeter

Braced frames
Moment frames

Reduce large axial forces at the core



Special Steel Plate Shear Walls

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