# 100 Eleventh Avenue New York, New York


**Tyler E. Graybill | Structural Option**
**AE Senior Thesis Presentation | April 12, 2010**
**Faculty Consultant: Professor Thomas E. Boothby**

## Introduction to 100 Eleventh Avenue

100 Eleventh Avenue
New York, New York



### General Information

- 22-story residential building
- Location……………………….Manhattan's West Chelsea District
- Size……………………………148,000 sf
- Project Cost……………………Unreleased

- The Players
  - Design Architect……………Jean Nouvel
  - Executive Architect…………Beyer Blinder Belle
  - Structural Consultant………DeSimone Consulting Engineers

## Presentation Outline


- Introduction to 100 Eleventh Avenue
- Proposal
  - Problem Statement
  - Proposed Solutions
- Structural Depth I: PT Perimeter Slab Design
  - Understanding Existing Design
  - Alternate System Design Results
- Structural Depth II: Transfer System Design
  - Understanding Existing Design
  - Alternate System Design Results
- Construction Management Breadth
  - PT Perimeter Slab
  - Alternate Transfer System
- Conclusions
- Acknowledgements
- Questions & Comments

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## Architectural Design Concept

- Panelized curtain wall system
  - 1650 windows uniquely sized and oriented
  - Bottom six levels enclosed by a second facade
- Building as a "vision machine"
- Curved facade meant to contour the corner of 19th street and West Side Highway

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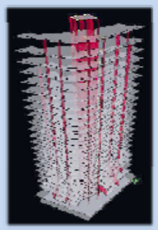
## Introduction to 100 Eleventh Avenue

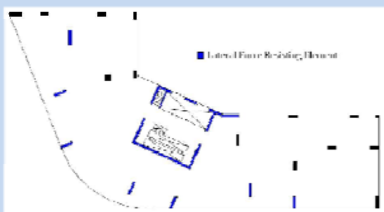
100 Eleventh Avenue
New York, New York

## Presentation Outline

### Existing Structural System

- Gravity System
  - 9” thick two-way concrete flat plate floor system
  - Concrete strength:
    - Slab – 6 ksi
    - Columns/Wall – 7-8 ksi
  - Typical spans of 18’ to 23’
- Lateral System
  - 12” core shear walls, in combination with seven “long” columns





Typical Floor Plan (Levels 7-21)

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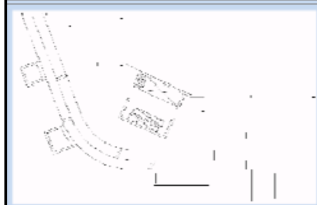
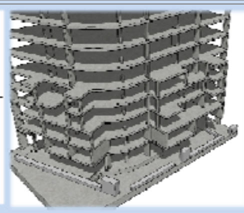


6th Level



## Existing Structural System

- Gravity System
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  - Typical spans of 18’ to 23’
- Lateral System
  - 12” core shear walls, in combination with seven “long” columns
- Intricate balcony system found at Levels 1 through 6
  - Cantilevered columns at Level 2 allow for column free space at street-level atrium

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Problem Statement

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# Presentation Outline

## Existing System – Perimeter Slab Strip

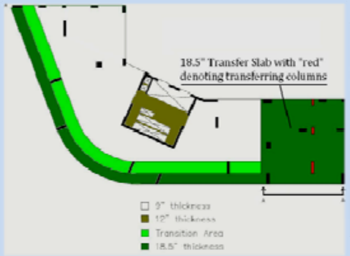
- Spans increase to maximum of 34 feet
- Facade load of 500 lb/ft
- As a result, slab thickens from 9” (typical) to 18.5” along 9.5’-wide portion of perimeter

- Advantages
  - Practical means of meeting strength and deflection requirements

- Disadvantages
  - Negative effect on exposed ceiling appearance
  - Decreased floor-to-ceiling height at perimeter
  - Increased weight and material usage

# Problem Statement






Section A-A

## Existing Systems – 19th Floor Transfer System

- 3 columns transfer to accommodate a building setback of 13'
- Forces transferred via 18.5" transfer slab, reinforced with #10's @ 6" o.c. E.W. (top and bottom of slab)

- Advantages
  - Easily formed

- Disadvantages
  - Very heavily reinforced

## Presentation Outline

# Proposed Solutions



## Thickened Perimeter Slab Strip

• Post-tension 9.5'-wide slab strip

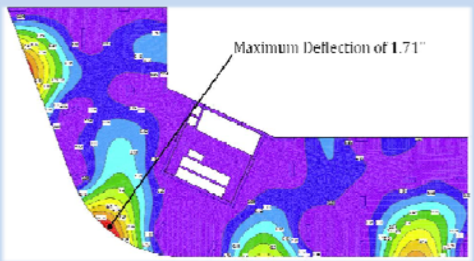
• Goal of Design
- *Reduce* 18.5" perimeter slab strip *to typical thickness of 9"* without significant increase in *cost* or *schedule*

## 19th Floor Transfer Slab

• Design alternate system using transfer beams in lieu of transfer slab

•Goal of Design
- Substantially reduce *cost*, *weight* and *material usage* of system without significant impact on *schedule*

Depth I: PT Perimeter Slab Design | 100 Eleventh Avenue New York, New York | Presentation Outline



Typical Floor without Thickened Perimeter

## Understanding the Existing Design

• 10" thickness required for flexural strength

• Critical Deflection limitations used by structural consultants
- $\Delta \leq 1$" (for portions of slab supporting facade)
- $\Delta \leq L/360$ (immediate)
- $\Delta \leq L/240$ (total)

• Conclusion: deflection limitations drove existing design

Depth I: PT Perimeter Slab Design

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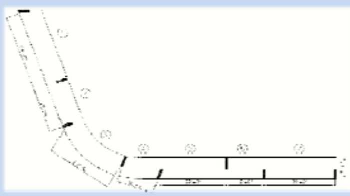
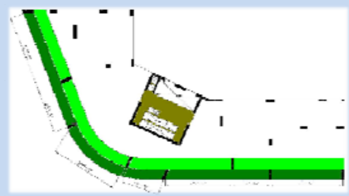
PRESENTATION OUTLINE



## Design Procedure

- Single design for typical floor of Levels 7 through 21
- Levels 2 through 6 require individual attention
- Design and analysis assumed curved perimeter to act as a single equivalent frame



# Depth I: PT Perimeter Slab Design

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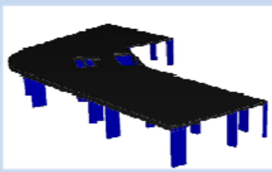

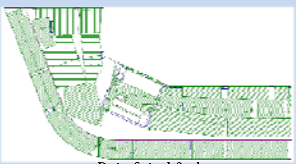

Design Strips defined

### Utilizing RAM Concept

- A finite element method (FEM) analysis program for elevated slabs
  - Linear elastic analysis
- FEM (as opposed to more traditional Equivalent Frame Method) advantageous in modeling highly irregular floors with no regular grid
- Links FEM analysis with concrete code by defining "design strips"

# Depth I: PT Perimeter Slab Design

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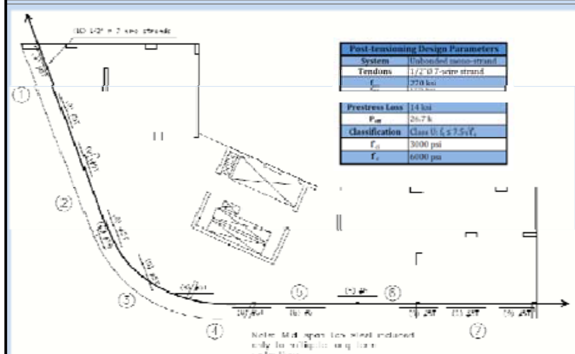
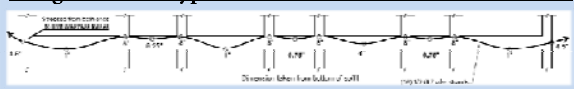


| Post-tensioning Design Parameters | |
|---|---|
| System | Unbonded mono-strand |
| Tendons | 1/2" Ø 7-wire strand |
| $f_{pu}$ | 270 ksi |
| [illegible] | [illegible] |
| Prestress Loss | 14 ksi |
| $P_{eff}$ | 26.7 k |
| Classification | Class U: $f_t \le 7.5\sqrt{f'_c}$ |
| $f'_{ci}$ | 3000 psi |
| $f'_c$ | 6000 psi |

### Design Results – Typical Floor



- (16) ½" Ø 7-wire strands
- P/A = 416 psi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# Depth I: PT Perimeter Slab Design

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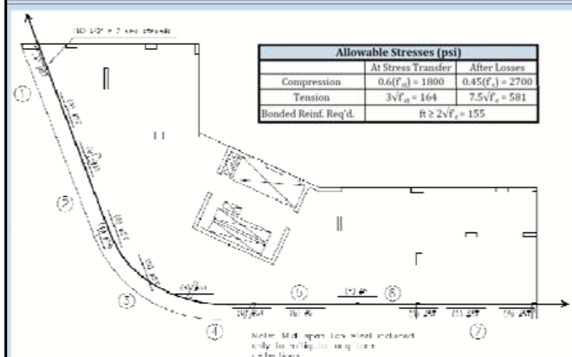

| Allowable Stresses (psi) | | |
|---|---|---|
| | At Stress Transfer | After Losses |
| Compression | $0.6(f'_{ci}) = 1800$ | $0.45(f'_c) = 2700$ |
| Tension | $3\sqrt{f'_{ci}} = 164$ | $7.5\sqrt{f'_c} = 581$ |
| Bonded Reinf. Req'd. | $ft \geq 2\sqrt{f'_c} = 155$ | |

## Design Results – Typical Floor

**Post-tensioning Design Summary**

| Item | Spans | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Span (ft) | 34'-0 | 19'-4" | 29'-6" | 16'-9" | 29'-3" | 16'-6" | 31'-6" |
| # of Tendons | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| P/A (psi) | 416 | 416 | 416 | 416 | 416 | 416 | 416 |
| Balanced Load (k/ft)* | 1.4 | 1.3 | 2.3 | 1.2 | 1.4 | 1.3 | 1.5 |
| % Dead Load Balanced | 58% | 48% | 77% | 51% | 58% | 50% | 65% |
| Midspan Total Deflection | 0.75" | 0.09" | 0.71" | 0.09" | 0.56" | 0.09" | 0.69" |
| Lesser of 1" & L/480 | 0.85" | 0.48" | 0.74" | 0.42" | 0.73" | 0.41" | 0.79" |
| Midspan Initial Service Stresses** | | | | | | | |
| $f_{top}$ (psi) | -148 | -212 | 96 | -175 | -69 | -214 | -116 |
| $f_{bot}$ (psi) | -473 | -235 | -422 | -160 | -292 | -251 | -494 |
| Midspan Service Stresses** | | | | | | | |
| $f_{top}$ (psi) | -580 | -262 | -310 | -142 | -332 | -200 | -620 |
| $f_{bot}$ (psi) | -73 | -72 | 82 | -145 | 79 | -224 | 81 |

| Item | Supports | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Column # | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1 |
| Support Initial Service Stresses** | | | | | | | | |
| $f_{top}$ (psi) | -802 | -203 | -491 | -375 | -348 | -228 | -383 | -651 |
| $f_{bot}$ (psi) | -368 | -119 | 32 | 2 | 22 | -85 | -78 | -229 |
| Support Service Stresses** | | | | | | | | |
| $f_{top}$ (psi) | -281 | 401 | 248 | 250 | 399 | 375 | 329 | -55 |
| $f_{bot}$ (psi) | -621 | -678 | -472 | -695 | -579 | -611 | -650 | -666 |

* Average balanced load = 1.3 k/ft

**Negative values denote compression

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## Depth I: PT Perimeter Slab Design

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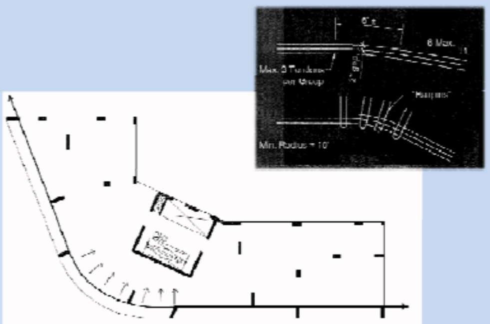
New York, New York

## Presentation Outline



### Additional Considerations

- Tendons to be stressed from both ends
- P/A > 300 psi
- Counteracting curved tendons desire to "straighten out"

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# Depth I: PT Perimeter Slab Design

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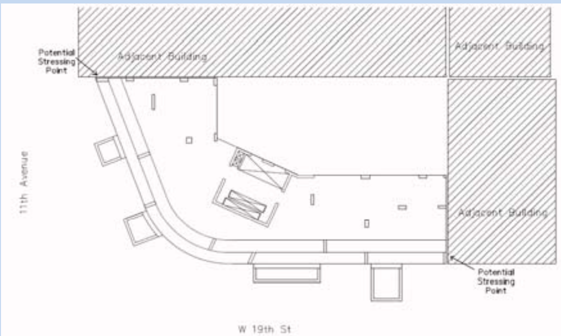

6th Floor Plan

## Design Results – Lower Floors

- Post-tensioned perimeter design complicated by balcony system

- Two key issues:
  (1) Proximity of neighboring buildings

## Presentation Outline




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# Depth I: PT Perimeter Slab Design

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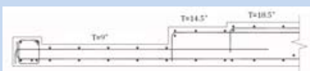
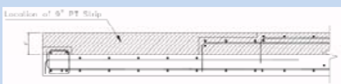


Existing

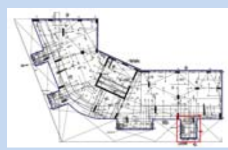


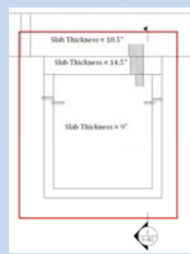
PT 9" slab superimposed on existing

## Design Results – Lower Floors

• Post-tensioned perimeter design complicated by balcony system

• Two key issues:
(1) Proximity of neighboring buildings
(2) Balcony slab drops





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# Depth II: Transfer System Design

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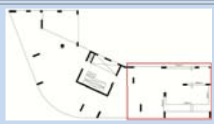
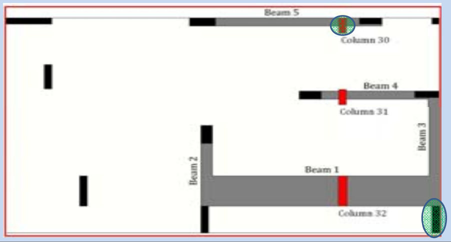


| Column Load Takedown Results | |
|---|---|
| Column | Load (k) |
| 30 | 122 |
| 31 | 165 |
| 32 | 290 |

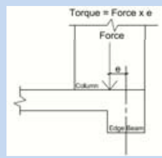



## Design Procedure

- (5) beams necessary to transfer Columns 30, 31 & 32

- Design must satisfy (3) general requirements:
  (1) Strength………………………*Flexure, Shear, Torsion*
  (2) Serviceability…………………*Deflection*
  (3) Architectural…………………*Beam depth limited to 18.5"*

- Consideration of Torsion





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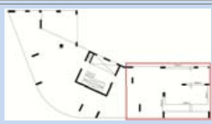

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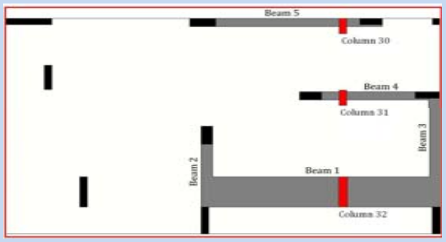


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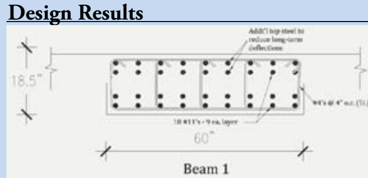


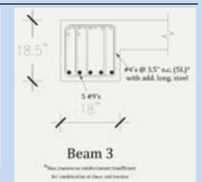


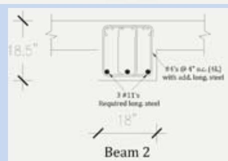


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100 Eleventh Avenue
New York, New York

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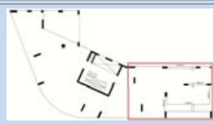

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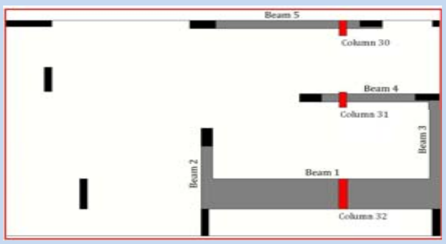


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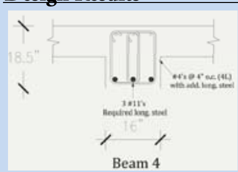


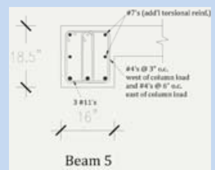



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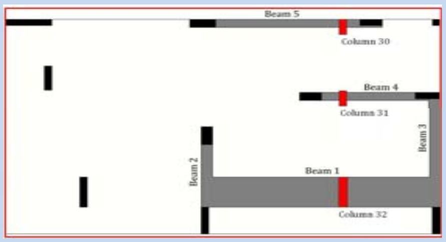


## Design Results

**Beam Design Summary**

| Beam ID | Span | Point Load Location | $M_u$ (ft-k) | $\phi M_n$ (ft-k) | $V_u$ (k) | $\phi V_n$ (k) | $T_u$ (ft-k) | $\phi T_n$ (ft-k) | All design paramteres satisfied? |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 31'-6" | 0.40L | +1651 | 1775* | 251 | 263 | - | - | No |
| 2 | 14'-0" | 0.34L | +221 | 301 | 152 | 175 | - | - | Yes |
| 3 | 20'-9" | 0.23L | +335 | 335* | 224 | ** | 37 | ** | No |
| 4 | 16'-0" | 0.28L | +232 | 297 | 152 | 171 | - | - | Yes |
| 5 | 23'-0" | 0.17L | -234 | 297 | 138 | 138 | 71 | 71 | Yes |

*Uses effective flange width as beam width in flexural strength calculation

** ACI 318-08 Eq. 11-18 not met (i.e. section not large enough for combined shear and torsion)

- **Beam 1: $\Delta_{total}$ = 2.74"**
  **$\Delta_{allowable}$ = L/240 = 1.58"** ✗
- **Beam 3: Section insufficient for combination of *shear* and *torsion* (ACI 318 Eq. 11-19)** ✗

## Presentation Outline

## Breadth Studies



### Breadth Topics

• Construction Management
- Importance → help determine success of alternate designs
  • Material Usage
  • Cost
  • Impact on Schedule

RSMeans Building Construction Cost Data 2009

• Shading
- Study of *exterior* shading strategy
- Not presented

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- Questions & Comments

# Construction Management Breadth

100 Eleventh Avenue
New York, New York

# Presentation Outline

| Perimeter Strip Material Take off | | | |
|---|---|---|---|
| Item | Concrete (cy) | Steel (ton) | Prestressed Steel (ton) |
| Existing Design | 1229 | 47 | 0 |
| Alternate Design | 696 | 16 | 11 |
| Material Savings | +533 | +31 | -11 |
| Total Weight Reduction | 2197 kips | | |
| Structure is 5.2% lighter* | | | |

*Compared to structure weight of 41,852 k calculated in Technical Report 1

| Existing Design | | | | | | |
|---|---|---|---|---|---|---|
| Item | Quantity | Costs ($) | | | | |
| | | Material | Labor | Equipment | Total | Total* |
| Steel Reinforcement (tons) | 46.8 | 77220 | 22932 | - | 100152 | 121680 |
| Cast-in-place Concrete (cy) | 1229 | 171691 | 33798 | 16346 | 221835 | 257353 |
| Total | - | 248911 | 56730 | 16346 | 321907 | 379033 |
| Adjusted for Location | - | $ 264,095 | $ 93,377 | $ 16,346 | $ 373,817 | $ 495,396 |

*Includes O&P

| Post-tensioned Slab Perimeter Design | | | | | | |
|---|---|---|---|---|---|---|
| Item | Quantity | Costs ($) | | | | |
| | | Material | Labor | Equipment | Total | Total* |
| Steel Reinforcement (tons) | 16.4 | 27060 | 8036 | - | 35096 | 42640 |
| Cast-in-place Concrete (cy) | 696 | 97231 | 15660 | 7586 | 120478 | 138434 |
| Prestressing Steel (lb) | 22794 | 14132 | 27353 | 456 | 41941 | 60860 |
| Total | - | 138423 | 51049 | 8042 | 197515 | 241934 |
| Adjusted for Location | - | $ 146,867 | $ 84,026 | $ 8,042 | $ 238,936 | $ 316,208 |

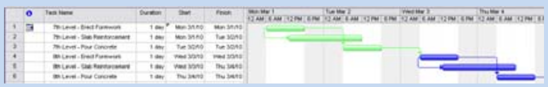
*Includes O&P

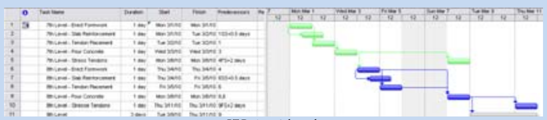
## Perimeter Slab Design – Material Usage / Cost

- Superstructure over 5% lighter
- Over $180,000 in savings
  - $12,000 per floor (roughly 7% of existing floor cost)

- High labor cost of installing tendons in NYC overcome by significant material reduction

Construction Management Breadth | 100 Eleventh Avenue New York, New York | Presentation Outline


Existing Design – 2 day cycle


PT Design – 3 day cycle

## Perimeter Slab Design – Impact on Schedule

- Existing Design → 2-day cycle (typical floors)
- Levels 7 through 21 erected in <u>30 days</u>

- PT Design → 3-day cycle
- Tendon placement
  - requires additional crew
  - (1) additional day per floor
- Levels 7 through 21 erected in <u>48 days</u>

Construction Management Breadth

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PRESENTATION OUTLINE

## Transfer System Design – Material Usage / Cost

- Superstructure 0.3% lighter
- $15,000 in savings

- Increased cost of beam formwork counteracts savings in material

| Transfer System Material Take off | | | |
|---|---|---|---|
| Item | Concrete (cy) | Steel (ton) | Beam Formwork (sfca) |
| Existing Design | 71 | 11 | 0 |
| Alternate Design | 42 | 6.5 | 370 |
| Material Savings | +29 | +4.5 | -370 |
| Total Weight Reduction | 127 kips | | |
| Transfer System is 40% lighter / Structure is 0.3% lighter* | | | |

*Compared to structure weight of 41,852 k calculated in Technical Report 1

| Existing Design | | | | | | |
|---|---|---|---|---|---|---|
| Item | Quantity | Costs ($) | | | | |
| | | Material | Labor | Equipment | Total | Total* |
| Slab Reinforcement (tons) | 11.2 | 18480 | 3369 | - | 21849 | 24102 |
| Cast-in-place Concrete (cy) | 71 | 9919 | 1953 | 944 | 12816 | 14867 |
| Total | - | 28399 | 5322 | 944 | 34665 | 38969 |
| Adjusted for Location | - | $ 30,131 | $ 8,759 | $ 944 | $ 39,835 | $ 50,933 |

*Includes O&P

| Transfer Beam Design | | | | | | |
|---|---|---|---|---|---|---|
| Item | Quantity | Costs ($) | | | | |
| | | Material | Labor | Equipment | Total | Total* |
| Slab Reinforcement (tons) | 1.6 | 2640 | 784 | - | 3424 | 4160 |
| Slab Cast-in-place Concrete (cy) | 27.3 | 3814 | 614 | 298 | 4726 | 5064 |
| Beam Formwork (sfca) | 370 | 408 | 1912 | - | 2320 | 3420 |
| Beam Reinforcing (tons) | 4.9 | 7595 | 3065 | - | 10660 | 13365 |
| Beam Cast-in-place Concrete (cy) | 7.7 | 1076 | 424 | 204 | 1703 | 2047 |
| Total | - | 15533 | 6799 | 502 | 22833 | 28057 |
| Adjusted for Location | - | $ 16,480 | $ 11,191 | $ 502 | $ 28,172 | $ 36,670 |

*Includes O&P

## Presentation Outline

**Construction Output from RS Means Building Construction Cost Data, 2009**

| Material | Unit | Output/Day |
|---|---|---|
| Forms in Place, Beam | sfca | 377 |
| Forms in Place, Flat Plate | sfca | 560 |
| Reinforcing, Beam | ton | 2.7 |
| Reinforcing, Slab, #4-#7 and higher | ton | 2.9 |
| Reinforcing, Slab, #7 and higher | ton | 4.9 |
| Concrete, Slab, 6-10" thick, Crane & Bucket | cy | 110 |
| Placing concrete, Slab, over 10" thick, Crane & Bucket | cy | 90 |
| Placing concrete, Beam, Crane & Bucket | cy | 45 |

### Transfer System Design – Impact on Schedule

- **Using RS Means output data:**

- **Existing Design ➔ 3 days**
  - 2 days to place rebar
  - 1 day for concrete pouring/finishing

- **Alternate Design ➔ 4.5 days**
  - (1) additional day for formwork
  - (0.5) additional days for rebar placement

# Overall Summary & Conclusions



## Perimeter Slab Design

| Alternate System Conclusions | | | | | | |
|---|---|---|---|---|---|---|
| Design | Strength, Service, and Architectural Req'ts Met? | Interior Appearance | Monetary Savings | Material Savings | Weight Reduction | Impact on Schedule |
| PT Perimeter Slab Strip | Yes | Improved | $100,000 | Significant | 2197 k | +10 days |
| Transfer Beam System | No | Worsened | $15,000 | Insignificant | 127 k | +1.5 days |

- **Design Goals Revisited:**

**- Thickness successfully reduced to 9"** ✓

**- Cost of design did not increase** ✓

**- Impact on schedule bearable considering improvements** ✓

**<u>Conclusion</u>:**
**Design is a satisfactory solution that improves the interior space**

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# Overall Summary & Conclusions

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## Transfer System Design

| Alternate System Conclusions | | | | | | |
|---|---|---|---|---|---|---|
| Design | Strength, Service, and Architectural Req'ts Met? | Interior Appearance | Monetary Savings | Material Savings | Weight Reduction | Impact on Schedule |
| PT Perimeter Slab Strip | Yes | Improved | $100,000 | Significant | 2197 k | +10 days |
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- **Design Goals Revisited:**
  - **- Design requirements could not be met** ✗
  - **- Insignificant savings in material, cost and weight** ✗
  - **- Impact on schedule insignificant** ✓

**<u>Conclusion</u>:**
**Even if design requirements could be satisfied, disadvantages far outweigh advantages**

## Presentation Outline

Overall Summary & Conclusions

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PRESENTATION OUTLINE

## Acknowledgements

***DeSimone Consulting Engineers*** DESIMONE

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- Professor Thomas Boothby
- Associate Professor M. Kevin Parfitt
- Associate Professor Robert Holland


- Introduction to 100 Eleventh Avenue
- Proposal
  - Problem Statement
  - Proposed Solutions
- Structural Depth I: PT Perimeter Slab Design
  - Understanding Existing Design
  - Alternate System Design Results
- Structural Depth II: Transfer System Design
  - Understanding Existing Design
  - Alternate System Design Results
- Construction Management Breadth
  - PT Perimeter Slab
  - Alternate Transfer System
- Conclusions
- Acknowledgements
- Questions & Comments

Tyler E. Graybill | Structural Option

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Tyler E. Graybill | Structural Option