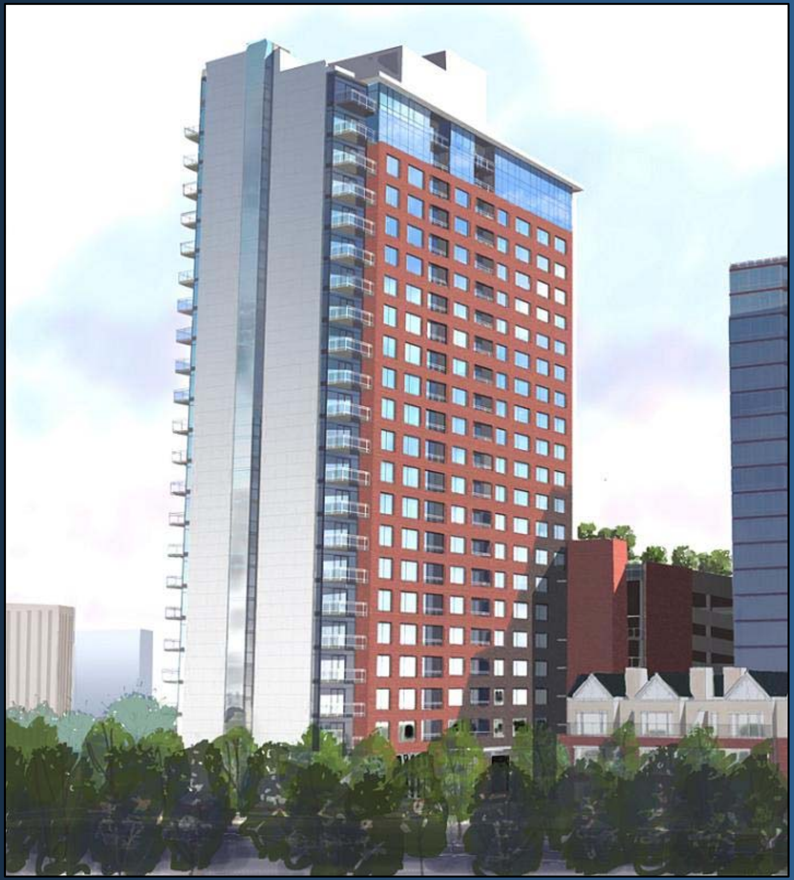
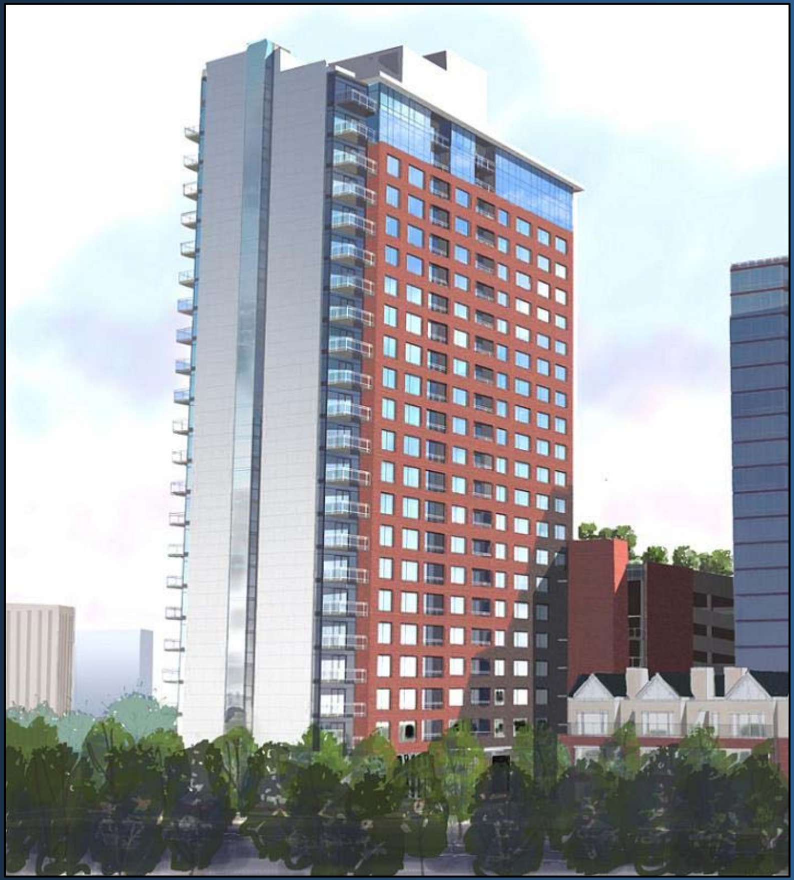
Senior Thesis Report:



Feasibility and Consequences in Staggered Truss Construction

River Tower at Christina Landing



Joseph Bednarz

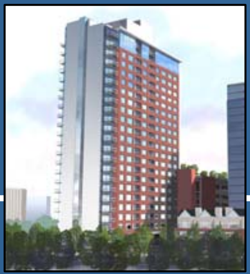
Structural Option

Spring 2006

Presentation Outline

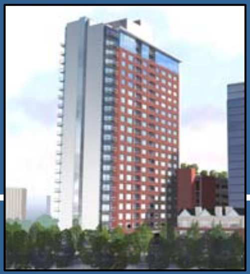
- Building Introduction
- Existing Structural System: Post-Tensioned Slab with Concrete Columns and Shear Walls
- Project Criteria
- Proposed System: Staggered Truss System
- Construction Feasibility and Cost Analysis
- Fire Protection Systems
- Conclusions

Building Introduction



- Project Location
  - Wilmington, DE
- 25-story condominium tower
- 7 story adjacent parking garage structure
- Entire structure has 435,000 SF
- Design-Bid-Build Project
- Overall cost of $46 Million

Project Team



BPG
The Buccini/Pollin Group

Building Owner/Developer

O'DONNELL & NACCARATO

Structural Engineers

BURT, HILL

Architects and MEP Engineers

Pennoni

Civil Engineers

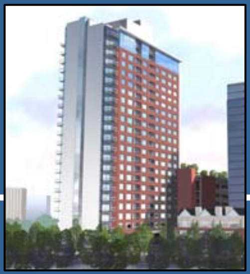
Gilbane

General Contractor

Lerch, Bates & Associates Inc.
Consulting Groups

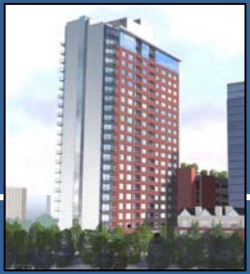
Elevator Consultants

Project Overview

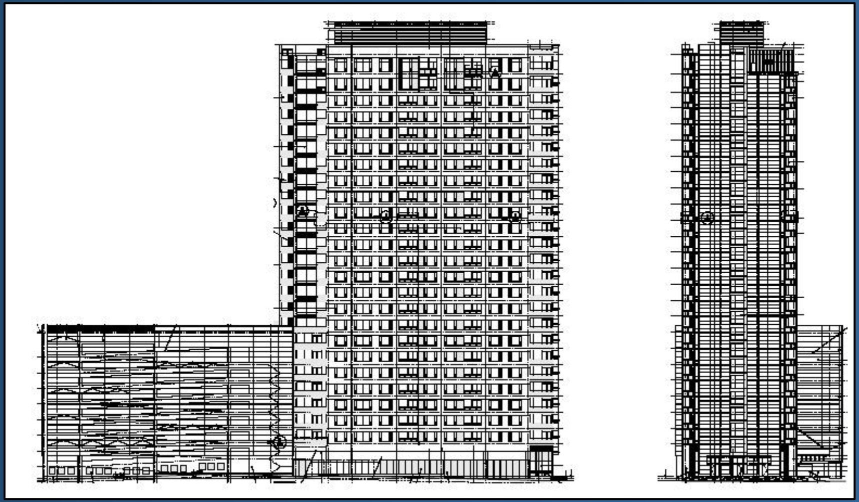


- Architecture
  - First seven floors interface with a parking garage
  - Eighth floor contains condo units with some public areas: Great Room, Fitness Center
    - Opens to open terrace (on roof of parking structure) with in-ground pool, roof garden, and observation deck
  - 23 stories of luxury condominium units
    - Top floors house penthouses and mechanical equipment
- Building Envelope
  - Brick-faced precast panels
  - Self-supporting

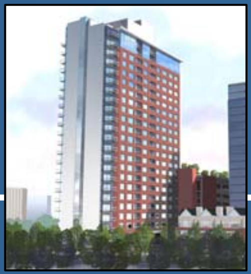
Existing Foundation System



- HP steel piles driven to 225 tons with a net bearing capacity of 200 tons
- Pile caps transfer loads from columns, where most piles are grouped
- Concrete grade beams support exterior walls

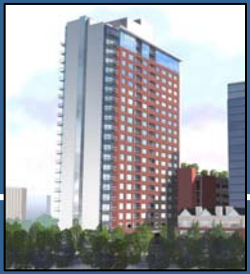


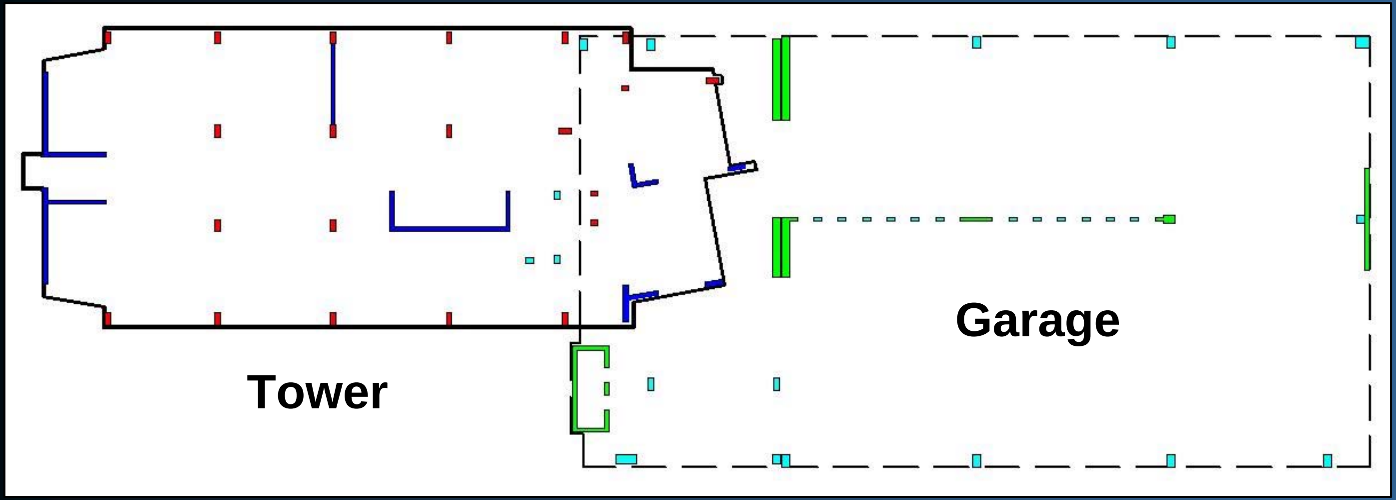
Existing Floor System



- First floor: 12” thick reinforced slab with #7’s spaced at 12 inches o.c., T&B
- Post-tensioned flat plate
  - 8” thickness
  - ½” round type 270 ksi tendons
- Concrete columns
  - Typical bay of 28’-6” by 23’-0”
  - Typical interior columns:
    - 16” x 52”
  - Typical exterior columns:
    - 16” x 36”

Existing Lateral System





Tower Columns

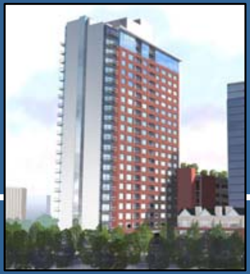
Tower Shear Walls

Garage Shear Walls

Garage Columns

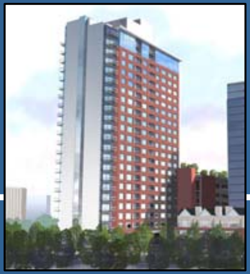
- Concrete shear walls
  - Vary 12-16” in depth, depending on location
- Concrete columns oriented in the strong direction to provide additional lateral resistance

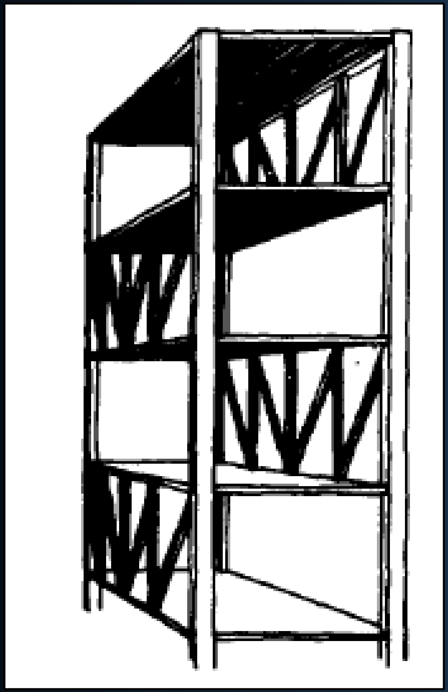
Project Criteria



- Open up architectural column layout
- Maintain floor thickness as best as possible
- Reduce system weight
- Improve cost efficiency and installation times

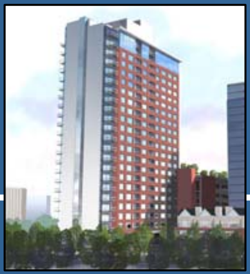
Proposed Structural System

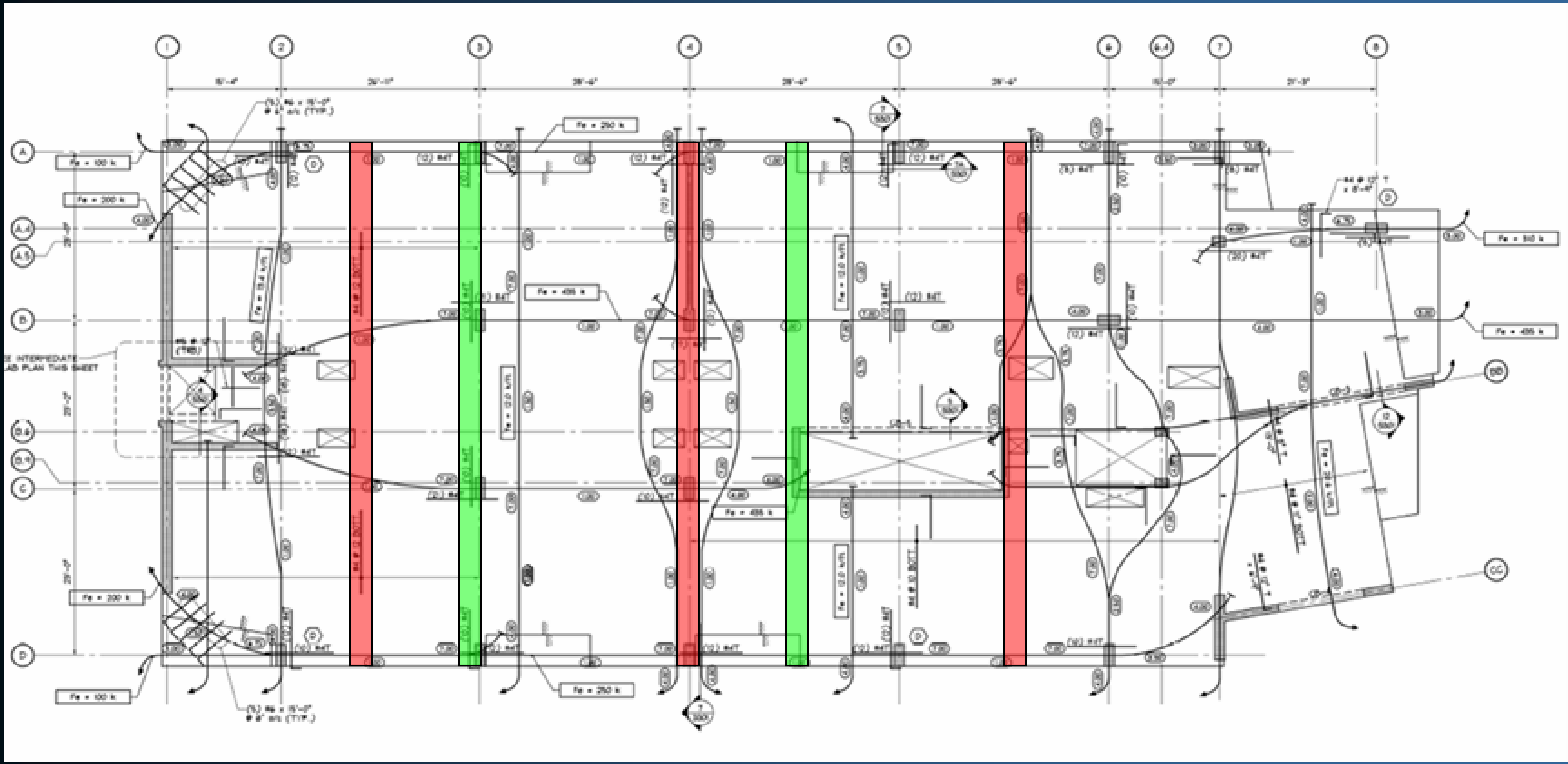


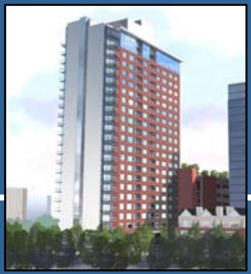


- Staggered Truss System
  - Trusses placed on alternating column lines
  - Columns oriented to resist lateral forces along with transverse trusses
  - Floor system acts as diaphragm, spanning from top chord of one truss to bottom chord of another

Existing Floor Plan / Proposed Floor Plan

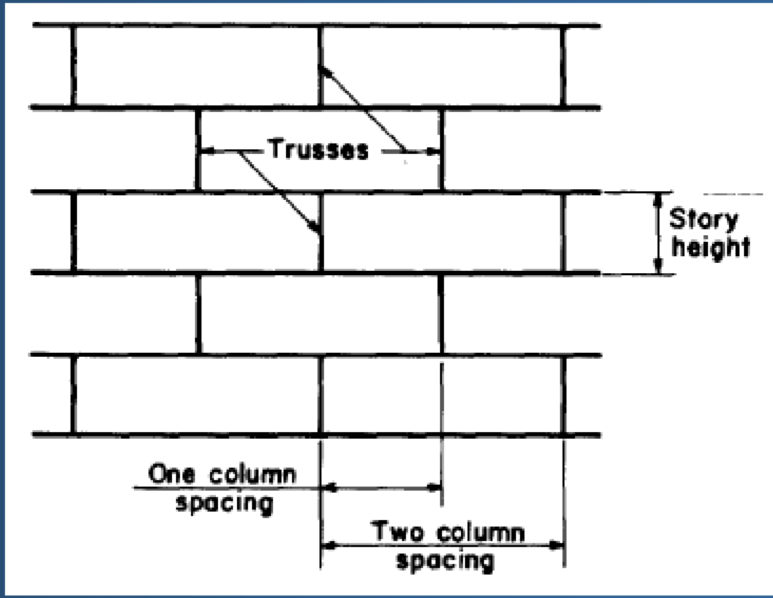






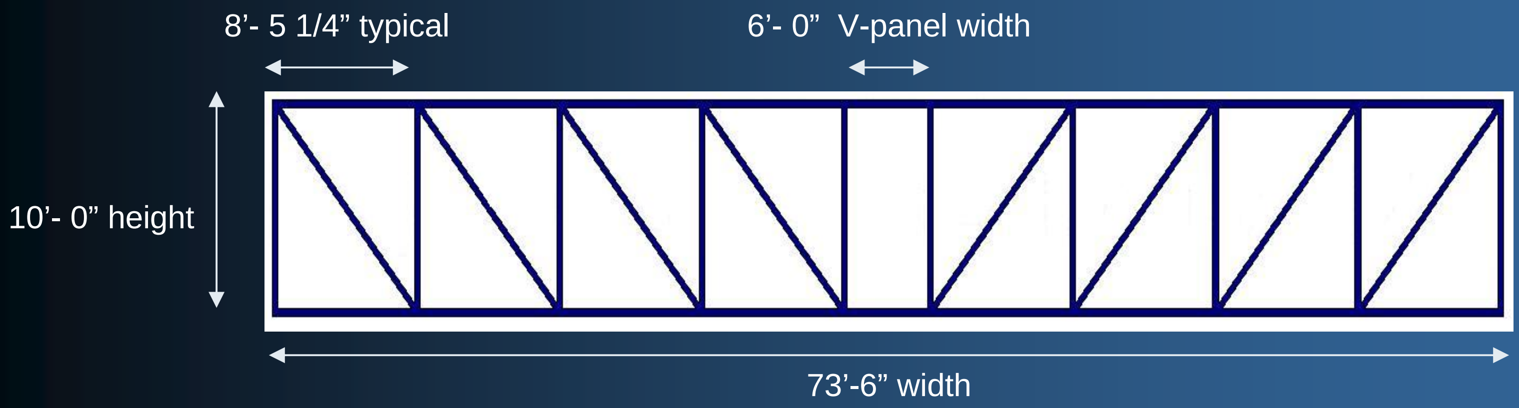
Potential Advantages

- Large column-free spaces while minimizing floor spans
- Columns that do remain will be smaller in size than the concrete columns
- Drifts minimized due to efficiency of truss
- Easier, faster, and potentially cheaper construction and erection

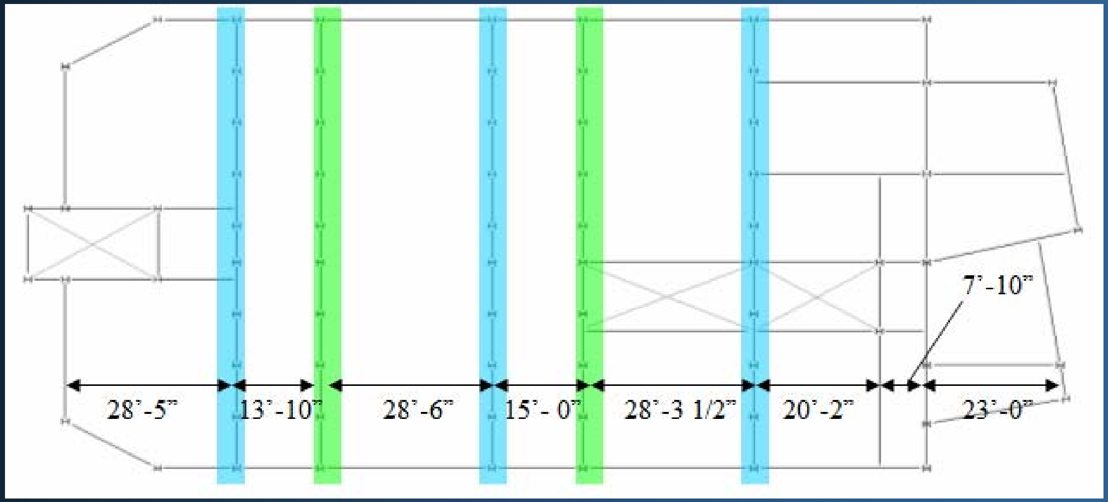


Specific Applications

- Trusses span full 73.5 ft width of the tower in the transverse direction
- Trusses oriented against controlling lateral (wind) forces
- Vierendeel Panel in center of each truss allows for existing corridor spaces

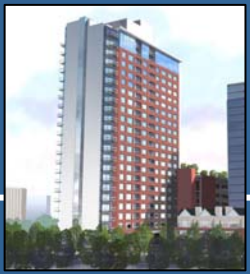


Structural Design



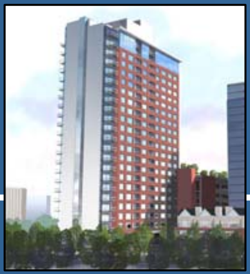
- Staggered Trusses placed in existing unit walls
- Moment frames used in irregular spaces at extreme ends of the building
- 8" precast hollow-core planks used as flooring system, laid in longitudinal direction (max span = 29 ft)

Methods of Design

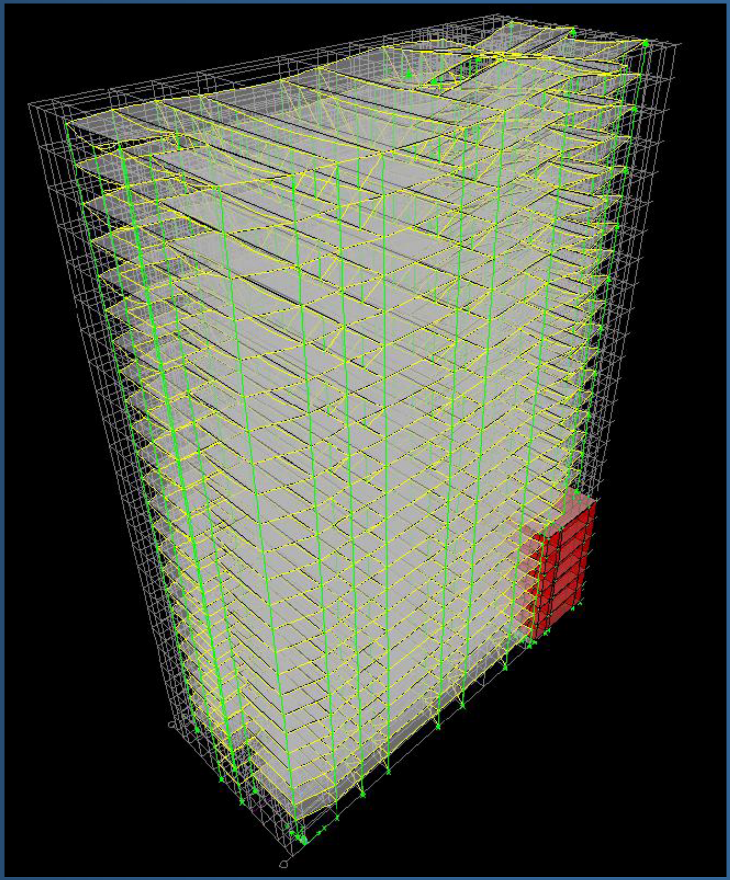


- Based on AISC Design Guide 14
- BOCA 1996 Building Code and ASCE 7
- Accounted for direct shear and torsional rigidity
  - Including accidental torsion
- Method of Joints used to calculate forces in each truss member
  - Based separately on gravity and lateral forces
- Transverse shear capacity verified in the precast plank diaphragm
- Truss columns designed to account for axial forces and bending

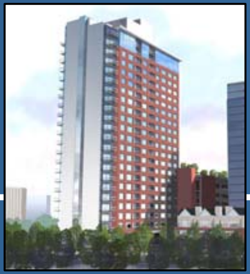
Structural Design



- ETABS Output
  - Resulted in larger truss chord and exterior column sizes
  - Several iterations using rigid diaphragm and non-rigid assumption
  - Based on similarities between design guide loads and those of past projects, hand calculations were judged more accurate
  - Discrepancy accounted for in cost estimates

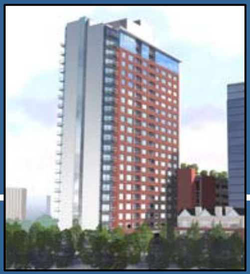


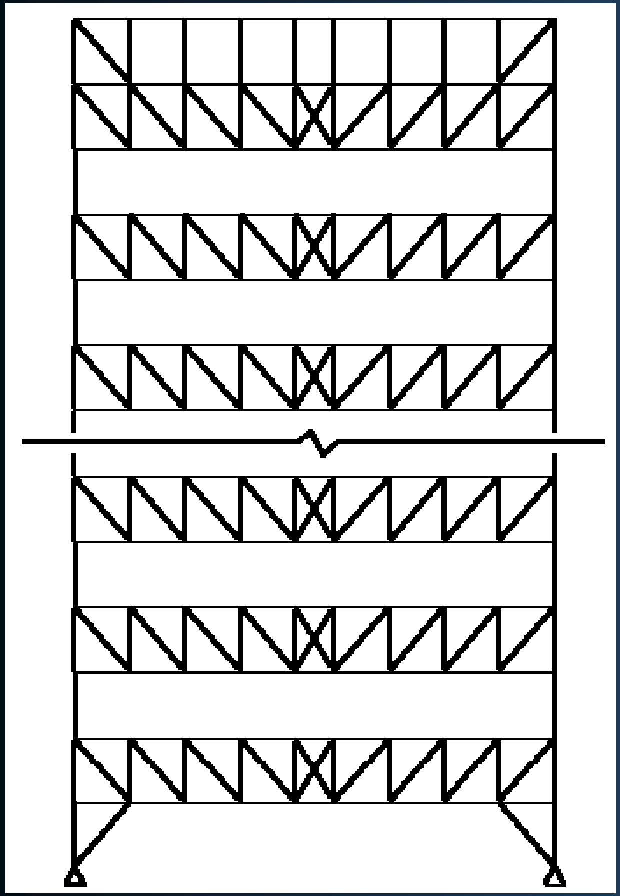
Design Consequences



- Foundation
  - HP piles would still be required (soil type)
  - Less concentration of piles and pile caps due to lower system dead weight
- Wind loading changes would be minimal due to the theoretical increase in floor thickness
- Seismic Forces
  - Story forces are reduced compared to existing condition with this lower building weight
  - Response Modification factor

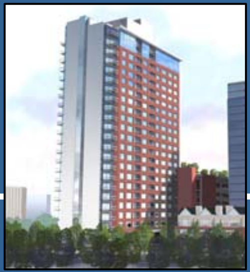
Design Results





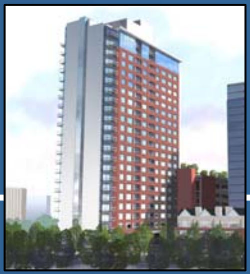
- Steel framing
  - Moment Frames: range from W18 to W36 members
  - W10 top and bottom chord members
  - Large W12 and W14 columns
  - HSS members for truss diagonal members

Additional Concerns



- Connections
  - Moment frame connections are difficult to install and expensive
  - Welded gusset plates used to connect web members to truss chords
- Architecture
  - Hallways and closets within truss openings in individual condominium units
  - Not enough width for typical ADA door frame

Feasibility of Construction

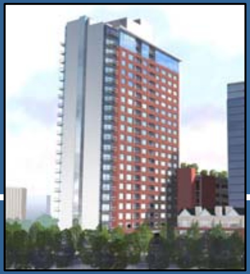


- Comparing Existing and Proposed Systems
  - Post-tensioned Concrete, columns, and shear walls rely on speed of wet trades
  - Staggered truss construction relies on prefabrication
    - Hollow-core planks
    - Trusswork
  - Height of tower, along with width of trusses, produces potential complexities (crane usage, etc.)
  - Not much leeway in the field for truss placement
  - Moment and truss connections are difficult and expensive

Cost Analysis

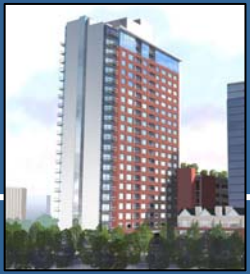
Existing System: Post-Tensioned Concrete Slab			
Type of Construction	Unit	Cost per Unit (Total Incl. O&P)	Estimated Total Cost
Prestressed Concrete	442.10 CY	$1,150.00	$7,689,638.27
CIP Concrete	1416.66 CY	$78.00	$110,499.30
Shear Walls	6886.64 CY	$283.50	$125,335.58
Concrete Columns	129.08 CY	$1,075.00	$138,765.14
Cost/SF = $31.27		Total Estimate:	$8,064,238.29
		Plus 5% Waste:	$8,467,450.21

Cost Analysis



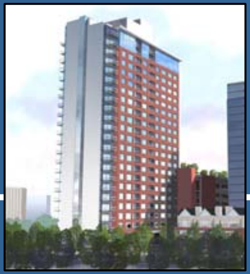
Proposed System: Staggered Truss System			
Type of Construction	Unit	Cost per Unit (Total Incl. O&P)	Estimated Total Cost
Steel Column	698.54 tons	$2,419.00	$2,025,773.25
Steel Braces	707.32 tons	$2,419.00	$2,051,213.50
Steel Beams/Chords	207.07 tons	$2,419.00	$600,501.55
Precast Planks	270,809 SF	$10.50	$2,843,494.50
Cost/SF = $31.94		Total Estimate:	$7,520,952.80
		Plus 5% Waste:	$7,897,000.44
		Plus 10% Connections:	$8,649,095.72

Comparison of Systems



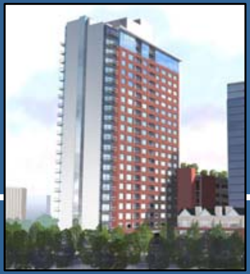
- Proposed Staggered Truss System is $181,645.51 more expensive than existing system
- Supposed benefits of staggered trusses?
  - Wilmington, DE: Premium for steel rather than concrete
  - High-rise construction: leads to cost increases for steel erection
    - Crane usage is necessary for higher elevations
  - Floor thickness still increases from existing 8 inches

River Tower Fire Systems



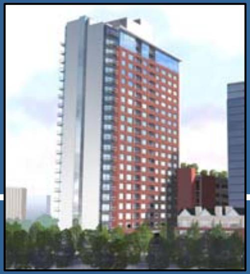
- Standpipe and Sprinklers
  - Wet Pipe Combined System
    - Constant flow of water
    - Main riser serves as the standpipe and services the sprinkler branch systems as well
    - Standpipe in each major stairwell to allow for maximum access
- Stairwell Pressurization
  - Open-air vents in each stairwell
  - Provides ventilation for evacuees and fire personnel while forces the smoke out when fire doors opened

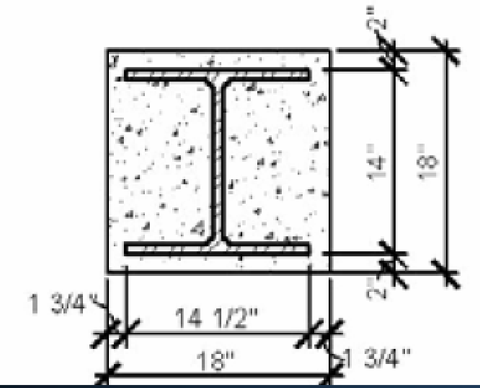
Fire Protection Systems



- Overview of Existing Conditions
  - Existing concrete structure provides plenty of inherent fire protection
  - River Tower: Primarily "light hazard," Type 1A classification by BOCA 1999
  - High-rise construction:
    - Levels over 75 feet: not reachable by fire department
    - Standpipes and sprinklers systems act against fire spread
    - Stairwell Pressurization provides smoke control

Types of Fireproofing



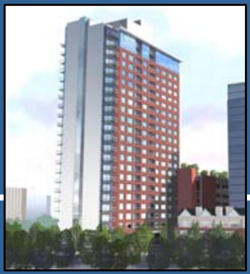


Concrete Encasement

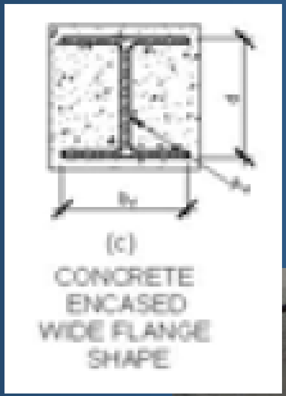
Gypsum Wallboard

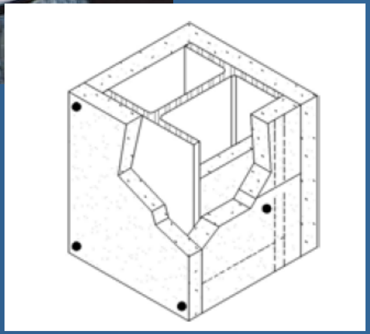
Spray-On Fire Resistant Material (SFRM)

Conclusions of Comparison

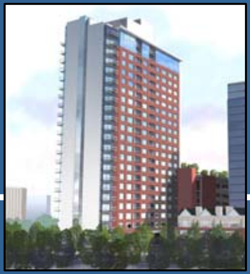


- Concrete Encasement
  - Thinnest: 1.35” average beyond flange thickness
  - Difficult, lengthy application
- Spray-On Fire Resistant Materials
  - Isolatek 800
  - 1.75” thickness required
  - Quickest/easiest application
- Gypsum Wallboard
  - Thickest application = 2”
  - Easily painted surface for aesthetics

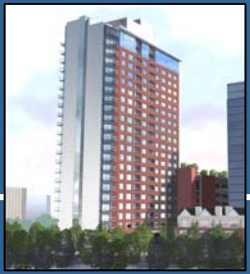




Conclusions

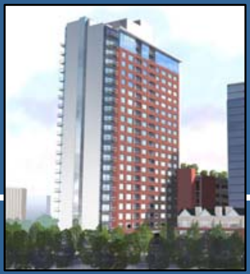


- Staggered Truss System is slightly more expensive than existing post-tensioned slab system
- Potentially faster/easier construction
  - Not as much reliance on wet trades
  - Proposed system has prefabricated materials
- Architectural difficulties despite potential opening of floor plan and column layout
- Negates the potential benefits of staggered truss system in this particular application



Questions?

Media Bibliography



- Images

  - <http://www.arcat.com/photos/templein/110191.jpg>
  - <http://www.southerninsulation.com/images/fsspray.jpg>
  - <http://www.conomos.com/images/applyfireproof.jpg>
  - <http://archrecord.construction.com/resources/conteduc/archives/0202aisc-3.asp>
  - <http://www.christinalanding.net>
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  - Ruddy, John, et al. *AISC Design Guide 19: Fire Resistance of Structural Steel Framing.* American Institute of Steel Construction, 2003.
  - <http://www.cala2.umn.edu/arch5512/KammerMcNallanGiesen_Fields/general/Rebar2.jpg>

Additional Information

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Additional Needs

- Fire Protection for Proposed Design
  - Existing architecture relatively the same, so most of existing systems are still sufficient
  - Steel needs additional fireproofing
    - Staggered truss system limits steel to infill walls between units mostly
    - Hollow-core precast planks provide inherent fireproofing between levels
    - 2 hour general fire rating required by BOCA 1999
    - 3 hour fire rating for interior bearing walls, columns, and trusses

Comparison of Materials

- Factors to consider:
  - Constructability
  - Cost
  - Aesthetics
  - Thickness
- W12x72 column used for comparison
- All of these materials prevent enough thermal transfer to the structural steel
  - As long as the fire exposure does not cause the average temperature at any cross section to elevate above 1,000 degrees F

Beam and Truss Protection

- Steel Beams and Girders
  - Hollow core planks provide inherent 2 hour fire rated protection from above
    - Also provide finished flooring surface with coating
  - SFRM makes most sense for flooring undersides
    - Hidden by drop ceilings or aesthetic use of gypsum
- Staggered Trusses
  - Rest in infill walls (3 hr fire rating)
  - Gypsum wallboard most efficient material
  - Door openings: intumescent coatings
    - Thinnest application possible to use where thickness is at a premium

Design Loads

- Gravity Loads
  - Live: 70 psf
  - Dead
    - 8” plank with 2” topping: 82.5 psf
    - Leveling compound: 5 psf
    - Structural Steel: 5 psf
    - Partitions/MEP: 12 psf

Total: 104.5 psf

Seismic Lateral Loads

- Existing System
- Seismic Category B
- <u>Basic Seismic Force Resisting System:</u>
  - Dual system with shear wall and intermediate concrete frame
- Response Modification Factor, R = 6
- Site Coefficient, S_4 = 2.0
- Equivalent Force Method Analysis
- Base Shear = V = 849.73 kips

Wind Lateral Loads

- Existing System
- Wind exposure category C
- Importance Factor = 1.04
- Controlling case: Wind in North-South Direction