# Structural Redesign of the Army National Guard Readiness Center

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The Department of Architectural Engineering
The Pennsylvania State University
April 13, 2010

## Presentation Outline

1. **Introduction & Building Overview**
   - *Introduction*
   - Location
   - Building Statistics
   - Existing Structural Conditions
2. Structural Depth Analysis
3. Breadth Studies
4. Recommendations & Conclusions
5. Questions



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   - Proposal Summary
   - Design Goals
   - Gravity System Redesign
   - Lateral System Redesign
   - Progressive Collapse Design
3. **Breadth Studies**
   - Construction Management Analysis
   - Acoustical Analysis
4. **Recommendations & Conclusions**
5. **Questions**

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## LOCATION

*•111 S. George Mason Dr., Arlington, Virginia*

*•Approximately 5 miles outside of Washington D.C.*

*•On the same site as the location of the current Army National Guard Building*

*•15 acre site*

▪Includes a 248,000 square foot existing facility, two 3-2tory parking garages, and several small out buildings.

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## BUILDING STATISTICS

•*Joint Headquarters Administrative Building*
- •5 Stories Above Grade and 3 Below
- •Includes Offices, Training Areas, Auditorium and more

•*Square Footage*
- •251,000 Gross Square footage

•*Architecture*
- •*Unique Triangular shape*
- •*Façade mimics existing building*

•*Project Duration*
- •December 2008-March 2011

•*Project Delivery Method*
- •Design-Bid-Build

•*Cost*
- • $100 Million

•*Anticipated to Achieve LEED Silver Rating*

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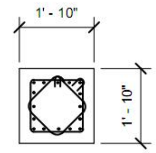
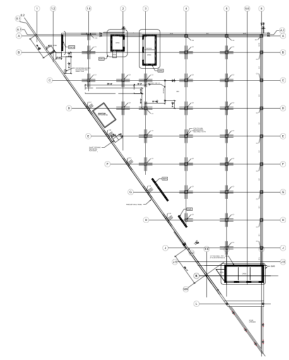
## Existing Gravity System

- **Floor System**
  - 9" Two-way reinforced concrete flat slab
  - Column strips and edge beams
  - $f'_c$=4,000 psi
  - Typical No. 6 and No. 8 reinforcement
- **Columns**
  - Cast-in-place reinforced normal weight concrete
  - Typical 22" x 22"
  - Typical No. 8 reinforcement
  - Typical No. 3 ties




- **Foundation**
  - 32" concrete mat slab

*Existing Structural Plan*



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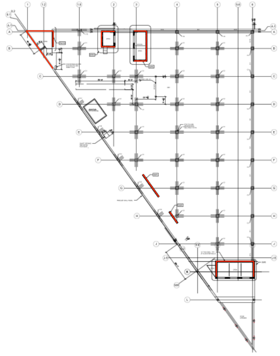
## EXISTING LATERAL SYSTEM

- **Lateral System**
    - Ordinary reinforced concrete shear walls
    - 12" Thickness
    - Both North-South and East-West direction
    - $f'_c$=4,500 psi
    - Located around elevator cores and stairwells as well as along the corridor of the long side

*Location of Shear Walls:*



# PRESENTATION OUTLINE



# PROPOSAL SUMMARY

- **Depth Study**
  - Redesign of the structural system to include a steel framing system as opposed to the existing cast-in-place concrete structure in order to compare the structural systems to determine which building material is more beneficial.
  - *Gravity System*
    - Composite metal decking with composite beams and steel columns
  - *Lateral System*
    - Ordinary-Moment Resisting Frames
  - *Progressive Collapse Design*
- **Breadth Topics**
  - Construction Management Analysis
  - Acoustics Analysis

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   - Lateral System Redesign
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## Design Goals

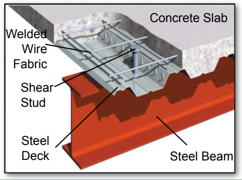
- Respect the existing layout and architectural features of the building
- Choose a single lateral system and layout that will work effectively
- Design the structural steel system for progressive collapse mitigation
- Design a structural steel system that reduces overall building costs
- Reduce the construction schedule by designing a steel structural system that is more efficient to erect

# PRESENTATION OUTLINE

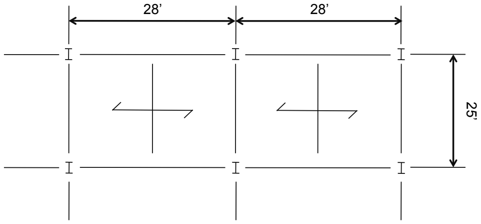


# GRAVITY SYSTEM REDESIGN

- **Beam, Girder, and Slab Design**
  - *Composite metal deck with concrete slab*
    - 3VLI, 19" gage metal deck
    - 3 ½" Concrete Slab
    - Advantages:
      - Slab design meets 3 hour fire rating
      - No shoring is required
      - Quicker and Easier to erect
    - Disadvantages:
      - Infill beams are required
      - Deeper floor assembly




*Typical Bay Sizes*:



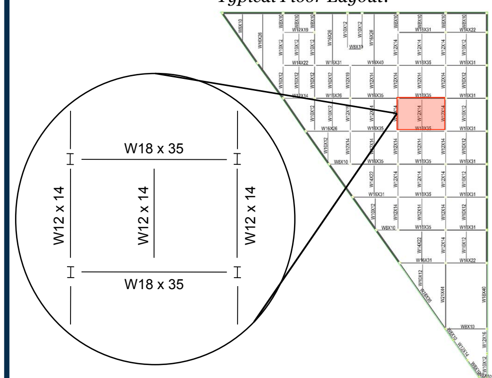
# Presentation Outline



# Gravity System Redesign

- **Beam, Girder, and Slab Design**
  - *Infill Beams and Girders*
    - Composite members
    - Typical beams: W12's
    - Typical Girders: W18's
    - Advantages:
      - Lighter than concrete
      - Span long and irregular bays
      - Erected Quicker than concrete
    - Disadvantages:
      - Require Fireproofing
      - Deeper floor assembly

*Typical Floor Layout:*



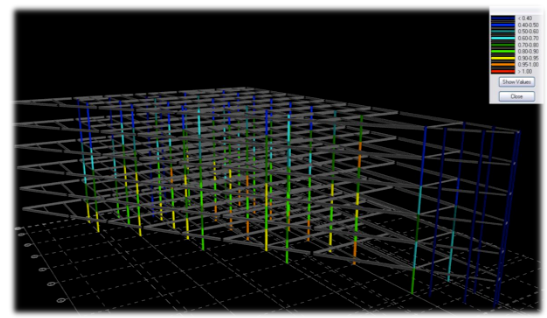
## PRESENTATION OUTLINE



## GRAVITY SYSTEM REDESIGN

- **Column Design**
  - Typical size: W10's
    - Live load reduction used in accordance with ASCE 7-05
    - Spliced at every other level
    - Optimized to increase the redundancy of shapes
    - Advantages:
      - Lighter than concrete
      - No affect on existing architecture
      - Erected Quicker than concrete
    - Disadvantages:
      - Require Fireproofing

*RAM Model – Interaction Diagrams:*



## LATERAL SYSTEM REDESIGN

- **Lateral System Design Loads**
  - *Wind Loads*
    - *Location Parameters for Arlington, VA*

| Building Location Parameters | |
|---|---|
| Basic Wind Speed (V) | 90 mph |
| Wind Enclosure Category | C |
| Importance Factor | 1.15 |
| Wind Directionality Factor ($K_d$) | 0.85 |
| Topographic Factor ($K_{zt}$) | 1 |

- *ASCE 7-05, Chapter 6*
  - Design Method 2 – Analytical Method
- *Controls lateral design in both East-West and North-South directions*

*Wind Forces in East-West Direction:*

**Wind Load Distribution in East-West Direction**

| Level | Height (Feet) | Tributary Area (Feet) | Windward (psf) | Leeward (psf) | Total (psf) | Story Force (Kips) | Story Shear (Kips) | Overturning Moment (Ft-Kips) |
|---|---|---|---|---|---|---|---|---|
| Roof | 82 | 17 | 16.1 | -11.62 | 27.72 | 109.68 | 0 | 546.21 |
| Penthouse | 65 | 13 | 15.36 | -11.62 | 26.98 | 81.63 | 109.68 | 2251.96 |
| 5T | 52 | 13 | 14.62 | -11.62 | 26.24 | 79.40 | 191.31 | 5603.75 |
| 4T | 39 | 13 | 13.65 | -11.62 | 25.27 | 76.46 | 270.71 | 11291.57 |
| 3T | 26 | 13 | 12.17 | -11.62 | 23.79 | 71.98 | 347.17 | 19826.98 |
| 2T | 13 | 13 | 11.28 | -11.62 | 22.9 | 69.29 | 419.15 | 31675 |
| 1T | 0 | 0 | 0 | 0 | 0 | 0 | **488.44** | **31675** |

*Wind Forces in North-South Direction:*

**Wind Load Distribution in North-South Direction**

| Level | Height (Feet) | Tributary Height (Feet) | Windward (psf) | Leeward (psf) | Total (psf) | Story Force (Kips) | Story Shear (Kips) | Overturning Moment (Ft-Kips) |
|---|---|---|---|---|---|---|---|---|
| Roof | 82 | 17 | 16.1 | -8.29 | 24.39 | 67.17 | 0 | 443.11 |
| Penthouse | 65 | 13 | 15.36 | -8.29 | 23.65 | 49.81 | 67.17 | 1554.41 |
| 5T | 52 | 13 | 14.62 | -8.29 | 22.91 | 48.25 | 116.98 | 3204.96 |
| 4T | 39 | 13 | 13.65 | -8.29 | 21.94 | 46.21 | 165.23 | 5477.1 |
| 3T | 26 | 13 | 12.17 | -8.29 | 20.46 | 43.09 | 211.44 | 8341.52 |
| 2T | 13 | 13 | 11.28 | -8.29 | 19.57 | 41.21 | 254.53 | 11762.66 |
| 1T | 0 | 0 | 0 | 0 | 0 | 0 | **295.74** | **11762.66** |

## PRESENTATION OUTLINE



## LATERAL SYSTEM REDESIGN

- **Lateral System Design Loads**
  - *Seismic Loads*
    - *Ground Parameters for site location*

| General Seismic Information | | |
|---|---|---|
| Occupancy Category | | III |
| Site Class | | D |
| Seismic Design Category | | B |
| Short Period Spectral Response | $S_S$ | 0.1799 |
| Spectral Response (1Sec) | $S_1$ | 0.0639 |
| Maximum Short Period Spectral Response | $S_{MS}$ | 0.288 |
| Maximum Spectral Response (1 Sec) | $S_{M1}$ | 0.1534 |
| Design Short Spectral Response | $S_{DS}$ | 0.192 |
| Design Spectral Response (1 Sec) | $S_{D1}$ | 0.102 |
| Response Modification Coefficient | R | 3.5 |
| Seismic Response Coefficent | $C_S$ | 0.018 |

    - *ASCE 7-05, Chapters 11 & 12*
      - Equivalent Lateral Force Analysis Method

*Seismic Forces:*

**Seismic Loads**

| Level | Height $h_x$ (ft) | Tributary Height (Ft) | Story Weight $w_x$ (Kips) | $h_x^k$ | $w_x h_x^k$ | $C_{VX}$ | Lateral Force $F_x$ (kips) | Story Shear $V_x$ (kips) | Moments $M_x$ (ft-kips) |
|---|---|---|---|---|---|---|---|---|---|
| Roof | 82 | 8.5 | 144 | 82.00 | 11808.00 | 0.03 | 7.90 | 0.00 | 0.00 |
| Penthouse | 65 | 13 | 1814 | 65.00 | 117910.00 | 0.34 | 78.87 | 7.90 | 67.15 |
| 5T | 52 | 13 | 1810 | 52.00 | 94120.00 | 0.27 | 62.95 | 86.76 | 698.31 |
| 4T | 39 | 13 | 1810 | 39.00 | 70590.00 | 0.20 | 47.22 | 149.72 | 2235.5 |
| 3T | 26 | 13 | 1810 | 26.00 | 47060.00 | 0.14 | 31.48 | 196.93 | 4488.78 |
| 2T | 13 | 13 | 298 | 13.00 | 3874.00 | 0.01 | 2.59 | 228.41 | 7253.62 |
| 1T* | 0 | 6.5 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | **231** | **10224** |
| **$\sum(w_i h_i^k)$ = 345,362** | | **$\sum(F_x)$ = V = 231 Kips** | | | **$\sum M_x$ = 10,224 'k** | | | | |
| **Total Building Weight(Above Grade) =9,495 kips** | | | | | | | | | |

* The Level 1T story weight is only weight of the columns whose base is at the ground floor. Weights of slabs, beams, and superimposed deads loads are not considered at the ground floor because the base shear is related only to the levels above grade and the components mentioned are at grade level.

## PRESENTATION OUTLINE



## LATERAL SYSTEM REDESIGN

- **Serviceability Standards**
  - *Allowable Drift & Displacement*
    - *Wind*

      **< h/400**
    - *Seismic*

      **< $0.020h_x$**
  - *Values taken from RAM model and compared to allowable drift and displacement values*
  - *Serviceability Controls in the East-West Direction*

*Drift in East-West Direction:*

| Story Drift in East - West Direction | | | | |
|---|---|---|---|---|
| Level | Story Height (ft) | Story Drift (in.) | Allowable Drift (h/400) | Result |
| Roof | 17 | 0.2966 | 0.51 | Good |
| Penthouse | 13 | 0.2770 | 0.39 | Good |
| 5T | 13 | 0.2483 | 0.39 | Good |
| 4T | 13 | 0.2180 | 0.39 | Good |
| 3T | 13 | 0.2100 | 0.39 | Good |
| 2T | 13 | 0.2048 | 0.39 | Good |

*Displacement in East-West Direction:*

| Displacement in East-West Direction | | | | |
|---|---|---|---|---|
| Level | Height (ft) | Displacement (in.) | Allowable Drift (H/400) | Result |
| Roof | 82 | 0.2308 | 2.46 | Good |
| Penthouse | 65 | 1.8973 | 1.95 | Good |
| 5T | 52 | 1.3890 | 1.56 | Good |
| 4T | 39 | 1.1252 | 1.17 | Good |
| 3T | 26 | 0.1632 | 0.78 | Good |
| 2T | 13 | 0.0918 | 0.39 | Good |

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- *Lateral System Redesign*
- Progressive Collapse Design

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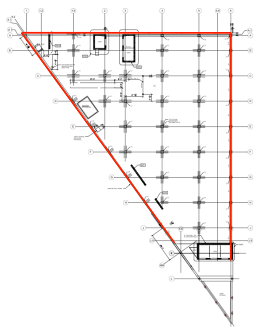
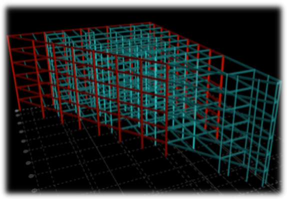
## Lateral System Redesign

- **Steel Moment Resisting Frames**
  - Located around the perimeter of the building
  - Controlled by wind loads in north-south direction and serviceability in east-west direction
  - Optimized to increase the redundancy of shapes
  - Advantages:
    - Lighter than concrete
    - Minimal affect on existing architecture
    - Erected Quicker than concrete
  - Disadvantages:
    - Require Fireproofing
    - Expensive connections
    - Deep Members

*Location of Moment Frames:*





*RAM Model:*

Green Elements – Gravity Members
Red Elements – Lateral Members

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## Progressive Collapse Design

- *Definition of Progressive Collapse*
    - Commentary found in ASCE 7-05 defines progressive collapse as…

      *"the spread of an initial local failure from element to element, eventually resulting in the collapse of an entire structure of a disproportionately large part of it."*

    - ASCE and material specific codes do not provide explicit and enforceable requirements

*General Services Administration (GSA)*

- Progressive Collapse Analysis and Design Guidelines (2003)

*Department of Defense (DoD)*

- Unified Facilities Criteria – Design of Buildings to Resist with Progressive Collapse (UFC 4-023-03)

# Presentation Outline



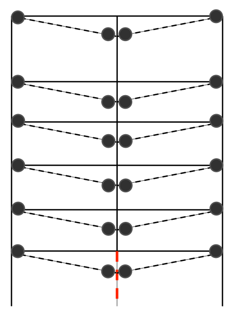
# Progressive Collapse Design

- *Analysis 1 - Direct Design Approach:*
  - Localizes building failure by requiring the structure be capable of bridging over missing structural elements
  - GSA Guidelines
  - Threat Level – **High Level of Protection**
  - Assumes instantaneous loss of critical column
  - Plastic Analysis using virtual work method
  - Load Combination: *2(DL+0.25LL)*
  - Demand Capacity Ratios (DCR) for each member

$$DCR = \frac{Q_{UD}}{Q_{CE}}$$

$Q_{UD}$=Demand Capacity
$Q_{CE}$=Expected Capacity

*Plastic Hinge Formation:*



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# PROGRESSIVE COLLAPSE DESIGN

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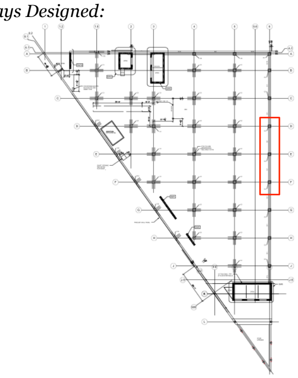
*Bays Designed:*



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    - Load Combination: *2(DL+0.25LL)*
    - Demand Capacity Ratios (DCR) for each member

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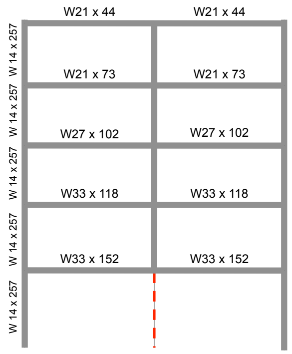
*Member Sizes:*



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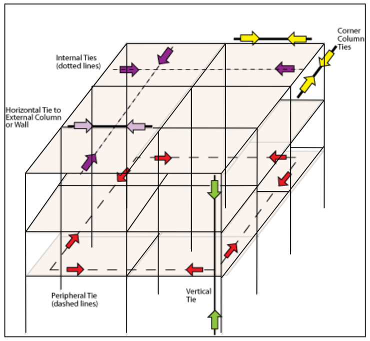
# PROGRESSIVE COLLAPSE DESIGN

- *Analysis 2 - Indirect Method:*
  - Requires consideration of strength, continuity, and ductility of connections for resisting progressive collapse
  - DoD Guidelines
  - Threat Level – **Low Level of Protection (LLOP)**
  - Requires the structure be mechanically tied
    - Peripheral Ties
    - Internal Ties
    - Ties to Columns
      - Vertical Ties
      - Horizontal Ties
  - Typical Moment connections can meet these requirements

*Tie Forces:*



## PROGRESSIVE COLLAPSE DESIGN

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  - Requires the structure be mechanically tied
    - Peripheral Ties
    - Internal Ties
    - Ties to Columns
      - Vertical Ties
      - Horizontal Ties
  - Typical Moment connections can meet these requirements

***Tie Force Requirement Equations:***

*Internal Tie Forces* = $0.5(1.2DL+1.6LL)S_tL_1$

*Peripheral Tie Forces* = $0.25(1.2\ DL+1.6LL)S_tL_1$

*Column Ties:*

Horizontal Tie Forces = $\text{LARGER}\left| \begin{matrix} 0.1(4)(A_{Trib})(1.2DL+1.6LL) \\ InternalTieForce \end{matrix} \right.$

Vertical Tie Forces = $(A_{TRIB})(1.2DL+1.6LL)$

| Tie Force Requirements | |
|---|---|
| Internal Tie Force | 40.92 kips |
| Peripheral Tie Force | 13.64 kips |
| Horizontal Tie Force | 40.92 kips |
| Vertical Tie Force | 164 kips |

# Presentation Outline



# Construction Management Analysis

- **Cost Analysis**
  - *Existing Concrete Structure Costs*

| Concrete Cost Summary | | | | |
|---|---|---|---|---|
| Building Components | Cost | | | |
| | Material | Equipment | Labor | Total |
| Concrete | $ 1,009,014.00 | | | $ 1,009,014.00 |
| Formwork | $ 1,396,830.00 | | $ 1,396,152.00 | $ 2,792,982.00 |
| Reinforcement | $ 967,950.00 | | $ 298,950.00 | $ 1,266,900.00 |
| Placement | | $ 94,221.00 | $ 269,880.00 | $ 364,101.00 |
| Slab Finish | | | $ 127,799.00 | $ 127,799.00 |
| Crane | | $ 341,280.00 | $ 113,760.00 | $ 455,040.00 |
| **Total** | **$ 3,373,794.00** | **$ 435,501.00** | **$ 2,206,541.00** | **$ 6,015,836.00** |

  - *Proposed Steel Structure Costs*

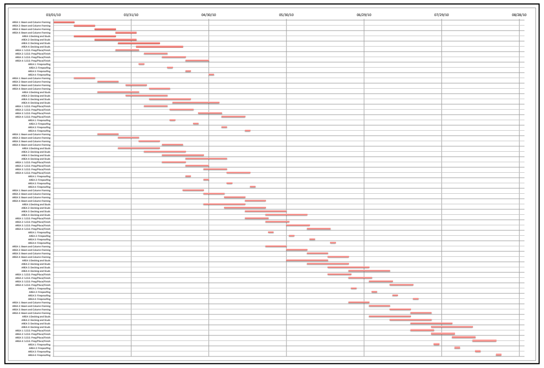
| Steel Cost Summary | | | | |
|---|---|---|---|---|
| Building Components | Cost | | | |
| | Material | Equipment | Labor | Total |
| Steel Framing | $ 3,437,500.00 | $ 158,400.00 | $ 434,500.00 | $ 4,030,400.00 |
| Metal Decking | $ 878,618.00 | $ 106,499.00 | $ 106,499.00 | $ 1,091,616.00 |
| Concrete | $ 334,512.00 | | | $ 334,512.00 |
| Placement | | $ 16,361.00 | $ 41,400.00 | $ 57,761.00 |
| Welded Wire Fabric | $ 118,584.00 | | $ 102,900.00 | $ 221,484.00 |
| Slab Finish | | | $ 47,925.00 | $ 47,925.00 |
| Fireproofing | | | $ 106,499.00 | $ 106,499.00 |
| **Total** | **$ 4,769,214.00** | **$ 281,260.00** | **$ 839,723.00** | **$ 5,890,197.00** |

## Presentation Outline



## Construction Management Analysis

- **Schedule Analysis**
  - *Existing Concrete Structure Costs*
    - 5 Construction Zones
    - Floor to Floor Construction
    - Multiple crews used for forming
    - Approximately 67 Days per Floor
    - ***Total Construction: <u>337 Days</u>***

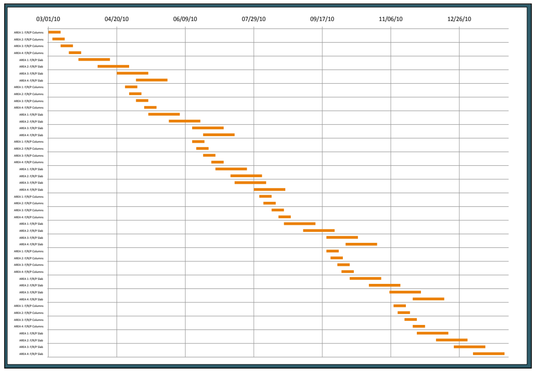


## Presentation Outline



## Construction Management Analysis

- **Schedule Analysis**
  - *Proposed Steel Structure Costs*
    - 5 Construction Zones
    - Floor to Floor Construction
    - Single crews used
    - Approximately 28 Days per Floor
    - ***Total Construction: <u>171 Days</u>***



## CONSTRUCTION MANAGEMENT ANALYSIS

- **Results**
  - *Reduced schedule by **166 days***
  - *Saved Approximately **$125,000***

| Structural System Comparison | | | |
|---|---|---|---|
| Exisiting Concrete Structure | | Proposed Steel Structure | |
| Time | | Time | |
| Days | 337 | Days | 171 |
| Cost | | Cost | |
| Material | $3,373,794.00 | Material | $4,769,214.00 |
| Labor | $2,206,541.00 | Labor | $839,723.00 |
| Equipment | $435,501.00 | Equipment | $281,260.00 |
| **TOTAL** | **$6,015,836.00** | **TOTAL** | **$5,890,197.00** |

## Presentation Outline



## Acoustical Analysis

- Due to reduction in the concrete thickness possible acoustical issues may be induced
- Noise transmission from the mechanical penthouse to the office spaces on Level 5T must be checked
- The area under two cooling towers was considered

*Area under Cooling Towers:*

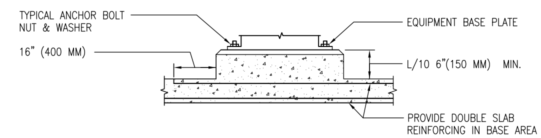
1. Introduction & Building Overview
2. Structural Depth Analysis

3. **Breadth Studies**
   - Construction Management Analysis
   - ***Acoustical Analysis***

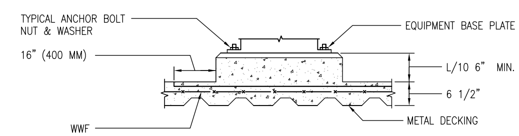
4. Recommendations & Conclusions
5. Questions

## ACOUSTICAL ANALYSIS

- Due to reduction in the concrete thickness possible acoustical issues may be induced
- Noise transmission from the mechanical penthouse to the office spaces on Level 5T must be checked
- The area under two cooling towers was considered
- Existing Floor System:
  - 9" Concrete slab
  - Additional 6" concrete below the equipment base
- Proposed Floor System:
  - 3 VLI metal deck with 3 ½" concrete slab
  - Additional 6" concrete below the equipment base




*Existing Penthouse Floor System*




*Proposed Penthouse Floor System*

## Presentation Outline



## Acoustical Analysis

- Results
  - The proposed floor system is adequate in restricting sound penetration
  - No additional acoustical materials are required

**Acoustics Analysis**

| Floor Design Criteria | Sound Pressure Level (dB) | | | | | |
|---|---|---|---|---|---|---|
| | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz |
| Likely Noise from Cooling Towers | 102 | 97 | 94 | 90 | 88 | 84 |
| Background Noise in Office | 45 | 40 | 35 | 30 | 25 | 20 |
| Required Noise Reduction | 57 | 57 | 59 | 60 | 63 | 64 |
| Sound Absorption Coefficient | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 |
| Total Room Absorption | 4.95 | 4.95 | 9.9 | 9.9 | 9.9 | 9.9 |
| $10\log(a_2/S)$ | -20 | -20 | -17 | -17 | -17 | -17 |
| **Required Transmission Lost** | **77** | **77** | **76** | **77** | **80** | **81** |
| **Floor Design Check** | **Sound Pressure Level (dB)** | | | | | |
| | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz |
| 6" Reinforced Concrete Slab | 38 | 43 | 52 | 59 | 67 | 72 |
| Metal Deck (19 Gage) | 17 | 22 | 26 | 30 | 35 | 41 |
| 4" Reinforced Concrete Slab | 48 | 42 | 45 | 56 | 57 | 66 |
| **Actual Transmission Lost** | **103** | **107** | **123** | **145** | **159** | **179** |

## Presentation Outline





## Design Goals

- ✓ Respect the existing layout and architectural features of the building
- ✓ Choose a single lateral system and layout that will work effectively
- ✓ Design the structural steel system for progressive collapse mitigation
- ✓ Design a structural steel system that reduces overall building costs
- ✓ Reduce the construction schedule by designing a steel structural system that is more efficient to erect

## PRESENTATION OUTLINE

1. Introduction & Building Overview
2. Structural Depth Analysis
3. Breadth Studies

4. **Recommendations & Conclusions**
   - Design Goal Analysis
   - *Recommendations*
   - Acknowledgements

5. Questions



## RECOMMENDATIONS

***The proposed steel framing and moment frames would be a feasible alternative to the existing cast-in-place concrete structure for the Army National Guard Readiness Center***

## Presentation Outline

1. Introduction & Building Overview
2. Structural Depth Analysis
3. Breadth Studies

4. **Recommendations & Conclusions**
   - Design Goal Analysis
   - Recommendations
   - ***Acknowledgements***

5. Questions

## Acknowledgements

I would like to thank the following individuals for their assistance in the completion of this thesis

**Tompkins Builders, Inc**
Everyone working on the Army National Guard Readiness Center Addition

**Army National Guard**
LTC Rodney Graham

**The Pennsylvania State University**
Thesis Consultants
- Dr. Thomas Boothby
- Professor Kevin M. Parfitt
- Professor Robert Holland

The entire Architectural Engineering Department and Professors at Penn State for their support and guidance over the years

**Family and Friends**
A special thank you to family, friends, and peers for the much needed support and help they have provided. It would have been a difficult process without their love and understanding throughout this process.

## Presentation Outline

1. Introduction & Building Overview
2. Structural Depth Analysis
3. Breadth Studies
4. Recommendations & Conclusions

**5. Questions**



## Questions