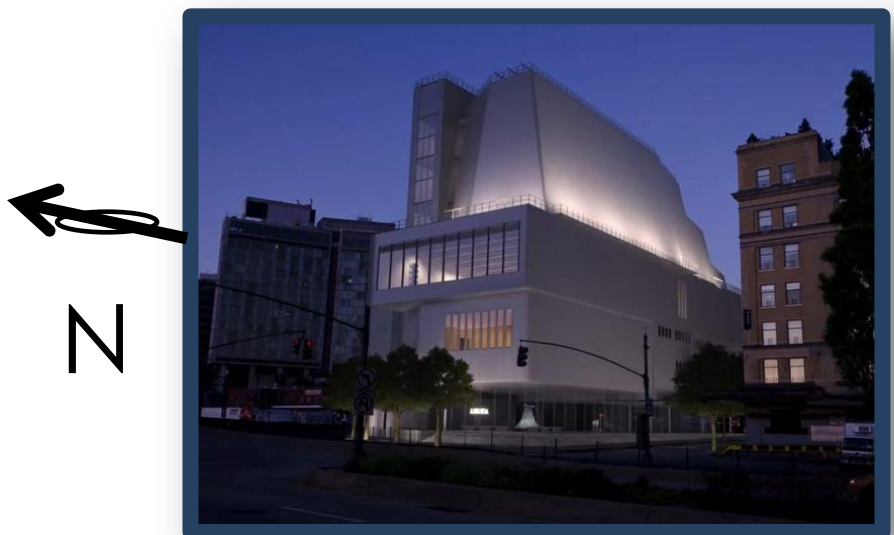




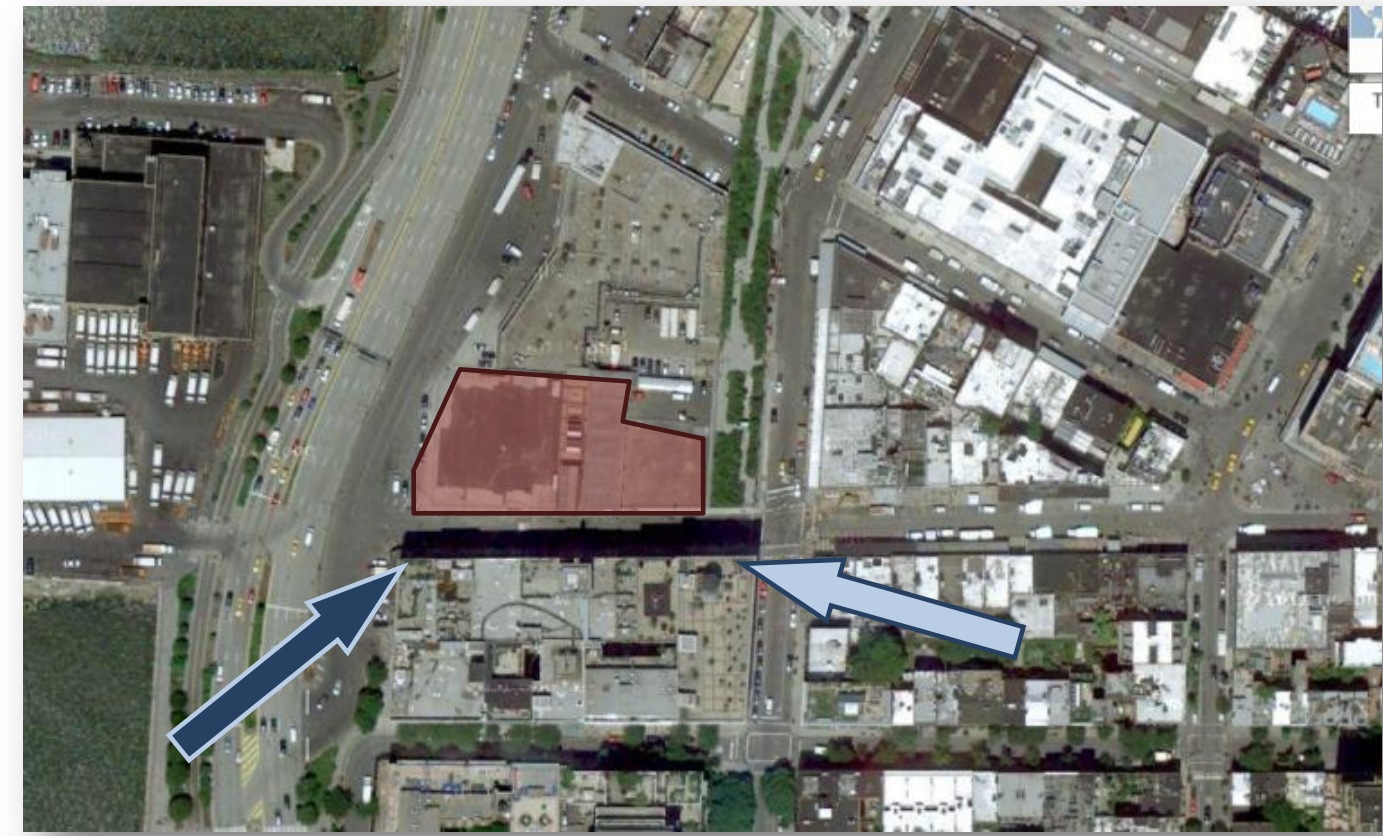
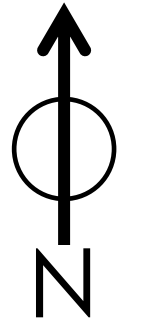


# OVERVIEW

- Building Introduction
  - **Building Overview**
  - Project Team
- Problem Background
- Proposed Structural System
- Architecture Considerations
- Comparative Summary



- Fully-Functional Facility
- 220,000 sq. ft.
- 150' tall
- 9 Stories, Varying Floor Heights
- May 2011 – December 2014
- Design-Bid-Build; Single Prime Contract
- \$266,345,323 GMP



[www.maps.google.com](http://www.maps.google.com)

- Building Introduction
  - Building Overview
  - **Project Team**
- Problem Background
- Proposed Structural System
- Architecture Considerations
- Comparative Summary



## PROJECT TEAM

**Owner:** Not Disclosed

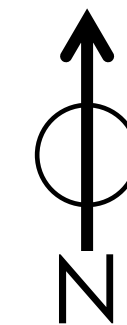
**General Contractor:** Turner Construction

**Design Architect:** Renzo Piano  
Building Workshop

**Executive Architect:** Cooper, Robertson  
& Partners

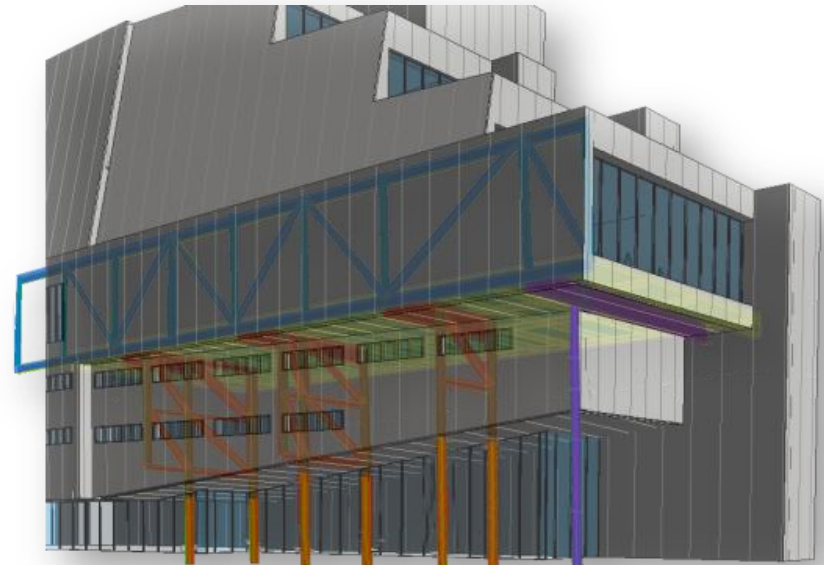
**Structural Engineer:** Robert Silman  
Associates

**Geotechnical:** URS Corporation



[www.maps.google.com](http://www.maps.google.com)

- Building Introduction
- Problem Background
  - Existing System
  - SE Corner Cantilever
  - **Problem Statement**
- Proposed Structural System
- Architecture Considerations
- Comparative Summary

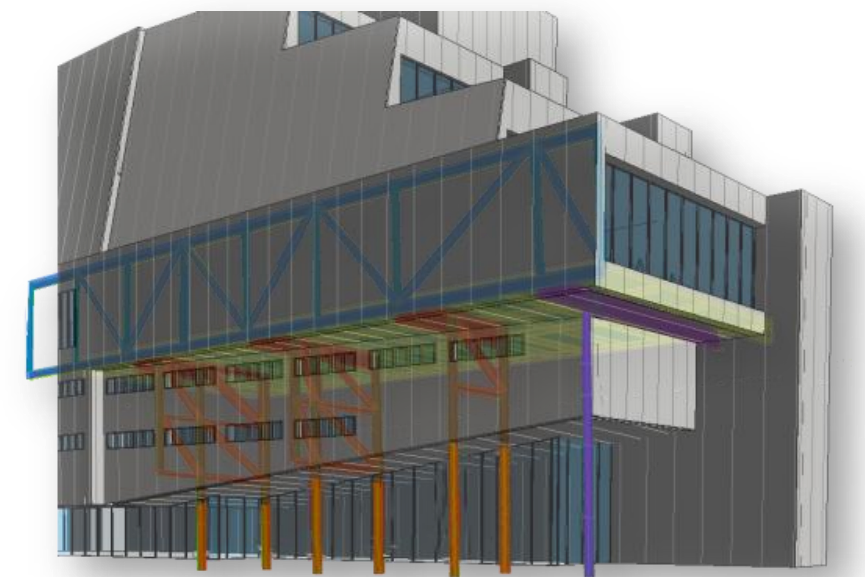


# PROBLEM STATEMENT

- 4 Columns Exposed
- Column 3-M.5 is Last Support
- Exists outside Building Envelope
- Architect Request for Removal



# SOLUTION GOALS



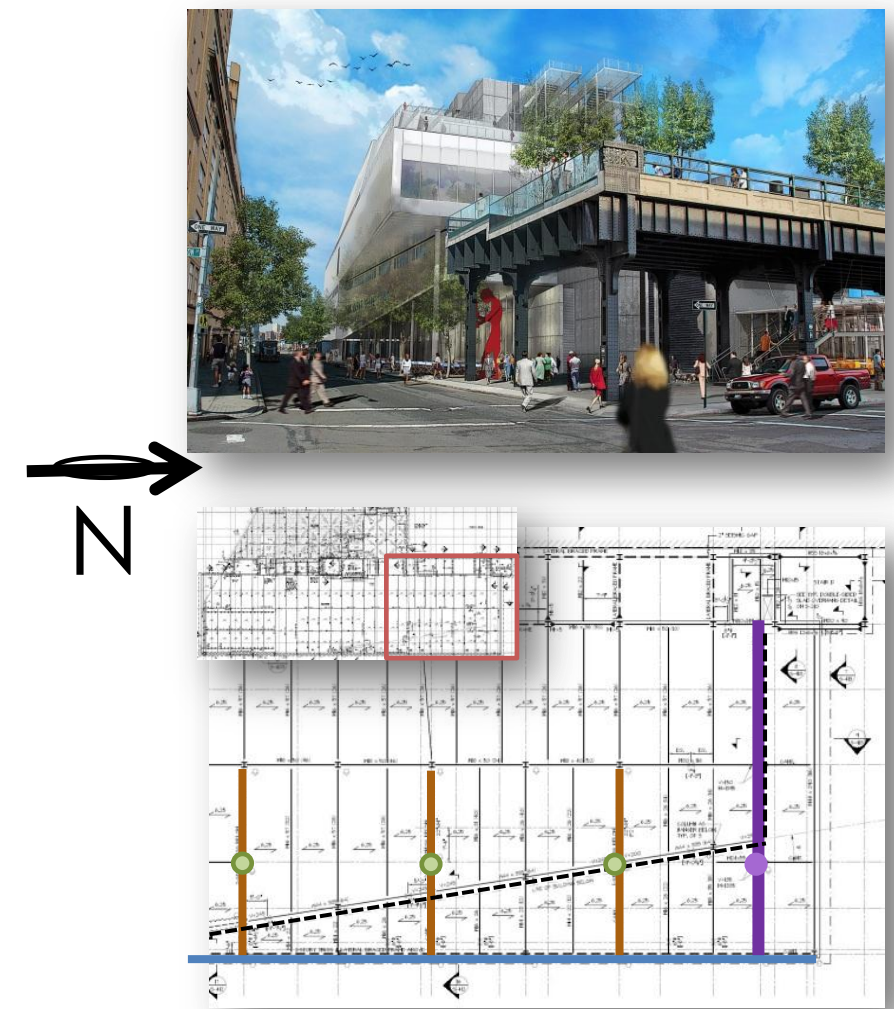
- Building Introduction
- Problem Background
- Proposed Structural System
  - **Solution Goals**
  - Load Path Comparison
  - Design Assumptions
  - Truss X
  - Foundations
  - Deflections
- Architecture Considerations
- Comparative Summary

- Structural Stability without 3-M.5
- Serviceability
- Minimize Architectural Impact
- Minimize Weight and Cost
- Work within Precedence
- Provide Enough Evidence for Decision

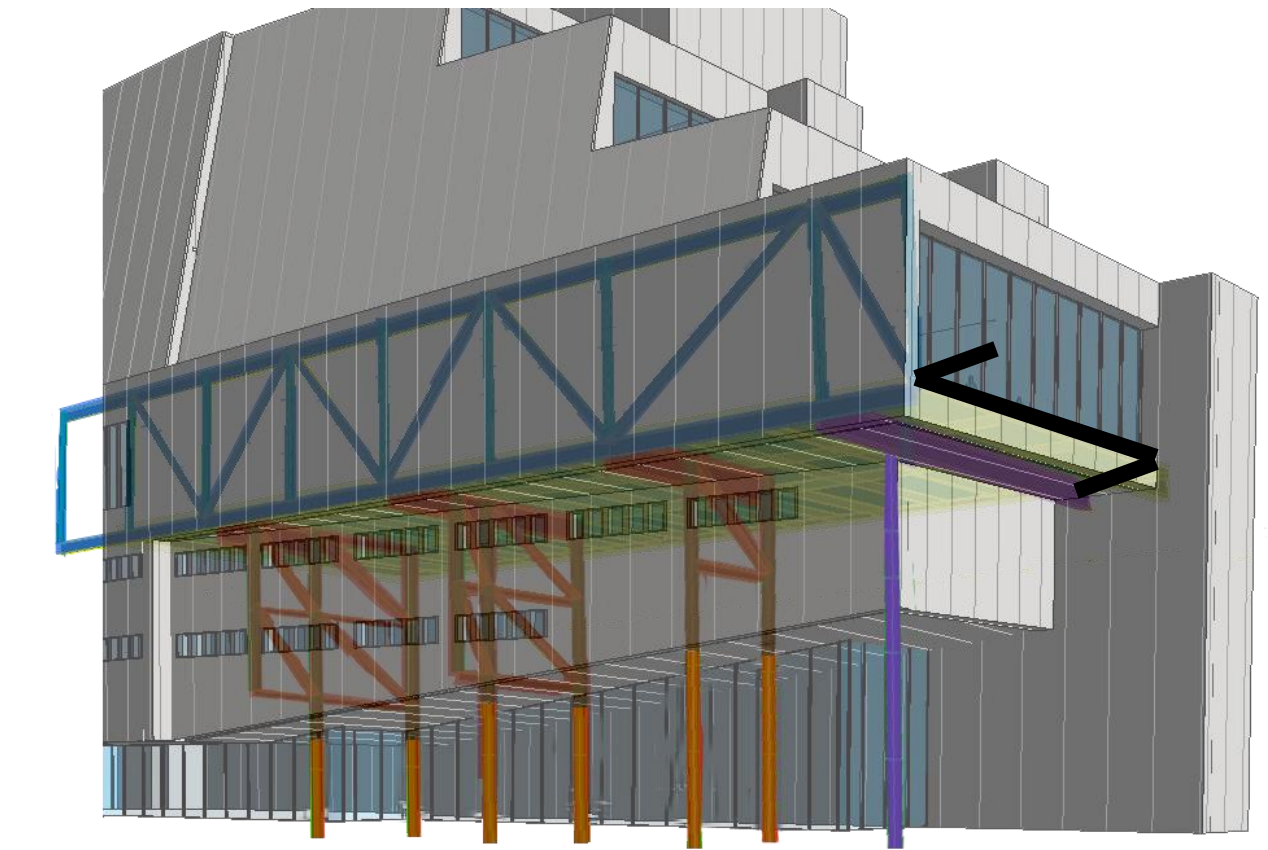


# CURRENT LOAD PATH

- Building Introduction
- Problem Background
- Proposed Structural System
  - Solution Goals
  - **Load Path Comparison**
  - Design Assumptions
  - Truss X
  - Foundations
  - Deflections
- Architecture Considerations
- Comparative Summary

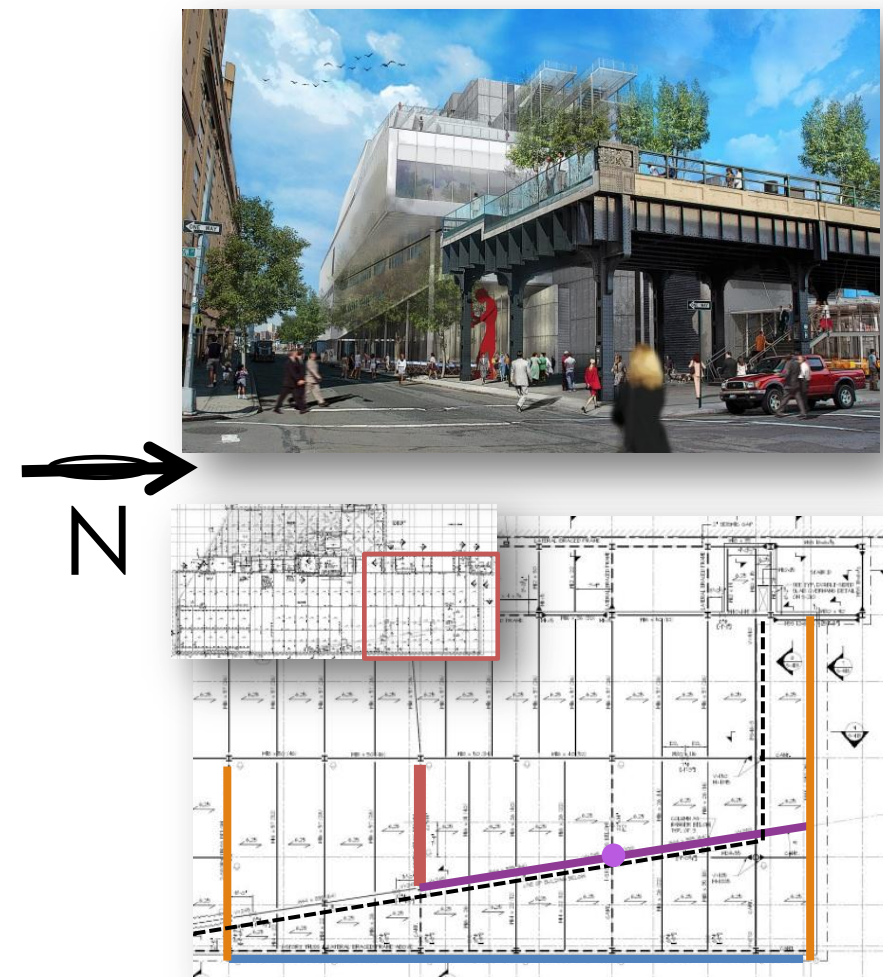


- Floor N-S
- Truss 0.9
- Trusses H, J, L
- 3-M.5, PG46-2

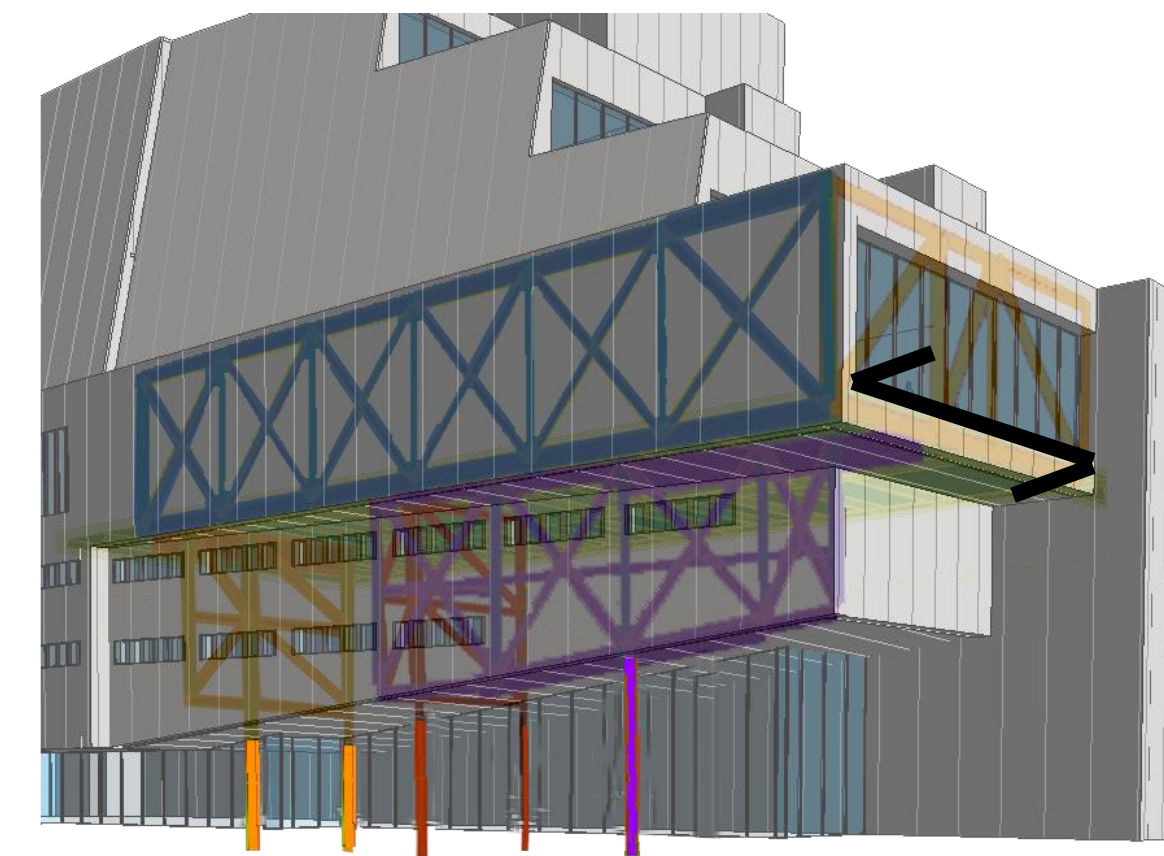


# PROPOSED LOAD PATH

- Building Introduction
- Problem Background
- Proposed Structural System
  - Solution Goals
  - **Load Path Comparison**
  - Design Assumptions
  - Truss X
  - Foundations
  - Deflections
- Architecture Considerations
- Comparative Summary



- Floor N-S
- Truss 0.9
- Trusses H, N.2
- Truss X
- Truss J





## DESIGN ASSUMPTIONS

## MODELING ASSUMPTIONS

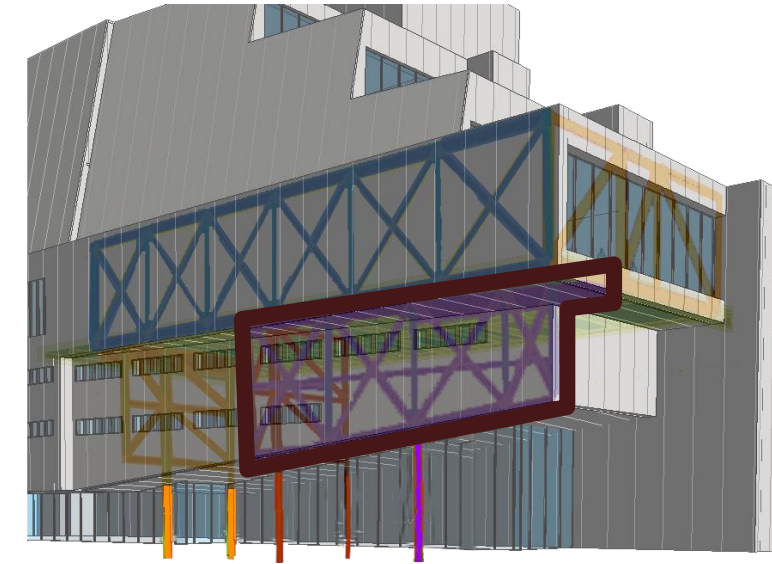
- Building Introduction
- Problem Background
- Proposed Structural System
  - Solution Goals
  - Load Path Comparison
  - **Design Assumptions**
  - Truss X
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- **1.2D + 1.6L + 0.5S**
- No Composite Action
- Concentric Connections
- No Impact on Lateral System

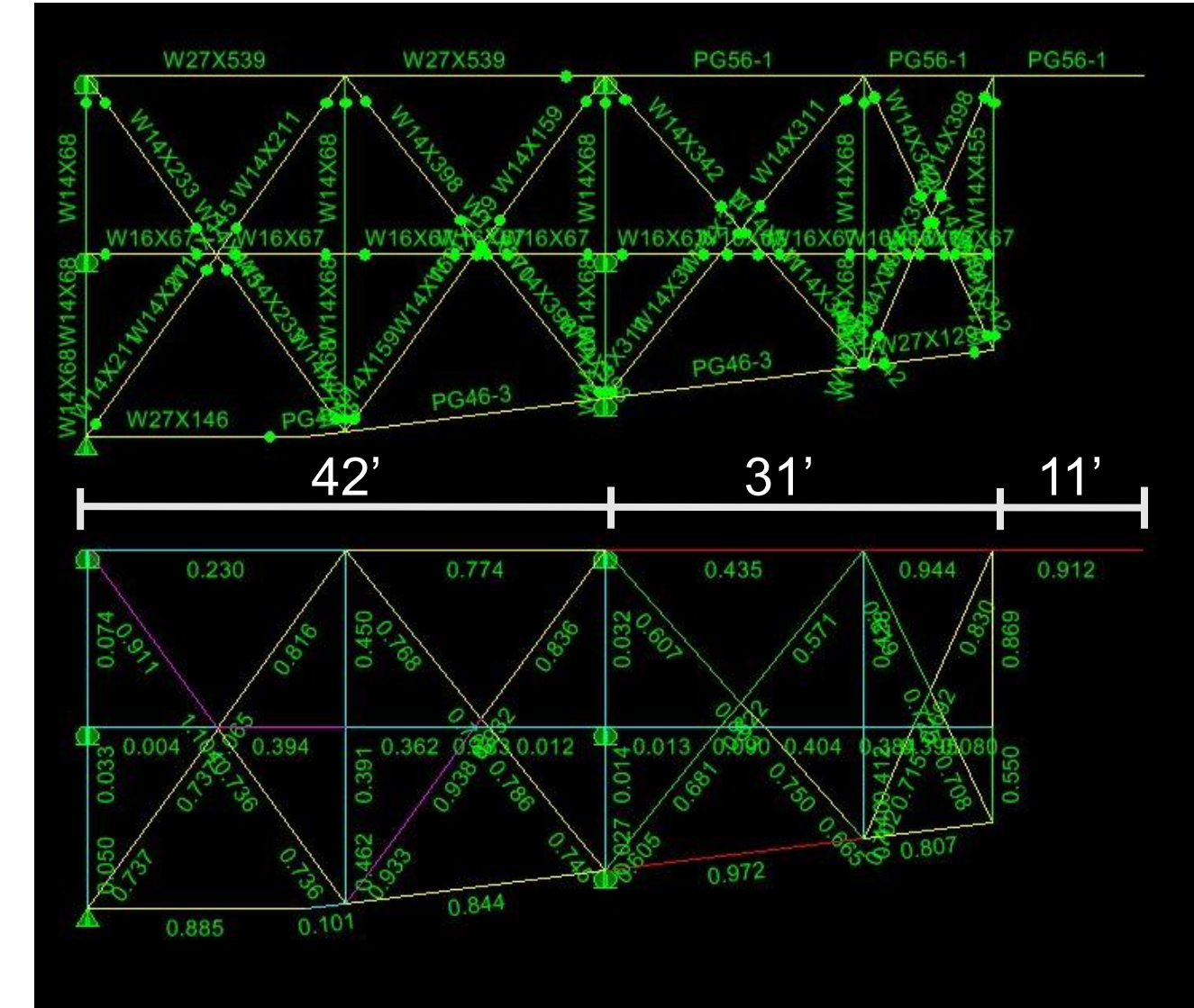
- Individual Models
- Itemized Reactions
- P-D Effects not Considered
- Deflections Checked Separate

# TRUSS X

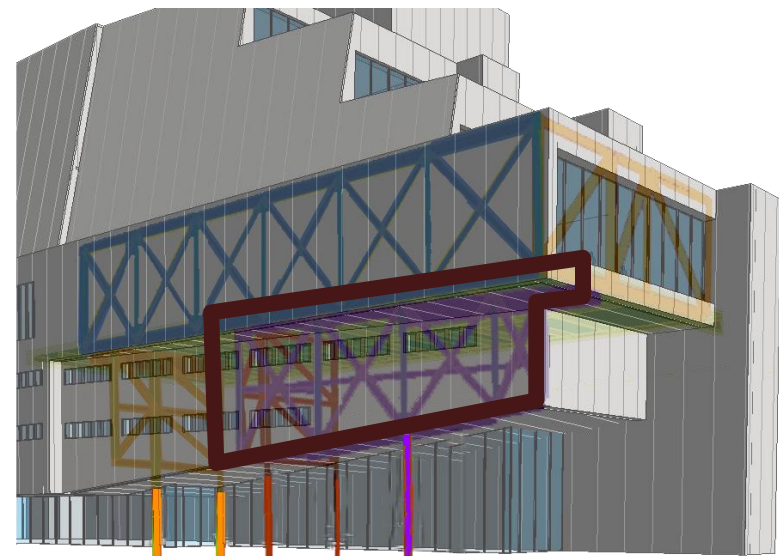
- Building Introduction
- Problem Background
- Proposed Structural System
  - Solution Goals
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  - Truss X
    - **Overview**
    - Custom Members
    - Summary
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- Point Loads at Panel Points
- Level 4 Beams for Bracing
- Truss J resists uplift



- Building Introduction
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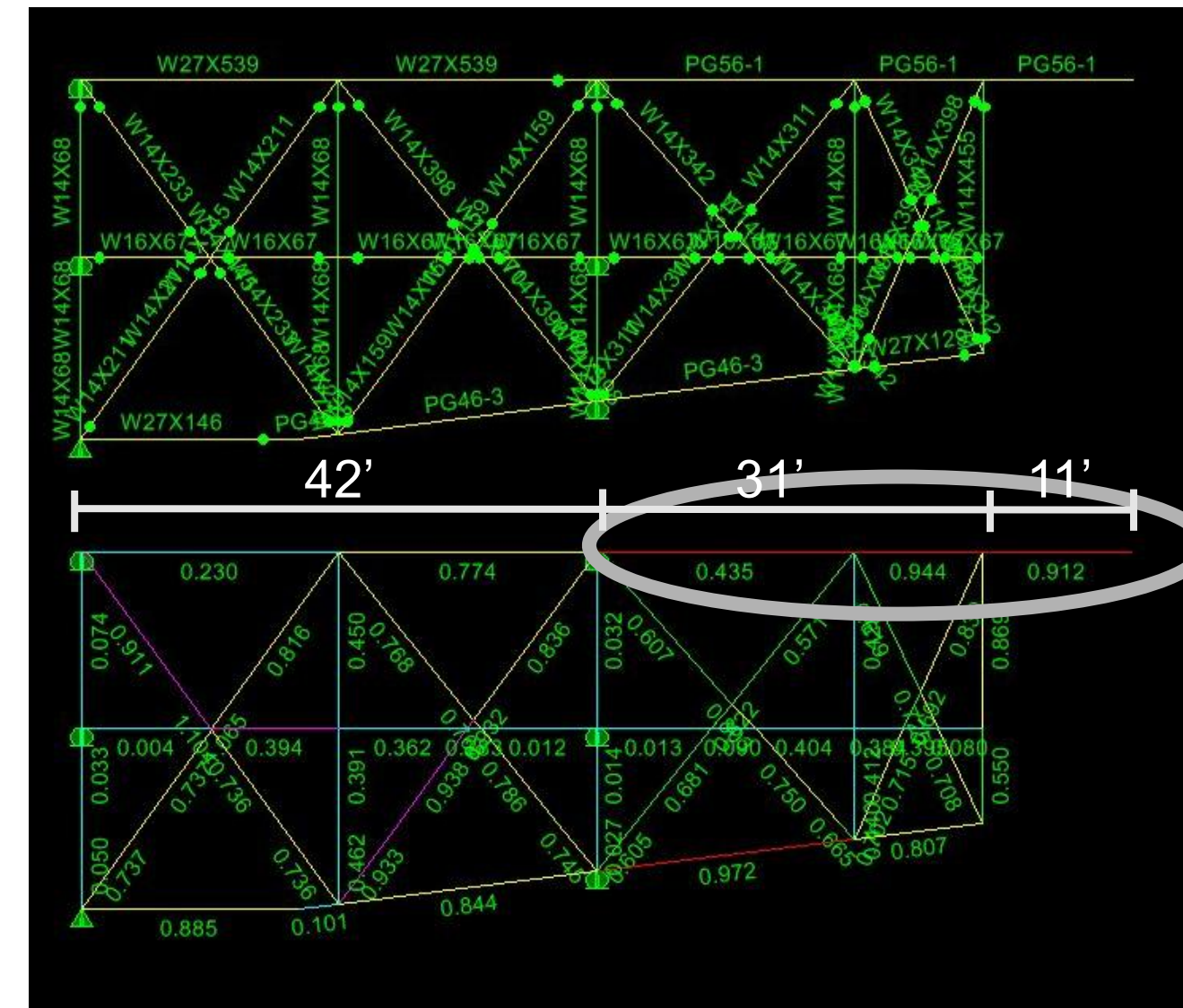


# TRUSS X

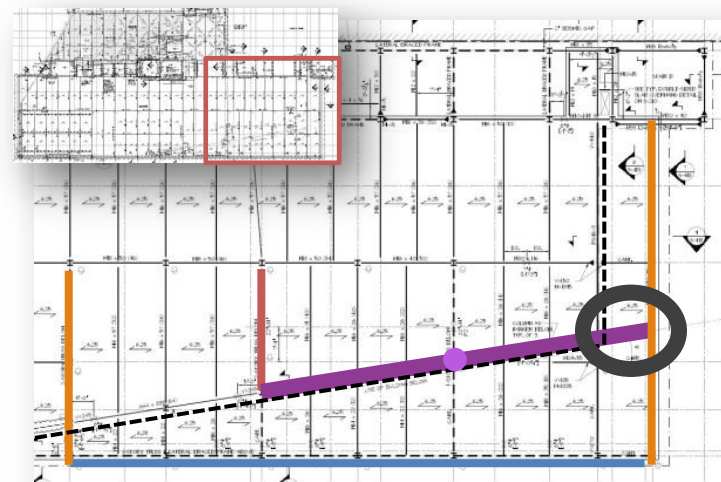
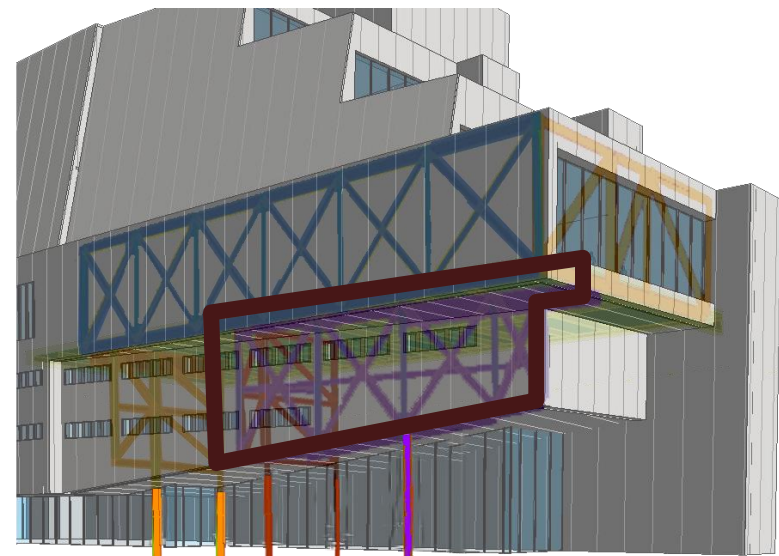
- $M_U = 40,700 \text{ ft-k}$
- $V_U = 3200 \text{ k}$
- $T_U = 1580 \text{ k}$

Member	Moment Capacity				Axial Capacity			
	$\phi M_{nx}$ (ft-k)	$L_p$ (in)	$L_p$ (ft)	Limit State	KL/r	KL/r lim	$\phi P_n$ (k)	Limit State
32.5	12197	473	39	Yielding	19.4	113	8395	Torsion
33-1	12518	479	40	Yielding	19.2	113	9446	Torsion
44-1	20520	609	51	Yielding	14.7	113	9532	Torsion
46-1	12555	648	54	Yielding	SL	SL	SL	SL
46-2	29550	657	55	Yielding	13.7	113	16775	Torsion
46-3	22170	631	53	Yielding	14.1	113	9724	Torsion
72-1	45090	815	68	Yielding	10.7	113	10174	Torsion

Level 5  
 $D = 1340 \text{ k}$   
 $L = 945 \text{ k}$   
 $S = 2 \text{ k}$   
 $P_U = 3200 \text{ k}$



- Building Introduction
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  - Load Path Comparison
  - Design Assumptions
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    - **Custom Members**
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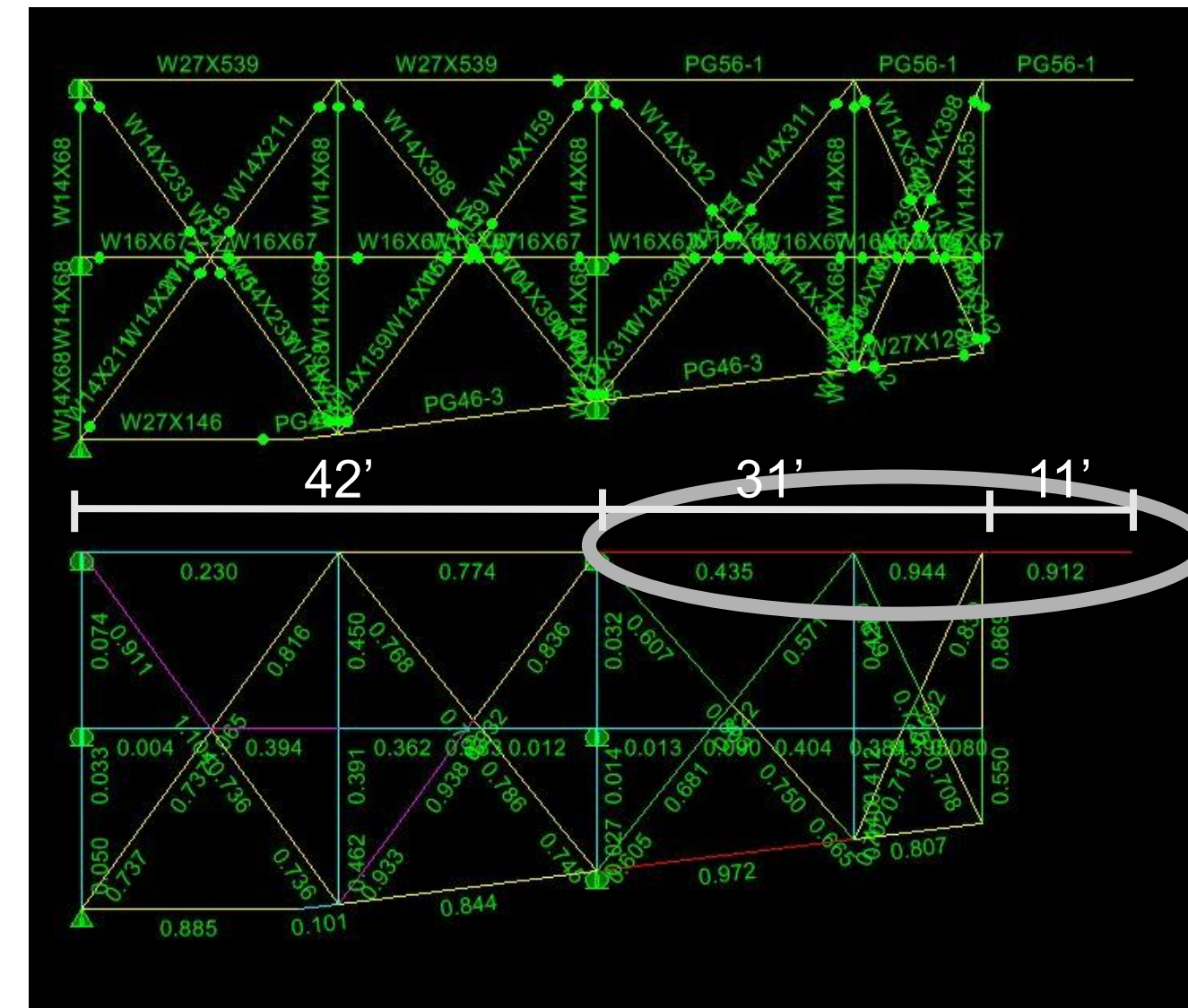


# TRUSS X

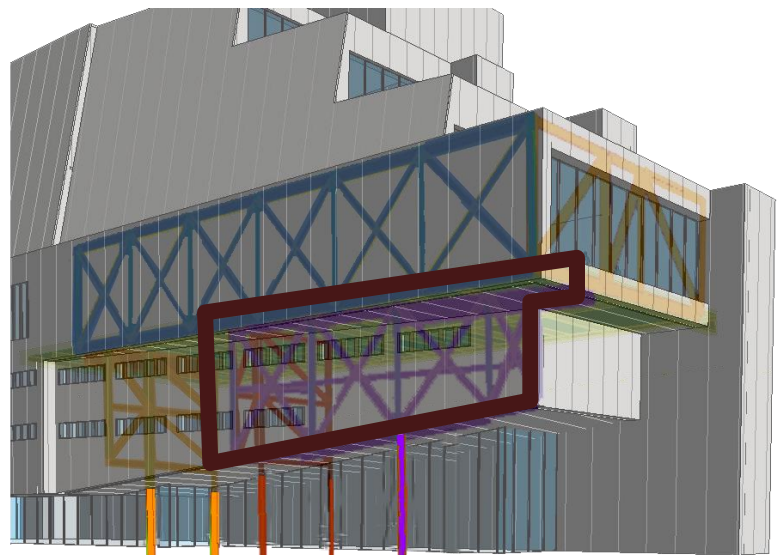
- $M_U = 40,700 \text{ ft-k}$
- $V_U = 3200 \text{ k}$
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 $D = 1340 \text{ k}$   
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 $P_U = 3200 \text{ k}$



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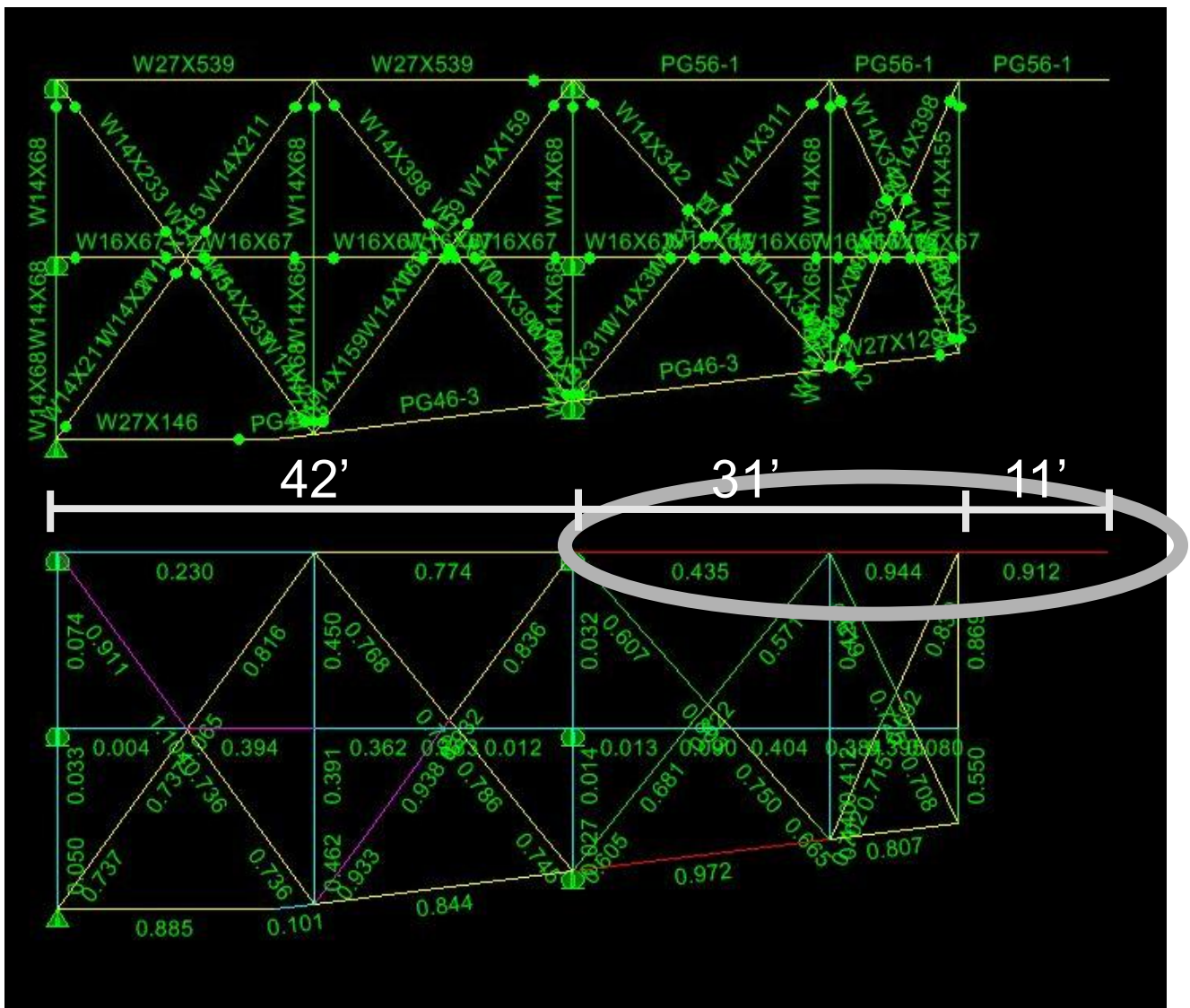


# TRUSS X

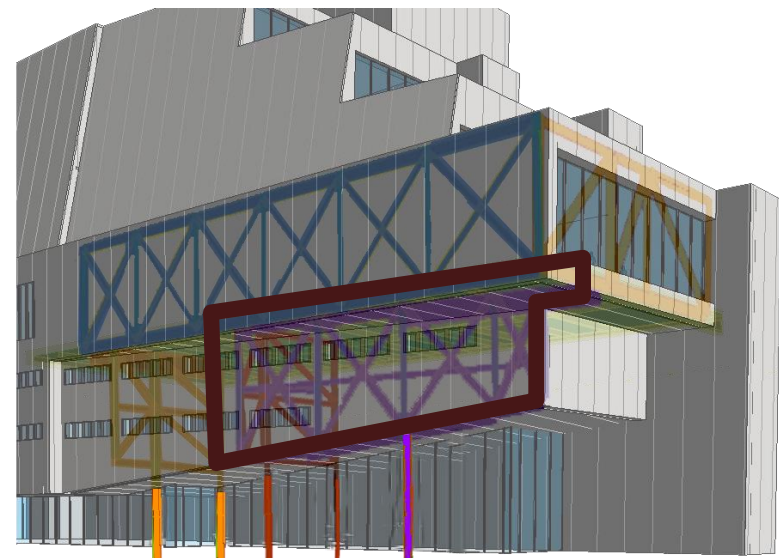
- $M_U = 40,700$  ft-k
- $V_U = 3200$  k
- $T_U = 1580$  k
- Achieves 94% Efficiency

	PG56-1		Capacity	
<b>Lb</b>	20	ft	$\phi M_n$	41571 ft-k
<b>D</b>	56	in	$\phi V_n$	3402 k
<b>B</b>	24	in	$\phi T_n$	25245 k
<b>tf</b>	10	in	$\phi P_n$	27541 k
<b>tw</b>	2.25	in		

Level 5  
 $D = 1340$  k  
 $L = 945$  k  
 $S = 2$  k  
 $P_U = 3200$  k

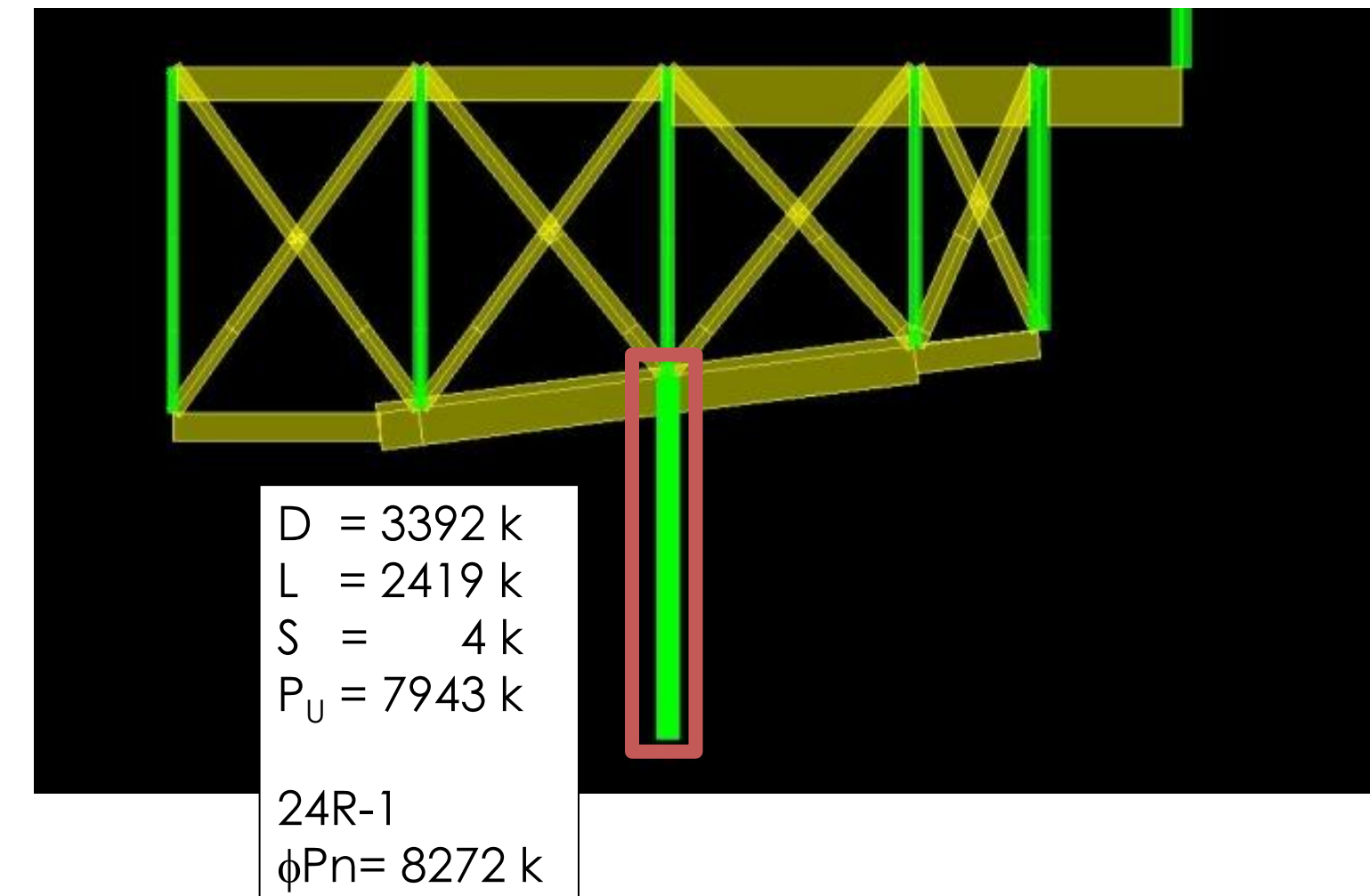


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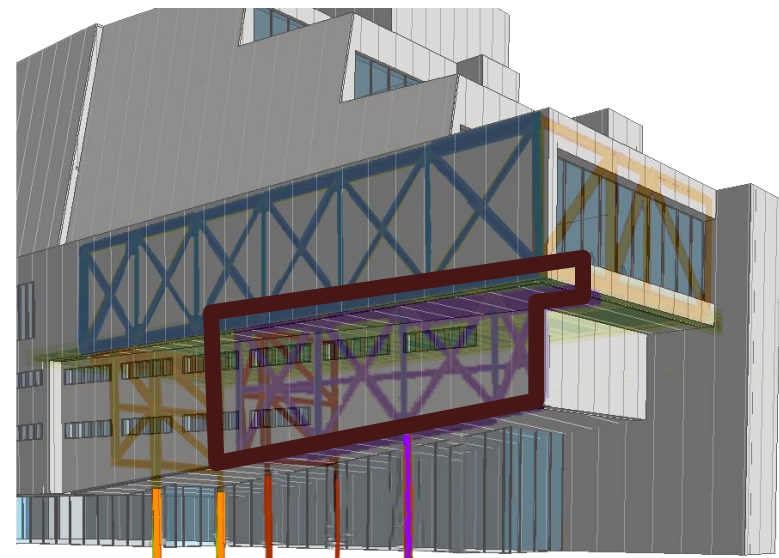


# TRUSS X

Shape	Lu	$\phi Mn$	$\phi Pn$	$\phi Tn$
15A	25	750	2421	2295
15B	25	624	2161	1685
22	25	1714	4389	3545

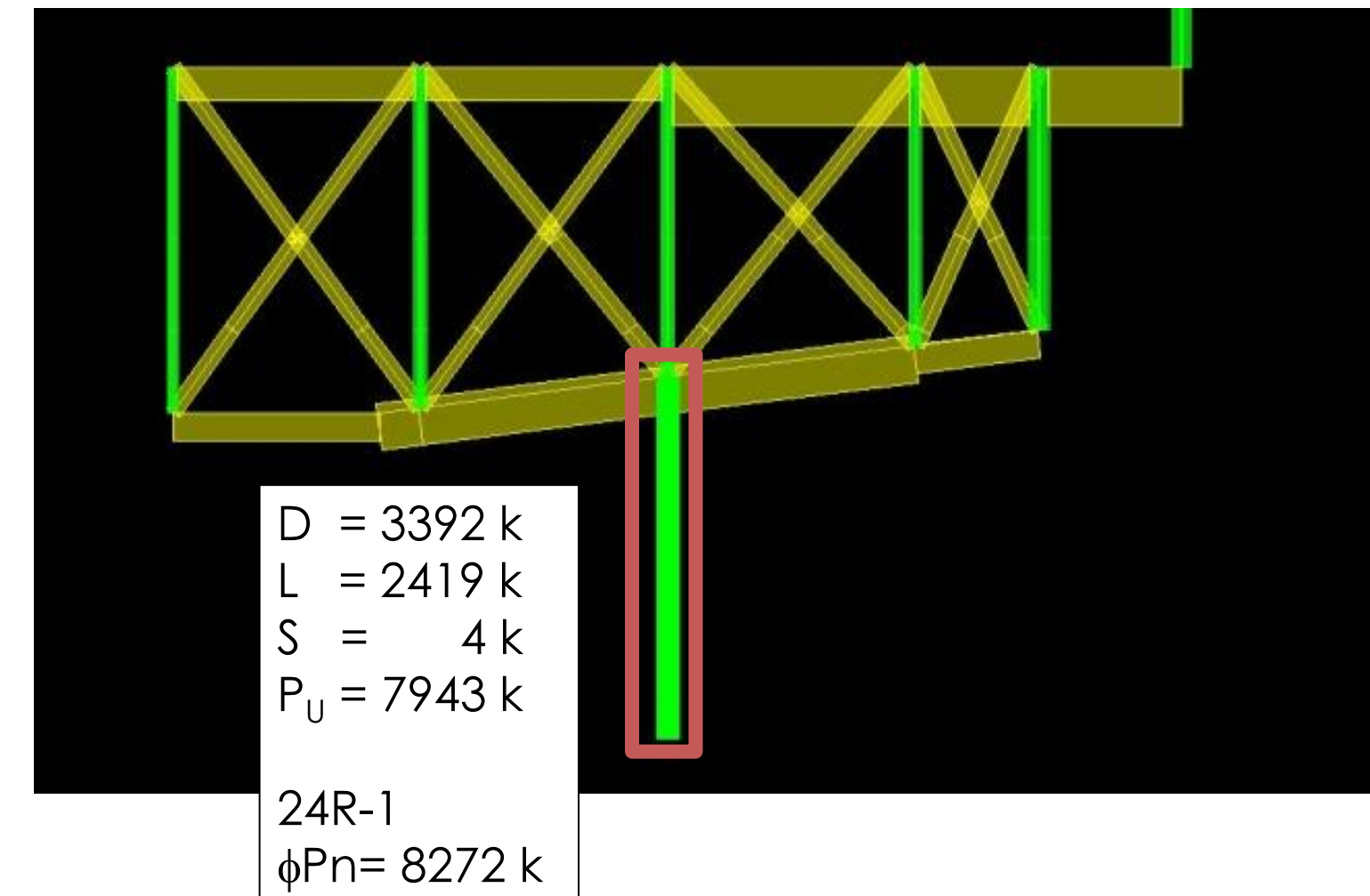


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- Problem Background
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  - Load Path Comparison
  - Design Assumptions
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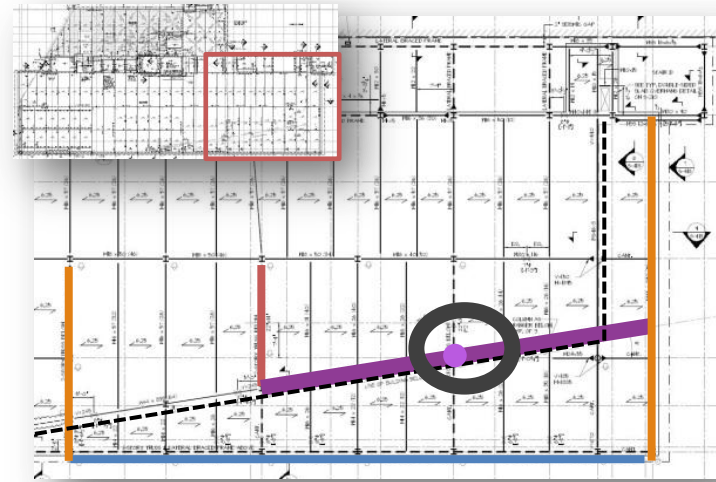
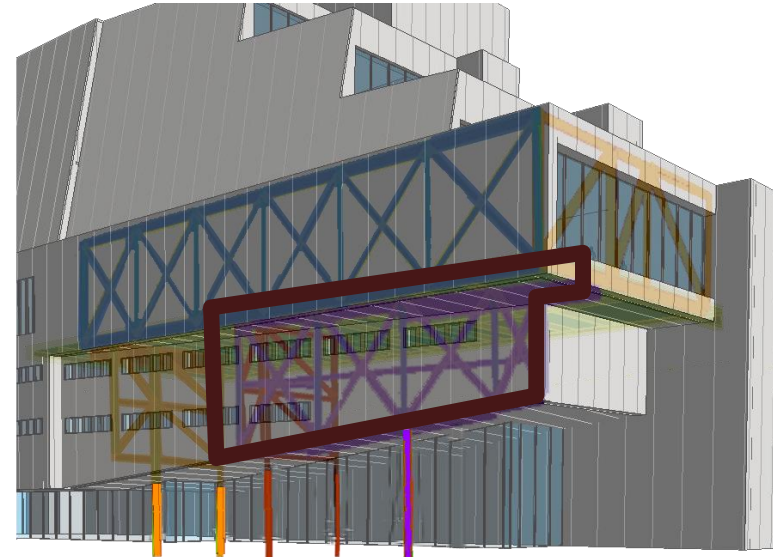


# TRUSS X

Pipe	
Do	24 in
t	1.75 in
Concrete	
f'c	15000 psi
fy	150 ksi
no.	11
n	16
Capacity	
$\phi P_n$	8272 k
$\phi T_n$	8053 k
$\phi M_n$	2754 ft-k

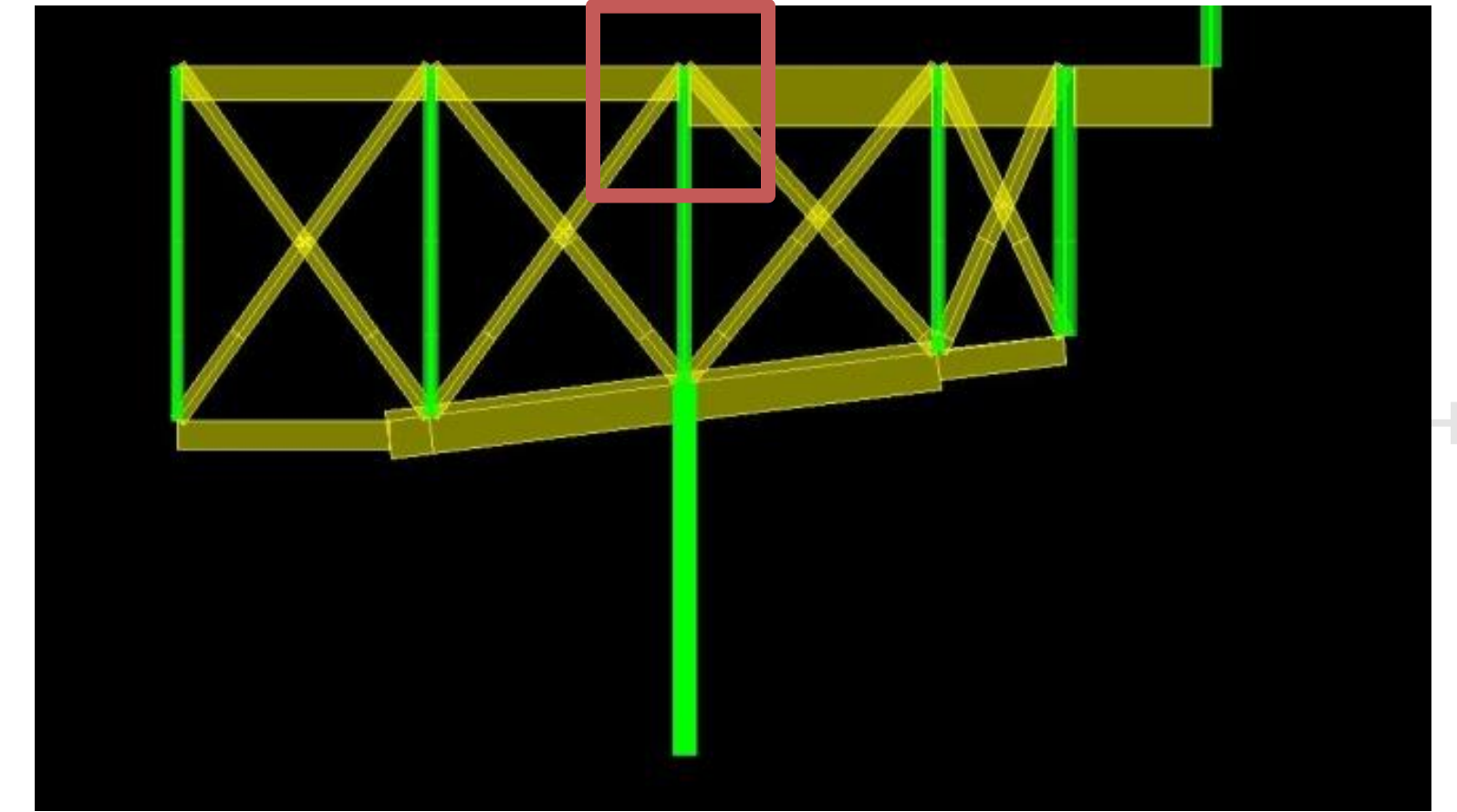


- Building Introduction
- Problem Background
- Proposed Structural System
  - Solution Goals
  - Load Path Comparison
  - Design Assumptions
  - Truss X
    - Overview
    - Custom Members
    - **Summary**
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## TRUSS X

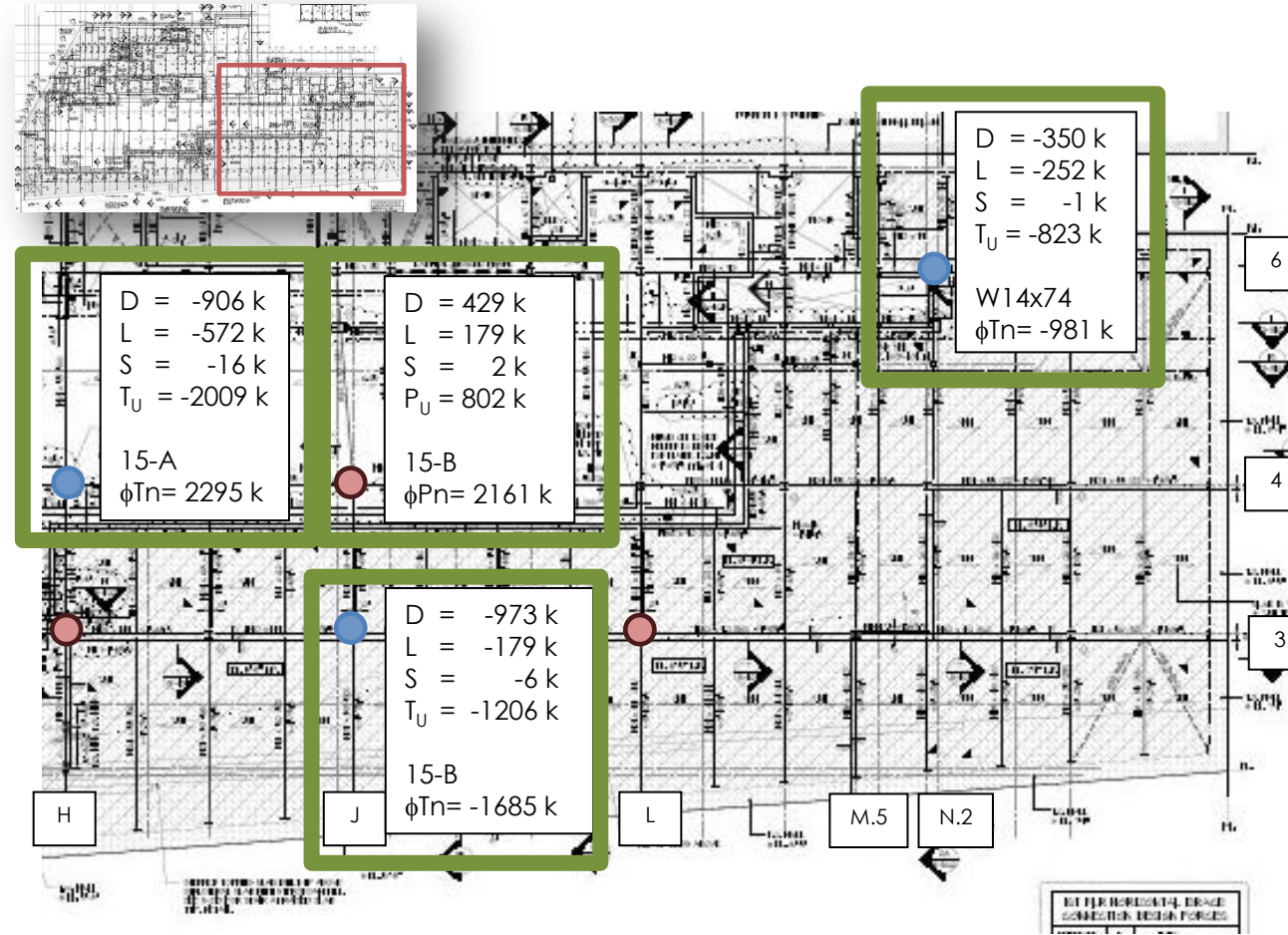
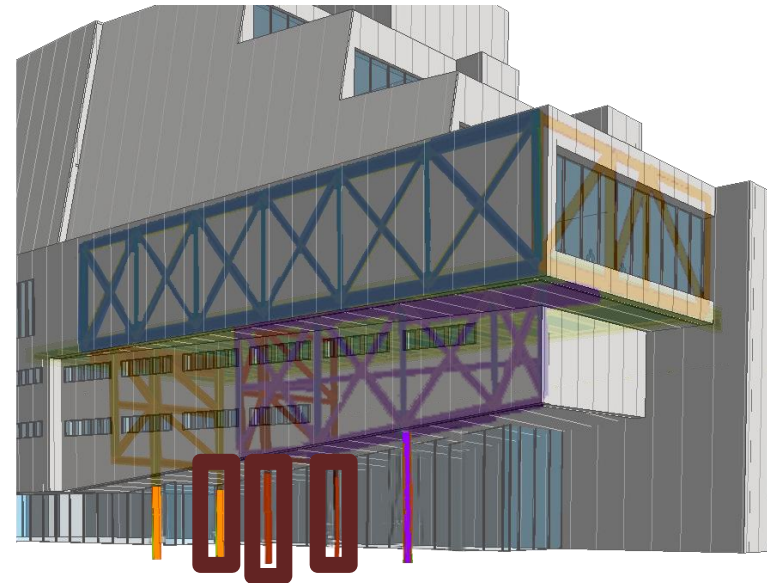
- Multiple Custom Sections
  - PG56-1
  - PG46-3
  - 24R-1
- W14x 68 – W14x455 – W27x539
- Eccentricity Issues
- Final Weight : 121.6 t





# TRUSS SUPPORTS

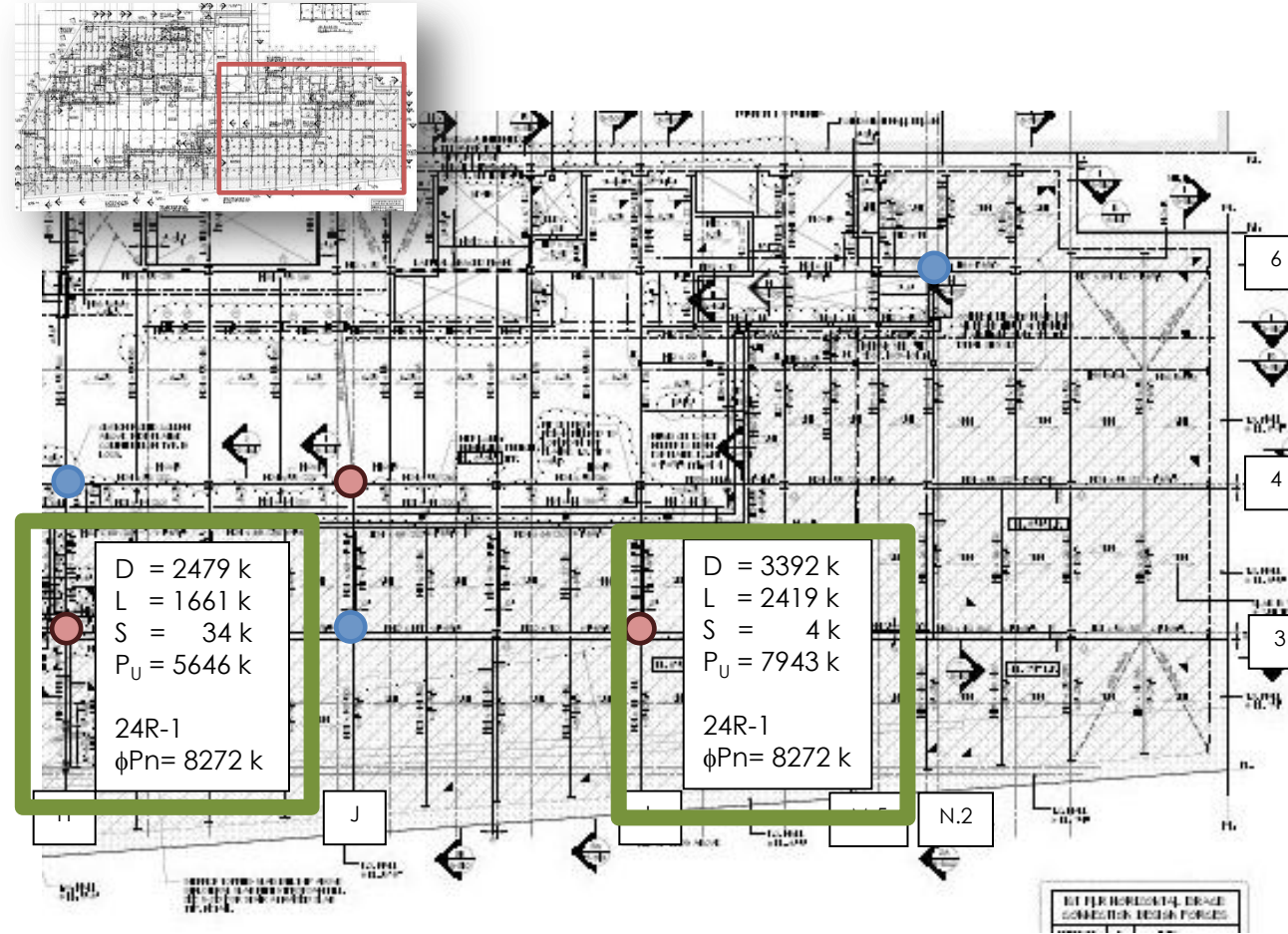
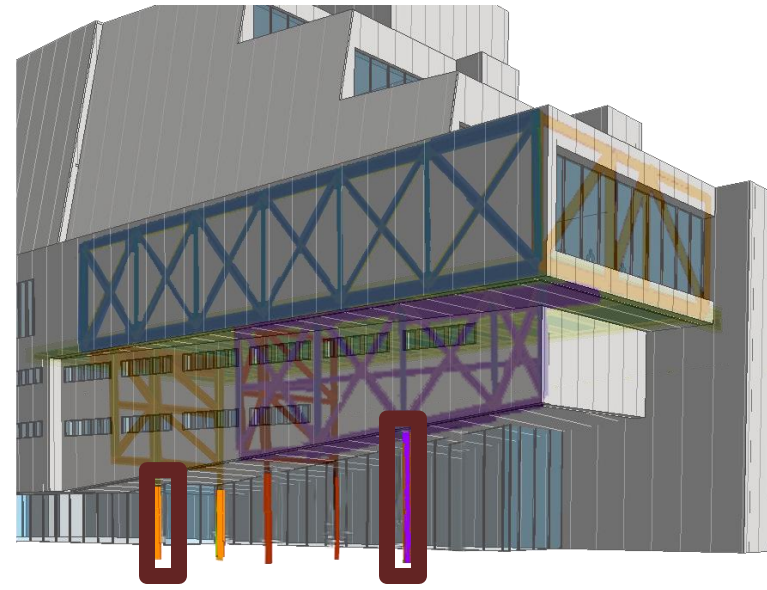
- Building Introduction
- Problem Background
- Proposed Structural System
  - Solution Goals
  - Load Path Comparison
  - Design Assumptions
  - Truss X
  - Foundations
    - **Truss Supports**
    - Caissons
  - Deflections
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Shape	Lu	φMn	φPn	φTn
<b>15A</b>	25	750	2421	2295
<b>15B</b>	25	624	2161	1685
<b>22</b>	25	1714	4389	3545

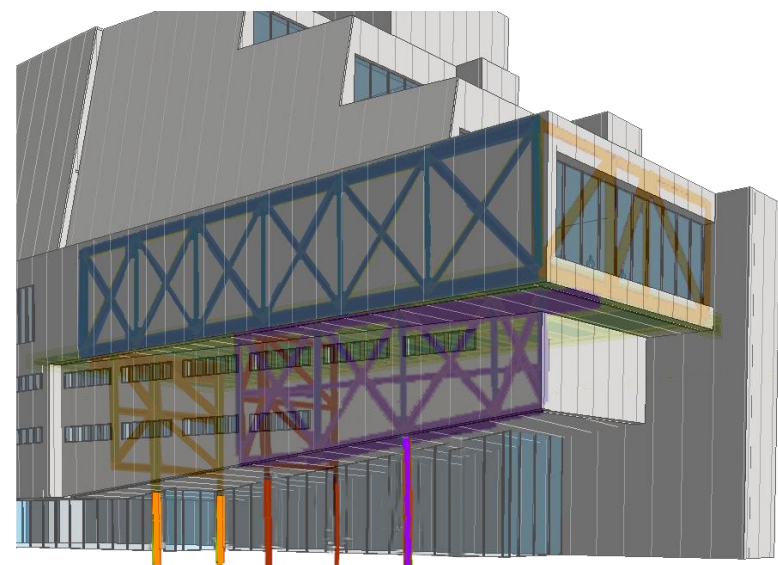
# TRUSS SUPPORTS

- Building Introduction
- Problem Background
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  - Solution Goals
  - Load Path Comparison
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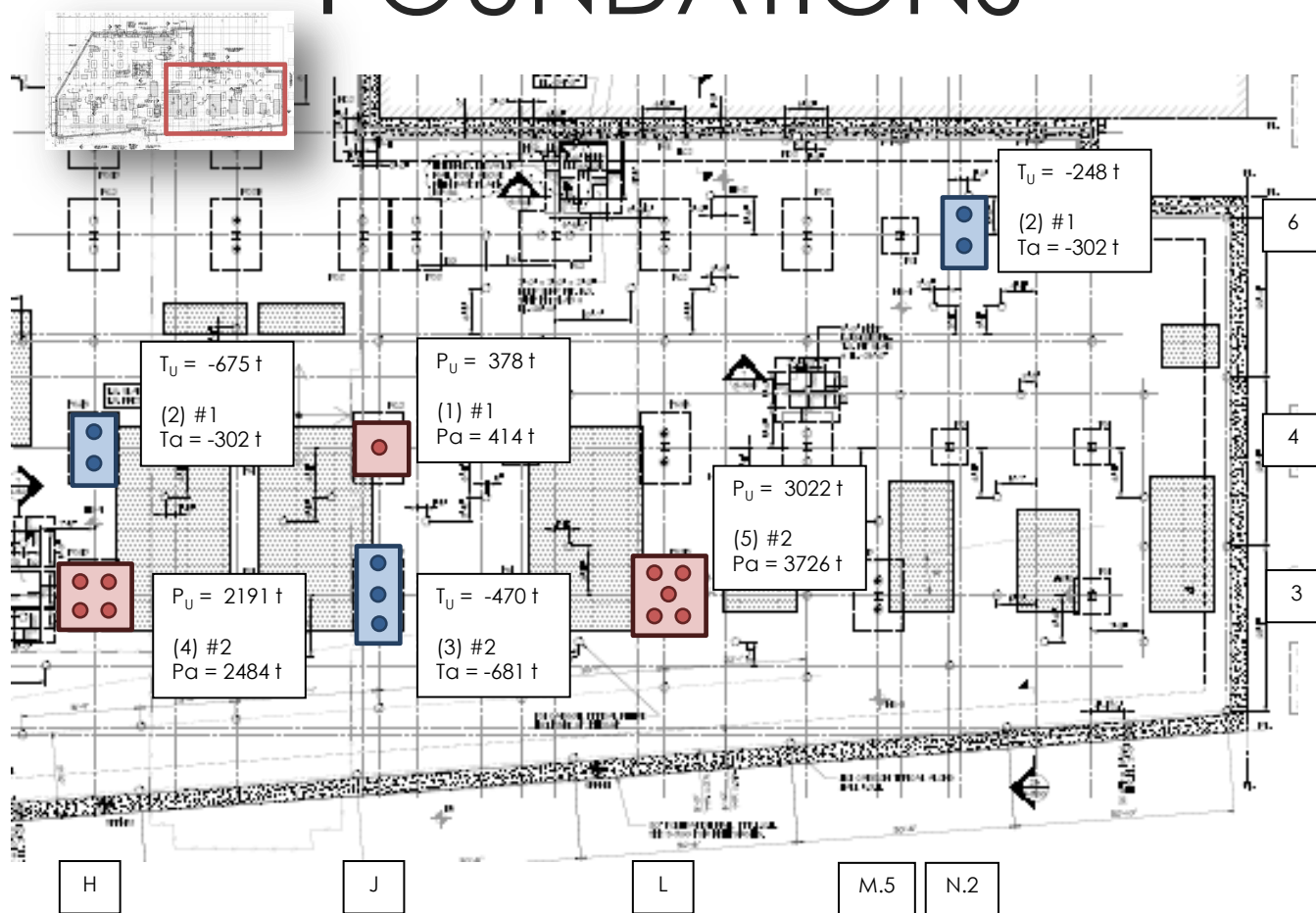


Pipe	
Do	24 in
t	1.75 in
Concrete	
f'c	15000 psi
fy	150 ksi
no.	11
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Capacity	
phi Pn	8272 k
phi Tn	8053 k
phi Mn	2754 ft-k

- Building Introduction
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    - **Caissons**
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# FOUNDATIONS

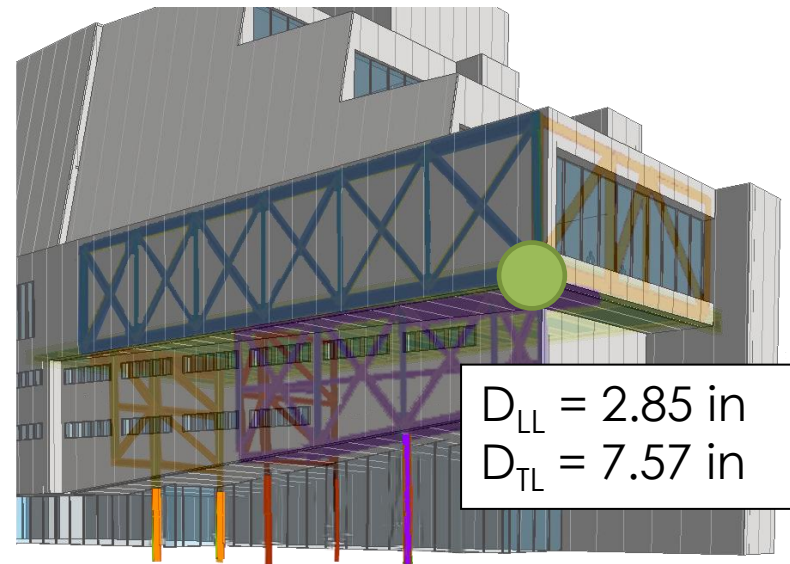


CAISSON SCHEDULE							
MARK	NOTES	CAISSON O.D.	CASING	CAISSON REINF. VERT. BARS	MIN. DEPTH OF ROCK SOCKET*	TENSION CAPACITY (TONS)	COMPRESSION CAPACITY (TONS)
1	TYPICAL, @PC/WALL	13.375"	1/2" THICK $F_y=80$ ksi	1 #24	11'-0"	151	414
2	HIGH CAPACITY	13.375"	1/2" THICK $F_y=80$ ksi	2 #24	16'-0"	227	621
3	TCI - NOT @PC/WALL	9.875"	1/2" THICK $F_y=80$ ksi	1 #24	15'-0"	151	91

**D+H+F+L+S+T**

# DEFLECTIONS & SERVICEABILITY

- Building Introduction
- Problem Background
- Proposed Structural System
  - Solution Goals
  - Load Path Comparison
  - Design Assumptions
  - Truss X
  - Foundations
  - **Deflections**
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- Comparative Summary

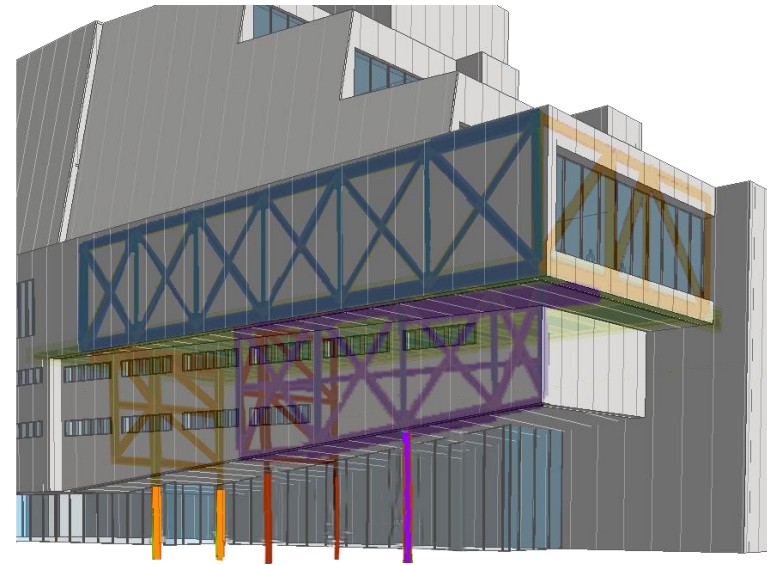


- Cantilever = 45'-10"
- IBC Chapter 16
  - Live Load =  $(\frac{1}{2}) \times 1/360 = 1/180$
  - Total Load =  $(\frac{1}{2}) \times 1/240 = 1/120$

Cantilever			
LL	Dalw	TL	Dalw
2.85	3.06	7.57	4.59

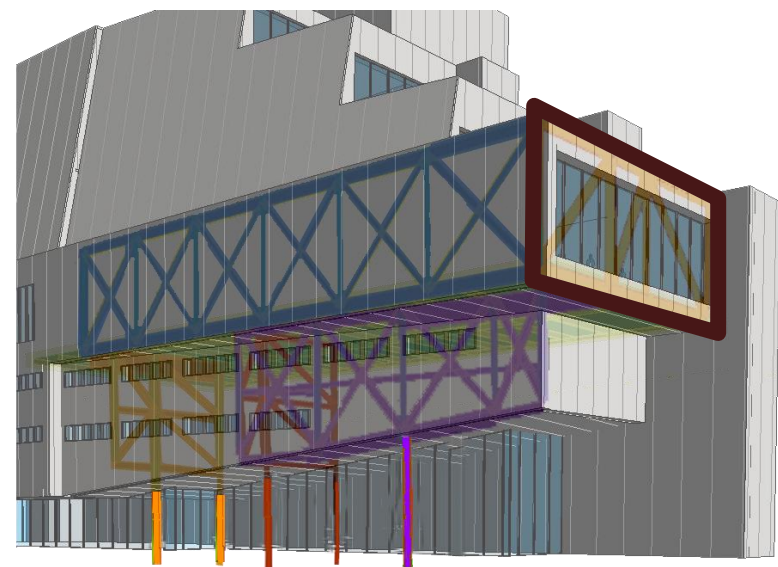
# ARCHITECTURE CONSIDERATIONS

- Building Introduction
- Problem Background
- Proposed Structural System
- **Architecture Considerations**
- Comparative Summary

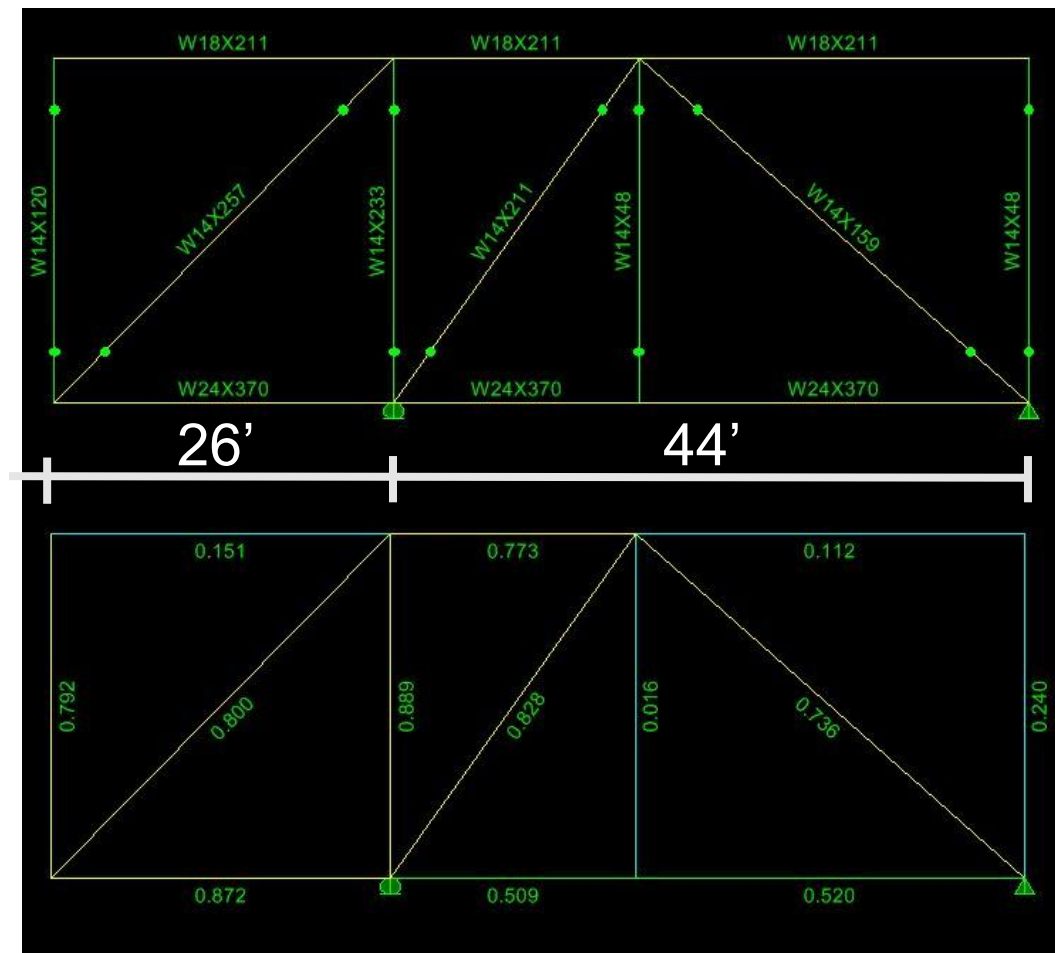


- Minimize Impact of Architecture
  - Open Office Spaces
  - **Panel Module Alignment**
  - Architectural Envelope
  - Façade and Glazing

- Building Introduction
- Problem Background
- Proposed Structural System
- **Architecture Considerations**
- Comparative Summary

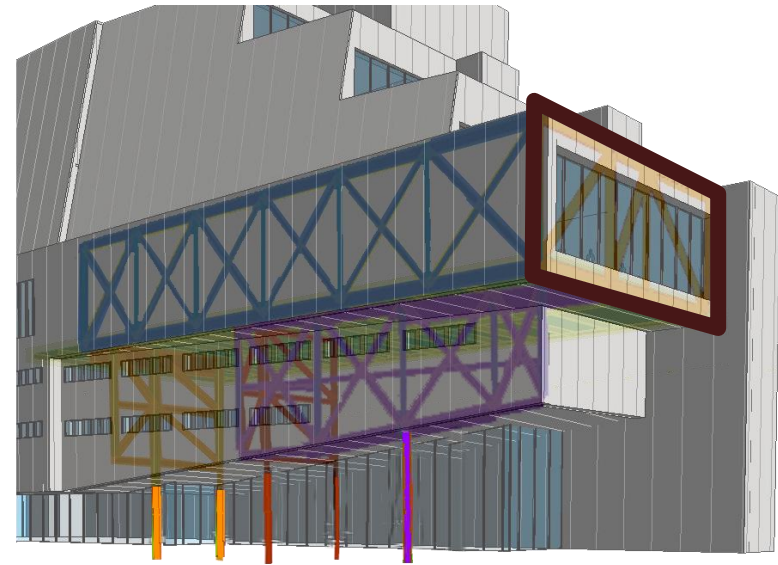


# PANEL MODULE ALIGNMENT



AMERICAN ART MUSEUM

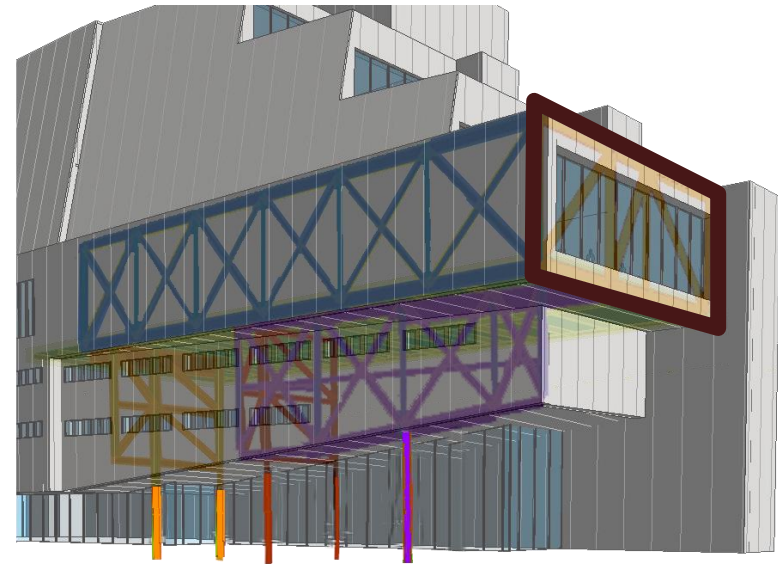
- Building Introduction
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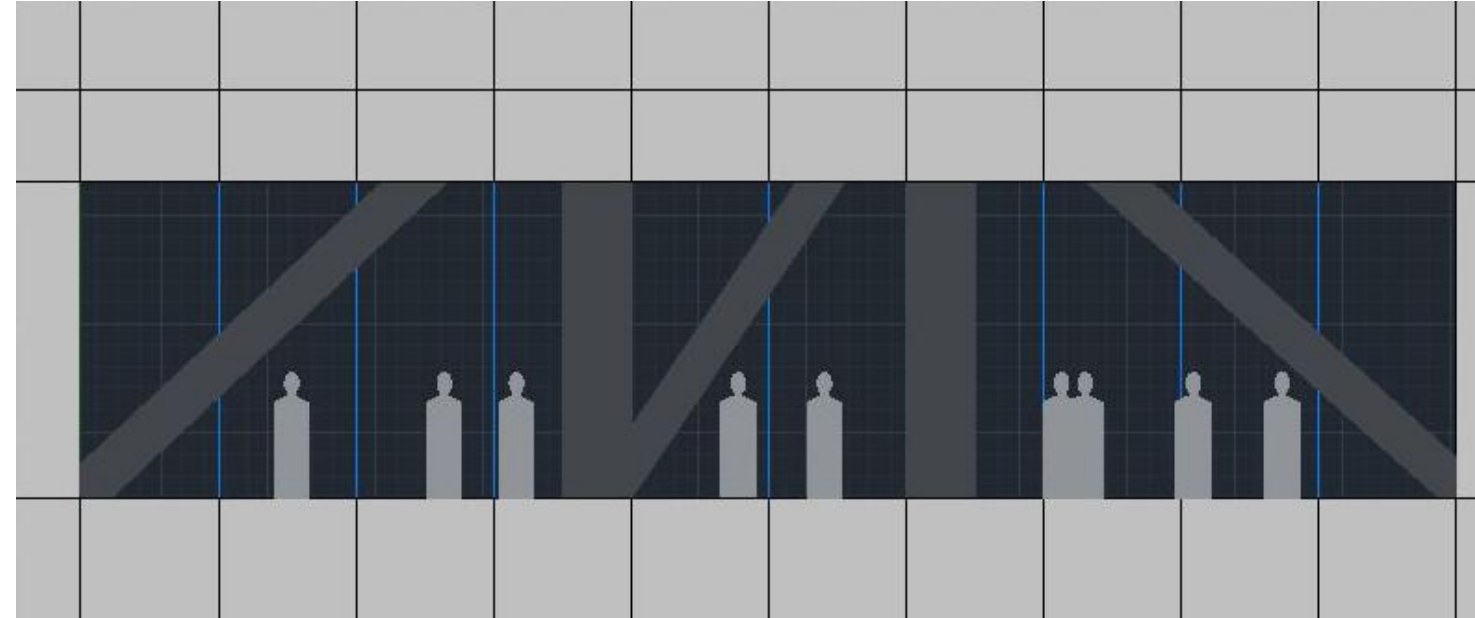
## PANEL MODULE ALIGNMENT



- Building Introduction
- Problem Background
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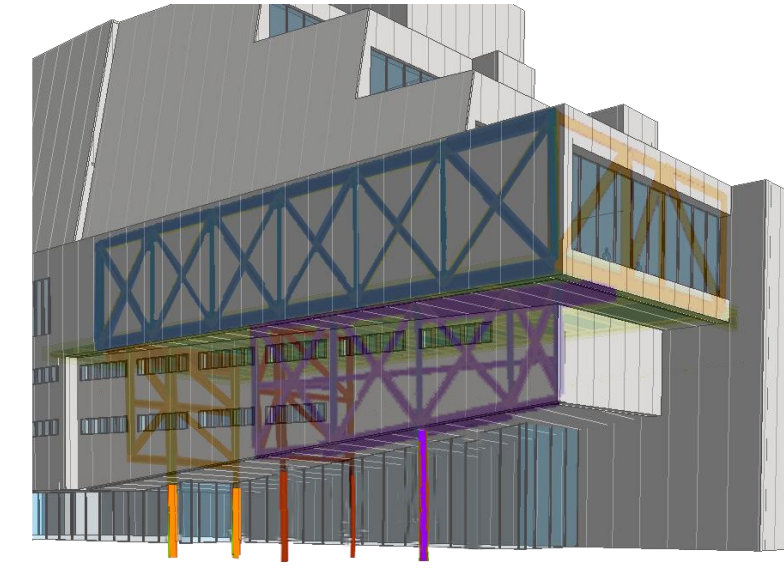
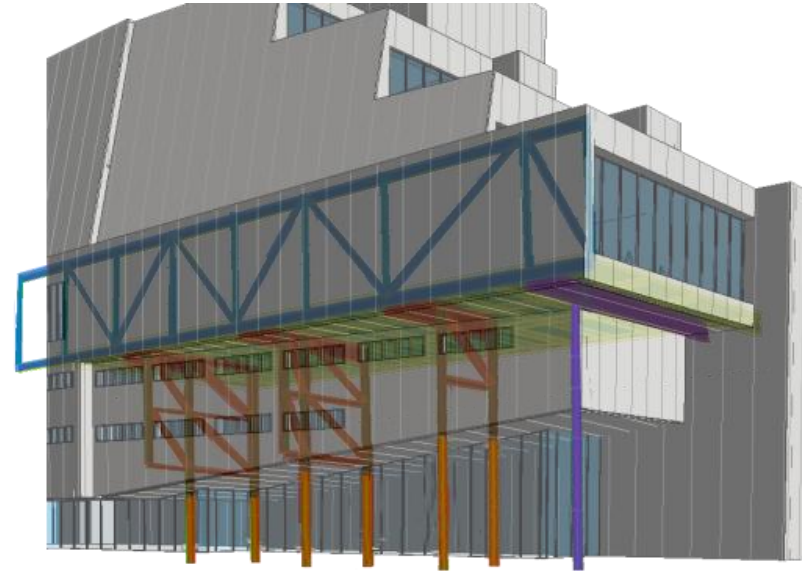
## PANEL MODULE ALIGNMENT





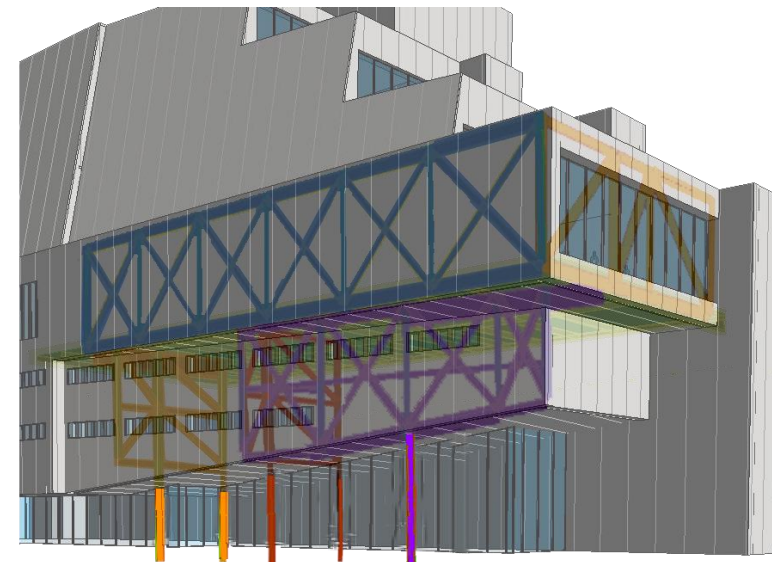
# COMPARATIVE SUMMARY

- Building Introduction
- Problem Background
- Proposed Structural System
- Architecture Considerations
- **Comparative Summary**



Structural Concerns	Current Design	Proposed Design
Remove Column 3-M.5	NO	YES
No. of Steps in Load Path	2	4
Max. Element Weight	45.1 t	121.6 t
Overall Weight	199.5 t	297.1 t
Max. Pile Group	2	5
No. of Custom Sections	10	12
Columns Max.O.D.	22"	24"
Max. f'c	5,000	15,000
Max. Total Deflection	-	-7.57 in
Acceptable Deflections	YES	NO
Architectural Concerns	Current Design	Proposed Design
Gallery Interference	NO	Truss N.2
Wall X Interference	NO	Truss X
Remove Truss L	NO	YES
Maintain Web Openings	YES	YES
Maintain Building Envelope	YES	YES
Construction Concerns	Current Design	Proposed Design
No. of Long Trusses	1	2
Cost of Superstructure	\$3,928,000	\$5,946,000
Cost of Foundations	\$238,000	335,000
Total Structural Cost	\$4,166,000	\$6,281,000
Total Difference		\$2,115,000

- Building Introduction
- Problem Background
- Proposed Structural System
- Architecture Considerations
- **Comparative Summary**



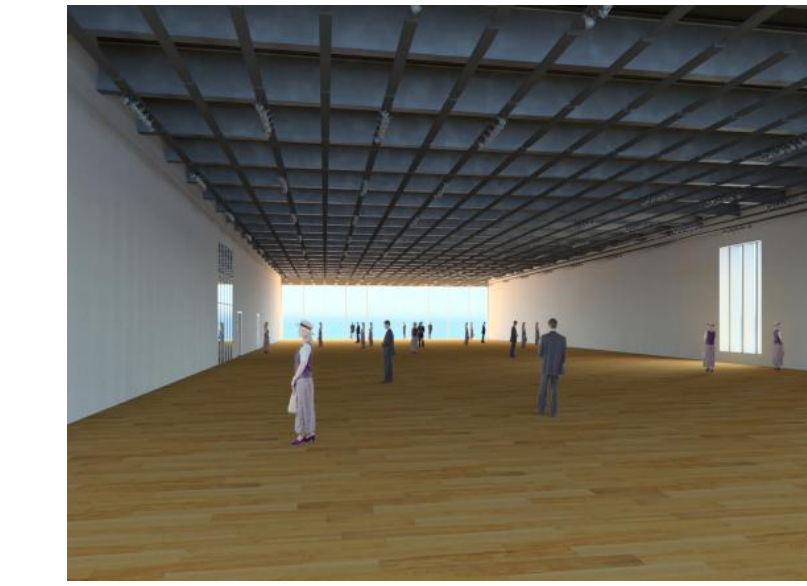
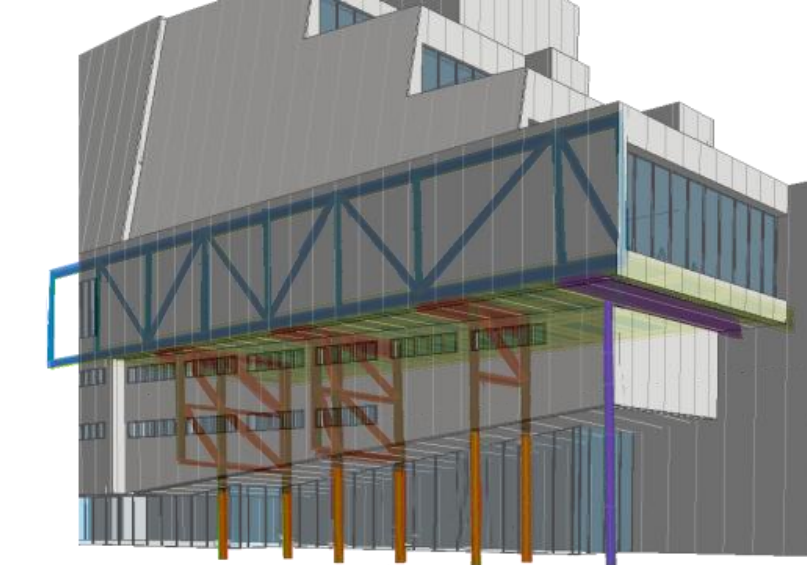
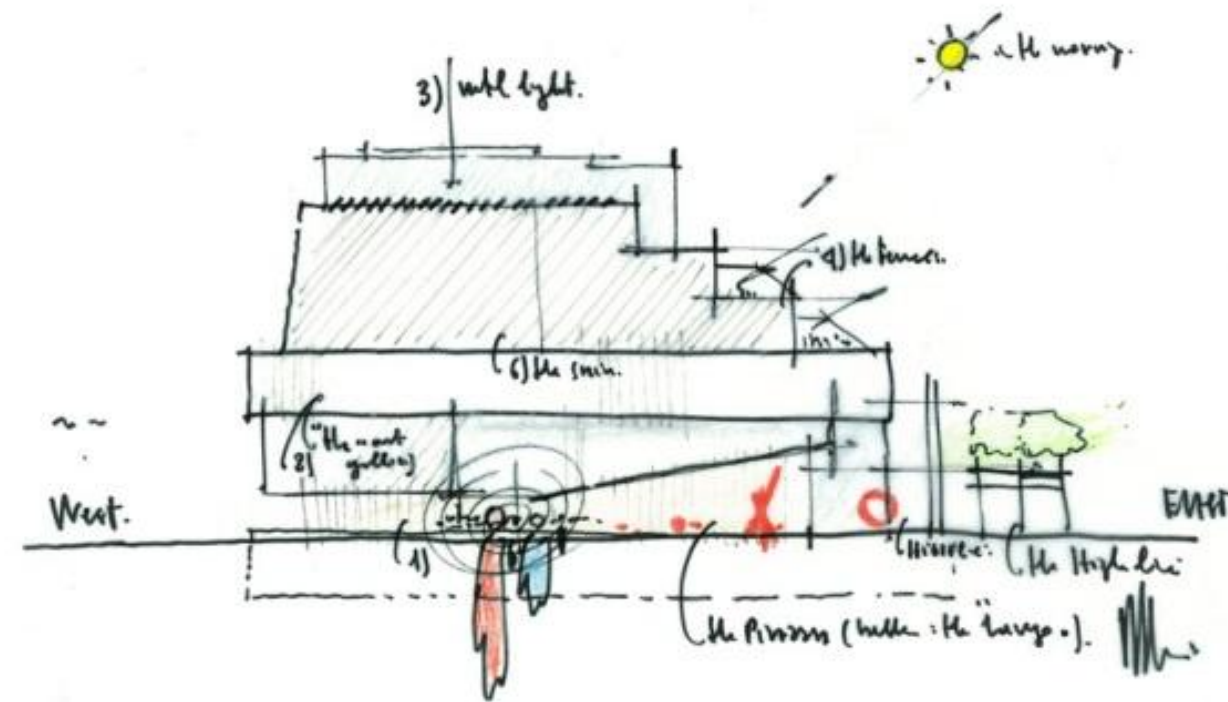
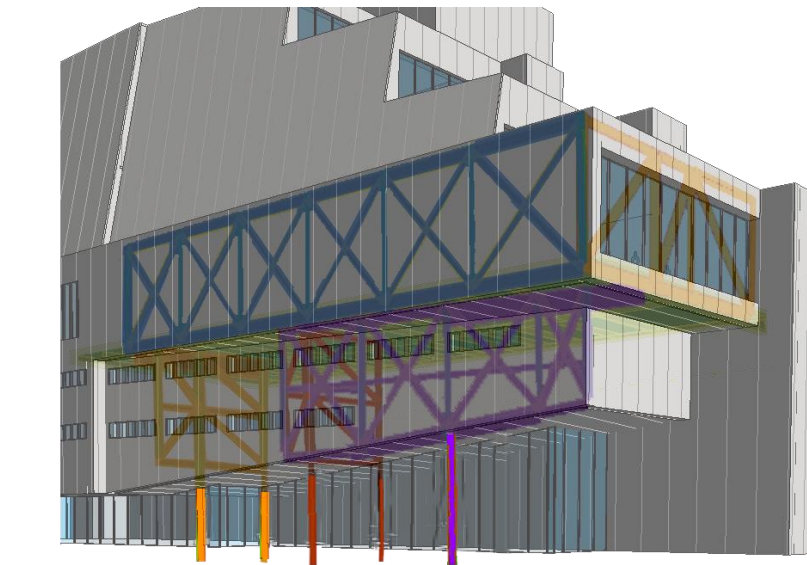
# ACKNOWLEDGEMENTS

- The Owner
- Turner Construction
  
- The AE Faculty
- Classmates
  
- Family, Friends

Structural Concerns	Current Design	Proposed Design
Remove Column 3-M.5	NO	YES
No. of Steps in Load Path	2	4
Max. Element Weight	45.1 t	121.6 t
Overall Weight	199.5 t	297.1 t
Max. Pile Group	2	5
No. of Custom Sections	10	12
Columns Max.O.D.	22"	24"
Max. f'c	5,000	15,000
Max. Total Deflection	-	-7.57 in
Acceptable Deflections	YES	NO
Architectural Concerns	Current Design	Proposed Design
Gallery Interference	NO	Truss N.2
Wall X Interference	NO	Truss X
Remove Truss L	NO	YES
Maintain Web Openings	YES	YES
Maintain Building Envelope	YES	YES
Construction Concerns	Current Design	Proposed Design
No. of Long Trusses	1	2
Cost of Superstructure	\$3,928,000	\$5,946,000
Cost of Foundations	\$238,000	335,000
Total Structural Cost	\$4,166,000	\$6,281,000
Total Difference		\$2,115,000

# JURY QUESTIONS?

- Building Introduction
- Problem Background
- Proposed Structural System
- Architecture Considerations
- **Comparative Summary**



Structural Concerns	Current Design	Proposed Design
Remove Column 3-M.5	NO	YES
No. of Steps in Load Path	2	4
Max. Element Weight	45.1 t	121.6 t
Overall Weight	199.5 t	297.1 t
Max. Pile Group	2	5
No. of Custom Sections	10	12
Columns Max.O.D.	22"	24"
Max. Fc	5,000	15,000
Max. Total Deflection	-	-7.57 in
Acceptable Deflections	YES	NO
Architectural Concerns	Current Design	Proposed Design
Gallery Interference	NO	Truss N.2
Wall X Interference	NO	Truss X
Remove Truss L	NO	YES
Maintain Web Openings	YES	YES
Maintain Building Envelope	YES	YES
Construction Concerns	Current Design	Proposed Design
No. of Long Trusses	1	2
Cost of Superstructure	\$3,928,000	\$5,946,000
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