Signature Boutique Offices , India

The Optimus

AE Senior Thesis 2013

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Building Information

- **Building Information**
- Existing structural system
- Thesis Statement
- Thesis Solution
- Gravity System
- Composite Floor system
- Lateral System
- Moment Connection Design
- Effect on foundations
- Conclusion

Building Information

- Office + Parking garage + Retail
- Ground + 17 floors
- 430,000 sq. ft.
- Max height: 230 ft.
- January 2012 – October 2013

Location and Site Map

Project Team

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- Owner + Project Manager + General Contractor: Lodha Group
- Architect: Pei Cobb Freed & Partners, New York
- Local Architect: Edifice Consultants Pvt. Ltd.
- Structural Engineer: Leslie E. Robertson Associates
- MEP Consultant: Spectral Consultants Pvt. Ltd.
- Lighting Designer: George Sexton Associates

LODHA
BUILDING A BETTER LIFE

PEI COBB FREED & PARTNERS Architects LLP

LERA
Structural Engineers

Architecture

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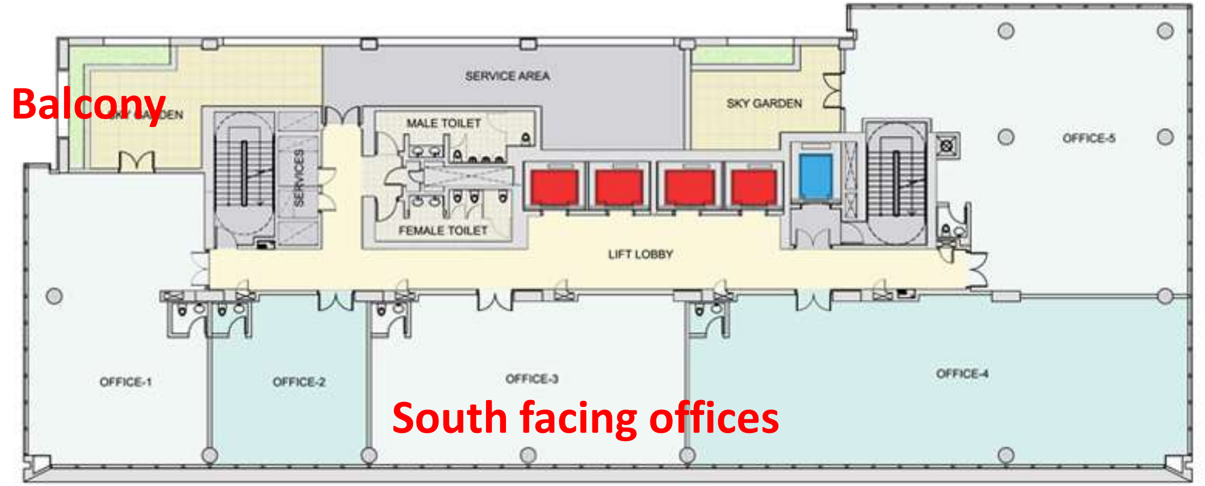
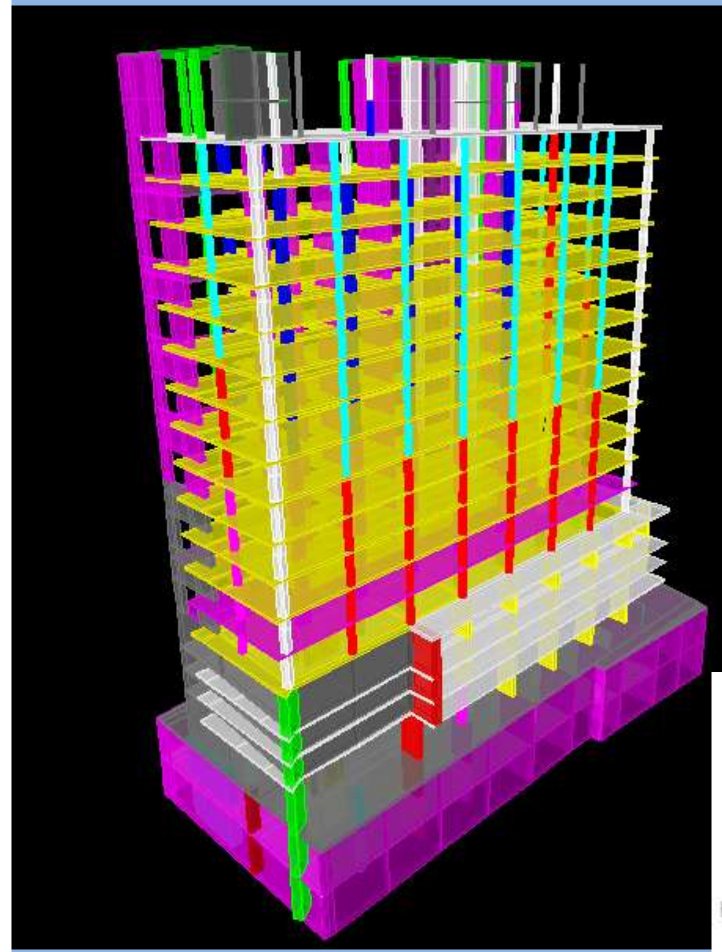
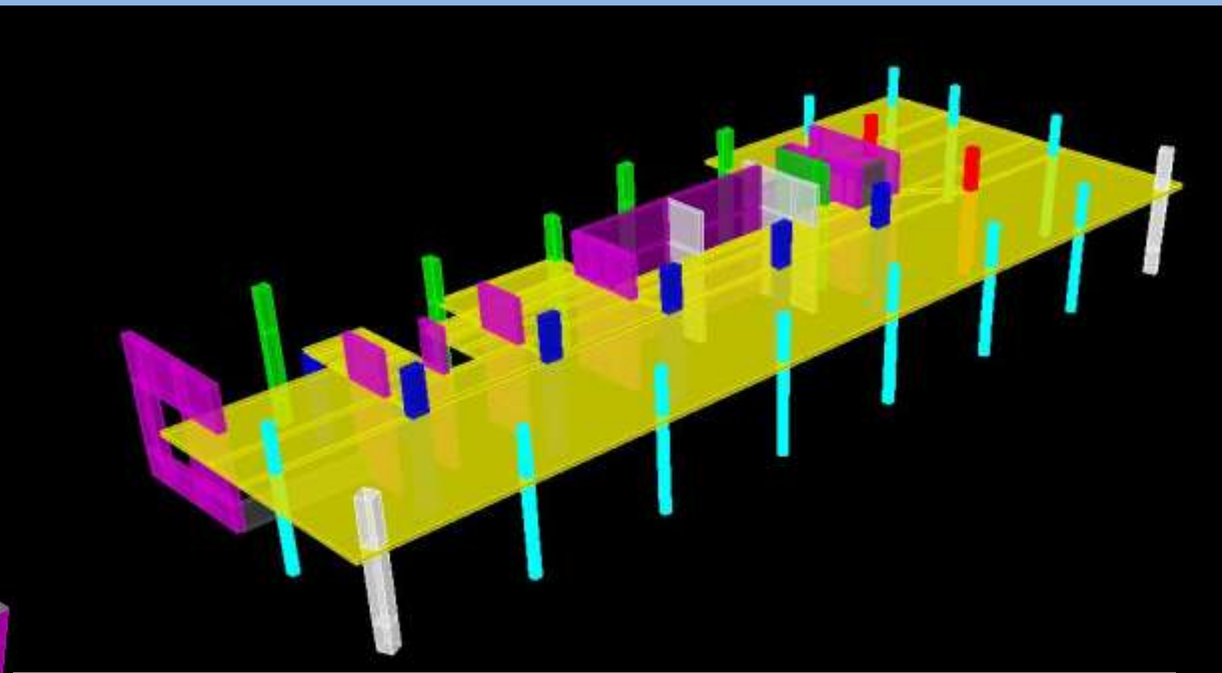
- Open Floor Plan
- South facing offices for panoramic views
- Balconies on every floor
- Façade: Glass + Aluminum + Stone, designed for
- Roof garden + Cafeteria + Gymnasium

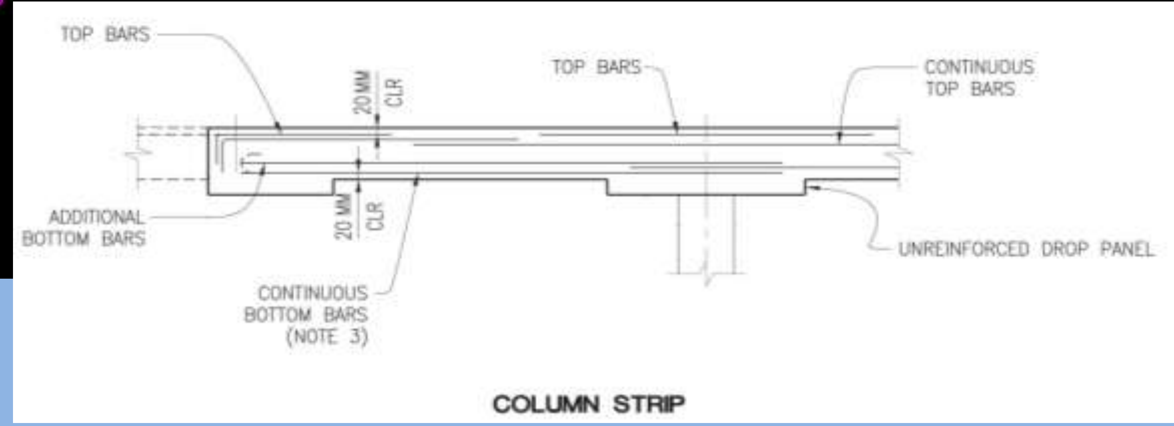


Existing Gravity System

- Open floor plan: Perimeter columns + 1 row of interior columns
- 8” flat slabs with additional 8” drop panels
- 3’x1.5’ to 3’x7’ rectangular columns for parking space
- 1.5’ to 3’ diameter circular columns in office spaces
- Building façade supported at cantilevered slab edges
- Concrete strength range from 5000 psi to 7000 psi



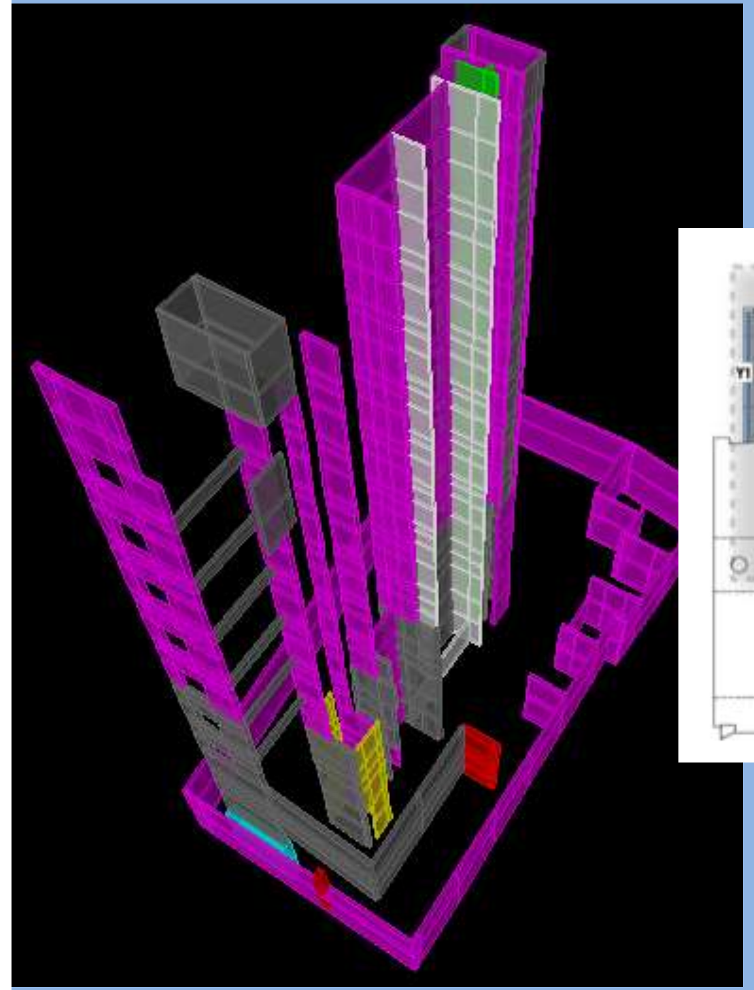


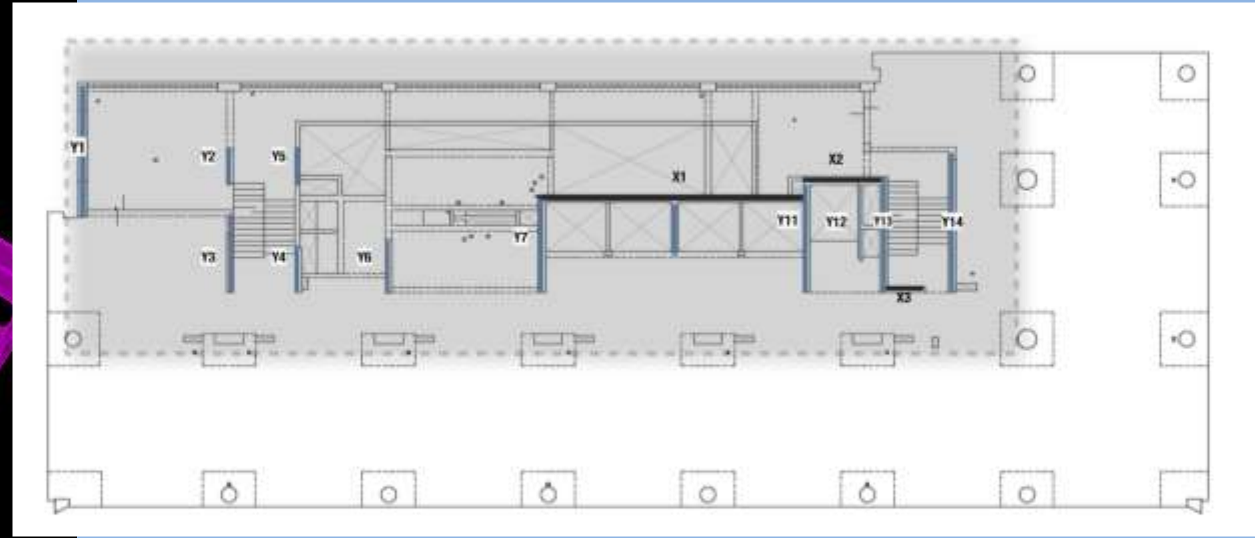


COLUMN STRIP

Existing Lateral System

- Reinforced concrete shear walls ranging from 12” to 20”
- 8 ft. to 25ft. walls in North-South direction and 47 ft. wall in East-West direction
- Shear walls wrap the elevator shaft and stairwells
- Due to proximity to the Arabian sea, wind loads control the lateral system





Shear wall layout

Concrete in India

- Concrete is a most prevalent building material
- Mumbai is called Concrete Jungle
- Client's perception that concrete is cheap
- Cheap labor
- Cheap design consultation
- Concrete design is comfort zone of most architects and engineers
- Lack of steel construction firms

Mumbai

Problems with concrete

- Environmental impact
- Hard to maintain quality control in India
- Cheap labor can sometimes be harmful.
- Member sizes get huge with taller buildings
- Future challenges require alternate materials

Building collapse in Mumbai


Image Courtesy of The Hindu Newspaper

Solution

- Explore benefits of Steel design
- Requires less but skilled labor
- Quality control easier
- Taller building can have smaller members
- Reduced weight of overall structure

Thesis Preview

- Analyze and design of gravity members
- Analyze and design lateral system
- Typical steel-connection design
- Cost-benefit analysis
- Integration and optimization with architecture
- Integration and optimization of facade

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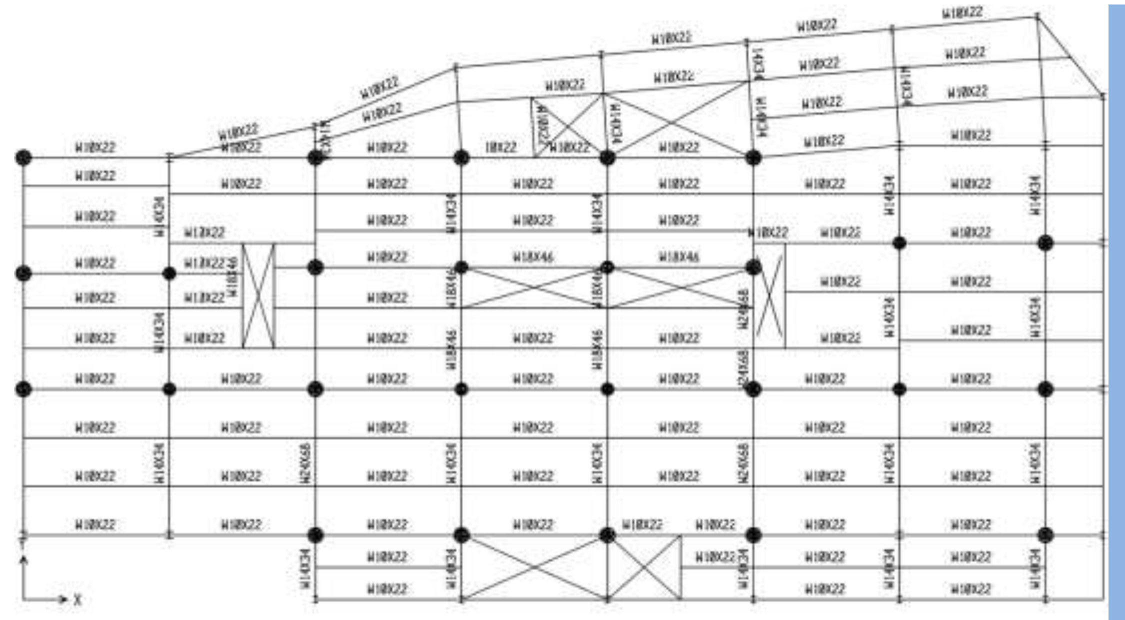
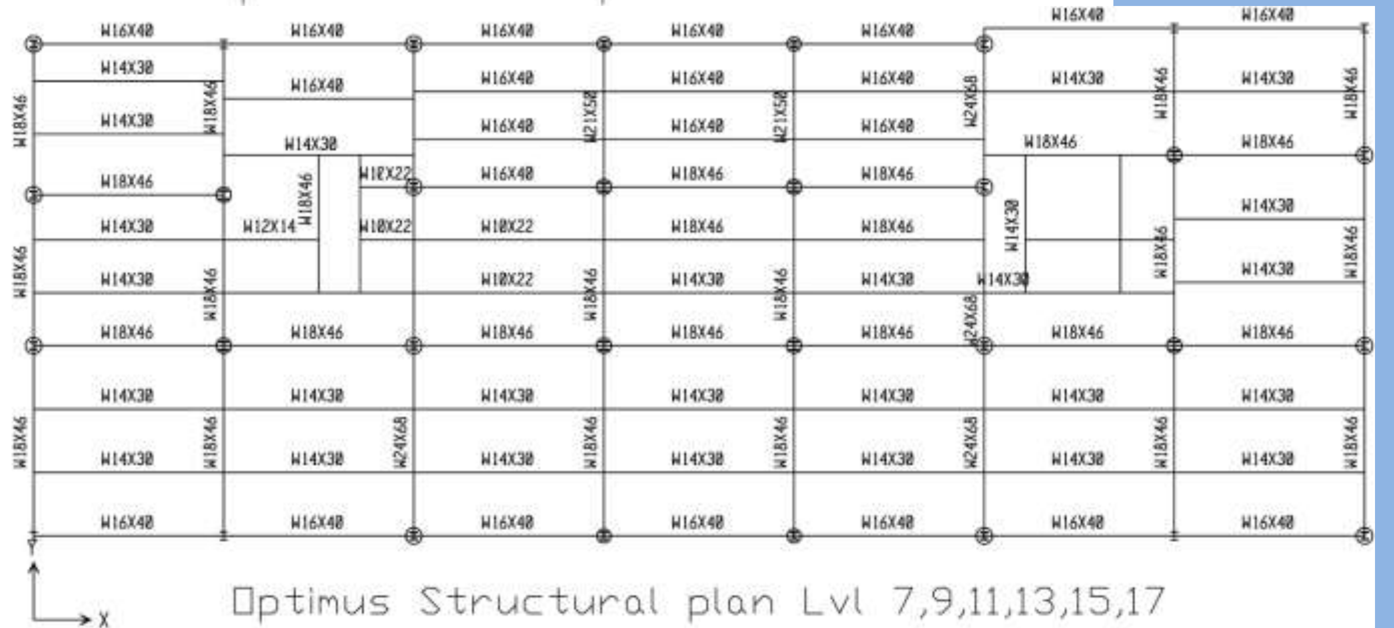
- Interior gravity columns - Steel wide-flange columns encased with reinforced concrete
- Edge columns – W14 and W12 Steel wide flange
- Superimposed dead Loads used from existing system
- Critical design load combination - 1.2Dead +1.6Live+0.5Roof Live (ASCE 7-10)

Structural floor plan



Optimus Structural plan Level 1 - 5

Parking floor plan



Optimus Structural plan Lvl 7,9,11,13,15,17

Office floor plan

New Gravity system

- Following AISC Manual Chapter I
- Columns mainly checked for compression, minimum size of steel core and critical elastic bucking
- Composite columns caused 40% reduction in column size in parking spaces compared to existing system

Design summary of critical interior gravity column

Story	Column	Critical Load Combos	P (kip)	Member	ϕPn (kip)	DCR ratio
LEVEL 1	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-3706	W14x176 dia28	3750	0.99
LEVEL 2	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-3572	W14x176 dia28	3750	0.95
LEVEL 3	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-3402	W14x176 dia26	3625	0.94
LEVEL 4	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-3271	W14x176 dia26	3625	0.90
LEVEL 5	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-3132	W14x145 dia 26	3315	0.94
LEVEL 6	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-2918	W14x145 dia 26	3315	0.88
LEVEL 7	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-2691	W14x145 dia 26	3315	0.81
LEVEL 8	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-2464	W14x120 dia 22	2587	0.95
LEVEL 9	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-2236	W14x120 dia 22	2587	0.86
LEVEL 10	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-2010	W14x120 dia 22	2587	0.78
LEVEL 11	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-1782	W14x120 dia 22	2587	0.69
LEVEL 12	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-1556	W14x120 dia 22	2815	0.55
LEVEL 13	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-1329	W14x120	1400	0.95
LEVEL 14	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-1105	W14x120	1400	0.79
LEVEL 15	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-875	W14x90	1050	0.83
LEVEL 16	C1	1.2(D+SDL) + 1.6L + 0.5Roof L	-651	W14x90	1050	0.62
LEVEL 17	C1	1.2(D+SDL) + 1.6RL + L	-460	W14x61	599	0.77
ROOF	C1	1.2(D+SDL) + 1.6RL + L	-278	W14x61	599	0.46

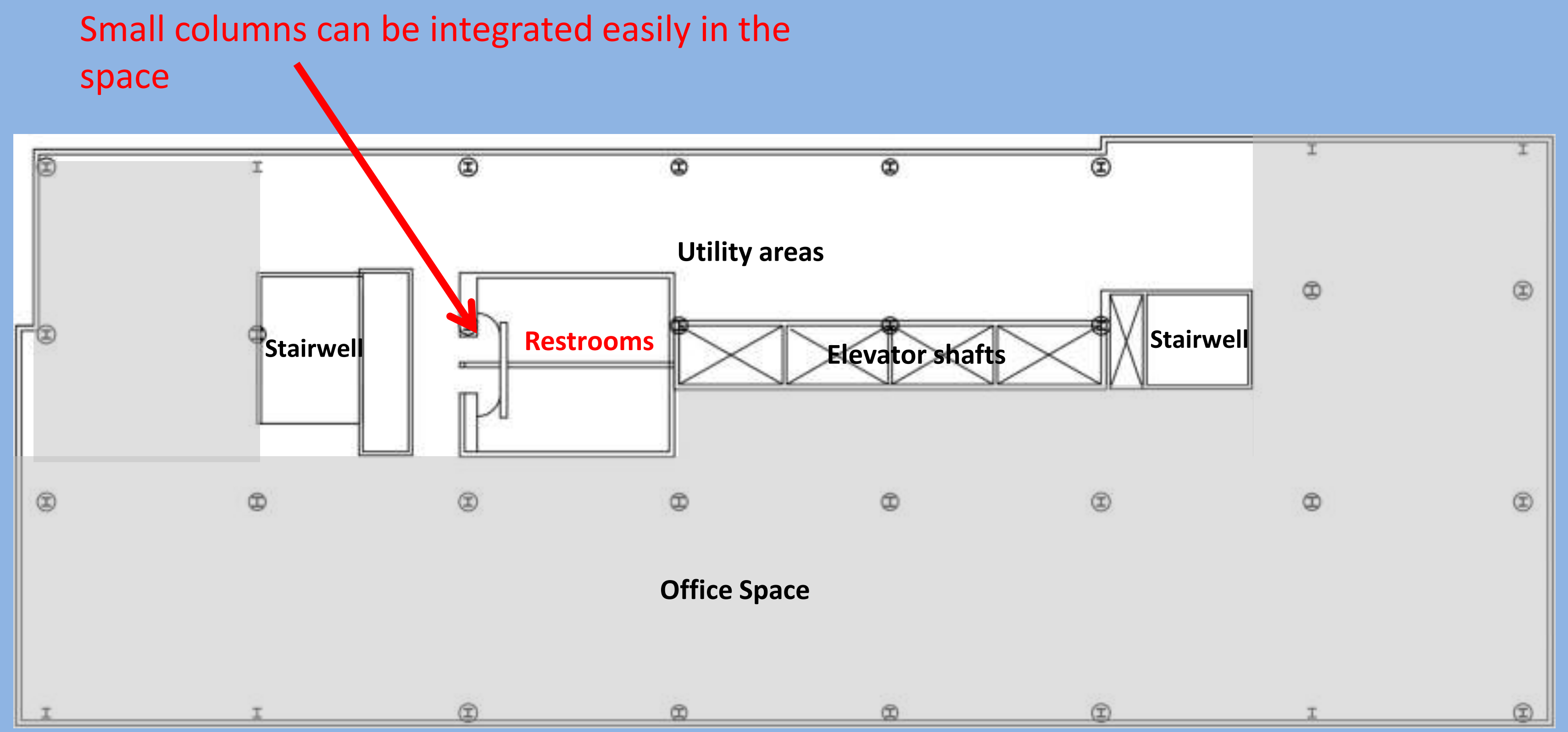
Design summary of critical edge gravity column

Story	Column	Critical Load Combos	P (kip)	Member	ϕPn (kip)	DCR ratio
LEVEL 1	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-2201	W14x257	2660	0.83
LEVEL 2	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-2121	W14x257	2660	0.80
LEVEL 3	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-2042	W14x176	2090	0.98
LEVEL 4	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-1964	W14x176	2090	0.94
LEVEL 5	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-1887	W14x176	2090	0.90
LEVEL 6	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-1737	W14x176	2090	0.83
LEVEL 7	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-1658	W12x152	1690	0.98
LEVEL 8	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-1462	W12x152	1690	0.87
LEVEL 9	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-1383	W12x152	1690	0.82
LEVEL 10	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-1188	W12x152	1690	0.70
LEVEL 11	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-1110	W12x106	1170	0.95
LEVEL 12	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-916	W12x106	1170	0.78
LEVEL 13	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-837	W12x106	1170	0.72
LEVEL 14	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-643	W12x72	806	0.80
LEVEL 15	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-566	W12x72	806	0.70
LEVEL 16	C40	1.2(D+SDL) + 1.6L + 0.5Roof L	-372	W12x50	413	0.90

Integration to architecture

- Optimized open floor plan
- Increased floor space in office and parking
- Less obstruction of interior columns to daylight
- Concrete encasing has fire-proofing advantage

Typical office floor plan

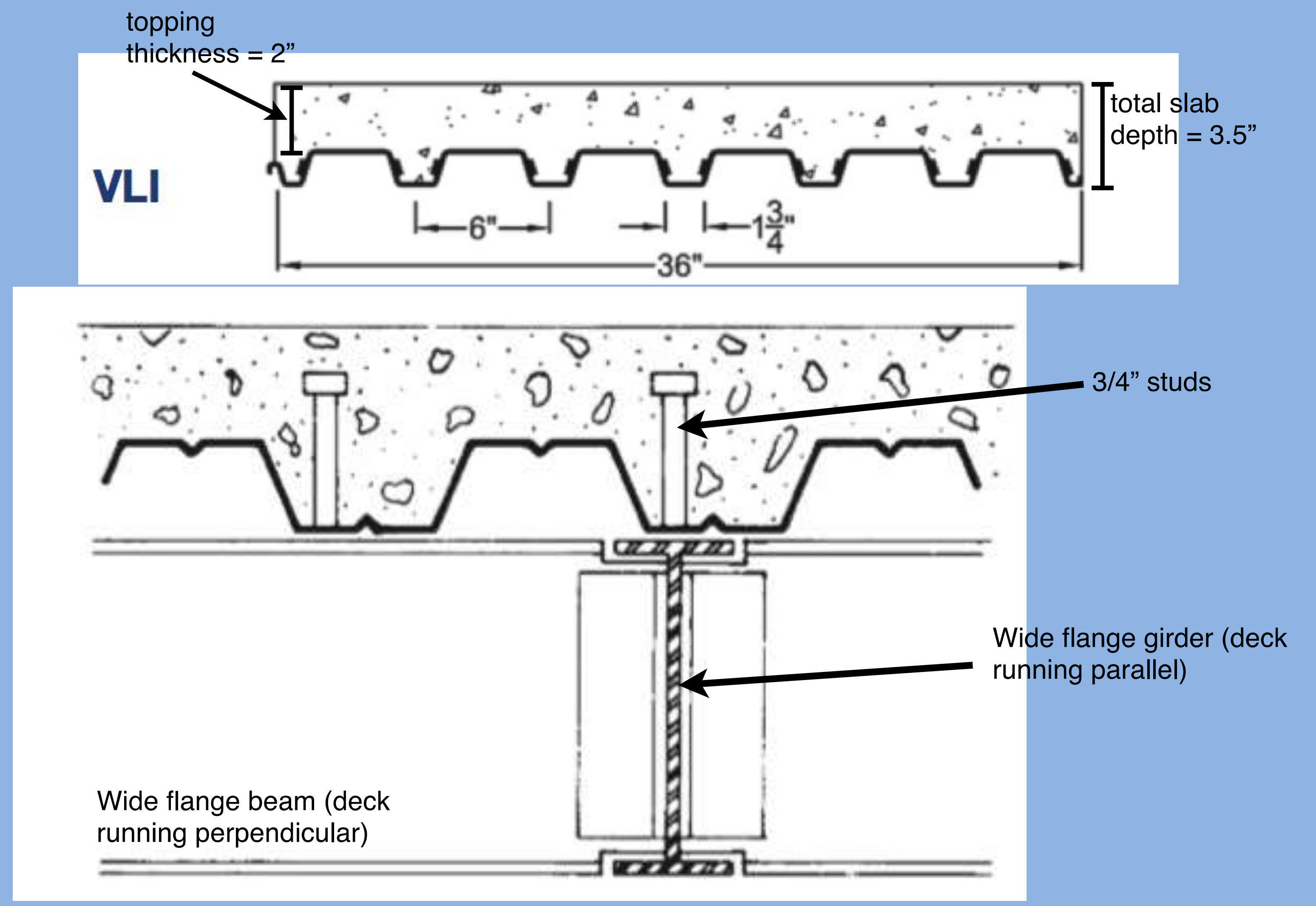


Typical office floor plan

Composite Floor System

- For typical office floor W14x30 beam and W18x46 girder with 1.5VLI20 Vulcraft deck used
- Steel deck runs perpendicular to beam and parallel to girder
- 1.2Dead + 1.6Live load combination used
- AISC Manual table 3.21 and 3.20 used to design a partially composite section

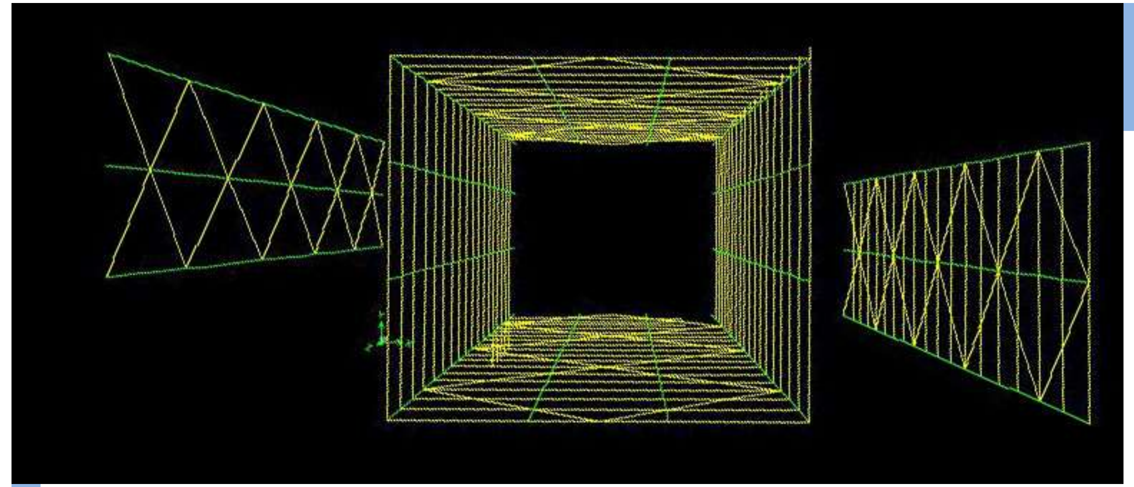
Composite system cross-section

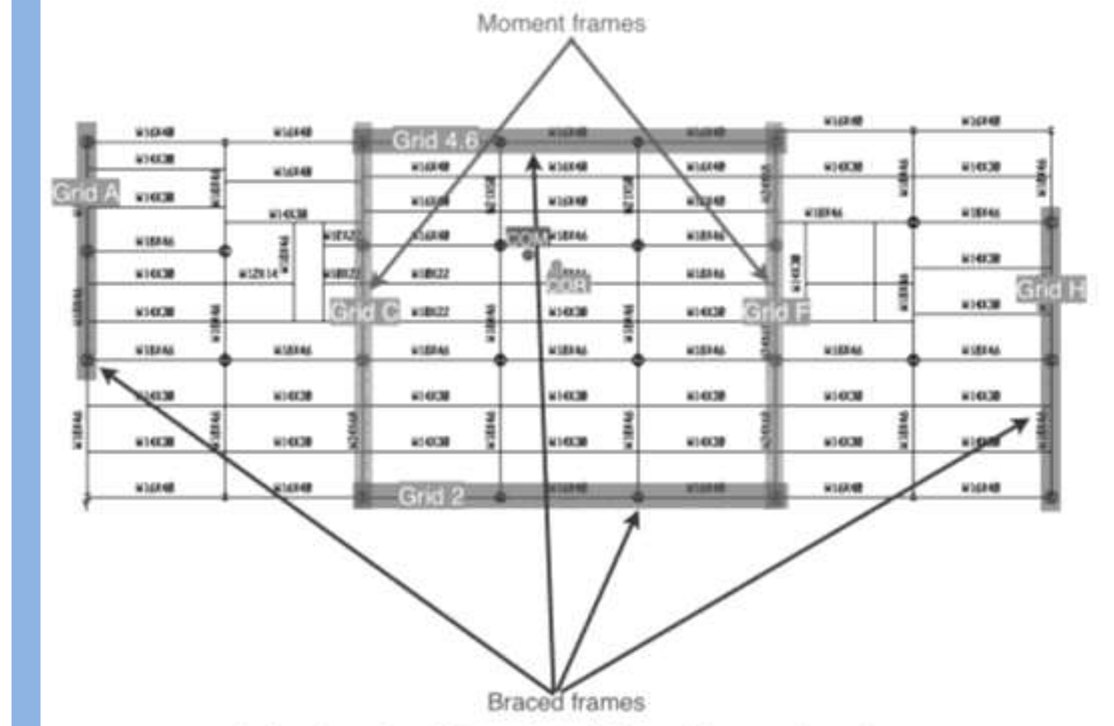


Typical cross-section of composite floor system

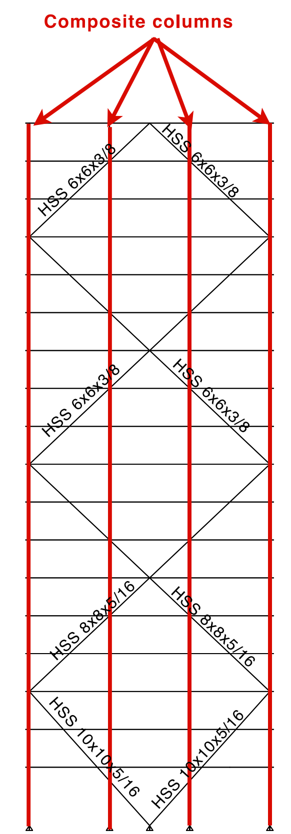
Lateral system

- 2 Moment frames in North-south direction
- 2 Braced frames in North-South direction
- 2 Braced frames in East-West direction
- All columns are steel wide flange W12 encased in reinforced concrete. Size range – 34” to 24”
- All columns designed for compression created due to lateral loads





Lateral system: Moment and Braced frames layout



Optimus Structural Elevation Grid 2

Lateral System: Braced frame Grid 2 and 4.6

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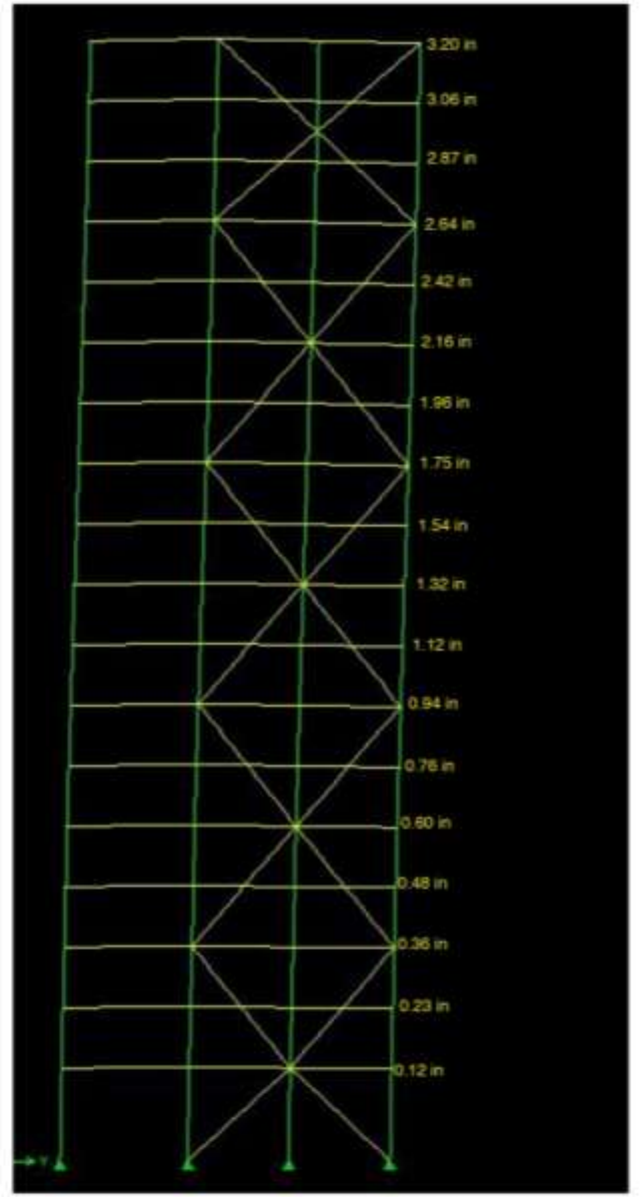
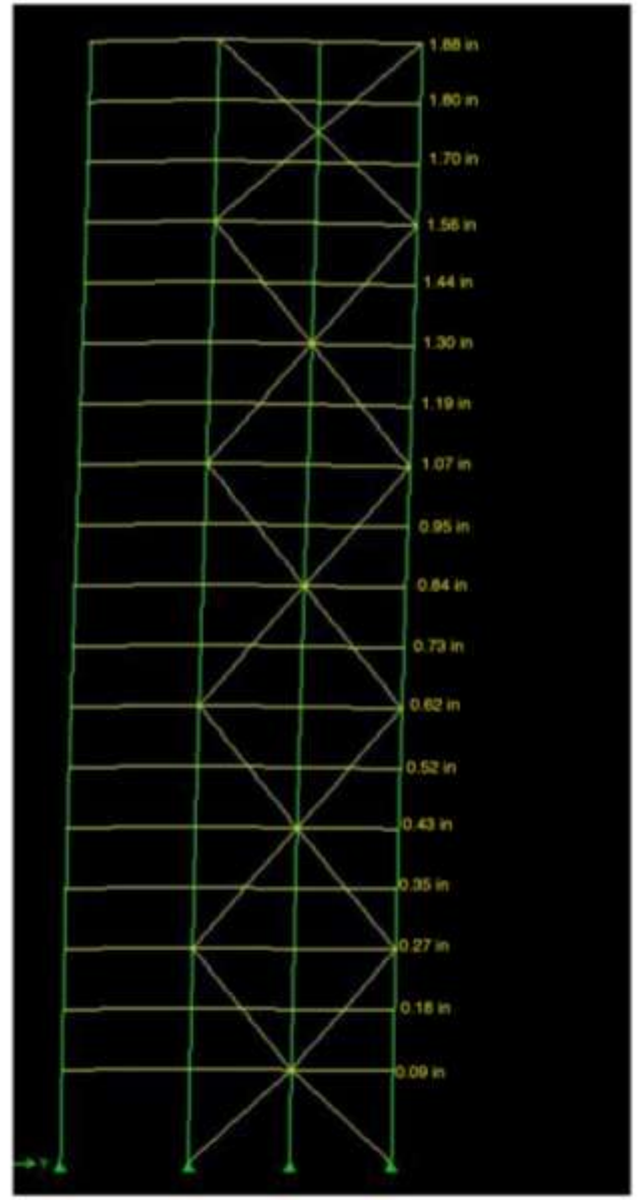
Lateral system

- ASCE 7-10 Directional procedure used to calculate wind loads and drifts
- ASCE 7-10 Equivalent Lateral Force Procedure and Modal Response Spectrum Analysis used
- The two seismic analysis procedures compared based on drifts and base shears

Drifts (inches)



Deflections due to critical seismic loadcase in North-South direction (Not including P-delta analysis)



Deflections due to Response Spectrum analysis in North-South direction (Not including P-delta analysis)

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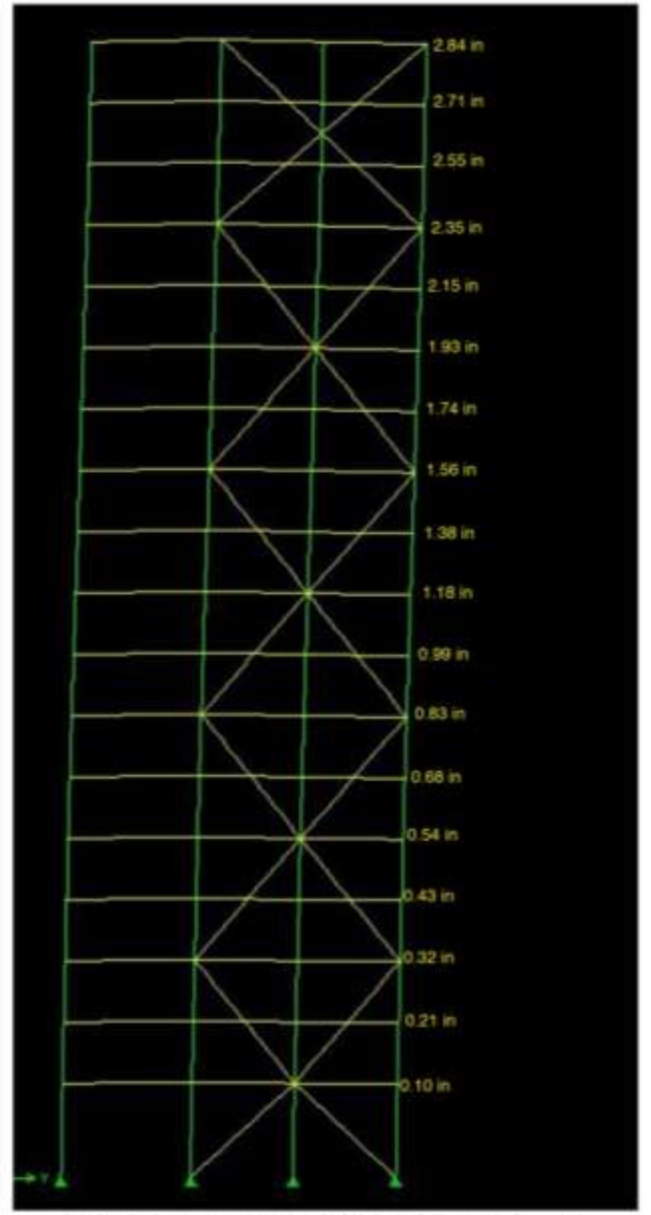
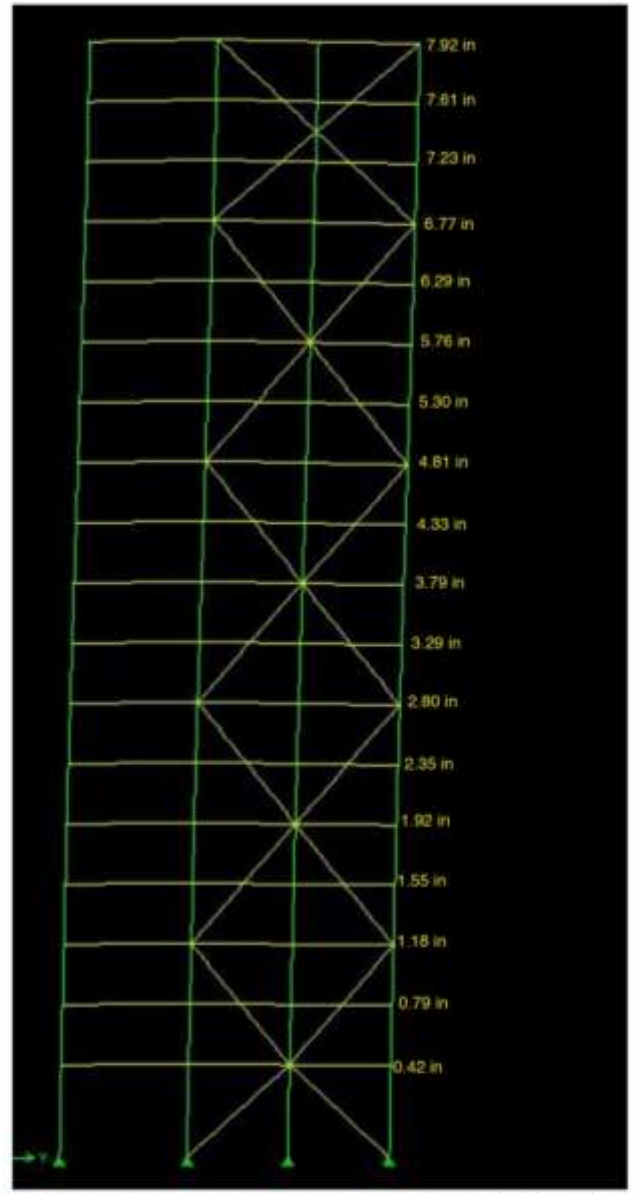
Lateral system

- Critical seismic loads compared to critical wind load based on drifts
- Design controlled by drifts and base shears due to Wind loads

Story Drifts (inches)



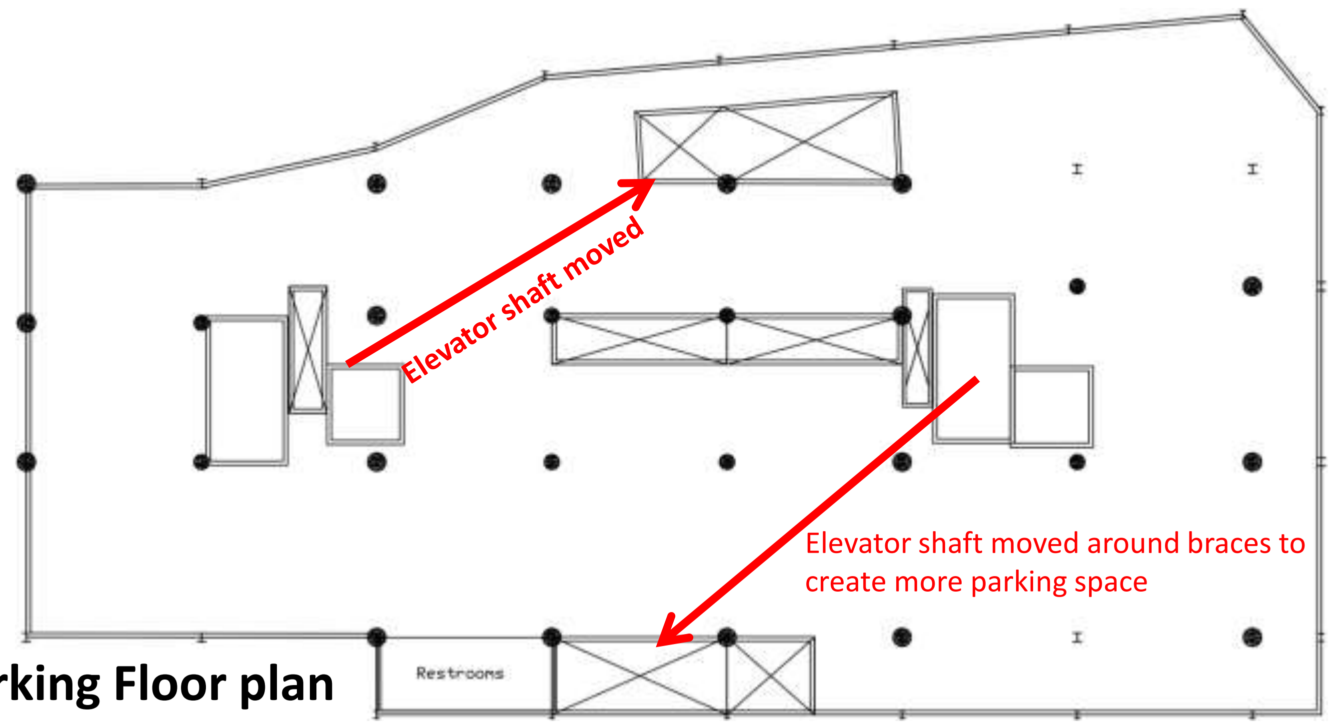
Deflections due to critical seismic load case in North-South direction (including P-delta analysis)



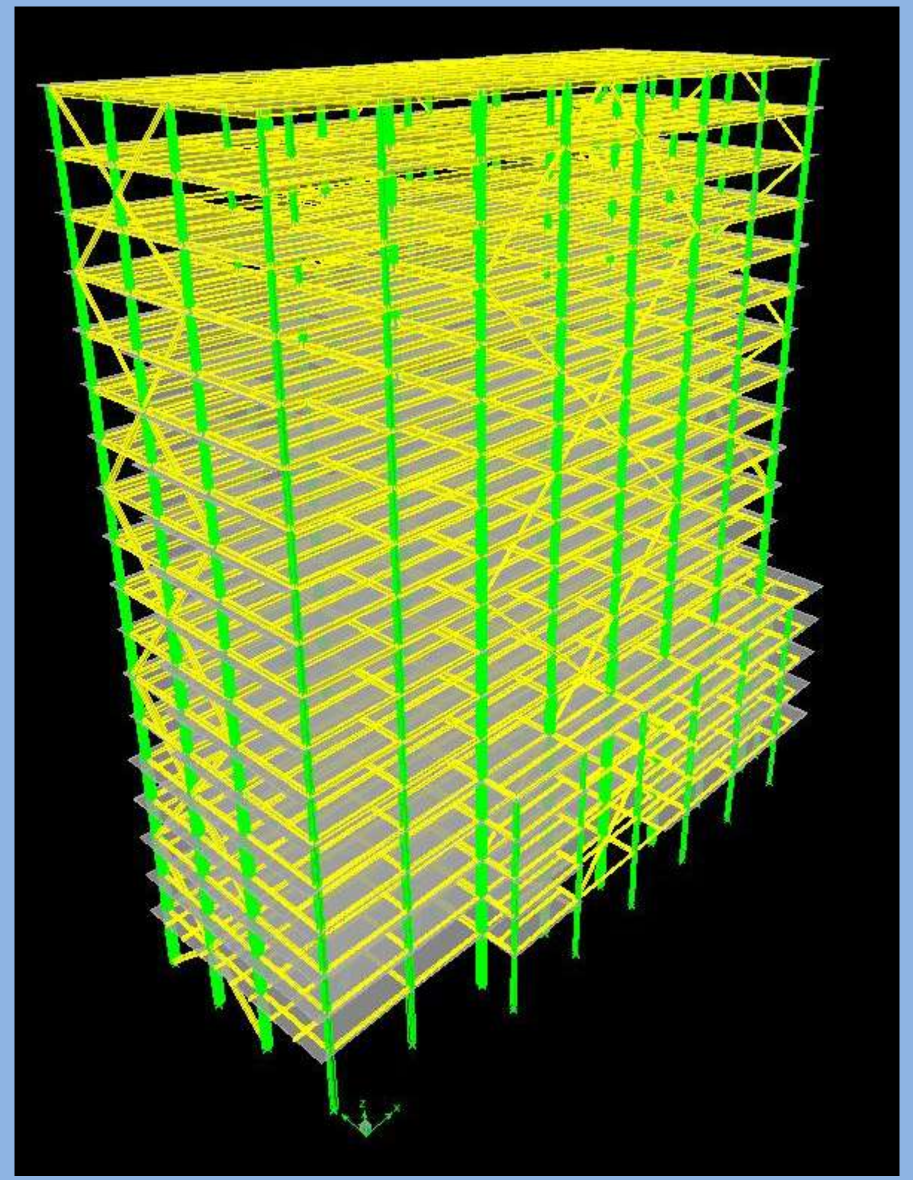
Deflections due to critical Windcase in North-South direction (P-delta analysis)

Integration to Architecture

- Moving braces to exterior creates more open space
- Exposing HSS braces as architectural elements
- Moving braces help improve parking space

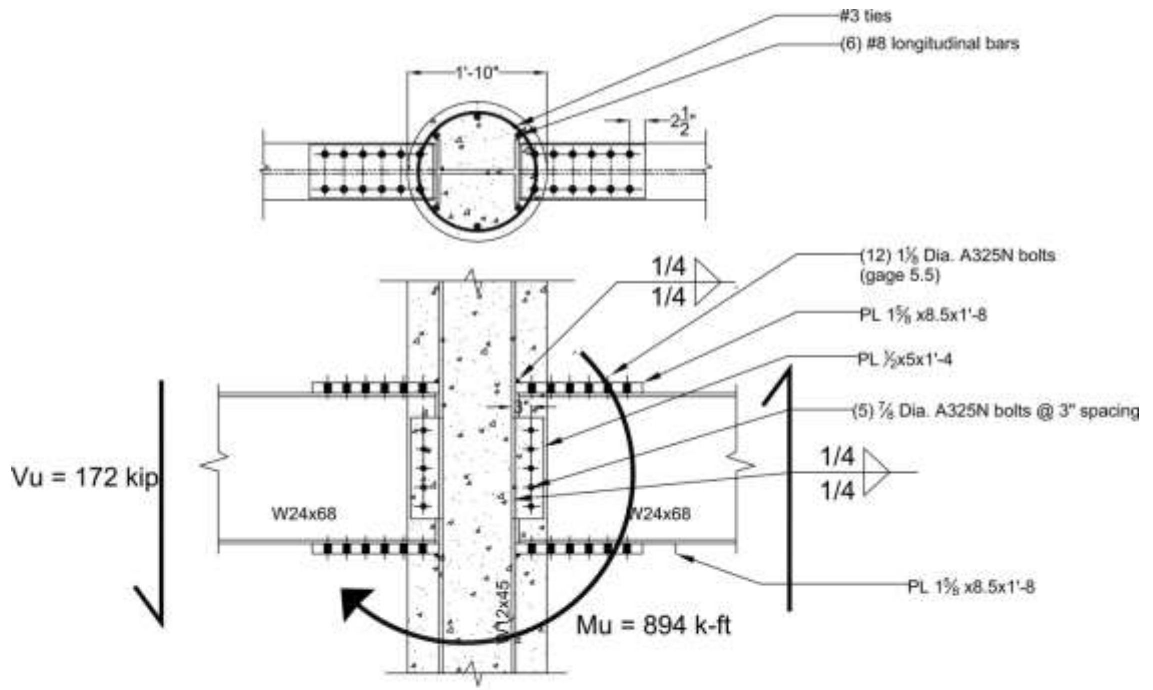


Parking Floor plan

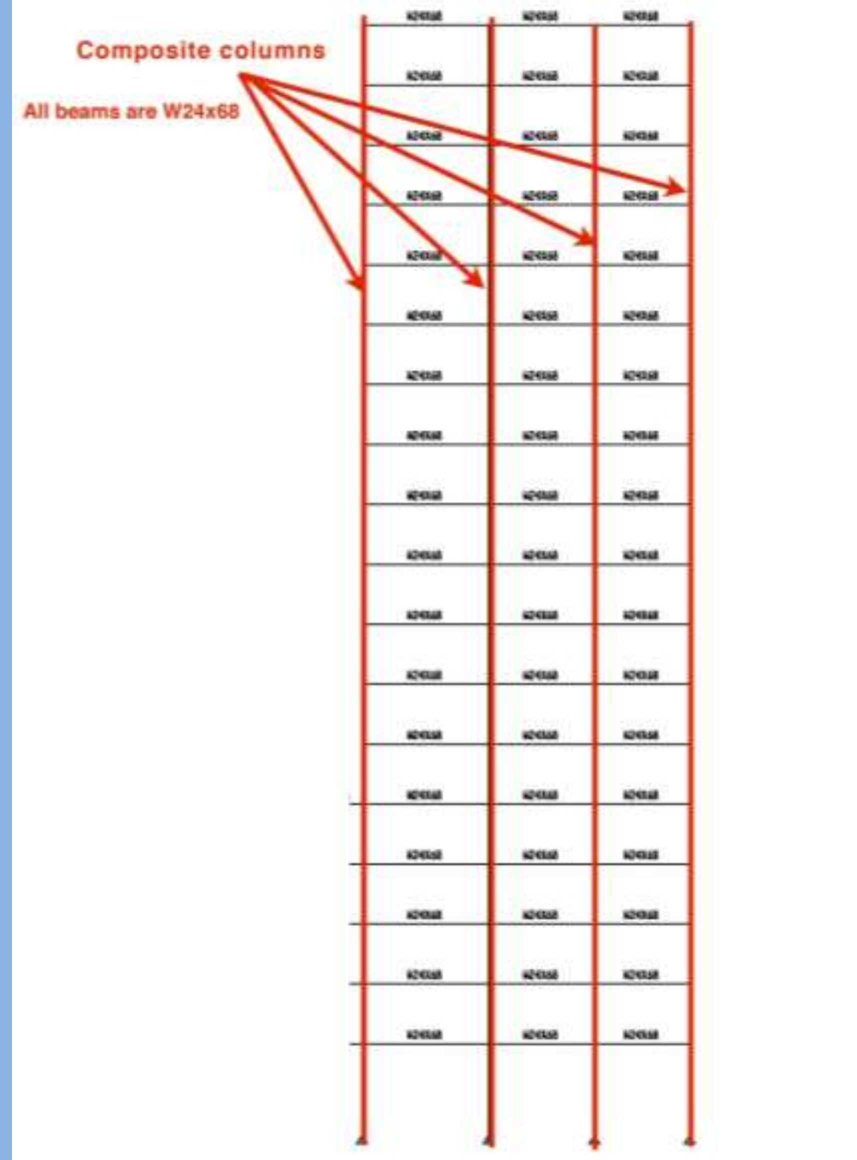


Connection Design

Moment frame



Flange plate bolted and web bolted moment connection



Lateral System: Moment frame Grid C and F

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Effect on foundations

- Existing building has 50” to 80” thick MAT foundation
- Dead load on foundation reduced from 25000 kip to 23000 kip

Acknowledgements

- Family and friends
- Engineers at Leslie E. Robertson Associates (New York and Mumbai offices)
- Pei Cobb Free & Partners Architects
- Lodha Group
- The AE faculty

Conclusion

- Every structural change follows architectural integration
- Adding steel building to skyline of Mumbai can improve city's image of concrete jungle
- Composite columns can be of great structural and architectural advantage to tall structures

- Cost benefit analysis resulted in higher price of steel structure
- However, increased floor space area, faster construction and reduced labor can cover up the extra cost of steel structure

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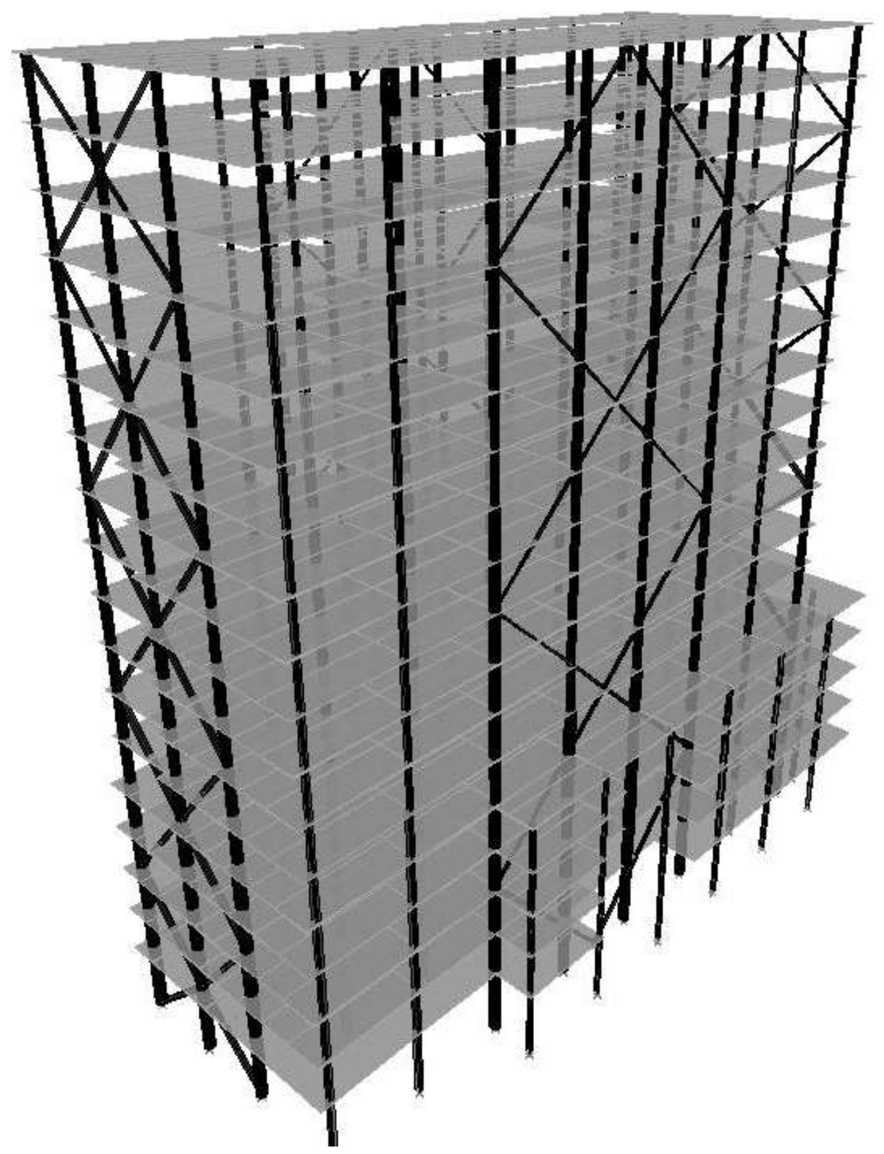
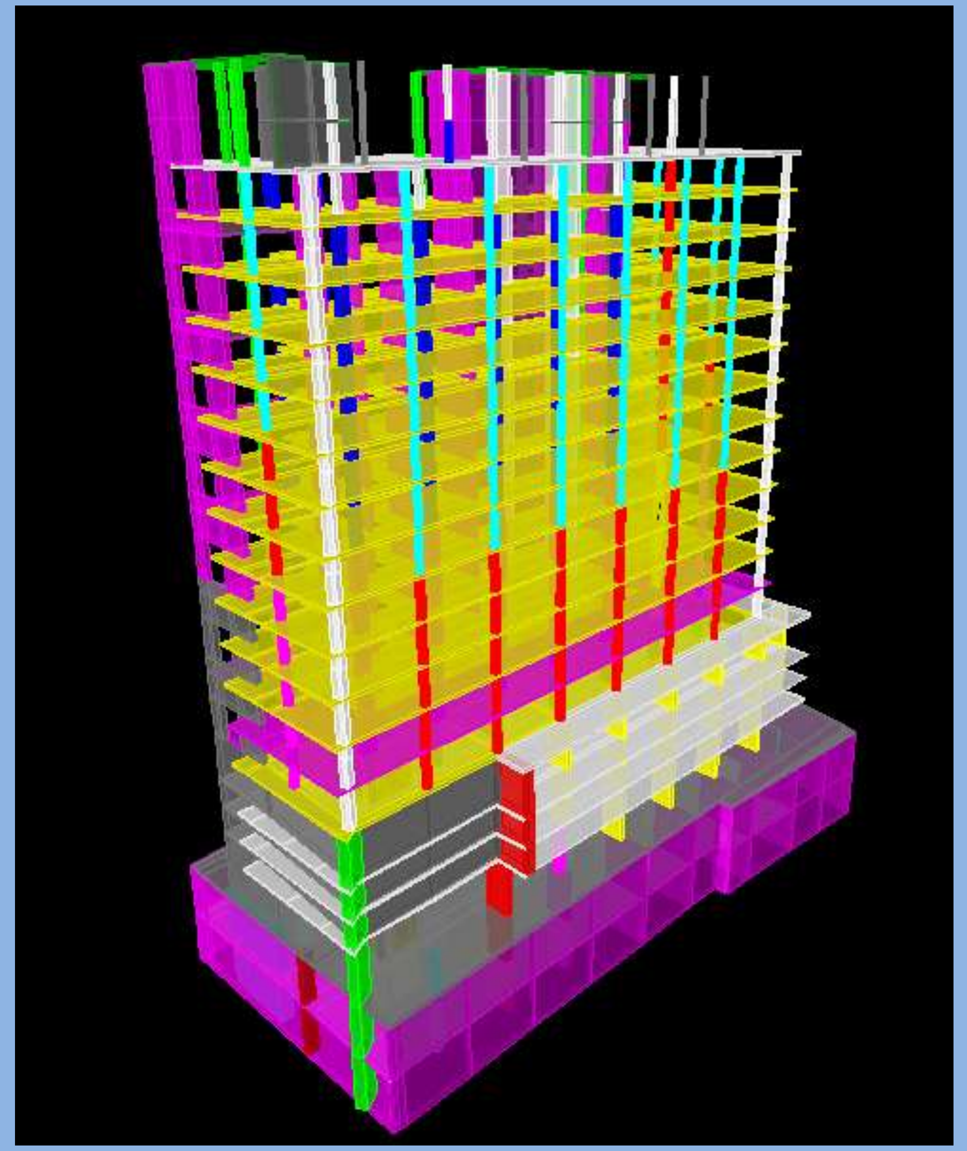
Steel structural system



Concrete structural system



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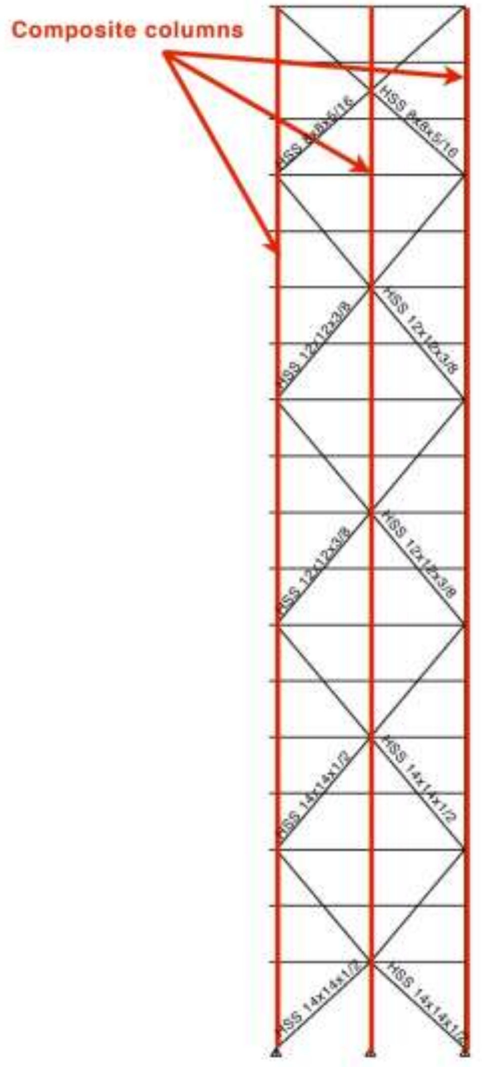
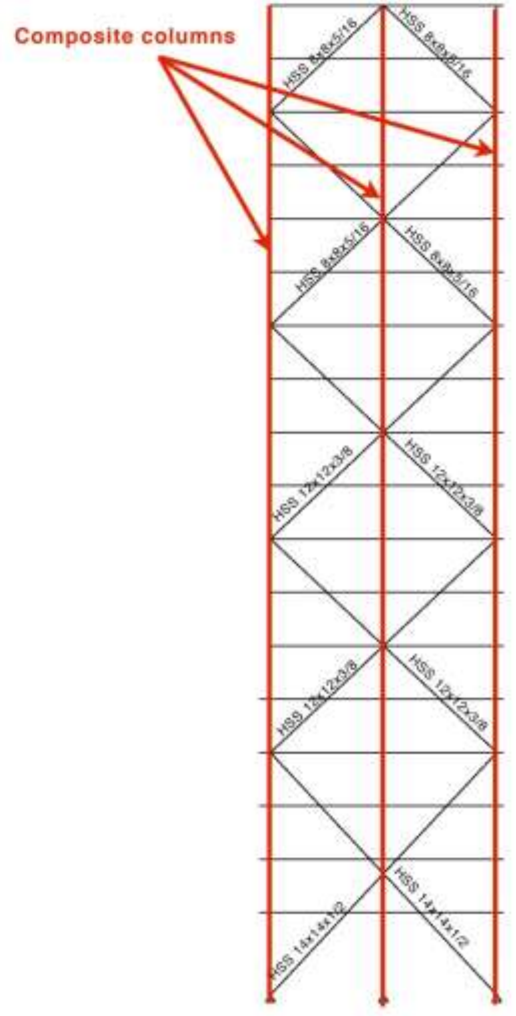


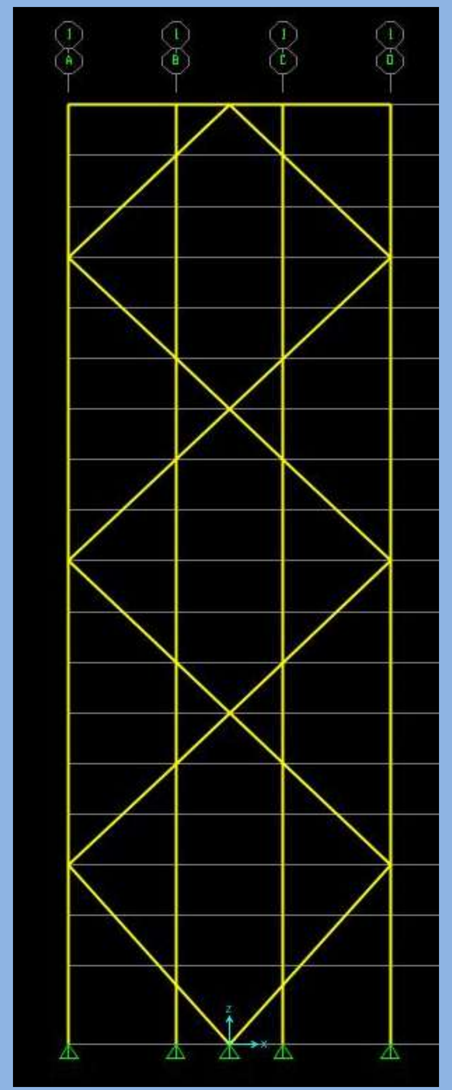
Lateral System: Braced frame Grid A

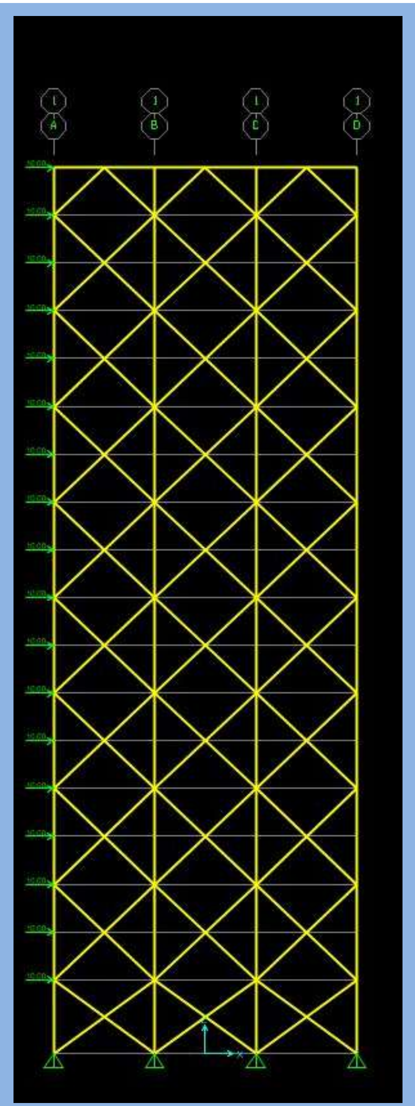


Lateral System: Braced frame Grid H

Appendix

Efficiency in bracing					
	Force (kip)	displacement (in)	stiffness	steel brace length	stiffness per unit length
R1	180	9.3	19	691.2	0.028
R2	180	6.5	28	2020.6	0.014
R3	180	4.1	44	1422.7	0.031
R4	180	28.6	6	1292	0.005


R1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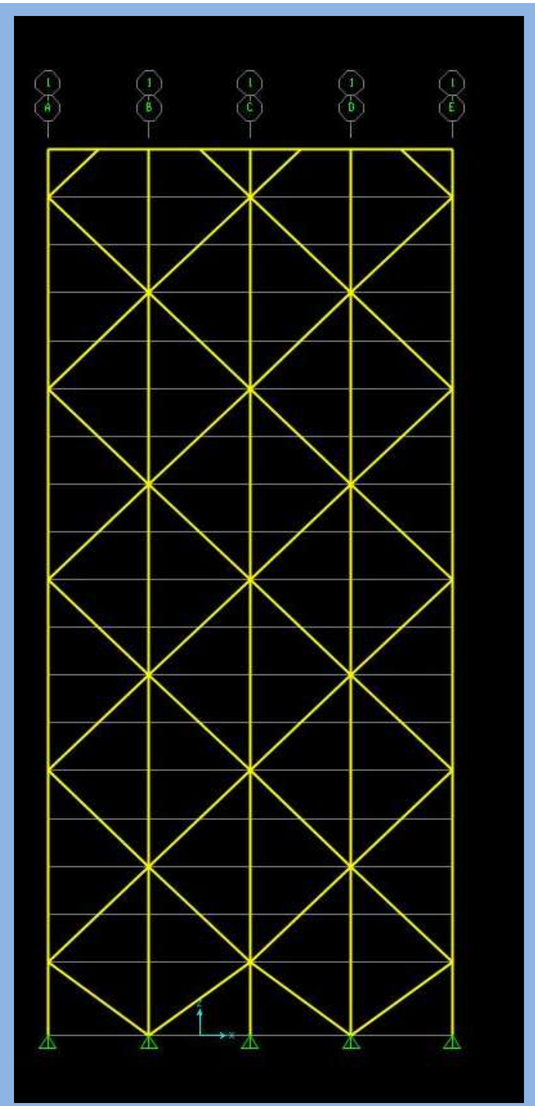
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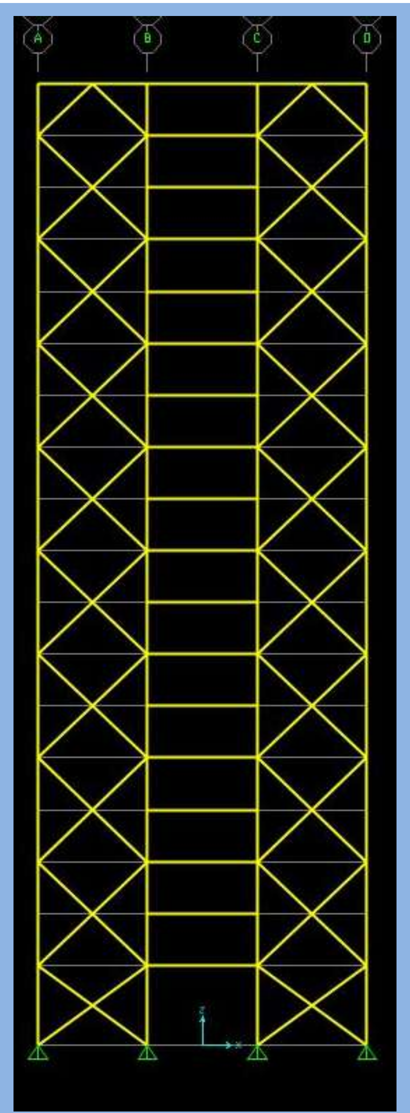
R4