Design of Post-tensioned Concrete Structures for Efficiency & Resilience

Leo Panian, SE
Principal

ENGINEERING

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Learning Objectives

At the end of this presentation, you will be able to...

- Identify strategies for designing safe and economical **PT concrete flat-slabs for buildings**
- Identify special considerations and effective approaches for designing **long-span PT floors**
- Identify key considerations for designing **PT concrete transfer girders** and other special structures
- Envision more robust, resilient **PT concrete systems for seismic resistance**

Overview

Design strategies for cost-effective and resilient buildings

- Floor assemblies for economy, performance, and functionality
- Long-span solutions, transfer girders, special-use structures
- Seismic solutions, resilient design

PT Gravity Systems

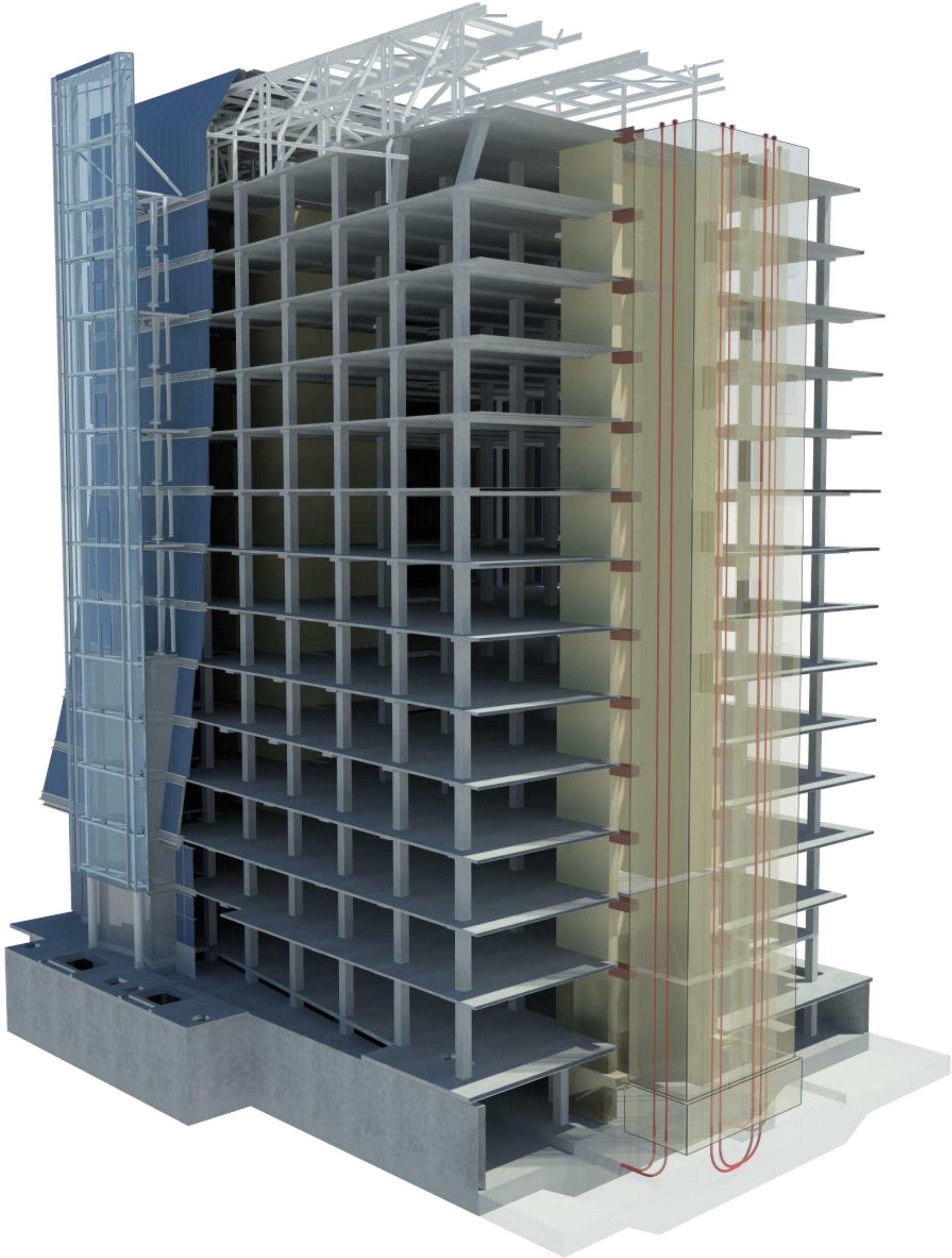
Floor assemblies

- Flat plates
- Long-span beams, girders
- Transfer girders

Conventional construction

Uncommon solutions

Cost-effectiveness, performance



PT Seismic Systems

Vertically stressed walls

Horizontally stressed beams

Unconventional

Improved seismic response

Resilience

Design Considerations

Constructability

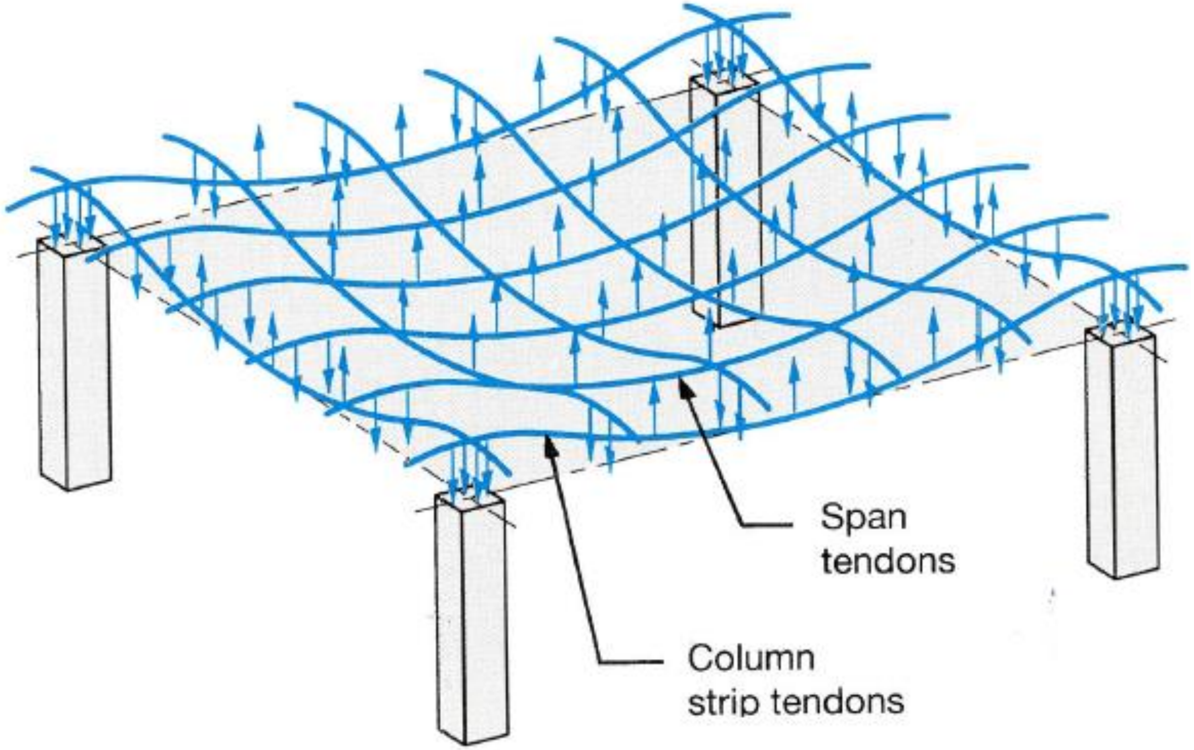
Cost

Carbon

Performance

- Deflections
- Vibration
- Drift

Concrete Floor Assemblies



Courtesy of VSL

Variety of buildings

Minimize materials, dimensions

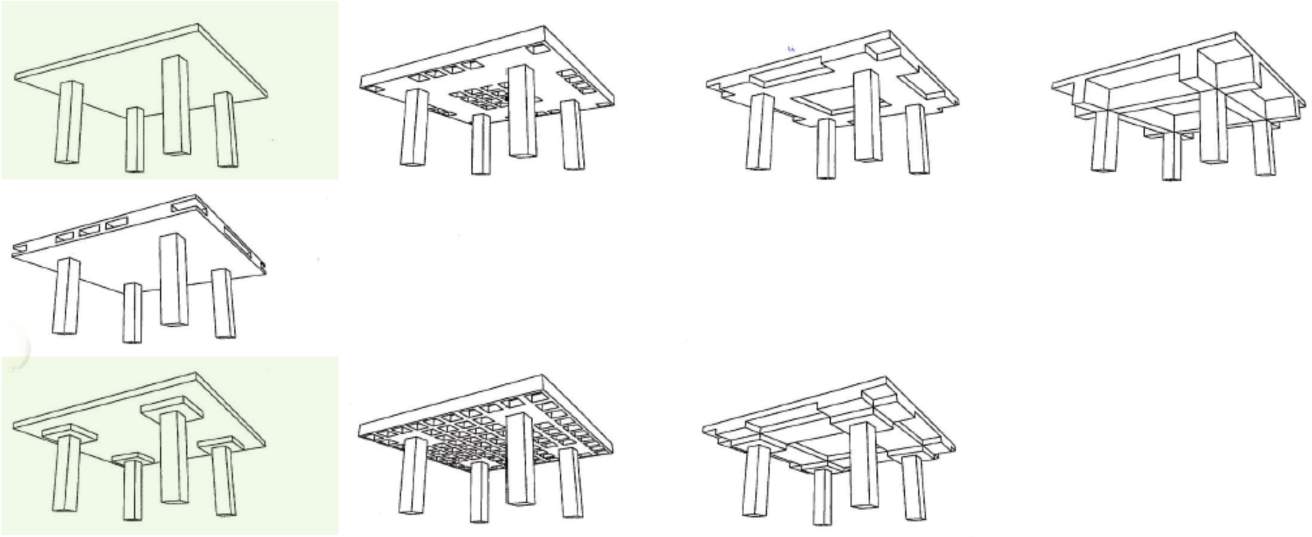
Control deflections

Shoring, stressing, sequence

Formwork, concrete, rebar, PT

System Selection

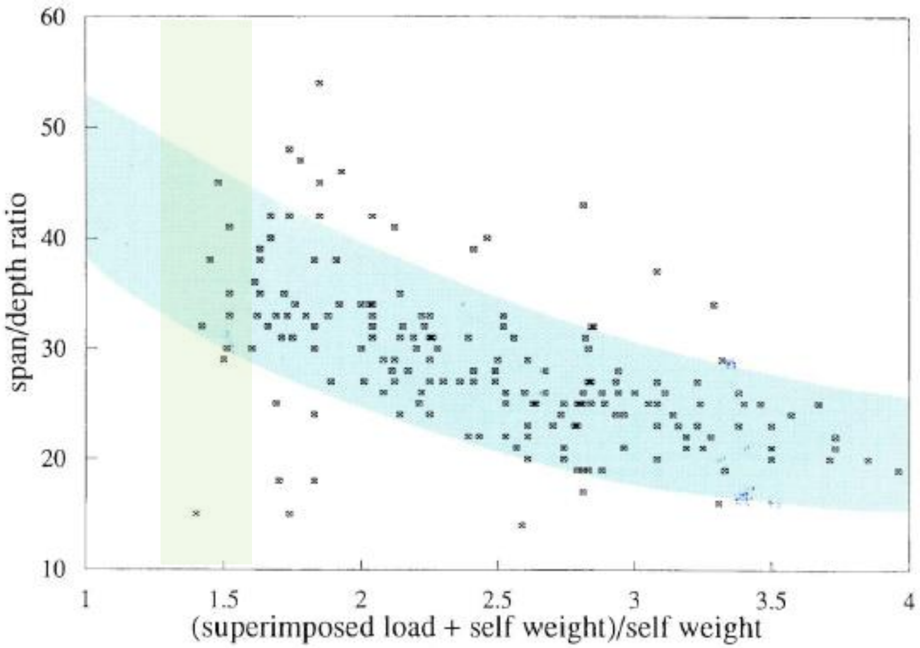
One way



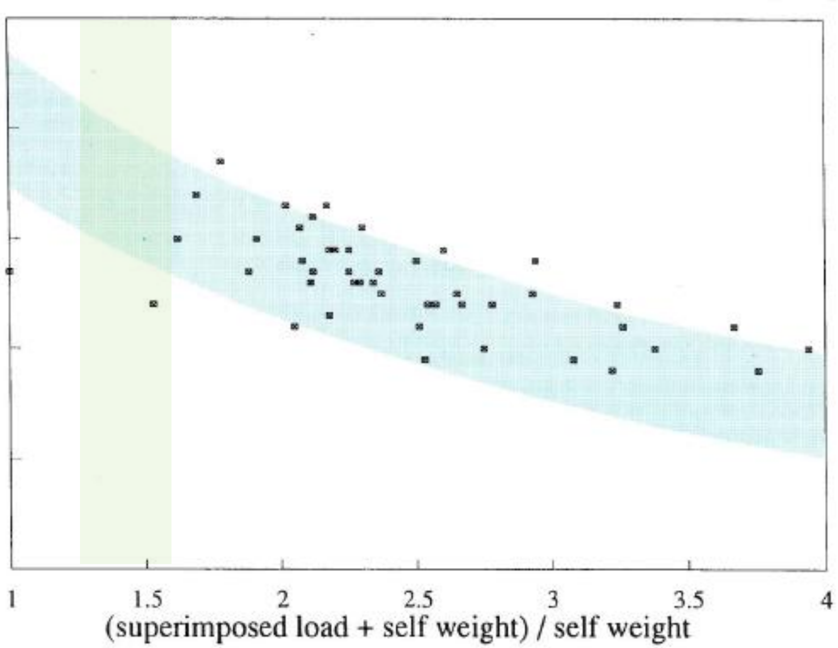
Two way

Span Efficiency

PT flat plate



PT slab with column caps



Courtesy of VSL

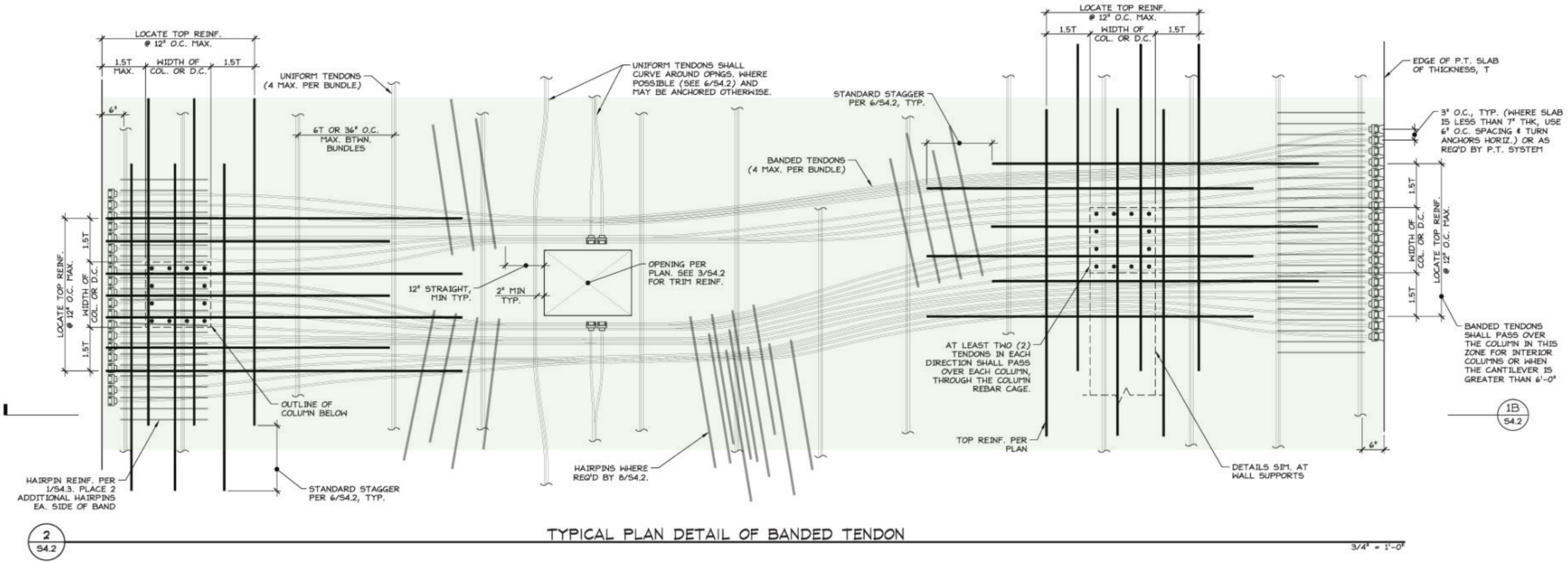
7” to 14” thick

25’ to 40’ span

Slender profile, large span-to-depth

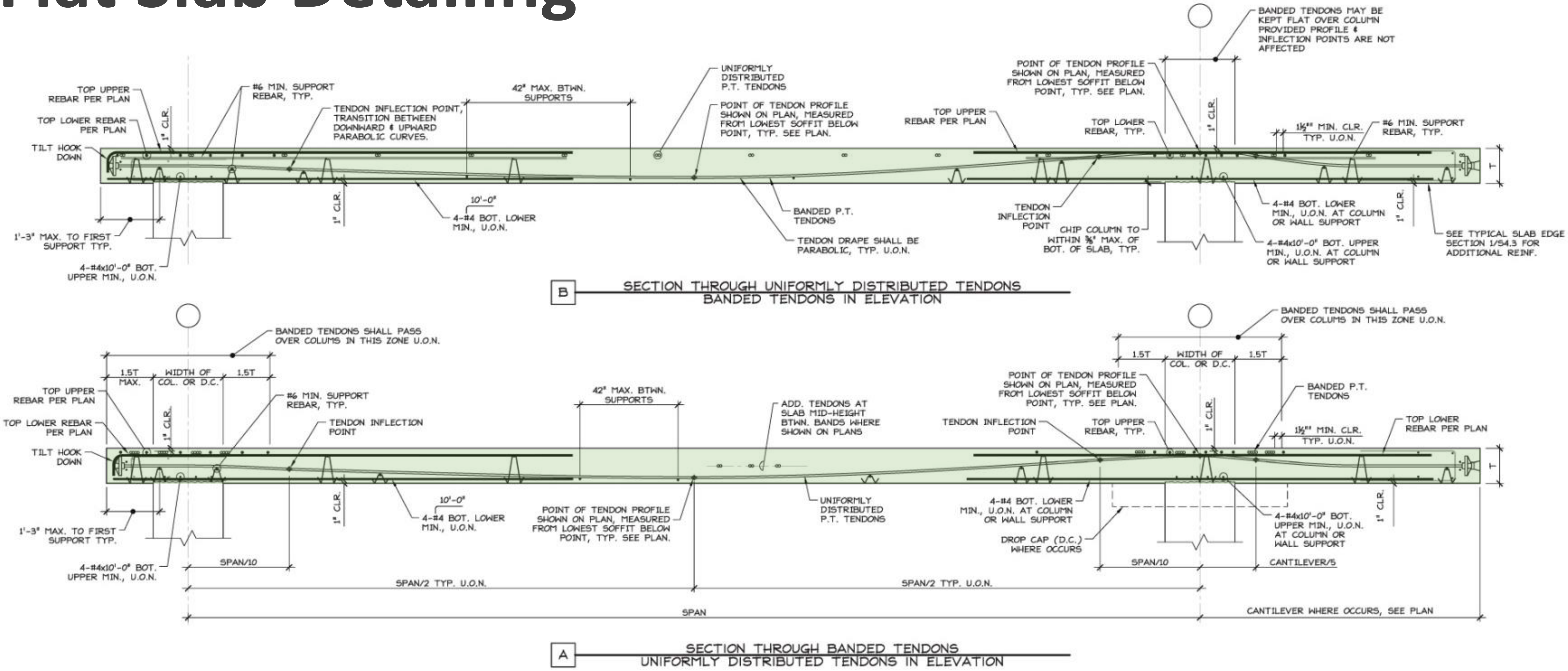
Limit deflection, punching shear at columns

Flat Slab Detailing



Coordinating rebar, tendons, anchorage, embeds, openings

Flat Slab Detailing



Managing tolerances for cover, tendon drape

Student Housing

7-story, 184,000 gsf residential

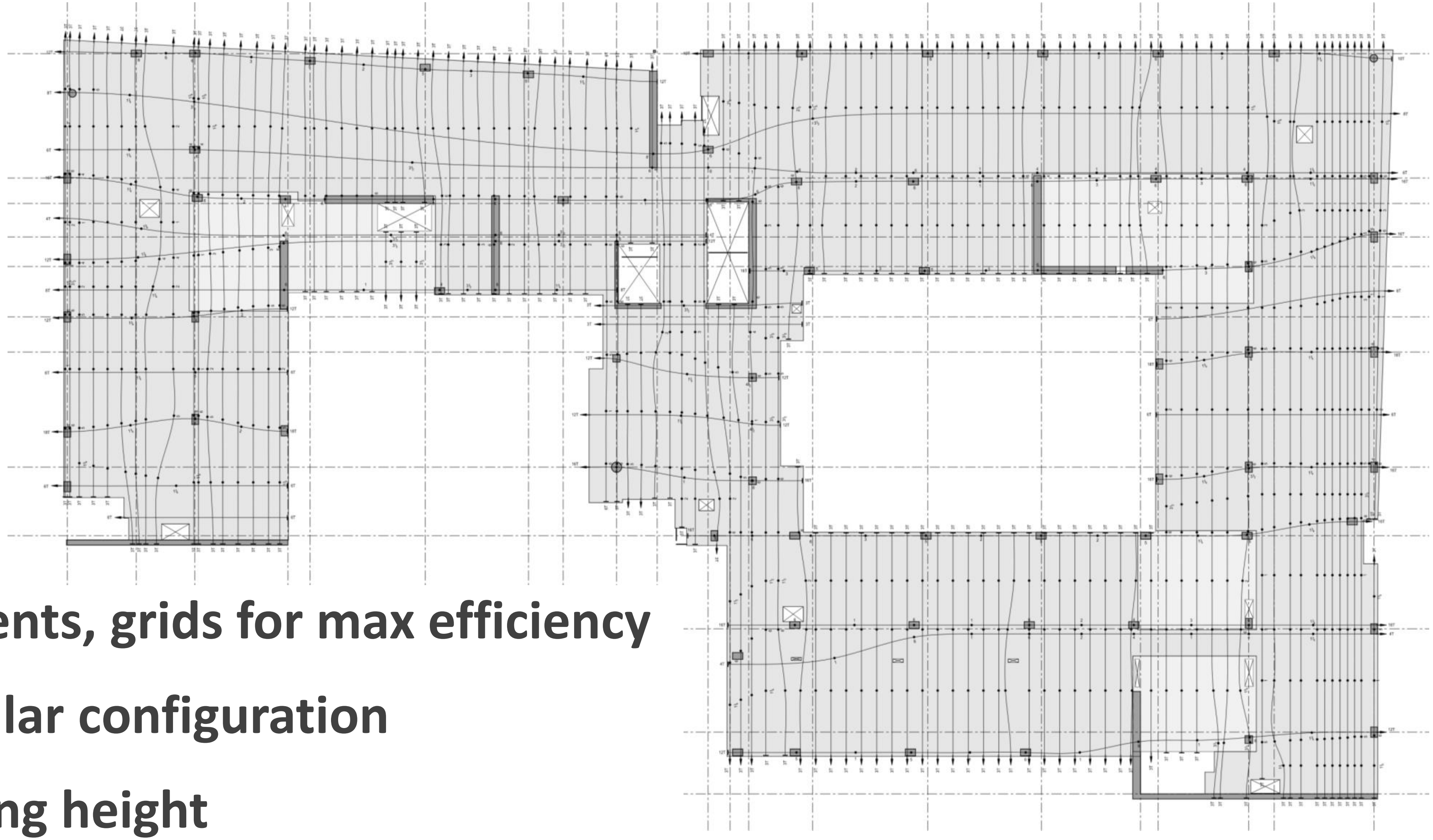
Landscaped podium

Ground floor retail, student services

P3 project, early design collaboration with OAC team

Planning for economy

Two-way PT Flat Plate



Span arrangements, grids for max efficiency

Adapt for irregular configuration

Minimize building height

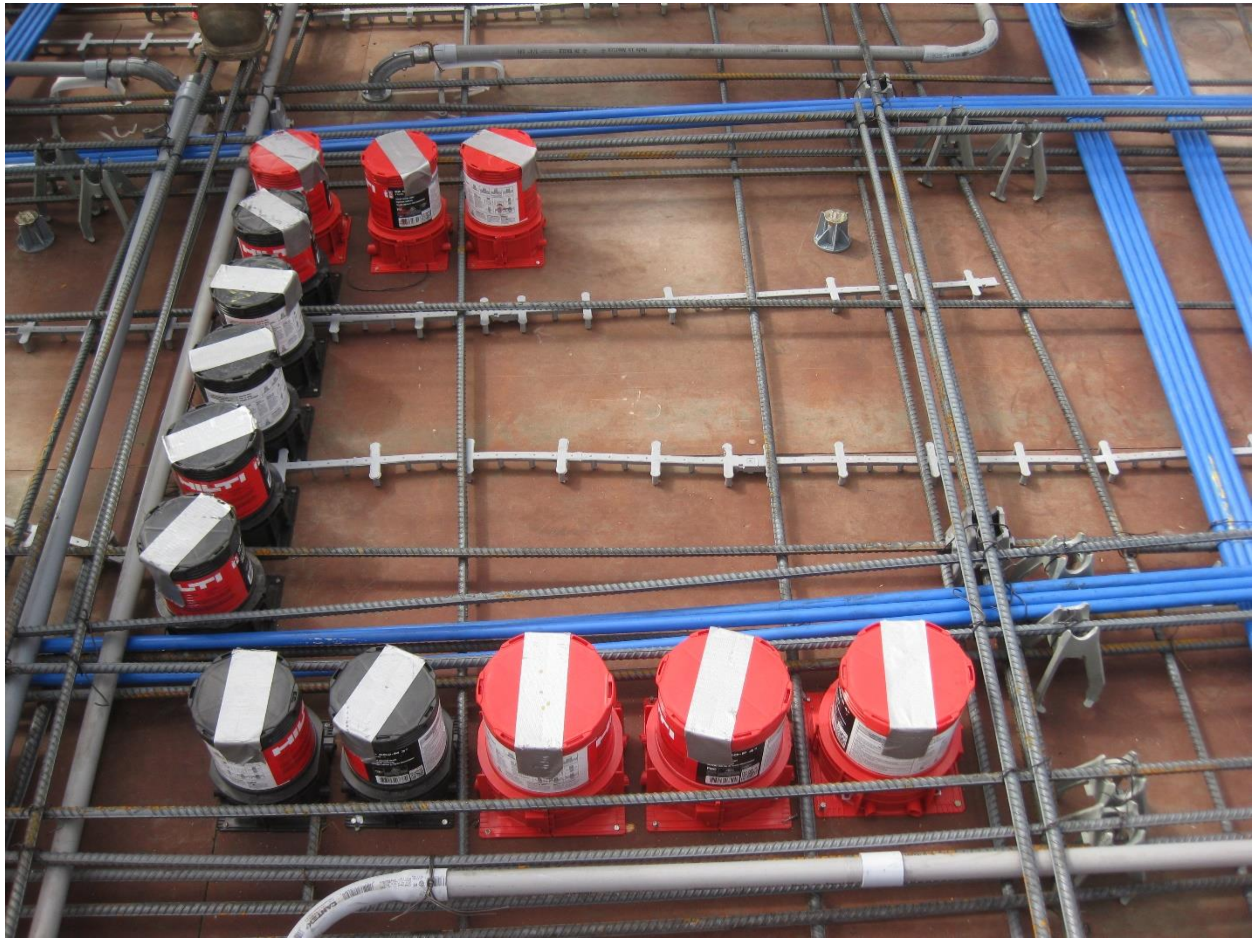
Slab Design

7” slabs

Detailed FEM for design & optimization

Performance validation

PT Slab Construction



Coordination of structural and nonstructural

HS Academic Building

Two-story art & science classroom

Exposed colored concrete

Long-span system for flexibility

One-way PT slab and girders

Floor Construction

8” slab, 23’ span, 9’ cantilevers

18” beams, 36’ span

27” girders, 48’ span

Floor Construction

Material efficiency

Deflection, vibration, acoustics

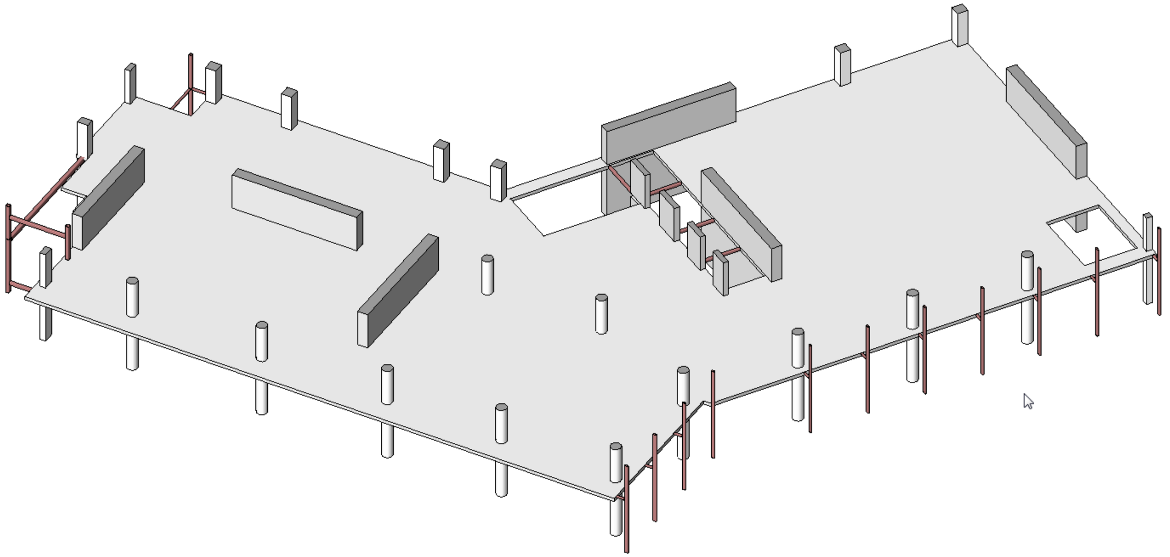
Program flexibility

Academic Building

Six-story campus building

Large tiered classrooms

Open collaboration areas



Long-span system for flexibility

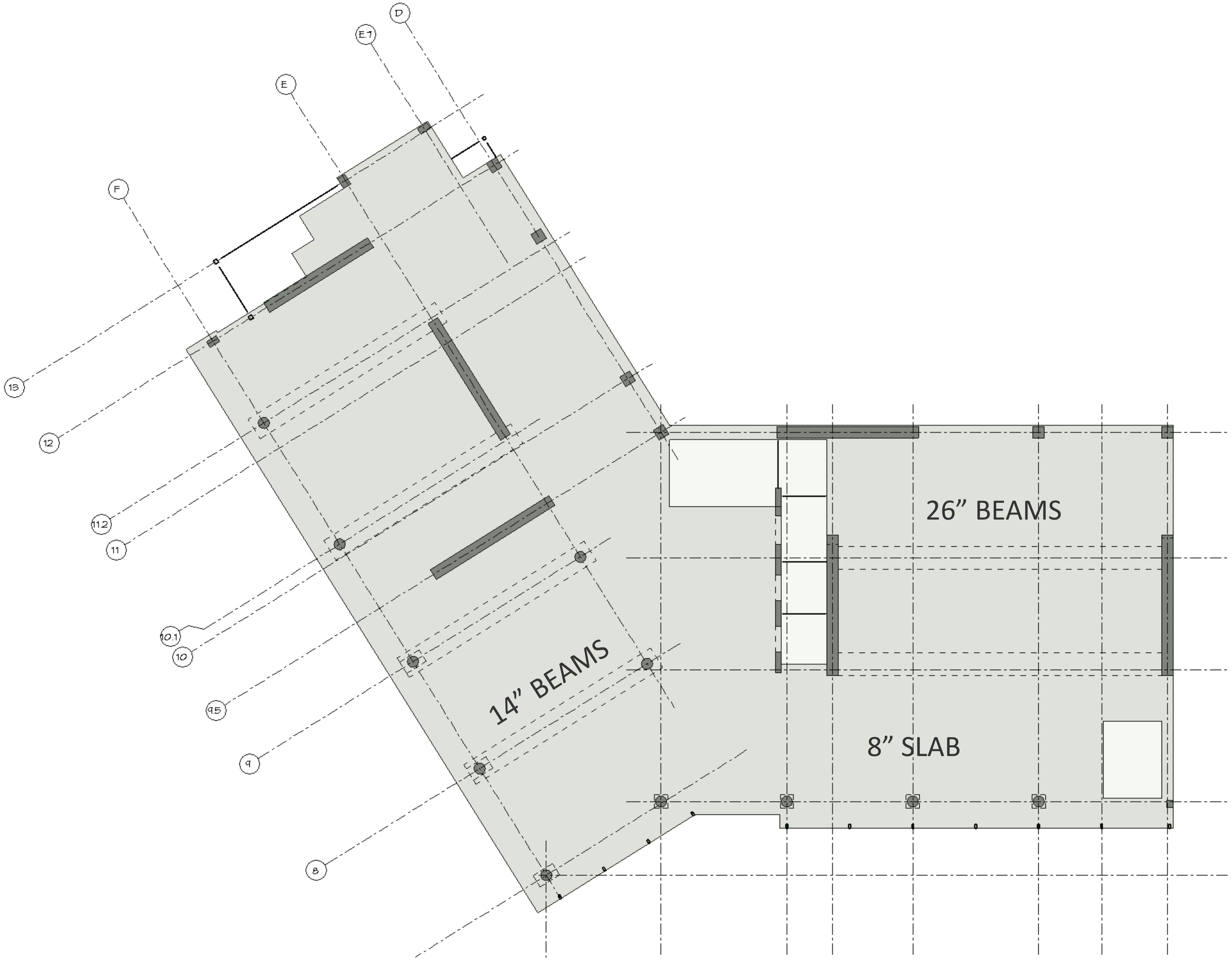
Two-way slab with integral beams

Floor Assemblies

Form follows program

Span requirements

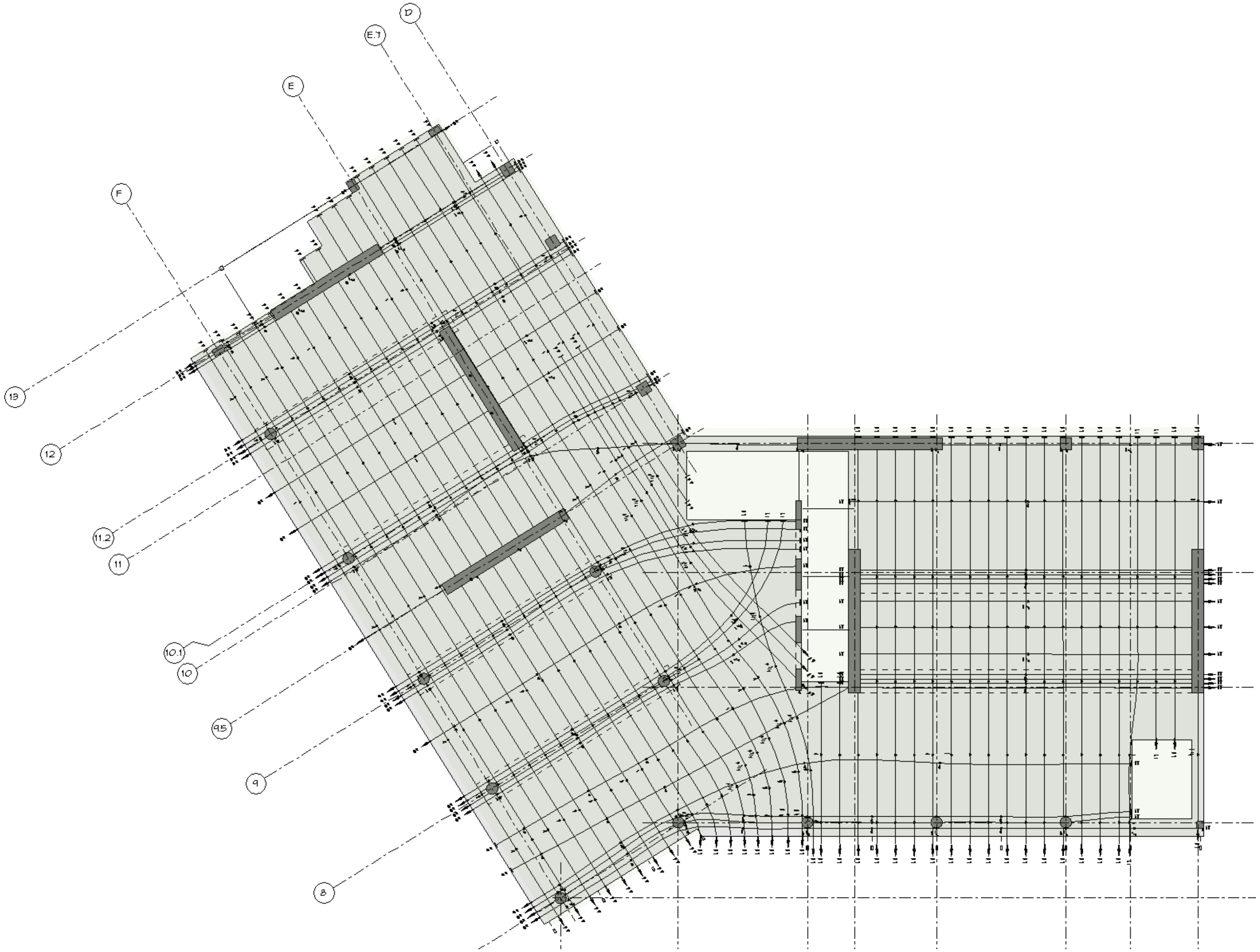
Ceiling heights



Floor Assemblies

Integrating one-way, two-way systems

Adapting to complex geometries



Floor Construction

Horizontal and vertical tendon curves, MEP integration

Floor Construction

Accommodating classrooms

Minimizing height

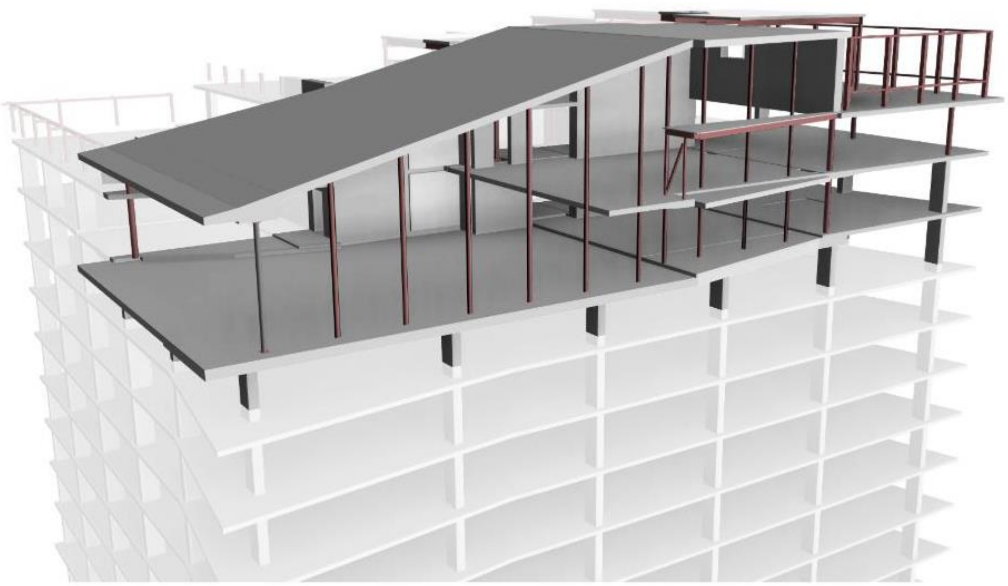
Deflection, vibration, acoustics

Superimposed loading

SF Conservatory of Music

Complex mixed-use – residential, student services, teaching, performance

Long-span Roof Structure

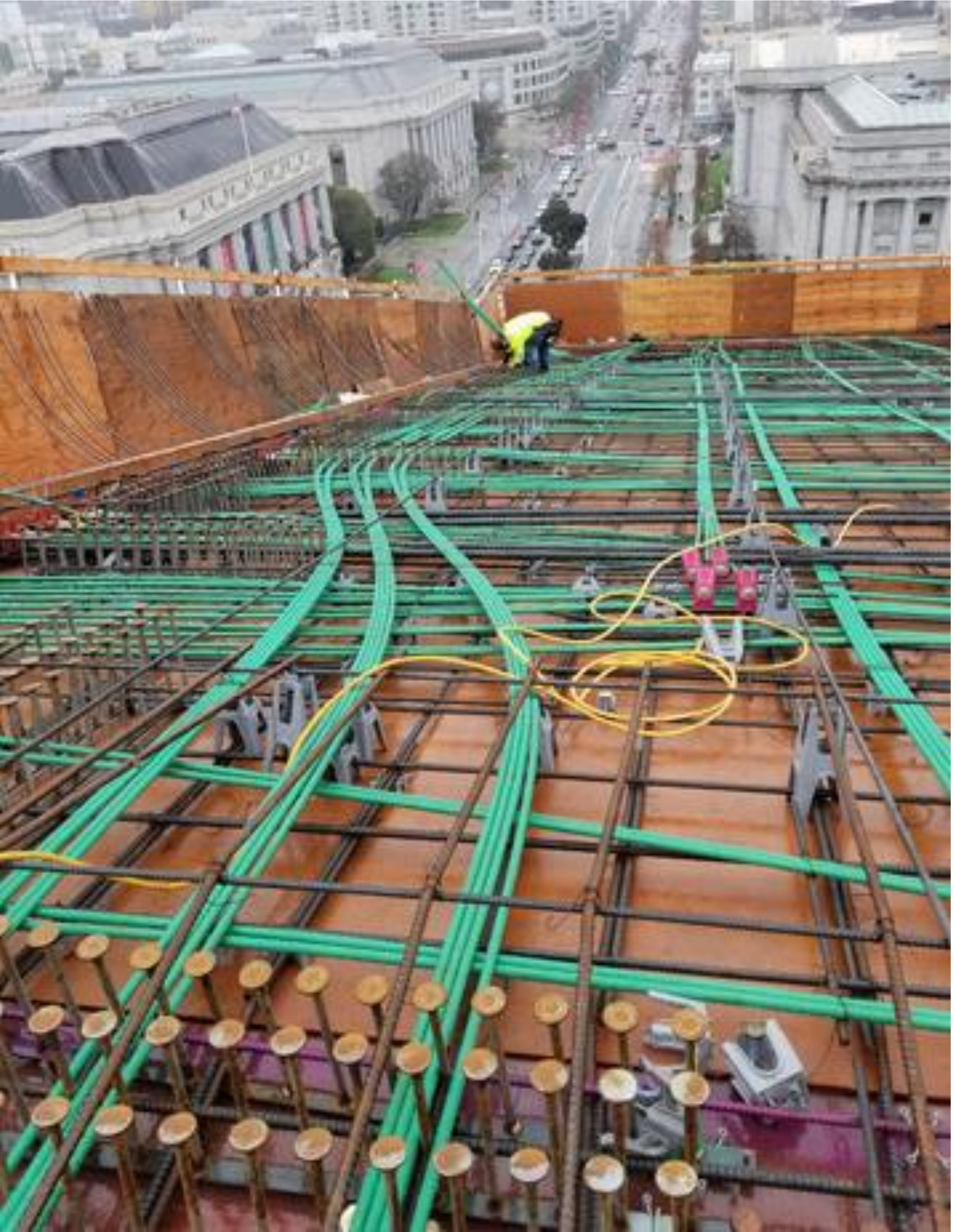


12” PT slab, 45’ span

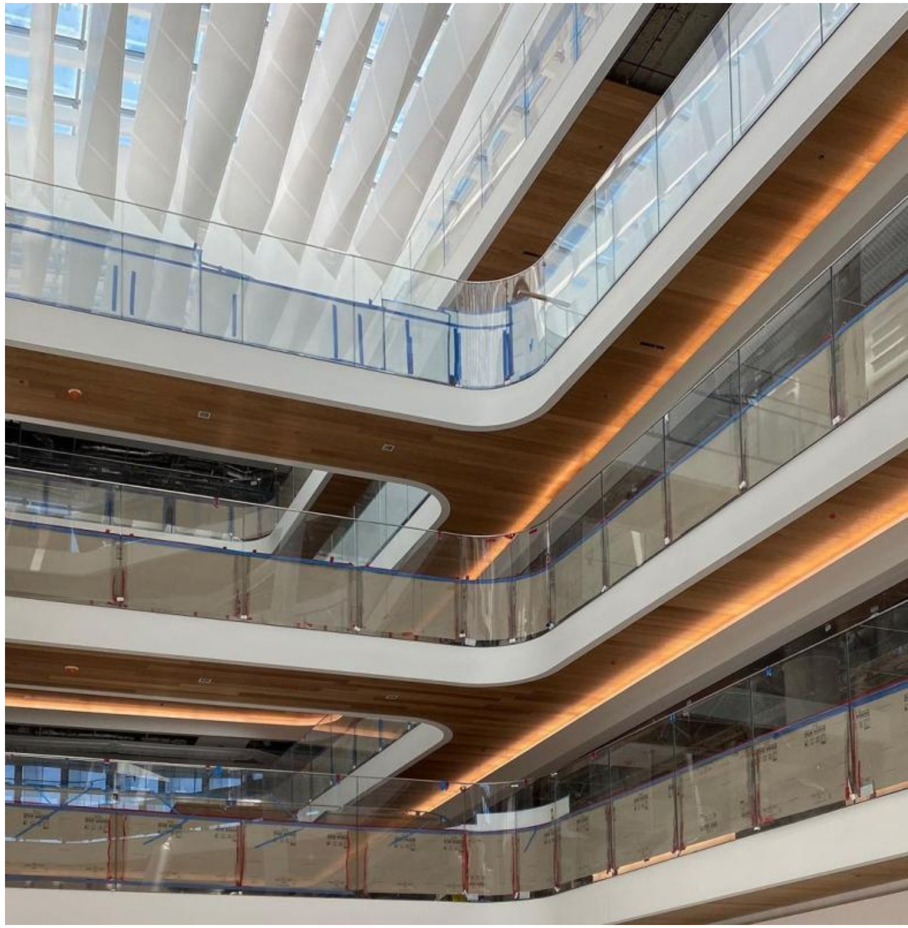
6” diameter steel columns

Articulating connections

Long-span Roof Structure

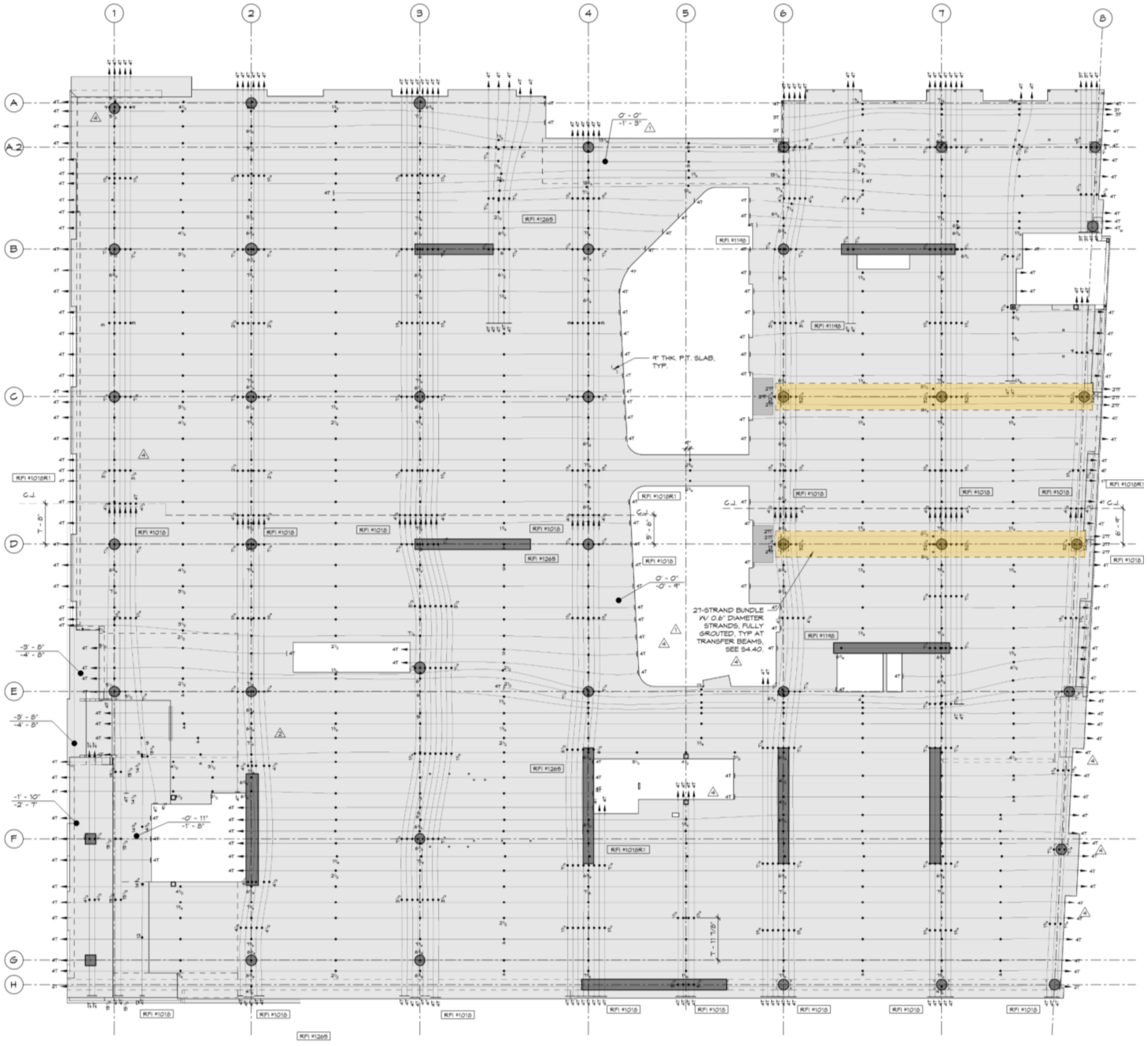


UCSF Treatment & Research Facility



Two way slabs and transfer girders

Slab and Girders



Adapting to complex program

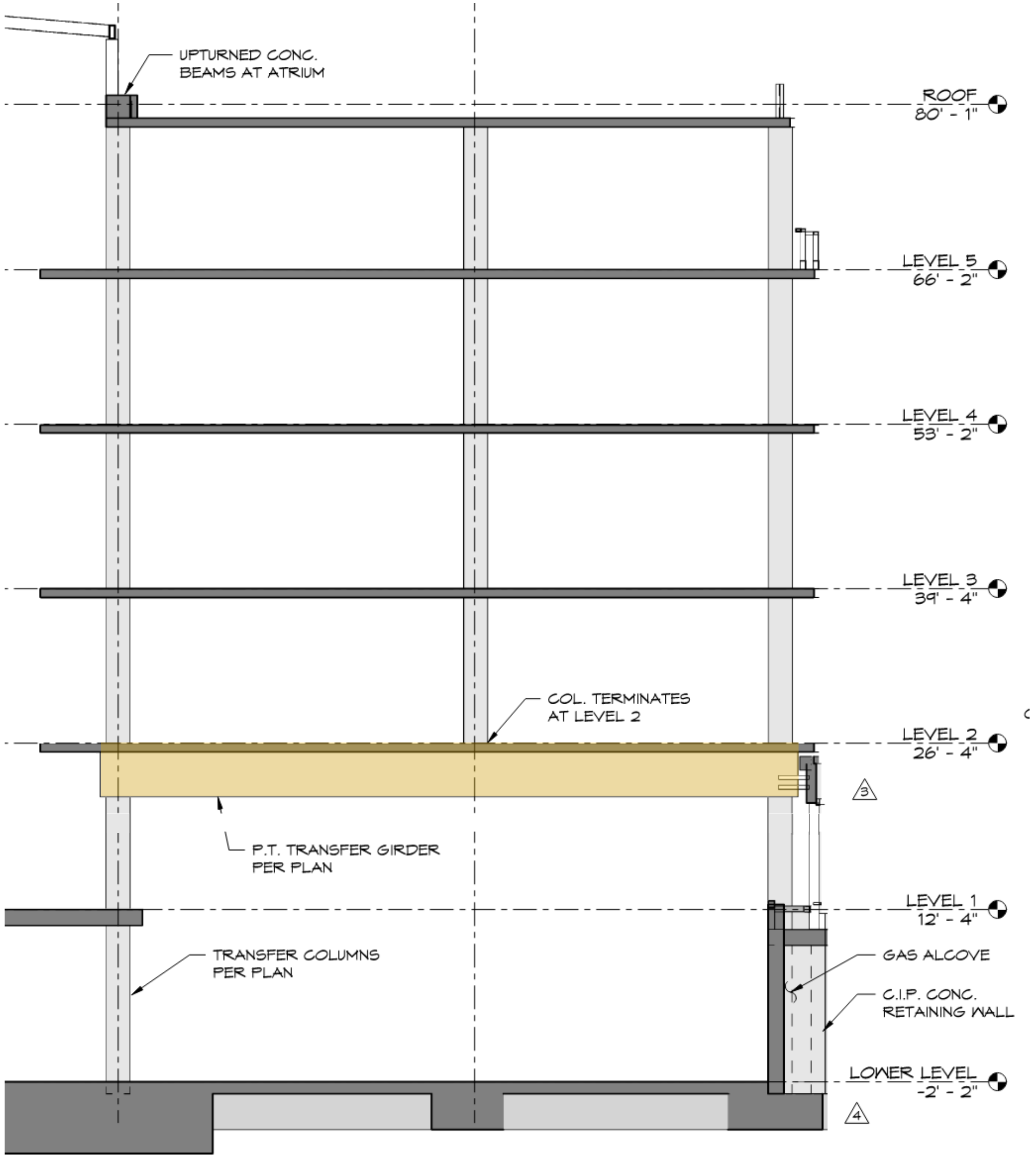
Transfer Girders

Pair of integral girders

56’ span, simply supported

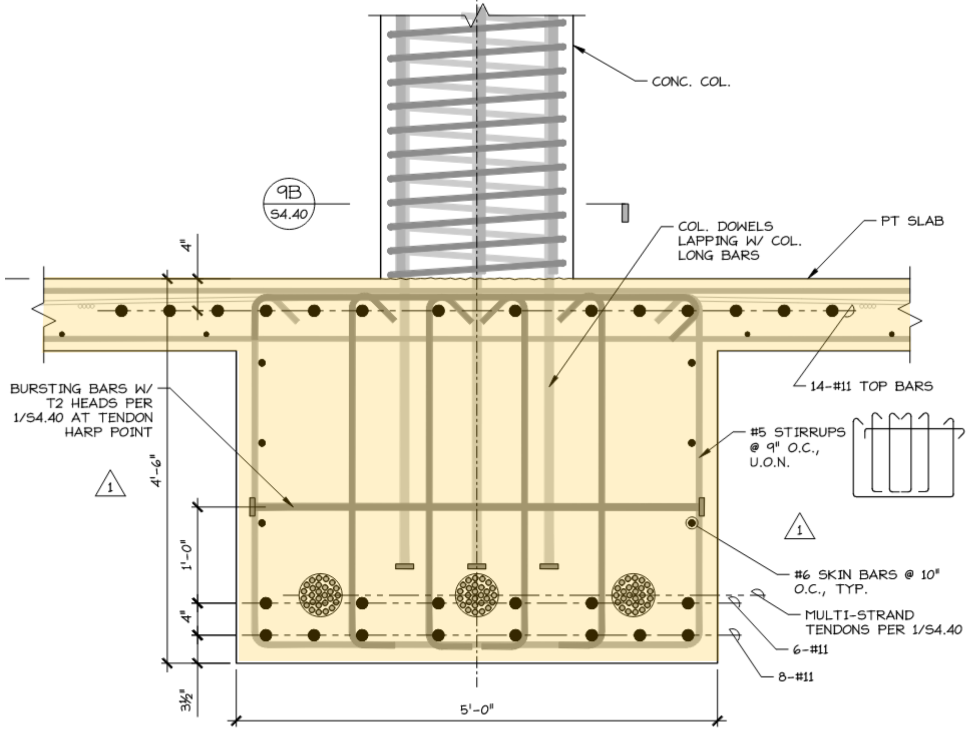
4’-6” deep, 5’-0” wide

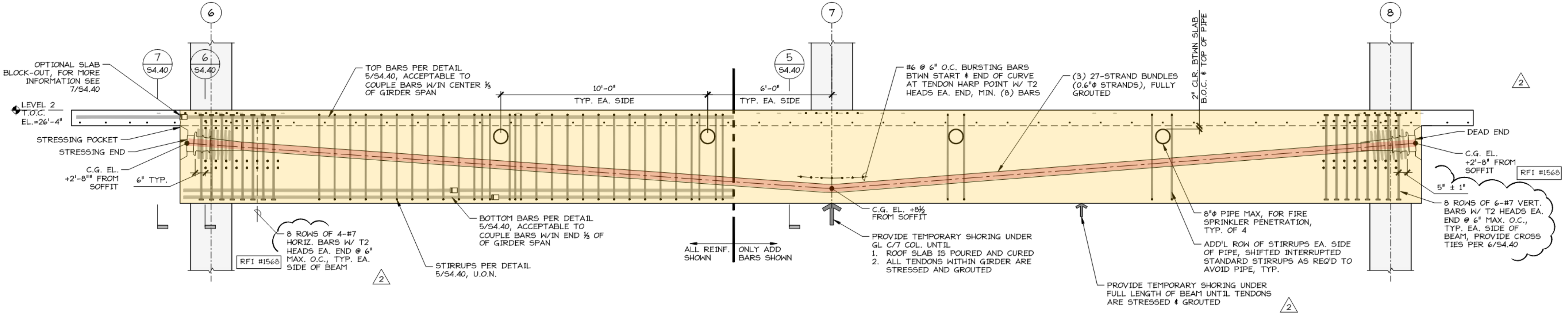
Continuously shored



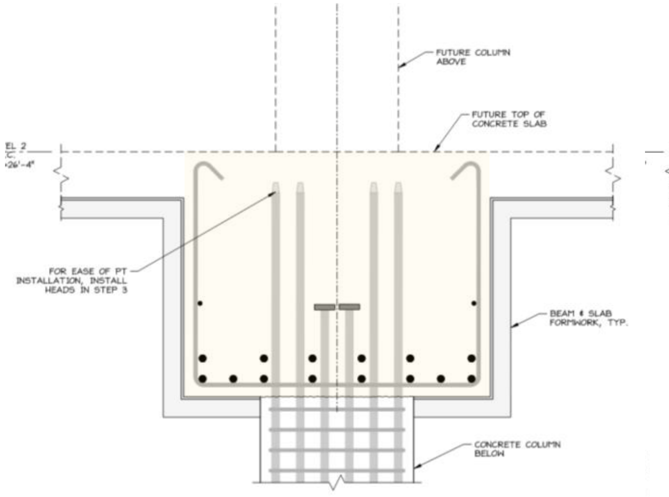
Transfer Girders

- **Harped tendons, single-end stressing**
- **27 - 0.6” diameter strands**
- **Confined anchorage zone**
- **Fully grouted**





Transfer Girders



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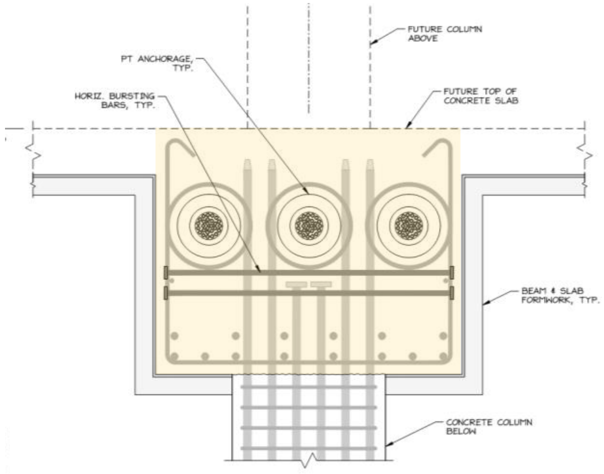

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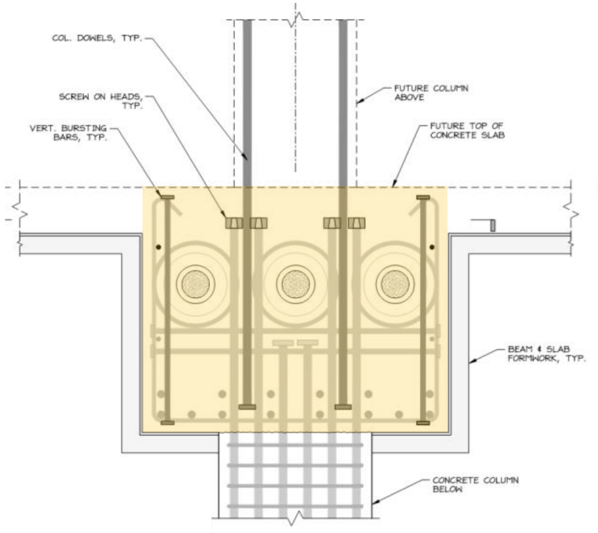

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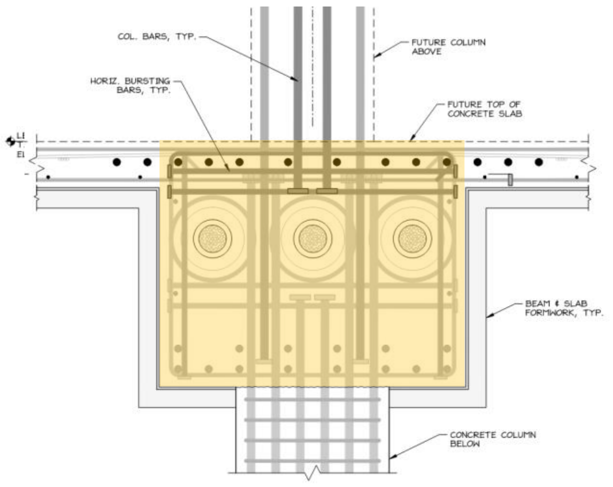


4

Sequencing steps

Girder Construction

Girder Construction

Girder Construction

SF Convention Center

Howard Street Viaduct

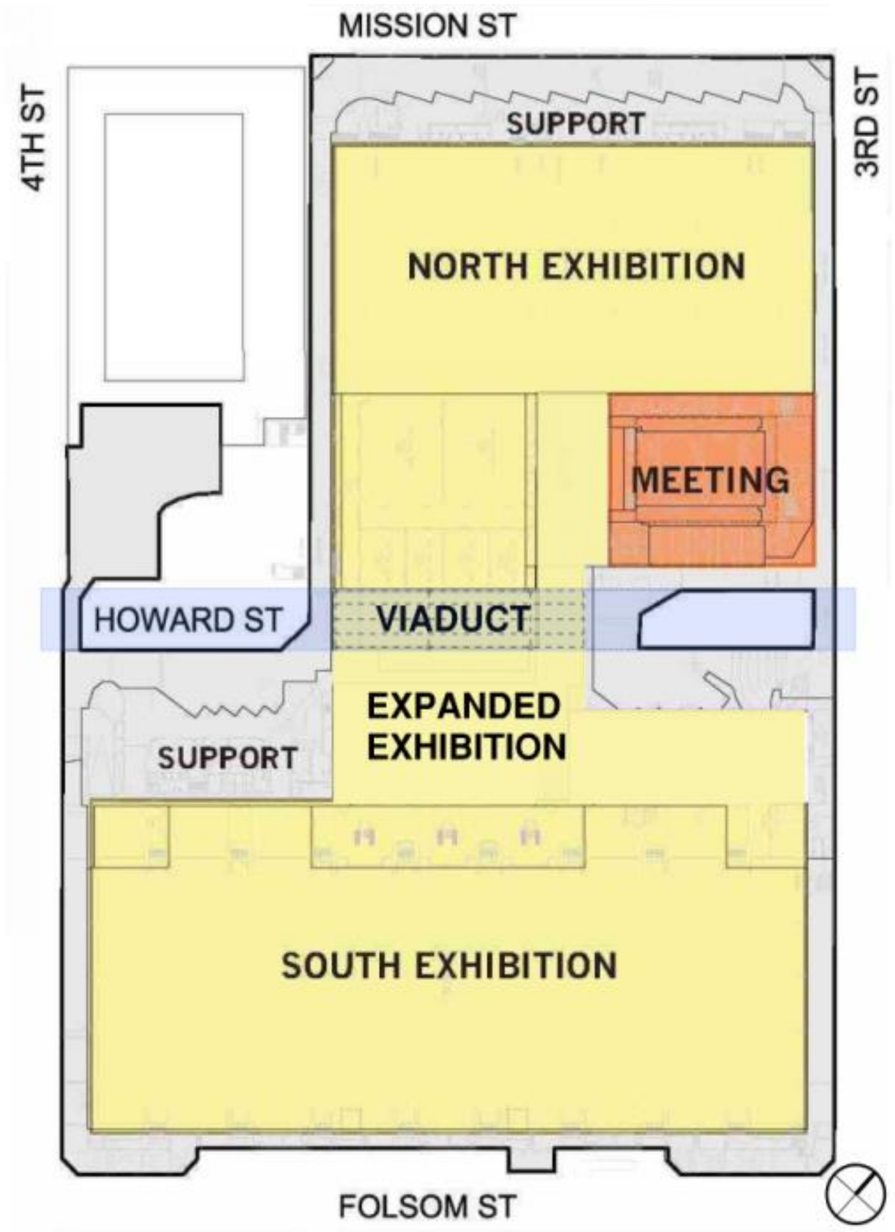
Link below-grade exhibition areas

Provide 20’-0” min. ceiling

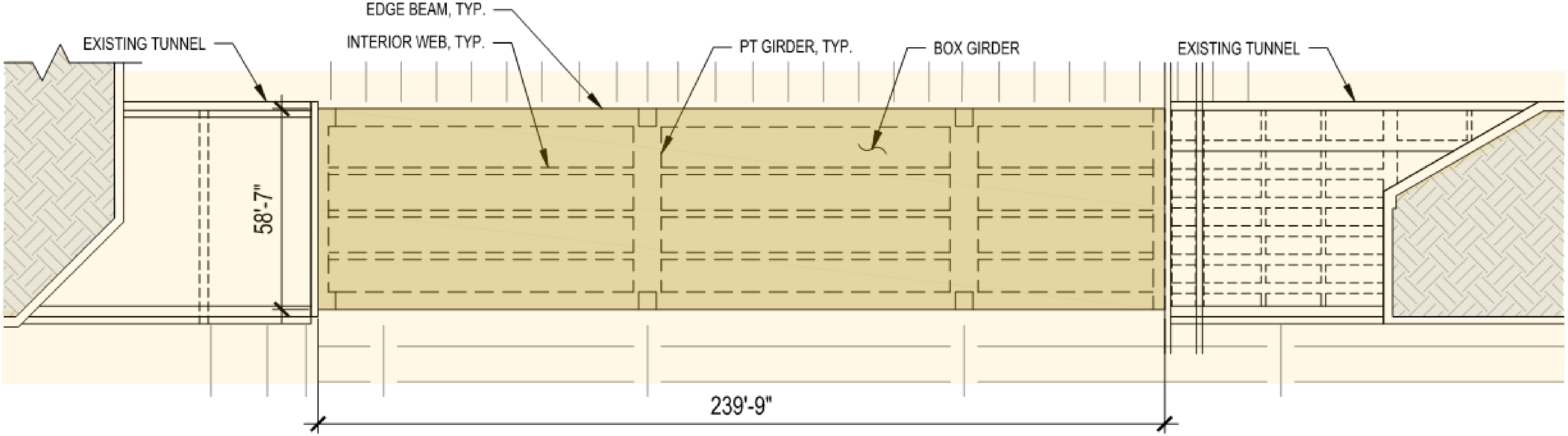
Accommodate street utilities

Isolate from traffic noise and vibration

Maintain conference facilities and traffic on Howard St. throughout construction

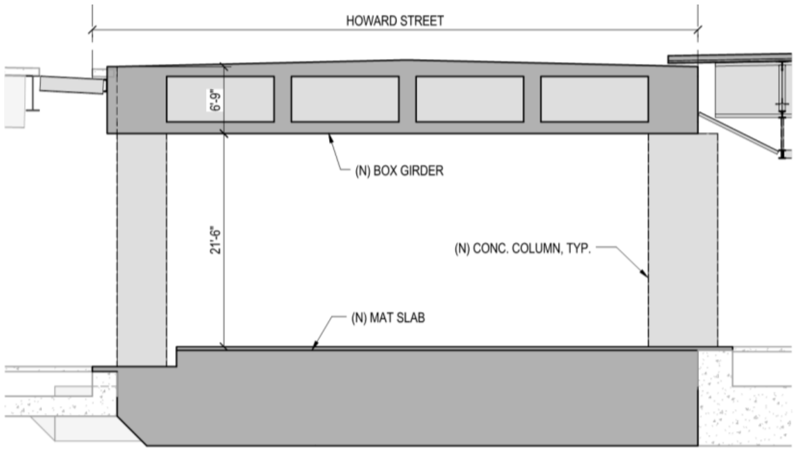


Howard Street Viaduct

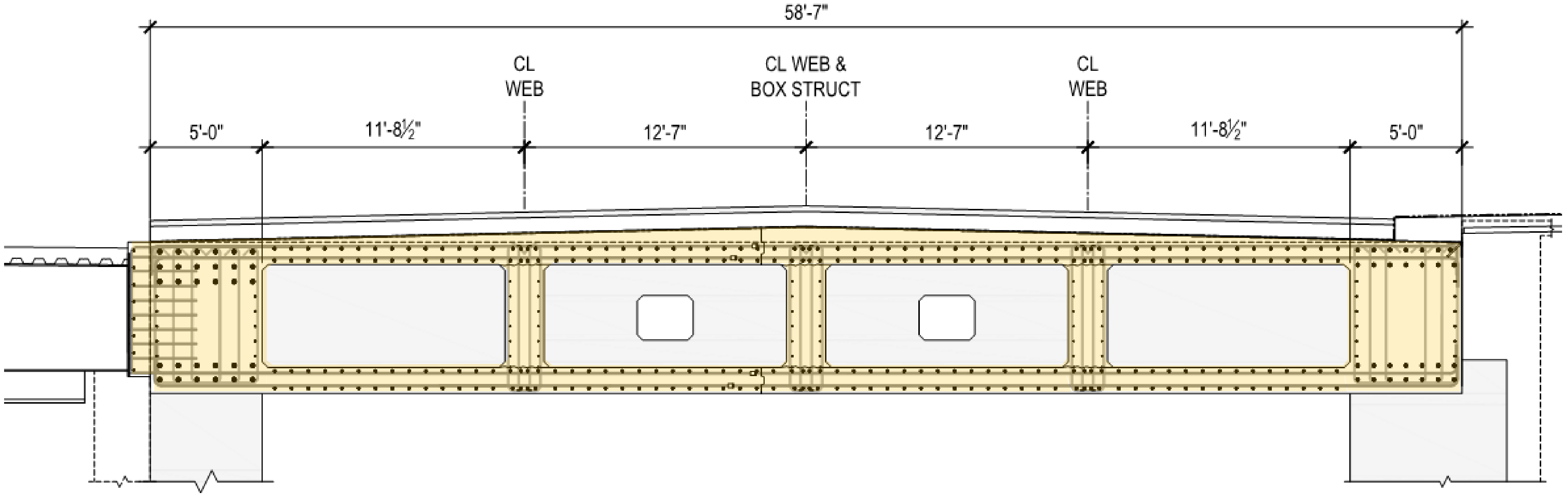


Supports public roadway

Convention space below

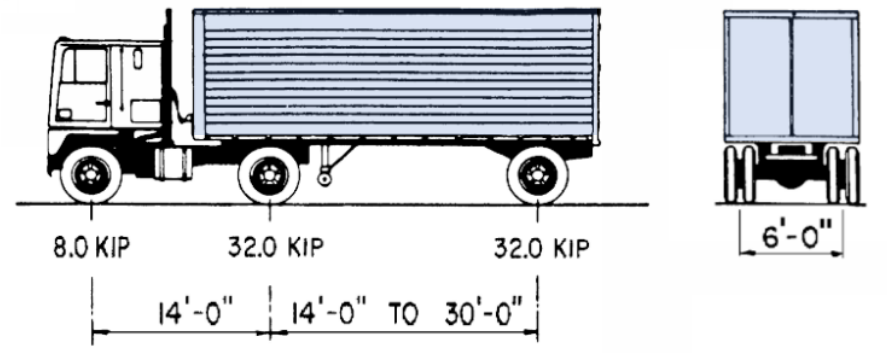


Viaduct Structure

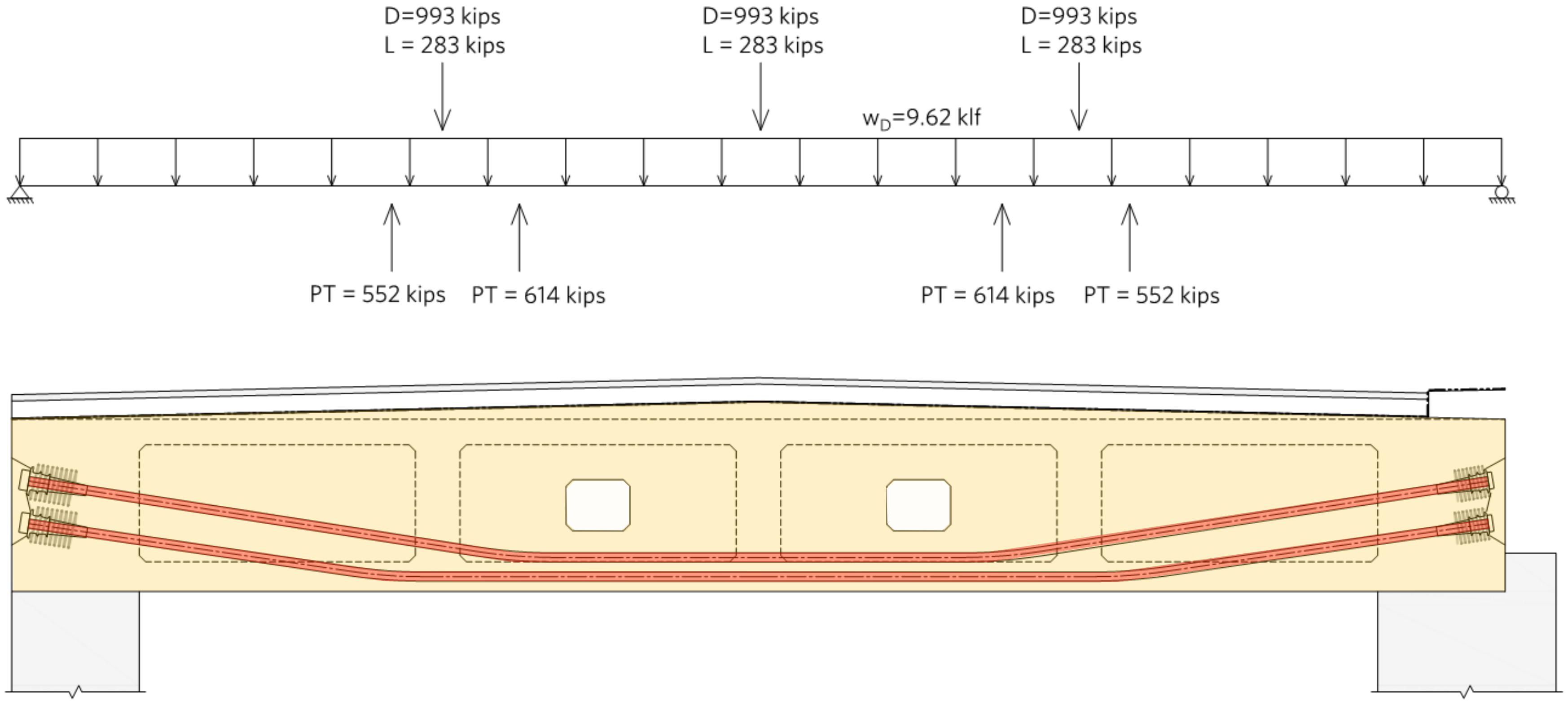


Combined criteria for AASHTO HS-20 truck and CBC emergency vehicle loading

6’-9” depth, 58’ span



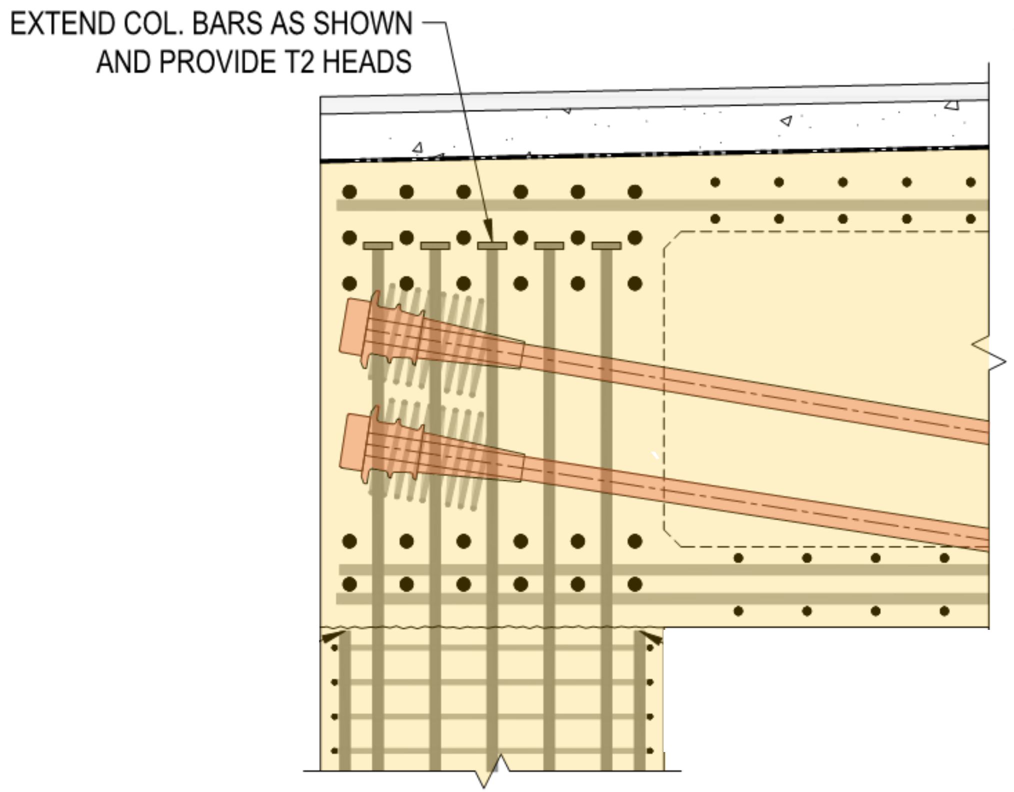
Long-span PT Girders

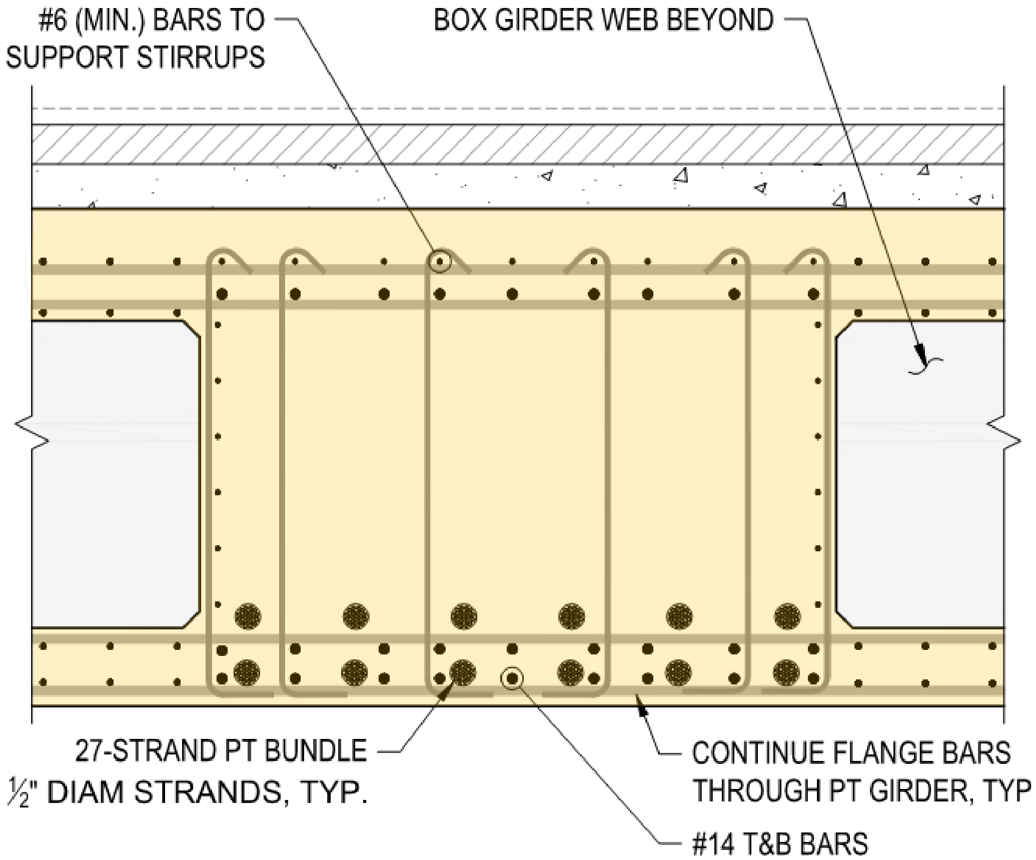


Harped tendon profiles

Deflection control

PT Girder Anchorage





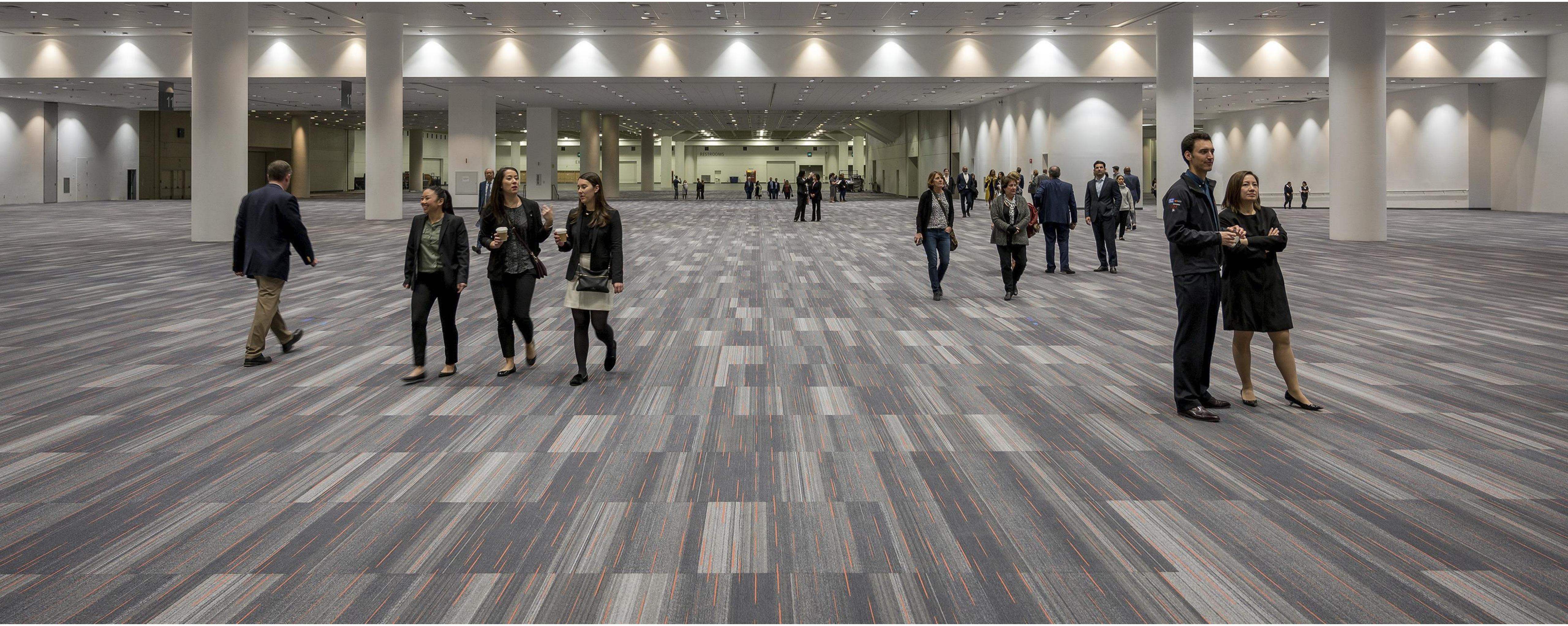
Class C – Partially prestressed, cracked

Grouted, bonded tendon bundles

Viaduct Construction

Viaduct Construction

SF Convention Center



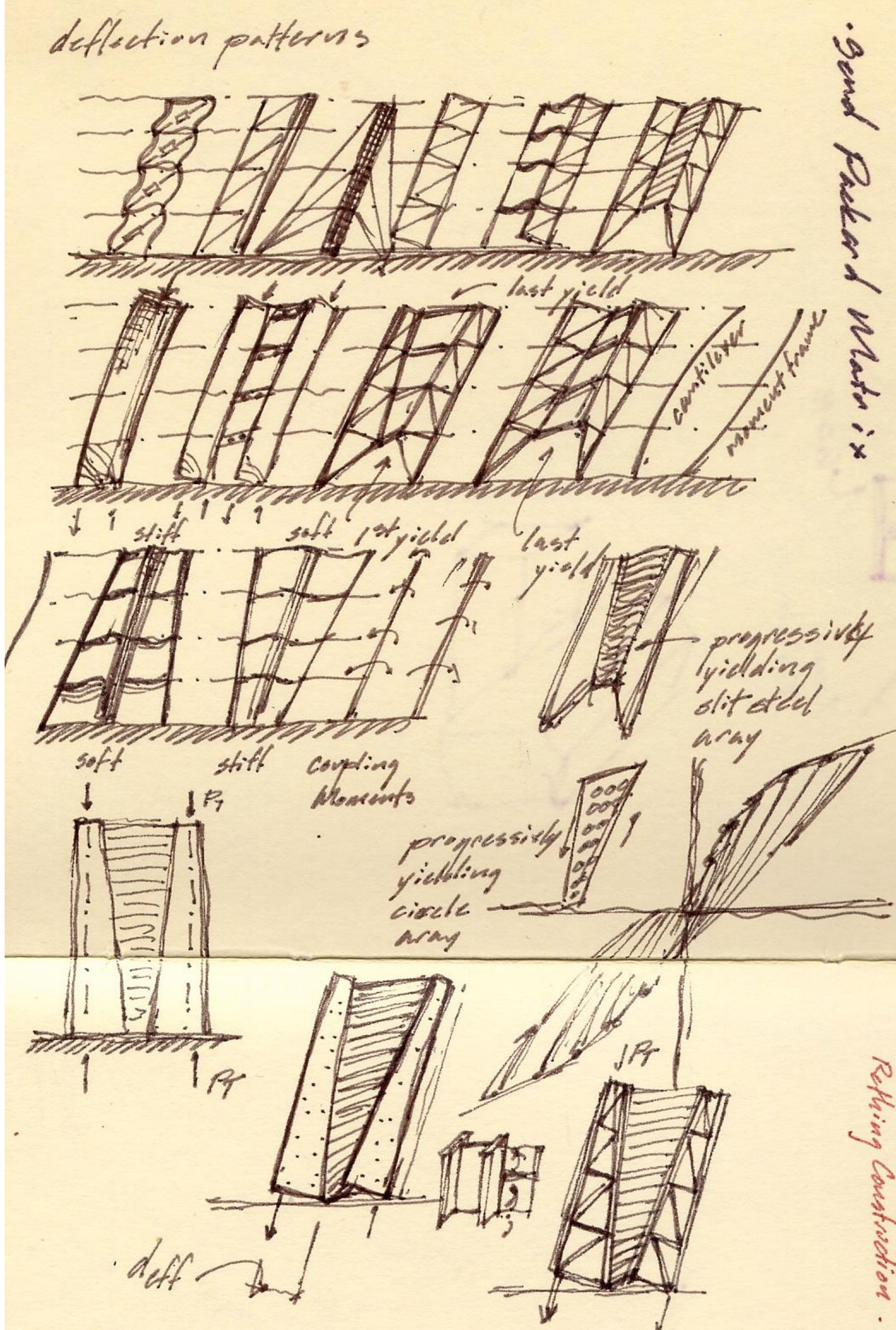
Resilient Seismic Design

Beyond structure

- Cladding, Interiors, MEP

Beyond forces

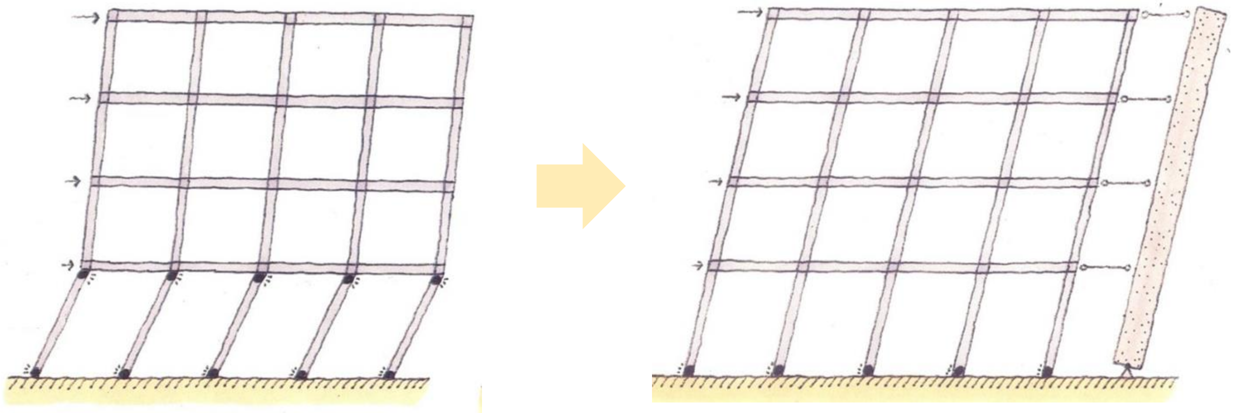
- Mode shaping & drift distribution
- Recentering
- Failure mechanism
- Ductility & damage
- Compatibility

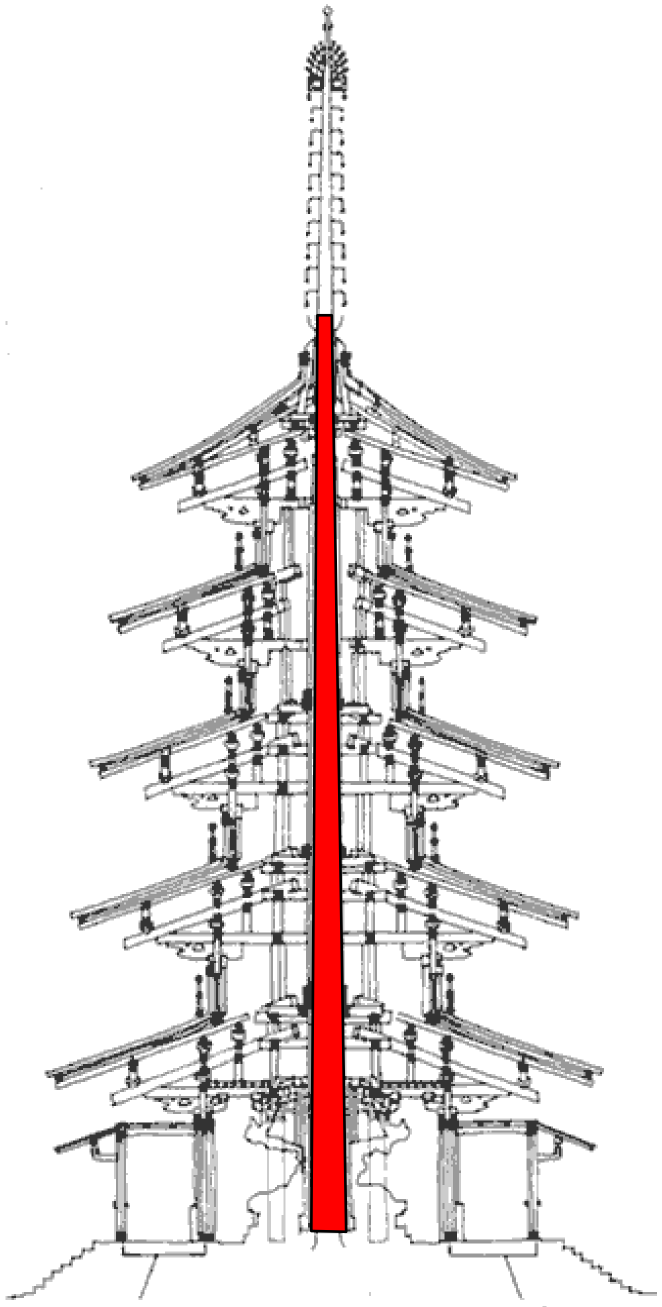


Mode Shaping

Elastic Spine / Strongback / Mast

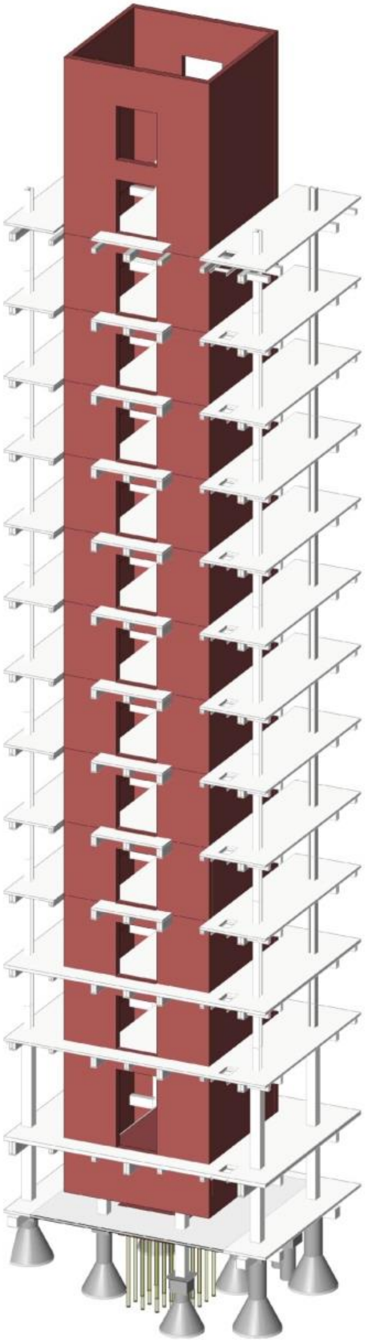
- Uniform drift – eliminate soft stories
- Minimize localized damage
- Maximize system ductility
- Protect building structure and systems



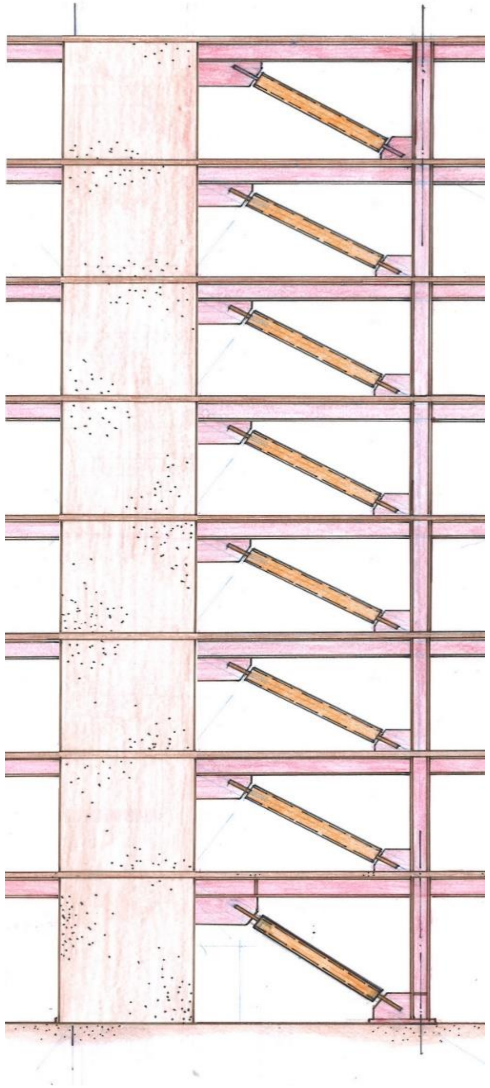


Mode Shaping

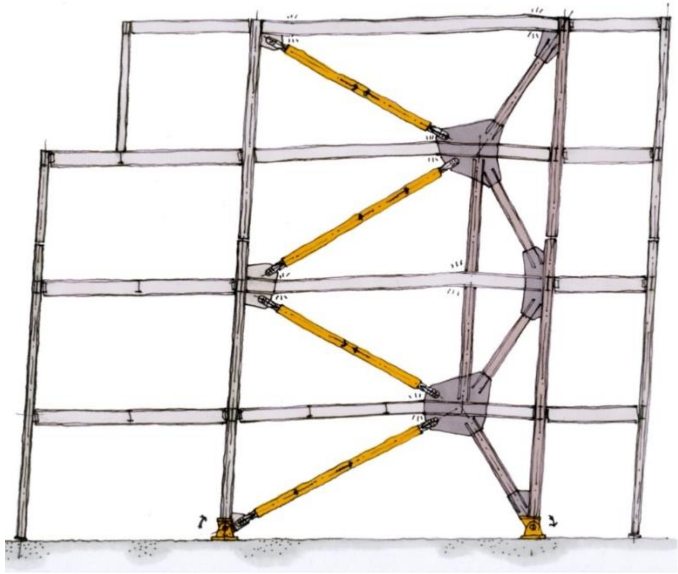
Concrete Walls



Hybrid



Steel Truss



Recentering Systems

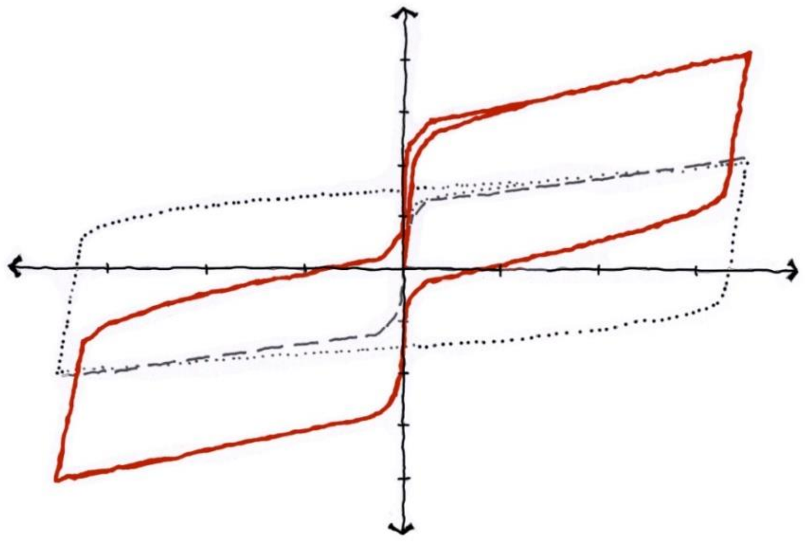
Post-tensioned walls, frames

PT for elastic restoring effect

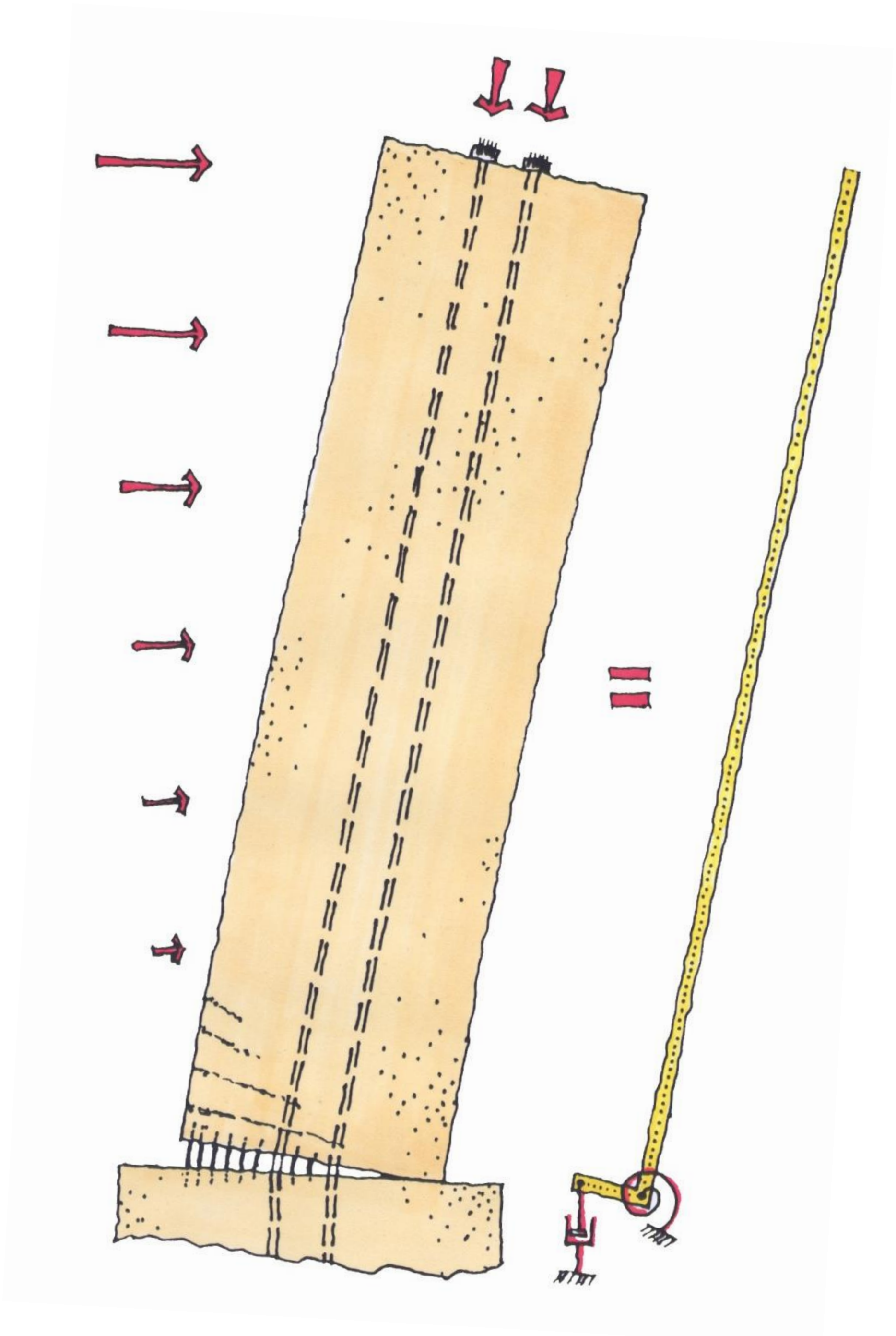
Energy dissipation through yielding

Spring – Damper

Force



Displacement



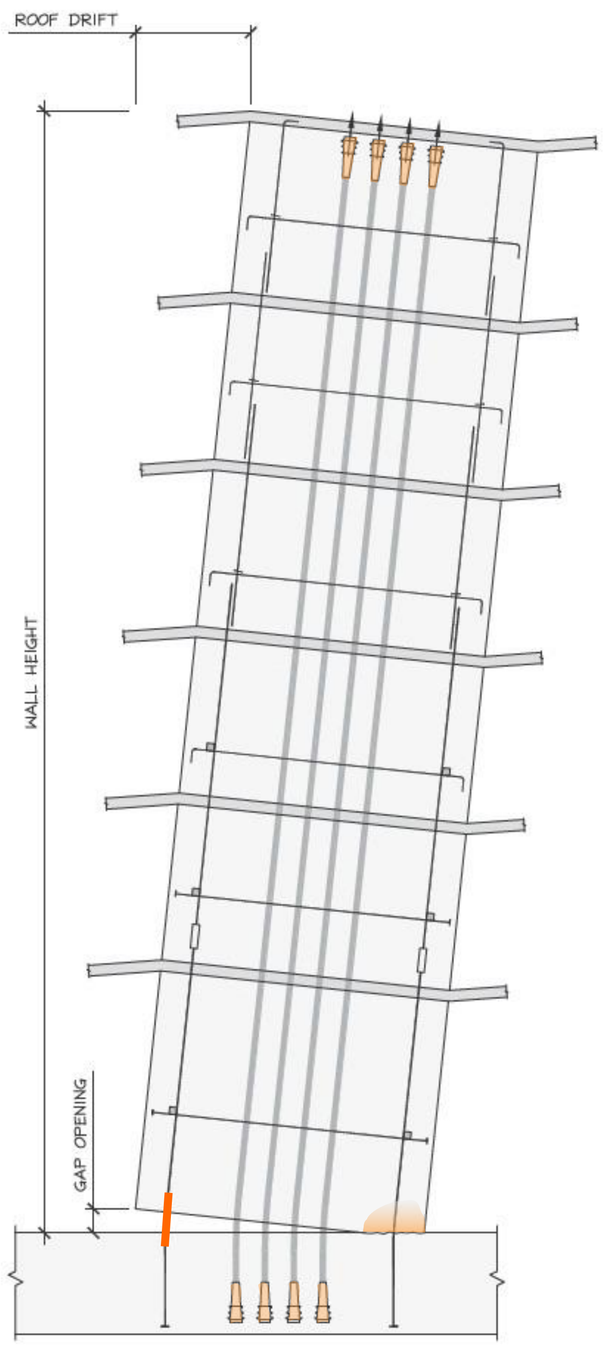
Recentering Systems

Proportioned for flexural yielding

Well defined plastic hinge zone, confined boundaries

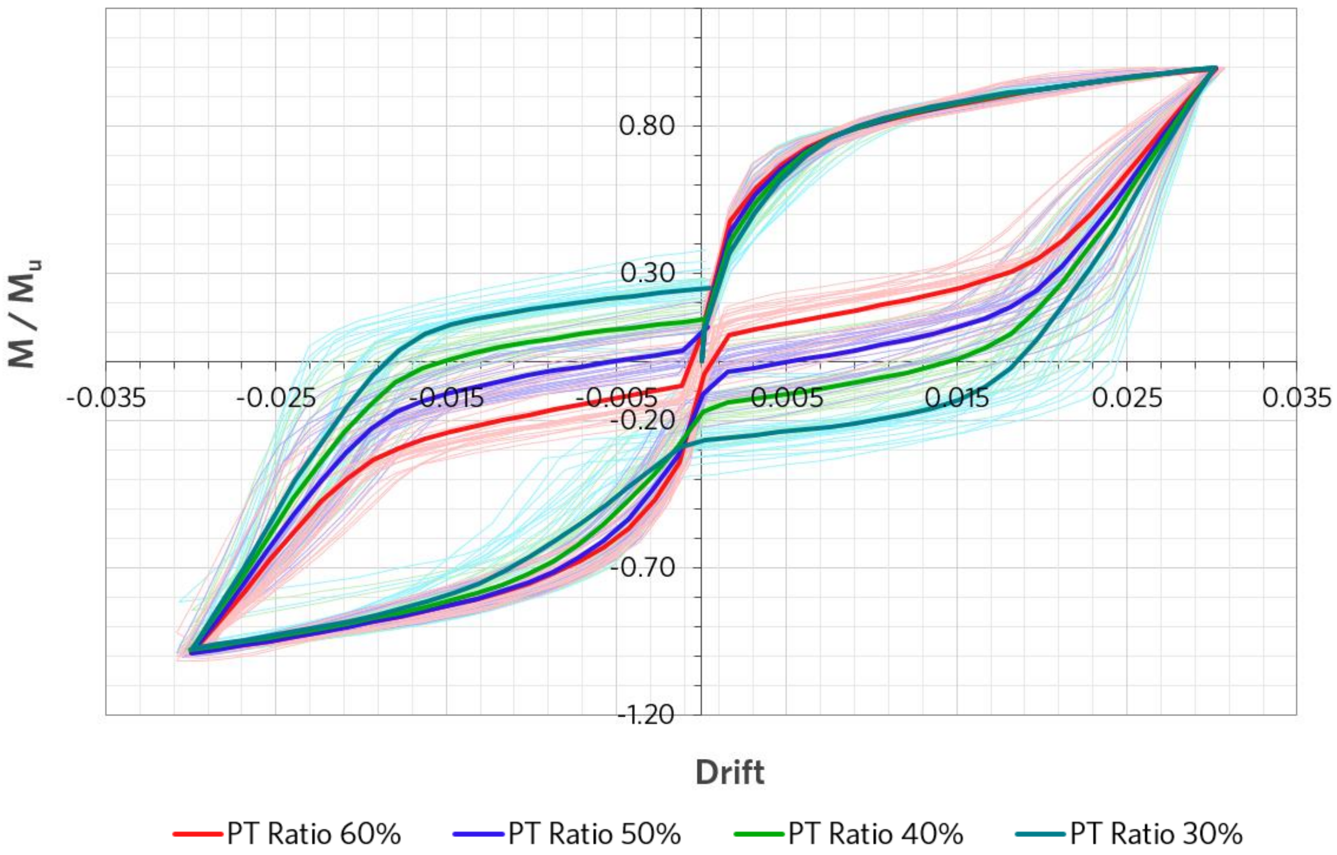
Capacity design, avoid shear failure, web crushing

Protect tendons – slenderness, unbonded

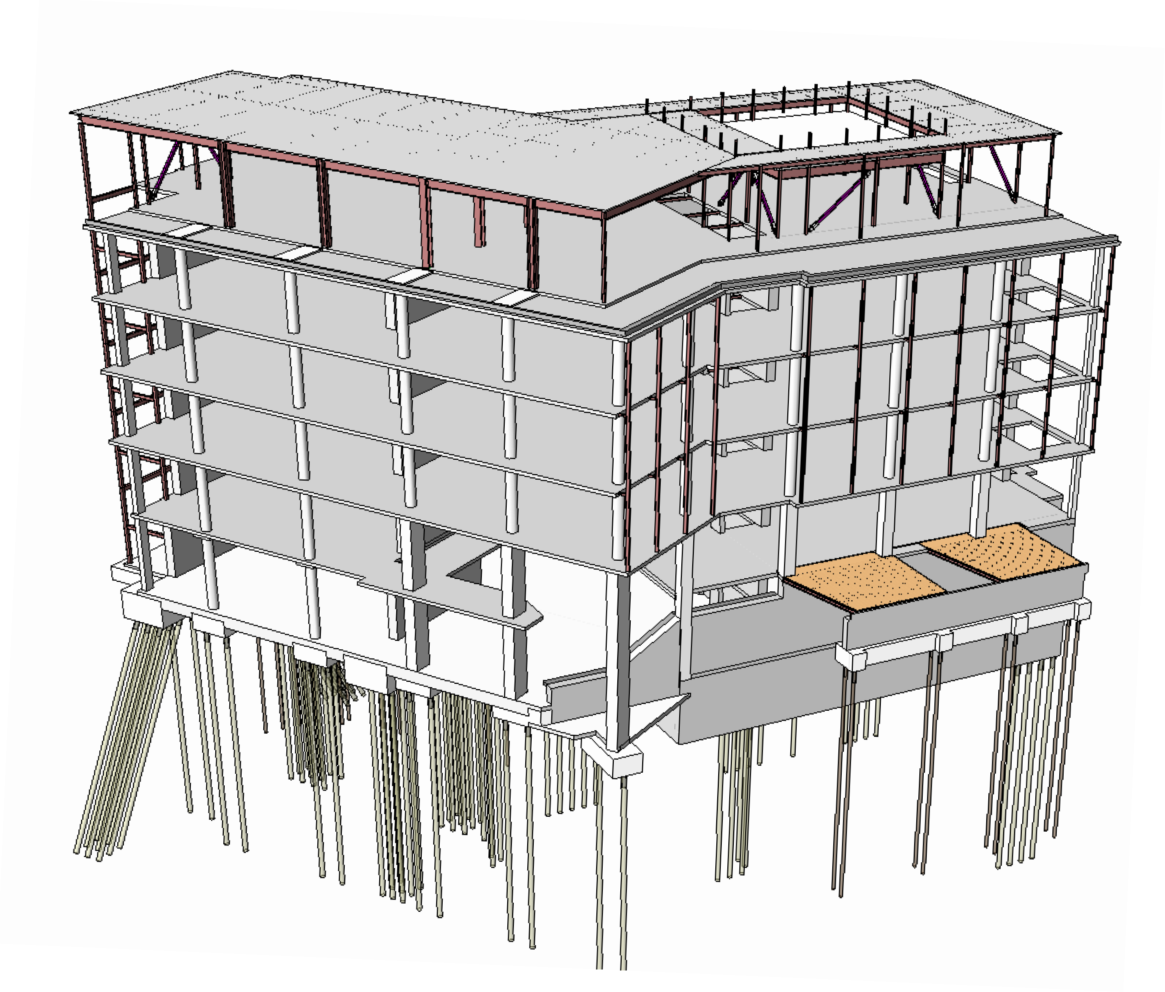


Recentering Parameter

Post-tensioning Ratio: $$\gamma_{PT} = \frac{A_{PT} f_{PTi}}{A_{PT} f_{PTi} + A_s f_y}$$



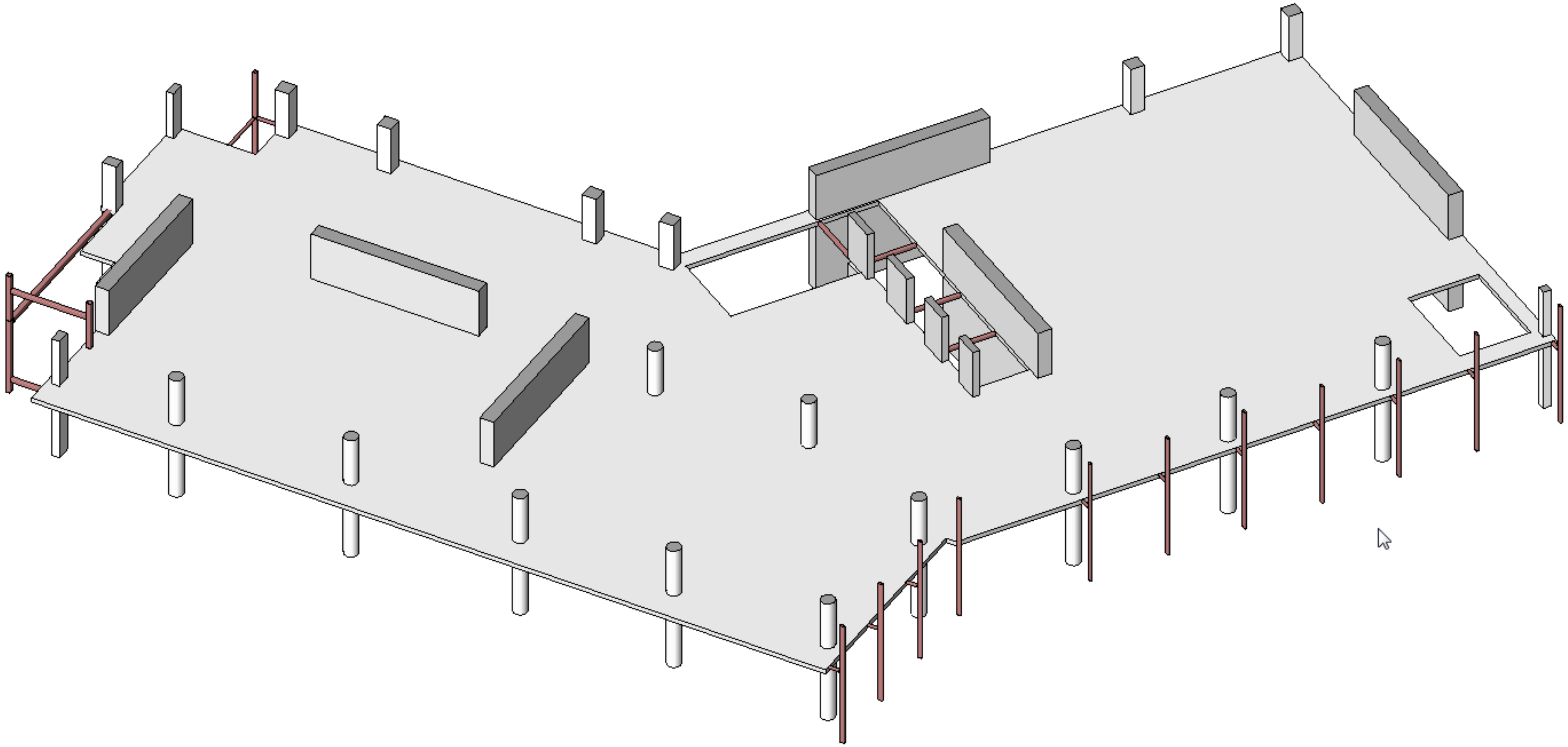
University Academic Building



PT Concrete Walls for Seismic Resistance

Shear walls clustered around large classrooms

Paired orthogonal configuration to minimize torsion

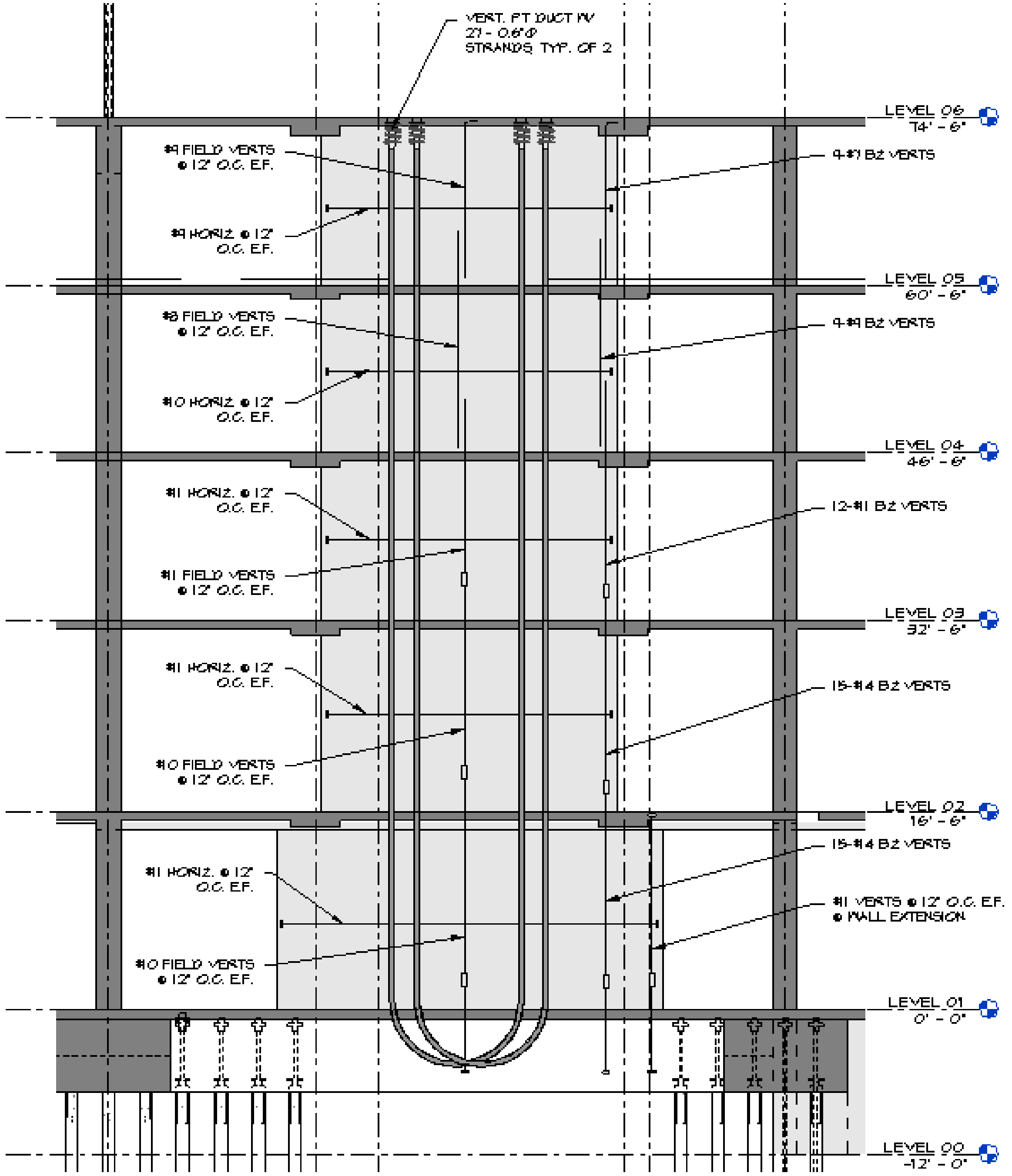


PT Recentering Walls

Vertical unbonded PT

Uniform inter-story drifts

Improved protection for façade, interiors, MEP

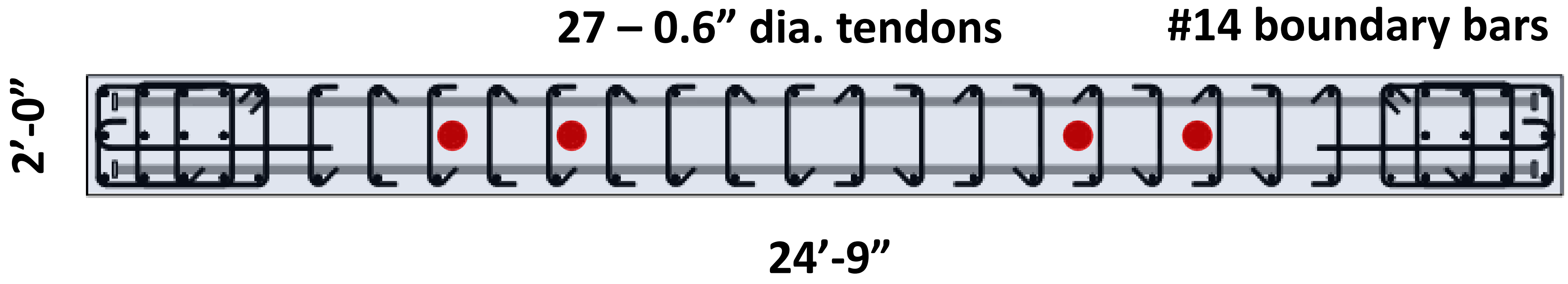


PT Recentering Walls

Combination of mild steel and unbonded PT:

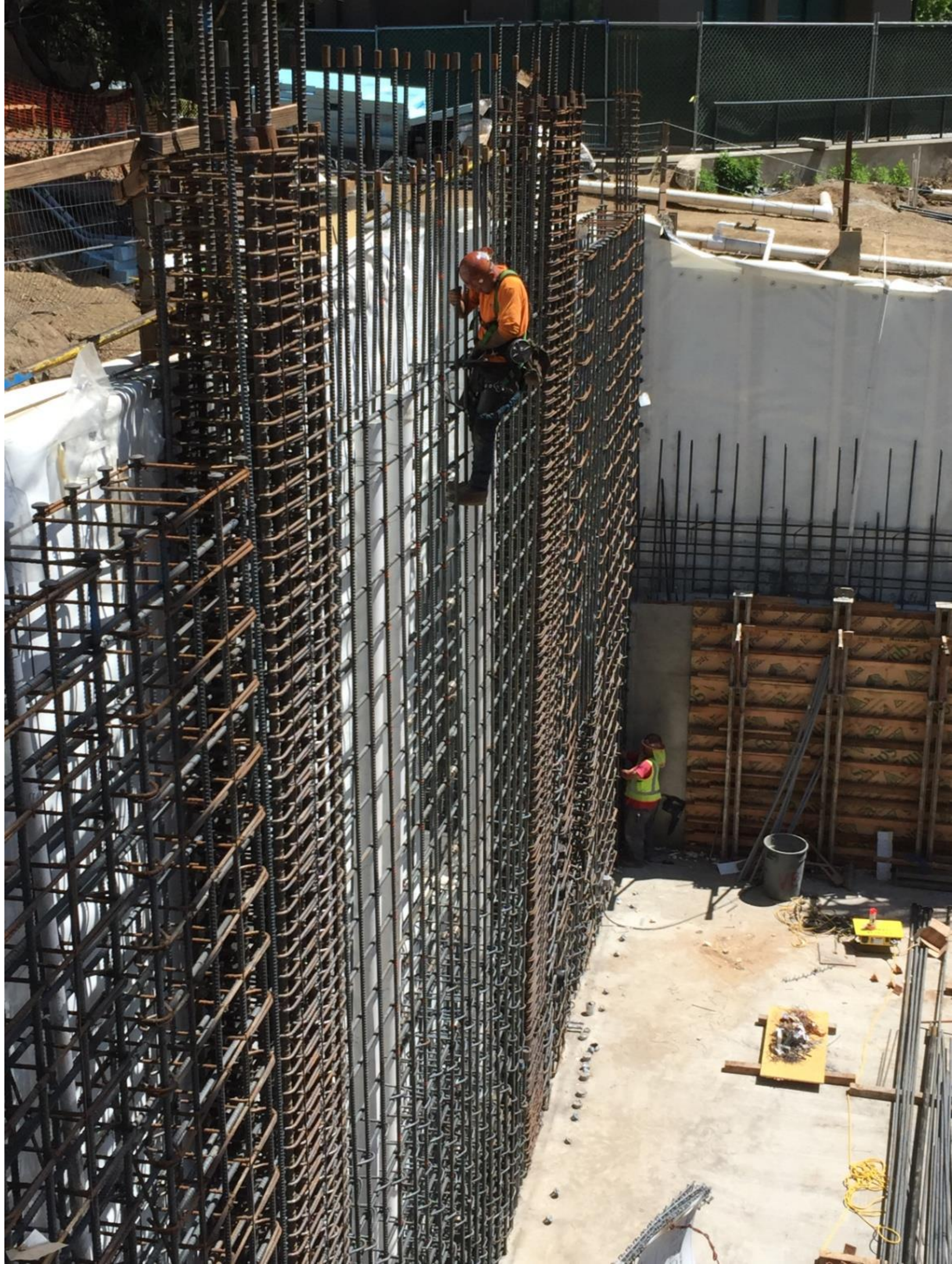
- Steel ratio = .011
- PT ratio = .48
- P/A = 620 psi

Detailing for constructability

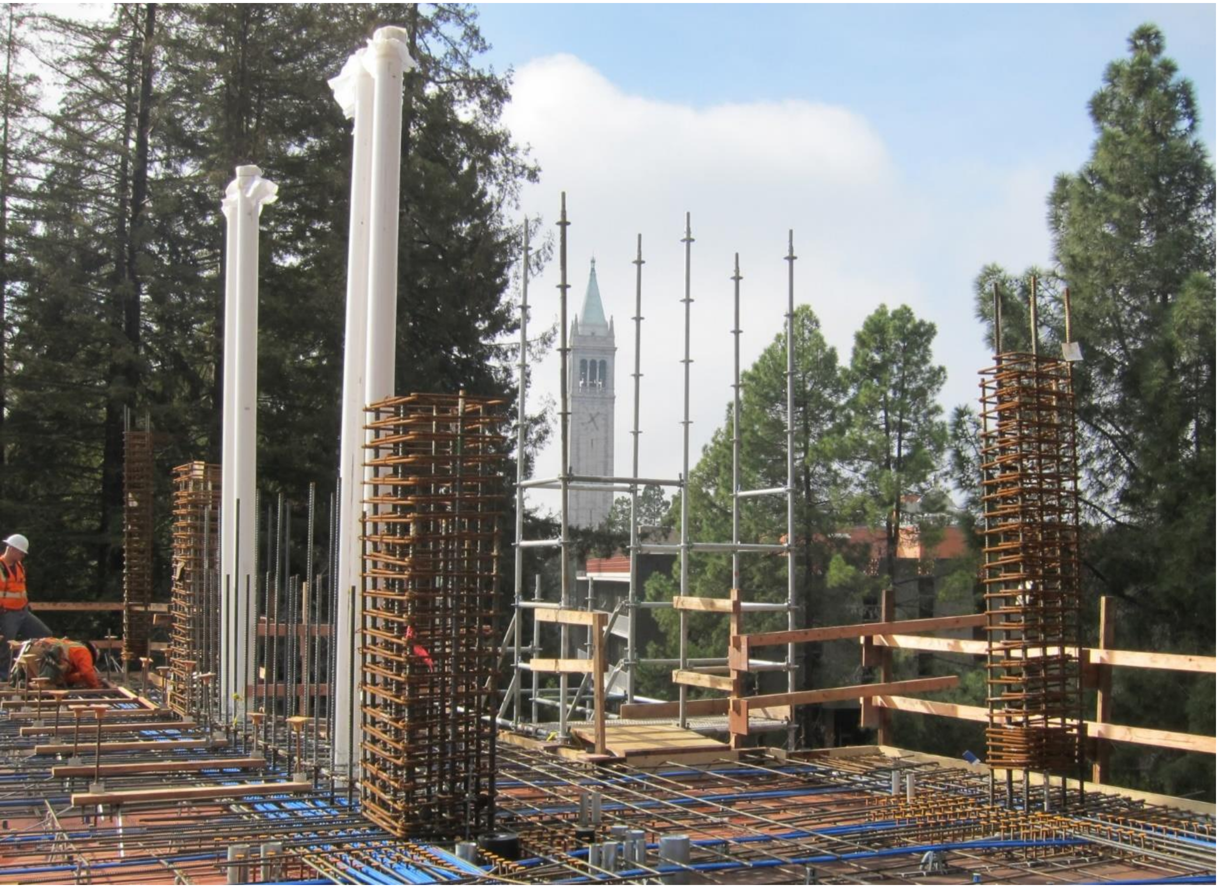


PT Wall Construction

PT Wall Construction



PT Wall Construction



Seismic Performance Criteria

Site-specific hazard

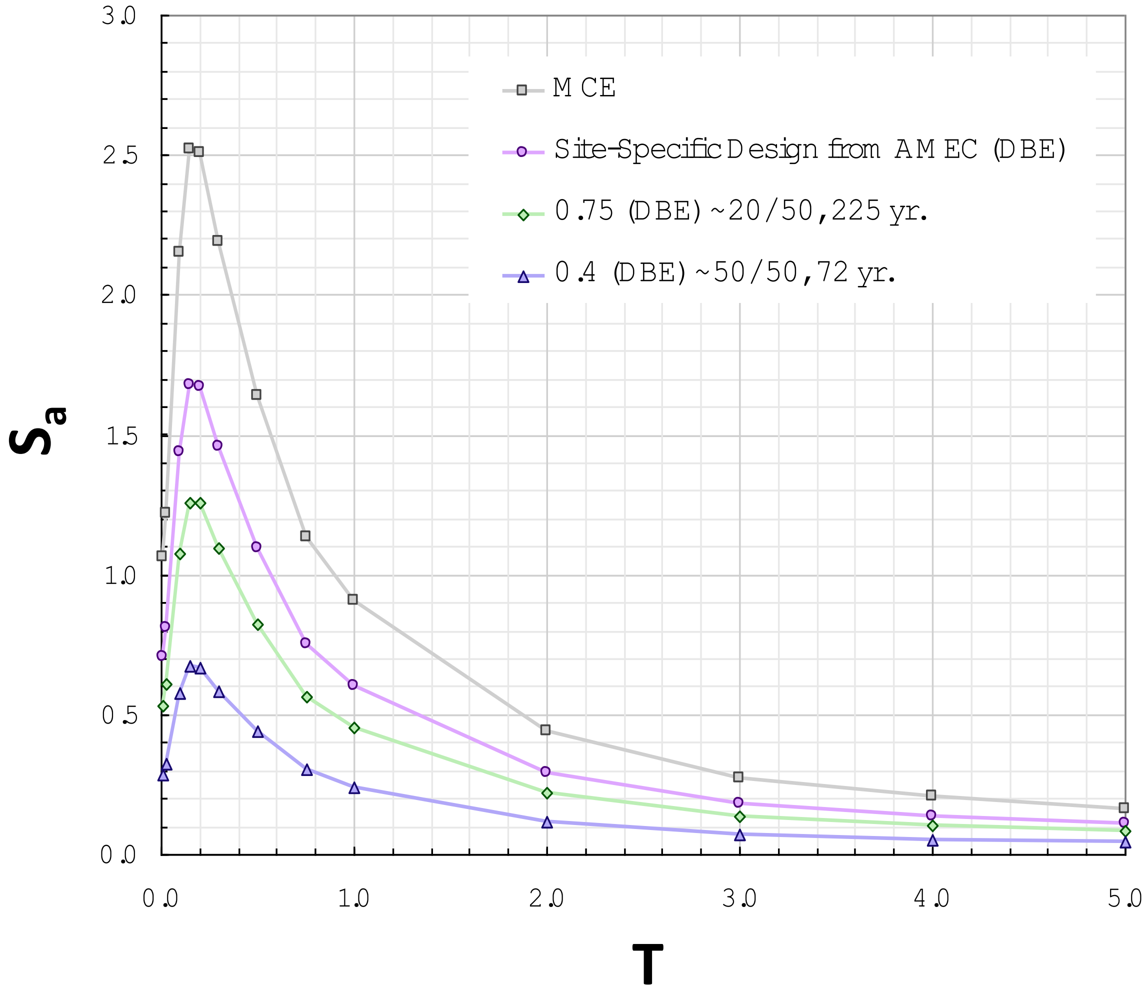
RSA for minimum design requirements

- Fixed foundations
- Rigid diaphragms

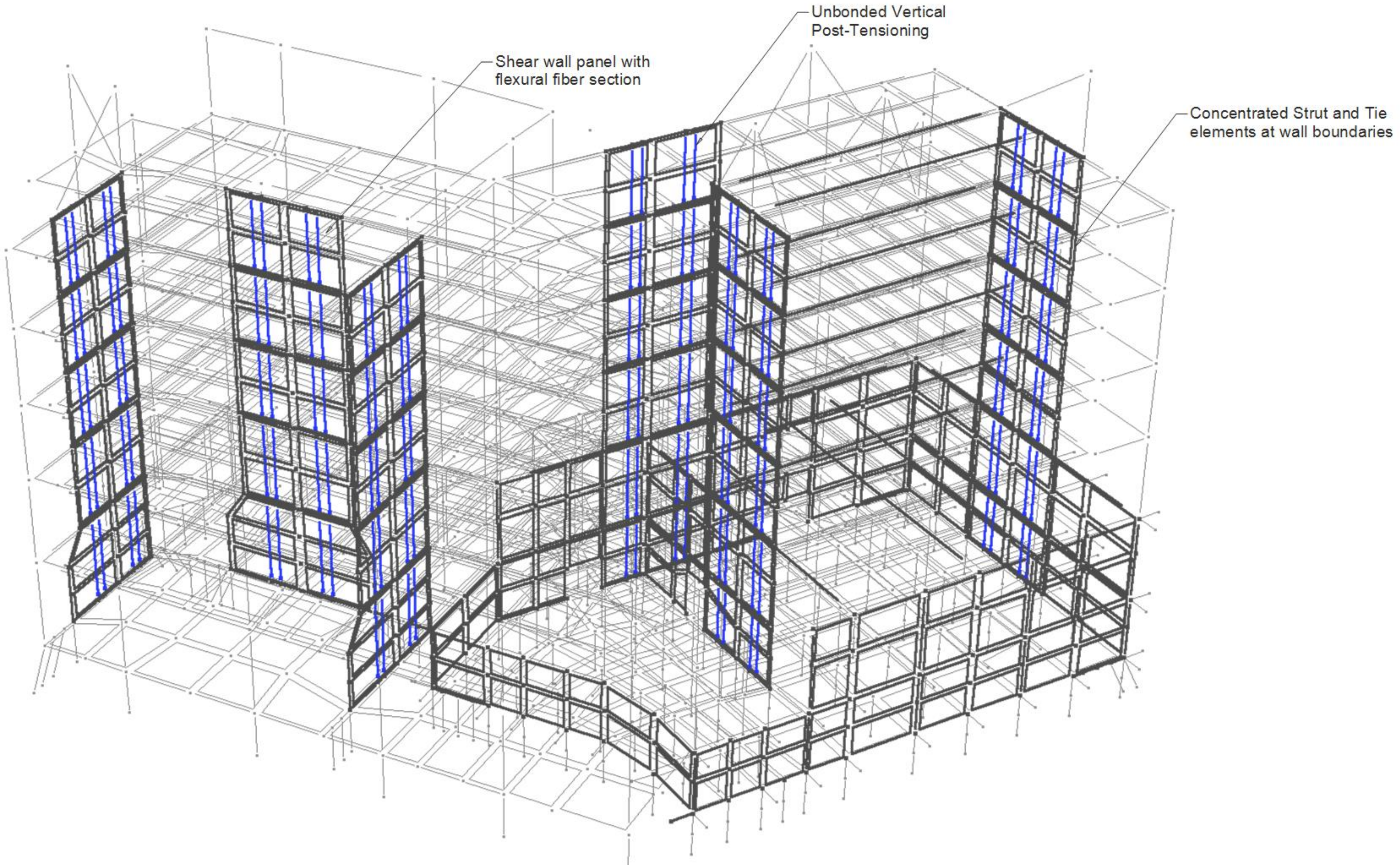
Detailed NLRHA for validation:

- 7 pairs of ground motions
- 4 hazard levels

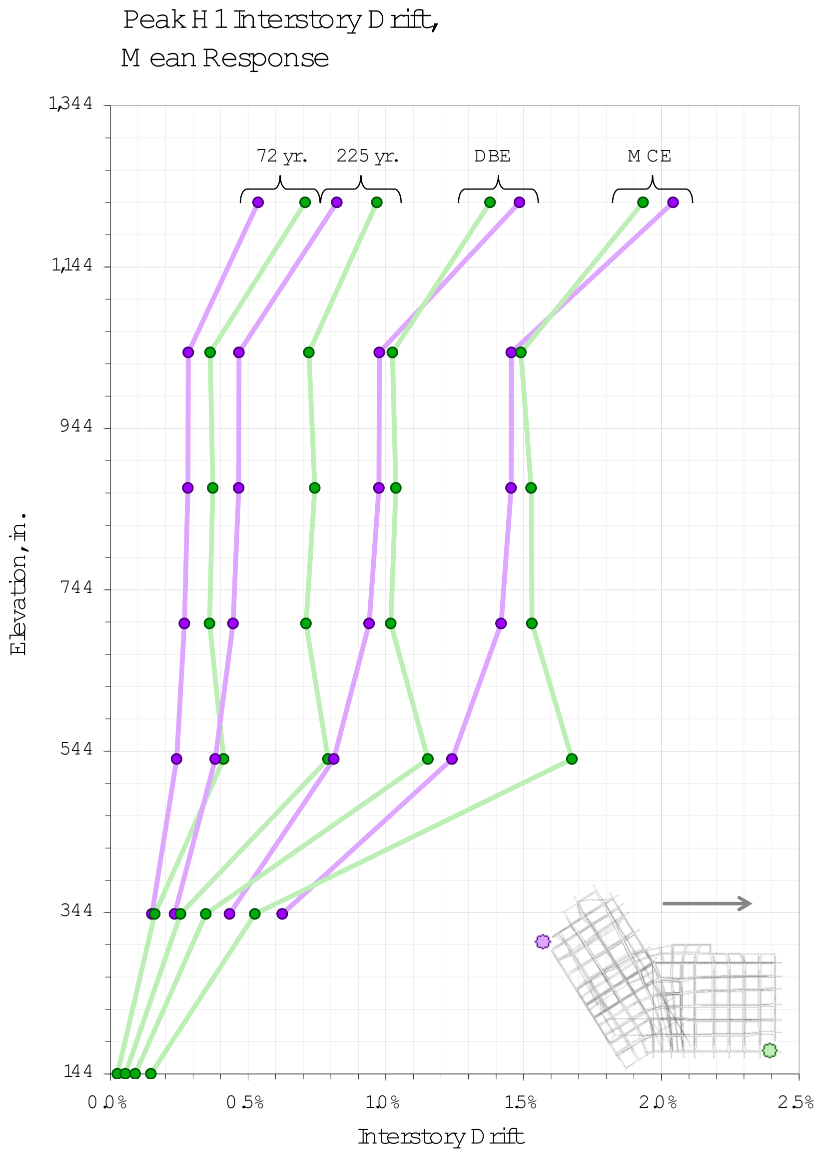
EQ Hazard Spectra

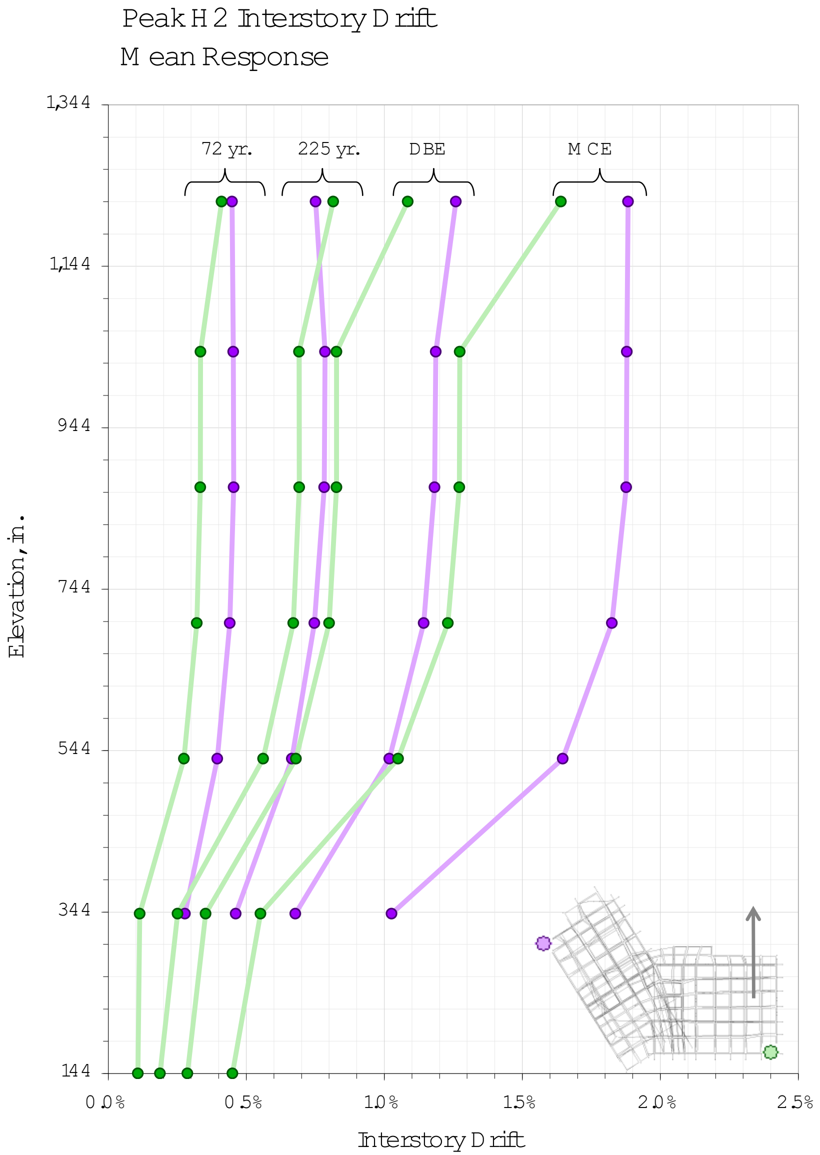


Detailed Analytical Validation



Drift Response from NLRHA

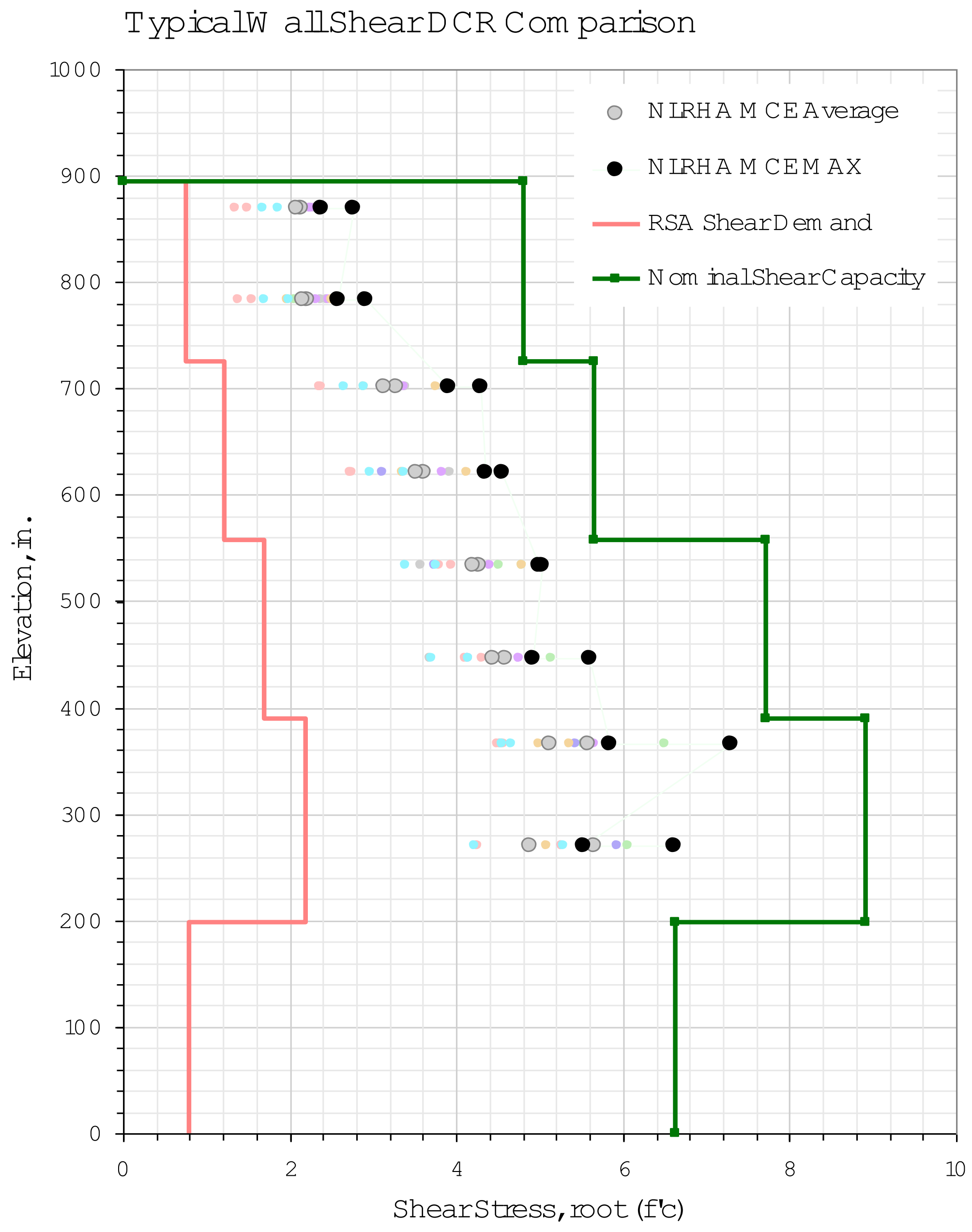




Capacity Design for Shear

RSA vs NLRHA response

Amplified shear demands



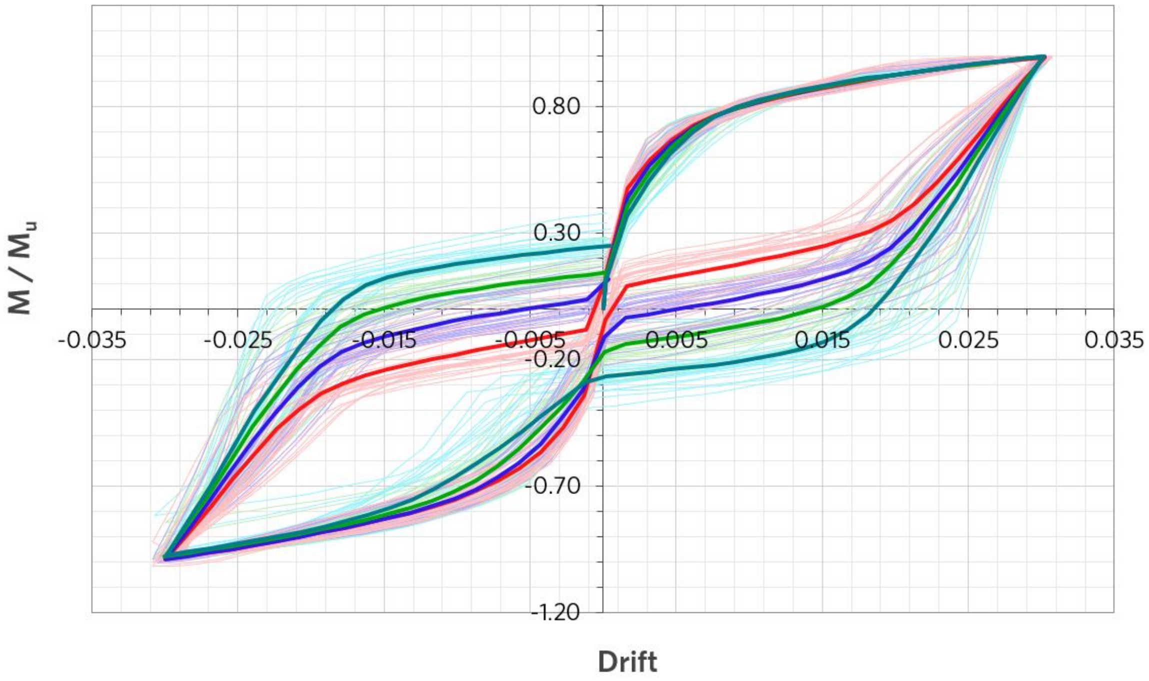
Residual Drift

No permanent deformations

Limited damage

Enhanced resilience

Post EQ functionality



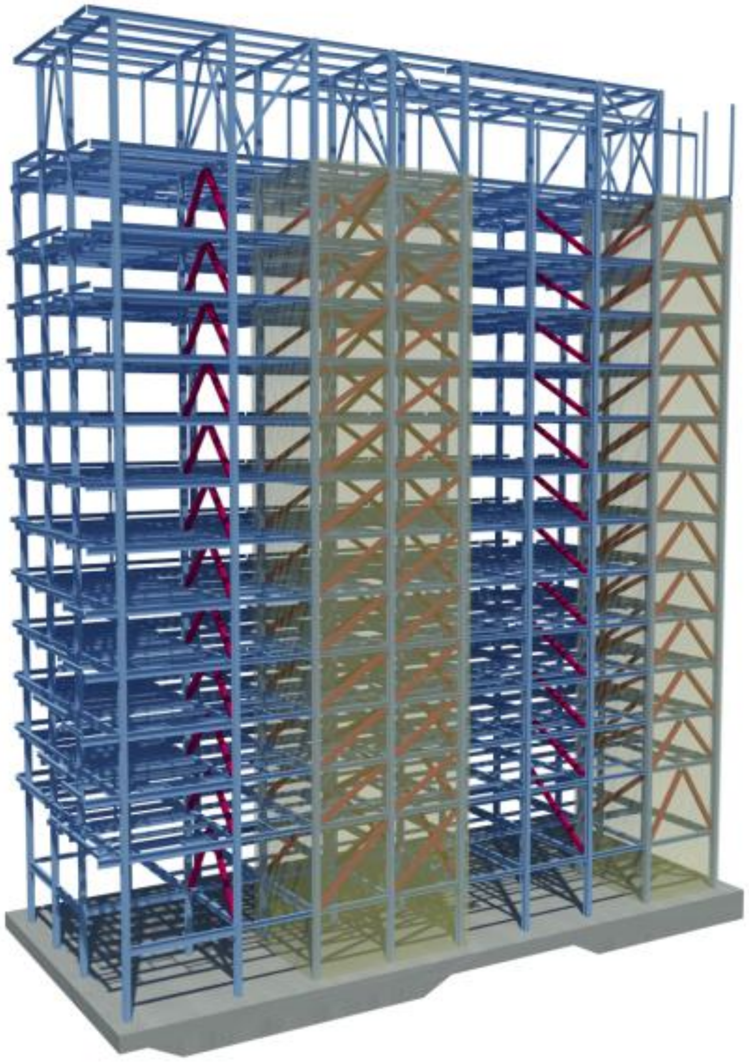
SFPUC HQ

First LEED Platinum office building in US

Enhanced seismic performance

Immediate occupancy mandate

SFPUC HQ Structure



Steel moment frame, viscous dampers

Concrete with PT cores

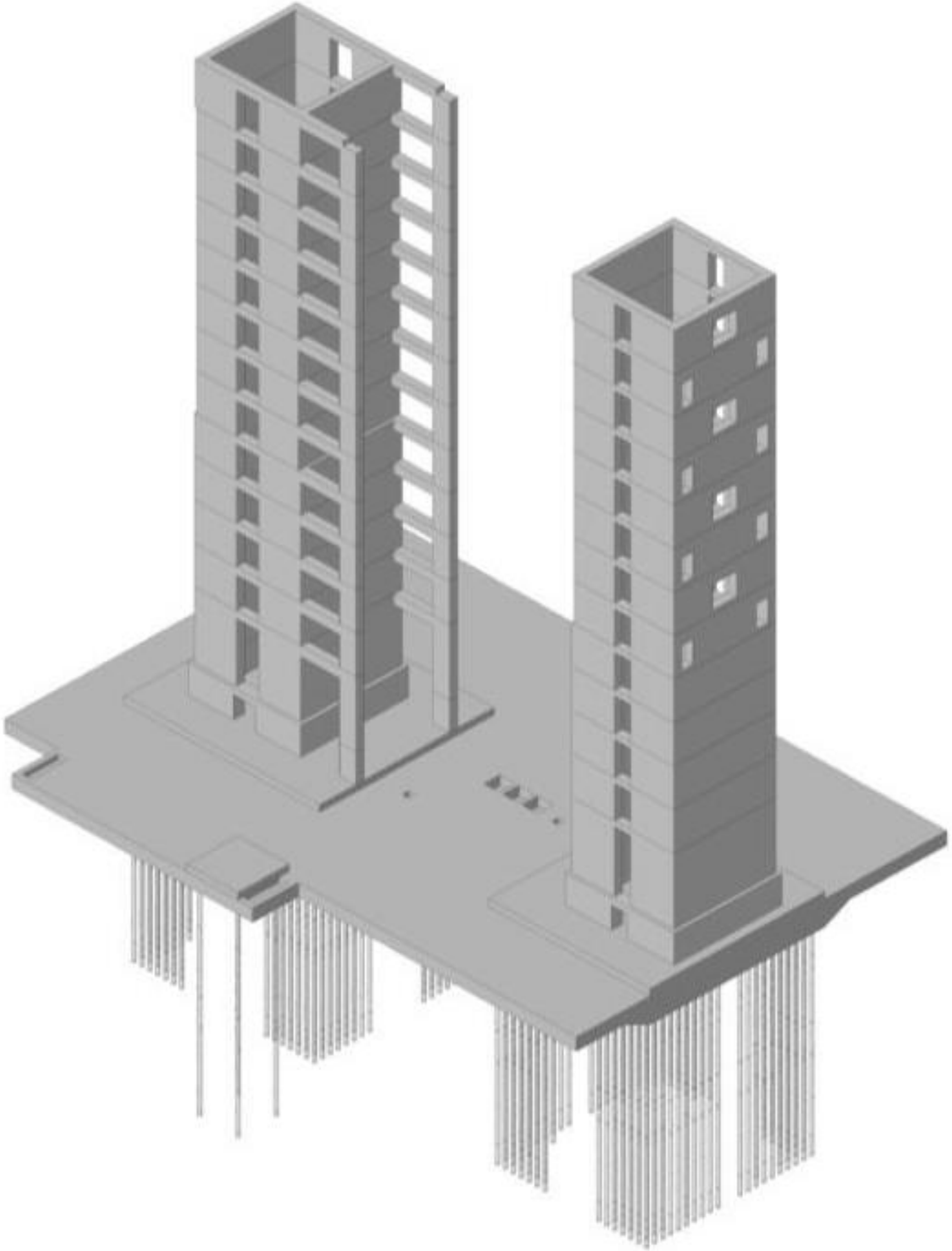
SFPUC HQ

Self-centering PT concrete core walls

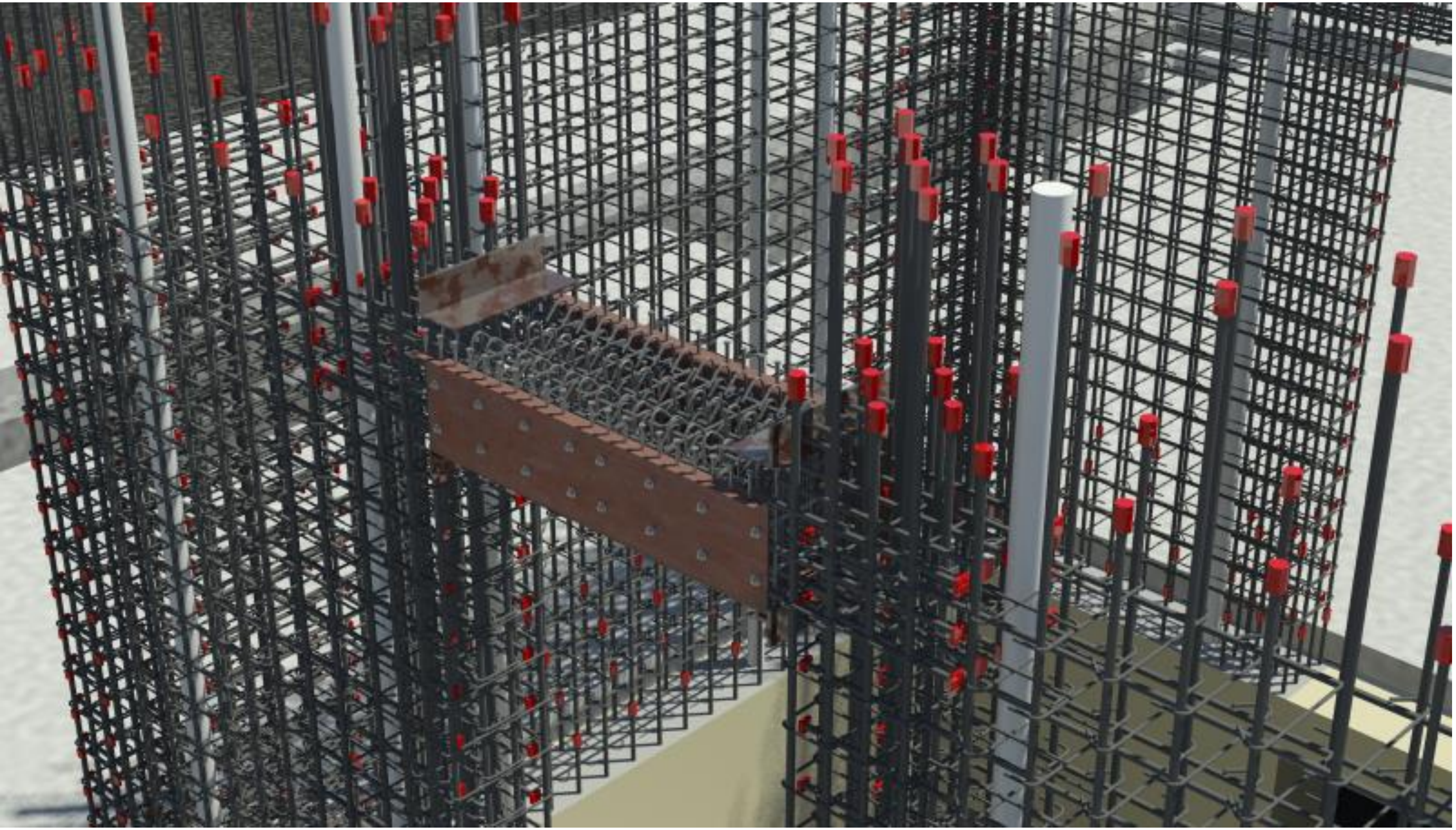
Composite link beams

Hybrid mat foundation with micro-piles

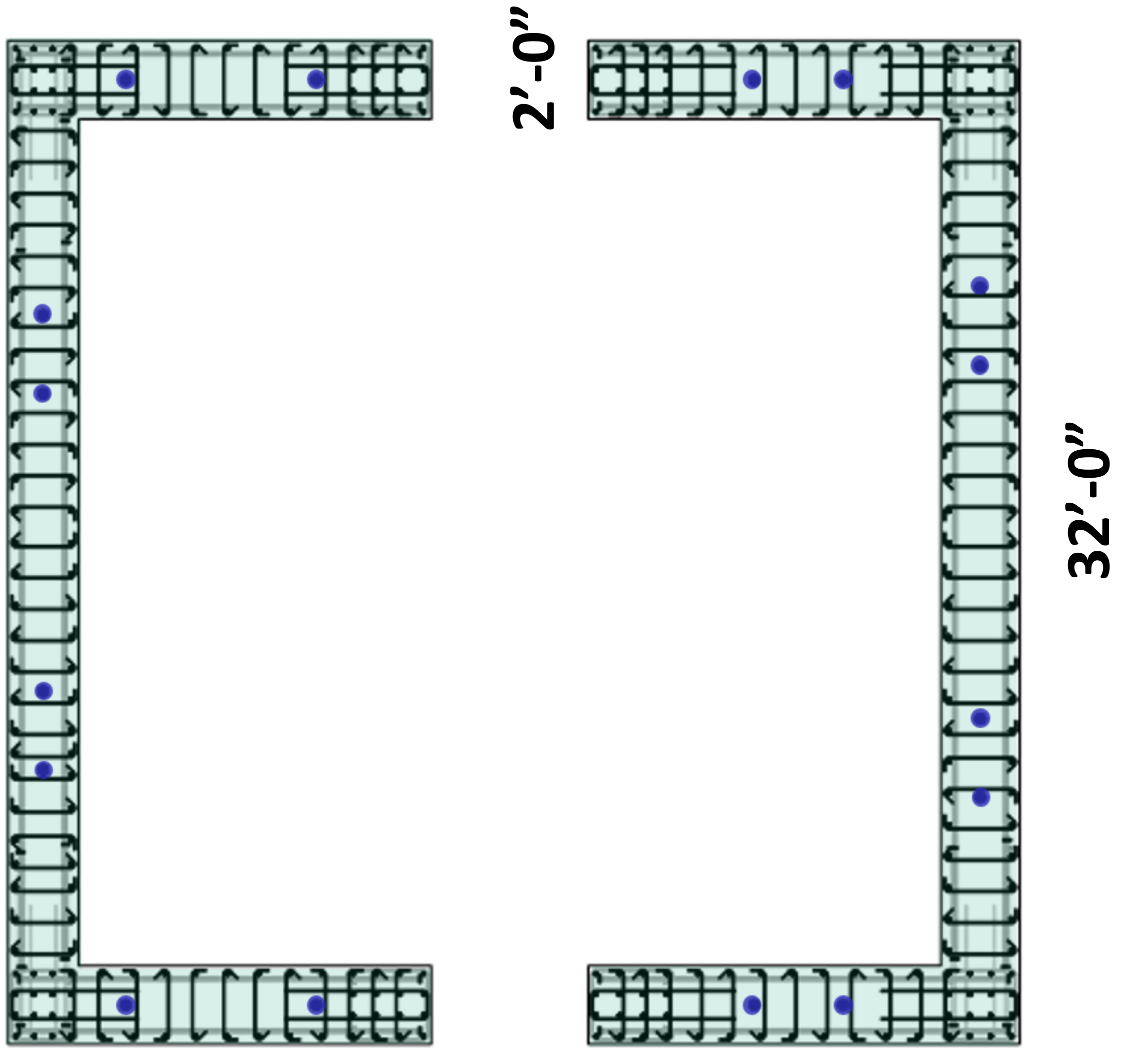
Immediate occupancy post-earthquake



Composite Coupling Beams



PT Core Walls



Mild steel and unbonded PT:

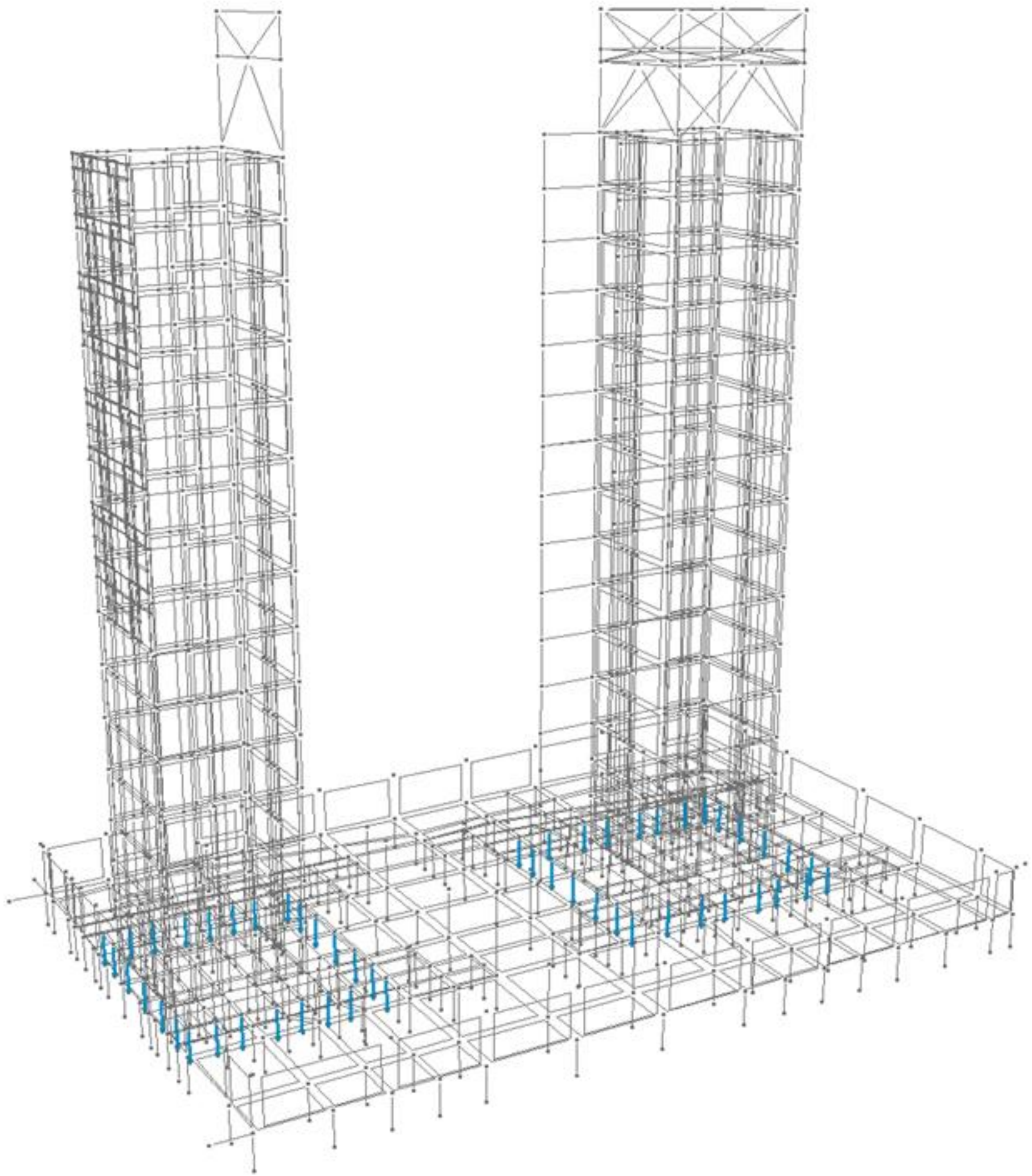
Steel ratio = .01

PT ratio = .38

P/A = 400 psi or .05 f’c

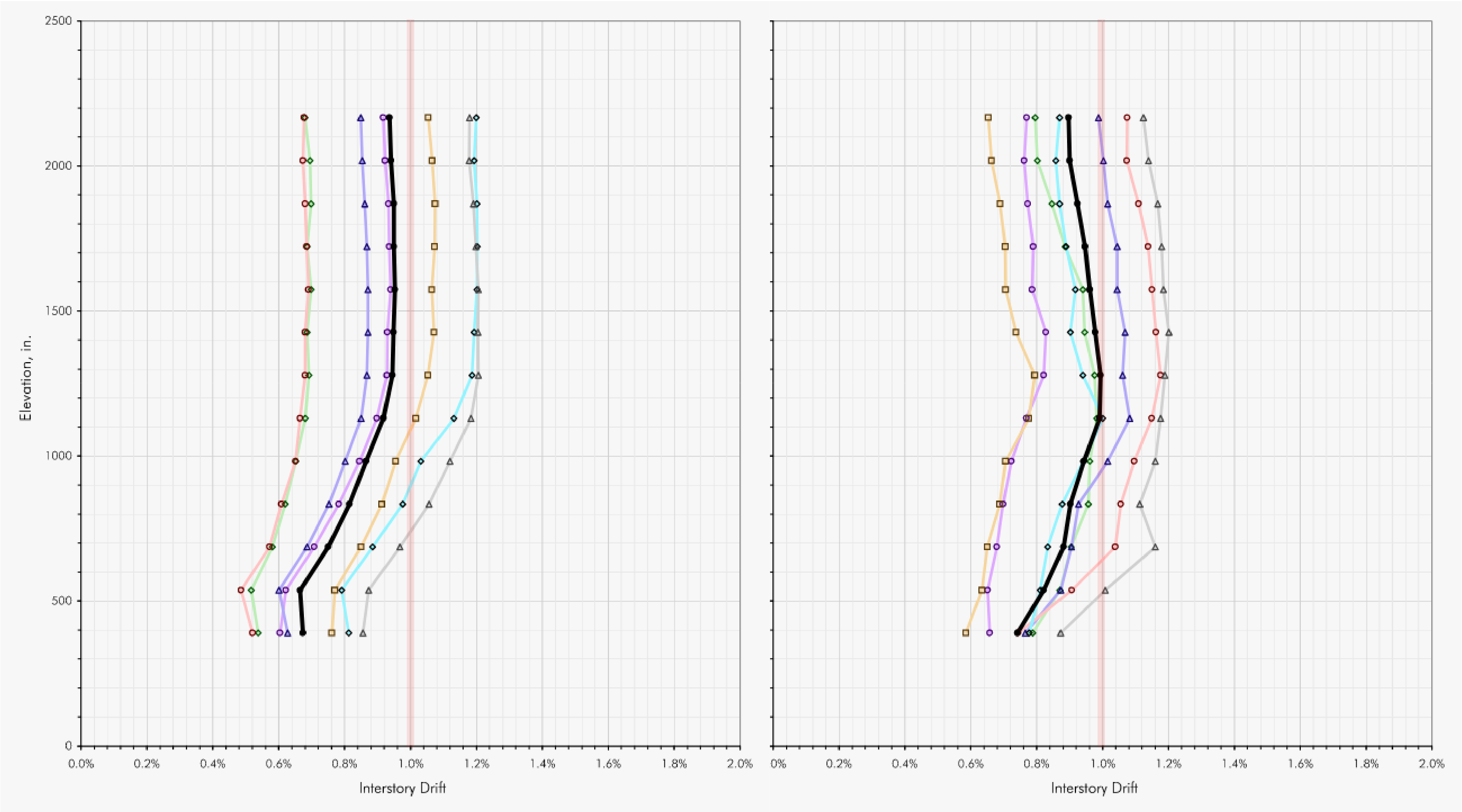
SFPUC HQ

NLRHA for detailed design and validation



Performance Based Design

Drifts for DBE



Construction

Mat foundation

Tendon anchorage

Construction

Core walls

Tendon ducts

Construction

Composite link beams

Seismic Resilience

Self-centering

Superior seismic performance

Limited damage

Protection of building systems

Immediate occupancy

Cost effective

Take Aways

Design strategies for efficient & resilient buildings with PT concrete

- Efficient floor assemblies
- Special use long-span beams, transfer girders
- Resilient, recentering shear walls for seismic resistance

This concludes the Educational Content of this activity

Leo Panian, SE
l.panian@tippingstructural.com

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