CONCRETE AND STEEL: TECHNOLOGY, ENGINEERING & DESIGN
(CASTED 2018)

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Composite Concrete-Steel Construction in Tall Buildings

Dr. Naveed Anwar

AIT Asian Institute of Technology

AIT Solutions
Technology · Engineering · Environment · Development · Management

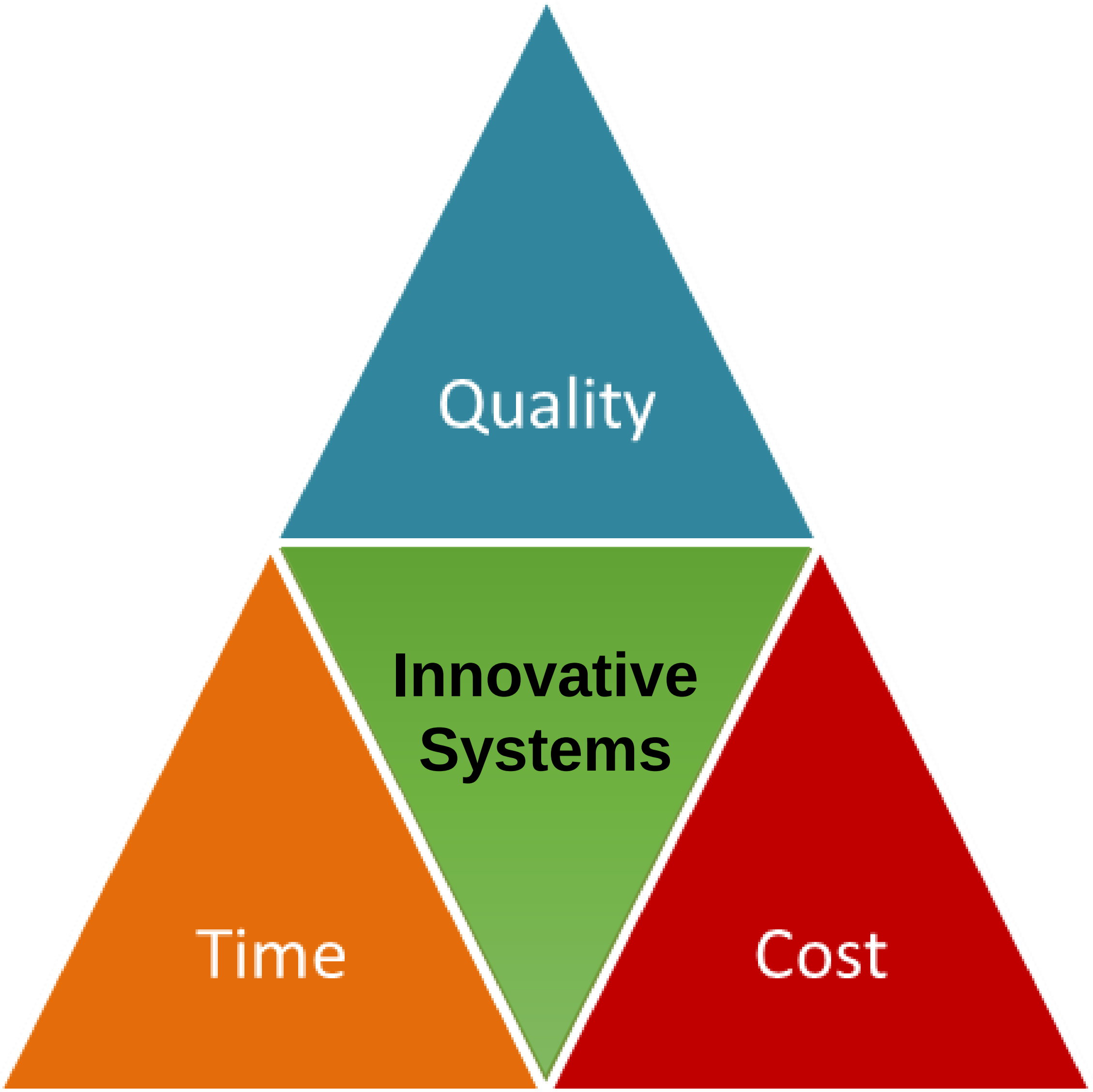
Composite and Mixed Systems

- Reinforced Concrete Only
- Steel Only

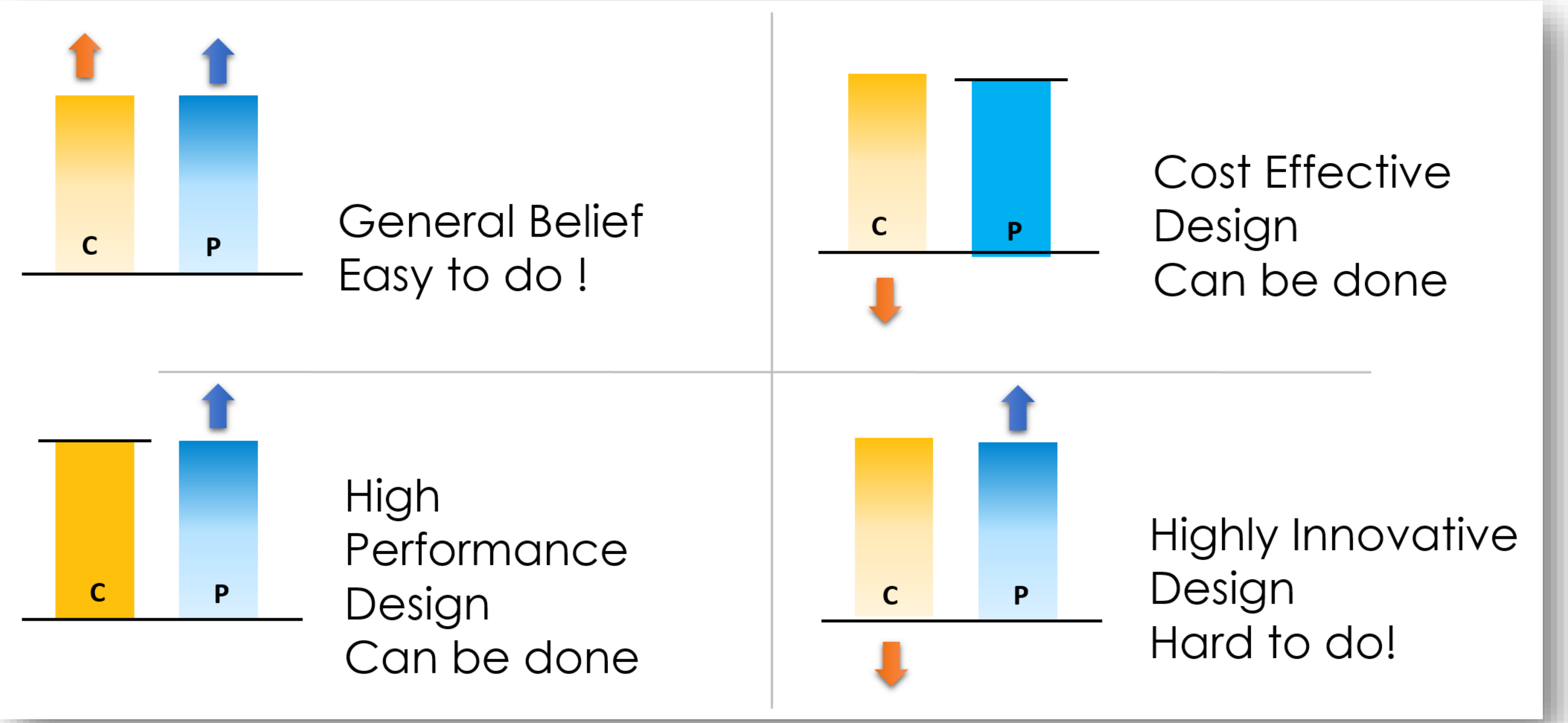
- **Composite** – Concrete and steel act together as one cross-section of a member
- **Mixed** – Steel and Concrete members jointly resist forces

Why Composite and Mixed Structural Systems?

Innovative systems needed
to balance the Triangle



Complexity is Increasing – Needing Innovations

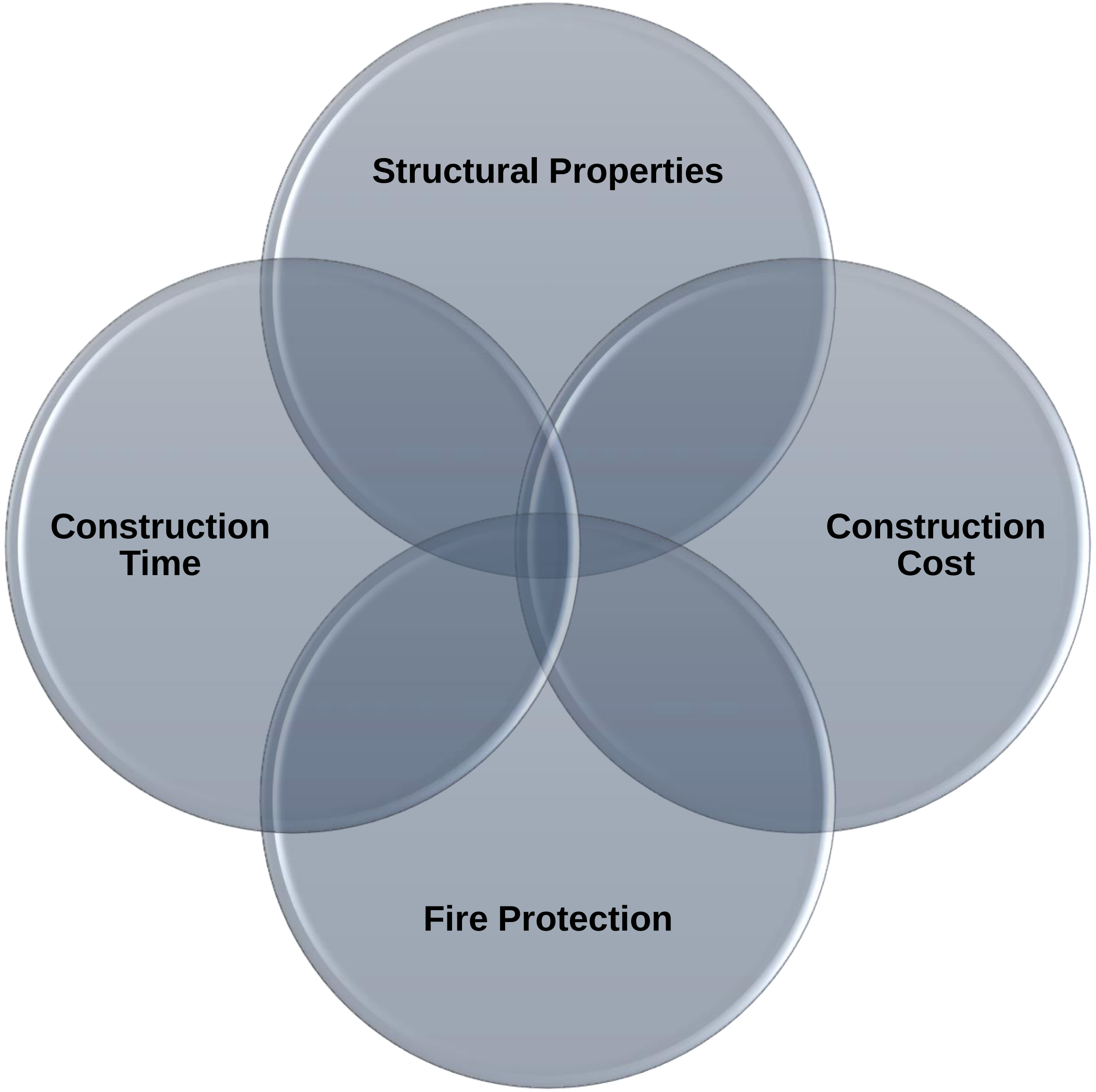


- Bigger, taller, complex forms, **but** Lighter, smaller, thinner structural elements
- High performance, **but** Lower cost

Innovative and Efficient Systems

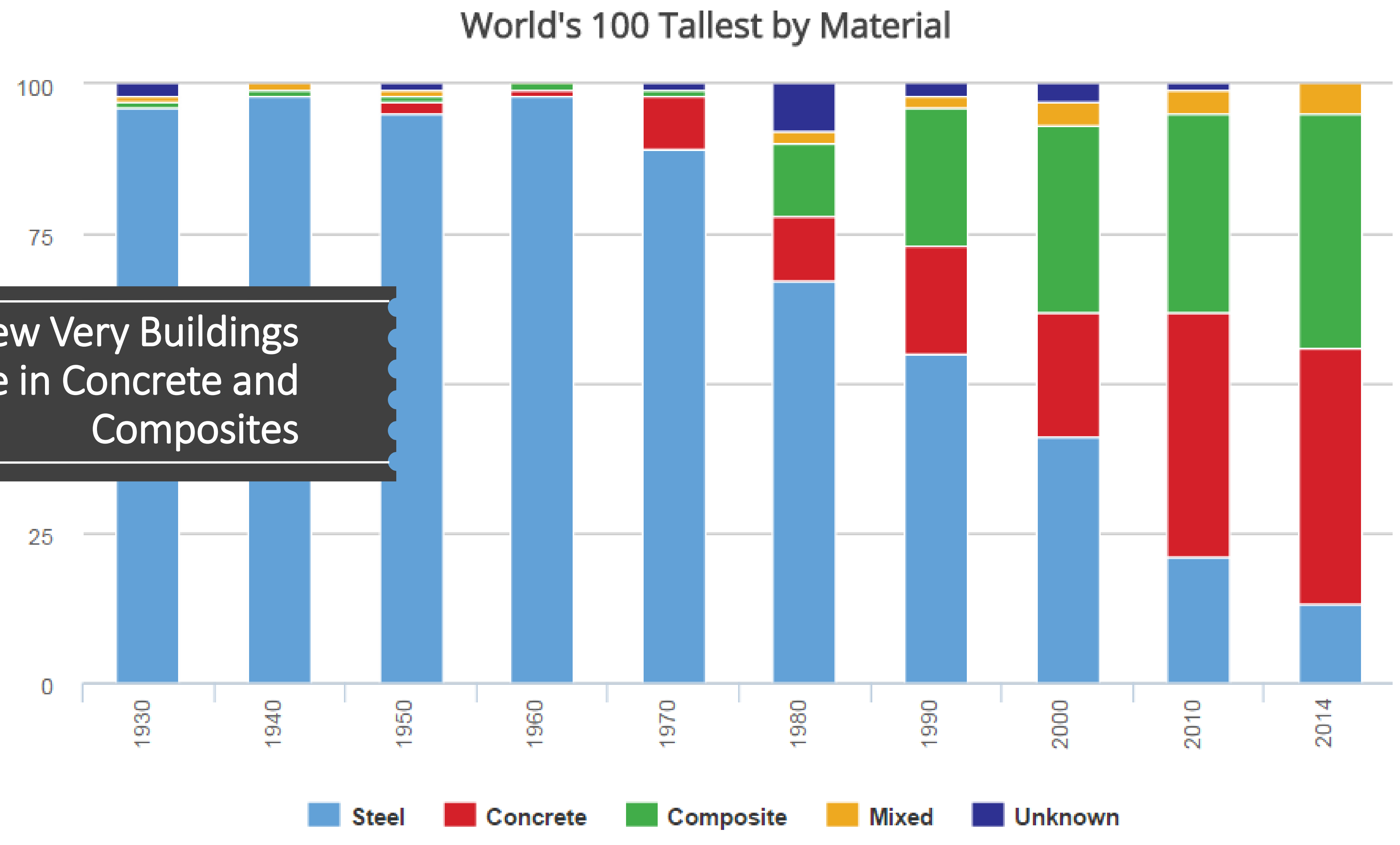
Developing	Developing new structural forms and systems
Improving	Improving the Systems that Already Developed • Improving the materials they are made off • Improving the way they are constructed • Combining materials effectively

Historical Factors Governing the Selection of Materials for Buildings



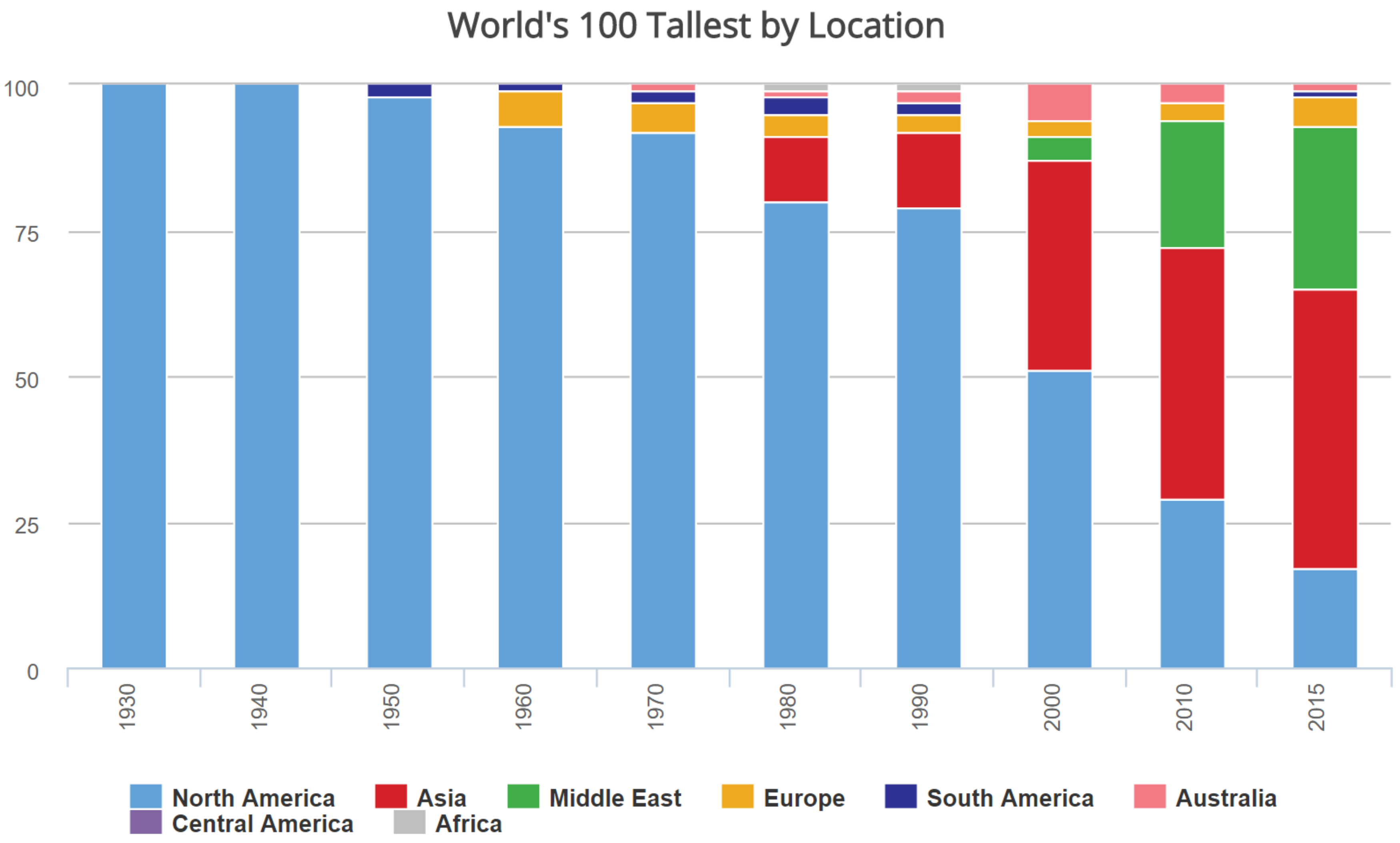
Composite And Mixed Structures

- Concrete is efficient in compression and steel in tension
- Concrete encasement restrains the steel against buckling
- Concrete provides protection against corrosion and fire
- Steel brings ductility into the structure



Most new Very Buildings are in Concrete and Composites

Most Tall Buildings in Asian Region



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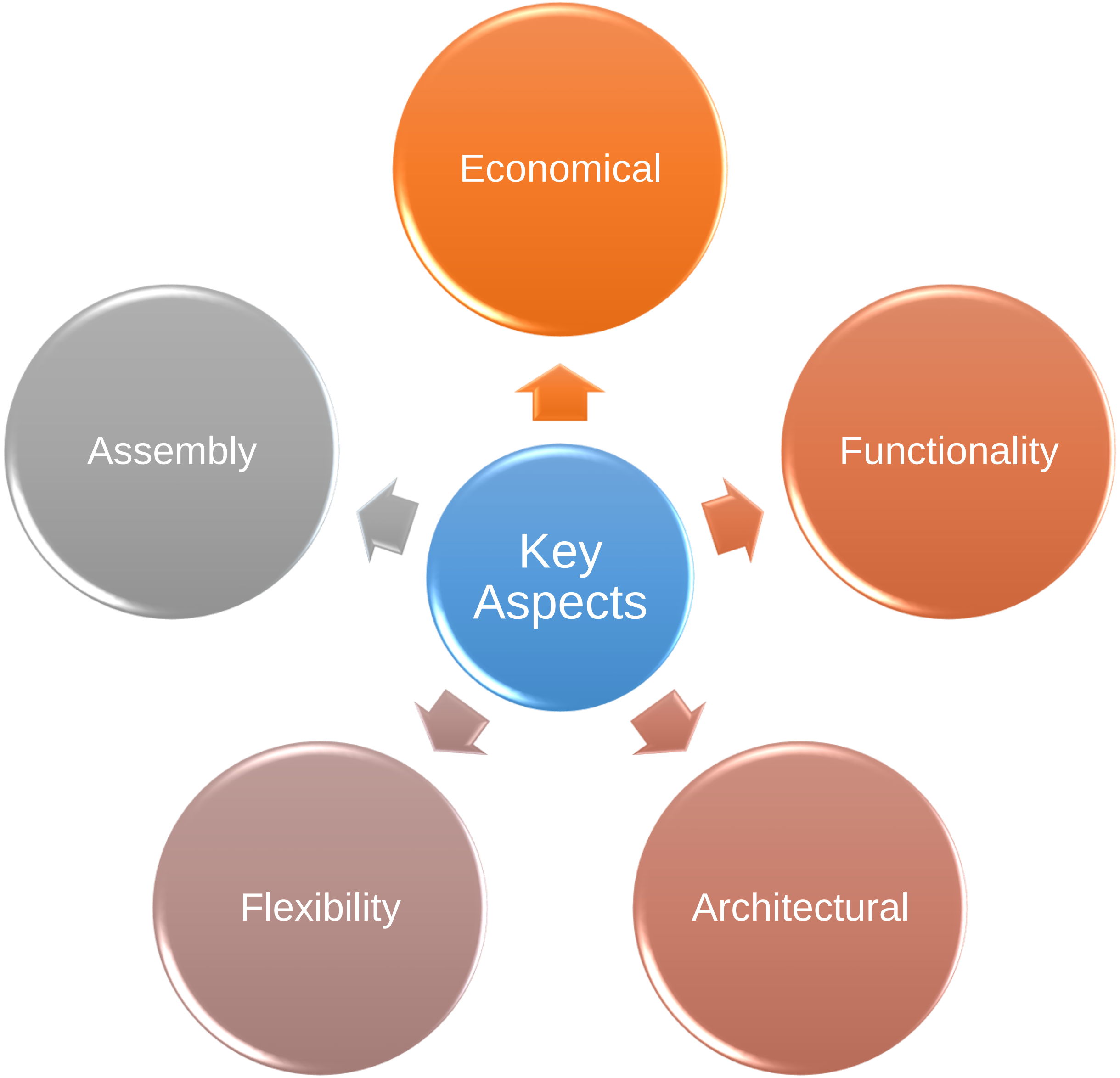
Composite Construction in Tall Buildings



Advantages for Architectural Aspects

01	02	03	04
Longer spans	Thinner slabs	More slender columns	More innovative opportunities

Economical Aspects

- Reduction of height and corresponding cost
- Longer spans with the same height - column free rooms
- Additional stories with the same total height of building
- Quicker time of erection

Assembly Aspects

- Working platforms of steel decking
- Permanent formwork
- Reinforcement of profiled steel sheetings
- Speed and simplicity of construction
- Better quality control

Design Aspects of Composite Construction

Concrete Steel Composite – Basic Systems

Encased	Concrete around Steel
Filled	Concrete inside Steel
Connected	Concrete and Steel Connected

Diversity of a Composite Cross-section Design Problem

Types of Materials and their Combinations	Types of Actions	Location of Reinforcement	Stress-Strain Curve	Cross-section Shape	Design Approach and Method
Un-reinforced Concrete Reinforced Concrete Partially Pre-stressed Concrete Fully Pre-stressed Concrete Fiber Reinforced Concrete Steel-Concrete Composite	Uniaxial Bending M_x or M_y only Uniaxial Bending and Axial Force, M_x or M_y and P Biaxial Bending, M_x and M_y Biaxial Bending and Axial Force, M_x and M_y and P	Singly Reinforced Doubly Reinforced Arbitrarily Reinforced	Simplified Rectangular Block Semi-Parabolic and Full Parabolic Curves Curves for Confined and Unconfined Concrete Linear Elastic Bilinear Elasto-Plastic Elastic, Post Elastic, Strain Hardening	Rectangular Circular Flanged General Polygonal Multi Cell Sections	Allowable Stress Design (ASD) Ultimate Strength Design (USD) Load Resistance Factor Design (LRFD) Performance Based Design (PBD)

The Need of an Integrated Theory for the Analysis of Composite Cross-sections

- Generally, the design of structural members can be divided and categorized in many ways based on
  - ✓ type of member
  - ✓ type of material
  - ✓ type of applied action
  - ✓ type of cross-section shape
  - ✓ design code, and design method, etc

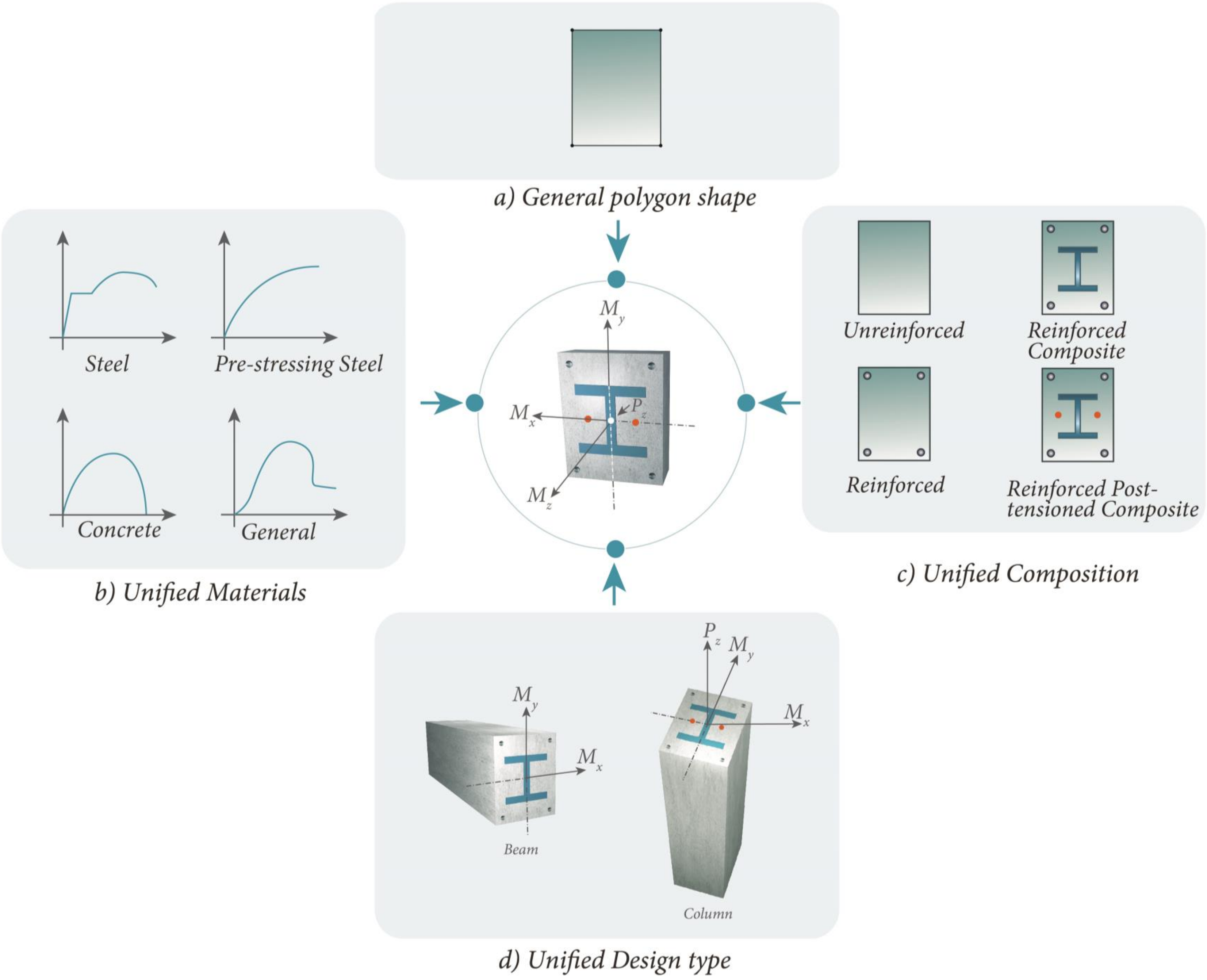
- Often each of these types and their combinations are treated separately and differently for the purpose of determining design strength of members

Integrated Axial Flexural Theory for RC and Composites

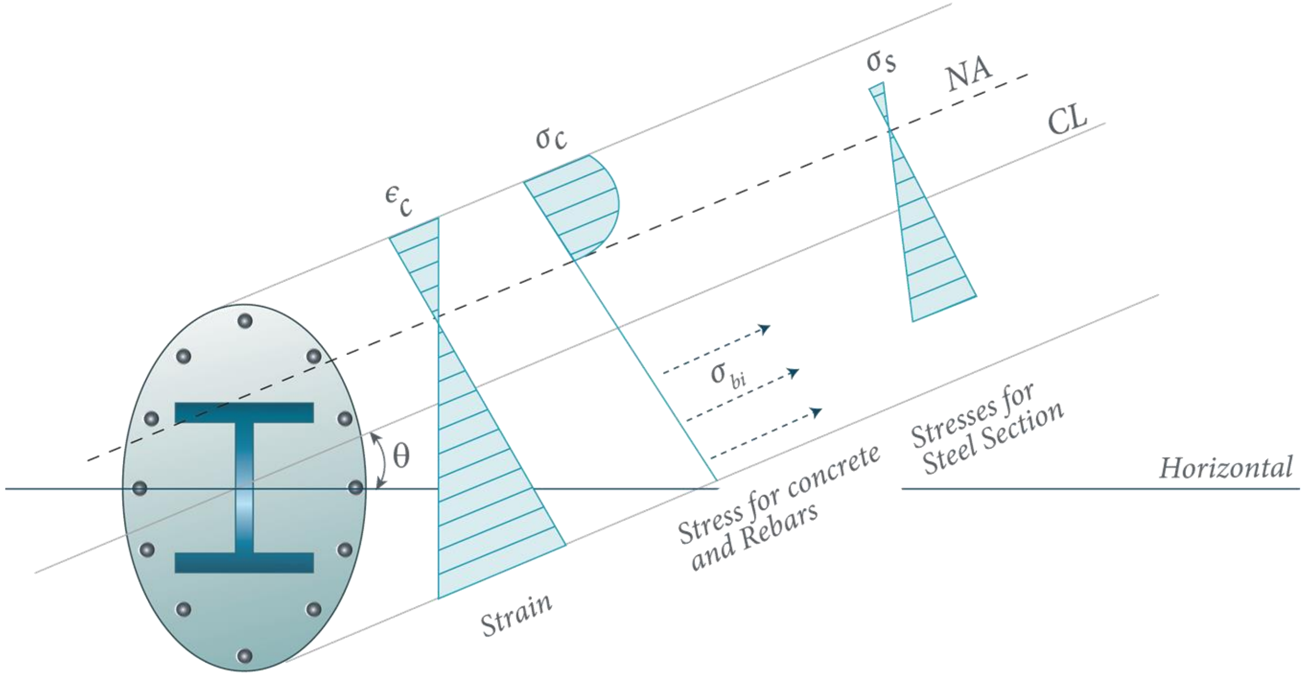
- It is possible to develop a single theory for determining the axial flexural stress resultants of most types of concrete members for all design methods and for most design codes

  - ✓ Unifying Beams and Columns
  - ✓ Unifying Reinforced, Pre-stressed Concrete and **Composite**
  - ✓ Unifying WSD and USD Methods
  - ✓ Unifying different Cross-section Types
  - ✓ Incorporating various stress-strain models

The Unification of Design Approach for Cross-sections



Response of Generalized Composite section

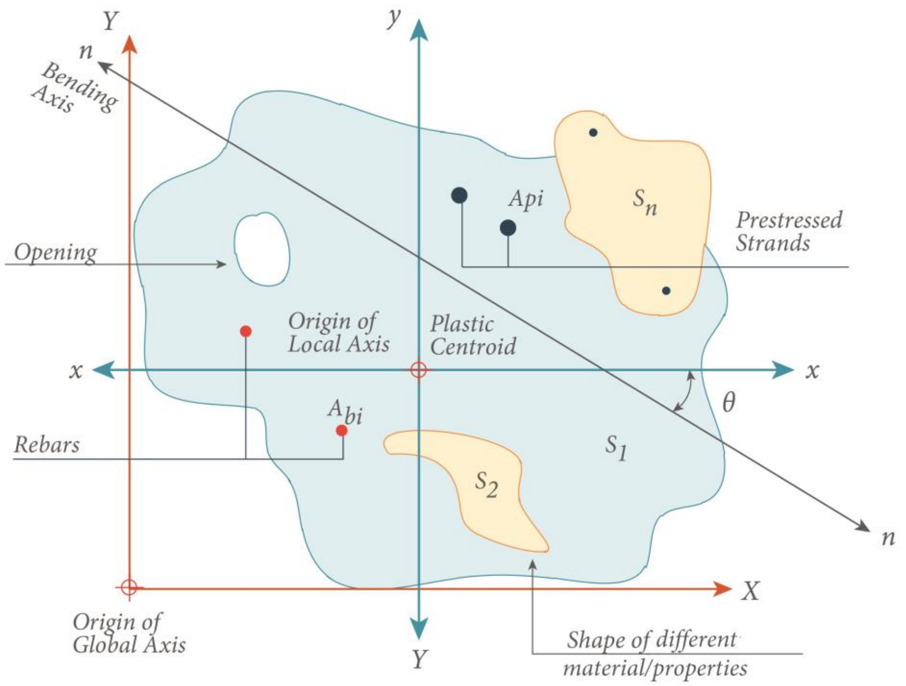


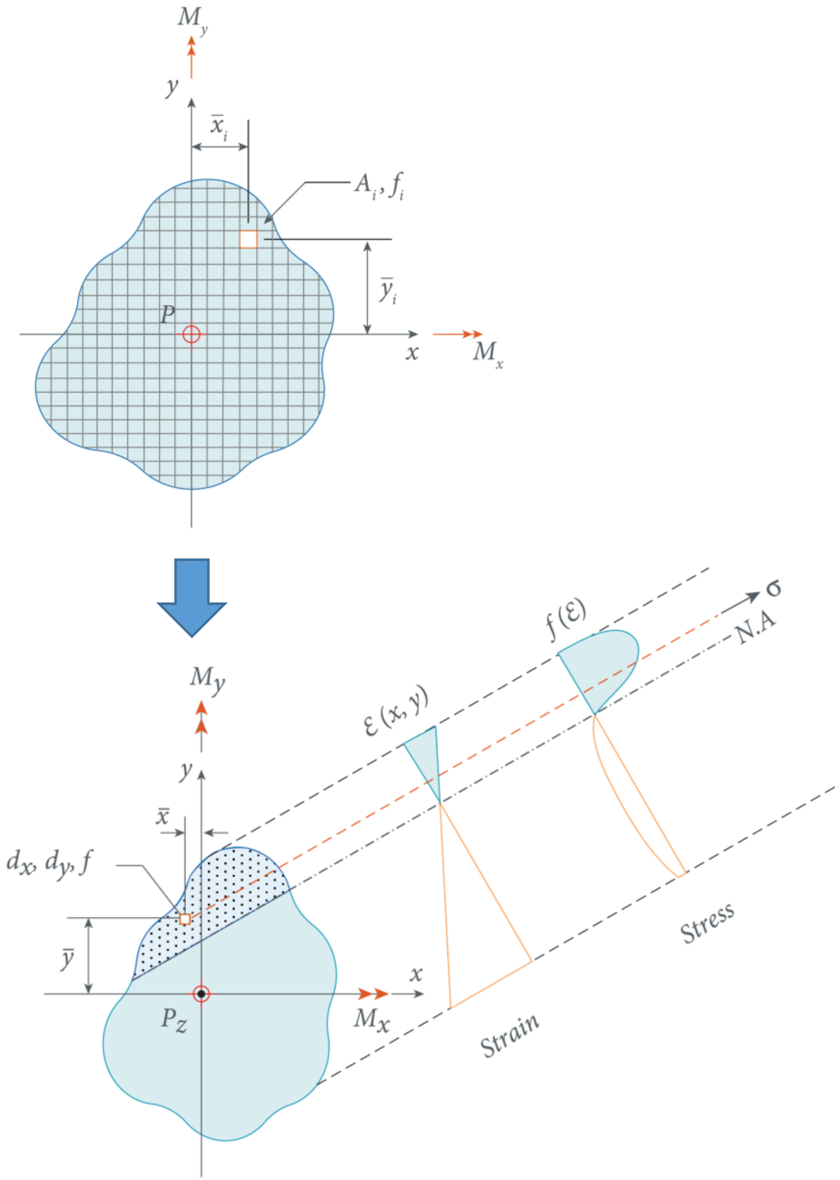
$$N_z = \varphi_1 \left[\frac{1}{\gamma_1} \int_x \int_y \sigma(x,y)\,dx\,dy \;\ldots + \frac{1}{\gamma_2} \sum_{i=1}^{n} A_i \sigma_i(x,y) \;\ldots \right]$$

$$M_x = \varphi_2 \left[\frac{1}{\gamma_1} \int_x \int_y \sigma(x,y)\,dx\,dy\,.\,y \;\ldots + \frac{1}{\gamma_2} \sum_{i=1}^{n} A_i \sigma_i(x,y)\; y_i \ldots \right]$$

$$M_y = \varphi_3 \left[\frac{1}{\gamma_1} \int_x \int_y \sigma(x,y)\,dx\,dy\,.\,x \;\ldots + \frac{1}{\gamma_2} \sum_{i=1}^{n} A_i \sigma_i(x,y)\; x_i \ldots \right]$$

Discretization and Application of General Fiber Approach





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Fiber Model - Equations

Equilibrium equation based on Integration

$$N_z = \int_A f_i dA; \quad M_x = \int_A f_i \bar{y}_i \, dA; \quad M_y = \int_A f_i \bar{x}_i \, dA$$

Equilibrium equation based on Summation

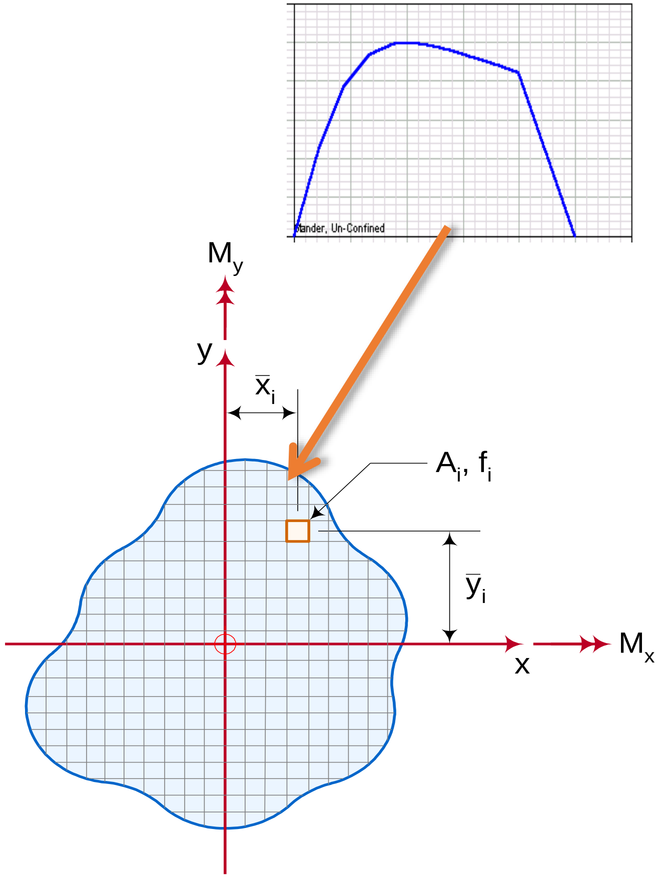
$$N_z = \sum_{i=1}^{n} f_i A_i \, ; \quad M_x = \sum_{i=1}^{n} f_i A_i \, \bar{y}; \quad M_y = \sum_{i=1}^{n} f_i A_i \, \bar{x}$$

Expanded Summation for Complex Models

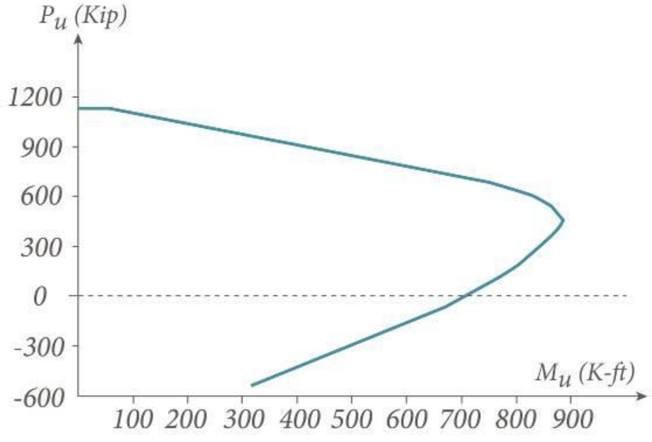
$$N_z = \phi_1 \left[\sum_{p=1}^{q} \frac{1}{\gamma_p} \left(\sum_{k=1}^{l} \left(\sum_{i=1}^{m} N_{zi} + \sum_{j=1}^{n} f_j A_j \right) \right) \right]$$

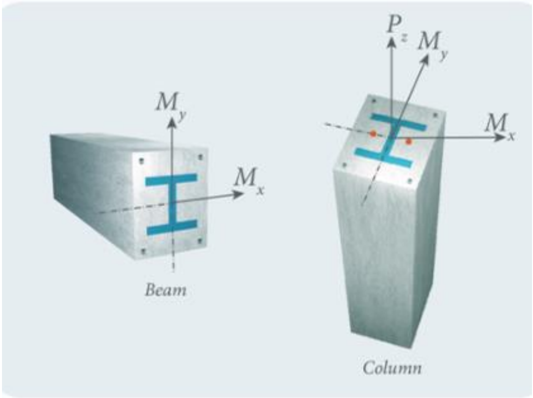
$$M_x = \phi_2 \left[\sum_{p=1}^{q} \frac{1}{\gamma_p} \left(\sum_{k=1}^{l} \left(\sum_{i=1}^{m} M_{xi} + \sum_{j=1}^{n} f_j A_j y_j \right) \right) \right]$$

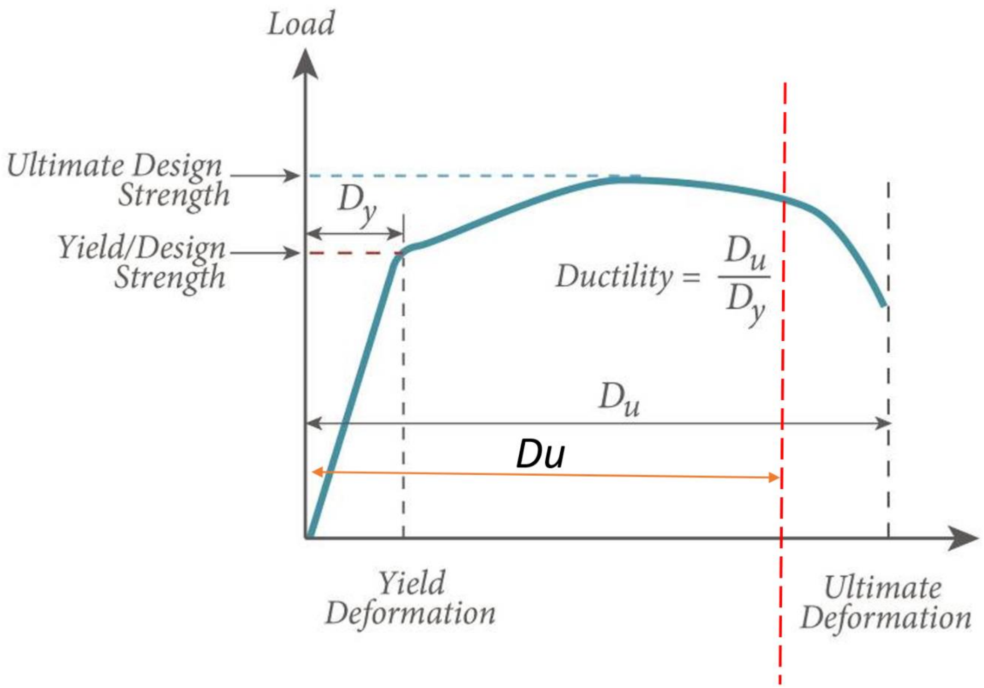
$$M_y = \phi_3 \left[\sum_{p=1}^{q} \frac{1}{\gamma_p} \left(\sum_{k=1}^{l} \left(\sum_{i=1}^{m} M_{yi} + \sum_{j=1}^{n} f_j A_j x_j \right) \right) \right]$$

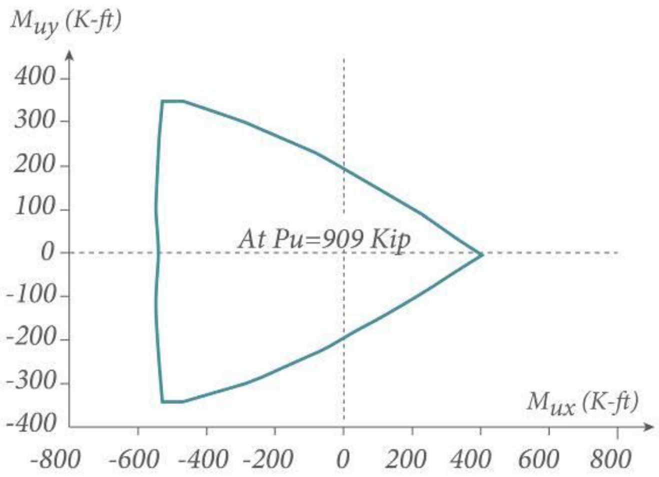


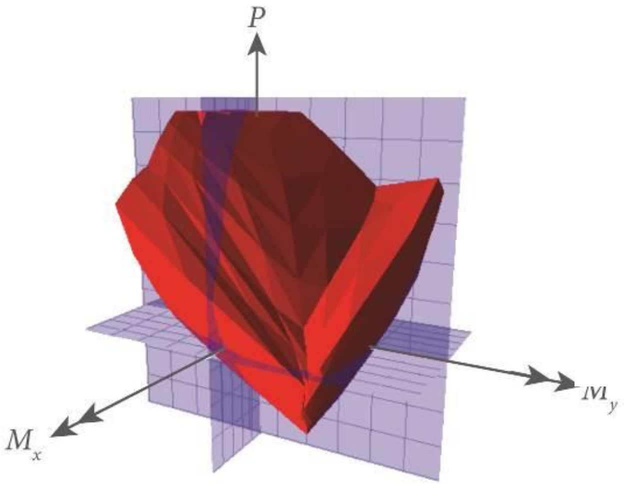
Axial-Flexural Response of Composite Cross-sections



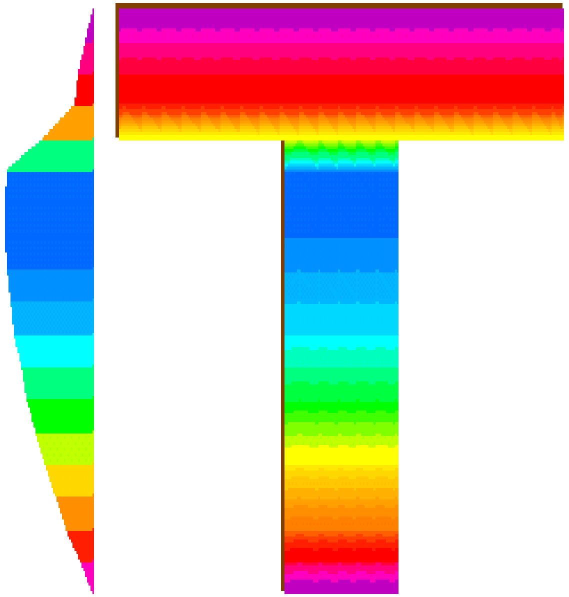




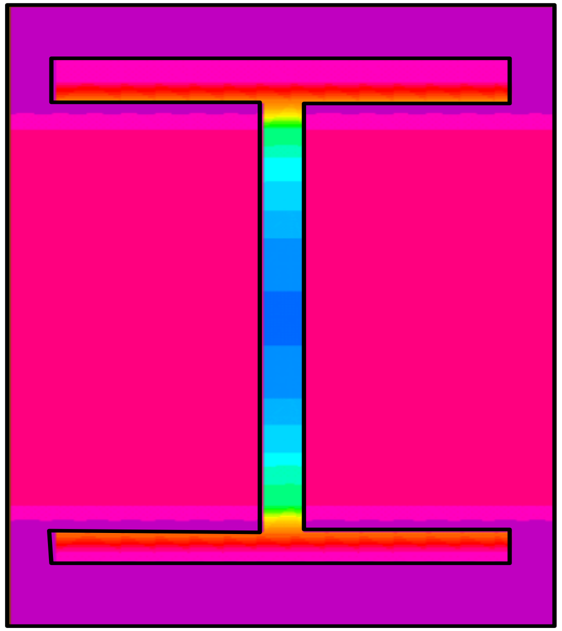




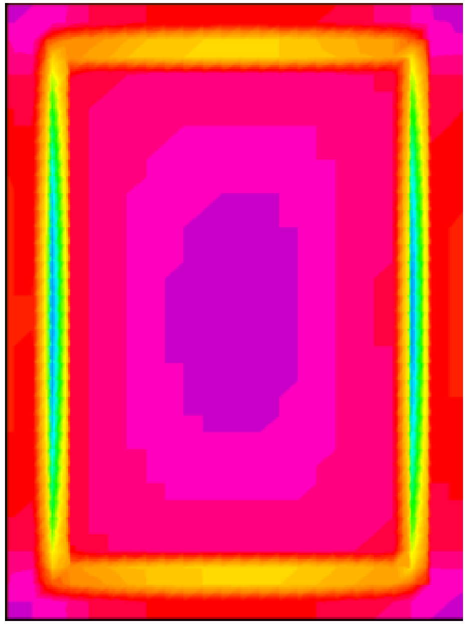
Shear and Torsion Response



Shear stress in a flanged section



Shear force in a concrete-steel composite section



Torsion Stresses in Steel Tube Filled Concrete

Typical Guidelines for Composite Design

Seismic Provisions for Structural Steel Buildings

July 12, 2016

Supersedes the *Seismic Provisions for Structural Steel Buildings* dated June 22, 2010, and all previous versions

Approved by the AISC Committee on Specifications

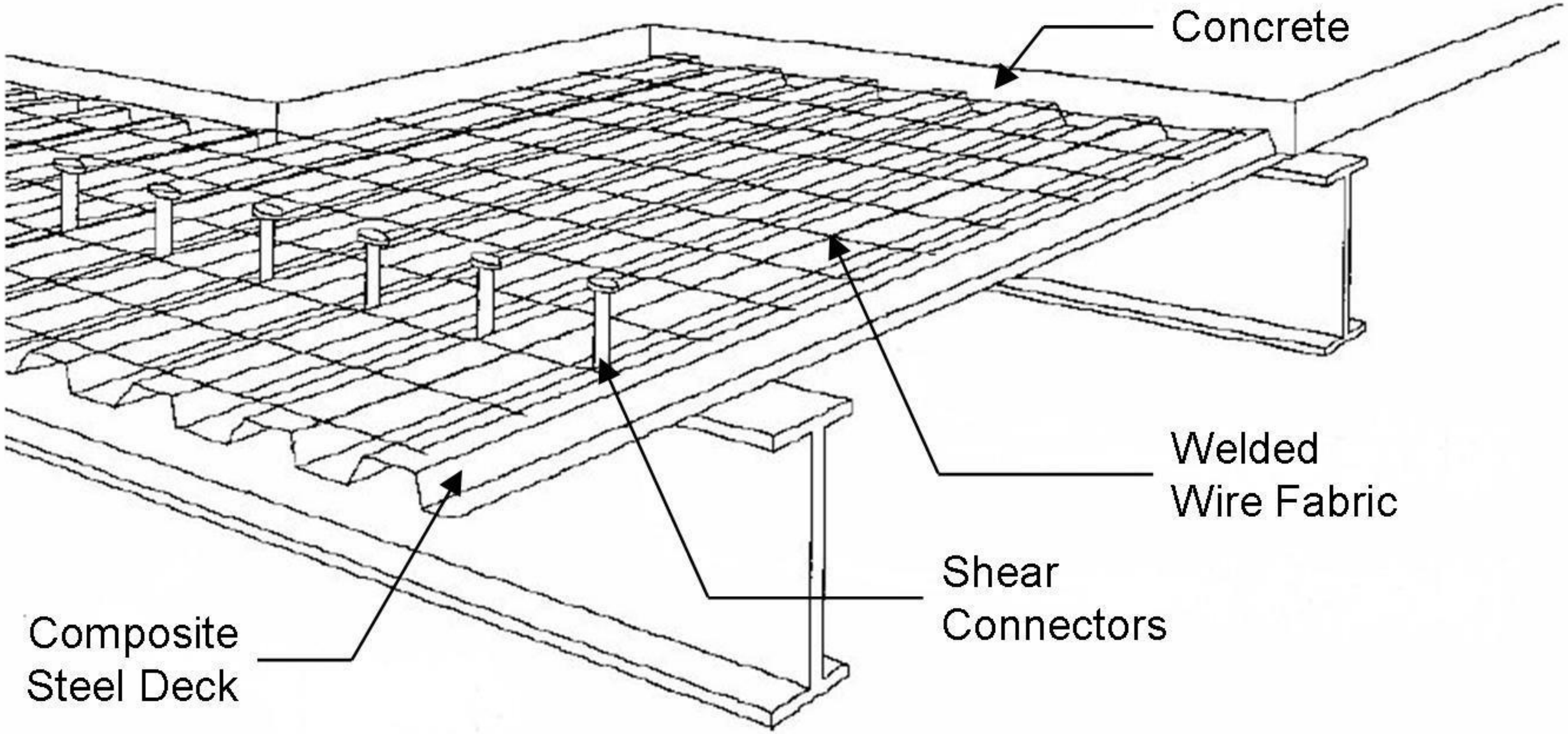
AMERICAN INSTITUTE OF STEEL CONSTRUCTION AISC FOUNDED 1921

Typical Applications in Tall Buildings

- Composite Floors and Beams
- Composite Columns
- Composite Shear Walls
- Composite Link Beams
- Transfer Girders

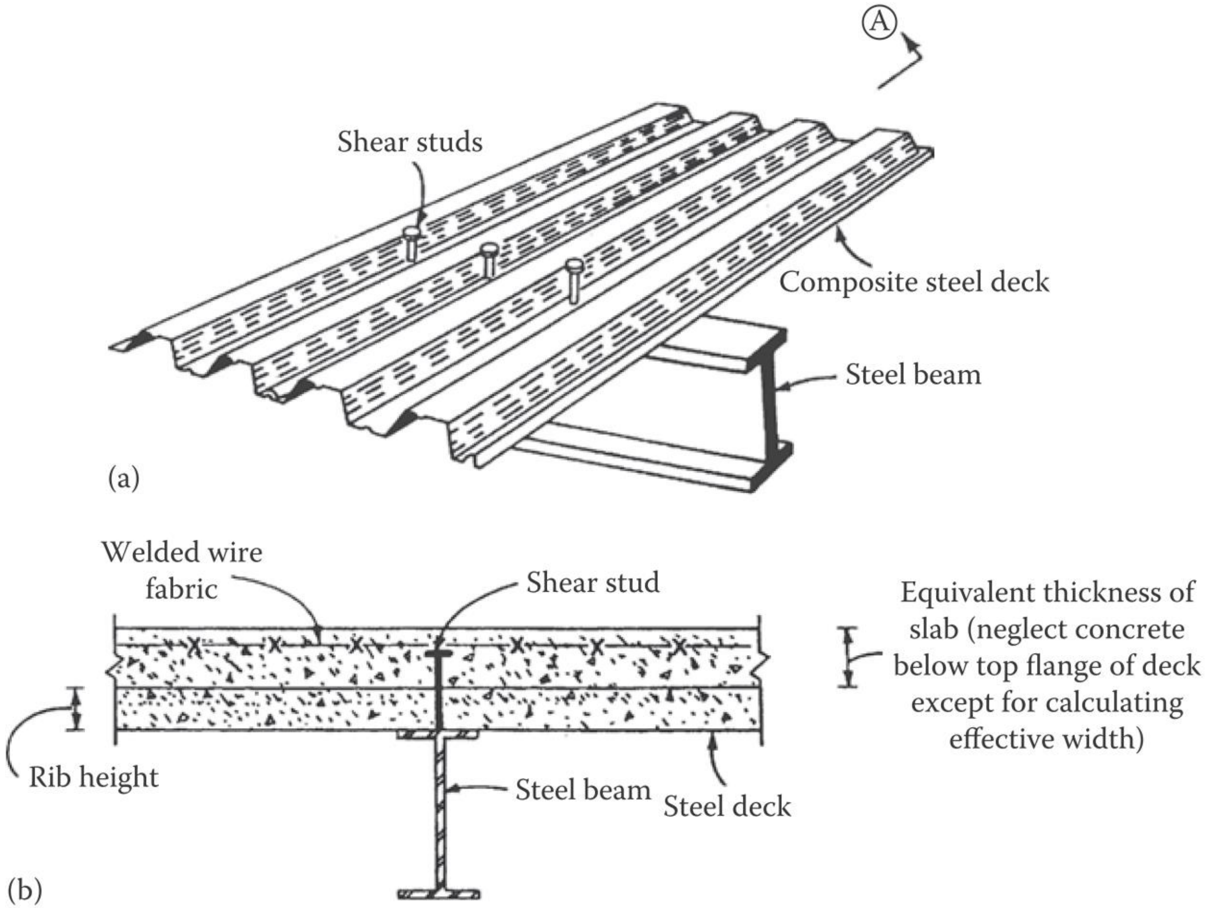
Composite Decks

Composite Floors

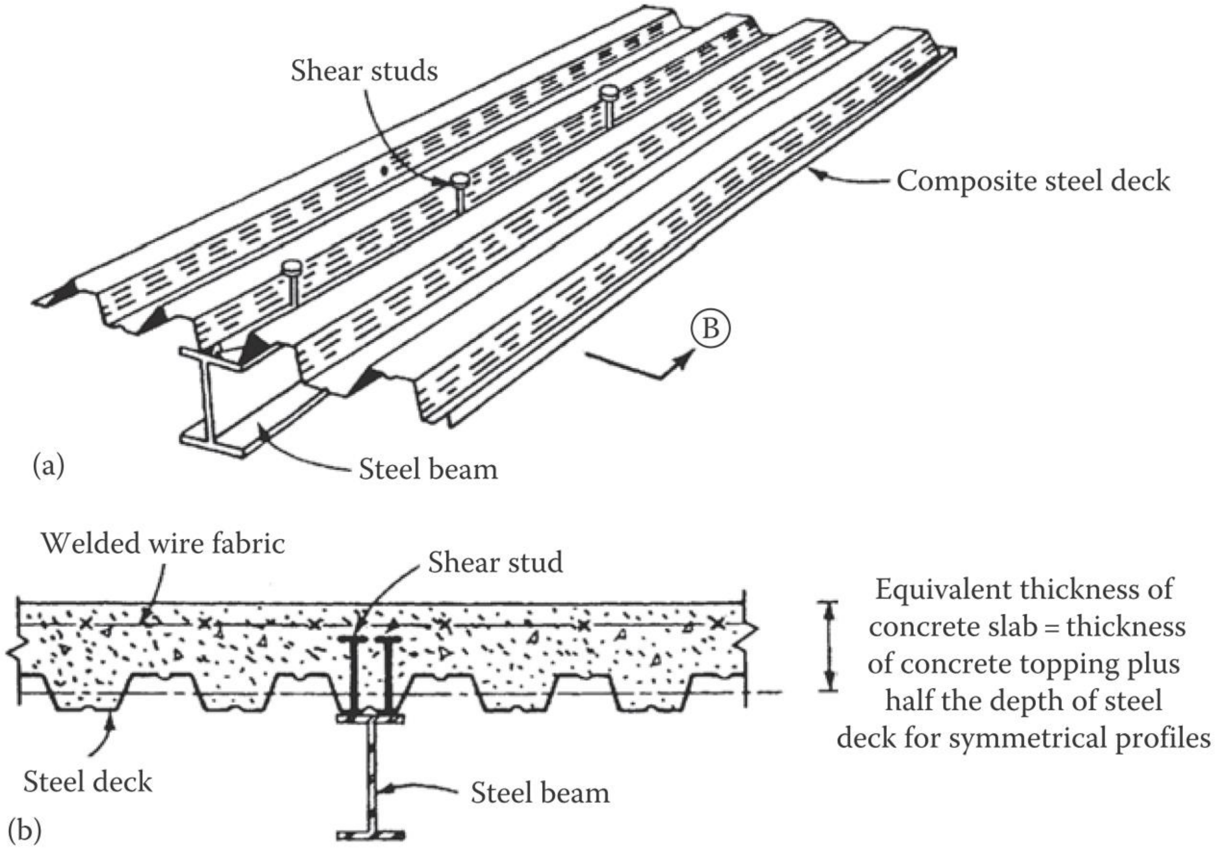


ASCE (2002)

Composite Beam with Deck Ribs Perpendicular to Beam



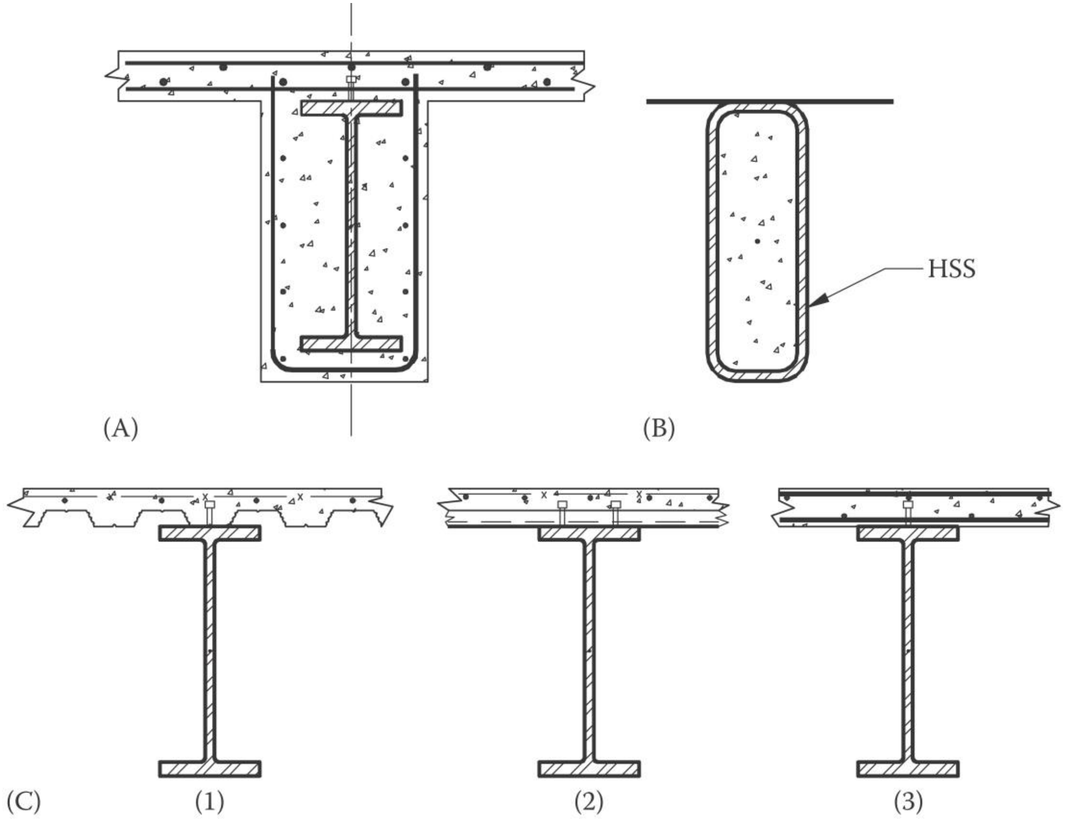
Composite Beam with Deck Ribs Parallel to Beam



(a) schematic view; (b) section showing equivalent thickness of slab

Taranath, B S (2016) Structural analysis and design of tall buildings: Steel and composite construction CRC press

Composite Beam Types



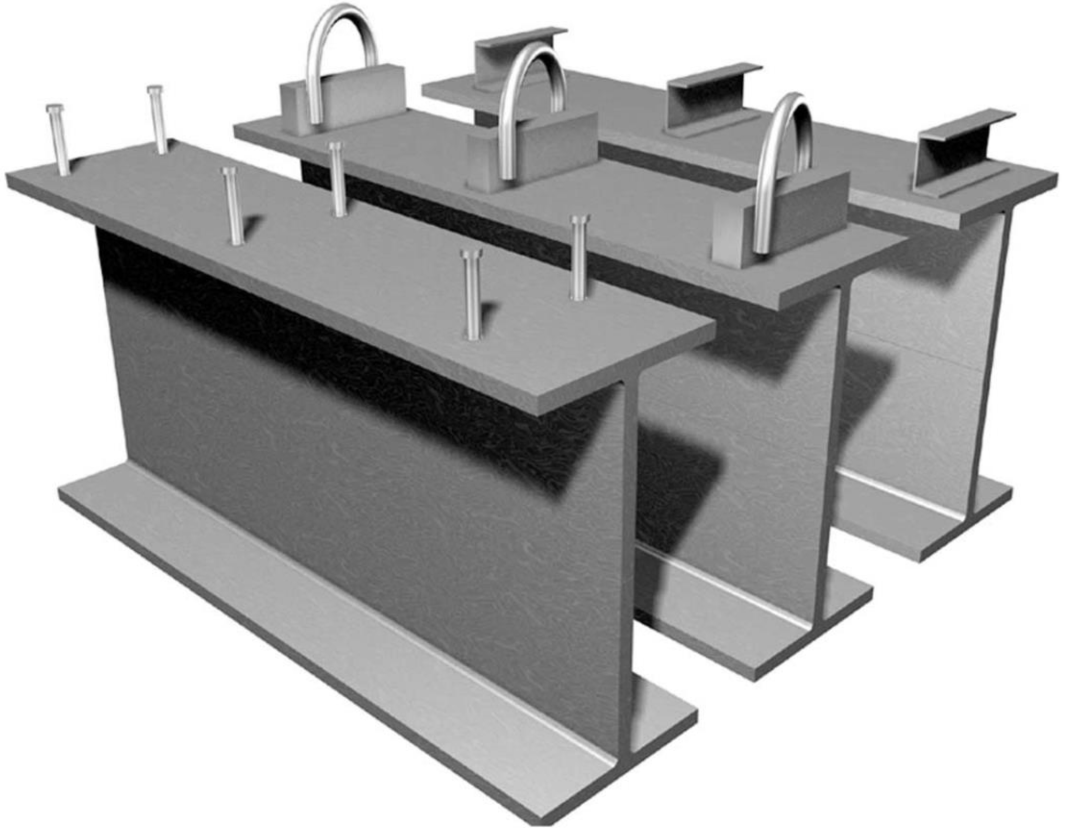
Three types of composite beams addressed in the AISC manual:
(A) fully encased steel beam;
(B) concrete filled HSS;
(C) steel beams with mechanical anchorage to slab (1) Steel deck parallel to beam;
(2) steel deck perpendicular to beam; (3) cast-in-place slab without steel deck

Taranath, B S (2016) Structural analysis and design of tall buildings: Steel and composite construction CRC press

Shear Connectors

Key to Composite Decks and Beams

Typical shear connector types for steel–concrete composite construction: studs, bars with hoops and channels

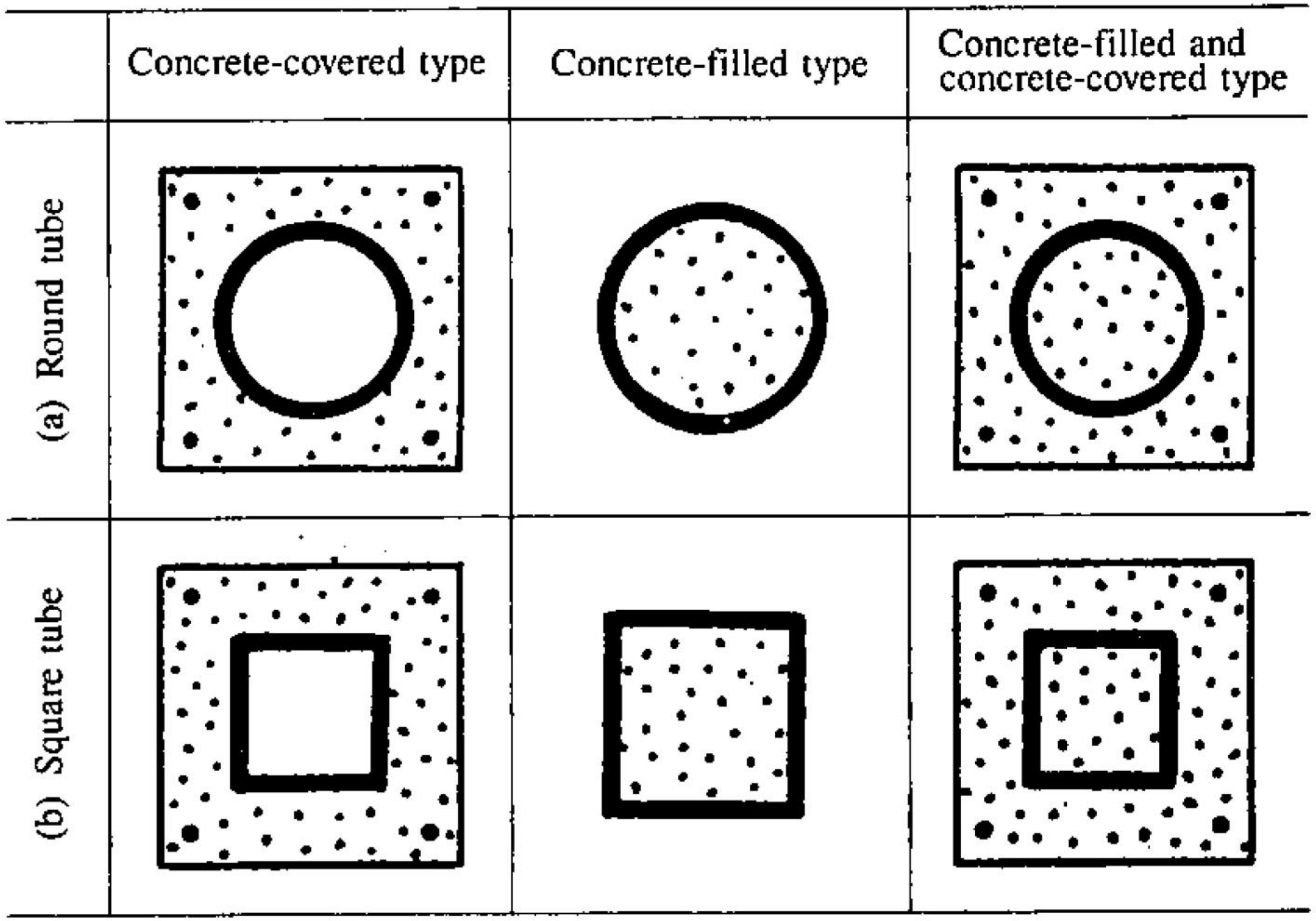


David Collings (2013) Steel-Concrete Composite Bridges - Designing with Eurocodes, Second edition

Composite Columns

Composite Columns

(Design Philosophy and Applications)



Peng, L (2014) “Form follows function – The composite construction and mixed structures in modern tall buildings”, International Journal of high-rise buildings, Volume 3, Number 3, pp 191-198

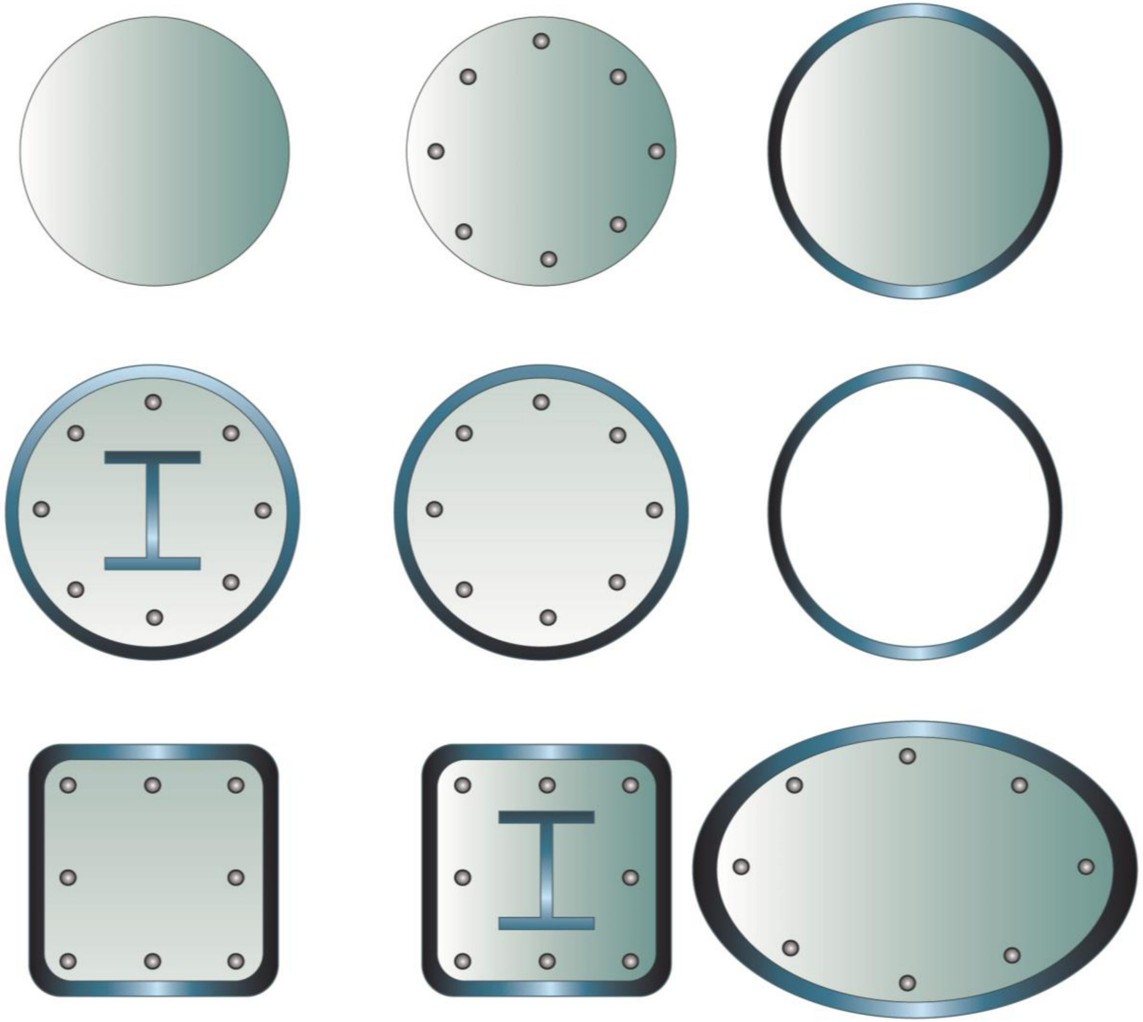
Advantages of Composite Columns

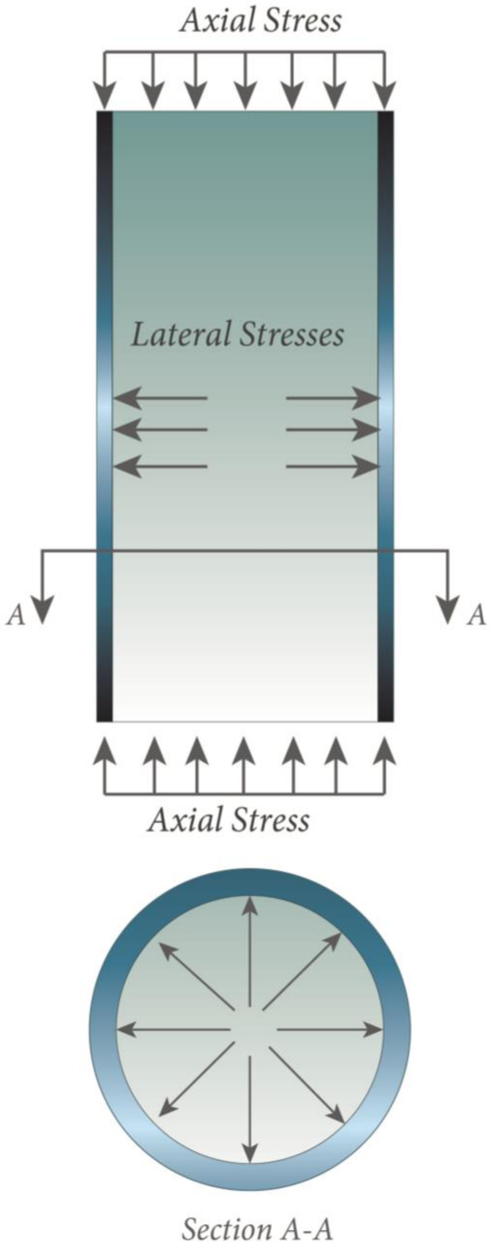
- Increased strength for a given cross-sectional dimension
- Increased stiffness, leading to reduced slenderness and increased buckling resistance
- Good fire resistance for concrete-encased columns
- Corrosion protection for encased columns
- Possible economic advantages over either pure steel or reinforced concrete alternatives

Taranath, B S (2016) Structural analysis and design of tall buildings: Steel and composite construction CRC press

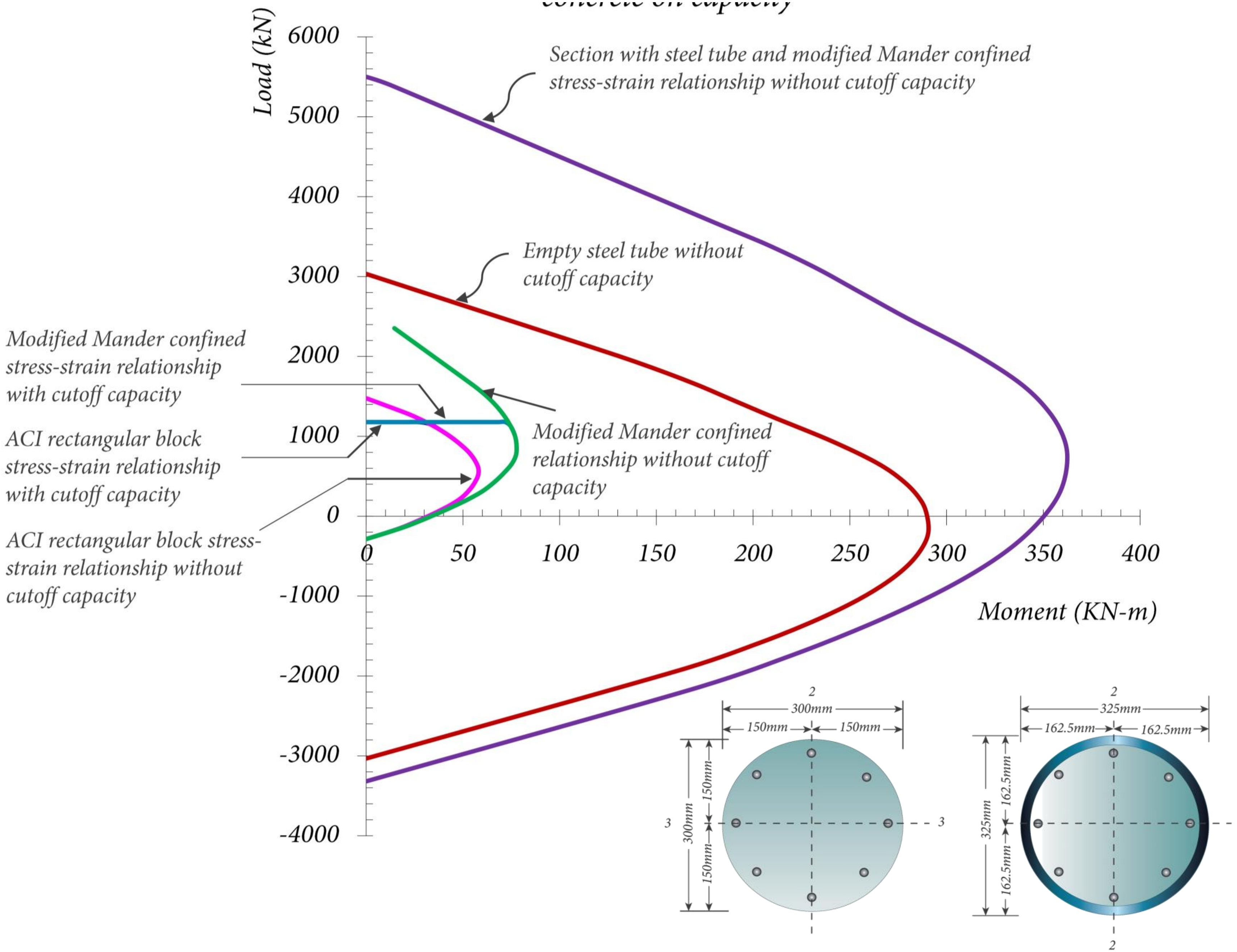
Concrete-filled Steel Tubes

Efficient Columns



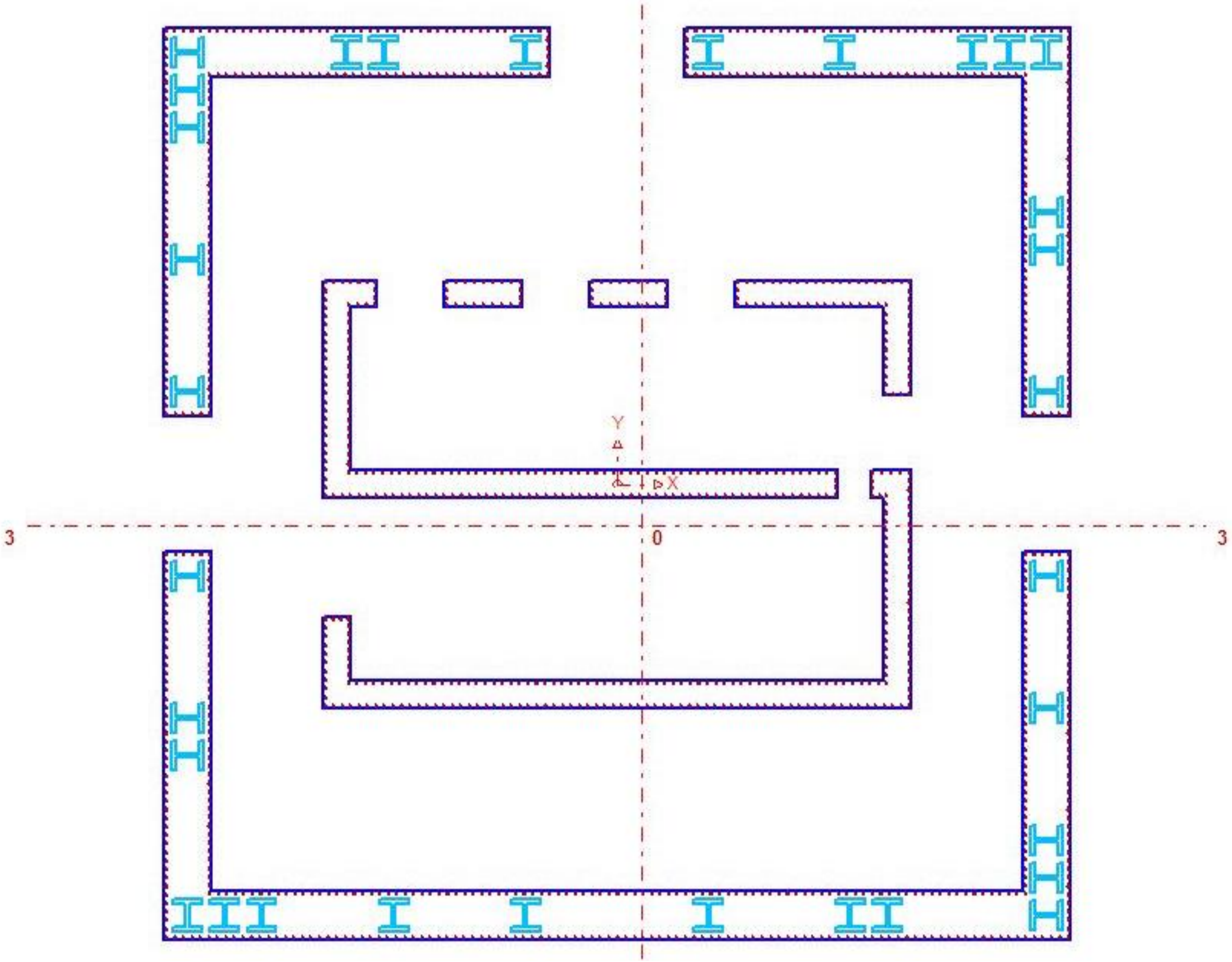


Axial-flexural Analysis of Concrete-filled Steel Tubes - An Example



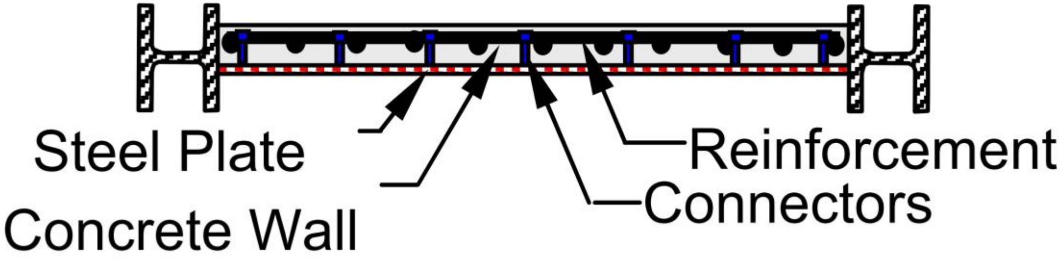
Composite Shear Walls

Composite Shear Walls

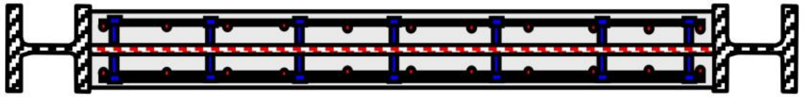


Composite Shear Wall Systems

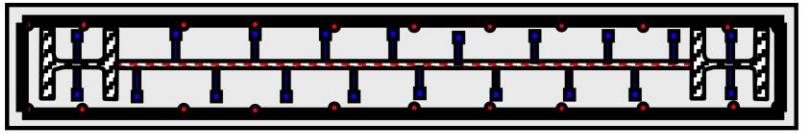
Type I - Concrete on One Side of Steel Plate



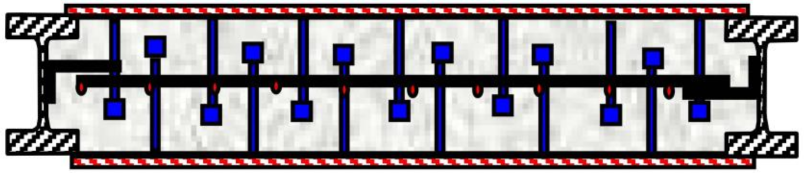
Type 2 - Concrete on Both Sides of Steel Plate



Type 3 – Steel Wall Encased in Concrete Wall

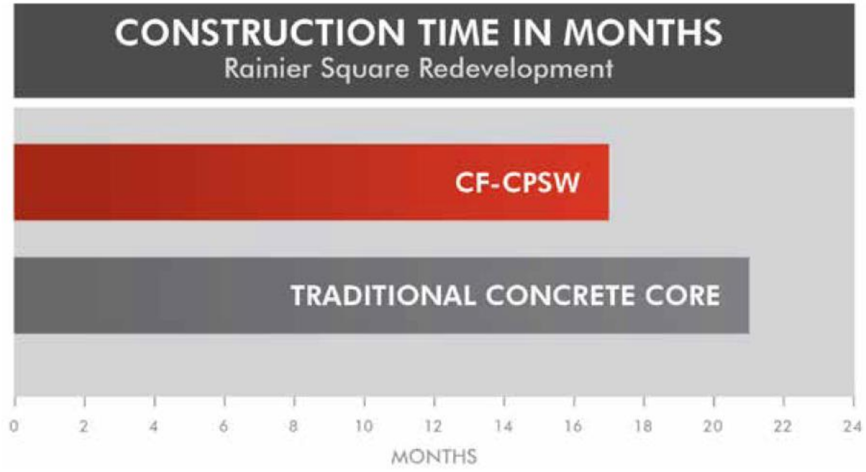


Type 4- Concrete Wall Cast in Steel Plates



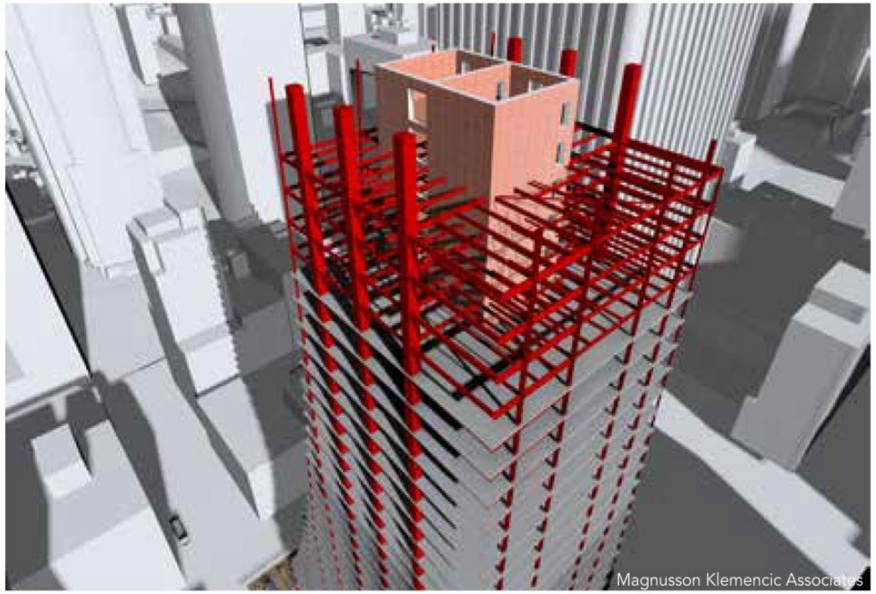
Astaneh-Asl A. “Seismic Behavior and Design of Composite Steel Plate Shear Walls.” Steel TIPS Report. Structural Steel Educational Council. Moraga, CA. 2002.

A Recent Development Of Composite Shear Walls



Brian Morgen is a principal and **Ron Klemencic** is chairman and CEO, both with Magnusson Klemencic Associates. **Amit Varma** is a professor with Purdue University's Lyles School Of Civil Engineering.

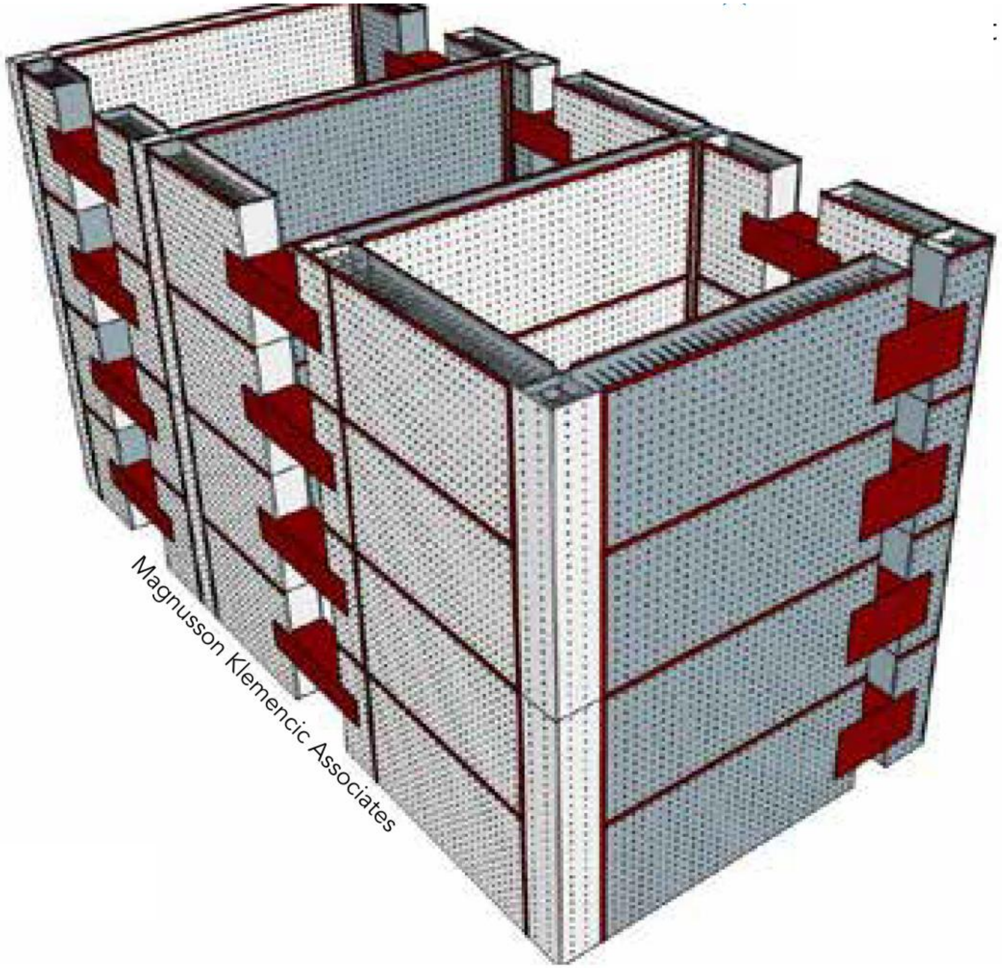
Concrete-filled Composite Plate Shear Wall (CF-CPSW) Core System



Morgen, B., Klemencic, R., and Varma, A. (2018). Core Solution. Modern Steel Construction, February 2018.

Concrete-filled Composite Plate Shear Wall (CF-CPSW) Core System

- The system includes prefabricated wall panels and boundary elements comprised of steel face plates, typically ½ in. thick, separated by 1-in.-diameter cross-connecting tie rods spaced 12 in. on center, both horizontally and vertically, with an overall wall assembly thickness varying from 21 in. to 45 in.
- These panels, which include integrally detailed composite (concrete-filled) coupling beams, are rapidly erected at the same pace as the balance of the steel erection.



Morgen, B., Klemencic, R., and Varma, A. (2018). Core Solution. Modern Steel Construction, February 2018.

Concrete-filled Composite Plate Shear Wall (CF-CPSW) Core System

- Once the panels are erected and the panel-to-panel connections are made, a self-consolidating concrete mix is placed in the space between the two plates.
- The concrete, combined with the steel plates, provides the ultimate strength and stiffness for the core wall assembly as a composite section.

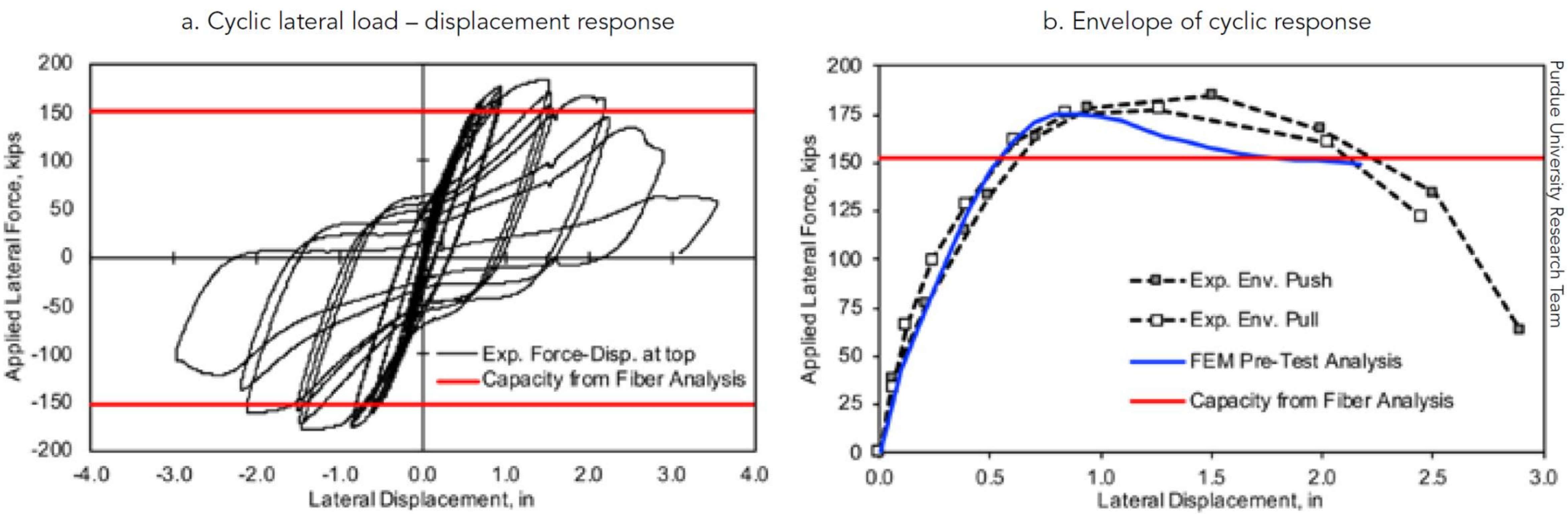
Morgen, B., Klemencic, R., and Varma, A. (2018). Core Solution. Modern Steel Construction, February 2018.

Role of Connecting Tie Rods

- Strength and stability of the un-concreted wall panels
- Lateral resistance and face plate bracing during the concrete infill
- Mechanical connectivity between the steel plates and in-fill concrete for composite action leading to enhanced axial and shear strength
- Confined pressure for the concrete for superior seismic performance
- Prevention of delamination modes through the plain concrete infill
- Out-of-plane shear strength
- Reduced slenderness of the steel plates

Morgen, B., Klemencic, R., and Varma, A. (2018). Core Solution. Modern Steel Construction, February 2018.

Verified Performance



Morgen, B., Klemencic, R., and Varma, A. (2018). Core Solution. Modern Steel Construction, February 2018.

Composite and Mixed System - China

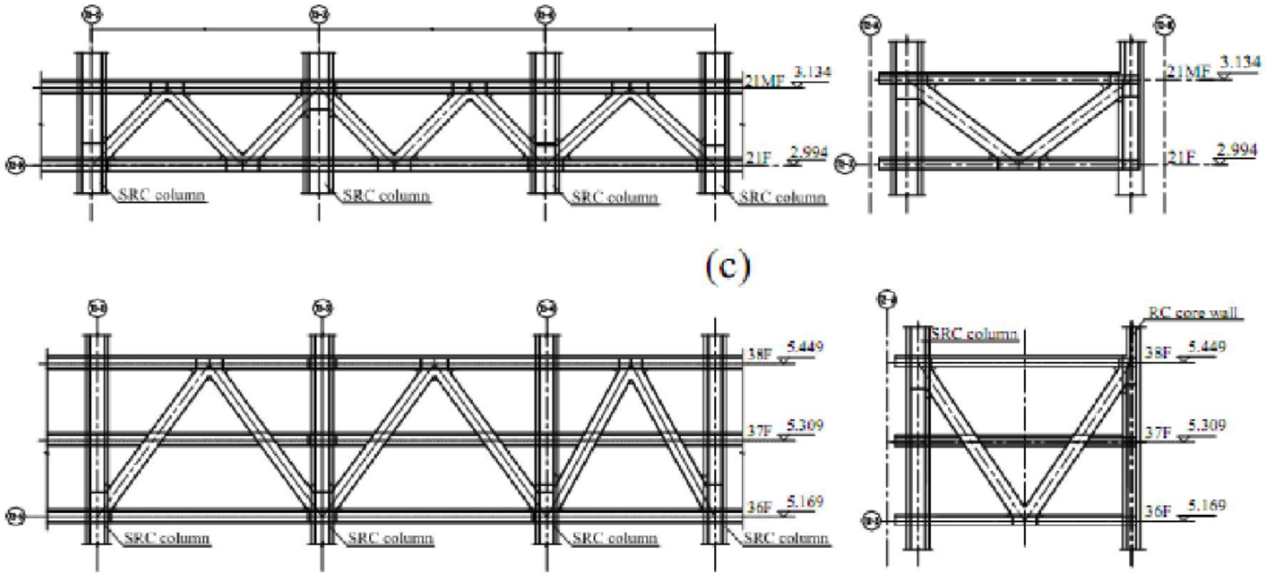
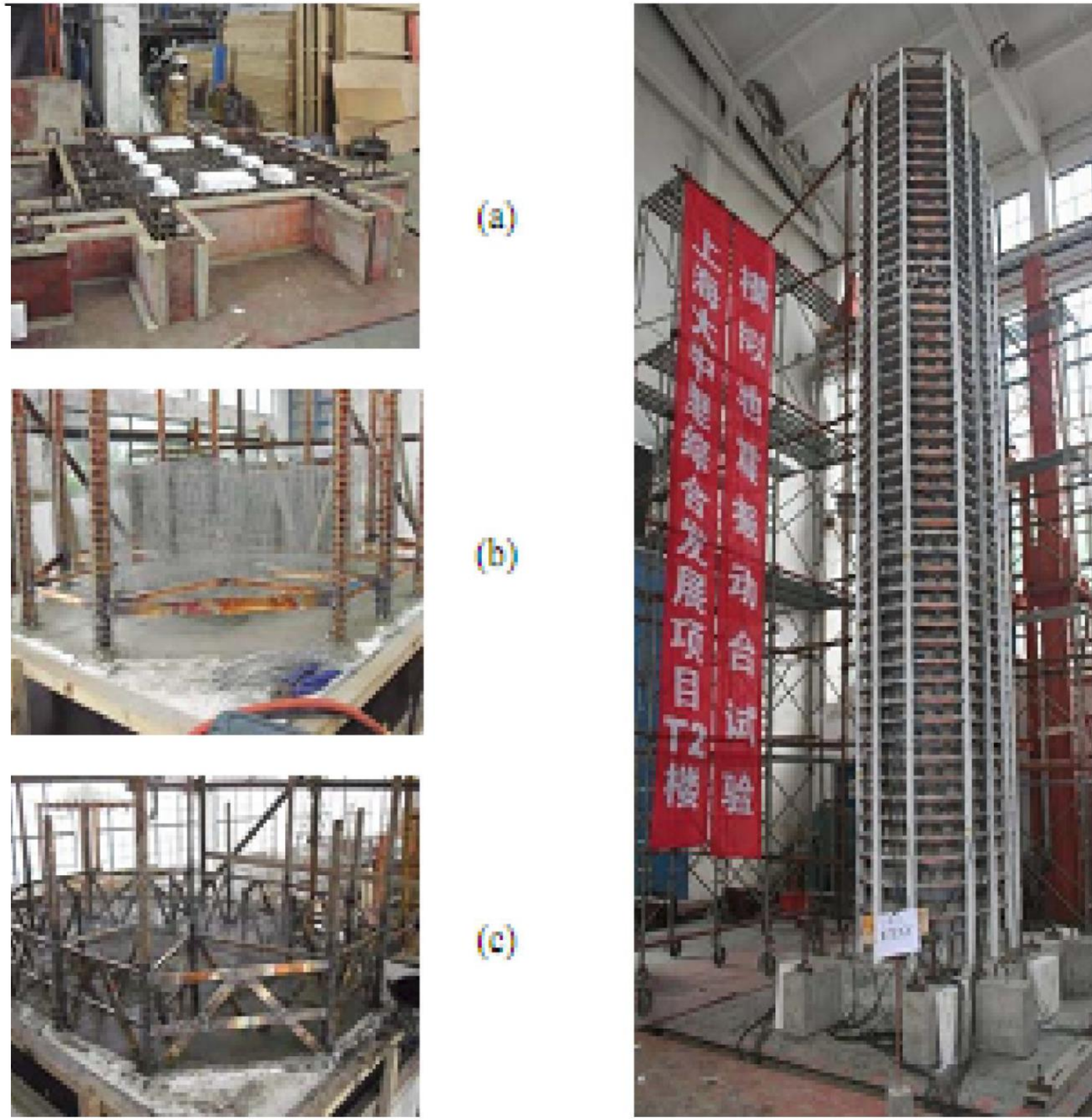
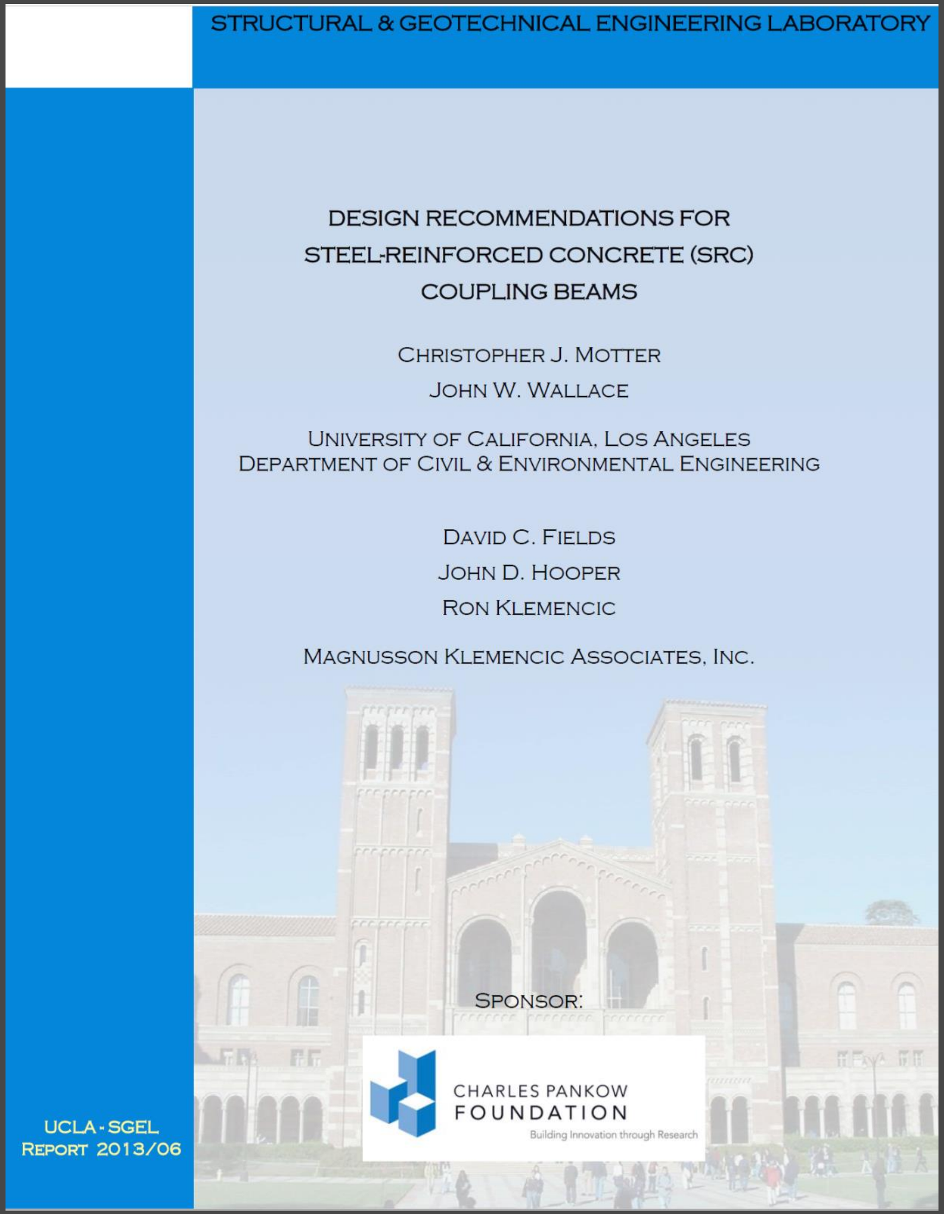


Figure 2.18 Typical design drawings of model structure
(Zhao , He , Lu, Zhou and Yu et al., 2012)



19 Test model (a) Base, (b) typical story,(c) strength layer ,(d) overv
(Zhao , He , Lu, Zhou and Yu et al., 2012)

Composite Link Beams


STRUCTURAL & GEOTECHNICAL ENGINEERING LABORATORY

DESIGN RECOMMENDATIONS FOR
STEEL-REINFORCED CONCRETE (SRC)
COUPLING BEAMS

CHRISTOPHER J. MOTTER
JOHN W. WALLACE

UNIVERSITY OF CALIFORNIA, LOS ANGELES
DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

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JOHN D. HOOPER
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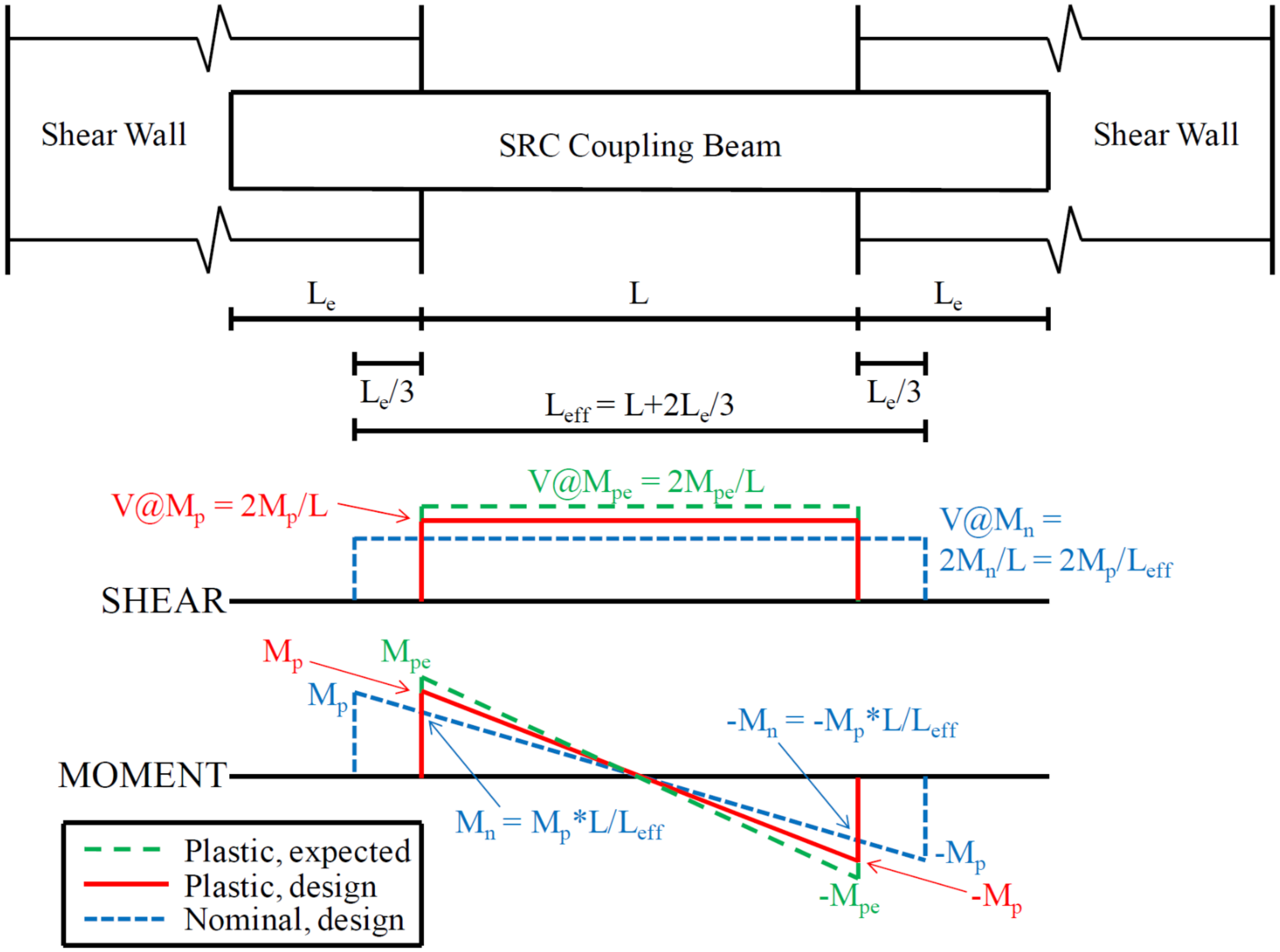


Figure 2.2. *Flexural Capacities and Shear Demands*

Composite Link Beams

Christopher J. Motter, UC Los Angeles
John W. Wallace, UC Los Angeles

Ron Klemencic, John Hooper, Dave Fields
Magnusson, Klemencic Associates

Some Related Work at AIT

Comparison of Various Systems

SEISMIC PERFORMANCE OF HYBRID CONCRETE-STEEL STRUCTURAL SYSTEM BUILDING

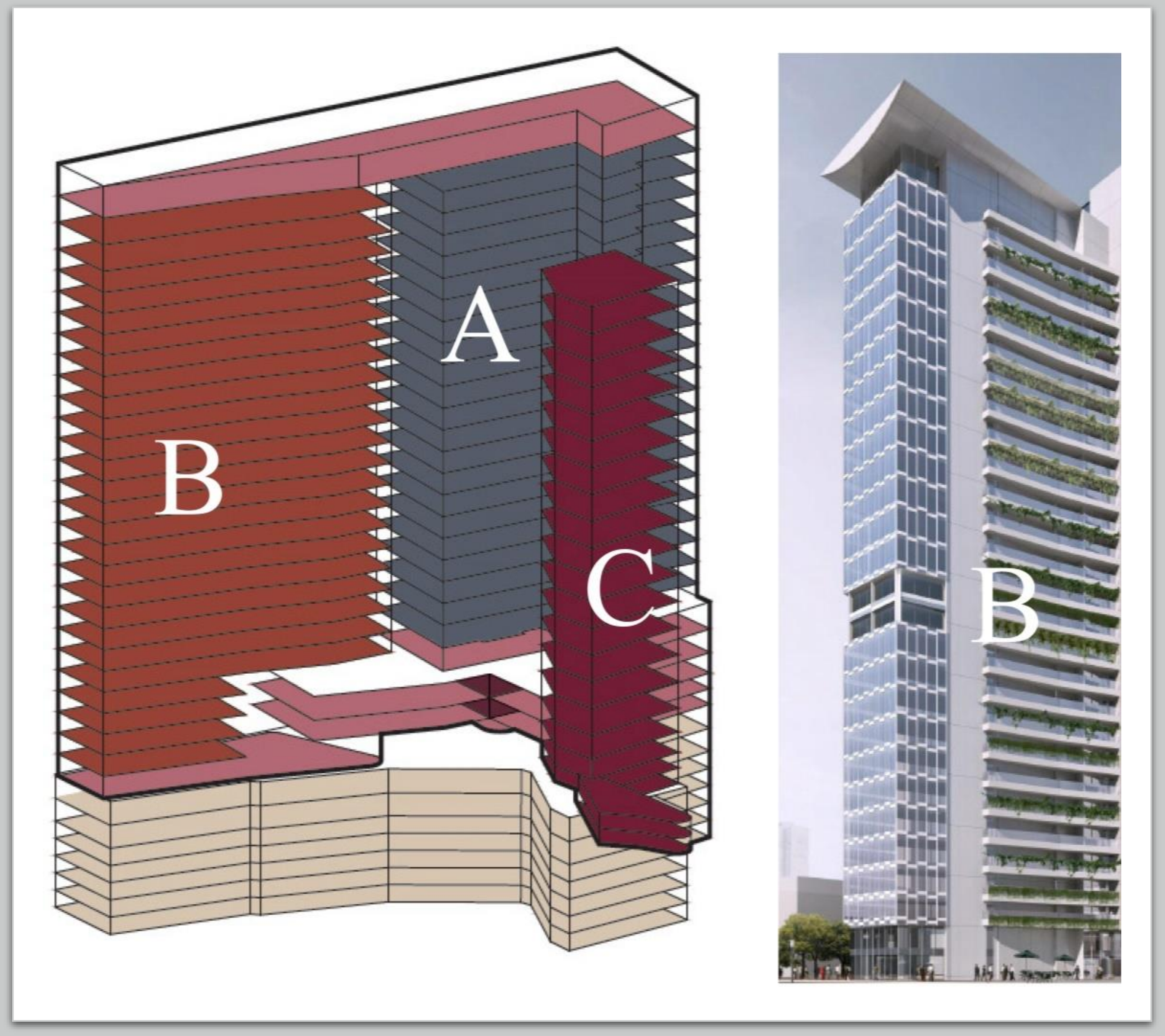
by

Mya Kyae Mone

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Engineering in Structural Engineering

(1) Selection of Structural Systems for

Building-A: RC Conventional Frame with Shear Wall
Building-B: Steel Moment Frame with Braces
Building-B1: Steel Simple Connection with Braces
Building-C: Hybrid Moment Frame with Shear Wall
Building-C1: Hybrid Simple Frame with Shear Wall



Design Review of a Composite Tall Building

Case Study 1

A Hotel, Dhaka, Bangladesh

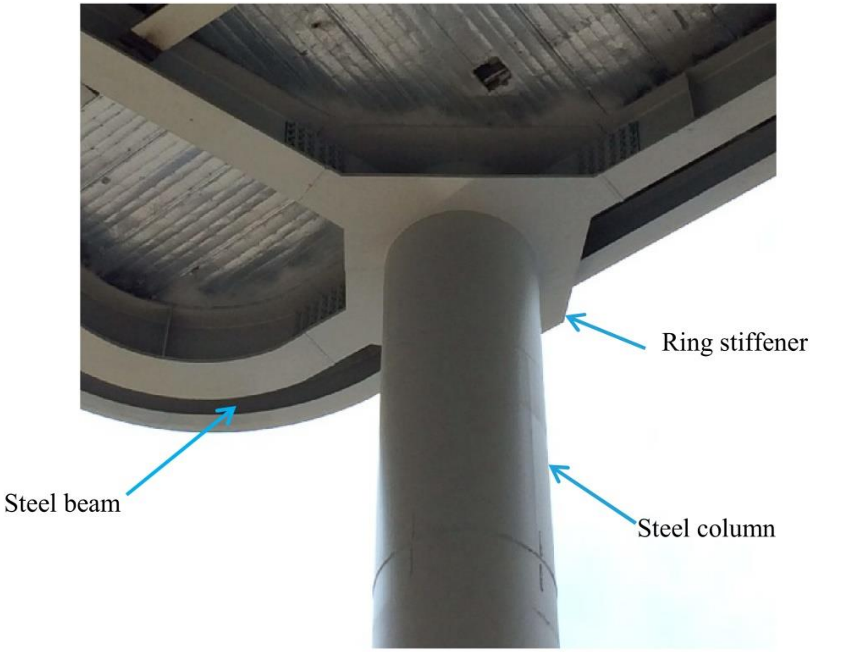
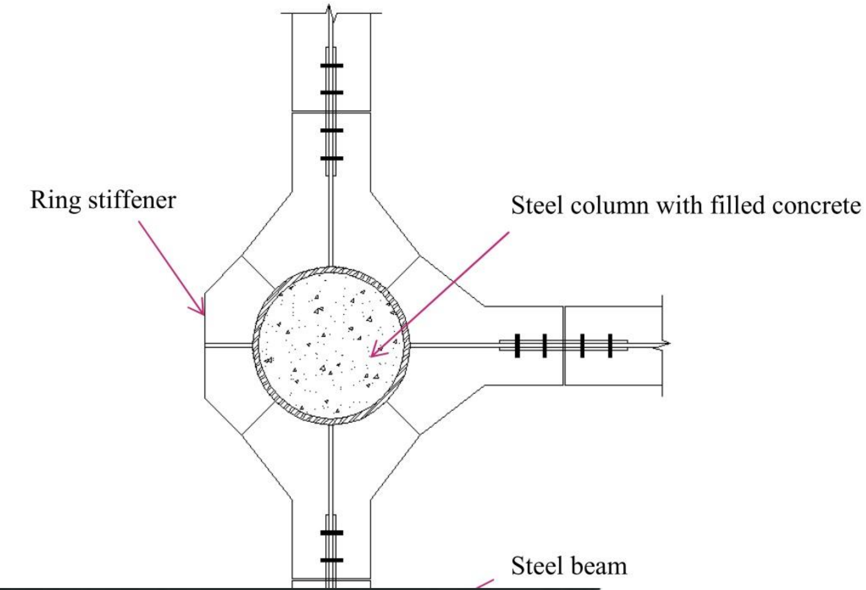


Figure 6-8 3Dview for circle steel column framing



Composite Columns

Composite Shear Walls

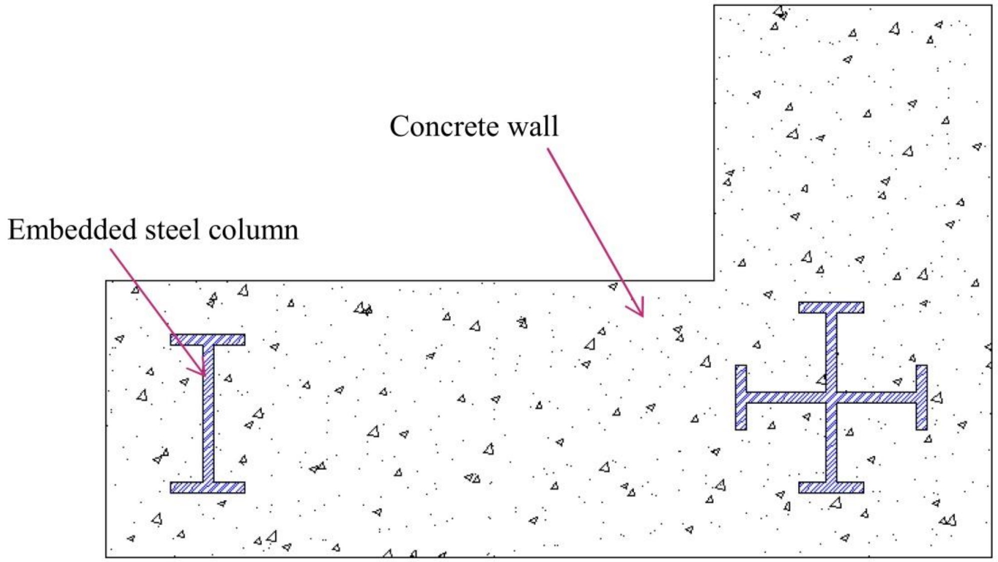
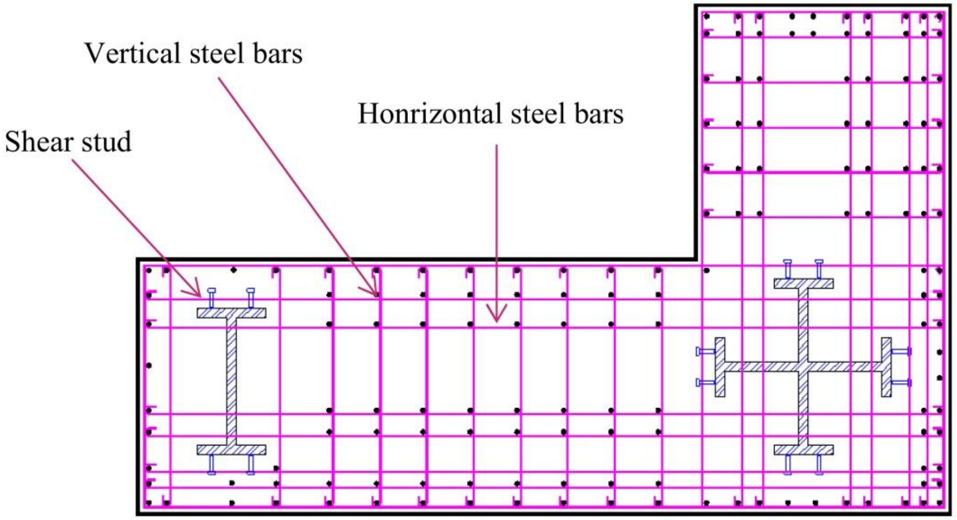
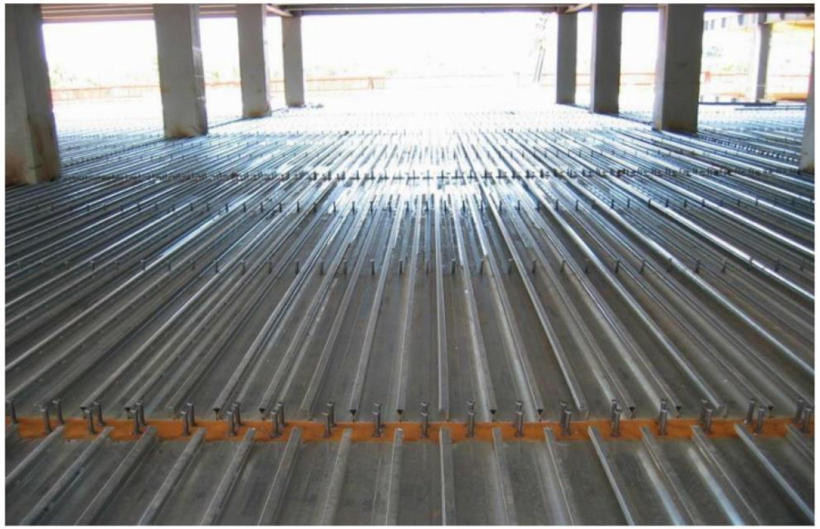


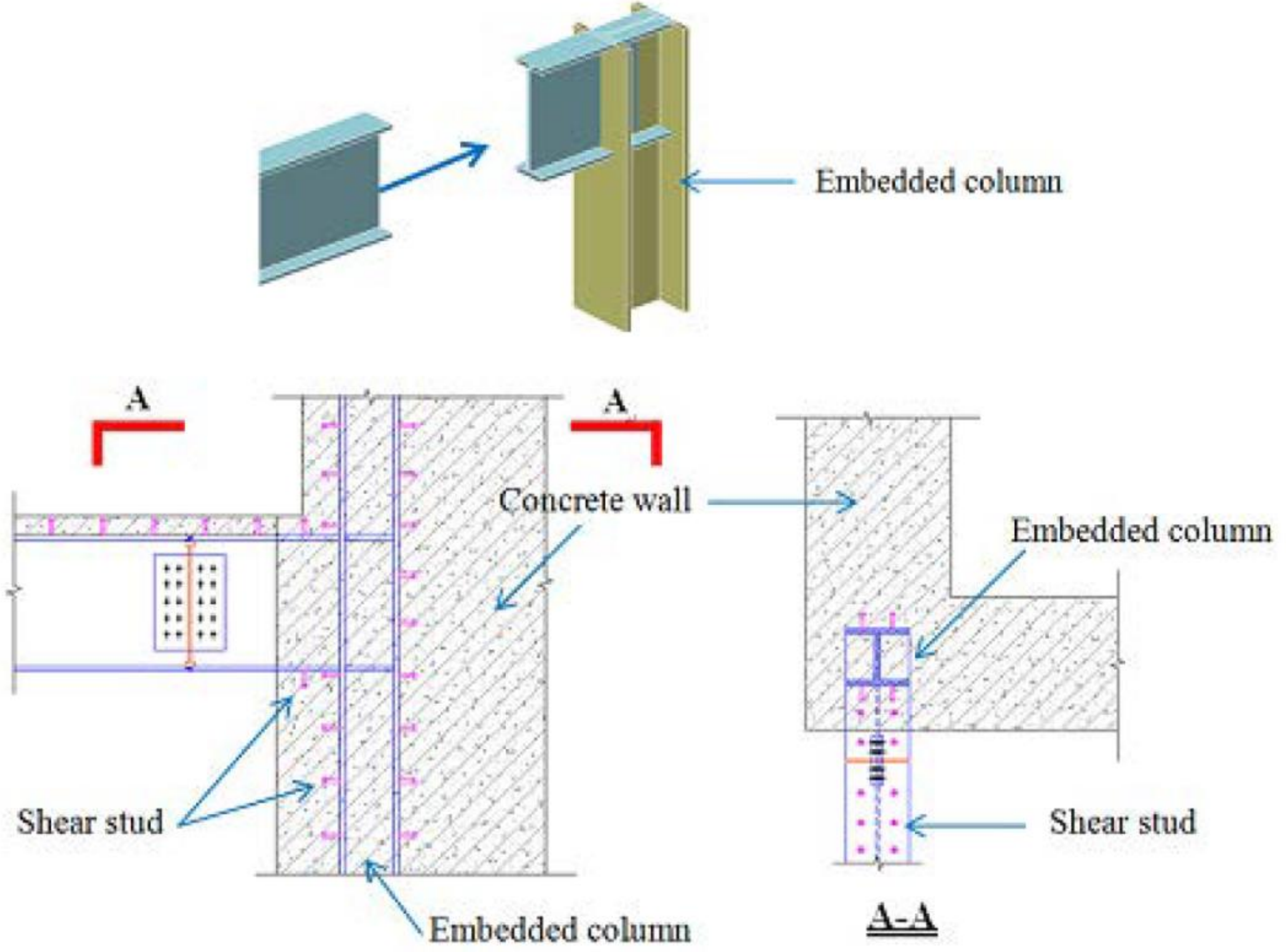
Figure 6-14 Shear wall section

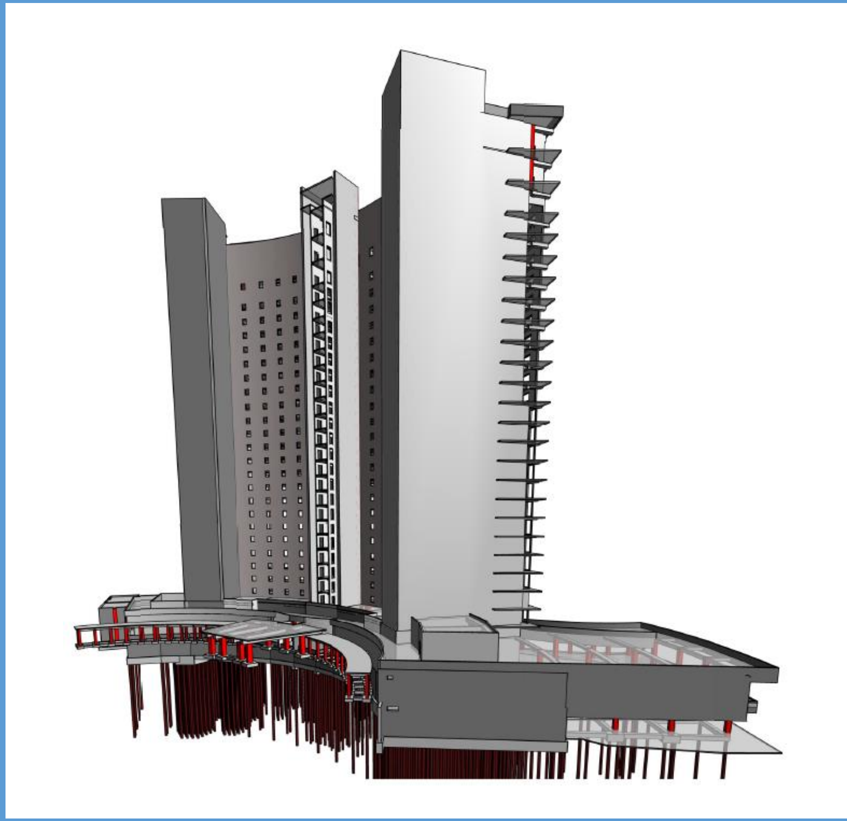


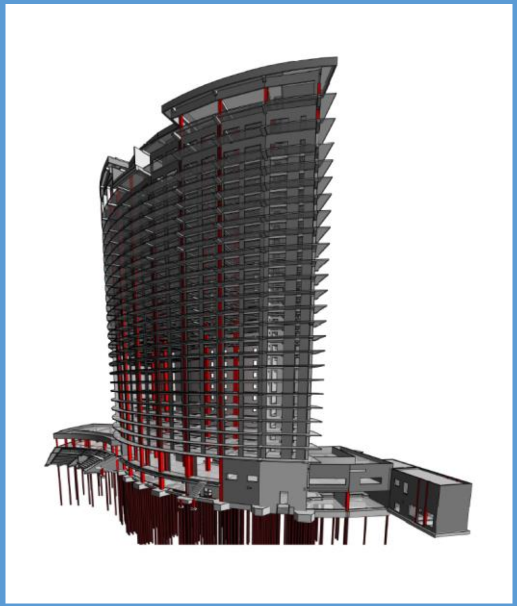
Composite Floor System



Composite Beam to Wall Connections



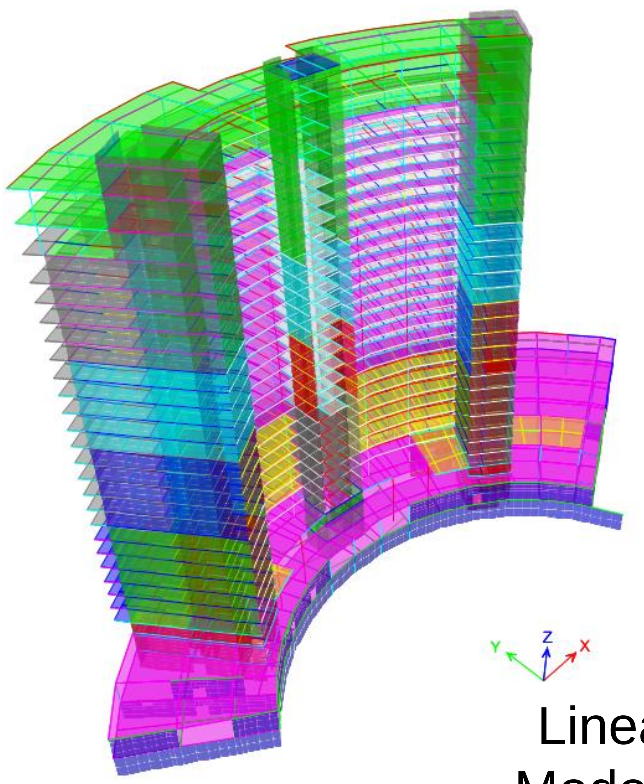




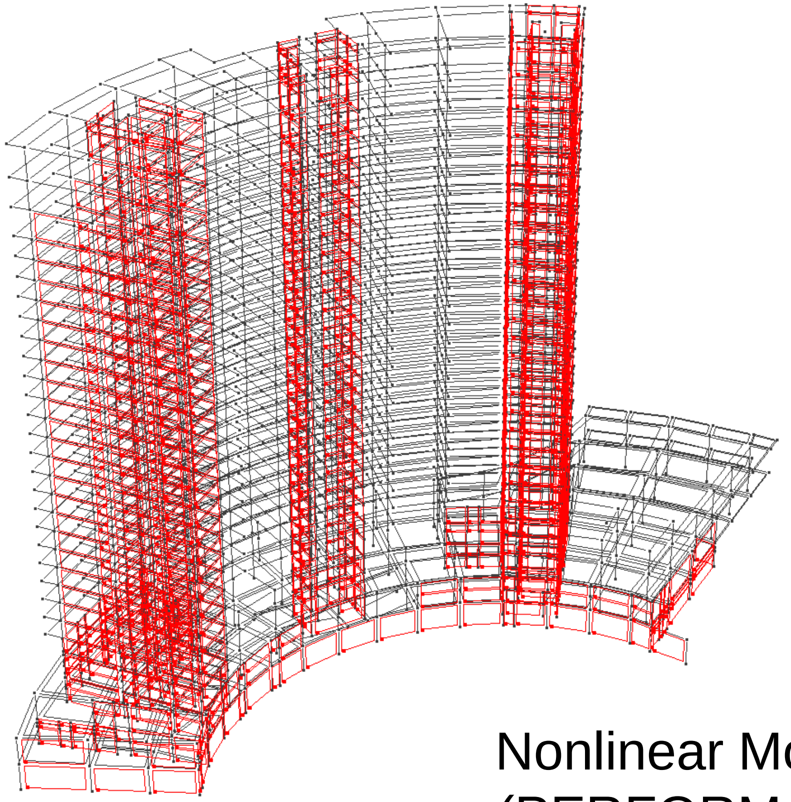
Structural Peer Review of a Composite Tall Building

Case Study 2

A Hotel, Guam

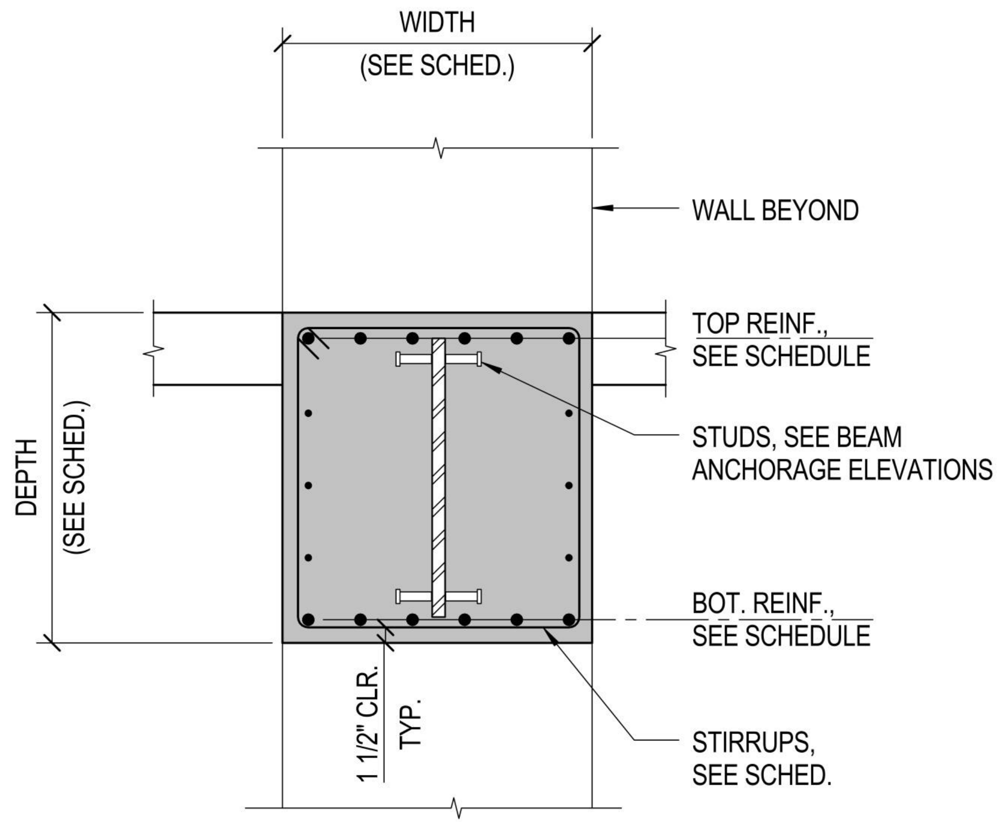


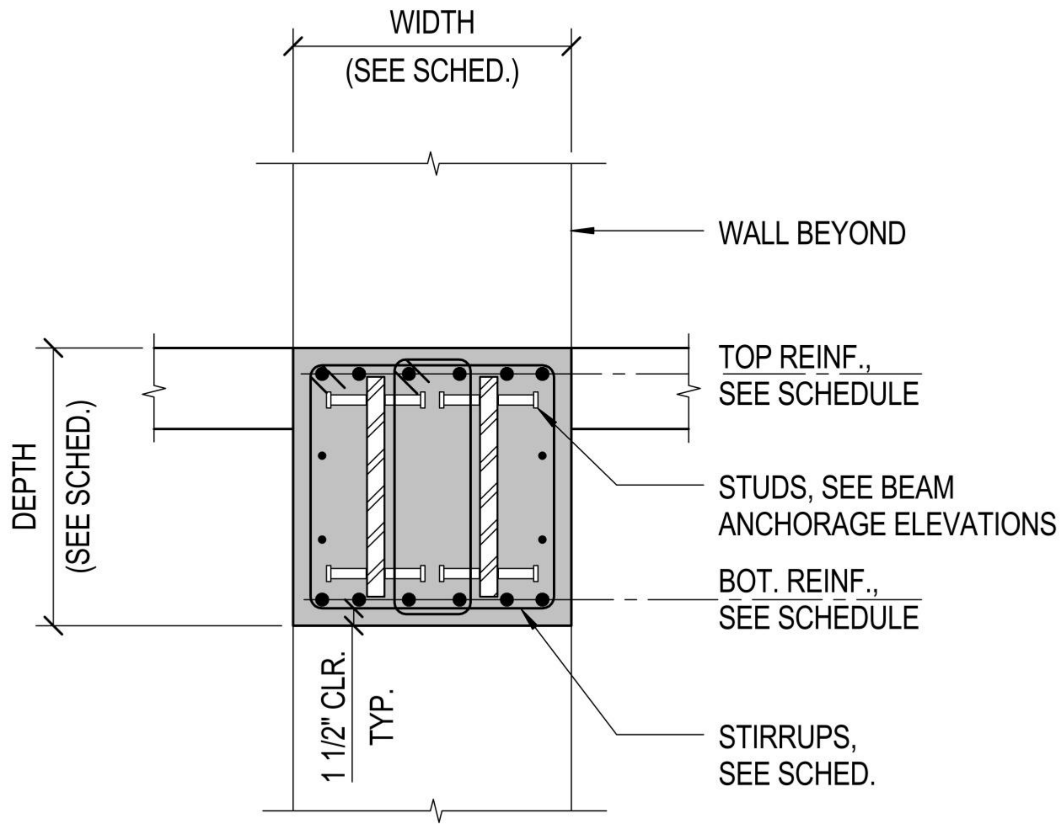
Linear Elastic Model (ETABS)



Nonlinear Model (PERFORM 3D)

Finite Element Modeling

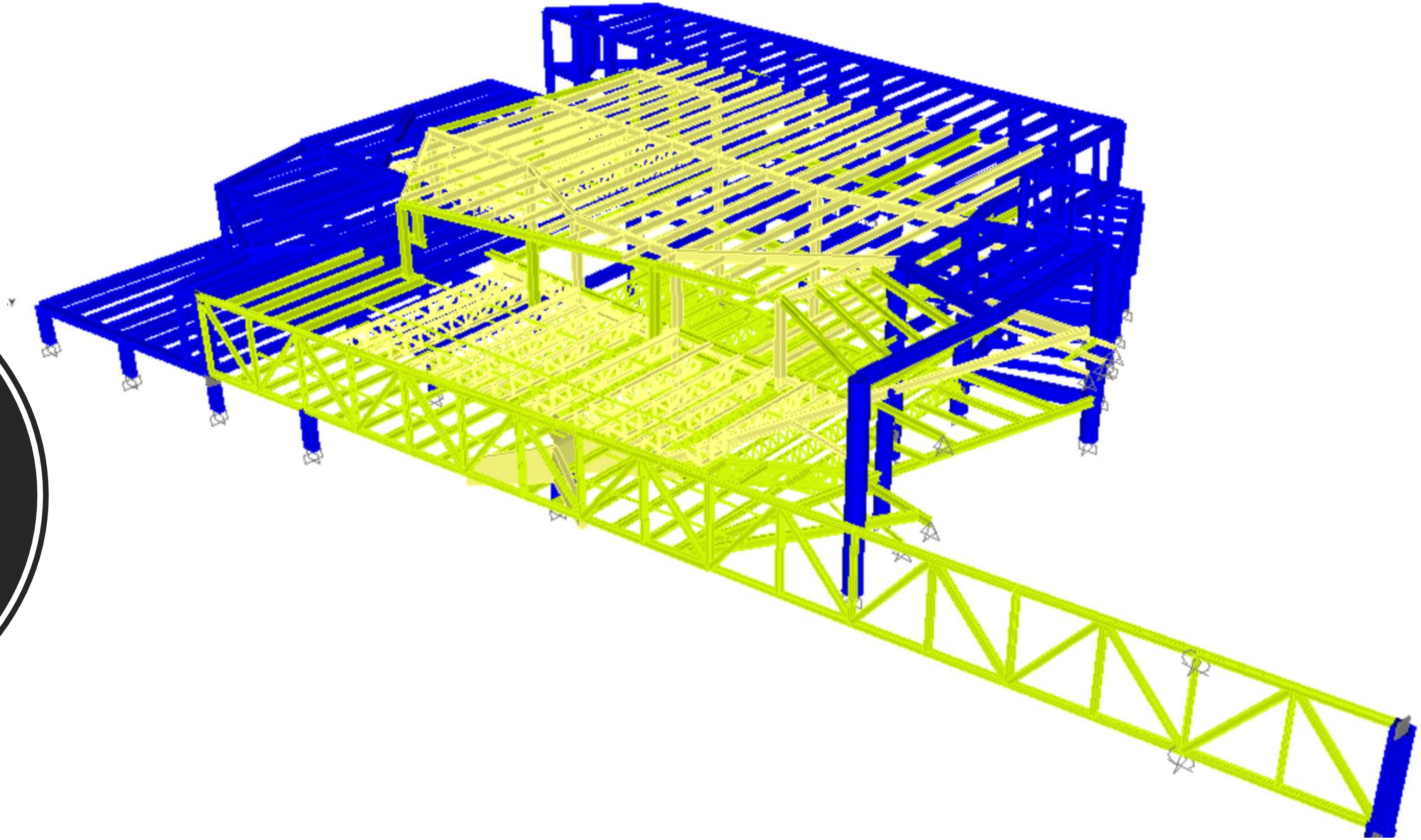




Composite Coupling Beams

Case -3

Mixed Structure



Makati, Philippines

Steel Trusses acting as Transfer Systems and roof of large column free spaces

Concluding Remarks

Concluding Remarks

Concrete and steel are the basic construction materials

Reinforced concrete has been a material of choice in Asia

Recently, Prestress has become popular in Tall Buildings

Future may belong to Composite and Mixed Systems

Thank you

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