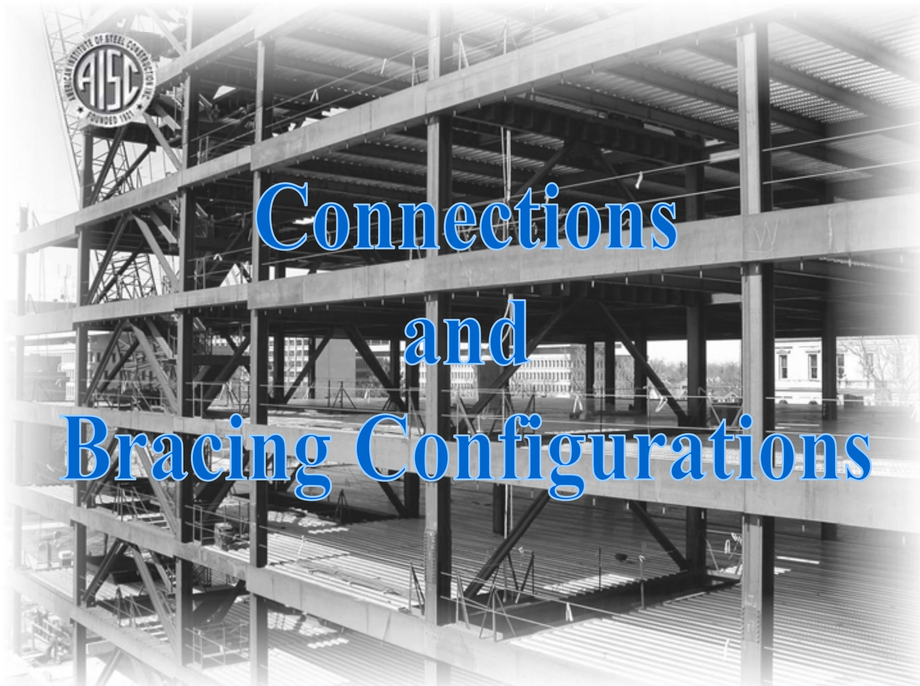


Introduction

This presentation was developed as a teaching aid with the support of the American Institute of Steel Construction. Its objective is to provide technical background and information for connections and bracing configurations. The information provided is based on common design and construction practices for structures of twelve stories or less.

The AISC Digital Library case study presentations document the construction of a steel frame for an office building. The case study includes photographs that were taken throughout the construction of the structural steel frame including detailing, fabrication, and erection. Project data including plans, schedules, specifications and other details are also included. The case study presentations are available in the Learning Opportunities section at www.aisc.org.

This presentation goes a step further in detail in the areas of connections and bracing configurations. A more in-depth background is provided and details of common connections and bracing configurations are presented.

The information is presented with concerns of a construction manager or general contractor in mind.

What Will You Gain From This Presentation?

- General knowledge of structural steel
- Knowledge of the types of steel frame connections defined in the American Institute of Steel Construction design specification
- An understanding of different types of connections used in structural steel frames
- Insight into the impacts of using certain connection types
- Familiarity with common bracing systems used in structural steel frames

Benefits of Structural Steel

Some benefits associated with use of structural steel for owners are:

- Steel allows for reduced frame construction time and the ability to construct in all seasons
- Steel makes large spans and bay sizes possible, providing more flexibility for owners
- Steel is easier to modify and reinforce if architectural changes are made to a facility over its life
- Steel is lightweight and can reduce foundation costs
- Steel is durable, long-lasting and recyclable (AISC 1999)

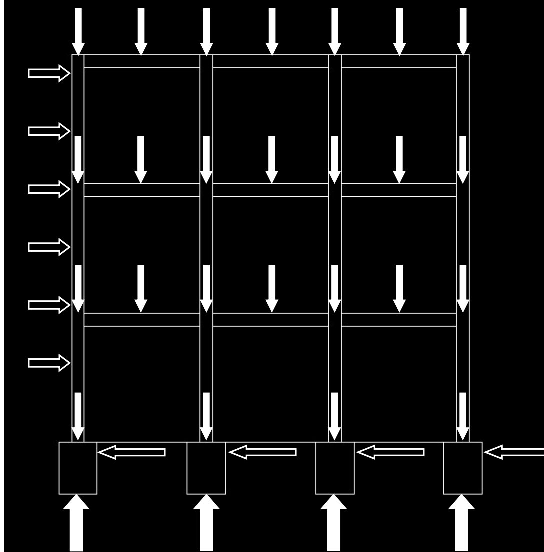
Unique Aspects of Steel Construction

Procurement and management of structural steel is similar to other materials, but there are some unique aspects to steel construction:

- Steel is fabricated off-site (above left)
- On-site erection is a rapid process (above right)
- This gives use of structural steel some scheduling advantages
- Coordination of all parties is essential for achieving potential advantages

(AISC 1999)

Forces On Structures

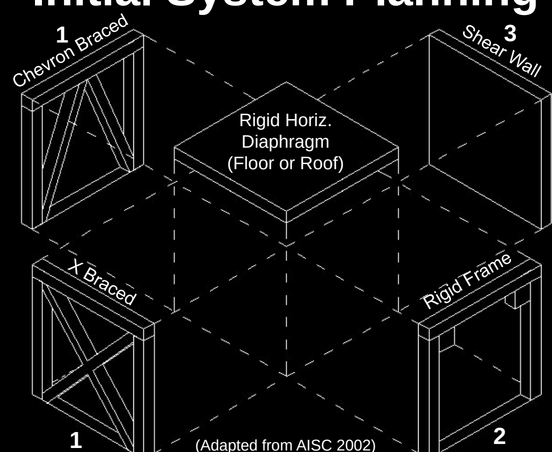


Structural Steel Frame Elevation

- Forces from gravity, wind, and seismic events are imposed on all structures
- Forces that act vertically are gravity loads
- Forces that act horizontally, such as stability, wind and seismic events (the focus of this discussion) require lateral load resisting systems to be built into structures
- As lateral loads are applied to a structure, horizontal diaphragms (floors and roofs) transfer the load to the lateral load resisting system

(AISC 2002)

Initial System Planning



(Adapted from AISC 2002)

- The type of lateral load resisting system to be used in a structure should be considered early in the planning stage
- Lateral stability as well as architectural needs must be met
- The three common lateral load resisting systems are:
  1. Braced Frames 2. Rigid Frames 3. Shear Walls

Braced Frames and Rigid Frames

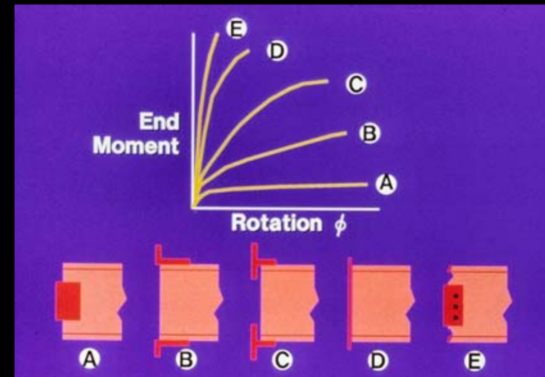
This presentation focuses on braced frames (left) and rigid frames (right)

Steel Frame Connection Types

The Specification for Structural Steel Buildings (AISC 2005) defines two types of connections:

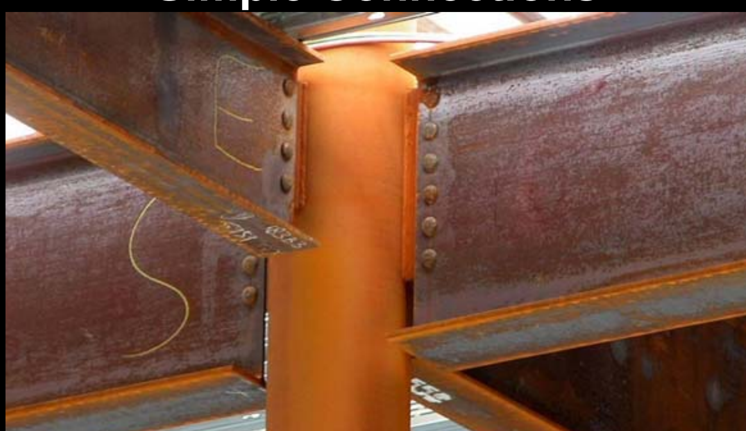
- Simple Connections (above left)
- Moment Connections (above right)
  - Fully-Restrained and Partially-Restrained

Steel Frame Connection Types



- All connections have a certain amount of rigidity
- Simple connections (A above) have some rigidity, but are assumed to be free to rotate
- Partially-Restrained moment connections (B and C above) are designed to be semi-rigid
- Fully-Restrained moment connections (D and E above) are designed to be fully rigid

Simple Connections



- Designed as flexible connections
- Connections are assumed to be free to rotate
- Vertical shear forces are the primary forces transferred by the connection
- Require a separate bracing system for lateral stability
- The following few slides show some common simple framing connections

Common Simple Connections

Single Plate Connection (Shear Tab)

A plate is welded to the supporting member and bolted to the web of the supported beam

Double Angle Connection

The in-plane pair of legs are attached to the web of the supported beam and the out-of-plane pair of legs to the flange or web of the supporting member

(Green, Sputo, and Veltri)

Common Simple Connections

Shear End Plate Connection

A plate is welded perpendicular to the end of the supported web and attached to the supporting member

Single Angle Connection

One leg is attached to the web of the supported beam and the other leg to the flange or web of the supporting member

(Green, Sputo, and Veltri)

Common Simple Connections

Seated Connection

An angle is mounted with one leg vertical against the supporting column, and the other leg provides a "seat" upon which the beam is mounted

A stabilizer connection is also provided at the top of the web

Tee Connection

The stem of a WT section is connected to the supported member and the flange attached to the supporting member

(Green, Sputo, and Veltri)

Moment Connections

- Designed as rigid connections which allow little or no rotation
  - Used in rigid frames
- Moment and vertical shear forces are transferred through the connection
- Two types of moment connections are permitted:
  - Fully-Restrained
  - Partially-Restrained

Moment Connections

Fully-Restrained (FR) Connections

- Have sufficient strength to transfer moments with negligible rotation between connected members
- The angle between connected members is maintained

Partially-Restrained (PR) Connections

- Have sufficient strength to transfer moments, but the rotation between connected members is not negligible
- The angle between connected members may change

(AISC 2005)

Common FR Connections

Welded Flange Plate Connection

Bolted Flange Plate Connection

Top and bottom flange-plates connect the flanges of the supported member to the supporting column

A single plate connection is used to transfer vertical shear forces

(Green, Sputo, and Veltri)

Common FR Connections

Bolted Extended End-Plate Connection

A plate is welded to the flanges and web of the supported member and bolted with high-strength bolts to the supporting column

(Green, Sputo, and Veltri)

Welded Flange Connection

Complete-joint-penetration groove welds directly connect the top and bottom flanges of the supported member to the supporting column

A shear connection on the web is used to transfer vertical shear forces

Common PR Connections

PR Moment Connection – Wind Only

A double angle simple connection transfers vertical shear forces while top and bottom flange plates resist moment forces produced by wind

Note that the size of the flange plate is relatively small in comparison to the beam flange

Top and Bottom Angle with Shear End Plate Connection

Angles are bolted or welded to the top and bottom flanges of the supported member and to the supporting column

A shear end plate on the web is used to transfer vertical shear forces

Rigid Frames

- Rigid frames, utilizing moment connections, are well suited for specific types of buildings where diagonal bracing is not feasible or does not fit the architectural design
- Rigid frames generally cost more than braced frames (AISC 2002)

Braced Frames

- Diagonal bracing creates stable triangular configurations within the steel building frame (AISC 2002)
- “Braced frames are often the most economical method of resisting wind loads in multi-story buildings (AISC 1991).”
- Some structures, like the one pictured above, are designed with a combination braced and rigid frame to take advantage of the benefits of both

Temporary Bracing

- Structural steel frames require temporary bracing during construction
- Temporary bracing is placed before plumbing up the structural frame
- This gives the structure temporary lateral stability
- Temporary bracing is removed by the erector

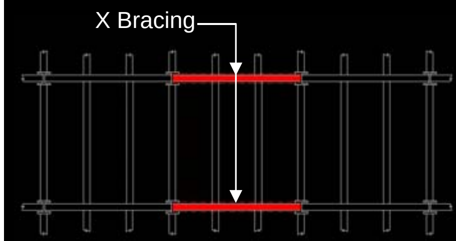
Temporary Bracing

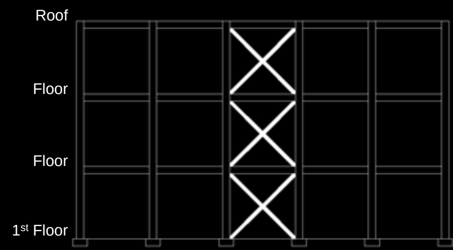
- In a braced frame, temporary bracing is removed after final bolt-up is complete and the permanent bracing system is in place
- In a rigid frame, temporary bracing is removed after final bolt-up is complete

Concentric Braced Frames

- Bracing is concentric when the center lines of the bracing members intersect
- Common concentric braced frames used in buildings today include:
  - X brace (above left)
  - Chevron (above right)
  - Two story X’s
  - Single diagonals
- X bracing is possibly the most common type of bracing
- Bracing can allow a building to have access through the brace line depending on configuration (AISC 2002)

X Bracing





Typical floor plan with X bracing

X-braced building elevation

- The diagonal members of X bracing go into tension and compression similar to a truss
- The multi-floor building frame elevation shown above has just one braced bay, but it may be necessary to brace many bays along a column line
- With this in mind it is important to determine the locations of the braced bays in a structure early in a project

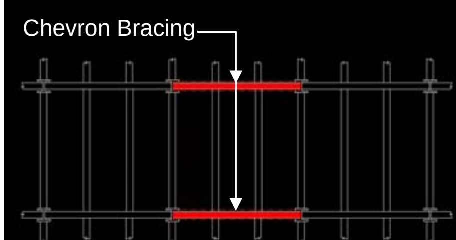
(AISC 2002)

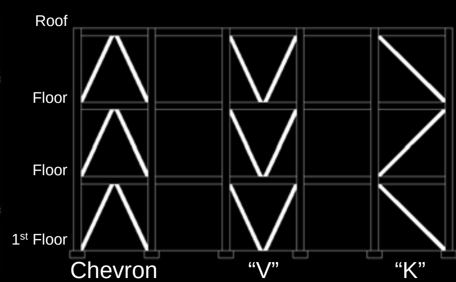
X Bracing

- Connections for X bracing are located at beam to column joints
- Bracing connections may require relatively large gusset plates at the beam to column joint
- The restriction of space in these areas may have an impact on the mechanical and plumbing systems as well as some architectural features

(AISC 2002)

Chevron Bracing





Typical floor plan with Chevron bracing

Elevation with several bracing configurations

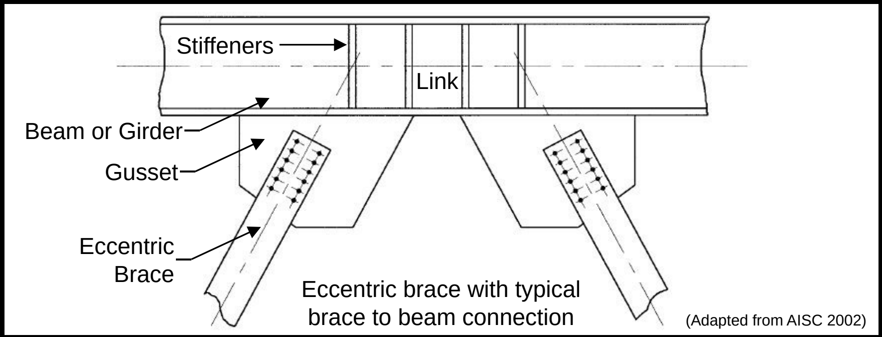
- The members used in Chevron bracing are designed for both tension and compression forces
- Chevron bracing allows for doorways or corridors through the bracing lines in a structure
- A multi-floor frame elevation using Chevron bracing is shown above

(AISC 2002)

Chevron Bracing

- Chevron bracing members use two types of connections
- The floor level connection may use a gusset plate much like the connection on X braced frames
- The bracing members are connected to the beam/girder at the top and converge to a common point
- If gusset plates are used, it is important to consider their size when laying-out mechanical and plumbing systems that pass through braced bays (AISC 2002)

Eccentrically Braced Frames



- Eccentric bracing is commonly used in seismic regions and allows for doorways and corridors in the braced bays
- The difference between Chevron bracing and eccentric bracing is the space between the bracing members at the top gusset connection
  - In an eccentrically braced frame bracing members connect to separate points on the beam/girder
- The beam/girder segment or "link" between the bracing members absorbs energy from seismic activity through plastic deformation (AISC 2002)

Eccentrically Braced Frames

- Eccentrically braced frames look similar to frames with Chevron bracing
- A similar V shaped bracing configuration is used

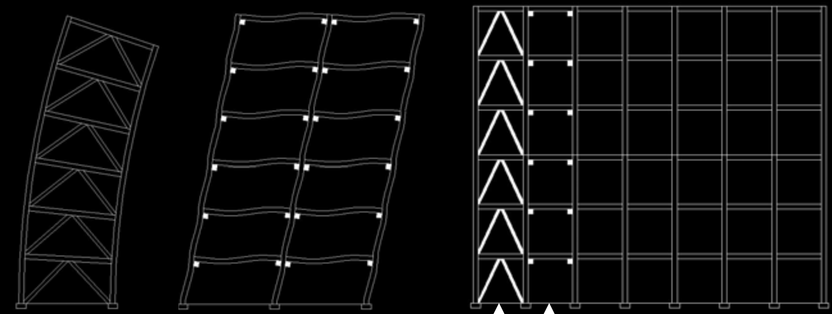
(AISC 2002)

Eccentrically Braced Frames

(EERC 1997)

Eccentric single diagonals may also be used to brace a frame

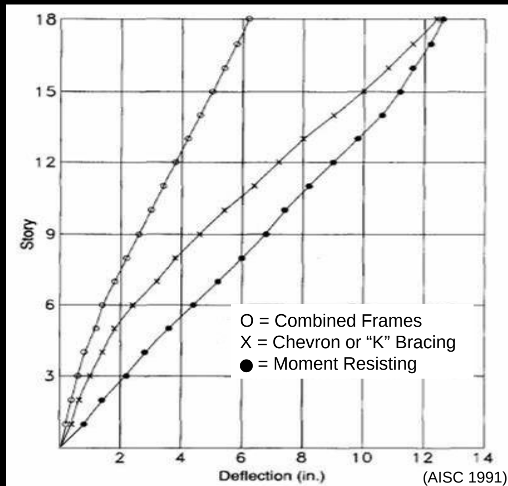
Combination Frames



- As shown above (left) a braced frame deflects like a cantilever beam while a moment resisting frame deflects more or less consistently from top to bottom
- By combining the two systems, reduced deflections can be realized
- The combination frame is shown above right

(AISC 1991)

Combination Frames



- The plot shows the moment resisting frame alone, the braced frame alone, and the combined frame
- The same wind load was used for each frame model (AISC 1991)

Bridge Crossframes

The Aspect ratio, girder spacing / girder depth, is the key factor in choosing economical crossframe configuration

- X-frames good for aspect ratios < 1
- K-frames good for aspect ratios > 1.5
- 1 < Aspect ratio < 1.5 - more subjective - client standard details or preferences may control selection of frame type

Structural Steel: The Material of Choice

References

AISC. (n.d.). *Steel Connections: Behavior and Practice* [35mm Slide Show with Script]. American Institute of Steel Construction, Inc. Chicago, IL.

AISC. (1989). *Specification for Structural Steel Buildings, Allowable Stress Design and Plastic Design, 9th ed.* American Institute of Steel Construction, Inc. Chicago, IL.

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Green, P. S., Sputo, T., and Veltri, P. (n.d.). *Connections Teaching Toolkit – A Teaching Guide for Structural Steel Connections.* American Institute of Steel Construction, Inc. Chicago, IL.

High-Rise Steel Structural Systems

Sources
- AISC – Economical Structural Steelwork

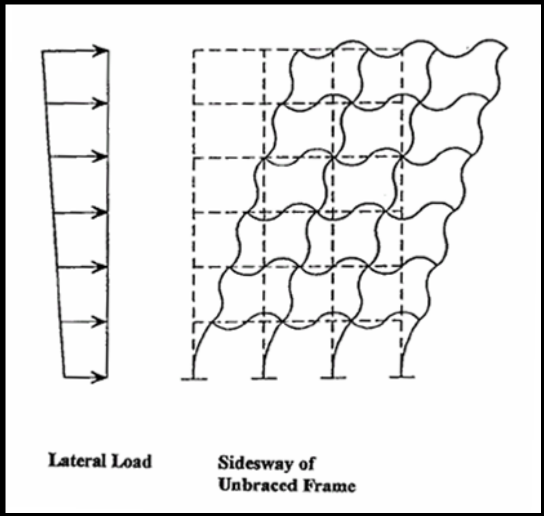
  Section 3 Framing Concepts and Connection Types
- Handbook of Structural Engineering

  Edited by WF Chen (CRC Press LLC)

  Chapter 12 Multistory Frame Structures

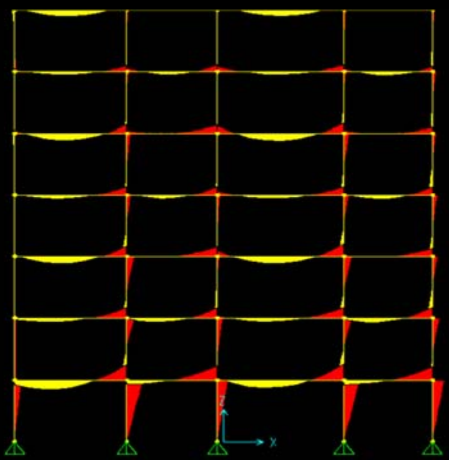
Unbraced (Rigid-Jointed) Frame

Resists loads mainly by flexure



Lateral Load Analysis

- Lateral loads
  - Seismic
  - Wind
- Frame Analysis
  - Portal method
  - FEA package (e.g.,SAP 2000)

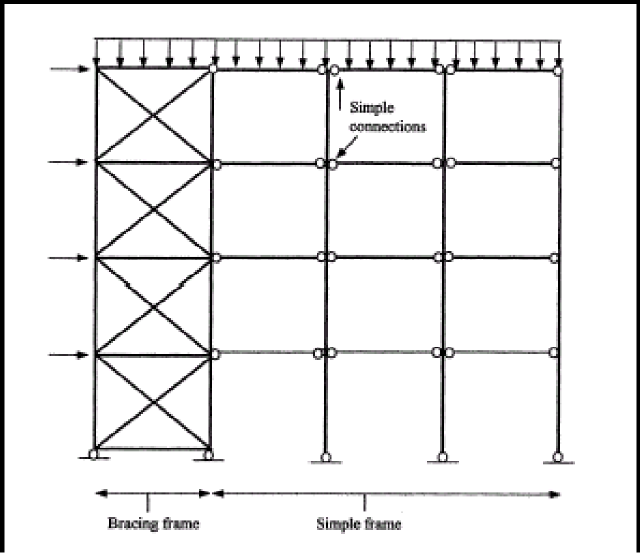


RIGID FRAME

- Derives its lateral stiffness mainly from the bending rigidity of frame members interconnected by rigid joints.
- The joints shall have adequate strength and stiffness and negligible deformations.
- A rigid unbraced frame should be capable of resisting lateral loads without relying on any additional bracing system for stability.
- The frame has to resist gravity as well as lateral forces.
- It should have adequate lateral stiffness against sidesway when it is subjected to horizontal wind or earthquake forces.

Simple Braced Frame

(Would collapse without braced bay, very easy analysis, simple connections)



Simple Frame (Pin-Connected)/1

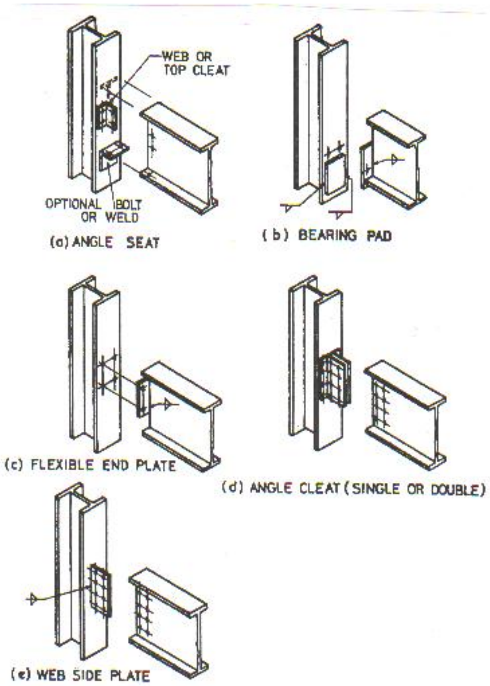
- Beams and columns are pin-connected and the system is incapable of resisting any lateral loads, unless it is attached to a bracing system.
- Lateral loads are resisted by the bracing systems while the gravity loads are resisted by both the simple frame and the bracing system.
- Bracing system can consist of triangulated frames, shear wall/cores or rigid jointed frames.
- Pin-jointed connections are easier to fabricate and erect. For steel structures, it is more convenient to join the webs of the members without connecting the flanges.

Simple Frame (Pin-Connected)/2

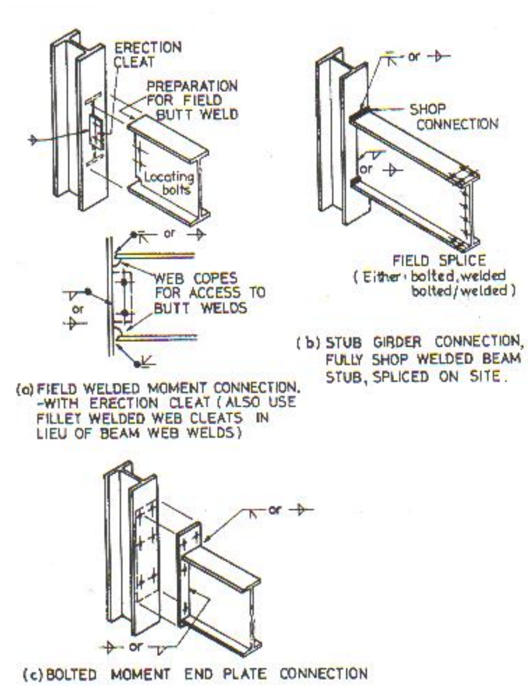
- Bolted connections are preferred over welded connections which normally require <u>weld inspection</u>, <u>weather protection</u> and <u>surface preparation</u>.
- It is easier to design and analyze a building structure that can be separated into a system resisting vertical loads and a system resisting horizontal loads.
- It is more convenient to reduce the horizontal drift by means of bracing systems added to the simple framing than to use unbraced frame systems with rigid connections.

CONNECTION TYPES (AISC 'Economical steelwork', 4th Edition

- Flexible (AISC Fig. 3.1) (Pinned), and
- Rigid Connections (AISC Fig. 3.2)



Flexible (Pinned) Connections



Rigid Connections

Flexible Connections

- Assumed to behave as a simple support
- Simple to fabricate
- Simple to erect
- Less costly of the two connection types

Rigid Connections

- More complex to fabricate
- More difficult to erect when tight tolerances are involved
- More costly of the two connection types
- The above connections can be used in the three basic framing systems available:
  - Two-way rigid framework (AISC Fig. 3.3)
  - One-way rigid/ one-way braced framework (AISC Fig. 3.4)
  - Two-way braced framework (AISC Fig. 3.5)

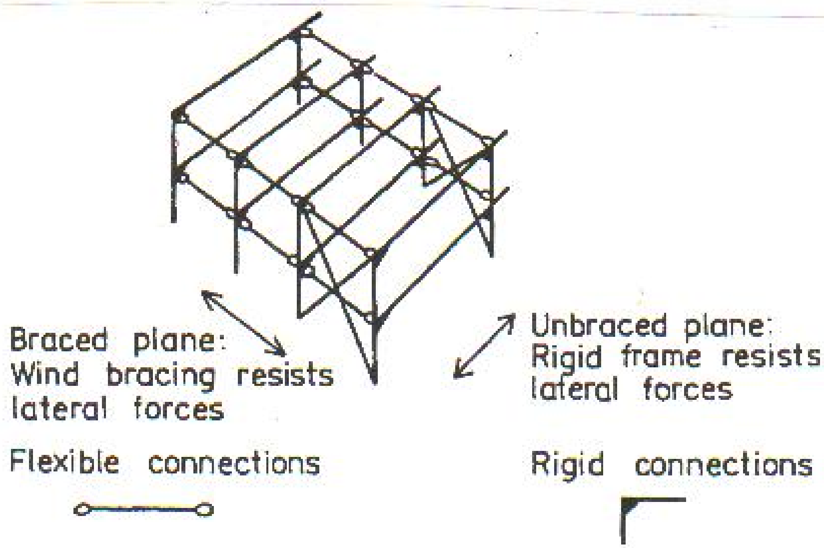


Fig 3.4 One-way braced, one-way rigid framework

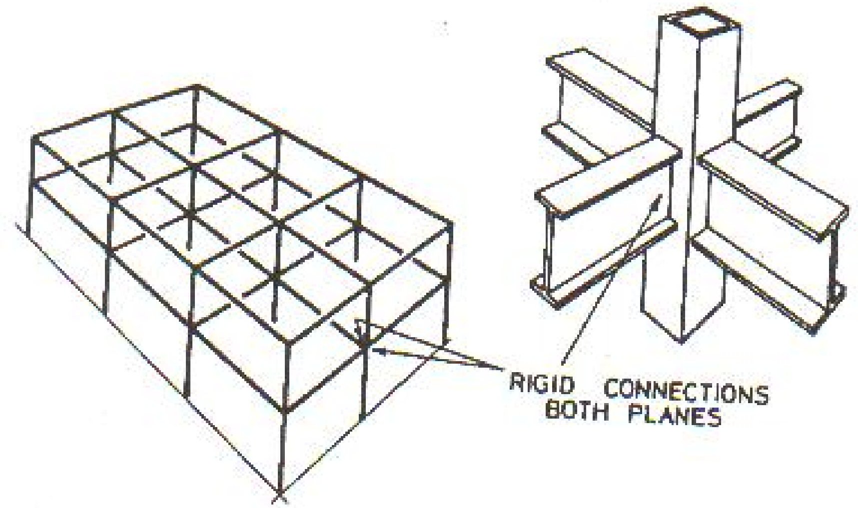


Fig 3.3 Two-way rigid framework

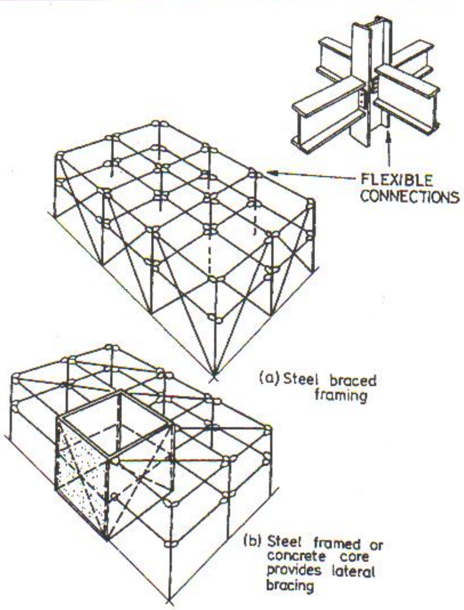


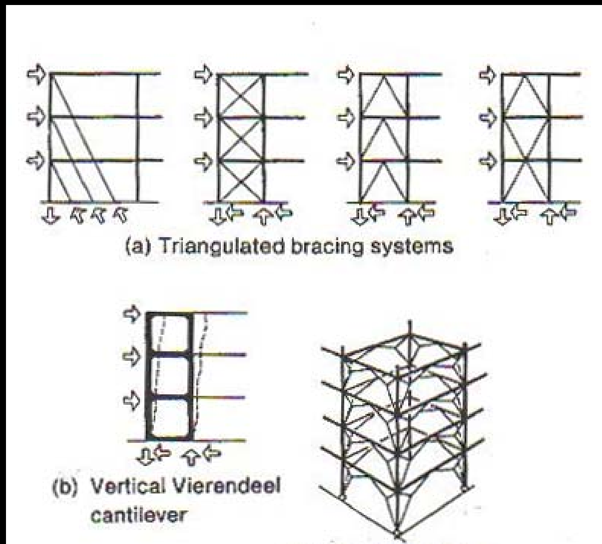
Fig 3.5 Two-way braced framework

Stabilizing Elements

To stabilize the framework in either one or two planes:

- Triangulated steel bracing panels
- Vertical Vierendeel cantilevers in steel
- Triangulated steel core
- Reinforced concrete or masonry cores or shear tubes
- Brick in-fill panels
- Light metal cladding

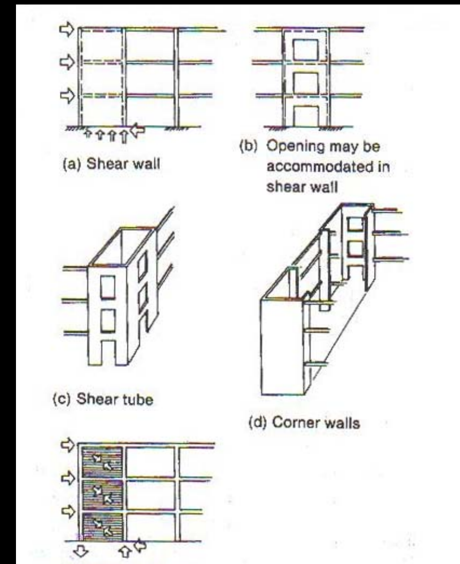
STABILIZING ELEMENTS IN STEEL


(a) Triangulated bracing systems

(b) Vertical Vierendeel cantilever

(c) Triangulated core

STABILIZING ELEMENTS IN CONCRETE


(a) Shear wall

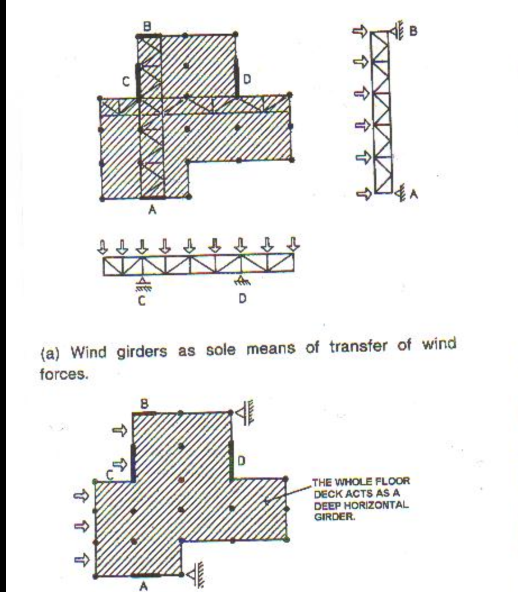
(b) Opening may be accommodated in shear wall

(c) Shear tube

(d) Corner walls

(e) Brick in-fill wall

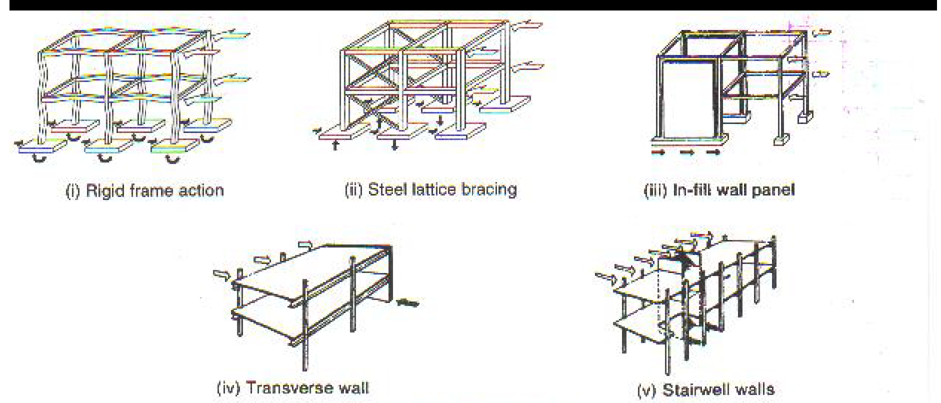
FLOOR DECK BRACING SYSTEMS



(a) Wind girders as sole means of transfer of wind forces.

(b) Concrete floor slab as diaphragm

ACTION OF LATERAL FORCE RESISTING SYSTEMS


(i) Rigid frame action

(ii) Steel lattice bracing

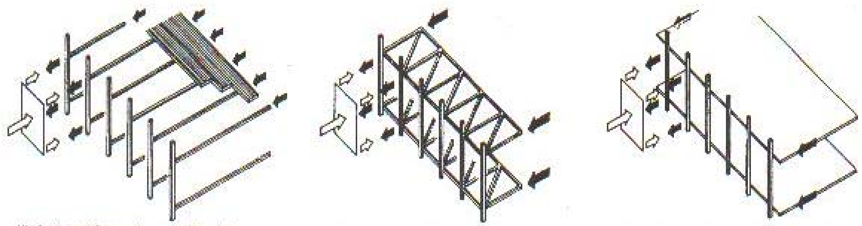
(iii) In-fill wall panel

(iv) Transverse wall

(v) Stairwell walls

(a) Vertical systems

ACTION OF LATERAL FORCE RESISTING SYSTEMS



(i) Lateral force transmitted to foundation at every column – no horizontal bracing

(ii) Horizontal wind girder

(iii) Use of floor as diaphragm

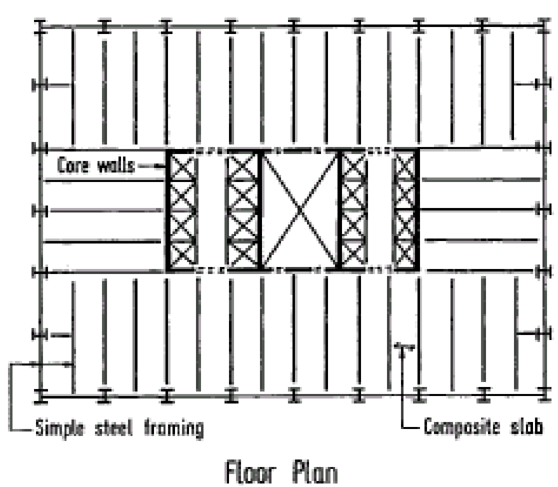
(b) Horizontal bracing systems

Fig 3.9 Action of lateral force resisting systems (from Ref 5.2)

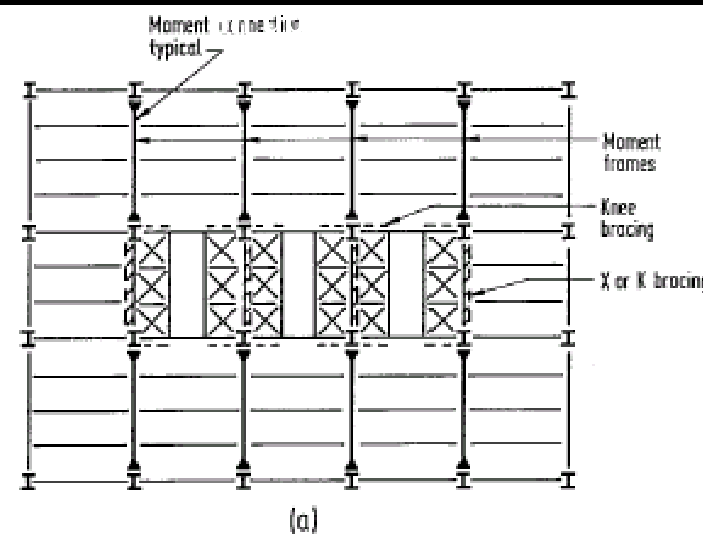
TALL BUILDING FRAMING SYSTEMS

- Core braced
- Moment truss
- Outrigger and belt
- Tube

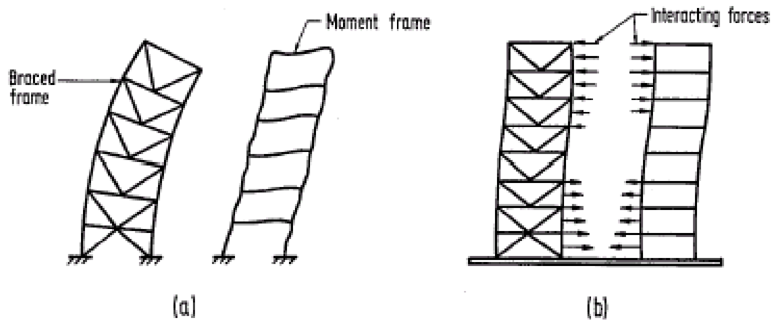
CORE BRACED SYSTEM
internal shear walls resists all lateral forces; Steel resists gravity loads



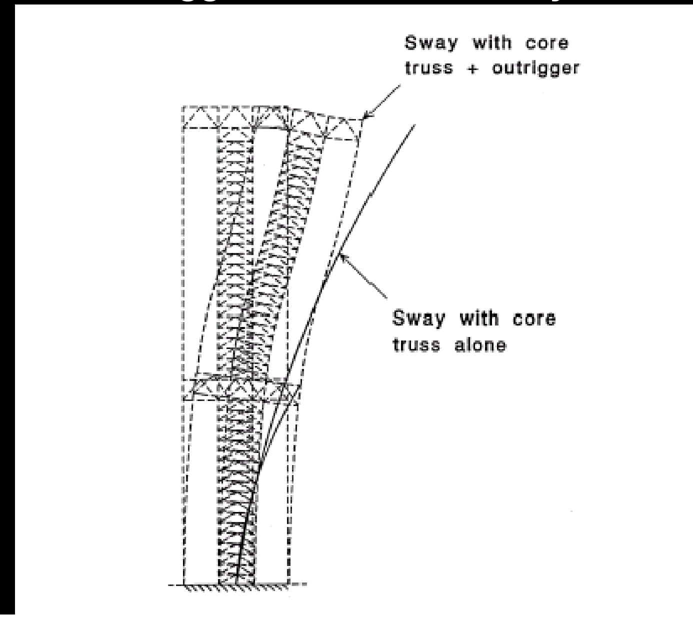
MOMENT-TRUSS SYSTEM
vertical shear truss and moment resisting frames; Truss minimizing sway in lower levels, rigid frame



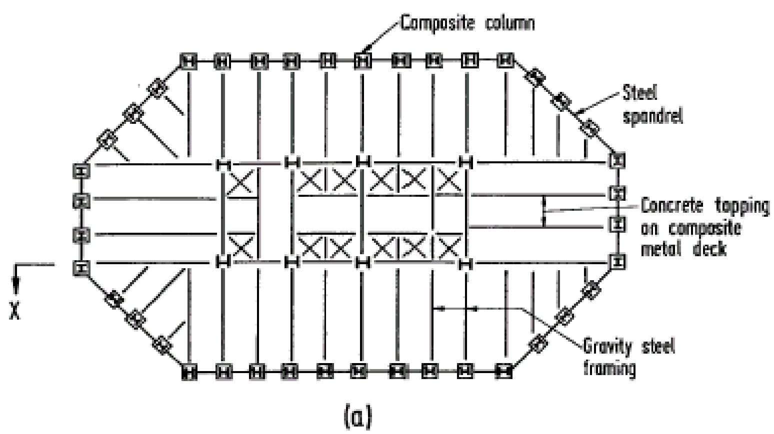
DEFORMATIONS OF MOMENT-TRUSS SYSTEM



Outrigger and Belt Truss System

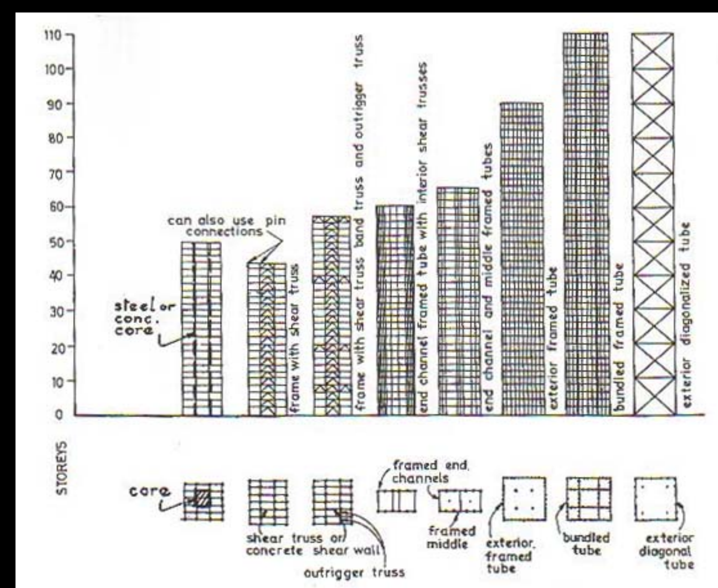


FRAMED TUBE SYSTEM - Hollow perforated tube

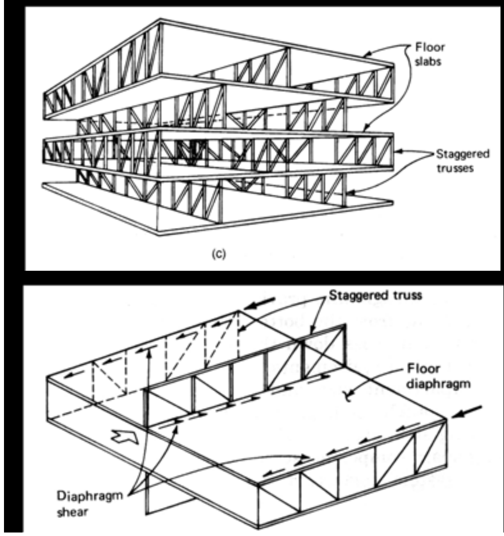


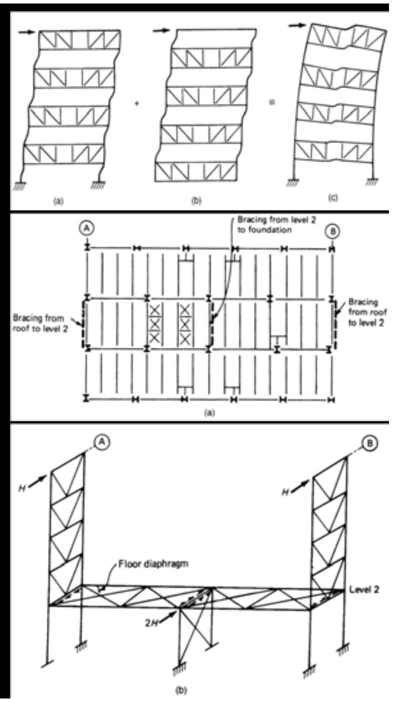
- Wide columns at close centers connected by deep beams.
- Tube resists all lateral forces of wind and earthquake.
- Interior its share of gravity loads.

OPTIMUM STEEL FRAMING SYSTEMS vs HEIGHT



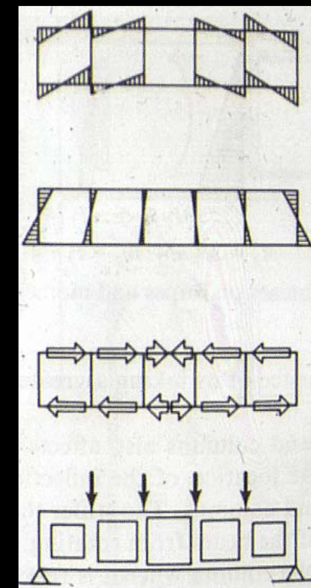
STAGGERED TRUSS



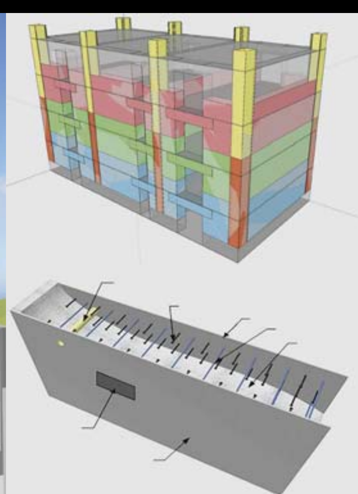


VIERENDEEL TURSS

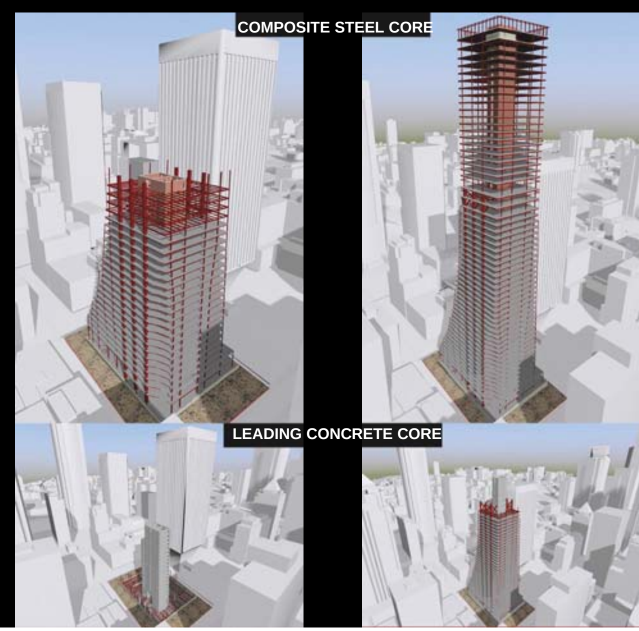
A Vierendeel truss has rigid, welded connections so does not require the diagonals usually seen in trusses. If used, the reason might have been to provide more space for ducts or openings within the truss by eliminating the diagonals.



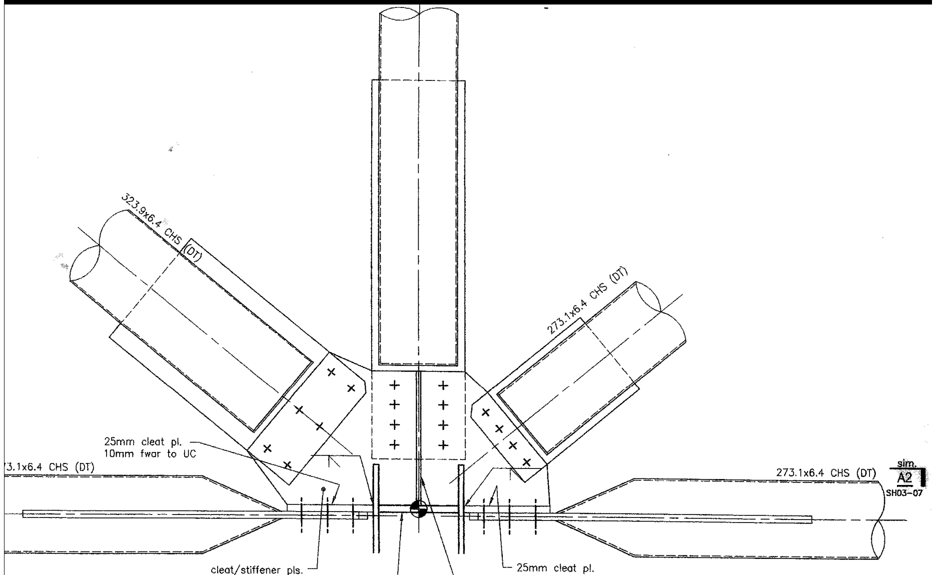
COMPOSITE STEEL FRAME FOR 850-FT-TALL SKYSCRAPER IN QUAKE-PRONE SEATTLE

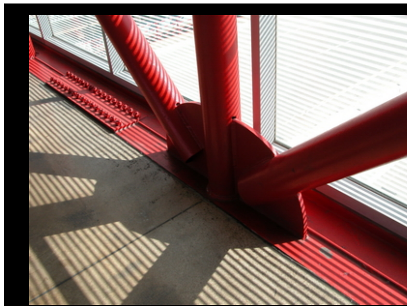


SPEED COMPARISON OF COMPOSITE STEEL FRAME



CONNECTION JOINING TUBULAR MEMBERS (CHS) CIRCULAR HOLLOW SECTIONS






United Airlines Terminal
O'Hare International Airport


The Rose Center for Earth and Space, NY

What types of structure are they?

- Burj Khalifa

- One World Trade Center

- Taipei 101

- Shanghai World Financial Center