Steel Structures

M.Sc. Structural Engineering

SE-505

Lecture # 1

Introduction/Revision

Steel Structures

Course Outline

Introduction

- Steel Structures
- Concept of Structural Design
- Review of basic concepts
- ASD and LFRD deign methods.

Review of Basic Mechanics

- Mechanics of thin-walled members and steel structures
- Small displacement theory of thin-walled members
- Linearly finite displacement
- Theory of Thin-Walled members.

Steel Structures

Course Outline (contd…)

Design of Steel Members

- Design of locally unstable elements and members in compression
- Biaxial bending of symmetrical section.
- Design for torsion: Pure torsion, Torsional stresses in I-Shaped steel section
- ASD/LRFD design for torsion
- Torsional buckling
- Elastic lateral torsional buckling
- Inelastic lateral torsional buckling
- Lateral buckling of channels, Zees, Monosymmetric I-Shaped sections and tees
- Lateral bracing design.

Steel Structures

Course Outline (contd…)

Composite Steel-Concrete Construction

- Composite action and its advantages
- Computation of elastic section properties
- Nominal moment strength of fully composite sections
- Shear connectors
- Deflections
- ASD/LRFD design procedures

Plastic Design

- Analysis and design of beams, portal and gable frames
- Second order effect
- Design of haunched connections
- Column bases
- Minimum weight design
- Shake down theorem
- Moment distribution

Steel Structures

Books

1. AISC, LRFD Specifications for Structural Steel Buildings, 2005. www.aisc.org
2. Steel Structural Design and Behavior By Salmon and Johnson, 3rd edition or latest.
3. Ductile Design of Steel Structures by Bruneau, Chia Ming Vong and Whittaker (1998)
4. Plastic Design of Steel Frames by Lynn S. Beedle.
5. LRFD Steel Design Aids in SI units by Zahid, Mahboob and Ashraf.
6. Steel Structures by Zahid, Mahboob and Ashraf (only for revision)

Steel Structures

What Are Steel Structures ?

"Steel Structures are assembly of structural steel shapes jointed together by means of riveted, bolted or welded connection".

Common Applications

1. Multi-storey buildings
2. Bridges
3. Industrial Buildings
4. Towers

Steel Structures

Main Categories of Steel Structures

1. Framework or Skeletal Systems

The main load carrying elements in this type are one-dimensional or line elements forming two-dimensional or three-dimensional frames.

Examples

- Frames works of industrial buildings
- Highway and railway large span bridges
- Multi-storey buildings, large halls, domes
- Towers, poles
- Trusses and rigidly connected frame structures.

Steel Structures

Main Categories of Steel Structures

2. Shell Systems

The main load carrying elements in this category of structures are plates and sheets besides some skeletal members.

Examples

- Gas Tanks for storage and distribution of gas.
- Tanks and reservoirs for liquid storage
- Bins and bunkers for the storage of loose materials
- Blast furnaces, air heaters
- Large diameter pipes

Steel Structures

Merit of Steel Construction

Freedom of Expression

Steel Structures

Creativity

Steel Structures

Creativity

Steel Structures

Easy Extension

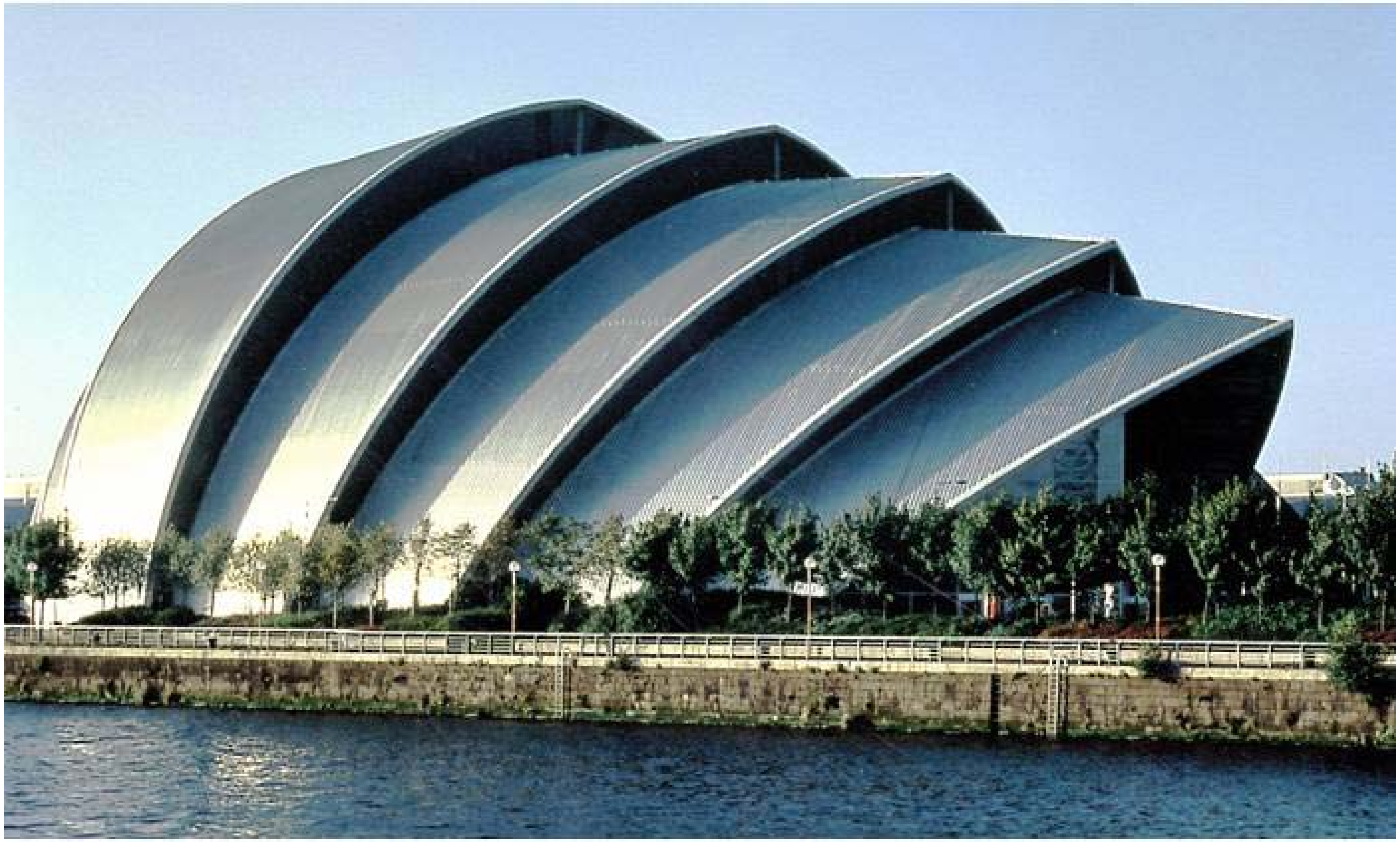
Steel Structures

Easy Fixing of Facade

Steel Structures

Easy and Efficient Fabrication

Steel Structures



Express Function

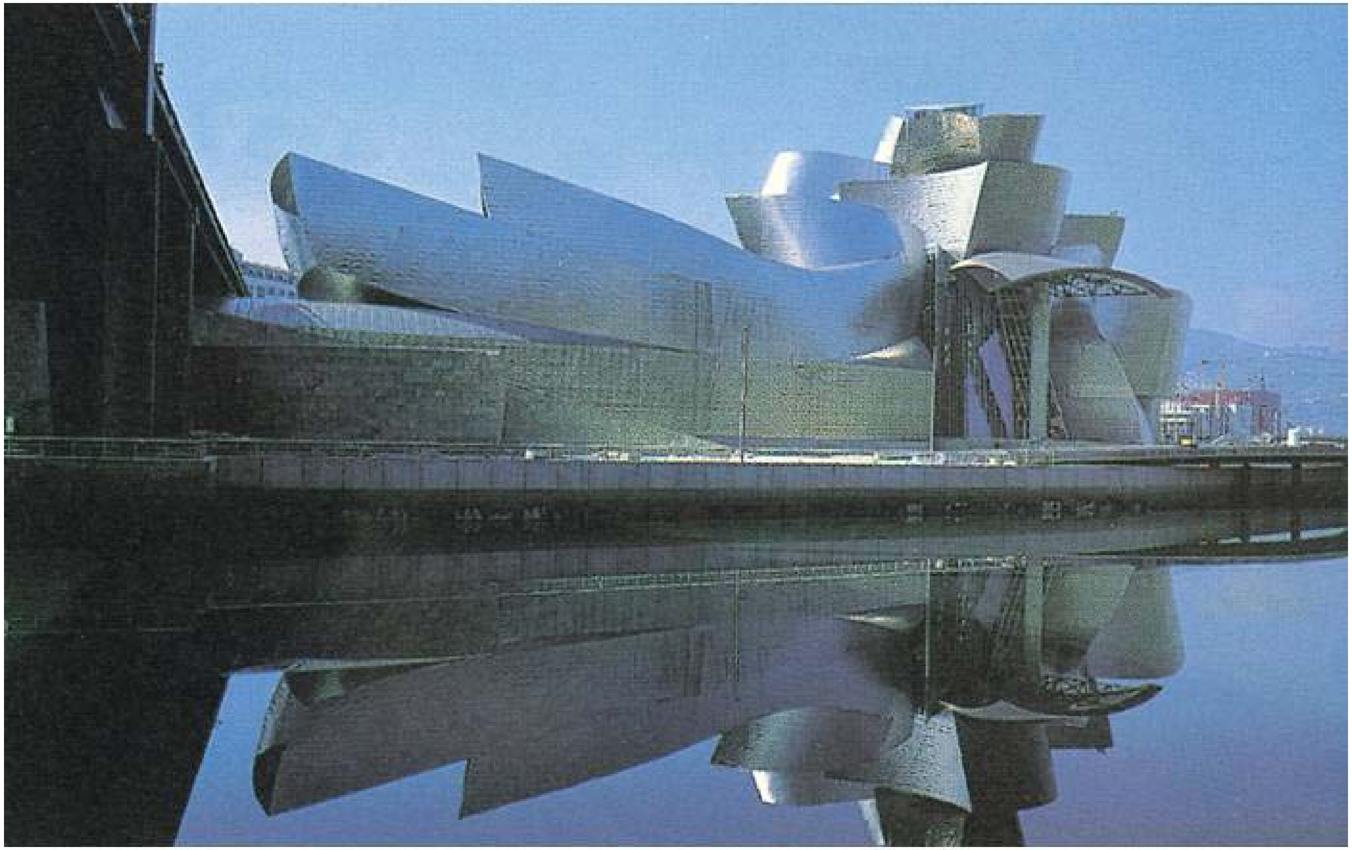
Steel Structures

Large Span

Steel Structures

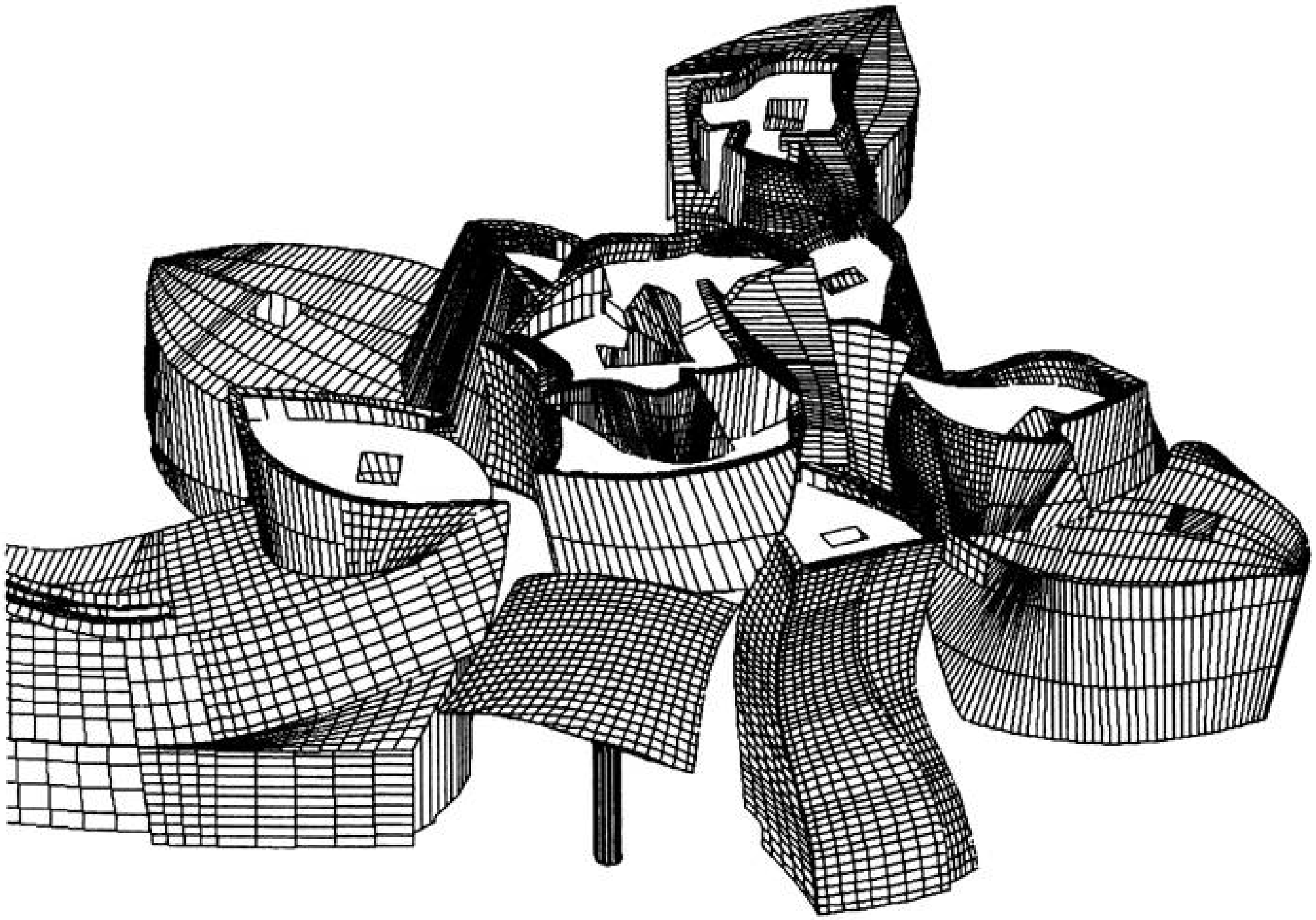
Large Span

Steel Structures



No Limit of Architectural Design

Steel Structures



No Limits of Architectural Design

Steel Structures

Recycling is possible

Steel Structures

Slender columns, more space

Steel Structures

Transparency

Steel Structures

Visible Connection

Steel Structures

Visible Connection

Steel Structures

Weather Independent Construction

Steel Structures

Weight/Strength Ratios for Different Materials

Material	$C = \gamma / f$ (m^{-1}) $\times 10^{-4}$
Aluminum	1.1
Steel	3.2
Wood	4.5
Concrete	24

Steel Structures

Demerits of Steel Construction

- High maintenance cost and more corrosion
- Fireproofing cost
- Susceptibility to buckling
- High initial cost
- Less availability

Steel Structures

Specifications

Specifications by the following organization are commonly used in steel structural design

- AISC (American Institute of Steel Construction)
- AWS (American Welding Society)
- AASHTO (American Association of State Highway and Transportation Officials)
- AREA (American Railway Engineering Association)
- ASTM (American Society for Testing and Materials)

Steel Structures

Design Methods

1. LRFD Method

Strength design method is based on the philosophy of dividing F.O.S. in such a way that **Bigger part** is applied on **loads** and **smaller part** is applied on **material strength.**

$$\phi \text{ Strength} \geq \text{Load Factor} \times \text{Service Loads}$$

$$\phi M_n \geq M_u \quad \phi V_n \geq V_u \quad \phi P_n \geq P_u$$

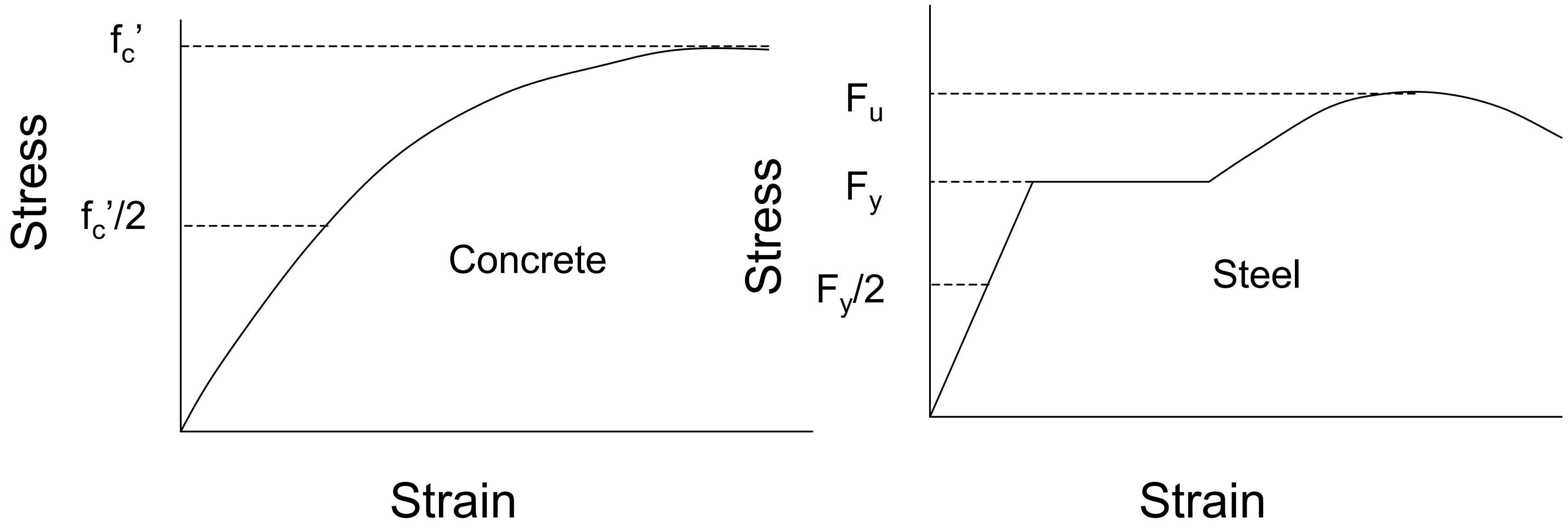
Steel Structures

2. Allowable Stress Design (ASD)

In allowable strength design the whole F.O.S. is applied on **material strength** and service loads (un-factored) are taken as it is.

Material Strength / F.O.S. ≥ Service Loads

In both Allowable stress design and LRFD, analysis is carried out in **elastic range**.



Basic Design Equation

- Used for design and capacity analysis in all types of design and analysis methods

Load effects x factor of safety = maximum internal resistance offered by material of structure

- Load effects may be axial force, shear force, bending moment and torque

Continued from previous slide

- Corresponding to each applied load action, there is a resistive force such as resisting axial force, resisting shear and resisting moment
- In design, applied actions and material resistances are equated to each other with some FOS
- A bending moment of $P\ell/4$ may never be obtained in a simply supported beam subjected to a central point load if the member is not sufficiently strong

Factor of Safety

- Value is always greater than one
- Brings the structure from state of collapse to a usable service state to avoid excessive deformations, cracking, and buckling, etc.
- Covers uncertainties in loads within limits
- Covers uncertainties in material strengths up to certain extent

Continued from previous slide

- Covers, in part, poor workmanship
- Covers unexpected behavior in theory due to simplifying assumptions or limited knowledge
- Reduces the effect of natural disasters
- Fabrication and erection stresses are taken care of
- Presence of residual stresses and local stress concentrations are safely considered

Comparison of FOS

- FOS in ASD is about 1.67
- FOS for LL in original LRFD is 1.7/0.9 or 1.889
- FOS for DL in original LRFD is 1.4/0.9 or 1.556
- FOS for LL in latest LRFD is 1.6/0.9 or 1.778
- FOS for DL in latest LRFD is 1.2/0.9 or 1.333
- Average FOS in latest LRFD is 1.63

  (2 live:1dead ratio)

Limit State

- Stage in loading after which the structure cannot fulfill its intended function
- Limit state may be related with strength or serviceability considerations
- Actual collapse is not necessary
- Strength limit states corresponds to maximum strengths, such as ultimate ductile flexural strength, ultimate shear strength, buckling failure, fatigue, plastic mechanism, overturning and sliding, etc.

Continued from previous slide

- Serviceability limit states are concerned with occupancy such as excessive deflections, undesirable vibrations, permanent deformations, excessive cracking and behavior in fire, etc.

- Structure should not cross any strength or serviceability limit for a perfect design

Strength and Ductility

- In general, structures are designed for strength against loads.
- Strength of a material means what maximum stresses may be developed
- Ductility means how much deformations are produced before final collapse

Continued from previous slide

- Sometimes, the design is more based on ductility than strength such as for earthquake loading
- For heaviest earthquakes, only ductility is provided for safety of life and perhaps not for complete safety of structure
- Time available before final collapse due to ductility is called warning before failure, persons may escape

Types of Design

- Allowable Stress Design (ASD)
- Strength Design, Load and Resistance Factor Design (LRFD), or Limit State Design
- Plastic Design

Allowable Stress Design

- Factor of safety is taken on RS of basic design equation, called safety factor, and denoted by Ω.

$$\text{External load effects} = \frac{\text{material resistances}}{\text{safety factor}}$$

$$R_a \leq R_n / \Omega$$

Advantages of ASD

- Elastic analysis for loads and elastic material behavior become compatible for design
- Senior engineers are used to this method
- Old famous books are according to this method
- Was the only method of design in past
- Is included as alternate method of design in AISC-05 Specifications.

Disadvantages of ASD

- Latest research and literature is very much limited
- Same factor of safety is used for different loads
- The failure mode is not directly predicted
- With some overloading, the material stresses increase but do not go to collapse (How to observe failure mode?)

Continued from previous slide

- The ductility and warning before failure cannot be studied precisely
- Results cannot be compared with experimental tests up to collapse

Strength Design or LRFD or Limit State Design

- Major part of FOS is applied on load actions called overload factor
- Minor part of FOS is taken on RS of design equation, becomes reciprocal of FOS, called resistance factor or capacity reduction factor (ϕ)

Continued from previous slide

- Resistance factor (ϕ) is lesser than or equal to 1.0 and is applied on material strength
- The design equation is checked for each strength and serviceability limit states one-by-one
- The design equation becomes:

$$R_u \leq \phi R_n$$

Advantages of Using LRFD

- Behavior at collapse including ductility, warning before failure and strain-hardening, etc. may be considered directly
- Every type of load may be given a different FOS depending upon its probability of overload, number of severe occurrences and changes in point of application

Continued from previous slide

- More safe structures result due to better awareness of structural behaviour near collapse
- Results can be compared with experiments up to collapse and with structural failures in the past
- Latest research and literature is available in this method
- Even if using ASD, this method provides a second alternative to check the designs

Continued from previous slide

- Economical in case dead loads are larger, such as in concrete structures
- More safety than ASD if live loads are greater in magnitude
- Plastic design may be incorporated with very few changes

Continued from previous slide

- The convenient elastic analysis for loads is generally used in this method
- The design procedure is similar to ASD with only slight modifications
- Using LRFD, steel and concrete design become consistent with each other

Disadvantages of LRFD

- Elastic behavior considered for load analysis and ultimate plastic behavior for material strengths are not compatible, however, percentage difference is less
- Engineers experienced in ASD have to become familiar with this technique

Continued from previous slide

- Old books and design aids become ineffective
- Validity of previous designs is still to be checked according to ASD

Plastic Design

- Same as LRFD with the difference that plastic analysis is used for load analysis
- Best available method
- Incompatibility in load analysis and material behavior is removed
- Very lengthy even for computer application due to plastic analysis

Current Situation Regarding Design Codes

- For concrete design, engineers have almost shifted to strength design or LRFD
- ACI has discontinued ASD as an alternate method of design
- For steel design, engineers are gradually shifting to Strength Design or LRFD, may take some time due to late start

Continued from previous slide

- AISC has only issued the combined LRFD/ASD specifications in 2005 after AISC-ASD 1988
- Most recent AISC-LRFD specifications were issued in 1994 and 1999
- AISC has included ASD only as an alternate method in specifications of 2005
- AASHTO has shifted its bridge and other designs to LRFD

Continued from previous slide

- The last AASHTO-ASD specifications will only be used for evaluating previous designs
- Most American states have opted not to use ASD for bridge design beyond 2005 or at the most 2007
- British specifications for concrete design are also according to this method, however, they refer to it as limit state design

Continued from previous slide

- American universities are only teaching Strength Design/LRFD to new engineers
- Universities of Pakistan are also teaching this method for concrete design
- For steel design, some Universities of Pakistan have switched to this method

Continued from previous slide

- It is expected that, in future, only one method will be used for practical design, that is, Strength Design or LRFD
- For research work and high-importance structures, plastic design is the best method

Steel Structures

3. Plastic Design

In plastic design, plastic analysis is carried out in order to find the behavior of structure near **collapse state**. In this type of design material strength is taken from **inelastic range**. It is observed that whether the failure is sudden or ductile. Ductile failure is most favorable because it gives an **warning** before the failure of structures

Steel Structures

Merits of LRFD Method

- We can study the type of failure, whether due to moment, axial force or shear force.
- Factor of safety can be given according to the importance of load and its probability of occurrence.
- LRFD gives economical design when dead load is relatively larger than live load.
- All latest research is carried out related to LRFD methods

Steel Structures

Limit State

"Stage in the loading after which the structure cannot fulfills its intended function due to strength or serviceability considerations".

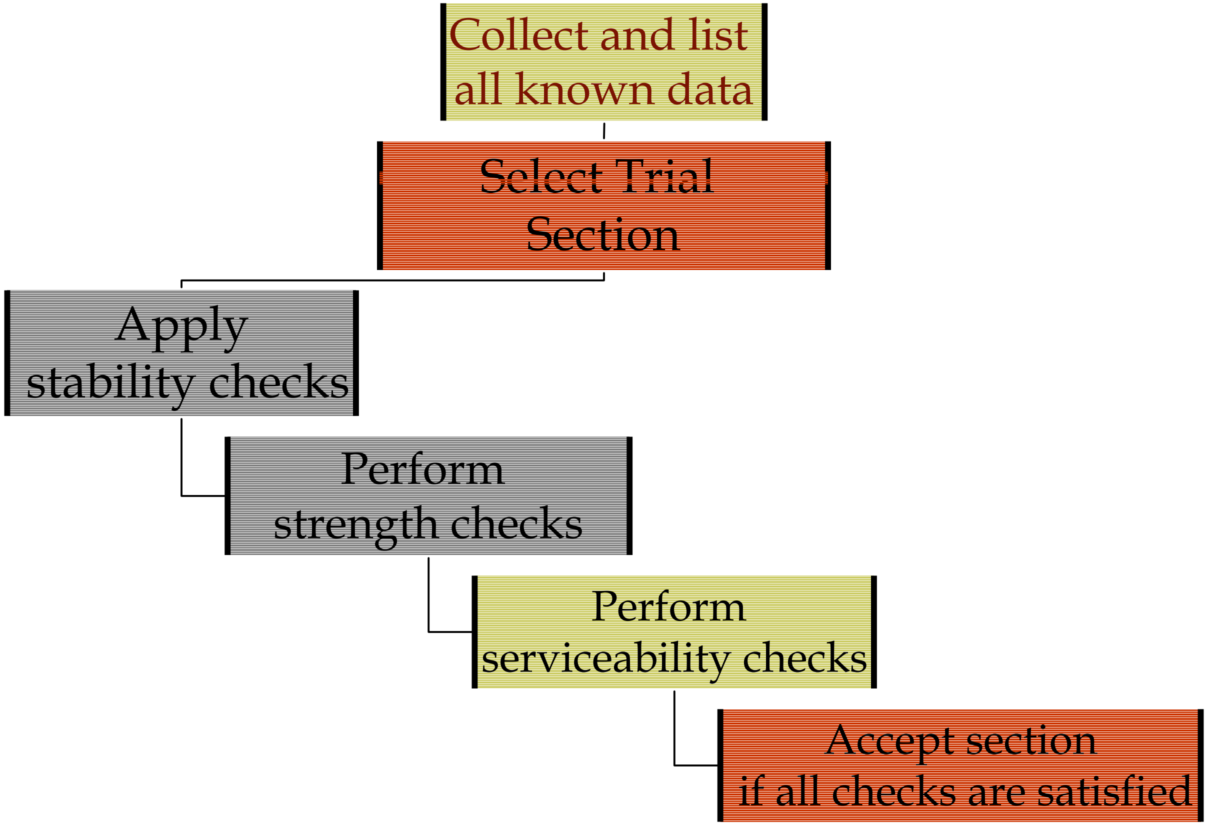
The term limit state is preferred compared with "failure" because in most of the cases of limit state, the actual failure or collapse does not occur.

Categories

- Strength limit state
- serviceability

Steel Structures

General Design Flow Chart



Steel Structures

Types of Structural Steel

Steel is divided into four categories depending on the carbon percentage

1. Low carbon steel C < 0.15 %
2. Mild carbon Steel C = 0.15 to 0.29 %
3. Medium carbon steel C = 0.3 to 0.59 %
4. High carbon steel C = 0.60 to 1.7 %

Most of the structural steel falls into the category of Mild Carbon Steel MILD STEEL (MS).

E value for steel = 185 to 230 GPa (Average 200 GPa)

Unit weight = 7850 kg/m^3

Unit weight of RCC is 2400 kg/m^3

Steel Structures

Different Structural Shapes/Sections

Hot Rolled Shapes

- W section, S section, Channel section, Angle section
- T section, HP section, Pipe Section
- Structural Tubing, Bars, Plate

Cold Formed Shapes

- Channels, Zees, I-shaped double channel, Hat, Angle

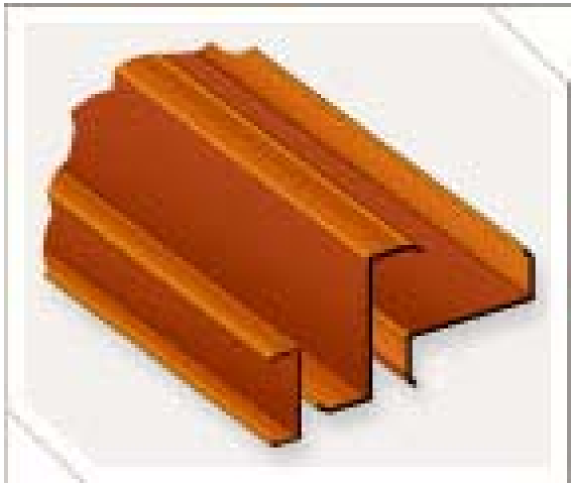
Built-Up Sections

- 4-angle box section
- Double angle
- Channels back to back/ face to face

Steel Structures

Hot Rolled Section

Steel Structures



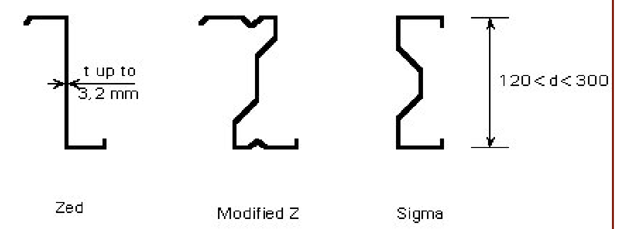
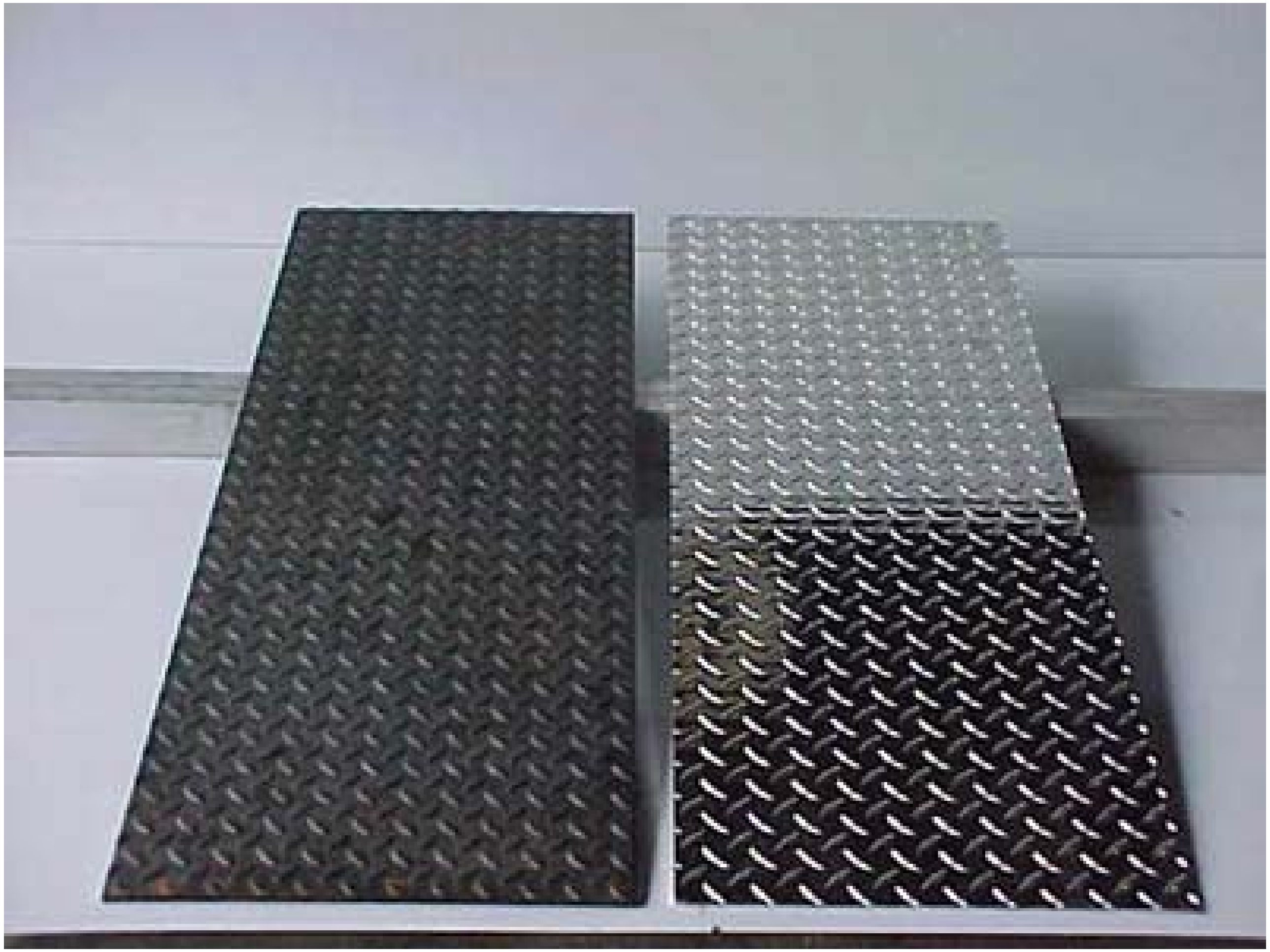


Figure 7 Common purlin and rail sections

Cold Formed Section

Steel Structures



Steel Diamond Plate

Steel Structures

Tension Member

"Members subjected to axial tensile force are called tension members"

In general the use of single structural shape is more economical than the built up section in case of tension member.

Gross Area of Cross Section, A_g

The total area of cross section present throughout the length of member

Steel Structures

Tension Member (contd…)

Net Area of Cross Section, A_n

When tension members have holes punched in them for rivets or bolts, the minimum reduced area after the holes are taken out is called the NET AREA.

Effective Net Area, A_e

The effective net area that can be considered to resist tension at a section throughout the holes may be somewhat smaller than the actual net area (An) because of stress concentration and other factors.

$$A_e = U\,A_n$$

Steel Structures

Tension Member (contd…)

Limit on Slenderness Ratio

Slenderness is not the criteria for the tension member design. But still

$$\frac{KL}{r} \leq 300$$

Otherwise:

- Member may sag excessively under its own weight
- Member may vibrate under wind forces or while supporting vibrating equipments

Steel Structures

Tension Member (contd…)

Design Equation

$$T_u \leq \Phi T_n$$

The design strength is smaller of

1. Yielding in gross section

$$T_n = F_y A_g \quad \text{and} \quad \Phi_t = 0.9$$

2. Fracture in the net section

$$T_n = F_u A_e \quad \text{and} \quad \Phi_t = 0.75$$

Tension Member (contd…)

Member Under Stress Reversal

If the member are subjected to different sense of forces (T_u & P_u) at different instances, it must be deign for stress reversal.

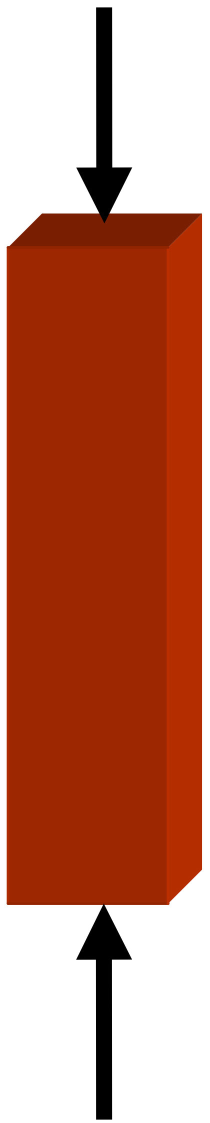
You will be on safer side if design for P_u and check the tensile capacity which must be greater than T_u.

There are three condition for the design of members under stress reversal but cannot be discussed here.

Steel Structures

Compression Member

"When a load tends to **squeeze or shorten a member**, then stresses produced are said to be compressive in nature and the member is called a compression member.



Steel Structures

Compression Member

(contd…)

- The compressive load tends to bend a member out of the plane of the load due to imperfection, simultaneous bending moment or even without all these.
- Tests on majority of practical columns show that they will fail at axial stresses well below the elastic limit of the column material because of their tendency to buckle.

Steel Structures

Compression Member (contd…)

In compression members the bolts and rivets, if present, are assumed to fill the holes and the entire gross area is available for resisting load.

$$A_g = A_n = A_e$$

Steel Structures

Compression Member (contd…)

Residual Stresses

"the stresses that remain in the member after it has been formed into a finished product, before the application of load"

Causes:

- Uneven cooling
- Cold bending of members beyond elastic limits
- Punching of holes and cutting operation
- welding

Steel Structures

Compression Member (contd…)

Limit of slenderness ratio

$$\frac{kL}{r_{min}} \leq 200$$

Instability of Columns

- Local instability
- Overall Instability

Steel Structures

Compression Member (contd…)

Local instability

Buckling of individual parts or plate elements of cross section without over all buckling

Width/Thickness ration controls local buckling

Un-stiffened elements have more chances of local buckling compared with stiffened elements

Overall instability

Column buckles as a whole between the supports or the braces about an axis whose corresponding slenderness ratio is bigger

Steel Structures

Compression Member (contd…)

Types of columns depending buckling behavior

1. Long Column

   Elastic buckling

2. Short Column

   Failure due to yielding, no buckling

3. Intermediate Columns

   Inelastic buckling, more strength than long column

Steel Structures

Compression Member (contd…)

Types of columns Sections for Local Stability

1. Compact Section

   Develop full plastic stress distribution before buckling

2. Non Compact Section

   Yield stress is developed at few, not all, locations and full plastic stress distribution is not developed

3. Slender Compression Section

   Buckle elastically before the yield stress is developed in any part of the section

Steel Structures

Compression Member (contd…)

Columns Strength Formula

$$\Phi_c P_n = \Phi_c F_{cr} \times A_g$$

F_{cr} = Critical Compressive Strength

Steel Structures

Beams

"Beam is a structural member in which major deformation is bending"

The bending moment is primarily produced due to transverse load

Types

1. Girder
2. Secondary Beams
3. Joists
4. Purlins
5. Stringers
6. Floor beams
7. Girts
8. Lintels
9. Spandrels

Steel Structures

Beams (contd…)

Plastic Section Modulus

$$Z_{req} = \frac{M_u}{\Phi F_y}$$

Stability of Beam Sections

1. Local Stability
    - Flange Local Buckling (FLB)
    - Web Local Buckling (WLB)
    - Web Crippling
2. Lateral Stability

   Lateral Torsional Buckling

Steel Structures

Beams (contd…)

Lateral Stability

Lateral Stability can be developed by

- Continuous Lateral Support
- Lateral Support at intervals

Types of Beam Section

1. Compact Section
2. Non Compact Section
3. Slender Section

Steel Structures

Beam Column

"Structural Members subjected to a combination of bending and axial stresses"

Sources of Moment

- Non verticality of columns
- Initial imperfection
- Bracketing projecting from columns
- Lateral loading e.g wind
- Moment transferred from beam to column through rigid connection

Steel Structures

Beam Column (contd…)

Controlling Design Factor

P-Delta Effect, Second Order Effects

" P-Delta effect is defined as the secondary effect of column axial loads and lateral deflection on the moment in the member".

- P-δ effect is small
- P-Δ effect is much larger

Steel Structures

Beam Column (contd…)

Interaction Equation

$$\frac{P}{P_{max}} + \frac{M_x}{M_{x\,max}} + \frac{M_y}{M_{y\,max}} \leq 1$$

For moment magnification we need to calculate

B1 = Moment magnification factor to take care of P-δ effects.

B2 = Moment magnification factor to take care of P-Δ effects

Steel Structures

Plate Girder

"A beam built-up from separate plate elements welded or riveted together"

- Plate girders are common for 60 m spans and have been used for many spans in excess of 120 m
- Truss become more economical for spans larger than the economical span range of pate girder
- Commonly used for railway bridges and in buildings for larger spans and heavy loading e.g. Crane Runway Girder

Steel Structures

Plate Girder (contd…)

Important Features

- Girders is non-compact in majority of cases.
- WLB is allowed.
- Post buckling strength is provided by the web stiffeners

Types of Stiffeners

- Intermediate stiffeners
- Bearing stiffeners

Steel Structures

Connections

"connections are devices used to join elements of a structure together at a point such that forces can be transferred between them safely"

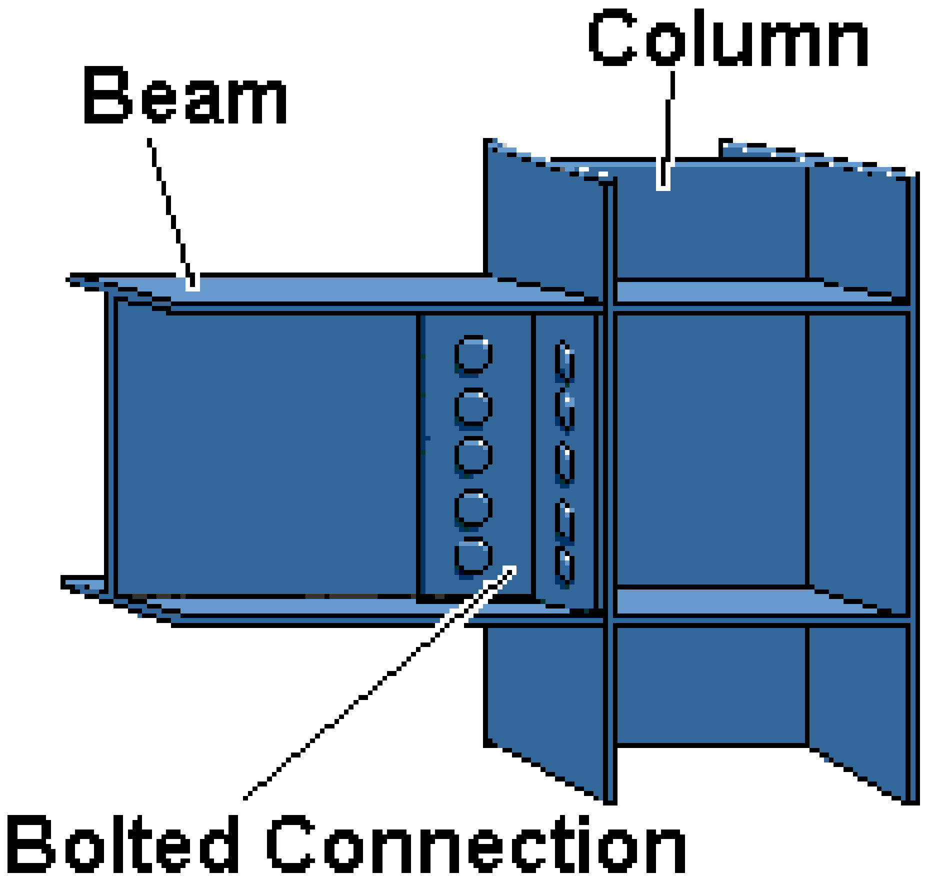
Types

- Truss connections
- Fully restrained connections
- Partially restrained connections

Steel Structures

Connection

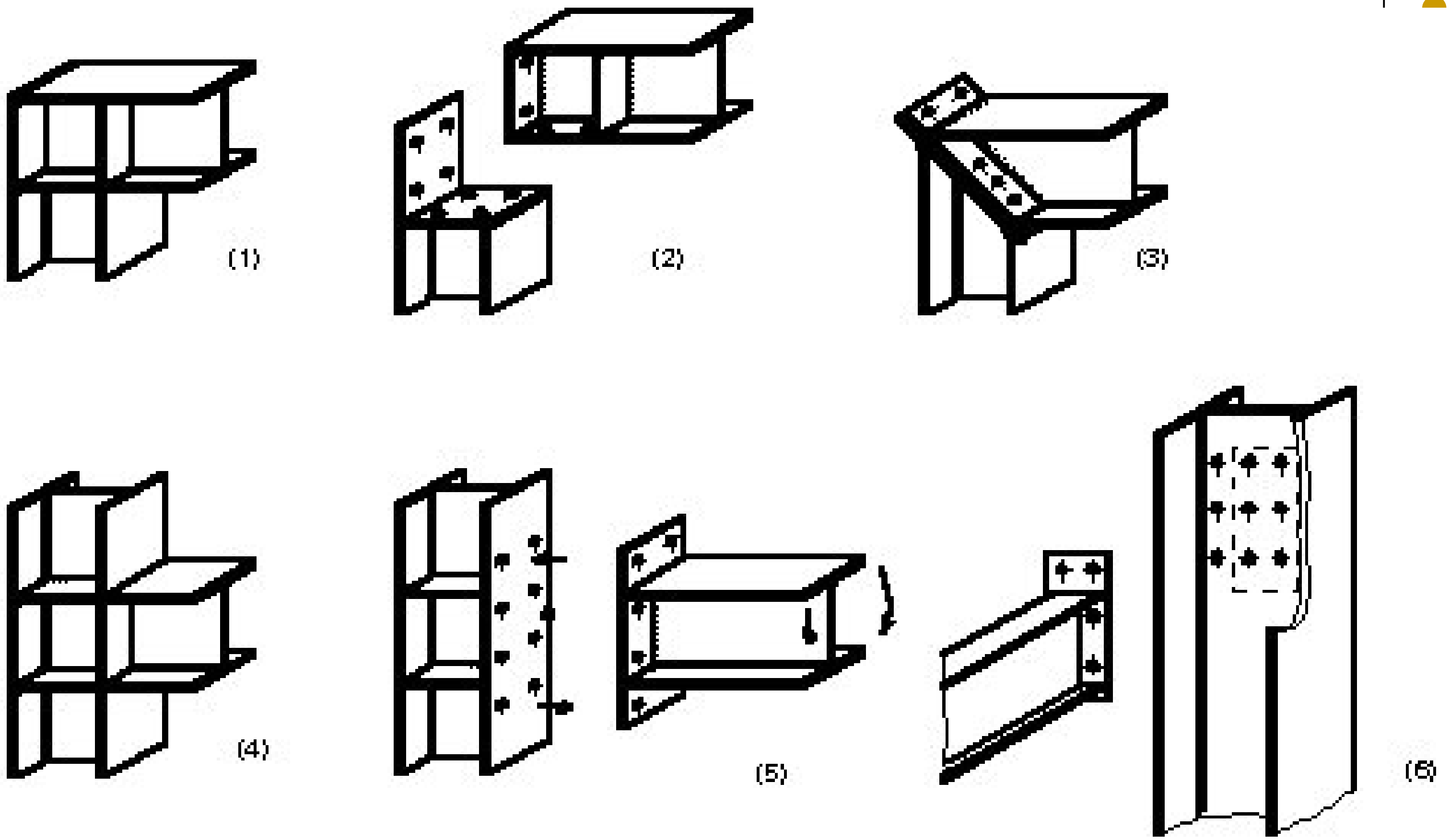
Steel Structures



Steel Structures

Earthquake Resistant Connection

Steel Structures



Beam Column Connections

Concluded