ENCE 455
Design of Steel Structures

1. Introduction

C. C. Fu, Ph.D., P.E.
Civil and Environmental Engineering Department
University of Maryland

Introduction

Following subjects are covered:

- Structural Design
- Types of Loads
- Specifications for design of steel structures
- Structural steel
- Grades of steel
- Steel shapes
- Properties of structural steel
- Design philosophy

Reading:

- Chapters 1 and 2 of Segui
- AISC Steel Construction Manual, 13th Ed.

Structural Design

- Definition: Determination of overall proportions and dimensions of the supporting framework and the selection of individual members.
- Responsibility: The structural engineer, within the constraints imposed by the architect (number of stories, floor plan,..) is responsible for structural design.

Important Factors in Design

- Safety (the structure doesn't fall down)
- Serviceability (how well the structure performs in term of appearance and deflection)
- Economy (an efficient use of materials and labor)

Design Specifications

- Provide guidance for the design of structural members and their connections.
- They have no legal standing on their own, but they can easily be adopted, by reference, as part of a building code.

Steel Specifications

Main:

- American Institute of Steel Construction (AISC) - Design of steel buildings and connections (www.aisc.org)
- American Association of St ate Highway and Transportation Officials (AASHTO) - Design of steel/reinforced concrete/timber bridges (www.aashto.org)

Others:

- American Iron and Steel Institute (AISI) - Cold-formed steel structures (www.steel.org)
- American Railway Engineering and Maintenance of Way Association - Steel railway bridges (www.arema.org)

(see AISC Manual pp 2-4 thru 2-7)

Building Code

- A legal document containing requirements related to such things as structural safety, fire safety, plumbing, and ventilation.
- It has the force of law and is administered by a city, a county, or other governmental agencies.
- It does not provide design procedures, but it specifies the design requirements.

National Model Codes

- Most of the municipalities adopt a model code and modify it to suit their particular needs.
- The BOCA National Building Code
- The Uniform/International Building Code (UBC/IBC)
- The Standard Building Code
  - The ASCE7-02, Minimum Design Loads for Building and Other Structures, is another nationally accepted document.

Types of Load

- Dead Loads (permanent; including self-weight, floor covering, suspended ceiling, partitions,..)
- Live Loads (not permanent; the location is not fixed; including furniture, equipment, and occupants of buildings)
- Wind Load (exerts a pressure or suction on the exterior of a building)

Types of Load (Cont.)

- Earthquake Loads (the effects of ground motion are simulated by a system of horizontal forces)
- Snow Load (varies with geographical location and drift)
- Other Loads (hydrostatic pressure, soil pressure)

Types of Load (Cont.)

- If the load is applied suddenly, the effects of IMPACT must be accounted for.
- If the load is applied and removed many times over the life of the structure, FATIGUE stress must be accounted for

History of Structural Steel

Iron

- Chief component of steel
- Wrought iron first used for tools around 4000 BC
- Produced by heating ore in a charcoal fire
- Cast and wrought iron used in the late 18C and early 19C
- in bridges

History of Structural Steel (cont.)

Structural Steel

- Steel is an alloy of primarily iron, carbon (1 to 2%) and small amount of other components (manganese, nickel, …)
- Fewer impurities and less carbon than cast iron
- Carbon contributes to strength but reduces ductility.
- Began to replace iron in construction in the mid 1800s
- First steel railroad bridge in 1874
- First steel framed building in 1884

Grade of Steel

Numerous grades of steel are available in the marketplace. The choice is dependent on

- Application
- Yield strength
- Composition

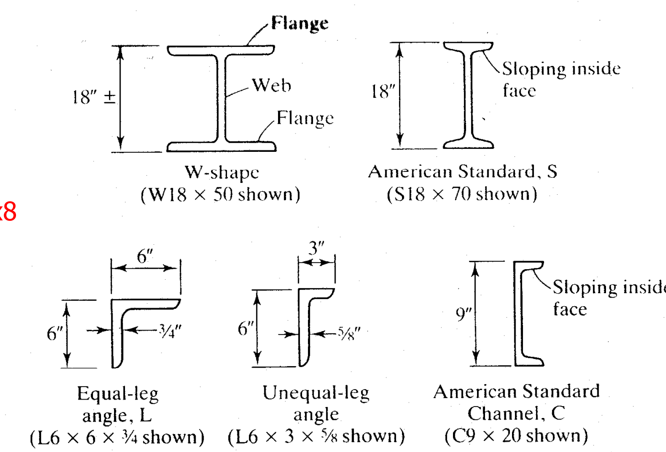
See the summaries on the AISC Manual Tables 2-1 thru 2-3 (Page 2-37 thru 2-39)

Steel Shapes

Hot-rolled shapes are produced from molten steel in a furnace that is poured into a continuous casting where the steel solidifies but does not cool completely. The partially cooled steel is then passed through rollers to achieve the desired shape.

Standard Cross-Sectional Shapes

W4 - W44
M3 – M12.5
S3 – S24
H8 – H14
C3 – C15
MC3 – MC18
L2½xL1½ - L8x8
WT2 – WT22
MT2 – MT6.25
ST1.5 – ST12

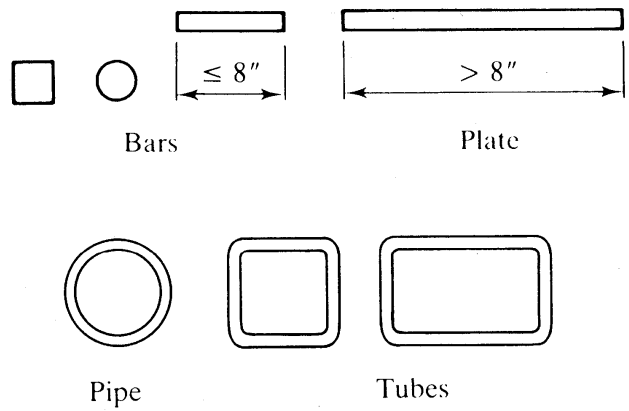


Standard Cross-Sectional Shapes

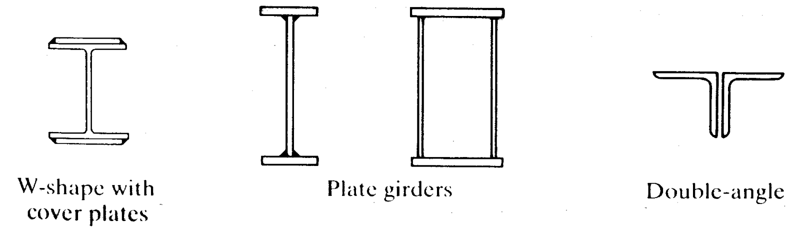
HSS2x1 – 20x12

HSS1.660 – 20.000

Pipe ½ Std. – 12 Std.
(x-Strong, xx-Strong)



Standard Cross-Sectional Shapes

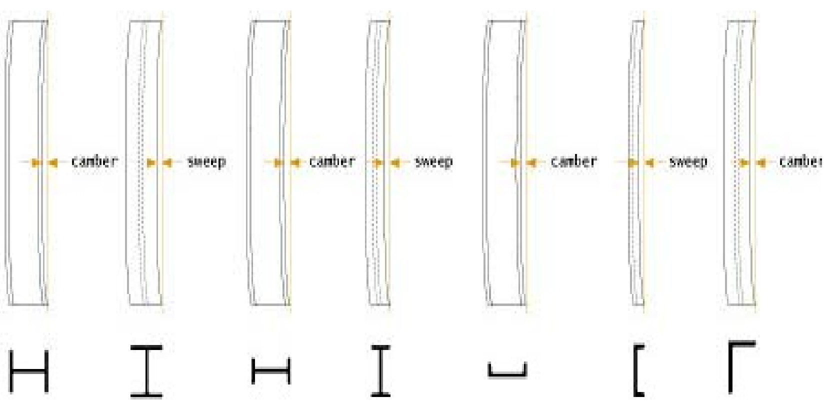


2L (LLBB or SLBB): 2L2x2 – 2L8x8

2C: 2C3 – 2C15
2MC: 2MC3 – 2MC18

Link to: LRFD Dimensions and Properties Presentation

Camber and Sweep



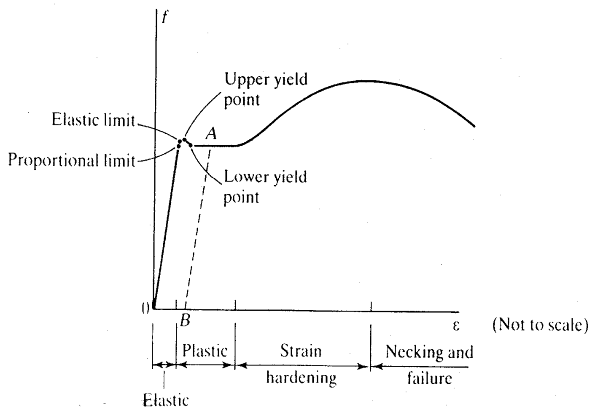
Steel Properties

- The important characteristics of steel for design purposes are:
  - yield stress (F_y)
  - ultimate stress (F_u)
  - modulus of elasticity (E)
  - percent elongation (ε)
  - coefficient of thermal expansion (α)

The Tension Test

4 Ranges of responses:

- Elastic
- Plastic (yield plateau)
- Strain hardening
- Necking and failure (strain softening)



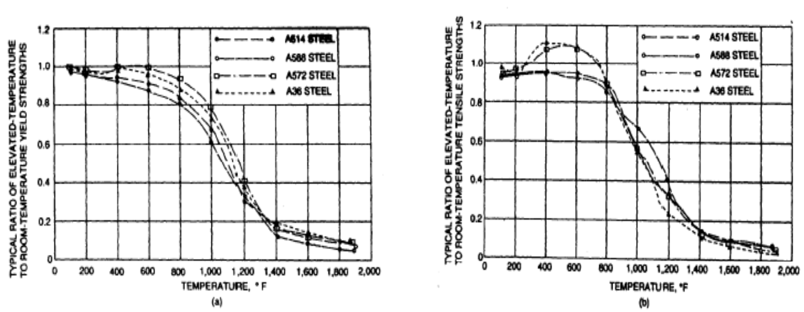
Effect of Temperature on the Properties of Steel

- Elevated temperatures generally degrade the properties of structural steel. Threshold temperatures vary as a function of mechanical property under consideration.
- Temperatures below room temperature do not have an adverse effect on y F but can have a significant effect on ductility.
- Behavior will transform from ductile to brittle at a threshold temperature rang e known as the Ductile-to- Brittle Transition Temperature (DBTT) range.

(See AISC Manual pp 2-30 thru 2-33)

Effect of Temperature on the Properties of Steel (cont.)

- For sample information on the effect of temperature on yield stress, tensile strength, and Young's modulus



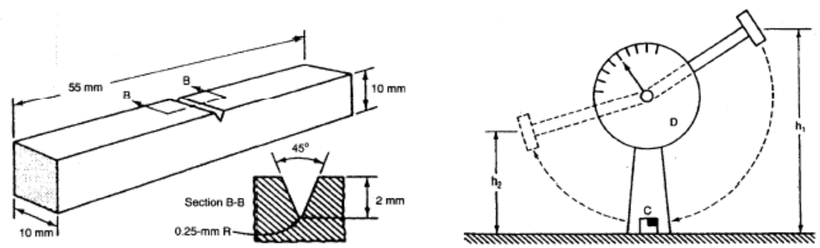
Material Toughness

- Charpy V-notch test was introduced
- Result of the test is a value for notch toughness (CVN) given by xx ft-lb at yy F. This is a characterization of the energy absorbed by the notched specimen

(See AISC Manual pp 2-33 thru 2-35)

Material Toughness (cont.)

Charpy V-notch test



Design Philosophies

- Allowable Stress Design Method (ASD)
- Load and Resistance Factor Design (LRFD)

ASD

- A member is selected such that the max stress due to working loads does not exceed an allowable stress.
- It is also called elastic design or working stress design.
  - F.S. = R_n/Q where R_n is the nominal strength and Q is the nominal service load
  - Allowable stress=Yield stress/Factor of Safety Ω
  - Actual stress ≤ Allowable stress

LRFD

- A member is selected such that its factored strength is more than the factored loads.
  - Σ(L factors x Loads) ≤ R factor x Resistance

    $\Sigma(\gamma_i \times Q_i) \leq \varphi \times R_n$
- Each load effect (DL, LL, ..)has a different load factor which its value depends on the combination of loads under consideration.

Basis of LRFD

- The load and resistance factors are based on extensive analytical studies and assessment of in-service conditions.
- Load factors account for randomness in load effects
- Resistance factors account for randomness in material properties and uncertainties in analysis and design theory, and fabrication and construction practices.
- Consideration is given to Mean, Variance, Standard Deviation, and Coefficient of Variation

Basis of LRFD (cont.)

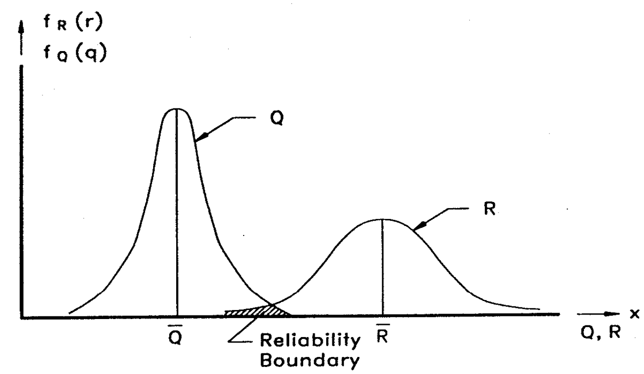


Fig. 3.4 Probability density functions for load and resistance.

Basis of LRFD (cont.)

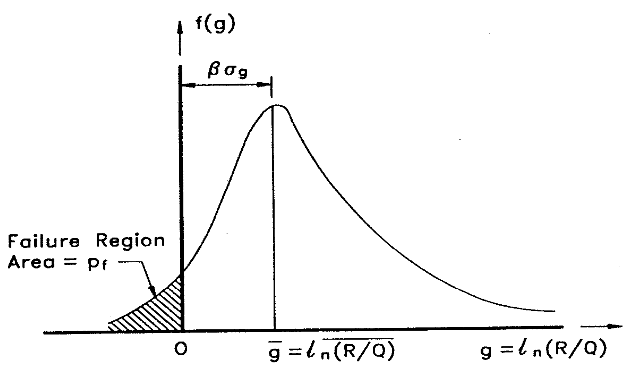


Fig. 3.5 Definition of safety index for lognormal R and Q.

Basis of LRFD (cont.)

Load Combinations	Objective Reliability Index β
Dead load + Live load (or Snow load)	3.0 for members 4.5 for connections
Dead load + Live load + Wind load	2.5 for members
Dead load + Live load + Earthquake load	1.75 for members

where Reliability Index β

$$\beta = \frac{\ln(R_m / Q_m)}{\sqrt{V_R^2 + V_Q^2}}$$

Load Factors

- The values are based on extensive statistical studies
  - DL only 1.4D
  - DL+LL+SL (LL domin.) 1.2D+1.6L+0.5S
  - DL+LL+SL (SL domin.) 1.2D+0.5L+1.6S
  - In each combination, one of the effects is considered to be at its "lifetime" max value and the others at their "arbitrary point in time " values.

(see AISC Manual pp 2-8 thru 2-10)

Resistance Factor

- The resistance factors range in value from 0.75 to 1.0 depending on the type of resistance (tension, bending, compression, ..)
- These factors account for uncertainties in material properties, design theory, and fabrication and construction practices.

History

- ASD has been the primary method used for steel design since the first AISC specifications was issued in 1923.
- In 1986, AISC issued the first specification for LRFD.
- The trend today is toward LRFD method, but ASD is still in use.

Advantages of LRFD

- It provides a more uniform reliability in all structures subjected to many types of loading conditions. It does not treat DL and LL as equivalent, thereby leading to a more rational approach.
- It provides better economy as the DL make up a greater percentage on a given structure.
  - Because DLs are less variable by nature than live loads, a lower load factor is used.
  - This may lead to a reduction in member size and therefore better economy.
- AISC Video (National Environmental Report.mht)