Load and Resistance Factor Design (LRFD)

Specifications and Building Codes:

- Structural steel design of **buildings** in the US is principally based on the specifications of the *American Institute of Steel Construction* (**AISC**).

  -- Current Specifications: 1989 ASD and 1999 LRFD.
  -- 1989 AISC Specification for Structural Steel Buildings – Allowable Stress Design and Plastic Design. (**ASD**)
  -- 1999 AISC Load and Resistance Factor Design Specification for Structural Steel Buildings. (**LRFD**)
  -- LRFD Manual: Manual of Steel Construction, Load and Resistance Factor Design, 3rd Edition, 2001.
  -- Manual of Steel Construction, 13th Edition, 2005 (combined ASD and LRFD provisions).

- Steel **bridge** design is in accordance with specifications of AASHTO: -- American Association of State Highway and Transportation Officials

- **Railroad bridge** design is in accordance with specifications of AREA: -- American Railway Engineering Association.

Design Philosophies:

1. Similar to *plastic design*, LRFD focuses on "limit state design", where strength or failure condition is considered.
2. Factored load $\leq$ factored strength, or
   $\sum$ (Loads $\times$ load factors) $\leq$ resistance $\times$ resistance factors
3. In general, load factors (>1) amplify loads, while resistance factors (<1) reduce strength.

Structural Safety Requirement:

ϕ Resistance factor

R_n The nominal resistance, or strength, of the component under consideration

Q_i A load effect (a force or a moment)

γ_i A load factor

ϕR_n is the called the *design strength*

$\sum_i \gamma_i Q_i$ is the summation of all the load effects

$$\boxed{\phi R_n \geq \sum_i \gamma_i Q_i}$$

Resistance Factors ϕ:

$$\phi = \begin{cases} 0.90 & \textit{Tension members (yielding state)} \\ 0.75 & \textit{Tension members (fracture state)} \\ 0.85 & \textit{Compression members} \\ 0.90 & \textit{Beams (flexure and shear)} \\ 0.75 & \textit{Fasteners} \end{cases}$$

Load Combinations:

D Dead load

E Earthquake load

L Live load

L_r Roof live load

R Rain load

S Snow load

W Wind load

$$\sum_i \gamma_i Q_i = \begin{cases} 1.4D \\ 1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R) \\ 1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (0.5L \text{ or } 0.8W) \\ 1.2D + 1.6W + 0.5L + 0.5(L_r \text{ or } S \text{ or } R) \\ 1.2D \pm 1.0E + 0.5L + 0.2S \\ 0.9D \pm (1.6W \text{ or } 1.0E) \end{cases}$$

Note:

$\sum_i \gamma_i Q_i$ is the summation of all the load effects.

The safety requitement may be written as

$$\frac{\sum_i \gamma_i Q_i}{\phi R_n} \leq 1.0 \quad \text{or} \quad \frac{\sum \text{Load effects}}{\text{Resistance}} \leq 1.0$$

- If more than one type of resistance is involved, this can be used to form the basis of an interaction formula. Note that the sum of the load-to-resistance ratios must be limited to unity.
- For example, if both bending and axial compression are acting, the interaction formula would be

$$\frac{P_u}{\phi_c P_n} + \frac{M_u}{\phi_b M_n} \leq 1.0$$

P_u	factored axial compressive load
$\phi_c P_n$	compressive design strength
M_u	factored bending moment
$\phi_b M_n$	flexural design strength

For biaxial bending, there will be two bending ratios:

$$\frac{P_u}{\phi_c P_n} + \left(\frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}} \right) \leq 1.0$$

where the *x* and *y* subscripts refer to bending about the *x* and *y* axes.

Glossary (Part 16 of LRFD – Specifications and Code):

Limit State: a condition in which a structure or component becomes unfit for service and is judged either to be no longer useful for its intended function (***serviceability limit state***) or to be unsafe (***strength limit state***).

Nominal loads: the magnitudes of the loads specified by the applicable code (Q_i).

Load factor: a factor that accounts for unavoidable deviations of the actual load from the nominal value and for uncertainties in the analysis that transforms the load into a load effect. (γ_i).

Factored load: the product of the nominal load and a load factor ($\gamma_i Q_i$).

Resistance: the *capacity of a structure or component* to resist the effects of loads, as determined by computation using specified material strengths and dimensions and formulas derived from accepted principles of structural mechanics or by field tests or laboratory tests of scaled models, allowing for modelling effects and differences between laboratory and field conditions. ***Resistance*** is a generic term that includes both ***strength*** and ***serviceability limit states.***

Nominal strength: the *capacity of a structure or component* to resist the effects of loads, as determined by computation using specified material strengths and dimensions and formulas derived from accepted principles of structural mechanics or by field tests or laboratory tests of scaled models, allowing for modelling effects and differences between laboratory and field conditions (R_n).

Resistance factor: a factor that accounts for unavoidable deviations of the actual strength from the nominal value and the manner and consequences of failure (ϕ).

Design strength: resistance (force, moment, stress, as appropriate) provided by element or connection; the product of the nominal strength and the resistance factor (ϕR_n).

Compact sections: capable of developing a fully plastic stress distribution and possess rotation capacity of approximately three before the onset of local buckling; i.e., local buckling is not an issue.

Noncompact sections: can develop the yield stress in compression elements before local buckling occurs, but will not resist inelastic local buckling at strain levels required for a fully plastic stress distribution.

Stiffener: a member, usually an angle or plate, attached to a plate or web of a beam or girder to distribute load, to transfer shear, or to prevent buckling of the member to which it is attached.

Examples