1.051 Structural Engineering Design

Recitation 6

Design Procedures of Tension Members In Accordance to the AISC-LRFD

Reference: Chapter D, Load & Resistance Factor Design – Manual of Steel Construction, American Institute of Steel Construction

Design Principle

$$P_u \leq \Phi_t \cdot P_n \qquad \text{and}$$
$$P_u \leq \Phi_t \cdot R_n$$

where P_u = design tensile strength (kips)
P_n = nominal tensile strength (kips)
R_n = block shear rupture strength (kips)
Φ_t = strength reduction factor

Failure Modes

- Yielding failure in the gross section
- Fracture failure in the net section
- Block shear rupture in the connection area

The LRFD code states that in estimating the design strength of a tension member, all failure modes should be considered. The governing design tensile strength is the smaller value obtained from the three cases. Note that the nominal strength is multiplied by its respective strength reduction factor. In other words, the controlling case can be either (a) yielding in the gross section, or (b) tensile fracture in the net section, or (c) block shear rupture in the connection region. The nominal strengths, or resistances, and their respective strength reduction factors of a tensile member for the three failure modes are presented below.

A. Yielding Failure

For yielding in the gross section, $\Phi_t = 0.9$

$$P_n = F_y \cdot A_g \qquad \text{LRFD Eq.(D1-1)}$$

where F_y = specified minimum yield stress (ksi)
A_g = gross area of the member (in.^{2})

B. Fracture Failure

For fracture in the net section, $\Phi_t = 0.75$

$$P_n = F_u \cdot A_e \qquad \text{LRFD Eq.(D1-2)}$$

where F_u = specified minimum tensile stress (ksi)
A_e = effective net area (in.^{2})

C. Block Shear Failure

For block shear rupture, $\Phi_t = 0.75$. One of two failure modes is possible - tensile fracture or shear fracture. The case with a larger fracture value is the controlling case.

Case 1 – Tensile fracture + Shear Yield

This case can be expressed as $F_u \cdot A_{nt} \geq 0.6 \cdot F_u \cdot A_{nv}$, that is, the tensile fracture value is equal to or exceeds the shear fracture value.

$$R_n = 0.6 \cdot F_y \cdot A_{gv} + F_u \cdot A_{nt} \qquad \text{LRFD Eq.(J4-3a)}$$

Case 2 – Shear Fracture + Tensile Yield

This case can be expressed as $F_u \cdot A_{nt} \leq 0.6 \cdot F_u \cdot A_{nv}$, that is, the tensile fracture value is equal to or less than the shear fracture value.

$$R_n = 0.6 \cdot F_u \cdot A_{nv} + F_y \cdot A_{gt} \qquad \text{LRFD Eq.(J4-3b)}$$

where A_{gv} = gross area subjected to shear (in.^{2})
A_{gt} = gross area subjected to tension (in.^{2})
A_{nt} = net area subjected to tension (in.^{2})
A_{nv} = net area subjected to shear (in.^{2})

Definition of Areas

1. Gross area

A_g = area of a cross-section with no holes

2. Net area

For N non-staggered holes,

$$A_n = A_g - N \cdot d_e \cdot t$$

For N staggered holes,

$$A_n = A_g - N \cdot d_e \cdot t + \sum_{i=1}^{N-1} \left(\frac{S_i^2}{4 \cdot g_i} \right) \cdot t$$

where d_e = bolt size + hole clearance (1/16)" + hole damage (1/16)" (in.)
t = member thickness (in.)
S = pitch (in.)
G = gage (in.)

3. Effective net area

$$A_e = U \cdot A_n \text{ (bolted)}$$
$$A_e = U \cdot A_g \text{ (welded)}$$

where U = reduction coefficient
= 0.9 for W, M, S, or tee sections and for connections to the flanges. Minimum of 3 bolts per line in the direction of stress
= 0.85 for all shapes and built-up cross sections not meeting the requirement of the U=0.9 case. Minimum of 3 bolts per line in the direction of stress
= 0.75 for all members whose connections having only 2 bolts per line in the direction of stress