Bracing System Design

Course Number: ST-02-206

PDH: 6

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Module 1: Introduction

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the primary roles and classifications of bridge bracing systems.
- **Evaluate** the torsional behavior (Saint-Venant vs. Warping) of open and closed girder sections.
- **Differentiate** between the four primary categories of structural bracing.

Executive Summary: Bracing systems are essential for both construction-stage stability and in-service performance. While they are often designated as secondary members in straight bridges, their role in controlling unbraced length and providing torsional stiffness is critical to preventing structural collapse.

Design Fundamentals

Bracing systems provide stability to primary girders and enhance the lateral and torsional stiffness of the bridge. According to AASHTO LRFD Specifications, braces are designated as **primary** or **secondary** based on whether a design force is obtained from structural analysis.

In horizontally curved bridges, braces are typically primary members. In straight bridges, while a first-order analysis may show no forces (leading to a secondary designation), the removal of these braces can lead to total collapse due to increased unbraced lengths.

Torsional Behavior of Open and Closed Girders

Torsional resistance in thin-walled bridge structures is categorized into two types of stiffness:

- **Saint-Venant Torsional Stiffness (Uniform Torsion):** Results in pure shear deformation in the plane of the plates. It is insensitive to support conditions and does not vary along the member length.
- **Warping Torsional Resistance (Non-uniform Torsion):** Associated with bending deformation in the plane of individual plates. It occurs when the cross-section distorts such that it is no longer a plane.

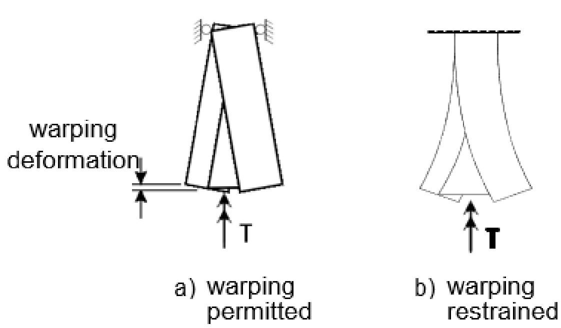

Figure 1: Warping Stiffness is Related to the Bending Stiffness of the Plate Elements.

Equation 1: Total Torsional Resistance

$$T_T = T_{UT} + T_W$$

Where:

- **TT** = Total torsional moment resistance
- **TUT** = Uniform torsional component
- **TW** = Warping torsional component

Equation 2: Uniform Torsion

$$T_{UT} = GJ\frac{df}{dx}$$

Where:

- **G** = Shear modulus
- **J** = Torsional constant
- **f** = Rotation of the cross section
- **x** = Longitudinal axis

Equation 3: Torsional Constant (Open Section)

$$J = \frac{1}{3}\sum\left(b_i t_i^3\right)$$

Where:

- **bi** = Width of plate elements
- **ti** = Thickness of plate elements

Equation 4: Torsional Constant (Single Cell Box/Tub)

$$J = \frac{4A_0^2}{\sum\left(\frac{b_i}{t_i}\right)}$$

Where:

- **A0** = Enclosed area of the box girder (mid-thickness)
- **bi** = Width of the ith plate
- **ti** = Thickness of the ith plate

Equation 5: Warping Torsion

$$T_W = EC_w\frac{d^3 f}{dx^3}$$

Where:

- **E** = Modulus of elasticity
- **Cw** = Warping constant

Equation 6: Warping Constant (I-Shaped Section)

$$C_W = I_y h_o^2 r(1-r)$$

Where:

- **Iy** = Moment of inertia about axis through the web
- **ho** = Spacing between flange centroids
- **r** = Ratio of compression flange inertia to total inertia (Iyc / Iy)

💡 **Design Tip:** Closed box or tub girders are dominated by Saint-Venant torsion. Their torsional stiffness can be **100 to 1,000 times greater** than a comparable I-section, making warping stresses in these sections usually negligible.

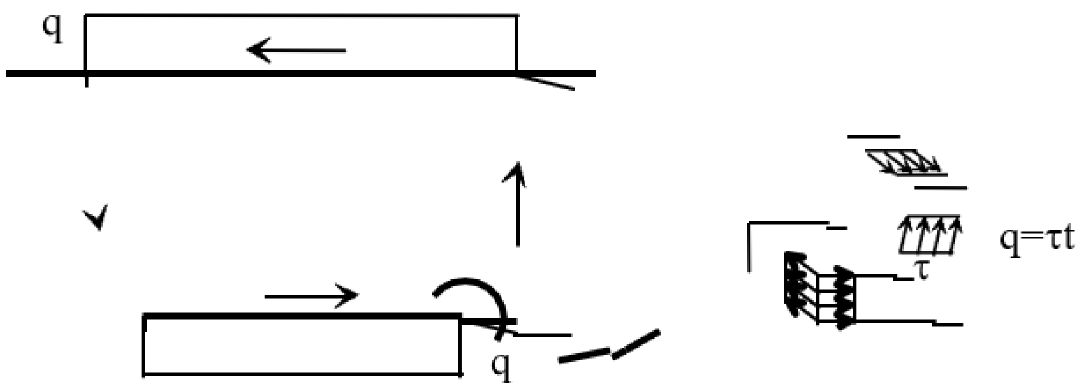

Figure 2: Shear Flow in Tub Girder Due to Saint-Venant Torsion

Lateral Torsional Buckling

For doubly-symmetric beams, the elastic buckling solution is defined as follows:

Equation 10: Elastic Buckling (Mcr)

$$M_{cr} = \frac{\pi}{L_b}\sqrt{EI_yGJ + \left(\frac{\pi E}{L_b}\right)^2 I_yC_w}$$

Where:

- **Lb** = Unbraced length
- **Other terms** = As defined in previous equations

🧮 **Calculation Note:** The first term under the radical relates to Saint-Venant stiffness, while the second term reflects warping stiffness. Effective bracing is achieved primarily by **restraining twist** of the section.

Categories of Bracing

Bracing systems are divided into four functional categories:

1. **Relative Bracing:** Controls the relative movement of two adjacent points (e.g., diagonal bracing, lateral trusses in tub girders).
2. **Nodal (Discrete) Bracing:** Controls deformation at a specific point (e.g., cross frames or diaphragms). The spacing between these defines the unbraced length.
3. **Lean-on Bracing:** Lightly loaded members provide stability to heavily loaded members through connecting struts.
4. **Continuous Bracing:** Connected along the entire length (e.g., a concrete deck attached via shear studs).

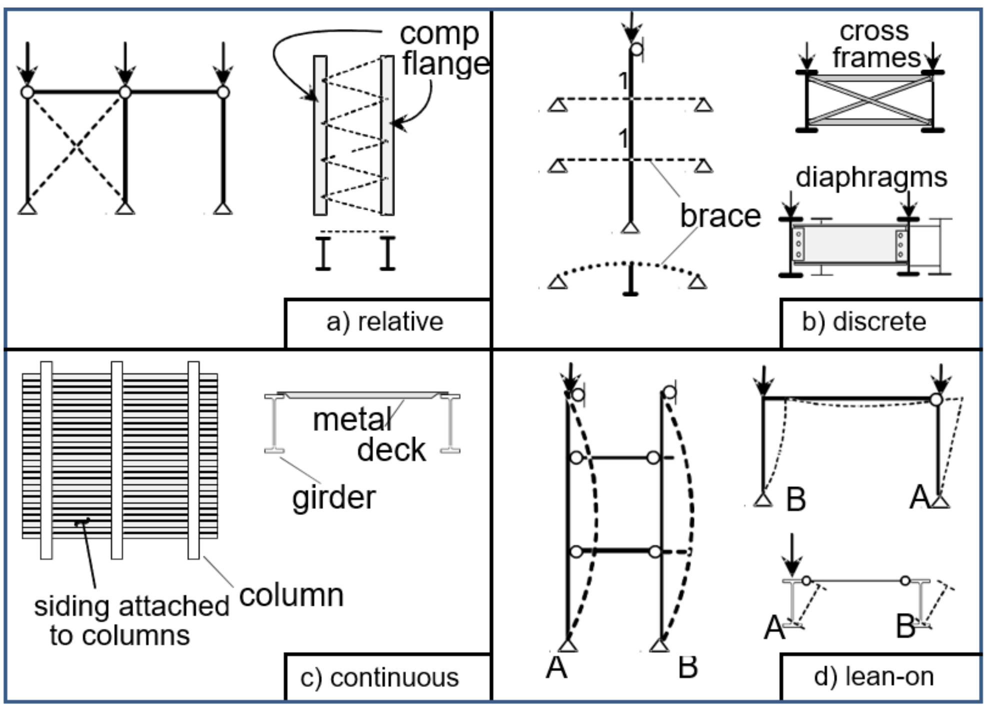

Figure 3: Categories of Bracing

Checkpoint Quiz

1. Which type of torsion dominates the behavior of closed tub girders?

a) Warping Torsion
b) Saint-Venant Torsion
c) Lateral Torsional Buckling
d) Non-uniform Torsion

Answer: (b). Saint-Venant torsion provides the primary resistance in closed sections, often making warping stresses negligible.

2. Which bracing category describes cross frames that restrain girder twist at a single location?

a) Relative Bracing
b) Continuous Bracing
c) Nodal (Discrete) Bracing
d) Lean-on Bracing

Answer: (c). Nodal braces control deformation at a specific point; cross frames are the primary example of nodal torsional bracing in bridges.