Lecture 11

STR403 - Metallic Bridges
“Box-Girder Bridges”

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Lecture 11: Box-Girder Bridges

Topics

- Introduction.
- Typical Cross-Section.
- Behavior of Box-Girder.

Introduction

Why Box Girder

- Suitable for medium span bridges (45-100 m)
- Large torsional stiffness, less LTB problems.
- Simpler to erect.

Introduction

Usual Span Ranges: Box girders are suitable for longer span than plate girders and allow larger span-to-depth ratios. The span to depth ratio will normally be around 20 to 25 for simple girders and around 25 to 35 for continuous girders. It is possible to reduce the depth, if necessary, at the expense of additional steel. The above ratios are valid for roadway bridges. For railway bridges the ratios should be smaller, say 15 and 20. The following table gives the economic span limits for roadway bridges:

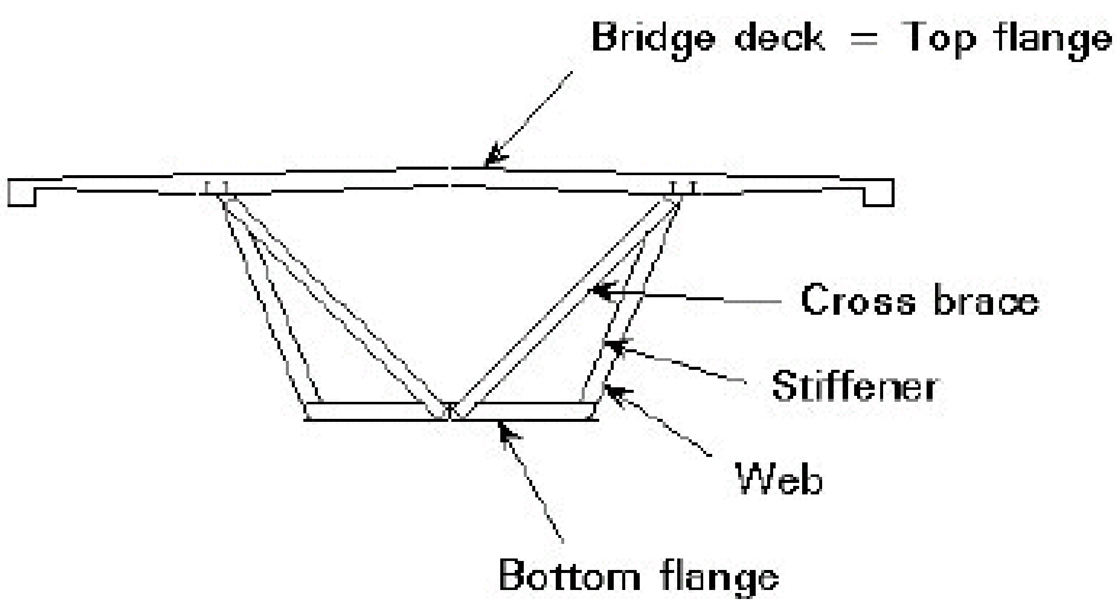
	Composite concrete deck	Orthotropic deck
Simple span	20 – 100	70 – 120
Continuous spans	30 – 140	100 – 250

The longest span so far is 300 m achieved in 1974 by costa de silva bridge in Rio de Janeiro.

Typical Cross-Section

Box-Girder Components

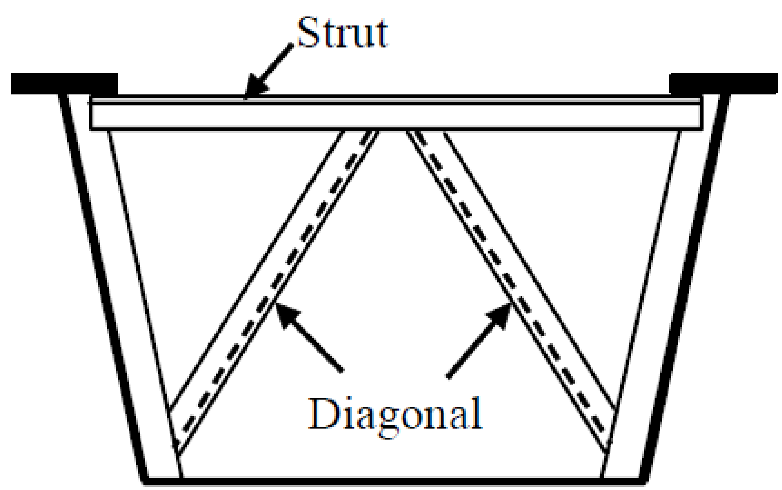
- Top Flange: concrete deck or orthotropic steel deck.
- Bottom Flange: stiffened plate.
- Web Plates: vertical or inclined.
- Diaphragms/Cross Bracing: intermediate and at support.



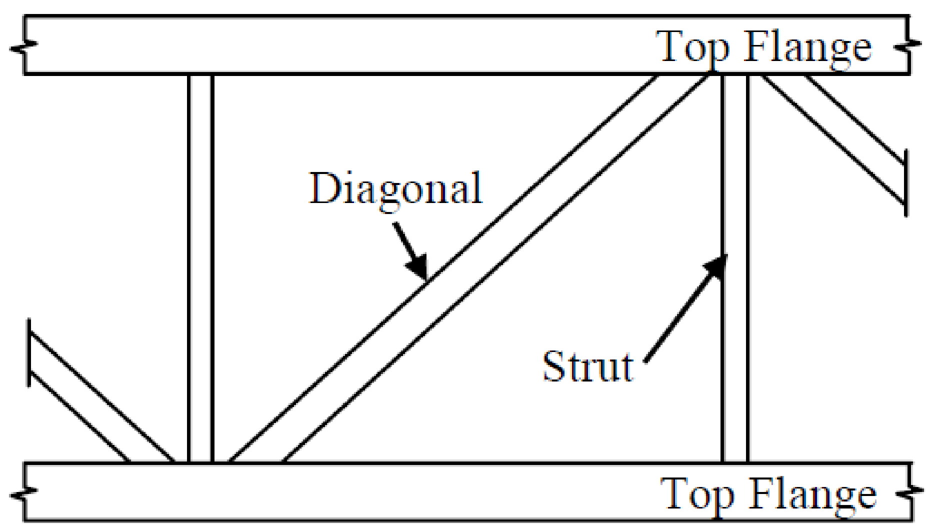
Typical Cross-Section

Box-Girder Components

(a) Internal Cross-Frame

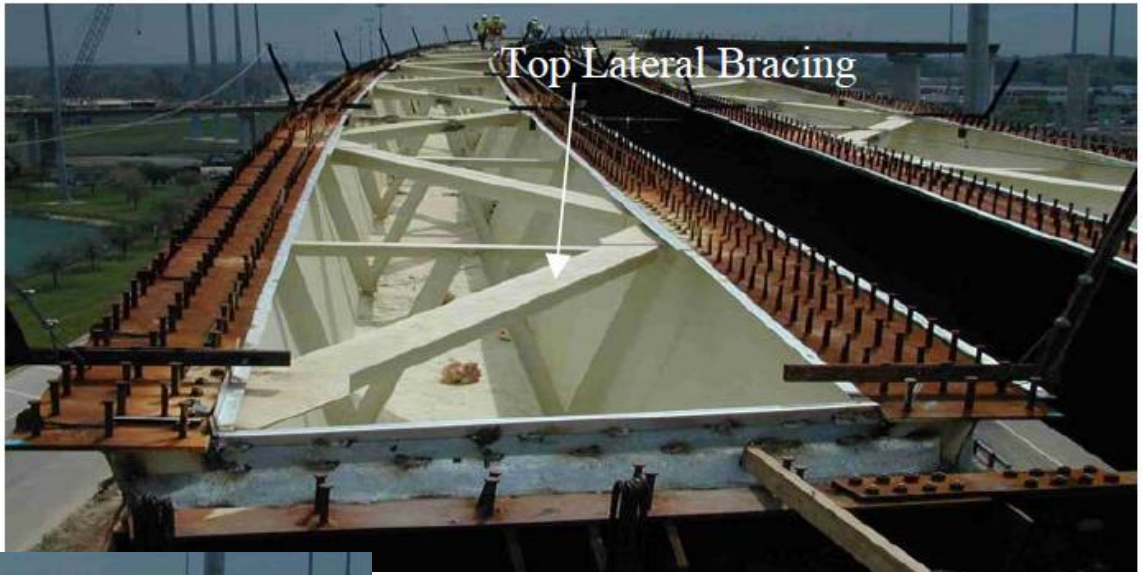


(b) Single Diagonal-Type Horizontal Top Truss



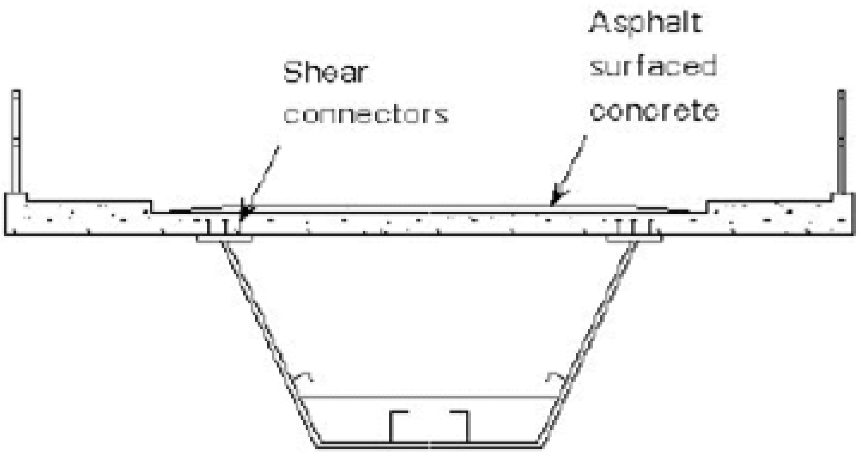
Typical Cross-Section

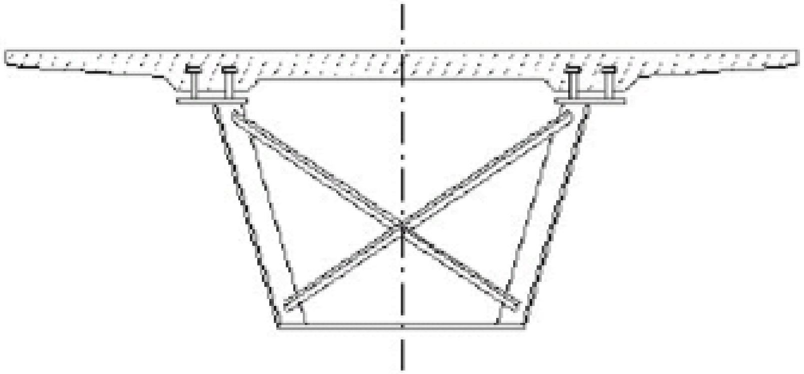
Box-Girder Components

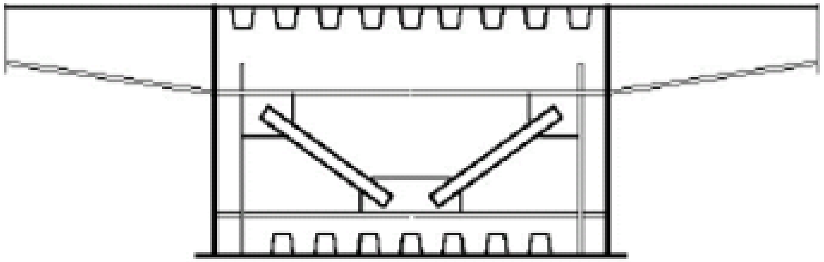


Typical Cross-Section

Single Box

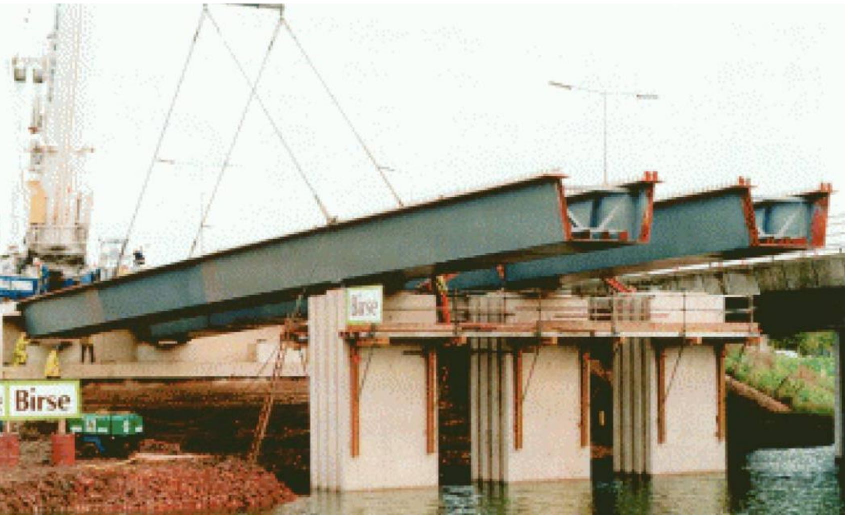


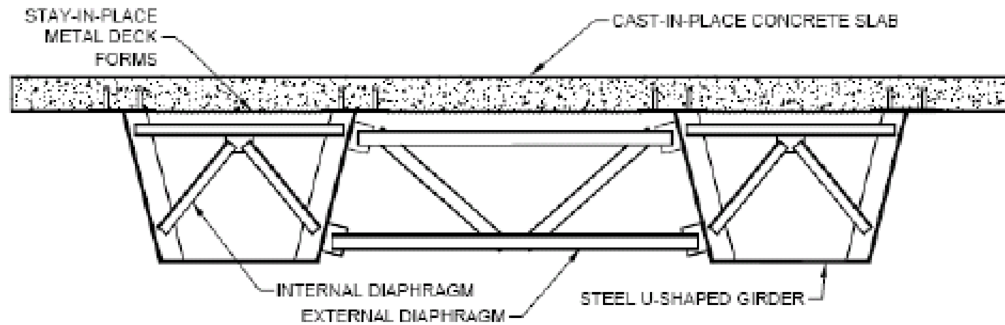


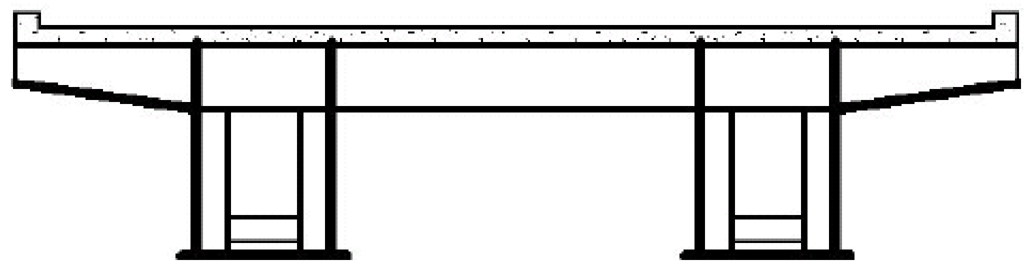


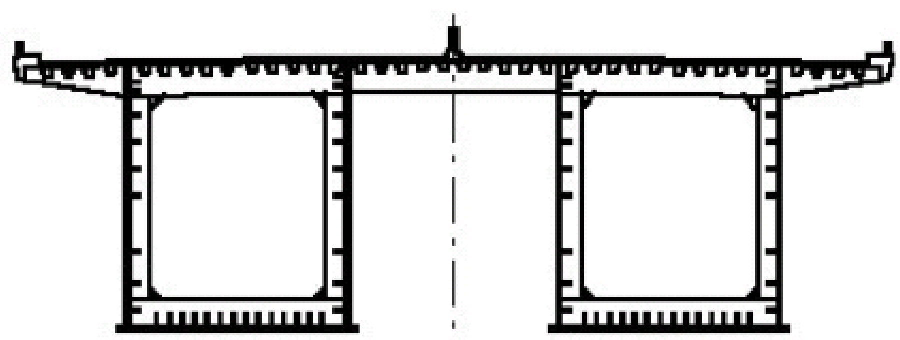
Typical Cross-Section

Multiple Box









Typical Cross-Section

Multiple Box

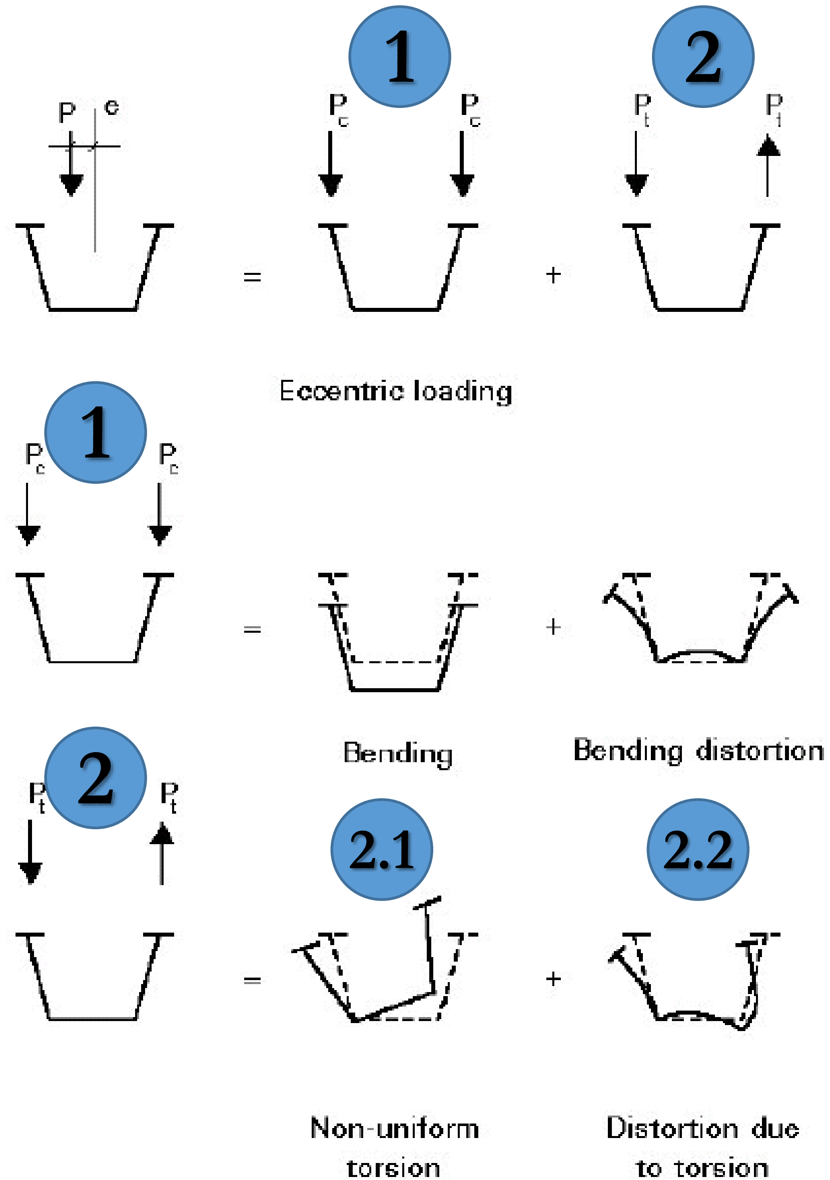
Behavior of Box-Girder

1 Symmetrical component with both webs subjected to two equal vertical loads:

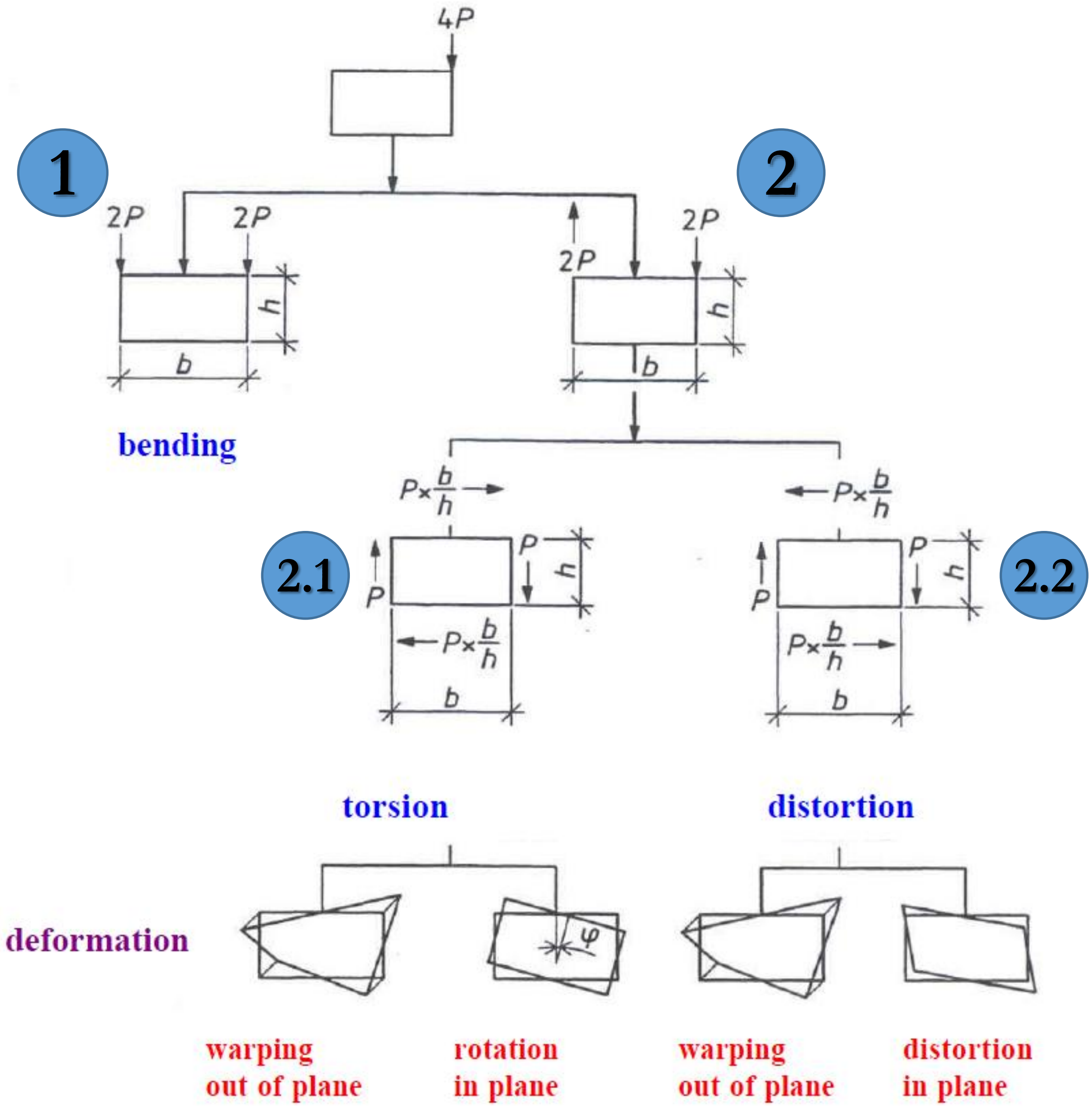
2 Anti-symmetrical component with the two webs subjected to two equal and opposite forces forming a couple.

- Shear & Bending stresses in vertical plan
- Bending Distorsion in open sections

- Torsion Shear Stresses.
- Torsion Distrosion.

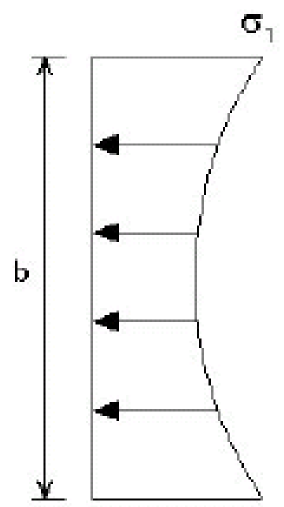


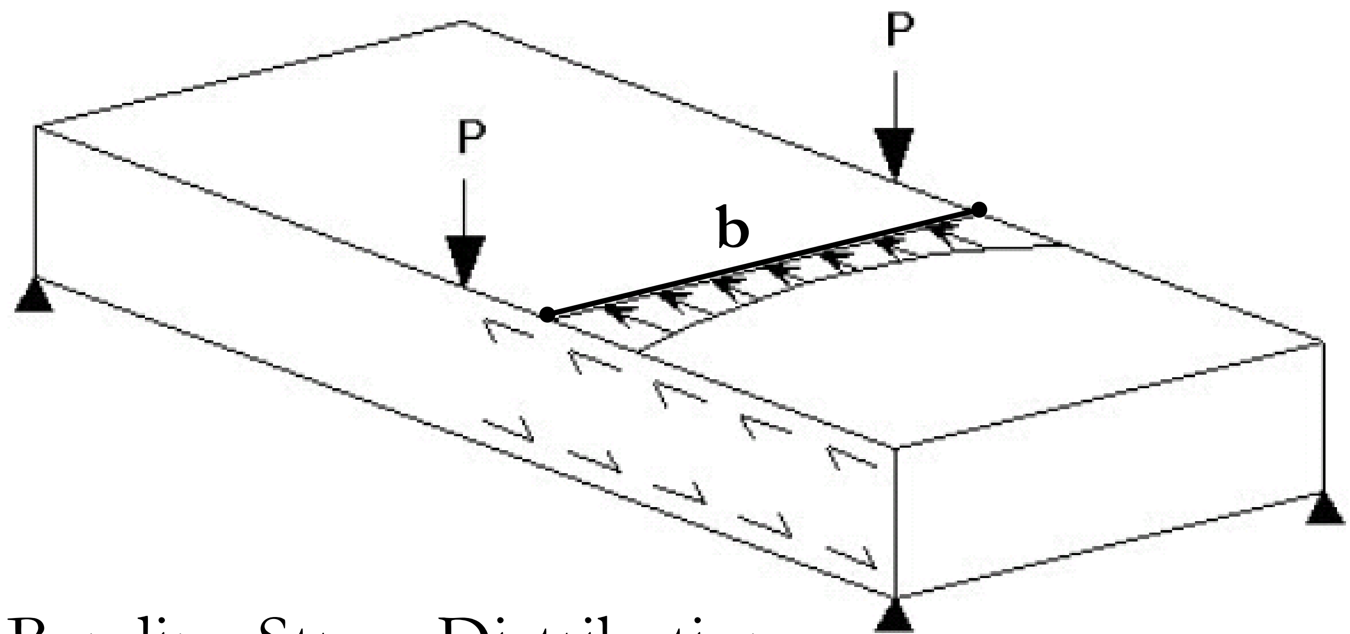
Behavior of Box-Girder



Behavior of Box-Girder

Shear Lag



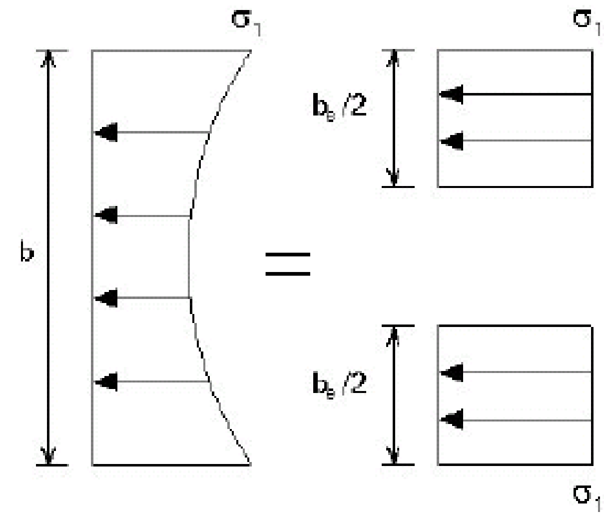


- Non-Uniform Bending Stress Distribution.
- Distorsion of the flange in its own plane due to the restraint of the web (plane section does not remain plane).

Behavior of Box-Girder

Shear Lag

- How do we account for the shear lag?
  - Use an effective (reduced) flange width **(be)**.
  - The reduction is a function of the (Span/Width) ratio **(L/b)** of the box.
  - Fortunately, for normal range of **L/b** ratios, the increase in peak stress is in the range of 10% to 20%.



Behavior of Box-Girder

- **British Standards BS5400:3/2000:**

a) $b_e = \psi b$ for portions between webs:

where

b = half the distance between centers of webs measured along the mid-plane of the flange plate;

b) $b_e = k\psi b$ for portions projecting beyond an outer web;

where

b = distance from the free edge of the projecting portion to the centre of the outer web; measured along the mid-plane of the flange plate;

$k = (1 - 0.15b/L)$;

L = span of a beam between centers of support, or in the case of a cantilever beam, between the support and the free end;

Behavior of Box-Girder

- **British Standards BS5400:3/2000:**

ψ = appropriate effective breadth ratio taken from Tables 7.1 – 7.3 for uniformly distributed loads;

a = 0 if there are no stiffeners on the flange within the width b in the span direction, otherwise:

$$a = \frac{\textbf{sectional area of flange stiffeners in width b}}{\textbf{sectional area of flange plate in width b}}$$

Values of ψ for intermediate values of b/L and a and for intermediate positions in the span may be obtained by linear interpolation.

Behavior of Box-Girder

Table 7.1 – Effective breadth ratio ψ for simply supported beams

b/L	Mid-span		Quarter span		Support	
	a = 0	a= 1	a = 0	a = 1	a = 0	a = 1
0.00	1.00	1.00	1.00	1.00	1.00	1.00
0.05	0.98	0.97	0.98	0.96	0.84	0.77
0.10	0.95	0.89	0.93	0.98	0.70	0.60
0.20	0.81	0.67	0.77	0.62	0.52	0.38
0.30	0.66	0.47	0.61	0.44	0.40	0.28
0.40	0.50	0.35	0.46	0.32	0.32	0.22
0.50	0.38	0.28	0.36	0.25	0.27	0.18
0.75	0.22	0.17	0.20	0.16	0.17	0.12
1.00	0.16	0.12	0.15	0.11	0.12	0.09

Behavior of Box-Girder

Table 7.2 – Effective breadth ratio ψ for interior spans of continuous beams

b/L	Mid-span		Quarter span		Support	
	a = 0	a = 1	a = 0	a = 1	a = 0	a = 1
0.00	1.00	1.00	1.00	1.00	1.00	1.00
0.05	0.96	0.91	0.85	0.76	0.85	0.50
0.10	0.86	0.72	0.68	0.55	0.41	0.32
0.20	0.58	0.40	0.42	0.31	0.24	0.17
0.30	0.38	0.27	0.30	0.20	0.15	0.11
0.40	0.24	0.18	0.21	0.14	0.12	0.08
0.50	0.20	0.14	0.16	0.11	0.11	0.07
0.75	0.15	0.10	0.10	0.08	0.09	0.06
1.00	0.13	0.09	0.09	0.07	0.07	0.05

Behavior of Box-Girder

Table 7.3 – Effective breadth ratio ψ for cantilever beams

b/L	Fixed end		Quarter span near fixed end		Free end	
	a = 0	a = 1	a = 0	a = 1	a = 0	a = 1
0.00	1.00	1.00	1.00	1.00	1.00	1.00
0.05	0.82	0.76	1.00	1.00	0.92	0.86
0.10	0.68	0.61	1.00	1.00	0.84	0.77
0.20	0.52	0.44	1.00	1.00	0.70	0.60
0.30	0.42	0.35	0.95	0.90	0.60	0.48
0.40	0.35	0.28	0.88	0.75	0.52	0.38
0.50	0.30	0.25	0.76	0.62	0.40	0.33
0.75	0.22	0.18	0.52	0.38	0.34	0.23
1.00	0.18	0.14	0.38	0.27	0.27	0.18

Behavior of Box-Girder

Local Buckling Behavior

- Compression Flange Buckling.
- Web Buckling due to Bending.
- Web Buckling due to Shear.

Behavior of Box-Girder

Compression Flange Buckling

- Stiffened Flange:

$$\frac{b}{t} \leq \frac{64}{\sqrt{F_y}}$$

- Unstiffened Flange:

$$\frac{b}{t} \leq \frac{21}{\sqrt{F_y}}$$

Behavior of Box-Girder

Web Buckling due to Bending

- Web is Non-Compact:

$$\frac{d_w}{t_w} \leq \frac{190}{\sqrt{F_y}}$$

- Web w/ One Longitudinal Stiffener at (d/5):

$$\left(\frac{d_w}{t_w}\right) \leq \frac{320}{\sqrt{F_y}}$$

- Web w/ Two Longitudinal Stiffeners at (d/5) and (d/2):

$$\left(\frac{d_w}{t_w}\right) \leq \frac{370}{\sqrt{F_y}}$$

Behavior of Box-Girder

Web Buckling due to Shear

$$\lambda_q = \frac{d/t}{132.5}\sqrt{F_y}$$

1 $\frac{dw}{tw} \le \frac{105}{\sqrt{F_y}}$ $\lambda_q \le 0.8$

Allowable Shear Stress: $q_b = 0.35Fy$

2 $\frac{dw}{tw} > \frac{105}{\sqrt{F_y}}$ $\lambda_q > 0.8$ …and No VL Stiffeners are used

Reduced Allowable Shear Stress q_b:

$$q_b = (1.5 - 0.625\lambda_q)\,0.35\,F_y \quad \rightarrow \quad 0.8 < \lambda_q \le 1.2$$

$$= \frac{0.9}{\lambda_q}(0.35F_y) \quad \rightarrow \quad \lambda_q > 1.2$$

Behavior of Box-Girder

Web Buckling due to Shear

$$\lambda_q = \frac{d/t}{132.5}\sqrt{F_y}$$

3 $\frac{dw}{tw} \rangle \frac{105}{\sqrt{F_y}}$ **λ_q>0.8 …and VL Stiffeners are used**

Reduced Allowable Shear Stress $\mathbf{q_b}$:

$$\lambda_q = \frac{d/t}{57}\sqrt{\frac{F_y}{k_q}}$$

$$k_q = 4 + 5.34/\alpha^2 \qquad (\alpha \langle 1)$$

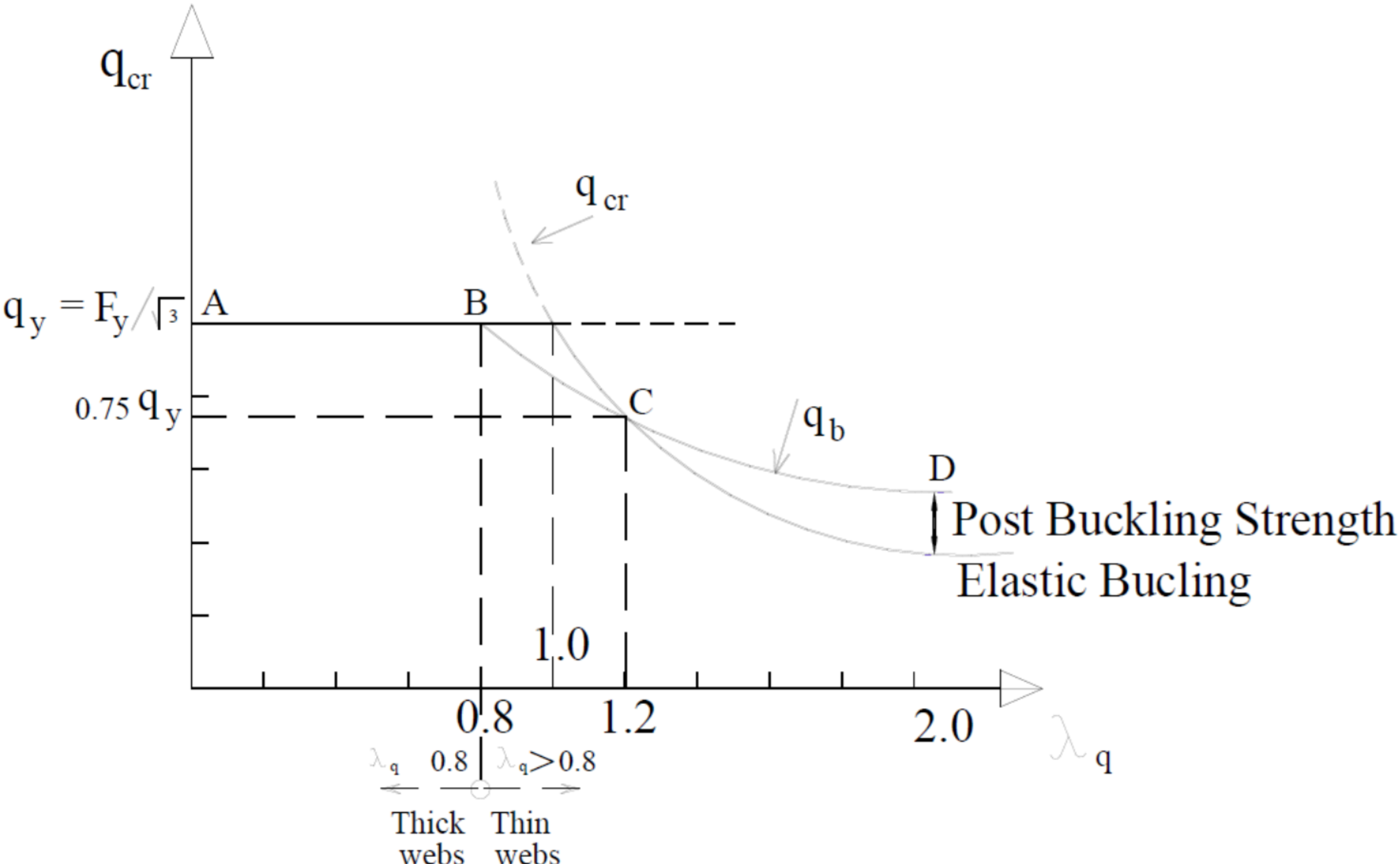
$$= 5.34 + 4/\alpha^2 \qquad (\alpha \rangle 1)$$

$$q_b = (1.5 - 0.625\lambda_q)\,0.35\,F_y \quad \longrightarrow \quad 0.8 < \lambda_q \le 1.2$$

$$= \frac{0.9}{\lambda_q}(0.35 F_y) \quad \longrightarrow \quad \lambda_q > 1.2$$

Behavior of Box-Girder

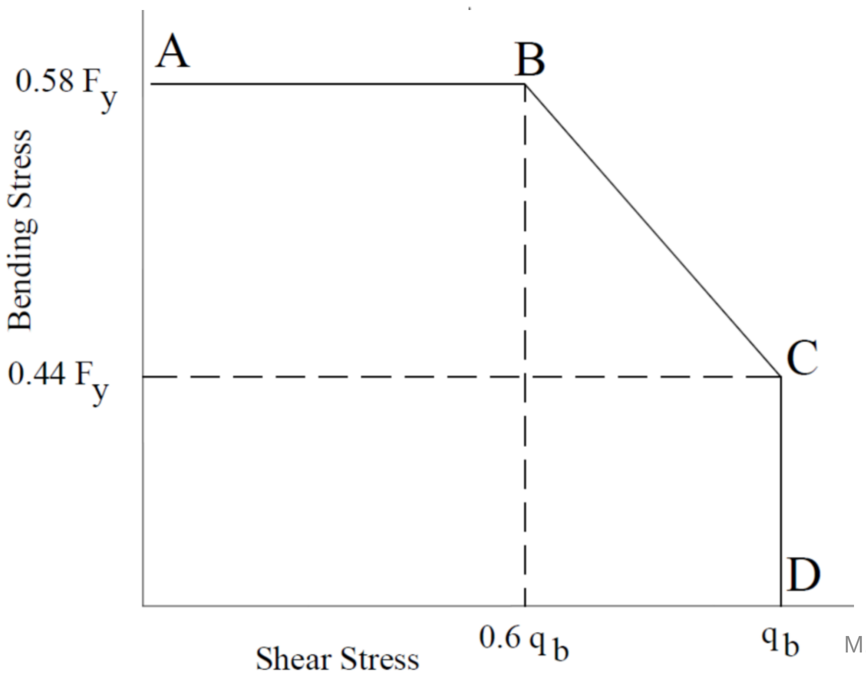
Web Buckling due to Shear



Behavior of Box-Girder

Combined Bending and Shear

The interaction diagram can be considered in 3 regions. In region AB, the applied shear stress q_{act} is low ($< 0.6\ q_b$) and the girder can sustain the full bending stress F_b based on the effective width b_{eff} for the compression flange. At the other extreme of the interaction diagram in region CD, the applied shear stress is high ($=q_b$) then the allowable bending stress is reduced to $0.44\ F_y$ to allow for the high shear. In the intermediate region BC the allowable bending stress is reduced linearly from $0.58\ F_y$ to $0.44\ F_y$.



$$F_b = [\ 0.8 - 0.36\ (q_{act}\ /\ q_b)]\ F_y.$$

Summary of Today's Topics

- Introduction.
- Typical Cross-Section.
- Behavior of Box-Girder.