# Steel Box Girder Bridges—Design Guides & Methods

CONRAD P. HEINS

**IN MEMORIAM**

**CONRAD P. HEINS**
**September 13, 1937**
**December 24, 1982**

During the past decade, there has been extensive use of steel box girders for straight and curved highway and transit structures.[13,14] To meet the need for use of such structural elements, design criteria had to be established. Therefore, the purpose of this paper is to present information relative to the design criteria in addition to information on preliminary plate sizes, design aids, and computer-aided design of steel box girder bridges.

## INTRODUCTION

Box girders have become a prominent element in the construction of major river crossings, highway interchanges, and transit systems. These types of structural elements are particularly attractive because of their high torsional stiffness, which is required when the bridge is curved.

With the advent of these bridges, appropriate design specifications[1,2,3] design guides[5,6,7] computer solutions[8,9] are required. Here is a summation of this information:

## DESIGN SPECIFICATIONS

There are at present a set of standard specifications,[1] which pertain to straight box girders for highway bridges. Guide specifications[2] are also being used for curved box structures, but to date have not been incorporated into the standard code.[1] Further research has also been conducted, which has resulted in a tentative strength or load factor design code for curved bridges.[3] All three of these codes[1,2,3] have been studied and the appropriate criteria for the design of each element of a box (i.e., top flange, bottom flange, web) categorized according to working stress method or strength method as given in Tables 1 and 2. The working stress criteria has recently been incorporated into a design oriented computer program.[9]

In addition to these basic specifications,[1,2,3] a new code[4] has been proposed for consideration, but has yet to be adopted.

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## DESIGN GUIDES

**Flange Areas**—In the design of any complex structure in which the section changes and the forces are not readily computed, it is useful to have data or empirical equations to select plate geometry, which can then be incorporated in a computer program[9] to automate the bridge design. Such information has been developed[5,6,7] and has resulted in the following:

i) Single-span bridge

$$A_T = 10d\left(1 - \frac{84}{L}\right)$$

$$A_B = 13d\left(1 - \frac{92}{L}\right)$$

ii) Two-span bridge

$$A_B^+ = \frac{1}{k}\,(0.00153L^2 - 0.223L + 13)$$

$$A_B^- = 1.17\,A_B^+\frac{F_y^-}{F_y^+}$$

$$A_T^+ = 0.64\,A_B^+$$

$$A_T^- = 1.60\,A_B^+\frac{F_y^-}{F_y^+}$$

**Table 1. Working Stress Design Requirements**

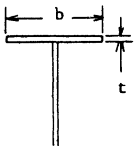
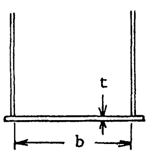
| Item | Straight | Curved |
|---|---|---|
| Compression Flange (positive moment)<br> | $\frac{b}{t} \leqq \frac{3250}{\sqrt{f_b}} \leqq 24$ | $\frac{b}{t} \leqq \frac{4400}{\sqrt{F_y}}$<br>and<br>$F_b = 0.55 F_y \left[1 - \frac{\left(\frac{l}{r'}\right)^2 F_y}{4\pi^2 E}\right] \rho_B \rho_w$<br>where<br>$\rho_B = \frac{1}{1 + \left(\frac{l}{R}\right)\left(\frac{l}{b}\right)}$ and $\rho_w = \rho_{w1}$ or $\rho_{w2}$, where;<br>$\rho_{w1} = \frac{1}{1 - \left(\frac{f_w}{f_b}\right)\left[1 - \frac{(l/b)}{75}\right]}$<br>or<br>$\rho_{w2} = \frac{0.95 + \frac{l/b}{[30 + 8000(0.1 - l/R)^2]}}{1 + 0.6\left(\frac{f_w}{f_b}\right)}$<br>if $\frac{f_w}{f_b}$ (+) use smaller $\rho_{w1}$ or $\rho_{w2}$<br>$\frac{f_w}{f_b}$ (−) use $\rho_{w1}$ |
| Compression Flange (negative moment)<br> | $\frac{b}{t} \leqq \frac{6140}{\sqrt{F_y}}$<br>$f_b \leqq 0.55 F_y$<br>$\frac{6140}{\sqrt{F_y}} \leqq \frac{b}{t} \leqq 60$ or $\frac{13,300}{\sqrt{F_y}}$<br>$f_b \leqq 0.55F_y - 0.224F_y \left[1 - \sin\frac{\pi}{2}\left(\frac{13,300 - b/t\sqrt{F_y}}{7160}\right)\right]$<br>$\frac{13,300}{\sqrt{F_y}} < \frac{b}{t} \leqq 60$<br>$f_b \leqq 57.6 \times 10^6 \left(\frac{t}{b}\right)^2$ | $\frac{b}{t} \leqq \frac{6140}{\sqrt{F_y}} \cdot X$<br>$F_b = 0.55 F_y \sqrt{1 - 9.2\left[\frac{f_v}{F_y}\right]^2}$<br>where $X = 1 + 4/3\left(\frac{f_v}{\sqrt{F_y}} - 0.15\right) \geqq 1$<br>$\frac{6140}{\sqrt{F_y}} < \frac{b}{t} \leqq \frac{13,300}{\sqrt{F_y}}$ or 60<br>$F_b = \left[0.326F_y + 0.224F_y\left\{\sin\frac{\pi}{2}\left(\frac{13,300 - b\sqrt{F_y}/t}{13,300 - 6140X}\right)\right\}\right]\Delta$<br>where<br>$\Delta = \sqrt{1 - 9.0\left(\frac{f_v}{F_y}\right)^2}$<br>if<br>$\frac{b}{t} \geqq \frac{13,300}{\sqrt{F_y}}$<br>$F_b$ is smaller of the following:<br>$F_b = 57.6\left(\frac{t}{b}\right)^2 \cdot 10^6\Delta$<br>$F_b = 57.6\left(\frac{t}{b}\right)^2 \times 10^6 - \frac{f_v^2}{113.4\left(\frac{t}{b}\right)^2} \times 10^6$ |

**Table 1.** *(continued)*

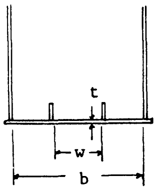
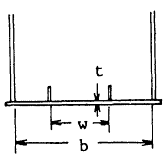
| Item | Straight | Curved |
|---|---|---|
| Compression Flange (negative moment) With Stiffener<br> | $\frac{w}{t} \leqq \frac{3070\sqrt{K}}{\sqrt{F_y}}$<br>$f_b \leqq 0.55F_y$<br>$\frac{3070\sqrt{K}}{\sqrt{F_y}} < \frac{w}{t} \leqq 60$ or $\frac{6650\sqrt{K}}{\sqrt{F_y}}$<br>$f_b \leqq 0.55F_y - 0.224F_y\left[1 - \sin\frac{\pi}{2}\frac{6650\sqrt{K} - \frac{w}{t}\sqrt{F_y}}{3580\sqrt{K}}\right]$<br>$\frac{6650\sqrt{K}}{\sqrt{F_y}} < \frac{w}{t} \leqq 60$<br>$f_b \leqq 14.4 \times 10^6 K\left(\frac{t}{w}\right)^2$<br>Stiffener requirement<br>with longitudinal Stiffener<br>$I_s \geqq \phi t^3 w$<br>where<br>$\phi = \begin{cases} 0.07K^3n^4 \text{ for } n > 1 \\ 0.125K^3 \text{ for } n = 1 \end{cases}$ | $\frac{w}{t} \leqq \frac{3070\sqrt{K}}{\sqrt{F_y}} \cdot X_1$<br>$F_b = 0.55F_y\sqrt{1 - 912\left(\frac{f_v}{F_y}\right)^2}$<br>where<br>$X_1 = 1\ (n > 1)$<br>$X_1 = 0.93 + \left(1.6 - \frac{K}{K_s}\right)\left(\frac{f_v}{F_y}\right) \geqq 1\ (n = 1)$<br>$2 \leqq K \leqq 4$<br>$K_s = \frac{5.34 + 2.84(I_s/wt^3)^{1/3}}{(n+1)^2} \leqq 5.34$ |
| Compression Flange (negative moment) With Stiffener<br> | | $\frac{3070\sqrt{K}}{\sqrt{F_y}}X_1 < \frac{w}{t} \leqq \frac{6650\sqrt{K}}{\sqrt{F_y}}X_2$ or 60<br>$F_b = \left[0.326F_y + 0.224F_y\left\{\sin\frac{\pi}{2}\frac{6650\sqrt{K}X_2 - \frac{w\sqrt{F_y}}{t}}{6650\sqrt{K}X_2 - 3070\sqrt{K}X_1}\right\}\right]\Delta$<br>Where<br>$\Delta = \sqrt{1 - 9.0\left(\frac{f_v}{F_y}\right)^2}$<br>$X_2 = 1 - 2.13\left(\frac{f_v}{F_y}\right)$<br>$+ 0.1\left\{\left(\frac{K}{K_s}\right) - 5.34\right\}^2\left(\frac{f_v}{F_y}\right)$<br>$\frac{6650\sqrt{K}X_2}{\sqrt{F_y}} < \frac{w}{t} \leqq 60$<br>$F_b$ is smaller value of<br>$F_b = 14.4K\left(\frac{t}{w}\right)^2\Delta\, 10^6$<br>or<br>$F_b = 14.4K\left(\frac{t}{w}\right)^2 \times 10^6 - \frac{f_v^2K}{14.4(K_s)^2\left(\frac{t}{w}\right)^2} \times 10^6$ |

**Table 1.** *(continued)*

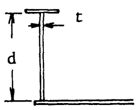
| Item | Straight | Curved |
|---|---|---|
| With Longitudinal and Transverse Stiffener | Use same formula, but use $K_1$ instead of $K$<br>$$K_1 = \frac{\left[1 + \left(\frac{a}{b}\right)^2\right]^2 + 87.3}{(n+1)^2 \left(\frac{a}{b}\right)^2 \lvert 1 + 0.1(n+1) \rvert}$$<br>$I_s \geq 8t^3 w$<br>$I_t \geq 0.10(n+1)^3 w^3 \frac{f_s}{E}\frac{A_f}{a}$<br>where<br>$a$: spacing of transverse stiffener<br>$f_s$: maximum longitudinal bending stress<br>$A_f$: Area of flange including longitudinal stiffener | |
| Web Without Stiffener<br><br><br>With Transverse Stiffener | $\frac{d}{t} \leq 150$<br>$f_v \leq \frac{5.625 \times 10^7}{(d/t)^2} \leq \frac{F_y}{3}$<br>$\frac{d}{t} \leq \frac{23{,}000.}{\sqrt{F_b}} \leq 170$<br>$d_0 \leq 1.5d$<br>$f_v \leq \frac{F_y}{3}\left[C + \frac{0.87(1-C)}{\sqrt{1+(d_0/d)^2}}\right]$<br>$C = \frac{2.2 \times 10^8 \lvert 1 + (d/d_0)^2 \rvert}{F_y (d/t)^2} \leq 1.0$<br>$d_0$ = stiffener spacing | Same<br>If $d_0/R \leq 0.02$ use straight girder criteria<br>If $d_0/R \geq 0.02$<br>$\frac{d}{t} \leq \frac{23{,}000}{F_b}\left\{1.19 - 10\left(\frac{d_0}{R}\right) + 34\left(\frac{d_0}{R}\right)^2\right\} \leq 170$<br>$d_0 \leq 1.5d$<br>$f_v = \frac{F_y}{3}\left[C + \frac{0.87(1-C)}{\sqrt{1+(d_0/d)^2}}\right]$<br>$C = \frac{2.2 \times 10^8 \lvert 1 + (d/d_0)^2 \rvert}{F_y (d/t)^2} \leq 1.0$ |
| Web With Transverse Stiffener | Stiffener Criteria<br>$I \geq \frac{d_0 t^3}{10.92} J$<br>$J = 25\left(\frac{d_0}{d}\right)^2 - 20 \geq 5.0$ | Stiffener Criteria<br>$I \geq d_o t^3 J$<br>$J = \left[25\left(\frac{d_o}{d}\right)^2 - 20\right] X \geq 5.0$<br>$X = 1.0$ for $\frac{d_0}{d} \leq 0.78$<br>$X = 1.0 + \left(\frac{\left(\frac{d_0}{d} - 0.78\right)}{1775}\right) Z^4; 0.78 \leq \frac{d_0}{d} \leq 1.0$<br>$Z = 0.95 \frac{d^2}{Rt}$<br>$\frac{b}{t} \leq \frac{2600}{\sqrt{F_y}}$ |

**Table 2. Strength Design Requirements**

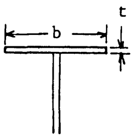
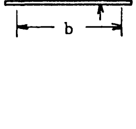
| Item | Straight | Curved |
|---|---|---|
| Compression Flange (positive moment)<br><br> | $\frac{b}{t} \le \frac{3200}{\sqrt{F_y}}$<br>$f_b = F_y$<br>if $\frac{3200}{\sqrt{F_y}} \le \frac{b}{t} \le \frac{4400}{\sqrt{F_y}}$<br>$f_b = F_y(1 - 3\lambda^2)$<br>$\lambda = \frac{1}{\pi}\frac{l}{b}\sqrt{\frac{F_y}{E}}$ | $\frac{b}{t} \le \frac{3200}{\sqrt{F_y}}$<br>$f_b = F_{bs}\bar{\rho}_B\bar{\rho}_w$<br>where<br>$\bar{\rho}_B = \frac{1}{1 + \frac{l}{b}\left(1 + \frac{l}{6b}\right)\left(\frac{l}{R} - 0.01\right)^2}$<br>$\bar{\rho}_w = 0.95 + 18\left[0.1 - \frac{l}{R}\right]^2 + \frac{\frac{f_w}{f_b}\left(0.3 - 0.1\frac{l}{R}\frac{l}{b}\right)}{\bar{\rho}_B F_y/F_{bs}}$<br>$F_{bs} = Fy(1 - 3\lambda^2)$<br>$\lambda = \frac{1}{\pi}\left(\frac{l}{b}\right)\sqrt{\frac{F_y}{E}}$<br>if $\frac{3200}{\sqrt{F_y}} \le \frac{b}{t} \le \frac{4400}{\sqrt{F_y}}$<br>$f_b \le F_{by}$<br>where<br>$F_{by} = F_{bs}\rho_B\rho_w$<br>$\rho_B = \frac{1}{1 + \frac{l}{R}\frac{l}{b}}$ and $\rho_w = \rho_{w1}$ or $\rho_{w2}$, where;<br>$\rho_{w1} = \frac{1}{1 - \frac{f_w}{f_b}\left(1 - \frac{l}{75b}\right)}$<br>$\rho_{w2} = \frac{0.95 + \frac{l/b}{30 + 8000(0.1 - l/R)^2}}{1 + 0.6(f_w/f_b)}$<br>if<br>$\frac{f_w}{f_b}$ (+) use smaller $\rho_{w1}$ or $\rho_{w2}$<br>$\frac{f_w}{f_b}$ (−) use $\rho_{w1}$ |
| Compression Flange (negative moment) Without Stiffener<br><br> | $\frac{b}{t} \leqq \frac{6140}{\sqrt{F_y}}$ then $F_{cr} = F_y$<br>$\frac{6140}{\sqrt{F_y}} < \frac{b}{t} \leqq \frac{13,300}{\sqrt{F_y}}$<br>then $F_{cr} = 0.592\, F_y\left(1 + 0.687 \sin\frac{\pi}{2}c\right)$<br>where $C = \frac{13,300 - \frac{b}{t}\sqrt{F_y}}{7160}$<br>$\frac{b}{t} > \frac{13,300}{F_y}$<br>then $F_{cr} = 105 \times 10^6(t/b)^2$ | $f_v \leqq 0.75\frac{F_y}{\sqrt{3}}$ and $\frac{b}{t} \leqq \frac{R_1}{\sqrt{F_y}}$<br>then $F_b = F_y \cdot \Delta$<br>$\frac{R_1}{\sqrt{F_y}} < \frac{b}{t} \leqq \frac{R_2}{\sqrt{F_y}}$ or 60<br>then $F_b = 26.21 \times 10^6 K\left(\frac{t}{b}\right)^2 - \frac{f_v^2 K}{26.21 \times 10^6 K_s\left(\frac{t}{b}\right)^2}$<br>also if<br>$0.75\frac{F_y}{\sqrt{3}} < f_v \leqq \frac{F_y}{\sqrt{3}}$<br>$\frac{b}{t} \leqq \frac{R_1}{\sqrt{F_y}}$<br>$F_b = F_y\Delta$ |

**Table 2.** *(continued)*

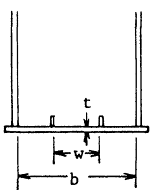
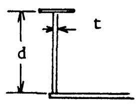
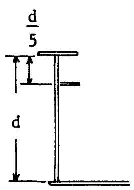
| Item | Straight | Curved |
|---|---|---|
| | | where<br>$R_1 = \dfrac{3070\sqrt{K}}{\sqrt{\dfrac{1}{2}\sqrt{\left(\Delta + \Delta^2 + 4\left(\dfrac{f_v}{F_y}\right)^2\left(\dfrac{K}{K_s}\right)^2\right)}}}$<br>$R_2 = \dfrac{6650\sqrt{K}}{\sqrt{\dfrac{1}{1.2}\left[\Delta - 0.4 + \sqrt{(\Delta - 0.4)^2 + 4\left(\dfrac{f_v}{F_y}\right)^2\left(\dfrac{K}{K_s}\right)^2}\right]}}$<br>$\Delta = \sqrt{1 - 3\left(\dfrac{f_v}{F_y}\right)^2}$<br>$K = 4$<br>$K_s = 5.34$ |
| Compression Flange (negative moment) With Stiffener<br><br> | $\dfrac{w}{t} \leqq \dfrac{3070\sqrt{K}}{\sqrt{F_y}}$<br>$F_{cr} = F_y$<br>$\dfrac{3070\sqrt{K}}{\sqrt{F_y}} < \dfrac{w}{t} \leqq \dfrac{6650\sqrt{K}}{\sqrt{F_y}}$<br>$F_{cr} = 0.592\, F_y \left(1 + 0.687 \sin \dfrac{C\pi}{2}\right)$<br>where<br>$C = \dfrac{6650\sqrt{K} - \dfrac{w}{t}\sqrt{F_y}}{3580\sqrt{K}}$<br>$\dfrac{w}{t} > \dfrac{6650\sqrt{K}}{\sqrt{F_y}}$<br>$F_{cr} = 26.2 \times 10^6 K\,(t/w)^2$ | $f_v \leq 0.75\dfrac{F_y}{\sqrt{3}}$ and $\dfrac{w}{t} \leq \dfrac{R_1}{\sqrt{F_y}}$<br>then $F_b = F_y\Delta$<br>$\dfrac{R_1}{\sqrt{F_y}} \leq \dfrac{w}{t} \leq \dfrac{R_2}{\sqrt{F_y}}$ or 60<br>then $F_b = F_y\left\{\Delta - 0.4\left\{1 - \sin\dfrac{\pi}{2}\left(\dfrac{R_2 - \dfrac{w\sqrt{F_y}}{t}}{R_2 - R_1}\right)\right\}\right\}$<br>$R_2 \leq w \leq 60$<br>$F_b = 26.21 \times 10^6\, K\left(\dfrac{t}{w}\right)^2 \dfrac{-f_v^2 K}{26.1 \times 10^6 K_s\left(\dfrac{t}{w}\right)^2}$<br>also if $0.75\dfrac{F_y}{\sqrt{3}} \leq f_v \leq \dfrac{F_y}{\sqrt{3}}$ and<br>$\dfrac{w}{t} \leq \dfrac{R_1}{\sqrt{F_y}}$<br>$F_b = F_y\,\Delta$<br>$R_1$, $R_2$ and $\Delta$ are given under compression flange without stiffener section and<br>$2 \leq K \leq 4$<br>$K_s = \dfrac{5.34 + 2.84\,(I_s/wt^3)^{1/3}}{(n+1)^2} \leq 5.34$ |
| | Stiffener Criteria | Stiffener Criteria |
| Compression Flange (negative moment) With Stiffener | $I_s \geq \phi t^3 w$<br>where $\phi = \begin{bmatrix} 0.07K^3n^4 \text{ for } n = 2,3,4,5 \\ 0.125K^3 \text{ for } n = 1 \end{bmatrix}$<br>and<br>$\dfrac{b'}{t'} \leqq \dfrac{2{,}600}{\sqrt{F_y}}$<br>where $b'$: depth of stiffener<br>$t'$: plate thickness of stiffener | $I_s \geq \phi t^3 w$<br>where:<br>$\phi = 0.07\, K^3 n^4$ for $n > 1$<br>$\phi = 0.125\, K^3\; n = 1$<br>$\dfrac{b}{t} \leq \dfrac{2{,}600}{\sqrt{F_y}}$ |

**Table 2.** *(continued)*

| Item | Straight | Curved |
|---|---|---|
| Web<br>Without<br>Stiffener<br><br><br>With<br>Transverse<br>Stiffener | $\frac{d}{t} \leq 150$<br>$V_u \leq 1.015 \times 10^8 t^3/d$ or<br>$V_u \leq 0.58\, F_y dt$<br>$\frac{d}{t} \leq \frac{36{,}500}{\sqrt{F_y}}$<br>$d_0 \leq 1.5\, d$<br>$V \leq V_p \left[C + \frac{0.87(1 - C)}{\sqrt{1 + (d_0/d)^2}}\right]$<br>where:<br>$V_p = 0.58\, F_y dt$<br>$C = 18{,}000 \left(\frac{d}{t}\right) \sqrt{\frac{1 + (d/d_0)^2}{F_y}} - 0.3 \leq 1.0$ | $\frac{d}{t} \leq 150$<br>$V_u \leq \frac{3.5Et^3}{d}$ or<br>$V_u \leq 0.58\, F_y dt$<br>$\frac{d}{t} \leq 150$<br>$d_0 \leq 1.5d$<br>$V \leq 0.58\, F_y dtC$<br>where:<br>$C = \left\{18{,}000\,(t/d) \sqrt{\frac{1 + (d/d_0)^2}{F_y}}\right\} - 0.3 \leq 1.0$ |
| Web With<br>Transverse and<br>Longitudinal<br>Stiffener<br><br> | $\frac{d}{t} \leq \frac{73{,}000}{\sqrt{F_y}}$<br>$d_0 \leq 1.5d$<br>and longitudinal stiffener is $d/5$ for compression flange. Shear requirements in accordance with transversely stiffened web criteria. | $\frac{36{,}500}{\sqrt{F_y}} \left[1 - 8.6 \left(\frac{d_0}{R}\right) + 34 \left(\frac{d_0}{R}\right)^2\right]$<br>$\leq \frac{d}{t} \leq \frac{73{,}000}{\sqrt{F_y}} \left[1 - 2.9 \sqrt{\frac{d_0}{R}} + 2.2 \left(\frac{d_0}{R}\right)\right]$<br>$d_0 \leq 1.5d$<br>and longitudinal stiffener is $d/5$ for compression flange shear requirements in accordance with transversely stiffened web criteria. |
| Transverse<br>Stiffener<br>Criteria | $b/t \leq \frac{2600}{\sqrt{F_y}}$<br>$b$ = projected width of stiffener and the gross area is $A \geq [0.15Bdt(1 - C)(V/V_u) - 18t^2]Y$<br>*where:*<br>$B$ = 1.0 for stiffener pairs<br>$B$ = 1.8 for single angles<br>$B$ = 2.4 for single plates<br>$C = 18{,}000\,(t/d) \sqrt{\frac{1 - (d/d_0)^2}{F_y}} - 0.3 \leqq 1$<br>and<br>$V_u$ = as given previously<br>$Y$ = ratio of web plate to stiffener plate yield strengths<br>$I \geq d_0 t^3 J$<br>$J = 2.5(d/d_0)^2 - 2 \geq 0.5$ | Same as straight except<br>$J = [2.5(d/d_0)^2 - 2]\, X \leq 0.5$<br>$X = 1.0$ when $(d_0/d) \leq 0.78$ and<br>$X = 1 + \left\{\frac{d_0/d - 0.78}{1775}\right\} Z^4$ when $0.78 < \frac{d_0}{d} \leqq 1.0$<br>where $Z = \frac{0.95 d_0^2}{Rt}$ |
| Longitudinal<br>Stiffener<br>Criteria | $\frac{b'}{t'} \leq \frac{2600}{\sqrt{F_y}}$<br>$I = dt^3 \left[2.4 \left(\frac{d_0}{d}\right)^2 - 0.13\right]$<br>$r \geq \frac{d_1 \sqrt{F_y}}{23{,}000.}$<br>$S_t \geq \frac{1}{3}\left(\frac{d}{d_0}\right) S_s$<br>$S_t$ = Section modulers of transverse stiffener<br>$S_s$ = Section modulers of longitudinal stiffener | Same criteria as straight |

iii) Three-span bridge

$$\left.\begin{aligned} A_T^+ &= \frac{n}{6.4k}(L_1 - 73) \\ A_B^+ &= \frac{n}{5k}(L_1 - 52) \end{aligned}\right\} \text{Exterior section}$$

$$\left.\begin{aligned} A_T^- &= \frac{n}{2.6k}(L_1 - 100) \\ A_B^- &= \frac{1}{kn}(0.964L_2 - 1.65L_2^2 \\ &\quad \times 10^{-3} - 70) \end{aligned}\right\} \text{Support}$$

$$\left.\begin{aligned} A_T^+ &= 0.95A_T^- - 0.011(A_T^-)^2 \\ &\quad - 5.4/k \\ A_B^+ &= \frac{n}{10k}(L_2 - 48) \end{aligned}\right\} \text{Interior section}$$

where: $k = \dfrac{N_B F_y d}{w_R \times 600}$

$F_y$ = yield point of material at specified section (ksi)
$L, L_1, L_2$ = span length (ft)
$w_R$ = roadway width (ft)
$N_B$ = number of boxes
$d$ = girder depth (inches)
$n = L_2/L_1$, $L_1$ = exterior span, $L_2$ = interior span
$A_T^+, A_T^-$ = total top flange area (in.$^2$) in positive or negative moment region
$A_B^+, A_B^-$ = total bottom flange area (in.$^2$) in positive or negative moment region

**Box Girder Geometry**—To select the final cross-sectional dimensions of a box girder bridge, along its length, many designs are required. To facilitate such designs, a study[6] was conducted to optimize the cross sections of single, two- and three-span straight box girder bridges. The specific geometry associated with these bridges are:

1. *Parametric details*
   Span length
   single-span: $L$ = 50 ft, 100 ft, 150 ft
   two-span: $L1$ = 50 ft, 100 ft, 150 ft
   $L2 = N.L1$, $N$ = 1.0, 1.2, 1.4, 1.6
   three-span: $L1$ = 50 ft, 100 ft, 150 ft
   $L2 = N.L1$, $N$ = 1.0, 1.2, 1.4, 1.6
   where $L2$ equals end span for two span or $L2$ equals center span for three span symmetrical bridge.
   Web depth: $d/L \leq 1/25$
   Top flange: $b/t \leq 23$. (positive moment region)
   Bottom flange width: 80 in., 100 in., 120 in.
   Bottom flange stiffener: $ST$ 7.5 × 25. (negative moment region)
   Concrete slab 8.5 in.
   Steel type $A36$, $F_y$ = 36 ksi
   $N = 9$, $3N = 27$, $f'c$ = 4 ksi
   Unit weight: steel 490 pcf, concrete 150 pcf
   General parameters
   parapit: 300 lbs./ft
   wearing surface: 15 lbs./ft$^2$
   miscellaneous concrete: 112 lbs./ft
   miscellaneous steel: 12%
2. *Procedure*
   The determination of the correct plate geometry the various bridges, involved the following prc dure:
   Fix span length $L$
   Select web depth $d = 12L/25$
   Select bottom flange width $W$ = 80 in.
   Select web thickness
   Select top flange width $b \leq 23t$
   Determine dead-load moments
   Determine location of cross sectional chan using data given in Tables 3 and 4 and Fig. 1
   Revise sections and computed dead-load, live-l forces and stress.
   Revise per specifications.
   Set bottom flange width $W$ = 100 in., repeat.
3. *Results*
   The procedure outlined above was followed for design of 81 bridges. The results of these designs single, two span and three span bridges are tabul in Tables 5, 6, and 7.

**Bracing Requirements**—The required cross diaphr bracing area,[10] as shown in Figs. 2 and 3, can be de mined from the following;

$$A_b \geqq 750 \frac{Sb}{d^2} \frac{t^3}{(d+b)} \text{ (in.}^2\text{)}$$

where

$s$ = Diaphragm spacing (in.)
$b$ = Width of box (in.), at bottom flange
$d$ = Depth of box (in.)
$t = \dfrac{A}{2(d+b)}$ = weighted section thickness (in
$A$ = Total cross sectional plate area (in.$^2$) a diaphragm location
$A_b$ = Required area of cross diaphragm bra (in.$^2$)

The bracing spacing requirement is given by the lowing:

$$s \leqq 12L\left(\frac{R}{200L - 7500}\right)^{1/2} \leqq 300 \text{ in.}$$

where
$L$ = Span length (ft)
$R$ = Radius of girder (ft)

Top lateral bracing is utilized in stiffening the box du shipment and erection. Such bracing can also provide

**Table 3**

| Span | No. cross sect. | Web Depth | Web Thickness | Top Flange Width | Top Flange Thickness | Bottom Flange Width | Bottom Flange Thickness | Bottom Stiffener $A$ | Bottom Stiffener $Ix$ | Bottom Stiffener no. | $At/Ab$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ** | 1 | 24.0 | 0.375 | 7.0 | 0.375 | 80.0 | 0.375 | | | | 0.175 |
| 50′-80″ | 2 | 24.0 | 0.375 | 11.75 | 0.5875 | 80.0 | 0.375 | | | | 0.460 |
| | 3 | 24.0 | 0.375 | 7.0 | 0.375 | 80.0 | 0.375 | | | | 0.175 |
| | 1 | 24.0 | 0.375 | 8.25 | 0.375 | 100.0 | 0.340 | | | | 0.165 |
| 50-100 | 2 | 24.0 | 0.375 | 13.75 | 0.625 | 100.0 | 0.340 | | | | 0.510 |
| | 3 | 24.0 | 0.375 | 8.25 | 0.375 | 100.0 | 0.340 | | | | 0.165 |
| | 1 | 24.0 | 0.375 | 8.75 | 0.4375 | 120.0 | 0.310 | | | | 0.170 |
| 50-120 | 2 | 24.0 | 0.375 | 13.75 | 0.750 | 120.0 | 0.310 | | | | 0.555 |
| | 3 | 24.0 | 0.375 | 8.75 | 0.4375 | 120.0 | 0.310 | | | | 0.170 |
| | 1 | 48.0 | 0.500 | 10.50 | 0.5625 | 80.0 | 0.500 | | | | 0.393 |
| 100-80 | 2 | 48.0 | 0.500 | 18.75 | 1.000 | 80.0 | 0.750 | | | | 0.625 |
| | 3 | 48.0 | 0.500 | 10.50 | 0.5625 | 80.0 | 0.500 | | | | 0.393 |
| | 1 | 48.0 | 0.500 | 11.75 | 0.750 | 100.0 | 0.375 | | | | 0.470 |
| 100-100 | 2 | 48.0 | 0.500 | 17.75 | 1.250 | 100.0 | 0.6875 | | | | 0.648 |
| | 3 | 48.0 | 0.500 | 11.75 | 0.750 | 100.0 | 0.375 | | | | 0.470 |
| | 1 | 48.0 | 0.500 | 15.50 | 0.750 | 120.0 | 0.375 | | | | 0.517 |
| 100-120 | 2 | 48.0 | 0.500 | 20.75 | 1.250 | 120.0 | 0.625 | | | | 0.692 |
| | 3 | 48.0 | 0.500 | 15.50 | 0.750 | 120.0 | 0.375 | | | | 0.517 |

** $L - b_w$.

eral stiffness to create a pseudo closed box and thus minimize the warping stresses. The required area for such bracing, as shown in Fig. 4, is given by;

$$A_{bl} \geqq 0.036 \text{ (in.}^2\text{)}$$

where

$A_{bl}$ = Required area of lateral bracing (in.$^2$)

**Natural Frequency**—The designer is often required to evaluate the vertical natural frequency $f$, especially if the structure is subjected to train loadings. Such evaluation, for curved structures, has been determined[11] and has resulted in the following equations:

$$f = \frac{\pi}{2k^2L^2}\left[\left(EI_x + \frac{EI_w}{R^2} - \frac{GK_TL^2}{R^2}\right)\Big/ M\right]^{1/2} \text{ (cps)}$$

**Table 4. Location of Section Changes for Negative Moment**

| Negative Region Moment | | | | | |
|---|---|---|---|---|---|
| Length (ft) | No. of Cros. sect. | $X_1$ | $X_2$ | $X_3$ | $X_4$ |
| $L < 49$ | 3 | $0.109L$ | $0.239L$ | | |
| $49 \leq L < 82$ | 4 | $0.081L$ | $0.172L$ | $0.282L$ | |
| $82 \leq L < 115$ | 5 | $0.065L$ | $0.136L$ | $0.215L$ | $0.310L$ |

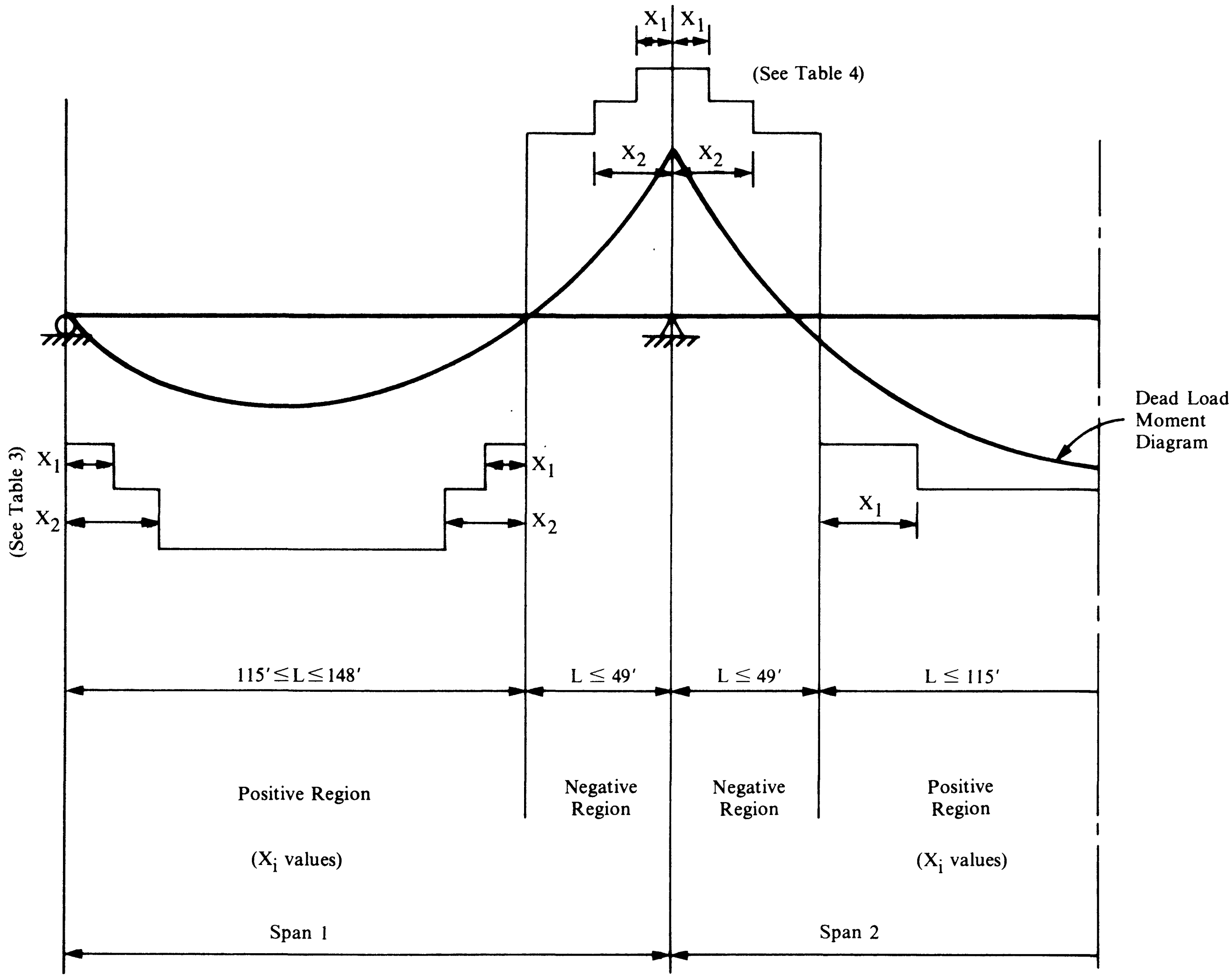



*Fig. 1. Example of location of section changes*

where:

$EI_x$ = bending stiffness (kip-in.$^2$)
$EI_w$ = warping stiffness (kip-in.$^4$)
$GK_T$ = torsional stiffness (kip-in.$^2$)
$R$ = radius (in.)
$M$ = mass (w/g) (kip-sec$^2$/in.)
$L$ = exterior span length (in.)
$k = Bn^2 + Cn + D$ (for simple spans, $k = 1$)

and $B$, $C$, $D$ are constants defined as:

| | $B$ | $C$ | $D$ |
|---|---|---|---|
| Two span | 0.242 | −0.80 | 1.55 |
| Three span | 0.367 | −1.24 | 1.87 |

and $n = L_{interior}/L_{exterior}$ $1.0 \leq n \leq 1.7$.

As approximations for the torsional properties, the following expressions may be used;

$$K_T = \frac{2t'(b'd')^2}{(d + b)}$$

$$L_W = \frac{t'b'^2d'^3}{24}\frac{(1 - b'/d')^2}{(1 + b'/d')^2}$$

where
$b'$ = average width of box
$d'$ = average depth of box
$t'$ = average plate thickness

**Ultimate Strength**—The ultimate strength determination of a curved box girder requires consideration of the interaction between the bending moment and torque. A com-

### Table 5. Single-Span Section Dimensions

| Span (ft) | No. cross sect. | Web | | Top Flange | | Bottom Flange | | Bottom Stiffener | | | $A_T/A_B$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | Thickness | Width | Thickness | Width | Thickness | $A$ | $Ix$ | no. | |
| 50 | 1 | 24.0 | 0.375 | 7.0 | 0.375 | 80.0 | 0.375 | | | | 0.175 |
| | 2 | 24.0 | 0.375 | 11.75 | 0.5875 | 80.0 | 0.375 | | | | 0.460 |
| | 3 | 24.0 | 0.375 | 7.0 | 0.375 | 80.0 | 0.375 | | | | 0.175 |
| 50 | 1 | 24.0 | 0.375 | 8.25 | 0.375 | 100.0 | 0.340 | | | | 0.165 |
| | 2 | 24.0 | 0.375 | 13.75 | 0.625 | 100.0 | 0.340 | | | | 0.510 |
| | 3 | 24.0 | 0.375 | 8.25 | 0.375 | 100.0 | 0.340 | | | | 0.165 |
| 50 | 1 | 24.0 | 0.375 | 8.75 | 0.4375 | 120.0 | 0.310 | | | | 0.170 |
| | 2 | 24.0 | 0.375 | 13.75 | 0.750 | 120.0 | 0.310 | | | | 0.555 |
| | 3 | 24.0 | 0.375 | 8.75 | 0.4375 | 120.0 | 0.310 | | | | 0.170 |
| 100 | 1 | 48.0 | 0.500 | 10.50 | 0.5625 | 80.0 | 0.500 | | | | 0.393 |
| | 2 | 48.0 | 0.500 | 18.75 | 1.000 | 80.0 | 0.750 | | | | 0.625 |
| | 3 | 48.0 | 0.500 | 10.50 | 0.5625 | 80.0 | 0.500 | | | | 0.393 |
| 100 | 1 | 48.0 | 0.500 | 11.75 | 0.750 | 100.0 | 0.375 | | | | 0.470 |
| | 2 | 48.0 | 0.500 | 17.75 | 1.250 | 100.0 | 0.6875 | | | | 0.648 |
| | 3 | 48.0 | 0.500 | 11.75 | 0.750 | 100.0 | 0.375 | | | | 0.470 |
| 100 | 1 | 48.0 | 0.500 | 15.50 | 0.750 | 120.0 | 0.375 | | | | 0.517 |
| | 2 | 48.0 | 0.500 | 20.75 | 1.250 | 120.0 | 0.625 | | | | 0.692 |
| | 3 | 48.0 | 0.500 | 15.50 | 0.750 | 120.0 | 0.375 | | | | 0.517 |
| 150 | 1 | 72.0 | 0.750 | 7.00 | 0.375 | 80.0 | 0.375 | | | | 0.175 |
| | 2 | 72.0 | 0.750 | 26.25 | 1.250 | 80.0 | 1.1875 | | | | 0.69 |
| | 3 | 72.0 | 0.750 | 7.00 | 0.375 | 80.0 | 0.375 | | | | 0.175 |
| 150 | 1 | 72.0 | 0.750 | 7.00 | 0.375 | 100.0 | 0.375 | | | | 0.14 |
| | 2 | 72.0 | 0.750 | 28.75 | 1.3125 | 100.0 | 1.0625 | | | | 0.71 |
| | 3 | 72.0 | 0.750 | 7.00 | 0.375 | 100.0 | 0.375 | | | | 0.14 |
| 150 | 1 | 72.0 | 0.750 | 7.00 | 0.375 | 120.0 | 0.375 | | | | 0.117 |
| | 2 | 72.0 | 0.750 | 30.50 | 1.4375 | 120.0 | 1.000 | | | | 0.731 |
| | 3 | 72.0 | 0.750 | 7.00 | 0.375 | 120.0 | 0.375 | | | | 0.117 |

Table 6. Two-Span Section Dimensions

| SPANS (ft) | No. cross sect. | Web | | Top Flange | | Bottom Flange | | Bottom Stiffener | | | $A_T/A_B$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | Thickness | Width | Thickness | Width | Thickness | $A$ | $Ix$ | no. | |
| ** | 1 | 24.0 | 0.375 | 7.50 | 0.375 | 80.0 | 0.375 | | | | 0.187 |
| 50-50 | 2 | 24.0 | 0.375 | 20.25 | 1.000 | 80.0 | 0.500 | 7.35 | 40.6 | 2 | 1.013 |
| | 3 | 24.0 | 0.375 | 7.50 | 0.375 | 80.0 | 0.375 | | | | 0.187 |
| | 1 | 24.0 | 0.375 | 8.375 | 0.4375 | 100.0 | 0.375 | | | | 0.195 |
| 50-50 | 2 | 24.0 | 0.375 | 21.25 | 1.125 | 100.0 | 0.5625 | 7.35 | 40.6 | 2 | 0.850 |
| | 3 | 24.0 | 0.375 | 8.375 | 0.4375 | 100.0 | 0.375 | | | | 0.195 |
| | 1 | 24.0 | 0.375 | 9.375 | 0.4375 | 120.0 | 0.375 | | | | 0.182 |
| 50-50 | 2 | 24.0 | 0.375 | 25.50 | 1.125 | 120.0 | 0.5625 | 7.35 | 40.6 | 3 | 0.850 |
| | 3 | 24.0 | 0.375 | 9.375 | 0.4375 | 120.0 | 0.375 | | | | 0.182 |
| | 1 | 24.0 | 0.375 | 6.500 | 0.375 | 80.0 | 0.375 | | | | 0.163 |
| 50-60 | 2 | 24.0 | 0.375 | 24.00 | 1.250 | 80.0 | 0.6875 | 7.35 | 40.6 | 2 | 1.090 |
| | 3 | 24.0 | 0.375 | 9.750 | 0.625 | 80.0 | 0.375 | | | | 0.406 |
| | 1 | 24.0 | 0.375 | 7.250 | 0.375 | 100.0 | 0.375 | | | | 0.145 |
| 50-60 | 2 | 24.0 | 0.375 | 29.00 | 1.250 | 100.0 | 0.6875 | 7.35 | 40.6 | 2 | 1.054 |
| | 3 | 24.0 | 0.375 | 11.00 | 0.625 | 100.0 | 0.375 | | | | 0.366 |
| | 1 | 24.0 | 0.375 | 7.750 | 0.375 | 120.0 | 0.375 | | | | 0.129 |
| 50-60 | 2 | 24.0 | 0.375 | 31.00 | 1.4375 | 120.0 | 0.6875 | 7.35 | 40.6 | 2 | 1.080 |
| | 3 | 24.0 | 0.375 | 12.75 | 0.625 | 120.0 | 0.375 | | | | 0.354 |
| | 1 | 24.0 | 0.4375 | 6.00 | 0.375 | 80.0 | 0.375 | | | | 0.15 |
| 50-70 | 2 | 24.0 | 0.4375 | 31.00 | 1.4375 | 80.0 | 0.9375 | 7.35 | 40.6 | 3 | 1.188 |
| | 3 | 24.0 | 0.4375 | 14.25 | 0.6875 | 80.0 | 0.500 | | | | 0.49 |
| | 1 | 24.0 | 0.4375 | 6.00 | 0.375 | 100.0 | 0.375 | | | | 0.12 |
| 50-70 | 2 | 24.0 | 0.4375 | 36.50 | 1.375 | 100.0 | 0.9375 | 7.35 | 40.6 | 3 | 1.07 |
| | 3 | 24.0 | 0.4375 | 16.00 | 0.8125 | 100.0 | 0.500 | | | | 0.52 |
| | 1 | 24.0 | 0.4375 | 6.00 | 0.375 | 120.0 | 0.375 | | | | 0.10 |
| 50-70 | 2 | 24.0 | 0.4375 | 41.00 | 1.625 | 120.0 | 1.000 | 7.35 | 40.6 | 3 | 1.11 |
| | 3 | 24.0 | 0.4375 | 18.00 | 0.875 | 120.0 | 0.4375 | | | | 0.60 |
| | 1 | 24.0 | 0.500 | 6.00 | 0.375 | 80.0 | 0.375 | | | | 0.15 |
| 50-80 | 2 | 24.0 | 0.500 | 31.00 | 1.500 | 80.0 | 1.000 | 7.35 | 40.6 | 3 | 1.162 |
| | 3 | 24.0 | 0.500 | 15.75 | 0.875 | 80.0 | 0.625 | | | | 0.55 |

**Table 6. Two-Span Section Dimensions**

| SPANS (ft) | No. cross sect. | Web | | Top Flange | | Bottom Flange | | Bottom Stiffener | | | $A_T/A_B$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | Thickness | Width | Thickness | Width | Thickness | $A$ | $Ix$ | no. | |
| 50–80 | 1 | 24.0 | 0.500 | 6.00 | 0.375 | 100.0 | 0.375 | | | | 0.12 |
| | 2 | 24.0 | 0.500 | 35.50 | 1.625 | 100.0 | 1.000 | 7.35 | 40.6 | 3 | 1.153 |
| | 3 | 24.0 | 0.500 | 18.75 | 0.875 | 100.0 | 0.5625 | | | | 0.583 |
| 50–80 | 1 | 24.0 | 0.500 | 6.00 | 0.375 | 120.0 | 0.375 | | | | 0.100 |
| | 2 | 24.0 | 0.500 | 42.00 | 1.8125 | 120.0 | 1.125 | 7.35 | 40.6 | 4 | 1.127 |
| | 3 | 24.0 | 0.500 | 19.75 | 1.000 | 120.0 | 0.5625 | | | | 0.585 |
| 100–100 | 1 | 48.0 | 0.5625 | 8.00 | 0.4375 | 80.0 | 0.375 | | | | 0.233 |
| | 2 | 48.0 | 0.5625 | 30.50 | 1.3750 | 80.0 | 0.9375 | 7.35 | 40.6 | 2 | 1.118 |
| | 3 | 48.0 | 0.5625 | 8.00 | 0.4375 | 80.0 | 0.375 | | | | 0.233 |
| 100–100 | 1 | 48.0 | 0.5625 | 9.50 | 0.4375 | 100.0 | 0.375 | | | | 0.222 |
| | 2 | 48.0 | 0.5625 | 35.50 | 1.4375 | 100.0 | 0.875 | 7.35 | 40.6 | 2 | 1.166 |
| | 3 | 48.0 | 0.5625 | 9.50 | 0.4375 | 100.0 | 0.375 | | | | 0.222 |
| 100–100 | 1 | 48.0 | 0.5625 | 10.25 | 0.500 | 120.0 | 0.375 | | | | 0.227 |
| | 2 | 48.0 | 0.5625 | 37.25 | 1.625 | 120.0 | 0.9375 | 7.35 | 40.6 | 2 | 1.076 |
| | 3 | 48.0 | 0.5625 | 10.25 | 1.625 | 120.0 | 0.375 | | | | 0.227 |
| 100–120 | 1 | 48.0 | 0.5625 | 6.25 | 0.375 | 80.0 | 0.375 | | | | 0.156 |
| | 2 | 48.0 | 0.5625 | 40.5 | 1.5625 | 80.0 | 1.500 | 7.35 | 40.6 | 2 | 1.054 |
| | 3 | 48.0 | 0.5625 | 15.50 | 0.750 | 80.0 | 0.625 | | | | 0.465 |
| 100–120 | 1 | 48.0 | 0.5625 | 6.50 | 0.375 | 100.0 | 0.375 | | | | 0.13 |
| | 2 | 48.0 | 0.5625 | 42.50 | 1.875 | 100.0 | 1.500 | 7.35 | 40.6 | 2 | 1.063 |
| | 3 | 48.0 | 0.5625 | 16.00 | 0.8125 | 100.0 | 0.500 | | | | 0.52 |
| 100–120 | 1 | 48.0 | 0.5625 | 7.00 | 0.375 | 120.0 | 0.375 | | | | 0.116 |
| | 2 | 48.0 | 0.5625 | 48.0 | 2.0625 | 120.0 | 1.5625 | 7.35 | 40.6 | 2 | 1.056 |
| | 3 | 48.0 | 0.5625 | 18.25 | 0.875 | 120.0 | 0.500 | | | | 0.532 |
| 100–140 | 1 | 48.0 | 0.625 | 6.75 | 0.375 | 80.0 | 0.375 | | | | 0.168 |
| | 2 | 48.0 | 0.625 | 39.25 | 1.875 | 80.0 | 1.750 | 7.35 | 40.6 | 2 | 1.051 |
| | 3 | 48.0 | 0.625 | 24.00 | 1.125 | 80.0 | 1.0625 | | | | 0.635 |
| 100–140 | 1 | 48.0 | 0.625 | 6.75 | 0.375 | 100.0 | 0.375 | | | | 0.135 |
| | 2 | 48.0 | 0.625 | 51.00 | 2.000 | 100.0 | 1.9375 | 7.35 | 40.6 | 2 | 1.053 |
| | 3 | 48.0 | 0.625 | 26.50 | 1.250 | 100.0 | 0.9375 | | | | 0.706 |

## Table 6. Two-Span Section Dimensions

| SPANS (ft) | No. cross sect. | Web | | Top Flange | | Bottom Flange | | Bottom Stiffener | | | $A_T/A_B$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | Thickness | Width | Thickness | Width | Thickness | $A$ | $Ix$ | no. | |
| 100–140 | 1 | 48.0 | 0.625 | 6.75 | 0.375 | 120.0 | 0.375 | | | | 0.113 |
| | 2 | 48.0 | 0.625 | 57.00 | 2.437 | 120.0 | 2.1875 | 7.35 | 40.6 | 2 | 1.058 |
| | 3 | 48.0 | 0.625 | 28.50 | 1.375 | 120.0 | 0.875 | | | | 0.75 |
| 100–160 | 1 | 48.0 | 0.6875 | 6.75 | 0.375 | 80.0 | 0.375 | | | | 0.168 |
| | 2 | 48.0 | 0.6875 | 40.5 | 1.9375 | 80.0 | 1.8125 | 7.35 | 40.6 | 2 | 1.083 |
| | 3 | 48.0 | 0.6875 | 27.00 | 1.375 | 80.0 | 1.3125 | | | | 0.707 |
| 100–160 | 1 | 48.0 | 0.6875 | 6.75 | 0.375 | 100.0 | 0.375 | | | | 0.135 |
| | 2 | 48.0 | 0.6875 | 48.00 | 2.0625 | 100.0 | 1.875 | 7.35 | 40.6 | 2 | 1.056 |
| | 3 | 48.0 | 0.6875 | 28.50 | 1.500 | 100.0 | 1.1875 | | | | 0.72 |
| 100–160 | 1 | 48.0 | 0.6875 | 6.75 | 0.375 | 120.0 | 0.375 | | | | 0.1125 |
| | 2 | 48.0 | 0.6875 | 51.0 | 2.4375 | 120.0 | 2.000 | 7.35 | 40.6 | 2 | 1.036 |
| | 3 | 48.0 | 0.6875 | 32.25 | 1.5625 | 120.0 | 1.0625 | | | | 0.79 |
| 150–150 | 1 | 72.0 | 0.75 | 7.25 | 0.4375 | 80.0 | 0.4375 | | | | 0.181 |
| | 2 | 72.0 | 0.75 | 39.0 | 1.6875 | 80.0 | 1.4375 | 7.35 | 40.6 | 2 | 1.144 |
| | 3 | 72.0 | 0.75 | 7.25 | 0.4375 | 80.0 | 0.4375 | | | | 0.181 |
| 150–150 | 1 | 72.0 | 0.75 | 9.00 | 0.500 | 100.0 | 0.375 | | | | 0.240 |
| | 2 | 72.0 | 0.75 | 41.00 | 1.875 | 100.0 | 1.4375 | 7.35 | 40.6 | 2 | 1.069 |
| | 3 | 72.0 | 0.75 | 9.00 | 0.500 | 100.0 | 0.375 | | | | 0.240 |
| 150–150 | 1 | 72.0 | 0.75 | 9.50 | 0.625 | 120.0 | 0.375 | | | | 0.264 |
| | 2 | 72.0 | 0.75 | 46.0 | 2.000 | 120.0 | 1.4375 | 7.35 | 40.6 | 2 | 1.066 |
| | 3 | 72.0 | 0.75 | 9.50 | 0.625 | 120.0 | 0.375 | | | | 0.264 |
| 150–180 | 1 | 86.0 | 0.8125 | 6.00 | 0.375 | 80.0 | 0.375 | | | | 0.150 |
| | 2 | 86.0 | 0.8125 | 40.00 | 1.75 | 80.0 | 1.625 | 7.35 | 40.6 | 2 | 1.076 |
| | 3 | 86.0 | 0.8125 | 13.0 | 0.625 | 80.0 | 0.5625 | | | | 0.361 |
| 150–180 | 1 | 86.0 | 0.8125 | 6.00 | 0.375 | 100.0 | 0.375 | | | | 0.12 |
| | 2 | 86.0 | 0.8125 | 45.0 | 1.9375 | 100.0 | 1.5625 | 7.35 | 40.6 | 2 | 1.116 |
| | 3 | 86.0 | 0.8125 | 14.0 | 0.75 | 100.0 | 0.500 | | | | 0.42 |
| 150–180 | 1 | 86.0 | 0.8125 | 6.0 | 0.375 | 120.0 | 0.375 | | | | 0.100 |
| | 2 | 86.0 | 0.8125 | 49.0 | 2.125 | 120.0 | 1.625 | 7.35 | 40.6 | 2 | 1.068 |
| | 3 | 86.0 | 0.8125 | 16.0 | 0.8125 | 120.0 | 0.4375 | | | | 0.495 |

**Table 6. Two-Span Section Dimensions**

| SPANS (ft) | No. cross sect. | Web | | Top Flange | | Bottom Flange | | Bottom Stiffener | | | $A_T/A_B$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | Thickness | Width | Thickness | Width | Thickness | $A$ | $Ix$ | no. | |
| | 1 | 100.0 | 0.9375 | 6.00 | 0.375 | 80.0 | 0.375 | | | | 0.150 |
| 150-210 | 2 | 100.0 | 0.9375 | 40.25 | 2.000 | 80.0 | 1.875 | 7.35 | 40.6 | 2 | 1.073 |
| | 3 | 100.0 | 0.9375 | 19.00 | 0.875 | 80.0 | 0.75 | | | | 0.554 |
| | 1 | 100.0 | 0.9375 | 6.00 | 0.375 | 100.0 | 0.375 | | | | 0.12 |
| 150-210 | 2 | 100.0 | 0.9375 | 49.00 | 2.0625 | 100.0 | 1.9375 | 7.35 | 40.6 | 2 | 1.043 |
| | 3 | 100.0 | 0.9375 | 20.5 | 0.9375 | 100.0 | 0.6875 | | | | 0.560 |
| | 1 | 100.0 | 0.9375 | 6.00 | 0.375 | 120.0 | 0.375 | | | | 0.100 |
| 150-210 | 2 | 100.0 | 0.9375 | 54.00 | 2.3125 | 120.0 | 2.0625 | 7.35 | 40.6 | 2 | 1.009 |
| | 3 | 100.0 | 0.9375 | 22.00 | 1.0625 | 120.0 | 0.625 | | | | 0.623 |
| | 1 | 115.0 | 1.0625 | 6.00 | 0.375 | 80.0 | 0.375 | | | | 0.15 |
| 150-240 | 2 | 115.0 | 1.0625 | 45.00 | 1.9375 | 80.0 | 2.0625 | 7.35 | 40.6 | 2 | 1.046 |
| | 3 | 115.0 | 1.0625 | 26.00 | 1.1250 | 80.0 | 1.0625 | | | | 0.688 |
| | 1 | 115.0 | 1.0625 | 6.00 | 0.375 | 100.0 | 0.375 | | | | 0.12 |
| 150-240 | 2 | 115.0 | 1.0625 | 50.00 | 2.4375 | 100.0 | 2.3125 | 7.35 | 40.6 | 2 | 1.054 |
| | 3 | 115.0 | 1.0625 | 28.0 | 1.25 | 100.0 | 0.9375 | | | | 0.7466 |
| | 1 | 115.0 | 1.0625 | 6.00 | 0.375 | 120.0 | 0.375 | | | | 0.100 |
| 150-240 | 2 | 115.0 | 1.0625 | 58.00 | 2.75 | 120.0 | 2.625 | 7.35 | 40.6 | 2 | 1.012 |
| | 3 | 115.0 | 1.0625 | 30.0 | 1.375 | 120.0 | 0.9375 | | | | 0.733 |

** *L*1-*L*2.

prehensive laboratory study,[12] in which composite and noncomposite negative and positive sections were tested, has resulted in the following interaction equation:

$$\left(\frac{M}{M_p}\right)^{3/2} + \left(\frac{T}{T_p}\right)^{3/2} \leq 1.0$$

where:

$M_p$ = plastic bending strength
$M$ = design bending moment
$T_p$ = plastic torsional strength
$T$ = design torsional moment

Subsequent examination of typical box girders and their moment capacities, as controlled by the current AASHTO specifications[1] and as given in Table 2, has also permitted development of a series of design charts[17] which permit rapid evaluation of these moments.

**Computerized Design**—The general response of single or continuous curved box girder bridges can be predicted by the solution of a series of coupled differential equations, when written in difference form as given in Fig. 5.

These equations have been subsequently incorporated into a computer program,[9] which automates the design/analysis of prismatic or nonprismatic straight or curved box girders as governed by the AASHTO criteria.[1,2]

The box girder may be either composite or noncomposite construction and can have integral transverse diaphragms spaced along the box and contain top lateral bracing. The

**Table 7. Three-Span Box Dimensions**

| SPANS (ft) | No. cross sect. | Web | | Top Flange | | Bottom Flange | | Bottom Stiffener | | | $A_T/A_B$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | Thickness | Width | Thickness | Width | Thickness | *A* | *Ix* | no. | |
| ** | 1 | 24.0 | 0.375 | 8.25 | 0.4375 | 80.0 | 0.375 | | | | 0.241 |
| 50-50-50 | 2 | 24.0 | 0.375 | 19.00 | 0.8125 | 80.0 | 0.4375 | 7.35 | 40.6 | 4 | 0.882 |
| | 3 | 24.0 | 0.375 | 6.00 | 0.375 | 80.0 | 0.375 | | | | 0.15 |
| | 1 | 24.0 | 0.375 | 9.75 | 0.4375 | 100.0 | 0.375 | | | | 0.227 |
| 50-50-50 | 2 | 24.0 | 0.375 | 20.25 | 0.875 | 100.0 | 0.4375 | 7.35 | 40.6 | 3 | 0.81 |
| | 3 | 24.0 | 0.375 | 6.00 | 0.375 | 100.0 | 0.375 | | | | 0.12 |
| | 1 | 24.0 | 0.375 | 10.25 | 0.500 | 120.0 | 0.375 | | | | 0.227 |
| 50-50-50 | 2 | 24.0 | 0.375 | 22.25 | 0.9375 | 120.0 | 0.500 | 7.35 | 40.6 | 3 | 0.695 |
| | 3 | 24.0 | 0.375 | 6.00 | 0.375 | 120.0 | 0.375 | | | | 0.100 |
| | 1 | 24.0 | 0.375 | 7.00 | 0.375 | 80.0 | 0.375 | | | | 0.175 |
| 50-60-50 | 2 | 24.0 | 0.375 | 22.25 | 1.000 | 80.0 | 0.375 | 7.35 | 40.6 | 3 | 1.483 |
| | 3 | 24.0 | 0.375 | 6.75 | 0.375 | 80.0 | 0.375 | | | | 0.1687 |
| | 1 | 24.0 | 0.375 | 7.75 | 0.375 | 100.0 | 0.375 | | | | 0.155 |
| 50-60-50 | 2 | 24.0 | 0.375 | 24.00 | 1.0625 | 100.0 | 0.4375 | 7.35 | 40.6 | 3 | 1.165 |
| | 3 | 24.0 | 0.375 | 7.25 | 0.375 | 100.0 | 0.375 | | | | 0.145 |
| | 1 | 24.0 | 0.375 | 7.75 | 0.375 | 120.0 | 0.375 | | | | 0.129 |
| 50-60-50 | 2 | 24.0 | 0.375 | 24.50 | 1.0625 | 120.0 | 0.500 | 7.35 | 40.6 | 3 | 0.8677 |
| | 3 | 24.0 | 0.375 | 7.00 | 0.375 | 120.0 | 0.375 | | | | 0.1167 |
| | 1 | 24.0 | 0.375 | 7.00 | 0.375 | 80.0 | 0.375 | | | | 0.175 |
| 50-70-50 | 2 | 24.0 | 0.375 | 24.0 | 1.125 | 80.0 | 0.5625 | 7.35 | 40.6 | 2 | 1.200 |
| | 3 | 24.0 | 0.375 | 8.50 | 0.375 | 80.0 | 0.375 | | | | 0.212 |
| | 1 | 24.0 | 0.375 | 8.00 | 0.375 | 100.0 | 0.375 | | | | 0.16 |
| 50-70-50 | 2 | 24.0 | 0.375 | 26.25 | 1.1875 | 100.0 | 0.5625 | 7.35 | 40.6 | 2 | 1.108 |
| | 3 | 24.0 | 0.375 | 9.00 | 0.4375 | 100.0 | 0.375 | | | | 0.21 |
| | 1 | 24.0 | 0.375 | 8.50 | 0.4375 | 120.0 | 0.375 | | | | 0.165 |
| 50-70-50 | 2 | 24.0 | 0.375 | 28.5 | 1.3125 | 120.0 | 0.6875 | 7.35 | 40.6 | 2 | 0.906 |
| | 3 | 24.0 | 0.375 | 10.00 | 0.500 | 120.0 | 0.375 | | | | 0.222 |
| | 1 | 24.0 | 0.4375 | 6.00 | 0.375 | 80.0 | 0.375 | | | | 0.15 |
| 50-80-50 | 2 | 24.0 | 0.4375 | 28.00 | 1.3125 | 80.0 | 0.8125 | 7.35 | 40.6 | 2 | 1.13 |
| | 3 | 24.0 | 0.4375 | 9.50 | 0.4375 | 80.0 | 0.375 | | | | 0.277 |

**Table 7. Three-Span Box Dimensions**

| SPANS (ft) | No. cross sect. | Web | | Top Flange | | Bottom Flange | | Bottom Stiffener | | | $A_T/A_B$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | Thickness | Width | Thickness | Width | Thickness | *A* | *Ix* | no. | |
| 50-80-50 | 1 | 24.0 | 0.4375 | 6.00 | 0.375 | 100.0 | 0.375 | | | | 0.12 |
| | 2 | 24.0 | 0.4375 | 31.00 | 1.375 | 100.0 | 0.750 | 7.35 | 40.6 | 2 | 1.136 |
| | 3 | 24.0 | 0.4375 | 11.50 | 0.500 | 100.0 | 0.375 | | | | 0.306 |
| 50-80-50 | 1 | 24.0 | 0.4375 | 6.00 | 0.375 | 120.0 | 0.375 | | | | 0.100 |
| | 2 | 24.0 | 0.4375 | 33.00 | 1.500 | 120.0 | 0.750 | 7.35 | 40.6 | 2 | 1.10 |
| | 3 | 24.0 | 0.4375 | 11.50 | 0.5625 | 120.0 | 0.375 | | | | 0.287 |
| 100-100-100 | 1 | 48.0 | 0.5625 | 12.75 | 0.5625 | 80.0 | 0.4375 | | | | 0.410 |
| | 2 | 48.0 | 0.5625 | 25.50 | 1.125 | 80.0 | 0.5625 | 7.35 | 40.6 | 2 | 1.275 |
| | 3 | 48.0 | 0.5625 | 6.00 | 0.375 | 80.0 | 0.375 | | | | 0.15 |
| 100-100-100 | 1 | 48.0 | 0.5625 | 14.00 | 0.625 | 100.0 | 0.4375 | | | | 0.40 |
| | 2 | 48.0 | 0.5625 | 28.50 | 1.1875 | 100.0 | 0.5625 | 7.35 | 40.6 | 2 | 1.203 |
| | 3 | 48.0 | 0.5625 | 6.00 | 0.375 | 100.0 | 0.375 | | | | 0.12 |
| 100-100-100 | 1 | 48.0 | 0.5625 | 15.50 | 0.6875 | 120.0 | 0.375 | | | | 0.4376 |
| | 2 | 48.0 | 0.5625 | 31.00 | 1.3125 | 120.0 | 0.6875 | 7.35 | 40.6 | 2 | 0.986 |
| | 3 | 48.0 | 0.5625 | 6.00 | 0.375 | 120.0 | 0.375 | | | | 0.100 |
| 100-120-100 | 1 | 48.0 | 0.5625 | 8.00 | 0.4375 | 80.0 | 0.375 | | | | 0.238 |
| | 2 | 48.0 | 0.5625 | 30.00 | 1.4375 | 80.0 | 0.9375 | 7.35 | 40.6 | 2 | 1.15 |
| | 3 | 48.0 | 0.5625 | 7.00 | 0.375 | 80.0 | 0.375 | | | | 0.175 |
| 100-120-100 | 1 | 48.0 | 0.5625 | 9.50 | 0.4375 | 100.0 | 0.375 | | | | 0.222 |
| | 2 | 48.0 | 0.5625 | 33.50 | 1.500 | 100.0 | 0.875 | 7.35 | 40.6 | 2 | 1.148 |
| | 3 | 48.0 | 0.5625 | 7.50 | 0.375 | 100.0 | 0.375 | | | | 0.15 |
| 100-120-100 | 1 | 48.0 | 0.5625 | 10.25 | 0.500 | 120.0 | 0.375 | | | | 0.228 |
| | 2 | 48.0 | 0.5625 | 37.00 | 1.625 | 120.0 | 0.875 | 7.35 | 40.6 | 2 | 1.145 |
| | 3 | 48.0 | 0.5625 | 8.50 | 0.375 | 120.0 | 0.375 | | | | 0.142 |
| 100-140-100 | 1 | 48.0 | 0.5625 | 7.50 | 0.4375 | 80.0 | 0.375 | | | | 0.219 |
| | 2 | 48.0 | 0.5625 | 34.0 | 1.6250 | 80.0 | 1.250 | 7.35 | 40.6 | 2 | 1.105 |
| | 3 | 48.0 | 0.5625 | 11.00 | 0.5625 | 80.0 | 0.4375 | | | | 0.353 |
| 100-140-100 | 1 | 48.0 | 0.5625 | 8.75 | 0.4375 | 100.0 | 0.375 | | | | 0.204 |
| | 2 | 48.0 | 0.5625 | 40.00 | 1.6875 | 100.0 | 1.250 | 7.35 | 40.6 | 2 | 1.08 |
| | 3 | 48.0 | 0.5625 | 12.50 | 0.625 | 100.0 | 0.4375 | | | | 0.357 |

## Table 7. Three-Span Box Dimensions

| SPANS (ft) | No. cross sect. | Web | | Top Flange | | Bottom Flange | | Bottom Stiffener | | | $A_T/A_B$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | Thickness | Width | Thickness | Width | Thickness | $A$ | $Ix$ | no. | |
| 100–140–100 | 1 | 48.0 | 0.5625 | 9.50 | 0.4375 | 120.0 | 0.375 | | | | 0.185 |
| | 2 | 48.0 | 0.5625 | 44.50 | 1.875 | 120.0 | 1.3125 | 7.35 | 40.6 | 2 | 1.059 |
| | 3 | 48.0 | 0.5625 | 15.00 | 0.6875 | 120.0 | 0.375 | | | | 0.458 |
| 100–160–100 | 1 | 48.0 | 0.625 | 6.00 | 0.375 | 80.0 | 0.375 | | | | 0.15 |
| | 2 | 48.0 | 0.625 | 39.00 | 1.750 | 80.0 | 1.5625 | 7.35 | 40.6 | 2 | 1.092 |
| | 3 | 48.0 | 0.625 | 18.00 | 0.8125 | 80.0 | 0.750 | | | | 0.332 |
| 100–160–100 | 1 | 48.0 | 0.625 | 6.00 | 0.375 | 100.0 | 0.375 | | | | 0.12 |
| | 2 | 48.0 | 0.625 | 43.00 | 1.875 | 100.0 | 1.500 | 7.35 | 40.6 | 2 | 1.075 |
| | 3 | 48.0 | 0.625 | 18.00 | 0.875 | 100.0 | 0.625 | | | | 0.504 |
| 100–160–100 | 1 | 48.0 | 0.625 | 6.00 | 0.375 | 120.0 | 0.375 | | | | 0.100 |
| | 2 | 48.0 | 0.625 | 46.00 | 2.0625 | 120.0 | 1.500 | 7.35 | 40.6 | 2 | 1.054 |
| | 3 | 48.0 | 0.625 | 20.00 | 0.875 | 120.0 | 0.5625 | | | | 0.519 |
| 150–150–150 | 1 | 72.0 | 0.750 | 17.25 | 0.750 | 80.0 | 0.6875 | | | | 0.47 |
| | 2 | 72.0 | 0.750 | 31.50 | 1.375 | 80.0 | 0.9375 | 7.35 | 40.6 | 2 | 1.154 |
| | 3 | 72.0 | 0.750 | 6.00 | 0.375 | 80.0 | 0.375 | | | | 0.15 |
| 150–150–150 | 1 | 72.0 | 0.750 | 18.75 | 0.8125 | 100.0 | 0.5625 | | | | 0.542 |
| | 2 | 72.0 | 0.750 | 34.50 | 1.500 | 100.0 | 0.875 | 7.35 | 40.6 | 2 | 1.183 |
| | 3 | 72.0 | 0.750 | 6.00 | 0.375 | 100.0 | 0.375 | | | | 0.12 |
| 150–150–150 | 1 | 72.0 | 0.750 | 20.00 | 0.9375 | 120.0 | 0.5625 | | | | 0.555 |
| | 2 | 72.0 | 0.750 | 37.50 | 1.625 | 120.0 | 0.875 | 7.35 | 40.6 | 2 | 1.161 |
| | 3 | 72.0 | 0.750 | 6.00 | 0.375 | 120.0 | 0.375 | | | | 0.100 |
| 150–180–150 | 1 | 72.0 | 0.750 | 10.00 | 0.4375 | 80.0 | 0.4375 | | | | 0.25 |
| | 2 | 72.0 | 0.750 | 37.50 | 1.750 | 80.0 | 1.500 | 7.35 | 40.6 | 2 | 1.093 |
| | 3 | 72.0 | 0.750 | 7.00 | 0.375 | 80.0 | 0.375 | | | | 0.15 |
| 150–180–150 | 1 | 72.0 | 0.750 | 11.00 | 0.5625 | 100.0 | 0.375 | | | | 0.33 |
| | 2 | 72.0 | 0.750 | 43.00 | 1.8125 | 100.0 | 1.4375 | 7.35 | 40.6 | 2 | 1.084 |
| | 3 | 72.0 | 0.750 | 7.75 | 0.375 | 100.0 | 0.375 | | | | 0.155 |
| 150–180–150 | 1 | 72.0 | 0.750 | 14.00 | 0.625 | 120.0 | 0.375 | | | | 0.388 |
| | 2 | 72.0 | 0.750 | 46.00 | 2.00 | 120.0 | 1.4375 | 7.35 | 40.6 | 2 | 1.066 |
| | 3 | 72.0 | 0.750 | 8.50 | 0.375 | 120.0 | 0.375 | | | | 0.142 |

Table 7. Three-Span Box Dimensions

| SPANS (ft) | No. cross sect. | Web | | Top Flange | | Bottom Flange | | Bottom Stiffener | | | $A_T/A_B$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Depth | Thickness | Width | Thickness | Width | Thickness | $A$ | $Ix$ | no. | |
| 150-210-150 | 1 | 72.0 | 0.750 | 8.50 | 0.375 | 80.0 | 0.4375 | | | | 0.182 |
| | 2 | 72.0 | 0.750 | 45.00 | 2.000 | 80.0 | 2.125 | 7.35 | 40.6 | 2 | 1.059 |
| | 3 | 72.0 | 0.750 | 17.00 | 0.750 | 80.0 | 0.6875 | | | | 0.464 |
| 150-210-150 | 1 | 72.0 | 0.750 | 9.50 | 0.4375 | 100.0 | 0.375 | | | | 0.222 |
| | 2 | 72.0 | 0.750 | 51.50 | 2.1875 | 100.0 | 2.125 | 7.35 | 40.6 | 2 | 1.06 |
| | 3 | 72.0 | 0.750 | 18.00 | 0.8750 | 100.0 | 0.625 | | | | 0.504 |
| 150-210-150 | 1 | 72.0 | 0.750 | 9.00 | 0.4375 | 120.0 | 0.375 | | | | 0.175 |
| | 2 | 72.0 | 0.750 | 58.00 | 2.500 | 120.0 | 2.250 | 7.35 | 40.6 | 2 | 1.086 |
| | 3 | 72.0 | 0.750 | 21.50 | 0.9375 | 120.0 | 0.5625 | | | | 0.597 |
| 150-240-150 | 1 | 72.0 | 0.8125 | 7.00 | 0.375 | 80.0 | 0.375 | | | | 0.175 |
| | 2 | 72.0 | 0.8125 | 52.00 | 2.250 | 80.0 | 2.750 | 7.35 | 40.6 | 2 | 1.063 |
| | 3 | 72.0 | 0.8125 | 23.50 | 1.125 | 80.0 | 1.0625 | | | | 0.622 |
| 150-240-150 | 1 | 72.0 | 0.8125 | 7.00 | 0.375 | 100.0 | 0.375 | | | | 0.140 |
| | 2 | 72.0 | 0.8125 | 57.50 | 2.500 | 100.0 | 2.6875 | 7.35 | 40.6 | 2 | 1.069 |
| | 3 | 72.0 | 0.8125 | 24.50 | 1.125 | 100.0 | 0.875 | | | | 0.63 |
| 150-240-150 | 1 | 72.0 | 0.8125 | 7.00 | 0.375 | 120.0 | 0.375 | | | | 0.117 |
| | 2 | 72.0 | 0.8125 | 62.00 | 2.750 | 120.0 | 2.625 | 7.35 | 40.6 | 2 | 1.082 |
| | 3 | 72.0 | 0.8125 | 26.0 | 1.125 | 120.0 | 0.750 | | | | 0.65 |

** *L*1-*L*2-*L*3.

basic configuration of a typical box and the type of cross diaphragms is shown in Figs. 2, 3 and 4.

The computer output contains influence line ordinates, stresses on top and bottom flanges at locations along the span due to dead load, superimposed dead load, and live load plus impact. The stress resultants include the effects of bending, warping and distortion, utilizing the automatically computed section properties.

Stress envelopes are given for fatigue design. Specifications (AASHTO) are used to establish allowable stresses, web and flange stiffening requirements and shear connector spacing, as given in Tables 1 and 2.

Resulting girder deflections and rotations, due to sequential concrete placements, can also be determined for specified length of pours. Composite/noncomposite actions may be assured after the concrete hardens.

The entire output sequence is as follows:

*Basic Data*

Job description
Girder geometry
Structural details
Concrete properties
Loading properties
Section details: span length, plate sizes, section properties, stiffener and bracing details, dead loads
Pouring sequence geometry

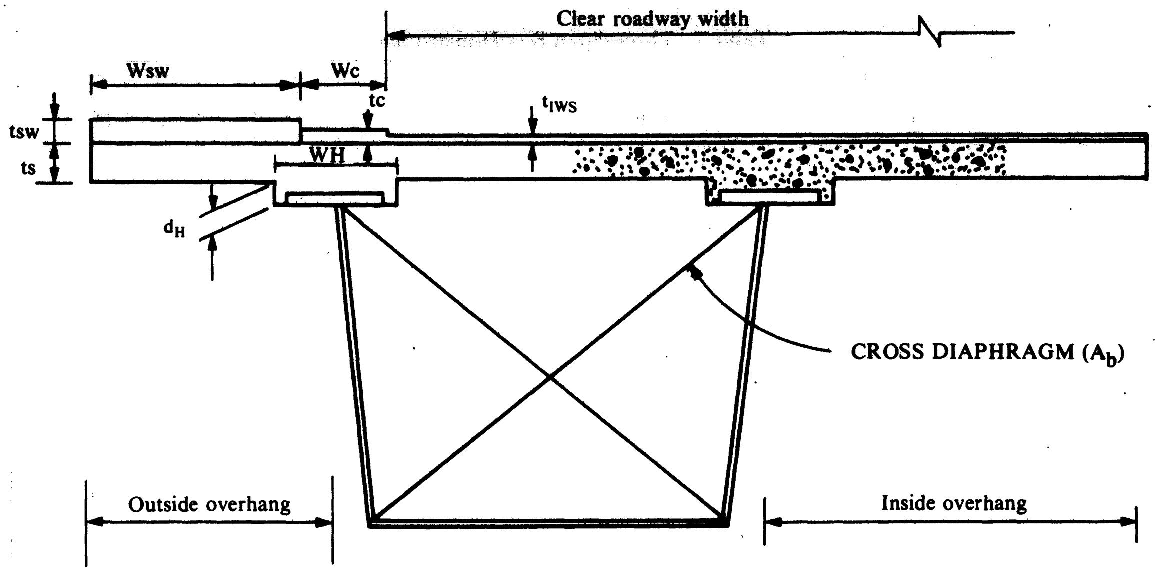



*Fig. 2. Structural details*

*Stresses*
- Dead-load normal stress
- Superimposed dead-load normal stress
- Live-load normal stress (positive and negative moment)

*Forces*
- Moment envelope
- Deflection envelope
- Shear envelope
- Vertical reaction envelope
- Torsion reaction envelope
- Torsion envelope
- Bimoment envelope
- Normal stress envelope
- Stress range envelope
- *d/t*, *b/t* requirements, web stress
- Theoretical web stiffener requirement
- Total stresses
- Shear connector spacing requirements
- Fatigue criteria
- Pouring sequence deflections
- Natural frequency
- Pouring sequence rotations

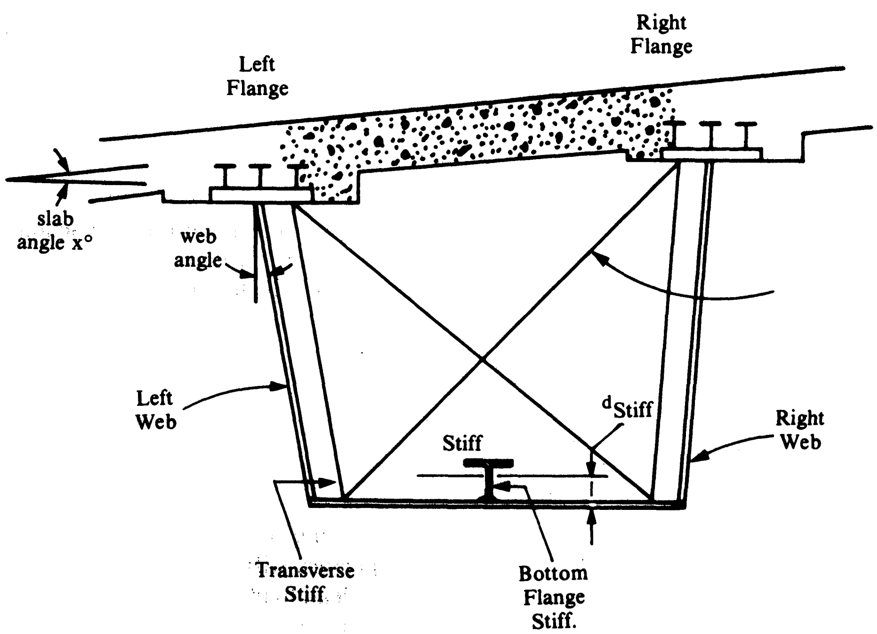



*Fig. 3. Cross section*

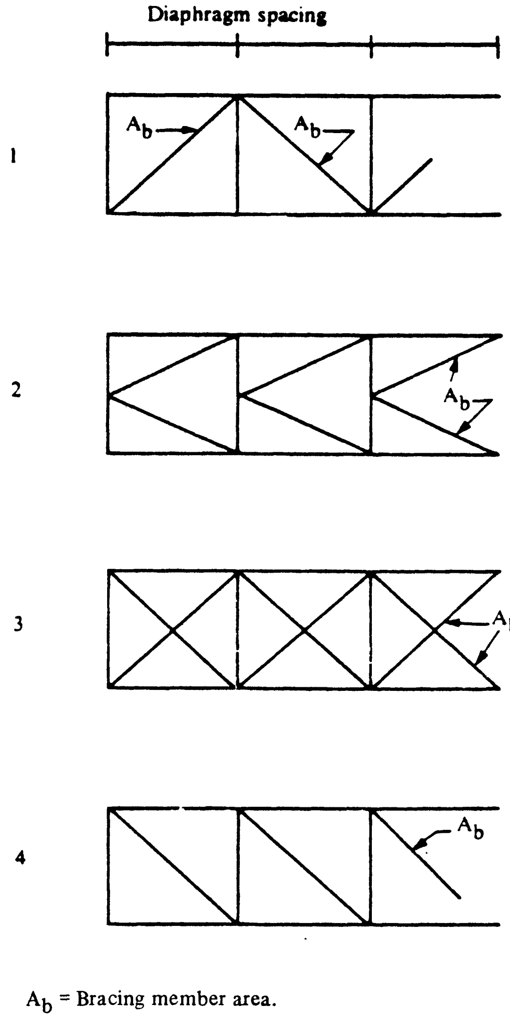



*Fig. 4. Bracing types (top lateral)*

**Field-Test Comparison to Theoretical Results**—The static and dynamic response of a full scale bridge structure, when subjected to a known truck loading, was examined during the Fall 1973.[16] The bridge consisted of twin steel boxes (4.5 ft × 8.8 ft) in composite action with a 9½-in. concrete slab. That part of the bridge under test was a three-span continuous with span lengths 100 ft, 130 ft, and 120 ft and centerline radius of 1,317 ft. The bridge was designed as a two-lane structure. The deformations and strains throughout the structure were measured during the application of the test vehicle. The resulting static load data were then examined and the results compared to the data obtained by the previously described analytical technique.[8,9]

In summary, the resulting induced stresses, at various locations along the structure, are described in Table 8. The sections are located as follows:

Section A 0.4 (exterior span)
Section B $1.0L_1$ (first interior support)
Section C $0.5L_2$ (midspan of interior span)

Examination of the data given in Table 8 indicates reasonable correlation between theory and experiment and the importance of the top lateral bracing during the dead-load response.

The resulting girder deflections at Section A and Section C are given in Table 9. The data shown in this table show comparisons between theory and tests, indicating reasonable correlation especially for live load effects. The discrepancy in the dead-load results is due to the sequential placement of the concrete and time dependent composite actions.

$$\begin{array}{c|c|c|c|c|c} & n-2 & n-1 & n & n+1 & n+2 \\ \hline n & \frac{EI_w}{R} & 4\left(\frac{EI_w}{R}\right)+\frac{h^2(EI_x+CK_t)}{R} & -\left[6\frac{EI_w}{R}+\frac{2h^2(EI_w+CK_t)}{R}\right] & 4\left(\frac{EI_w}{R}\right)+\frac{h^2(EI_x+CK_t)}{R} & -\frac{EI_w}{R} \\ \phi & -EI_w & 4EI_w+h^2CK_t & -\left[6EI_w+2h^2CK_t+\frac{h^4EI_x}{R^2}\right] & 4EI_w+h^2CK_t & -EI_w \end{array} = -m_z h^2$$

$$\begin{array}{c|c|c|c|c|c} n & -\left(\frac{EI_w}{R}+EI_x\right) & 4\left(\frac{EI_w}{R^2}+EI_x\right)+\frac{h^2CK_t}{R^2} & -\left[6\left(\frac{EI_w}{R^2}+EI_x\right)+\frac{2h^26K_t}{R^2}\right] & 4\left(\frac{EI_w}{R^2}+EI_x\right)+\frac{h^26K_t}{R^2} & -\left(\frac{EI_w}{R^2}+EI_x\right) \\ \phi & -\frac{EI_w}{R} & 4\left(\frac{EI_w}{R}\right)+\frac{h^2(EI_x+CK_t)}{R} & -\left[6\left(\frac{EI_w}{R}\right)\frac{2h^2(EI_x+CK_t)}{R}\right] & 4\left(\frac{EI_w}{R}\right)+\frac{h^2(EI_x+6K_t)}{R} & -\frac{EI_w}{R} \end{array} = -q_y h^2$$

*Fig. 5. Curved girder finite difference equation*

**Table 8. Prototype Bridge Test-Stresses**

| Cross Sections | Loading | Test (ksi) | Theory (ksi) With bracing | Theory (ksi) Without bracing |
|---|---|---|---|---|
| A | DL | 7.70 | 6.25 | 9.02 |
| | LL + I | 2.32 | 2.65 | 2.65 |
| | Total | 10.02 | 8.90 | 11.67 |
| B | DL | −5.14 | −4.96 | −6.66 |
| | LL + I | − .76 | −1.05 | −1.05 |
| | Total | −5.90 | −6.01 | −7.71 |
| C | DL | 6.12 | 3.26 | 4.27 |
| | LL + I | 1.83 | 2.07 | 2.07 |
| | Total | 7.95 | 5.33 | 6.34 |

**Table 9. Prototype Bridge Test-Vertical Deflections**

| Cross Section | Loading | Test (in.) | Theory With bracing | Theory Without bracing |
|---|---|---|---|---|
| A | DL | 1.19 | 0.88 | 0.93 |
| | LL + I | 0.20 | 0.23 | 0.23 |
| | Total | 1.39 | 1.11 | 1.16 |
| C | DL | 0.50 | 0.51 | 0.47 |
| | LL + I | 0.26 | 0.27 | 0.27 |
| | Total | 0.76 | 0.78 | 0.74 |

In general, results indicate the curved girder finite difference theory provides an excellent technique for box girder design.

## CONCLUSIONS

This paper presents the results of various research which has permitted a better understanding of steel box girder bridges and the development of design criteria. Through use of these design data, more efficient and rapid design of such structures can be achieved, and a better service to the public provided.

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