FINAL REPORT

RELIABILITY VALIDATION OF HIGHWAY BRIDGES DESIGNED BY LRFD

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16. Abstract

The reliability index is examined for steel girder highway bridges designed by AASHTO *LRFD* Strength I limit state for flexure and shear. The reliability analysis is based on the extensive stochastic finite element method (SFEM). The SFEM takes advantages of the conventional advanced first-order second-moment (AFOSM) in that it considers the mechanic connection between the critical member and other members in the whole structure. Simply supported multigirder steel bridges with span length of 30 ft to 120ft and girder spacing of 4 ft to 12 ft are designed. The bridges are modeled as grillage beam systems. The sectional and material properties as well as dead and live loads are treated as basic design variables. The results obtained in this study indicate that the reliability index is very sensitive to the lateral distribution of live loads such as HS20 truck loading. Consequently, a simplified reliability analysis method for multigirder bridges can be used in the analysis. This simplified method can avoid the complex computation in SFEM yet achieve good accuracy. Based on this study, the AASHTO *LRFD* specification for Strength I limit state for flexure is a conservative design of steel girder bridges. However, the design based on Strength I limit state for shear achieves the target safety level.

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METRIC CONVERSIONS

N × 1,000 = kN

ft × 0.3048 = m

inch × 2.54 = cm

kip (force) × 4.448 = kN

kip (mass) × 454 = kg (mass)

mph × 1.609 = km/h

psi × 6.895 = kPa

ksi × 6.895 = Mpa

DISCLAIMER

Prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation.

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1. INTRODUCTION

The commencement of AASHTO *LRFD Specifications* (1998) is an important development in bridge design philosophy. The AASHTO *LRFD Specifications* (1998) introduced a design conception and approach different from AASHTO *Standard Specifications* (1996) for highway bridges. The advantages of a design based on load and resistance factor design (LRFD) method include the consideration of variability in both resistance and load, obtainable uniform levels of safety for different limit states and bridge types without performing complex probability or statistical analysis, and rationality and consistence in the design (Barker and Puckett 1997). The basic design expression in the AASHTO *LRFD* (1998) Specifications that must be satisfied for all strength and serviceability limit states, both global and local, is given as

$$\eta \sum \gamma_i Q_i \leq \phi R_n \tag{1-1}$$

where Q_i = the force effect; R_n = the nominal resistance; γ_i = the statistically based load factor applied to the force effects; ϕ = the statistically based resistance factor applied to nominal resistance; and η = a load modification factor.

In the development of the new code, Nowak (1993) achieved a uniform safety margins among the highway bridges of various types, span lengths, and girder spacings. The load and resistance factors in Eq. (1-1) were determined by transferring from design experience inherent in the old code. The concept of girder distribution factor was used and the bridge structure was simplified into an isolated single girder. The reliability analysis is based on the advanced first order and second moment (AFOSM) approach. Recently, a more advanced reliability analysis, namely stochastic finite element method (SFEM), has been used for the structural reliability analysis. The SFEM approach was employed to validate the steel structures designed in accordance with AISC *LRFD* (1986) approach (Mahadevan and Haldar 1991). The SFEM is capable of involving the consideration of the element in an actual structural configuration and the effect of statistical correlation among the random parameters of the structure. The objective of this study is to examine the reliabilities of steel girder highway bridges using the extensive SFEM.

Chapter 2 presents the two theories about structural reliability analysis, the advanced first order second moment (AFOSM) method and the stochastic finite element method (SFEM). Bridge design based on AASHTO LRFD *Specifications* is described in Chapter 3. The design examples include both noncomposite and composite multigirder steel bridges with a span length from 30 ft (9.14 m) to 120 ft (36.58 m) and a girder spacing from 4 ft (1.22 m) to 12 ft (3.66 m). Chapter 4 introduces two finite element models for multigirder steel bridges, grillage model and three dimensional slab on girder model. The grillage model is used in the SFEM algorithm given in Chapter 2. The three dimensional slab on girder model is used for an extensive computation of load lateral distribution of live loads. In Chapter 5, the reliability analysis based on SFEM is performed for the bridge examples designed in Chapter 3. Chapter 6 summarizes the findings, recommendations, and conclusions obtained in this research.

2. THEORY FOR STRUCTURAL RELIABILITY ANALYSIS

2.1 ADVANCED FIRST ORDER SECOND MOMENT (AFOSM) METHOD

According to the AFOSM approach, one performance criterion of a structural system can be defined as a limit state in the following form:

$$g(\mathbf{X}) = g(\mathbf{R}(\mathbf{X}), \mathbf{S}(\mathbf{X})) = 0 \qquad (2\text{-}1)$$

where $\mathbf{X} = \{X_1, X_2, \Lambda, X_n\}^T$, the vector of the basic parameters of the structure and external loads, usually nonnormal and correlated; $\mathbf{R}(\mathbf{X})$ = the vector of resistance variables; $\mathbf{S}(\mathbf{X})$ = the vector of load effects.

For the convenience of computation, the nonnormal design variables X_i $(i = 1, \Lambda, n)$ are transformed into the space of uncorrelated standard normal variables $\mathbf{Y} = \{Y_1, Y_2, \Lambda, Y_n\}^T$. When transformed into the space of $\mathbf{Y}$, the performance criterion in Eq. (2-1) becomes:

$$g(\mathbf{X}) = G(\mathbf{Y}) = 0 \qquad (2\text{-}2)$$

The point $\mathbf{Y}^*$ on the limit-state surface with the minimum distance to the origin is the most probable failure point or the design point. The minimum distance is a measure of reliability, i.e., the reliability index denoted by $\beta = \sqrt{\mathbf{Y}^{*T}\mathbf{Y}^*}$. The following efficient formula is used to compute the design point $\mathbf{Y}^*$ (Madsen et al. 1986):

$$\mathbf{Y}_{i+1} = \left[\mathbf{Y}_i^T \alpha_i + \frac{G(\mathbf{Y}_i)}{\left\| \nabla G(\mathbf{Y}_i) \right\|} \right] \alpha_i \tag{2-3}$$

where $\nabla G(\mathbf{Y}_i) = \left\{ \partial G(\mathbf{Y}_i) / \partial Y_1, \ldots, \partial G(\mathbf{Y}_i) / \partial Y_n \right\}^T$, the gradient vector of the performance function at $\mathbf{Y}_i$; $\mathbf{Y}_i$ = the design point in the *i*th iteration; $\alpha_i = -\nabla G(\mathbf{Y}_i) / \left\| \nabla G(\mathbf{Y}_i) \right\|$, the unit vector normal to the limit-state surface away from the origin.

In this study, the transformation from **X** to **Y** is accomplished by the following approximate approach (Ang and Tang 1984):

(1) The variables X_i ($i = 1, \ldots, n$) are transformed into standard normal variables **Z**:

For normal variables X_m, $Z_m = (X_m - \mu)/\sigma$ (2-4a)

For lognormal variables X_n, $Z_n = (In X_n - \lambda)/\zeta$ (2-4b)

where μ = the mean value of X_m; σ = the standard deviation of X_m; λ = the mean of In(X_n); ζ = the standard deviation of In(X_n).

(2) The standard normal variables **Z** are transformed into independent standard normal variables Y_i:

$$Z_i = \sum_{j=1}^{i} \alpha_{ij} Y_j \tag{2-5}$$

2.2 STOCHASTIC FINITE ELEMENT METHOD (SFEM)

One of the advantages of SFEM lies in that it can efficiently compute the gradients of nodal displacement vector, **U**, and nodal force vector, **F**, to basic design variables X_j, $j = 1, \ldots, n$. Based on the theory by Zienkiewicz, O.C. (1971), the following provides the derivation of expression of the gradients with assumption of a linear elastic behavior of the structure.

1. The derivatives of displacement vector to design variables - $\partial \mathbf{U} / \partial X_j$:

Given a bridge structure, the external loads and the nodal displacements exist the following equilibrium relationship:

$$\mathbf{F} = \mathbf{K}\mathbf{U} \qquad (2\text{-}6)$$

where **F** = the external load vector; **U** = the nodal displacement vector; and **K** = the global stiffness matrix.

Differentiating Eq. (2-6) to basic variable X_j gives

$$\frac{\partial \mathbf{F}}{\partial X_j} = \left(\frac{\partial \mathbf{K}}{\partial X_j} \right) \cdot \mathbf{U} + \mathbf{K} \cdot \left(\frac{\partial \mathbf{U}}{\partial X_j} \right) \quad j = 1, \ldots, n \qquad (2\text{-}7)$$

thus

$$\frac{\partial \mathbf{U}}{\partial X_j} = \mathbf{K}^{-1} \cdot \left[\frac{\partial \mathbf{F}}{\partial X_j} - \left(\frac{\partial \mathbf{K}}{\partial X_j} \right) \cdot \mathbf{U} \right] \quad j = 1, \ldots, n \qquad (2\text{-}8)$$

2. The derivatives of nodal force vector to design variables - $\partial \mathbf{F} \big/ \partial X_j$:

For the element *e*, the nodal forces, $\mathbf{F}^e$, consist of two parts: $\mathbf{F}_1^e$ and $\mathbf{F}_2^e$:

$$\mathbf{F}^e = \mathbf{F}_1^e + \mathbf{F}_2^e \qquad \text{(2-9)}$$

where $\mathbf{F}_1^e$ = the forces induced by displacement of the nodes, $\mathbf{F}_1^e = \mathbf{K}^e \mathbf{U}^e$; $\mathbf{F}_2^e$ = the nodal forces required to balance any distributed loads acting on the element.

Differentiating Eq. (2-9) to basic variable X_j gives

$$\frac{\partial \mathbf{F}^e}{\partial X_j} = \frac{\partial \mathbf{F}_1^e}{\partial X_j} + \frac{\partial \mathbf{F}_2^e}{\partial X_j} \qquad j = 1, \ldots, n \qquad \text{(2-10)}$$

where the first term on the right-hand side can be written as:

$$\frac{\partial \mathbf{F}_1^e}{\partial X_j} = \left(\frac{\partial \mathbf{K}^e}{\partial X_j} \right) \cdot \mathbf{U}^e + \mathbf{K}^e \cdot \left(\frac{\partial \mathbf{U}^e}{\partial X_j} \right) \qquad j = 1, \ldots, n \qquad \text{(2-11)}$$

and the second term on the right-hand side, $\frac{\partial \mathbf{F}_2^e}{\partial X_j}$, representing partial derivative of $\mathbf{F}_2^e$ to basic variable X_j, can be explicitly expressed.

Table 2-1 gives the basic variables considered in the reliability analysis for noncomposite steel girder bridges. Tables 2 and 3 present the statistical data for various loads and sectional properties.

Table 2-1. Basic Variables for Noncomposite Steel Bridges

No.	Symbol	Description
1	DL_1	Dead load on exterior girders, including barrier and concrete slab
2	DL_2	Dead load on interior girders, including concrete slab
3	DL_3	Dead load on end diaphragms
4	DL_4	Dead load on intermediate diaphragms
5	WS	Future wearing surface
6	LNL	0.64 kips/ft for Lane load
7	TL	72kips weight for Truck load
8	IM	Dynamic load allowance
9	I_1	Moment of Inertia of all five girders
10	I_2	Moment of Inertia of end diaphragms
11	I_3	Moment of Inertia of intermediate diaphragms
12	Z_x	Plastic section modulus
13	E	Modulus of elasticity
14	G	Shear modulus of elasticity
15	F_y	Yield strength
16	J_1	Torsional constant of all five girders
17	J_2	Torsional constant of end diaphragms
18	J_3	Torsional constant of intermediate diaphragms
Note: 1 kip = 4448 N; 1 ft = 0.3048 m		

Table 2-2. Statistical Data of Loads

Load Types	**Dead Load** DL_i [a]	**Wearing Surface** WS	**Lane Load** LNL	**Truck Load** TL	**Dynamic Load Allowance** IM
Bias Factor	1.03	1.0	1.15	1.15	1.15
COV	0.08	0.25	0.12	0.18	0.18
Distribution type	Normal	Normal	Normal	Normal	Normal

Table 2-3. Statistical Data of Sectional and Material Properties

Variables	**Moment of Inertia** I_i [a]	**Plastic Section Modulus** Z_x [a]	**Modulus of Elasticity** E [a]	**Yield Strength** F_y [b]	**Shear Modulus of Elasticity** G [a]	**Moment of Inertia** J_i [c]
Bias Factor	1.0	1.0	1.0	1.12	1.0	1.0
COV	0.05	0.05	0.06	0.0866	0.06	0.05
Distribution type	Lognormal	Lognormal	Lognormal	Lognormal	Lognormal	Lognormal

Note:

a. Statistics of I, Z_x, E, and G are obtained from Mahadevan and Haldar (1991) and Galambos and Ravindra (1978);

b. Statistics of F_y is computed from the results by Novak (1993) and Mahadevan and Haldar (1991); and

c. Statistics of J are assumed to be the same as those of I.

3. DESIGN OF BRIDGES BASED ON LRFD APPROACH

3.1 DESIGN EXAMPLES BASED ON STRENGTH I LIMIT STATE FOR FLEXURE

3.1.1 NONCOMPOSITE STEEL GIRDER BRIDGES

To study the reliability of noncomposite girder bridges, there are a total of 75 simply supported noncomposite steel bridges designed according to the Strength I limit state for flexure of AASHTO *LRFD* (1998). Span length ranges from 30 ft (9.14 m) to 90 ft (27.43 m) and girder spacing varies from 4 ft (1.22m) to 12 ft (3.66m). These bridges are of I-beam sections and are designed on the basis of HL-93 loading. These bridges have a roadway width of 20 ft (6.10 m) to 52 ft (15.85 m) with the number of lanes of 2, 2, 3, 3, and 4, respectively. The concrete deck thickness is 8 inches (0.20m). The deck overhang is 2ft (0.61m) in width. The typical cross section of the bridge is shown in Fig. 3-1. All five girders have identical section and are transversely connected with each other by diaphragms intermediately and at end. The number of intermediate diaphragms is 1, 2, and 3, respectively, for 30 ft (9.14 m), 60 ft (18.29 m), and 90 ft (27.43 m) span length. The design of diaphragms is accordance with the Standard Plans for Highway Bridge Superstructures (1982) from the U.S. Department of Transportation.

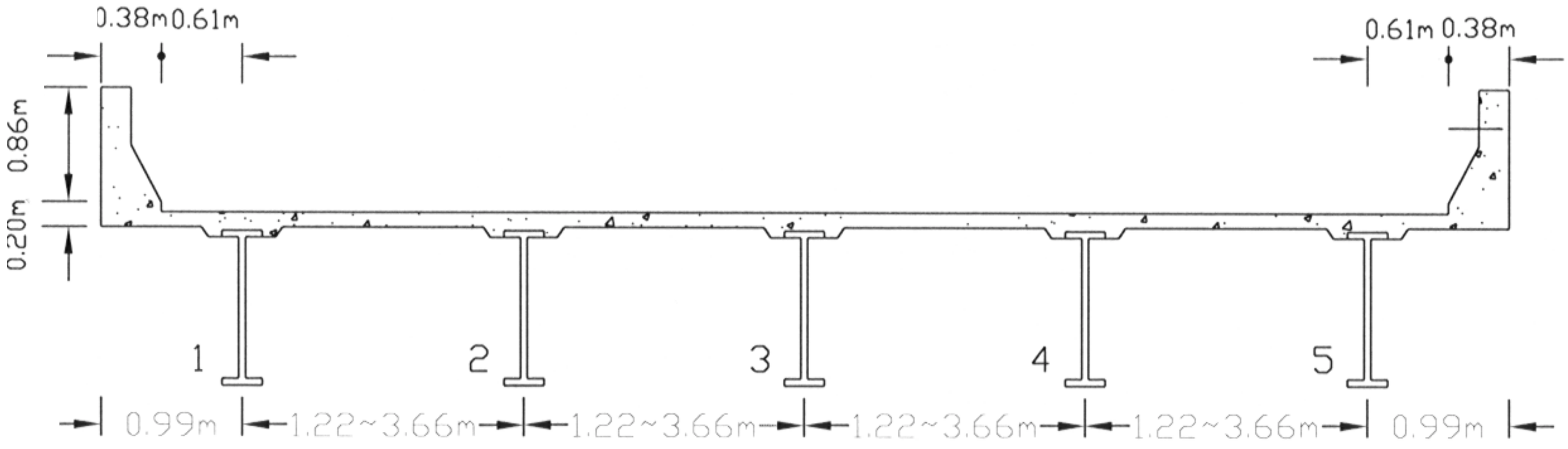


Fig. 3-1. Typical Cross Section of the Bridges

All bridges were designed according to AASHTO *LRFD* Strength I limit state for flexure:

$$\phi_f \, M_n \geq M_u \tag{3-1}$$

where M_n = the nominal resistance moment; M_u = the ultimate moment induced by live and dead loads; and ϕ_f = the resistance factor for flexure (ϕ_f = 1.0).

For exterior girders, various loads include the dead loads (self-weight of barrier, slab, steel beam, and wearing surface) and live loads (truck load with impact and lane load).

For interior girders, various loads include the dead loads (self-weight of slab, steel beam, and wearing surface) and live loads (truck load with impact and lane load).

The factored moment by the dead and live loads is:

$$M_u = \eta \left[1.25 \cdot M_{DL} + 1.5 \cdot M_{WS} + 1.75 \cdot mg \cdot M_{LL} (1.0 + IM) \right] \tag{3-2}$$

in which $\eta = \eta_D \cdot \eta_R \cdot \eta_I \geq 0.95$, a load modifier; η_D = a factor relating to ductility; η_R = a factor relating to redundancy; η_I = a factor relating to operational importance; M_{DL} = the moment caused by self-weight of structural components and nonstructural attachments; M_{WS} = the moment caused by self-weight of wearing surfaces and utilities; M_{LL} = the moment caused by design loading HL-93; *mg* = the load distribution factor including multilane live load factor; and *IM* = the vehicular dynamic load allowance.

All beams are selected from the standard hot-rolled W-Shapes listed in the AISC *Manual* (1994). In this study, it is assumed that (1) the compression flange satisfies the width-thickness ratio; and (2) the unbraced length is very short due to intermediate diaphragms. In fact, most shapes listed in the AISC *Manual* (1994) satisfy the flange requirement. Hence, the moment strength reaches its plastic moment strength.

$$M_n = Z_x F_y \tag{3-3}$$

For load lateral distribution factor, Nowak (1993) used the following formula for interior girders with two or more lane loaded:

$$DF = 0.15 + \left(\frac{S}{3}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2} \tag{3-4}$$

in which S = girder spacing (ft); L = span length (ft). (1ft = 0.3048m).

Table D-1 in Appendix D shows a set of design examples. Table D-1 only gives the designation of the shapes. Refer to AISC *Manual* (1994) for detailed data. The relative errors between M_n ($\phi_f = 1.0$) and M_u are generally controlled less than ±0.03.

3.1.2 COMPOSITE STEEL GIRDER BRIDGES

To study the reliability of composite girder bridges, there are a total of 100 simply supported composite steel bridges designed according to the Strength I limit state for flexure of AASHTO

LRFD (1998). Span length ranges from 30 ft (9.14 m) to 120 ft (36.58 m) and girder spacing varies from 4 ft (1.22m) to 12 ft (3.66m). These bridges are of I-beam sections and are designed on the basis of HL-93 loading. These bridges have a roadway width of 20 ft (6.10 m) to 52 ft (15.85 m) with the number of lanes of 2, 2, 3, 3, and 4, respectively. The concrete deck thickness is 8 inches (0.20m). The deck overhang is 2ft (0.61m) in width. All five girders have identical section and are transversely connected with each other by diaphragms intermediately and at end. The number of intermediate diaphragms is 1, 2, 3, and 4, respectively, for 30 ft (9.14 m), 60 ft (18.29 m), 90 ft (27.43 m), and 120 ft (36.58 m) span length. The design of diaphragms is accordance with the Standard Plans for Highway Bridge Superstructures (1982) from the U.S. Department of Transportation.

All bridges were designed according to AASHTO *LRFD* Strength I limit state for flexure:

$$\phi_f M_n \geq M_u \tag{3-5}$$

where M_n = the nominal resistance moment; M_u = the ultimate moment induced by live and dead loads; and ϕ_f = the resistance factor for flexure (ϕ_f = 1.0).

For exterior girders, various loads include the dead loads (self-weight of barrier, slab, steel beam, and wearing surface) and live loads (truck load with impact and lane load).

For interior girders, various loads include the dead loads (self-weight of slab, steel beam, and wearing surface) and live loads (truck load with impact and lane load).

The factored moment by the dead and live loads is:

$$M_u = \eta\left[1.25 \cdot M_{DL} + 1.5 \cdot M_{WS} + 1.75 \cdot mg \cdot M_{LL}(1.0 + IM)\right] \tag{3-6}$$

in which $\eta = \eta_D \cdot \eta_R \cdot \eta_I \geq 0.95$, a load modifier; η_D = a factor relating to ductility; η_R = a factor relating to redundancy; η_I = a factor relating to operational importance; M_{DL} = the moment caused by self-weight of structural components and nonstructural attachments; M_{WS} = the moment caused by self-weight of wearing surfaces and utilities; M_{LL} = the moment caused by design loading HL-93; mg = the load distribution factor including multilane live load factor; and IM = the vehicular dynamic load allowance.

For load lateral distribution factor, Nowak (1993) used the following formula for interior girders with two or more lane loaded:

$$DF = 0.15 + \left(\frac{S}{3}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2} \tag{3-7}$$

in which S = girder spacing (ft); L = span length (ft). (1ft = 0.3048m).

In the design, it is difficult to select the standard hot-rolled W-Shapes listed in the AISC *Manual* (1994). In this study, a typical beam section is determined as shown in Fig. 3-2. This section meets the requirements for compact section: $t_f = 1.5\ t_w$, $b_f = 15\ t_w$, and $h = 40\ t_w$.

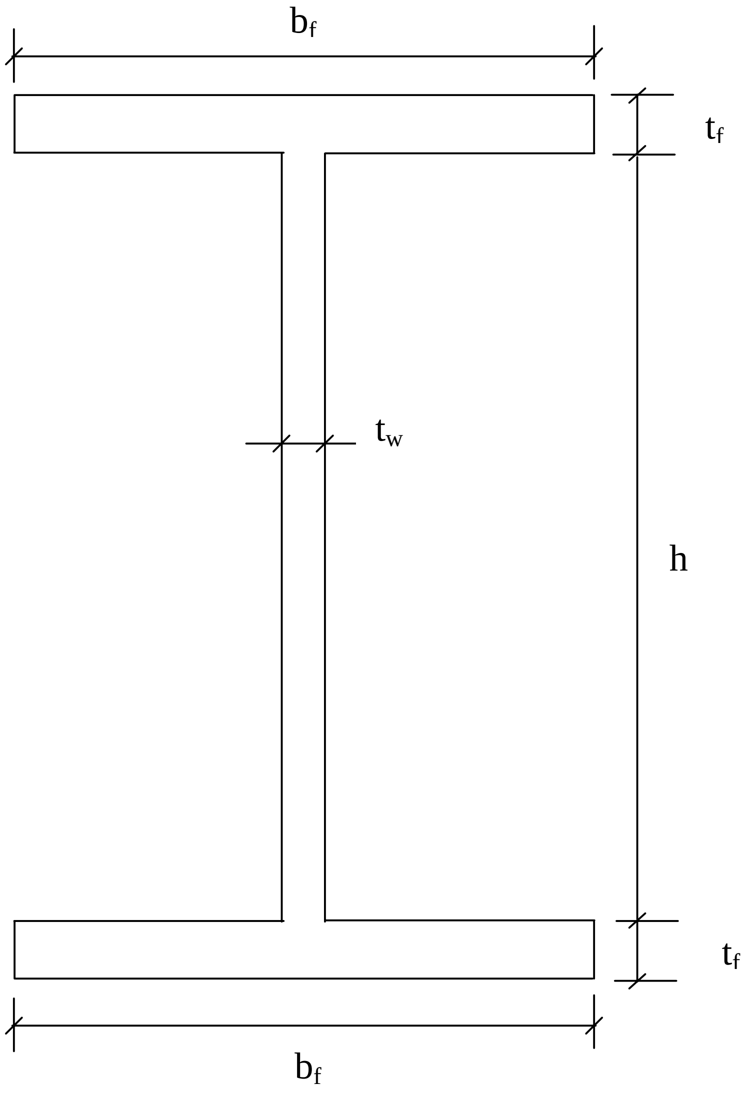


Fig. 3-2. Typical Beam Section

Calculation of plastic moment, M_n, for positive bending sections is as follows:

CASE I:

PNA in web

Condition: $P_t + P_w \geq P_c + P_s + P_{rb} + P_{rt}$

$$\overline{Y} = \left(\frac{D}{2}\right)\left[\frac{P_t - P_c - P_s - P_{rt} - P_{rb}}{P_w}\right]$$

$$M_p = \frac{P_w}{2D}\left[\overline{y}^2 + \left(D - \overline{y}\right)^2\right] + \left[P_s d_s + P_{rt} d_{rt} + P_{rb} d_{rb} + P_c d_c + P_t d_t\right]$$

CASE II:

PNA in top flange

Condition: $P_t + P_w + P_c \geq P_s + P_{rb} + P_{rt}$

$$\overline{Y} = \left(\frac{t_c}{2}\right)\left[\frac{P_w + P_t - P_s - P_{rt} - P_{rb}}{P_c}\right]$$

$$M_p = \frac{P_c}{2t_c}\left[\overline{y}^2 + \left(t_c - \overline{y}\right)^2\right] + \left[P_s d_s + P_{rt} d_{rt} + P_{rb} d_{rb} + P_w d_w + P_t d_t\right]$$

CASE III:

PNA in slab, below P_{rb}

Condition: $P_t + P_w + P_c \geq \left(\frac{C_{rb}}{t_s}\right) P_s + P_{rb} + P_{rt}$

$$\overline{Y} = \left(t_s\right)\left[\frac{P_c + P_w + P_t - P_{rt} - P_{rb}}{P_s}\right]$$

$$M_p = \left(\frac{\overline{y}^2 P_s}{2t_s}\right) + \left[P_{rt} d_{rt} + P_{rb} d_{rb} + P_c d_c + P_w d_w + P_t d_t\right]$$

CASE IV:

PNA in slab, at P_{rb}

Condition: $P_t + P_w + P_c + P_{rb} \geq \left(\frac{C_{rb}}{t_s}\right)P_s + P_{rt}$

$$\overline{Y} = C_{rb}$$

$$M_p = \left(\frac{\overline{y}^2 P_s}{2t_s}\right) + \left[P_{rt}d_{rt} + P_c d_c + P_w d_w + P_t d_t\right]$$

CASE V:

PNA in slab, above P_{rb}

Condition: $P_t + P_w + P_c + P_{rb} \geq \left(\frac{C_{rt}}{t_s}\right)P_s + P_{rt}$

$$\overline{Y} = \left(t_s\right)\left[\frac{P_{rb} + P_c + P_w + P_t - P_{rt}}{P_s}\right]$$

$$M_p = \left(\frac{\overline{y}^2 P_w}{2t_s}\right) + \left[P_{rt}d_{rt} + P_{rb}d_{rb} + P_c d_c + P_w d_w + P_t d_t\right]$$

where all the symbols are illustrated in Fig. 3-3.

Table D-2 in Appendix D shows a set of design examples. The relative errors between M_n (ϕ_f = 1.0) and M_u are controlled less than ±0.03.

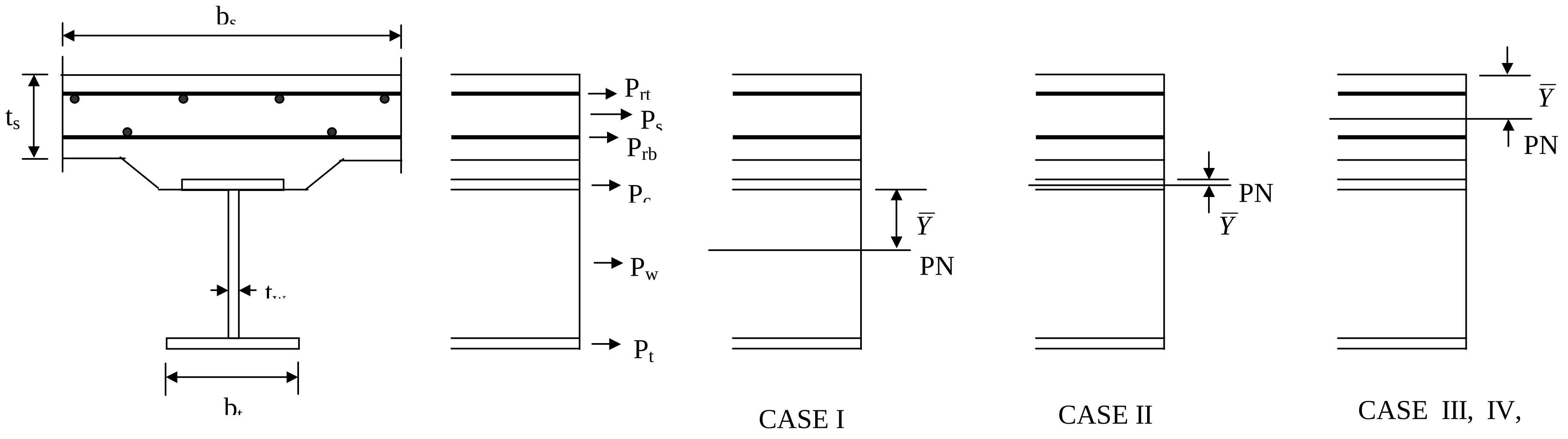


Fig. 3-3. Symbols for Calculation of Plastic Moment

3.2 DESIGN EXAMPLES BASED ON STRENGTH I LIMIT STATE FOR SHEAR

To study the reliability of girder bridges, there are a total of 100 simply supported composite steel bridges designed according to the Strength I limit state for shear of AASHTO *LRFD* (1998). Span length ranges from 30 ft (9.14 m) to 120 ft (36.58 m) and girder spacing varies from 4 ft (1.22m) to 12 ft (3.66m). These bridges are of I-beam sections and are designed on the basis of HL-93 loading. These bridges have a roadway width of 20 ft (6.10 m) to 52 ft (15.85 m) with the number of lanes of 2, 2, 3, 3, and 4, respectively. The concrete deck thickness is 8 inches (0.20m). The deck overhang is 2ft (0.61m) in width. All five girders have identical section and are transversely connected with each other by diaphragms intermediately and at end. The number of intermediate diaphragms is 1, 2, 3, and 4, respectively, for 30 ft (9.14 m), 60 ft (18.29 m), 90 ft (27.43 m), and 120 ft (36.58 m) span length. The design of diaphragms is accordance with the Standard Plans for Highway Bridge Superstructures (1982) from the U.S. Department of Transportation.

All bridges were designed according to AASHTO *LRFD* Strength I limit state for shear:

$$\phi_f V_n \geq V_u \tag{3-8}$$

where V_n = the nominal resistance shear; V_u = the ultimate shear induced by live and dead loads; and ϕ_v = the resistance factor for flexure (ϕ_v = 1.0).

For exterior girders, various loads include the dead loads (self-weight of barrier, slab, steel beam, and wearing surface) and live loads (truck load with impact and lane load).

For interior girders, various loads include the dead loads (self-weight of slab, steel beam, and wearing surface) and live loads (truck load with impact and lane load).

The factored shear by the dead and live loads is:

$$V_u = \eta\left[1.25 \cdot V_{DL} + 1.5 \cdot V_{WS} + 1.75 \cdot mg \cdot V_{LL}(1.0 + IM)\right] \tag{3-9}$$

in which $\eta = \eta_D \cdot \eta_R \cdot \eta_I \geq 0.95$, a load modifier; η_D = a factor relating to ductility; η_R = a factor relating to redundancy; η_I = a factor relating to operational importance; V_{DL} = the shear caused by self-weight of structural components and nonstructural attachments; V_{WS} = the shear caused by self-weight of wearing surfaces and utilities; V_{LL} = the shear caused by design loading HL-93; mg = the load distribution factor including multilane live load factor; and IM = the vehicular dynamic load allowance.

For load lateral distribution factor, Nowak (1993) used the following formula for interior girders with two or more lane loaded:

$$DF = 0.4 + \left(\frac{S}{6}\right) - \left(\frac{S}{25}\right)^2 \tag{3-10}$$

in which S = girder spacing (ft); L = span length (ft). (1ft = 0.3048m).

In the design, it is difficult to select the standard hot-rolled W-Shapes listed in the AISC *Manual* (1994). In this study, a typical beam section is determined as shown in Fig. 3-2. This section meets the requirements for compact section.

Nominal shear resistance of unstiffened webs, V_n, is

1. Web slenderness

$$\frac{D}{t_w} \leq 2.46\sqrt{\frac{E}{F_{yw}}}$$

$$V_n = V_p = 0.58F_{yw}Dt_w$$

2. Web slenderness

$$\frac{D}{t_w} \leq 3.07\sqrt{\frac{E}{F_{yw}}}$$

$$V_n = 1.48t_w^2\sqrt{EF_{yw}}$$

3. Web slenderness

$$\frac{D}{t_w} > 3.07\sqrt{\frac{E}{F_{yw}}}$$

$$V_n = \frac{4.55t_w^3E}{D}$$

Table D-3 in Appendix D shows a set of design examples. The relative errors between V_n (ϕ_f = 1.0) and V_u are generally controlled less than ±0.03.

4. FINITE ELEMENT MODELS FOR BRIDGES

This chapter introduces two finite element models for multigirder steel highway bridges: grillage model and three dimensional slab on girder model.

4.1 GRILLAGE MODEL

These multigirder bridges are modeled as grillage beam systems. The node parameters are:

$$\delta^e = \left\{ \delta_i \quad \delta_j \right\}^T \tag{4-1}$$

where $\delta_i = \left\{ w_{zi} \quad \theta_{xi} \quad \theta_{yi} \right\}^T$ = the displacement vector of the left joint; $\delta_j = \left\{ w_{zj} \quad \theta_{xj} \quad \theta_{yj} \right\}^T$ = the displacement vector of the right joint; *w* = vertical displacement in the *z*-direction, and θ_x and θ_y = rotational displacements about *x*- and *y*-axes, respectively, as shown in Fig. 4-1. Figure 4-2 shows the plan of one bridge and the corresponding grillage model. More details refer to Wang et al. (1992) and Huang et al. (1993).

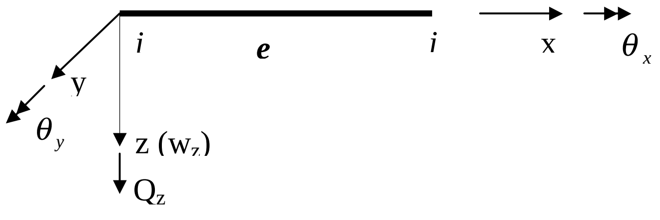
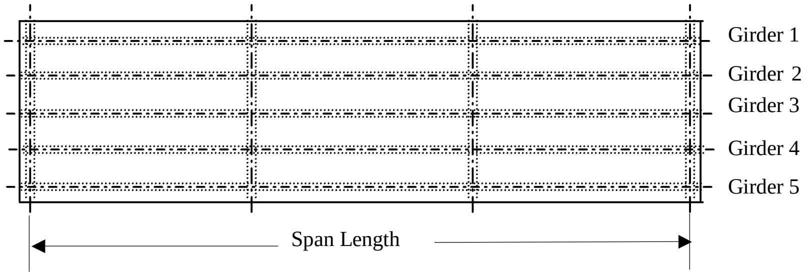
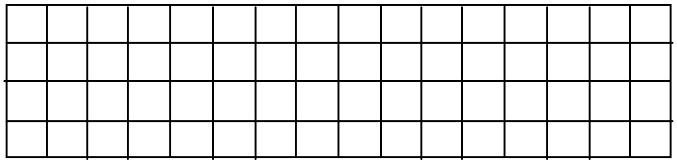


Fig. 4-1. Grillage Element *e*



(a) Plan of bridges



(b) Grillage model

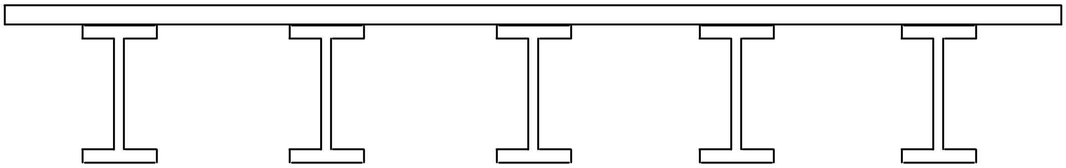
Fig. 4-2. Typical Bridge Plan and Grillage Model

4.2 THREE-DIMENSIONAL SLAB ON GIRDER MODEL

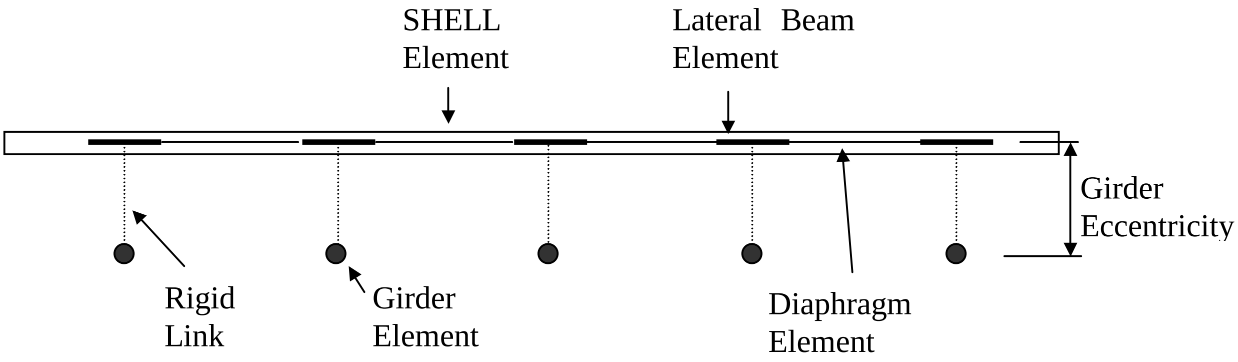
Plate bending (PLATE) elements are used to model the bridge deck for the noncomposite model and the composite girder model. However, in the case where composite action is modeled with the eccentric girder model, a plate bending and stretching (SHELL) elements are used. Four node PLATE and SHELL elements were chosen for all bridge models.

Girders, stiffeners, and beam type diaphragms are all modeled using standard beam elements. A rigid link is assumed to connect the centroid of the eccentric members to the midsurface of the slab. The rigid link does not exist physically, but it represents the manner in which the stiffness of eccentric members is mathematically formulated in finite element analysis.

Figure 4-3 shows three dimensional finite element cross section described above.



(a) Bridge Cross Section



(b) Three Dimensional Finite Element Cross Section

Fig. 4-3. Three Dimensional Finite Element Cross Section

5. RELIABILITY ANALYSIS FOR STEEL GIRDER BRIDGES

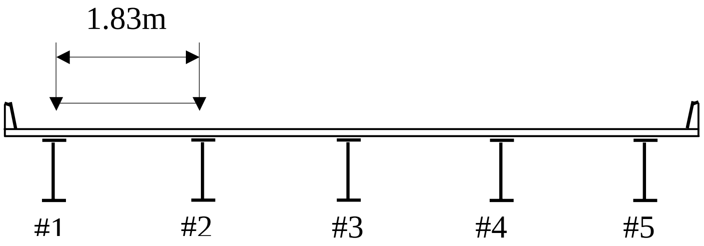
5.1 DEVELOPMENT AND CALIBRATION OF THE SFEM MODELS

5.1.1 Static Analysis

Based on the SFEM theory stated in Chapters 2, a Fortran program ‘*reli.for*’ is written to perform the SFEM-based reliability analysis. The function for static analysis of bridge structures in the Fortran program ‘*reli.for*’ has been verified using a sample bridge shown in Fig. 5-1:

Span length L = 60 ft (18.29 m)
Girder Spacing S = 7 ft (2.13 m)
Slab thickness = 8 inches (0.203m)
Five steel girders
Simply supported

Truck position in transverse direction is also shown in Fig. 5-1. The results are shown in Table 5-1. The design loads are included, such as truck load, lane load, future wearing surface, as well as self-weight of girders, concrete slab, and barriers. From Table 5-1, it is seen that the difference of the total moment at midspan is less than 0.2%.



All girders: W24x131, Spacing = 7 ft, thickness of slab = 8in

Fig. 5-1. One Design Example (*L* = 60ft)

Table 5-1. Comparison of Static Moment (kips-ft)

Load type	**Truck**	**Lane Load**	**Self weight** [b]	**Future surface** [c]
Computed [a]	798.9	287.53	2234.67	589.56
Theoretical	800	288	2238.41	590.56
Error (%)	0.14	0.16	0.17	0.17

Note:

a. Sum of all five girders.

b. Self-weight includes barrier, forms, diaphragms, main girder and concrete slab. The input data used are 0.09746 kips/in for exterior girders, 0.0732 kips/in for interior girders, 0.0 kips/in for end diaphragms, and 0.0 kips/in for intermediate diaphragms.

c. The density of wearing surface is assumed to be $\gamma_{ws} = 2.846e-4 kips/in^3$.

5.1.2 Reliability Analysis

It is difficult to exactly validate the results from the developed SFEM program using other methods, such as Monte Carlo simulation. Hence, a comparison is made between SFEM and AFOSM results. In the AFOSM approach, there are 7 design variables selected: DL_1, WS, LNL, TL, IM, Z_x, and F_y. Table 5-2 gives three bridges with a span length of 30 ft (9.14 m), 60 ft (18.29 m), and 90 ft (27.43 m) using the control design by the exterior girder. The girder spacing is 6 ft (1.83 m). From initial study, it is found that there exists difference in the lateral distribution of dead and live load between the two methods. For the convenience of comparison, the moments acting on the critical girder in the AFOSM method are adjusted to be exactly the same as those in the SFEM. Table 5-3 shows the calculated reliability indices. Table 5-4 shows the calculated basic variables at design point $\mathbf{X}^*$. From the results obtained by the two methods shown in Tables 5-3 and 5-4, it is seen that (1) the reliability indices, β, by SFEM are slightly higher than those by AFOSM; (2) the difference in β increases with span length; and (3) the results at design point $\mathbf{X}^*$ are consistent and similar. The comparison provides the evidence that the developed SFEM model is reliable. Table 5-3 also gives the reliability indices without adjustment of moment. It is seen that the difference without moment adjustment is much higher than the one with adjustment. This indicates that the lateral distribution of dead and live loads is more important than the factors considering the randomness of design variables on other girders in the reliability analysis.

Table 5-2. Three Design Examples

Cases		Exterior (η = 0.95)	
Span length *L* (ft)	**Girder Spacing *S* (ft)**	**Girder Size**	**Error [a]**
30	6	W21×83	-0.023
60	6	W27×217	-0.001
90	6	W40×331	0.000

Note:

a. error = $(M_r - M_u)/M_u$
b. 1 ft = 0.3048 m

Table 5-3. Reliability Index β

Cases		SFEM		AFOSM With exact adjustment			AFOSM Without adjustment	
***L* (ft)**	***S* (ft)**	β	**Iteration No.**	β	**Iteration No.**	**Difference [a]**	β	**Difference [a]**
30	6	3.043	10	2.989	7	0.054	2.995	0.047
60	6	3.475	9	3.401	7	0.074	3.118	0.356
90	6	3.693	14	3.603	7	0.090	3.129	0.564

Note:
a. difference = β_{SFEM} - β_{AFOSM}; and
b. 1 ft = 0.3048 m

The gradient, α_i^*, in Eq. (16), often referred to as the sensitivity factor, is a measure of the sensitivity of the reliability index to inaccuracies in the value of X_i^* at the design point. Table 5-5 presents the sensitivities of β to nine variables, in the order of significance of $|\alpha_i^*|$. The sensitivity factors not given herein generally have absolute values less than 0.01. The uncertainties in the variables corresponding to smaller $|\alpha_i^*|$ have less influence on β. All the seven variables used in the AFOSM method have the most important influence on reliability index. Because only those variables with very small sensitivity factors are neglected in AFOSM approach, the insignificant difference observed in Table 5-3 is rational.

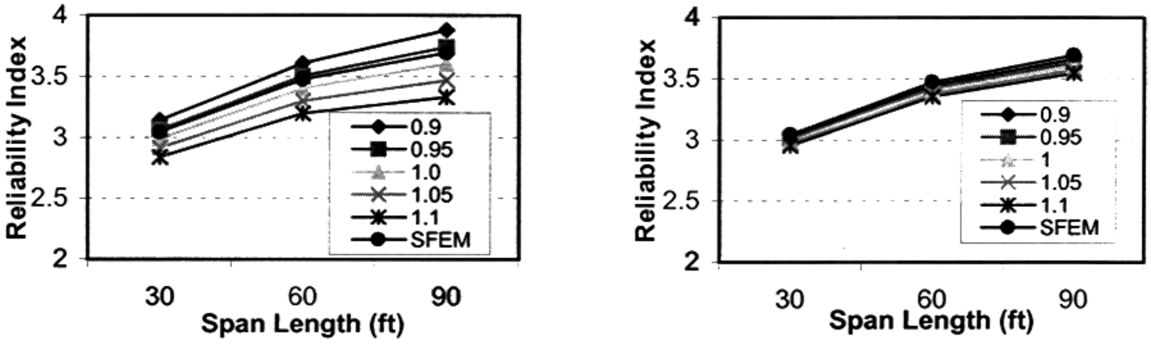
As it is mentioned earlier, the reliability index is very sensitive to load lateral distribution. According to previous researches, it is very complicated to accurately and simply express the lateral distribution of live load. For example, Shahawy and Huang (2001) studied the specified formula by AASHTO *LRFD* (1998) for concrete girder bridges and found significant errors from –25% to 70%. To investigate the effect of load distribution, a range of –10% to 10% of deviation from the moment by SFEM is used for dead, wearing surface, lane, and truck (with dynamic impact) loads. The control design of exterior girder is used. The girder spacing is 6ft (1.83m). Figure 5-2 shows the variation of reliability index β to the deviation of distributed loads on exterior girder. The results by SFEM are also shown in Fig. 5-2. In the cases of *TL* and *DL*, it can be seen that a 10 percent of deviation in lateral distribution can cause much larger difference than the use of the extensive SFEM model. Therefore, it is concluded that the accurate expression of load lateral distribution plays an important role in the AFOSM-based reliability analysis.

Table 5-4. Basic Variables at the Design Point X*

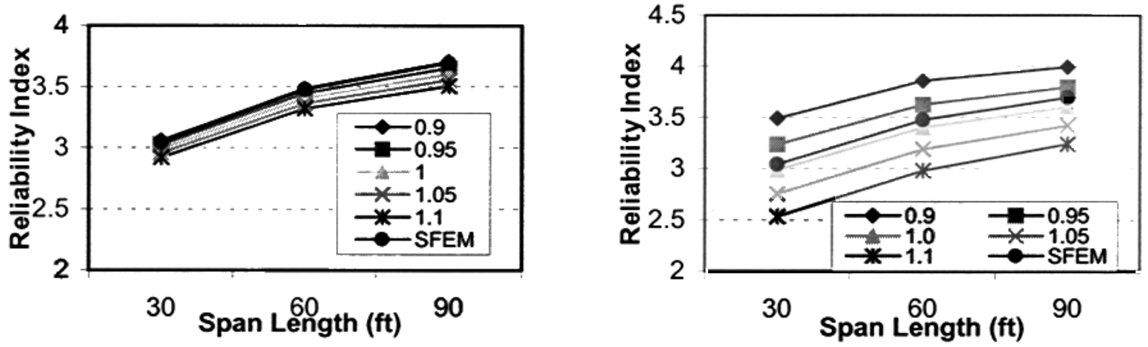
Variable	L = 30ft, S = 6ft		L = 60ft, S = 6ft		L = 90ft, S = 6ft	
	SFEM	AFORM	SFEM	AFORM	SFEM	AFORM
DL	9.166E-02	9.267E-02	1.037E-01	1.060E-01	1.142E-01	1.181E-01
WS	3.040E-04	3.056E-04	3.108E-04	3.136E-04	3.171E-04	3.210E-04
LNL	6.318E-02	6.333E-02	6.371E-02	6.399E-02	6.423E-02	6.458E-02
TL	1.046E+02	1.065E+02	1.045E+02	1.068E+02	1.023E+02	1.047E+02
IM	3.583E-01	3.611E-01	3.585E-01	3.616E-01	3.555E-01	3.588E-01
Z_x	1.848E+02	1.843E+02	6.614E+02	6.587E+02	1.329E+03	1.322E+03
F_y	3.290E+01	3.354E+01	3.167E+01	3.249E+01	3.096E+01	3.190E+01
Note: 1 ft = 0.3048 m						

Table 5-5. Sensitivities of β to Basic Variables

Order No.	L = 30ft, S = 6ft		L = 60ft, S = 6ft		L = 90ft, S = 6ft	
	Variable	α_i^*	Variable	α_i^*	Variable	α_i^*
1	F_y	-0.759	F_y	-0.791	F_y	-0.815
2	TL	0.481	TL	0.418	Z_x	-0.389
3	Z_x	-0.380	Z_x	-0.385	TL	0.354
4	IM	0.157	IM	0.138	WS	0.123
5	WS	0.088	WS	0.105	IM	0.116
6	DL_1	0.084	LNL	0.093	LNL	0.106
7	LNL	0.082	DL_1	0.088	DL_1	0.097
8	DL_2	0.035	DL_2	0.064	DL_2	0.094
9	E	-0.015	I_1	0.006	I_1	0.004
Note: 1 ft = 0.3048 m						



(a) DL (b) WS



(c) LNL (d) TL

Fig. 5-2. Variation of Reliability Index to the Deviation of Distributed Loads on Exterior Girder

All the bridges in Table 5-6 are, respectively, analyzed using the SFEM and the AFOSM approaches. Figure 5-3 shows the relationship between the difference in β and the ratio of discrepancy in total moment on the controlling girder. The difference in β is defined as (β_{SFEM} - β_{AFOSM}). The ratio of discrepancy in total moment is defined as (M_{SFEM} - M_{AFOSM})/M_{AFOSM}. It can be seen that the sparsely distributed dots almost follows a straight line. Therefore, a trend line with fitting equation is also shown in Fig. 5-3. The slope of the line is about -9.3, i.e., a 10% more total moment used in AFOSM than that in SFEM. It will subsequently lead to 0.93 less in β. This study further quantifies the sensitivity of reliability index to laterally distributed moment.

Table 5-6. Design Examples

Cases		**Exterior** (η = 0.95)		**Interior** (η = 1.0)	
Span length L (ft)	**Girder Spacing (ft)**	**Girder Size**	**Error** [a]	**Girder Size**	**Error** [a]
30	4	W21×83	-0.023	W16×77	0.022
30	6	W21×83	0.001	W16×100	-0.005
30	8	W27×84	-0.025	W21×101	0.021
30	10	W18×119	0.021	W24×104	-0.020
30	12	W21×111	0.023	W12×210	0.007
60	4	W36×170	0.003	W24×162	-0.012
60	6	W27×217	-0.001	W33×169	-0.016
60	8	W30×235	0.004	W24×279	0.026
60	10	W36×230	-0.002	W40×215	0.003
60	12	W40×235	-0.024	W44×230	0.000
90	4	W40×297	0.016	W36×232	0.030
90	6	W40×331	0.000	W36×300	0.019
90	8	W40×392	0.003	W36×359	-0.025
90	10	W40×431	-0.021	W36×439	-0.002
90	12	W40×466	0.007	W36×527	0.044

Note:

a. error = $(M_r - M_u)/M_u$

b. 1 ft = 0.3048 m

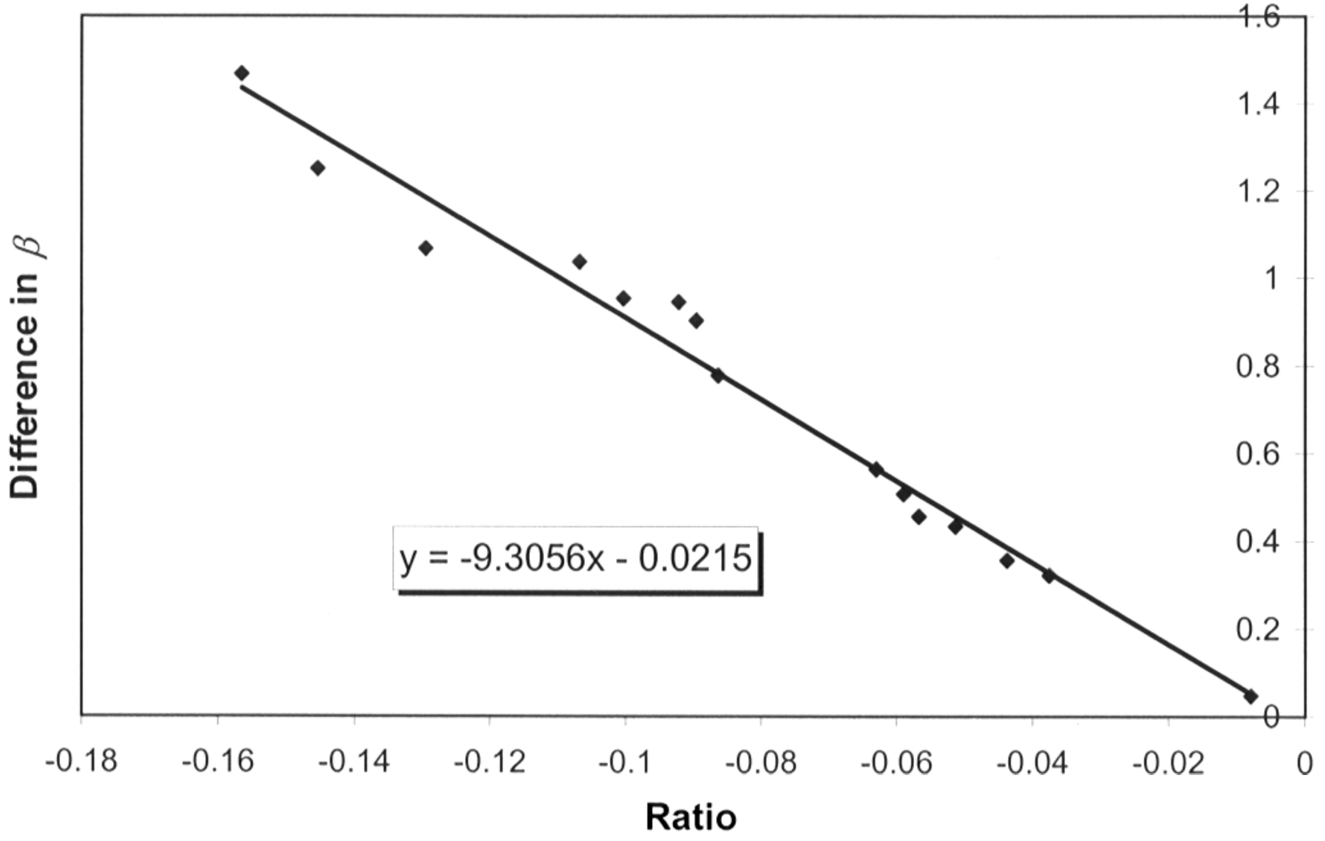


Fig. 5-3. Relationship between the Difference in β and Ratio of Discrepancy in Total Moment

5.2 STRENGTH I LIMIT STATE FOR FLEXURE

5.2.1 Noncomposite Steel Bridges

Table D-1 gives the noncomposite steel bridges designed according to AASHTO *LRFD* Specifications (1998) Strength Limit I for flexure. The design is controlled by the larger requirement of exterior or interior girder. There are four cases considered for load modifier: η = 0.95, 1.0, 1.05, and 1.1. According to AASHTO *LRFD* Specifications (1998) commentary, the corresponding target reliability index, β_T, is 3.0, 3.5, 3.8, and 4.0, respectively. Figure 5-4 shows the calculated reliability indices using AFOSM approach. Figure 5-5 shows the calculated reliability indices using SFEM approach. While other data are selected from the AISC *Manual* (1994), the required plastic section modulus, Z_x, is used in this analysis to ensure $M_n = M_u$. This can eliminate the errors coming from inequity. From Fig. 5-4, it can be seen that the reliability indices computed by AFOSM are uniformly distributed, generally above the target. That some points locate below the target is mainly due to the statistical data selected for the design variables. For example, the bias factor for live load suggested by Novak (1993) ranges from 1.10 to 1.20. In this study it is taken as 1.15. Using the extensive SFEM as shown in Fig. 5-5, it can be seen that the reliability indices turn out to be more sparsely distributed and are generally greater than the target. The reliability indices corresponding to a lower value of η = 0.90 are also shown in Fig. 5-5. The extensive SFEM indicates that a load modifier, η, which is 0.05 less than the specified value, achieves the same target safety level.

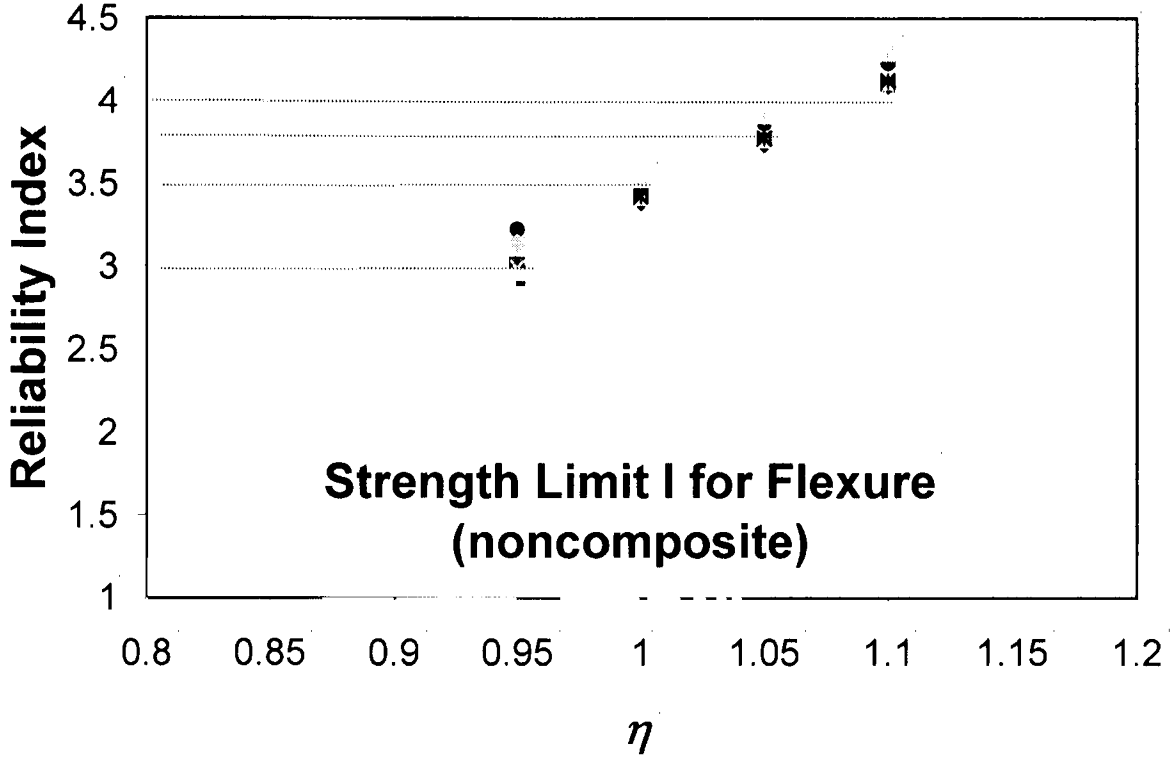


Fig. 5-4. Reliability Indices for Strength Limit I for Flexure of Noncomposite Bridges

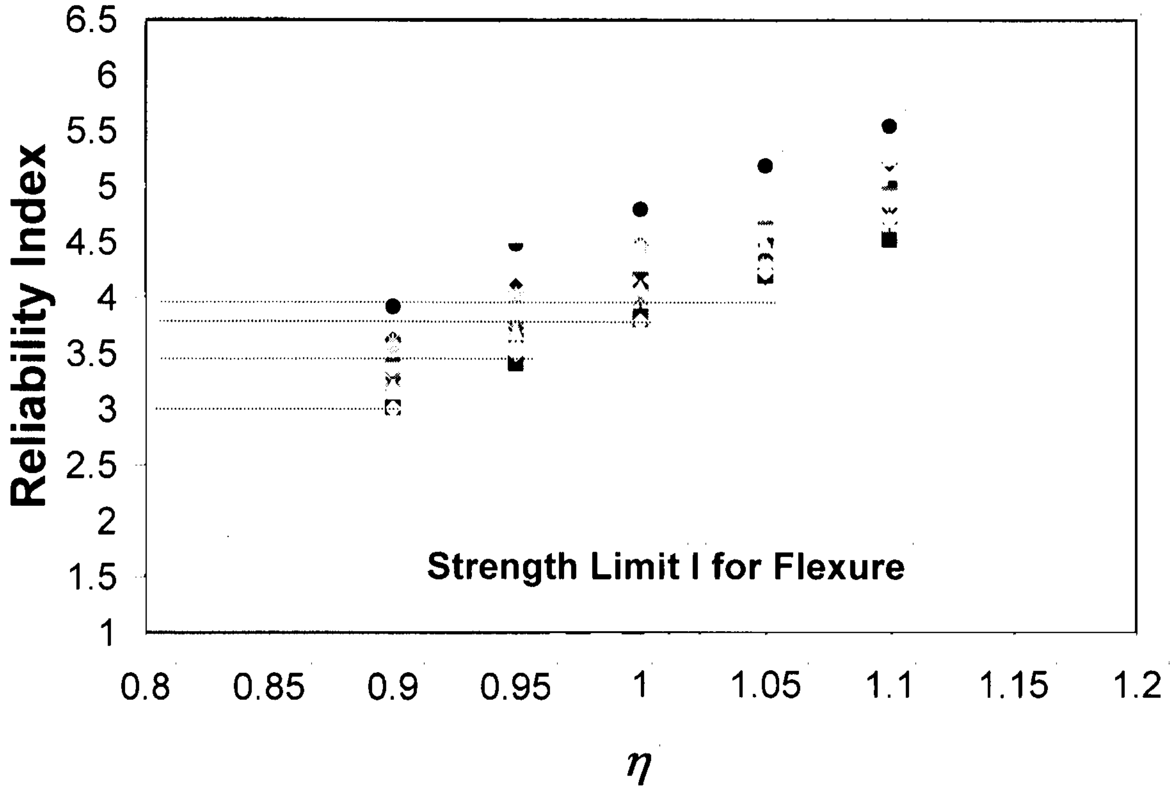


Fig. 5-5. Reliability Indices for Strength Limit I for Flexure of Noncomposite Bridges

5.2.2 Composite Steel Bridges

Table D-2 gives the noncomposite steel bridges designed according to AASHTO *LRFD* Specifications (1998) Strength Limit I for flexure. The design is controlled by the larger requirement of exterior or interior girder. There are four cases considered for load modifier: η = 0.95, 1.0, 1.05, and 1.1. According to AASHTO *LRFD* (1998) commentary, the corresponding target reliability index, β_T, is 3.0, 3.5, 3.8, and 4.0, respectively. Figure 5-6 shows the calculated reliability indices using AFOSM approach. Figure 5-7 shows the calculated reliability indices using SFEM approach. From Fig. 5-6, it can be seen that the reliability indices computed by AFOSM are uniformly distributed, generally above the target. That some points locate below the target is mainly due to the statistical data selected for the design variables. For example, the bias factor for live load suggested by Novak (1993) ranges from 1.10 to 1.20. In this study it is taken as 1.15. Using the extensive SFEM as shown in Fig. 5-7, it can be seen that the reliability indices turn out to be more sparsely distributed and are generally greater than the target. The reliability indices corresponding to a lower value of η = 0.90 are also shown in Fig. 5-7. The extensive SFEM indicates that a load modifier, η, which is 0.05 less than the specified value, achieves the same target safety level.

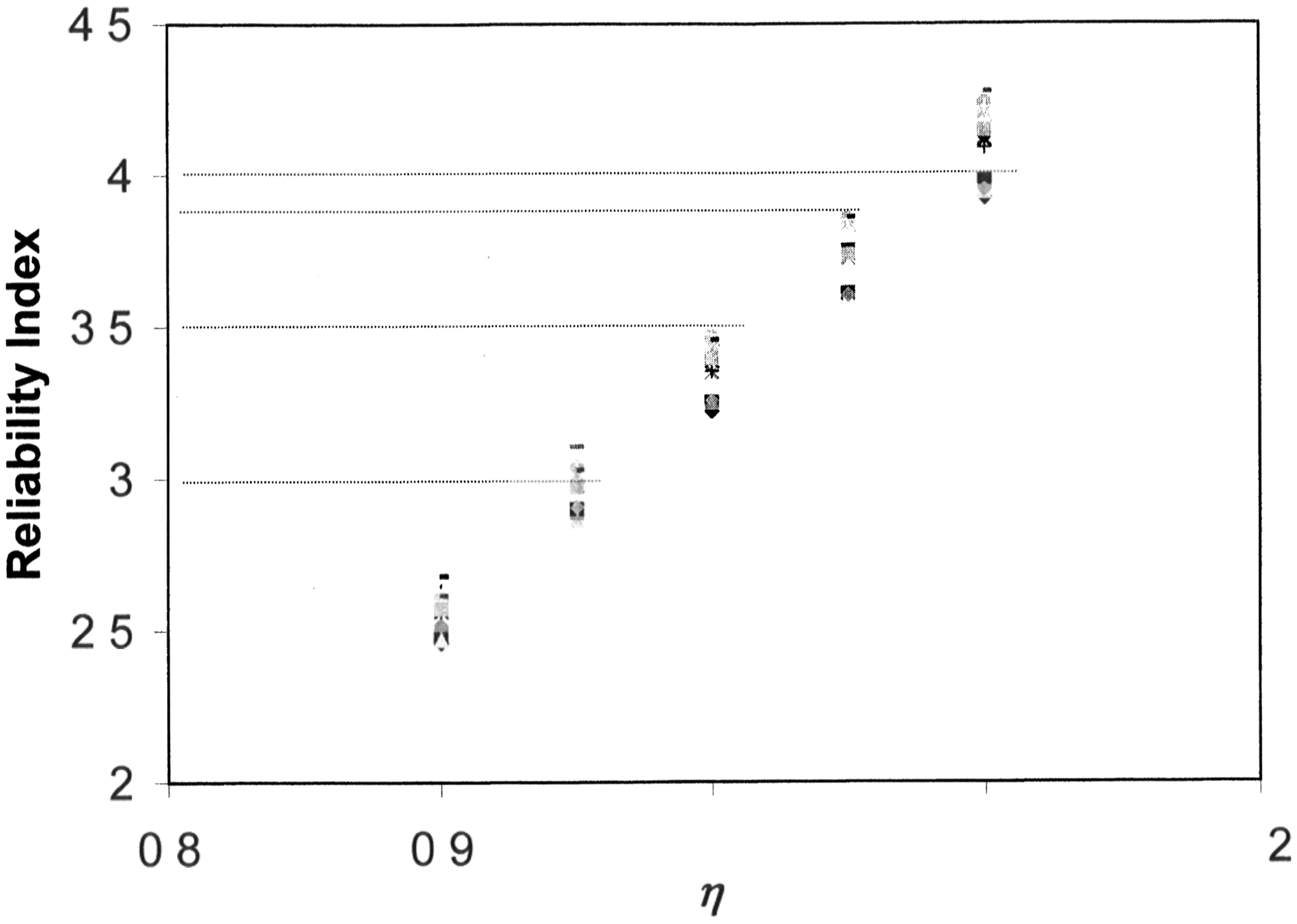


Fig. 5-6 Reliability ndices fo Strength Limit for Flexure of Composite Bridges (AFOSM)

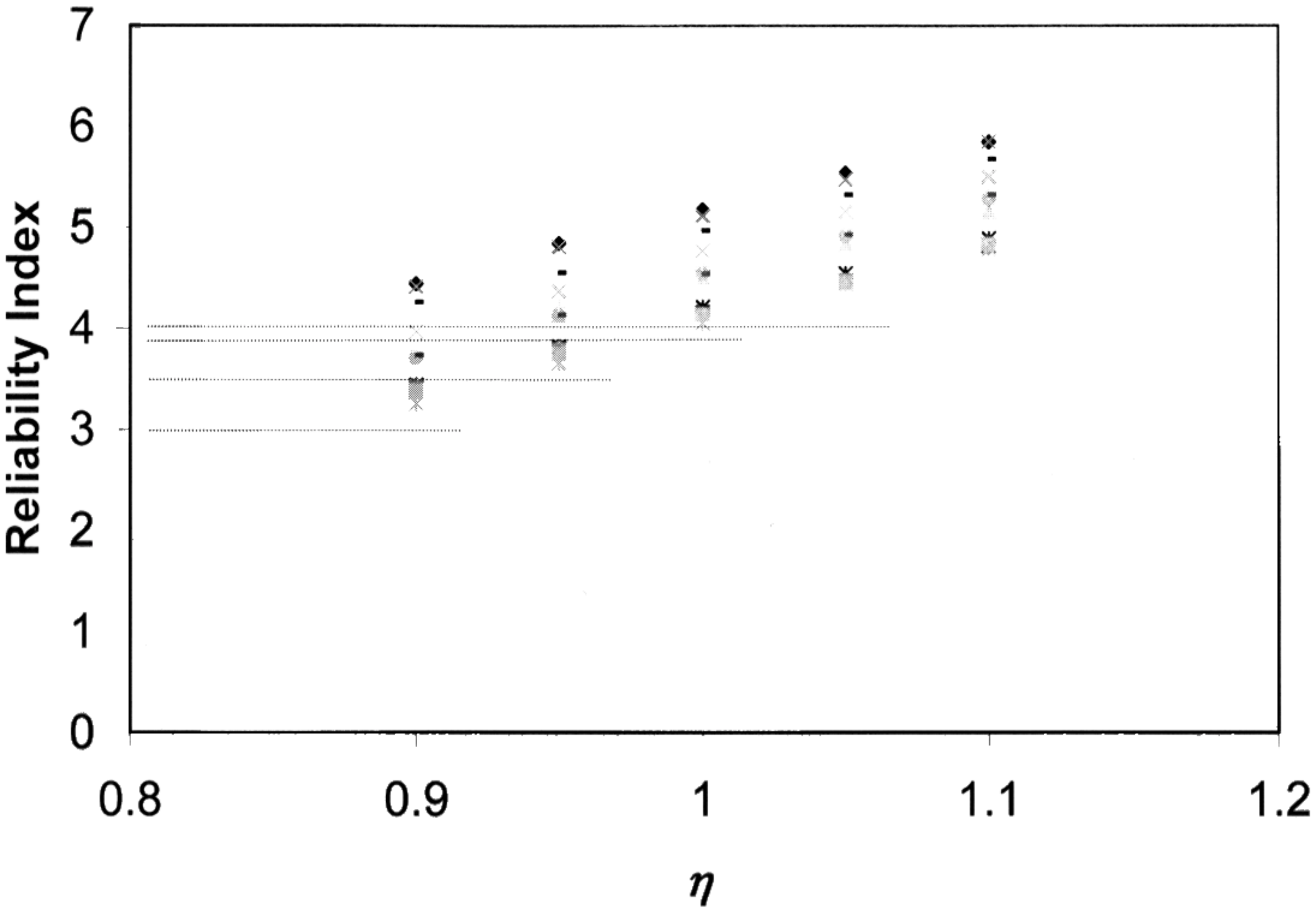


Fig. 5-7. Reliability Indices for Strength Limit I for Flexure of Composite

5.3 STRENGTH I LIMIT STATE FOR SHEAR

Table D-3 gives the composite steel girder bridges designed according to AASHTO *LRFD* Specifications (1998) Strength Limit I for shear. The design is controlled by the larger requirement of exterior or interior girder. There are four cases considered for load modifier: η = 0.95, 1.0, 1.05, and 1.1. According to AASHTO *LRFD* (1998) commentary, the corresponding target reliability index, β_T, is 3.0, 3.5, 3.8, and 4.0, respectively. Figure 5-8 shows the calculated reliability indices using AFOSM approach. Figure 5-9 shows the calculated reliability indices using SFEM approach. From Figure 5-8, it can be seen that the reliability indices computed by AFOSM are not uniformly distributed very well. Some points apparently locate below the target. This means that the use of load lateral distribution formula in Eq. (3-10) leads to unsafe results. Using the extensive SFEM as shown in Fig. 5-9, it can be seen that the reliability indices turn out to be more sparsely distributed and are generally higher than the target. The reliability indices corresponding to a lower value of η = 0.90 are also shown in Fig. 5-9. The results in Fig. 5-9 indicate that a load modifier, η, which is 0.05 less than the specified value, will not achieve the same target safety level.

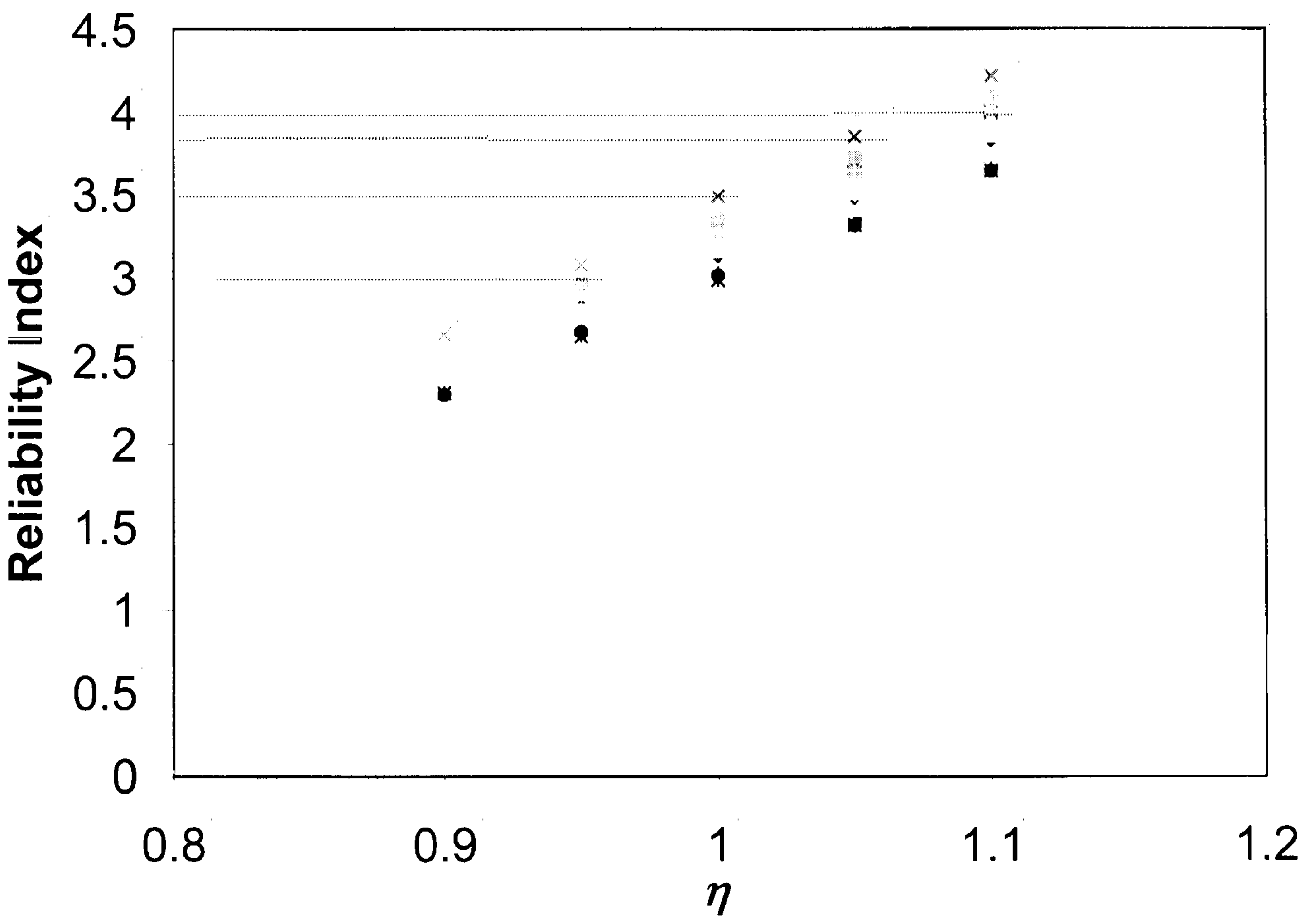


Fig. 5-8. Reliability Indices for Strength Limit I for Shear (AFOSM)

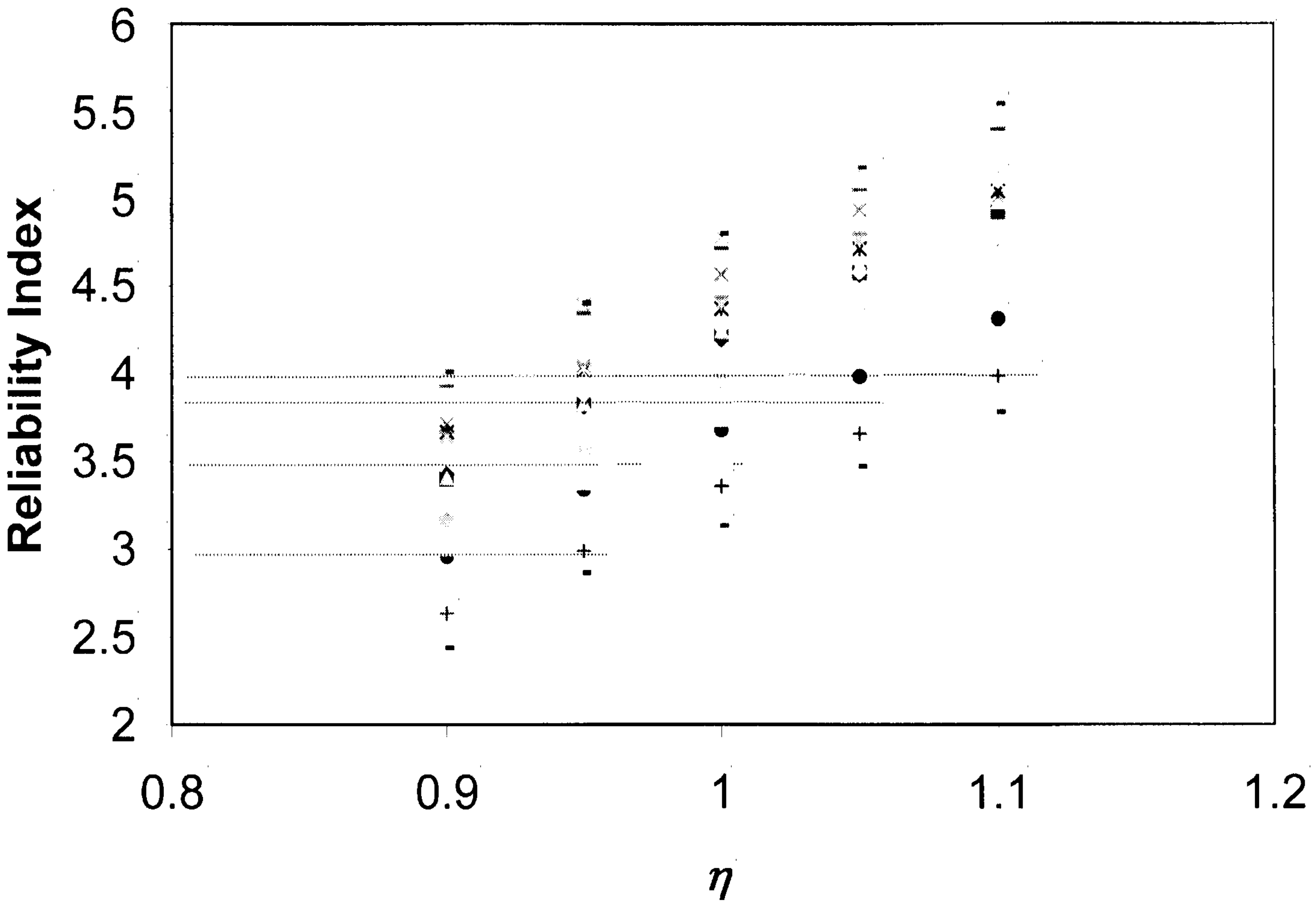


Fig. 5-9. Reliability Indices for Strength Limit I for Shear (SFEM)

6. SUMMARIES, RECOMMENDATIONS, AND CONCLUSIONS

6.1 SUMMARIES

In this study, an extensive approach, namely stochastic finite element method, is used to examine the reliability level for multigirder steel highway bridges. Nearly three hundred bridges are designed according to the Strength I limit state of AASHTO *LRFD Specifications* (1998). These bridges have a span length varying from 30 ft (9.14 m) to 120 ft (36.58 m) and a girder spacing from 4 ft (1.22 m) to 12 ft (3.66 m). The basic principles of SFEM are presented in this study. A Fortran program "*reli.for*" is written according to the SFEM algorithm. This program is validated using the results from static and reliability analysis. Two limit states used in this study are Strength I limit state for flexure and for shear, respectively. Noncomposite and composite behaviors are considered. For the purpose of calibrating the actual safety level in AASHTO *LRFD Specifications* (1998), the reliability index of these design examples are calculated.

6.2 RECOMMENDATIONS

Based on the reliability analysis of noncomposite steel girder bridges, it can be concluded that the reliability index, β, is very sensitive to the lateral distribution of dead and live loads including the self-weight of barrier, slab, and girder as well as truck loading. However, the reliability index, β, is not sensitive to the randomness of design variables on other members. Therefore, a practical procedure is suggested for the reliability analysis of this kind of bridges:

1. Compute factored moment, M_u, on the critical member using Eq. (15);

2. Select a W-Shape from AISC *Manual* to most closely satisfy $M_n = M_u$;
3. Refine the laterally distributed dead, surface wearing, lane, and truck loads, using an deliberate model such as the 3D model with plate/shell/beam elements used by Shahawy and Huang (2001);
4. Put the refined loads on the controlling girder; and
5. Perform reliability analysis using the conventional AFOSM.

This procedure avoids the complicated computation inherent in SFEM, yet achieves good accuracy. In the examples given, it is found that AFOSM produces slightly conservative results compared with SFEM.

6.3 CONCLUSIONS

For noncomposite steel girder bridges, based on the extensive SFEM, the calculated reliability indices are generally much higher than the target. The load modifier, η, which is 0.05 less than the specified value, may be used for the design of noncomposite steel girder bridges using AASHTO *LRFD* Strength I limit state for flexure.

For composite steel girder bridges, using the extensive SFEM, the calculated reliability indices are generally much higher than the target. The load modifier, η, which is 0.05 less than the specified value, may be used for the design of composite steel girder bridges using AASHTO *LRFD* Strength I limit state for flexure.

For multigirder bridges, using the extensive SFEM, the calculated reliability indices are generally higher than the target. The load modifier specified by AASHTO *LRFD* Specifications, η, should be used for the design of steel girder bridges using Strength I limit state for shear to achieve the target safety level.

REFERENCES

AASHTO (1998). *LRFD Bridge Design Specifications*, 2nd ed., American Association of State Highway and Transportation Officials, Washington, D.C.

AISC (1986). *Manual of Steel Construction Load & Resistance Factor Design*, 1st Ed., American Institute of Steel Construction, Chicago, IL.

AISC (1994). *Manual of Steel Construction Load & Resistance Factor Design*, 2nd Ed., American Institute of Steel Construction, Chicago, IL.

Ang, A. H-S and Tang, W.H. (1984). *Probability Concepts in Engineering Design, Vol. II: Decision, Risk and Reliability,* John Wiley & Sons, Inc., New York.

Barker, R. M. and Puckett, J.A. (1997). *Design of Highway Bridges Based on AASHTO LRFD Bridge Design Specifications*, John Wiley & Sons, Inc., New York.

Galambos, T.V. and Ravindra, M.K. (1978), "*Properties of Steel For Use in LRFD,*" ASCE, ST9, 1459-1468.

Haldar, A. and Mahadevan, S. (2000). *Reliability Assessment Using Stochastic Finite Element Analysis*, John Wiley & Sons, New York.

Mahadevan, S. and Haldar, A. (1991). Stochastic FEM-based Validation of LRFD, *Journal of Struct. Engrg.*, ASCE, Vol. 117, No. 5, pp. 1393-1412.

Nowak, A.S. (1993). *Calibration of LRFD Bridge Design Code,* NCHRP Report 368, National Research Council, Washington, D.C.

Shahawy, M. and Huang, D.Z. "A parametric study of lateral load distribution in concrete slab-on-girder bridges," *ACI Struct. J.*, Vol. 98, No. 4, pp. 1-10.

US DOT (1982). *Standard Plans for Highway Bridge Superstructures*, U.S. Department of Transportation, Federal Highway Administration.

Zienkiewicz, O.C. (1971). *The Finite Element Method in Engineering Science*, McGraw-Hill, London.

Zokaie, T. et al (1992). “Distribution of Wheel Loads on Highway Bridges,” NCHRP 12-26/1, Proposed changes in AASHTO, Imsben and Associates, Sacramento, CA.

APPENDIX A

USER'S MANUAL FOR THE SFEM MODEL

INTRODUCTION

In this project, a computer program entitled “*reli.for*” was developed for the reliability analysis of multigirder highway bridges.

User’s Guide

The computer program consists of the following parts:

- Source file: *reli.for*;
- Input data: *tes.dat* and *car.dat*; and
- Output data: *tes.out*

The definition of the input and output data is again given as follows.

INPUT FILES

1. TES.DAT

(1) N, M, MLX, MLY, NB, NEG, NIJ, NG, NP, NQ, NQG, NC, LX, LC, III

N - Total Number of Nodes/Joints
M - Total Number of Elements
MLX - Total Number of Elements in X-direction (see Fig.1)

MLY - Total Number of Elements in Y-direction (see Fig.1)
NB - Total Number of Restrained Deflections at Supports
NEG - Total Number of the Kinds of Materials
NIJ - Total Number of the Kinds of Cross Section Properties
NG - Total Number of the Kinds of Uniform Masses
NP - Total Number of the Needed Frequencies
NQ - Total Number of the Needed Frequencies for the Iteration
(generally, NQ = NP+4 (3-5))
NQP - Total Number of the Lumped Masses
NC - Total Number of the Master-slave Joints (0)
LX - Index of Initial Vibration Mode Shapes
(generally = 0)
LC - Index for Checking Input Data (0)
III - Index for Free- and Force-vibration Analysis
(1 - for free-vibration analysis; 0 - for force vibration)

(2) GG, EPS

GG - Acceleration of Gravity (= 386.4 in/Sec.^{2})
EPS - Needed Accuracy (could be equal to 1.0E -3)

(3) I, KI, X(I), Y(I) - Information of Joints

I - Number of Joint
KI - Index of Automatically Forming the Coordinates of Joints (0)
X(I) - X-coordinate of Joint I
Y(I) - Y-coordinate of Joint I

(4) QN(NG) - Uniform Mass per Unit (Kips/in)

(5) EG(NEG,2) - Modulus of Materials

The first column: modulus of elasticity; and
The second column: shear modulus.

(6) GJI(NIJ,3) - Properties of Cross Sections

GJI(NIJ,1) - Area of the section
GJI(NIJ,2) - Inertia of bending moment
GJI(NIJ,3) - Inertia of torsion moment

(7) I, KI, IHL(I), IHR(I), NQQ(I), NM(I), NS(I) - Information of Element

I - Number of Element
KI - Index of Automatically Forming the Information of Elements
IHL(I) - Number of the Left Node of Element I
IHR(I) - Number of the Right Node of Element I
NQQ(I) - Number of Mass of Element I (corresponding to QN(NG))
NM(I) - Number of Material of Element I (corresponding to EG(NEG,2))
NS(I) - Number of Sectional Property of Element I (corresponding to GJI(NIJ,3))

(8) If NGQ is not equal to 0, input the data: NGQ(I), GQ(I)

NGQ(I) - Number of Node Applied a Lumped Mass
GQ(I) - Magnitude of the Lumped Mass

(9) NBC(NB,2) - Boundary Condition

NBC(NB,1) - Number of Node at Support
NBC(NB,2) - Index of Direction of Restrained Deformation
    1 - Z-direction
    2 - Rotation about X-axis
    3 - Rotation about Y-axis

(10) NKD, NKS, MCAR, NCAR, ISR, NPTS, IPLOT, SL, SSL, VO, ST, STP, ZAA, ZAB

NKD - Total Number of Analyzed Cross Sections
NKS - Index of Truck Type
  3 - HS20-44
MCAR - Total Number of Loading Trucks
NCAR - Total Times of Loading Truck Length (the distance between the starting point of a moving truck and the left end of bridge)
ISR - 0
NPTS - Total Number of Data Points for Surface Roughness
IPLOT - 0
SL - Span Length of Bridge (in)
SSL - 0
VO - 0
ST - 0
STP - 0
ZAA, ZAB - 0
FV(NKD,2) - 0
DGX(I) - Transverse Distance of Each Rear Wheel to the Side Girder (X-coordinate of each rear wheel)

(11) I, BIAS(I), COV(I) – STATISTICAL DATA FOR VARIABLES

BIAS(I) – Bias Factor
COV(I) – Coefficient of Variation

2. CAR.DAT

(1) AL(11) - Distance Between Axles

AL(1) - L1 (see Figs.2 to 7)
AL(2) - L2 (see Figs.2 to 7)

......

......

AL(11) - L11 (see Fig. 7)

(2) AS(6), AD(6)

AS(6) - Spacing of Suspensions
- AS(1) - s1 (see Fig. 4)
- ....

AD(6) - Spacing of wheels
- AD(1) - d1 (see Fig. 4)
- ....

(3) AKSY(I) - 0

(4) AKTY(I) - 0

(5) ADSY(I) - 0
(6) ADTY(I) - 0
(7) AFY(I) - 0
(8) AM(I) - 0

(9) D(I) - 0

(10) V(I) - 0

OUTPUT FILES

1. TES.OUT

All the notations in the TES.OUT are the same as those in TES.DAT and CAR.DAT.

TES.DAT

```
95,166,18,10,1,4,5,28,33,0,0,0,0,18,0
386.4,1.E-3
          1,          0,   0.000000E+00,   0.000000E+00
          2,          0,   0.000000E+00,     144.000000
          3,          0,   0.000000E+00,     288.000000
          4,          0,   0.000000E+00,     432.000000
          5,          0,   0.000000E+00,     576.000000
          6,          0,      60.000300,   0.000000E+00
          7,          0,      60.000300,     144.000000
          8,          0,      60.000300,     288.000000
          9,          0,      60.000300,     432.000000
         10,          0,      60.000300,     576.000000
         11,          0,     120.000600,   0.000000E+00
         12,          0,     120.000600,     144.000000
         13,          0,     120.000600,     288.000000
         14,          0,     120.000600,     432.000000
         15,          0,     120.000600,     576.000000
         16,          0,     180.000900,   0.000000E+00
         17,          0,     180.000900,     144.000000
         18,          0,     180.000900,     288.000000
         19,          0,     180.000900,     432.000000
         20,          0,     180.000900,     576.000000
         21,          0,     240.001200,   0.000000E+00
         22,          0,     240.001200,     144.000000
         23,          0,     240.001200,     288.000000
         24,          0,     240.001200,     432.000000
         25,          0,     240.001200,     576.000000
         26,          0,     300.001500,   0.000000E+00
         27,          0,     300.001500,     144.000000
         28,          0,     300.001500,     288.000000
         29,          0,     300.001500,     432.000000
         30,          0,     300.001500,     576.000000
         31,          0,     360.001800,   0.000000E+00
         32,          0,     360.001800,     144.000000
         33,          0,     360.001800,     288.000000
         34,          0,     360.001800,     432.000000
         35,          0,     360.001800,     576.000000
         36,          0,     420.002100,   0.000000E+00
         37,          0,     420.002100,     144.000000
         38,          0,     420.002100,     288.000000
         39,          0,     420.002100,     432.000000
```

```
40,      0,   420.002100,    576.000000
41,      0,   480.002400,   0.000000E+00
42,      0,   480.002400,    144.000000
43,      0,   480.002400,    288.000000
44,      0,   480.002400,    432.000000
45,      0,   480.002400,    576.000000
46,      0,   540.002700,   0.000000E+00
47,      0,   540.002700,    144.000000
48,      0,   540.002700,    288.000000
49,      0,   540.002700,    432.000000
50,      0,   540.002700,    576.000000
51,      0,   600.003000,   0.000000E+00
52,      0,   600.003000,    144.000000
53,      0,   600.003000,    288.000000
54,      0,   600.003000,    432.000000
55,      0,   600.003000,    576.000000
56,      0,   660.003300,   0.000000E+00
57,      0,   660.003300,    144.000000
58,      0,   660.003300,    288.000000
59,      0,   660.003300,    432.000000
60,      0,   660.003300,    576.000000
61,      0,   720.003600,   0.000000E+00
62,      0,   720.003600,    144.000000
63,      0,   720.003600,    288.000000
64,      0,   720.003600,    432.000000
65,      0,   720.003600,    576.000000
66,      0,   780.003900,   0.000000E+00
67,      0,   780.003900,    144.000000
68,      0,   780.003900,    288.000000
69,      0,   780.003900,    432.000000
70,      0,   780.003900,    576.000000
71,      0,   840.004200,   0.000000E+00
72,      0,   840.004200,    144.000000
73,      0,   840.004200,    288.000000
74,      0,   840.004200,    432.000000
75,      0,   840.004200,    576.000000
76,      0,   900.004500,   0.000000E+00
77,      0,   900.004500,    144.000000
78,      0,   900.004500,    288.000000
79,      0,   900.004500,    432.000000
80,      0,   900.004500,    576.000000
81,      0,   960.004800,   0.000000E+00
82,      0,   960.004800,    144.000000
83,      0,   960.004800,    288.000000
84,      0,   960.004800,    432.000000
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      87,        0,    1020.005000,     144.000000
      88,        0,    1020.005000,     288.000000
      89,        0,    1020.005000,     432.000000
      90,        0,    1020.005000,     576.000000
      91,        0,    1080.005000,   0.000000E+00
      92,        0,    1080.005000,     144.000000
      93,        0,    1080.005000,     288.000000
      94,        0,    1080.005000,     432.000000
      95,        0,    1080.005000,     576.000000
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137.0,36300.0,277.0
60.0,320.0,0.01
9.96,635.0,1.02
12.6,874.0,1.23
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19,5,2,7,2,1,1
36,0,87,92,2,1,1
37,5,3,8,2,1,1
54,0,88,93,2,1,1
55,5,4,9,2,1,1
72,0,89,94,2,1,1
73,5,5,10,1,1,1
90,0,90,95,1,1,1
91,1,1,2,4,1,3
94,0,4,5,4,1,3
95,1,6,7,3,1,2
98,0,9,10,3,1,2
99,1,11,12,3,1,2
102,0,14,15,3,1,2
103,1,16,17,3,1,2
106,0,19,20,3,1,2
107,1,21,22,3,1,2
110,0,24,25,3,1,2
111,1,26,27,5,1,2
114,0,29,30,5,1,2
115,1,31,32,3,1,2
118,0,34,35,3,1,2
119,1,36,37,3,1,2
122,0,39,40,3,1,2
123,1,41,42,3,1,2
126,0,44,45,3,1,2
```

```
127,1,46,47,5,1,4
130,0,49,50,5,1,4
131,1,51,52,3,1,2
134,0,54,55,3,1,2
135,1,56,57,3,1,2
138,0,59,60,3,1,2
139,1,61,62,3,1,2
142,0,64,65,3,1,2
143,1,66,67,5,1,2
146,0,69,70,5,1,2
147,1,71,72,3,1,2
150,0,74,75,3,1,2
151,1,76,77,3,1,2
154,0,79,80,3,1,2
155,1,81,82,3,1,2
158,0,84,85,3,1,2
159,1,86,87,3,1,2
162,0,89,90,3,1,2
163,1,91,92,4,1,3
166,0,94,95,4,1,3
1,1,2,1,3,1,4,1,5,1,91,1,92,1,93,1,94,1,95,1
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0.01,72.0
1,1.05,0.08
2,1.05,0.08
3,1.05,0.08
4,1.05,0.08
5,1.00,0.25
6,1.15,0.12
7,1.15,0.18
8,1.15,0.18
9,1.00,0.05
10,1.00,0.05
11,1.00,0.05
12,1.0,0.05
13,1.00,0.06
14,1.00,0.06
15,1.12,0.0866
16,1.00,0.05
17,1.00,0.05
18,1.00,0.05
```

RELI.OUT

```
  N    M  MLX  MTY   NB  NEG  NIJ   NG   NP   NQ  NQG  NC   LX  LC  NBV  ITRA
 95  166   18    4   10    1    4    5   28   33    0    0    0    0   18    0
  GG       EPS
 .386E+03    .100E-02
   I       X(I)         Y(I)
     1       .000       .000
     2       .000    144.000
     3       .000    288.000
     4       .000    432.000
     5       .000    576.000
     6     60.000       .000
     7     60.000    144.000
     8     60.000    288.000
     9     60.000    432.000
    10     60.000    576.000
    11    120.001       .000
    12    120.001    144.000
    13    120.001    288.000
    14    120.001    432.000
    15    120.001    576.000
    16    180.001       .000
    17    180.001    144.000
    18    180.001    288.000
    19    180.001    432.000
    20    180.001    576.000
    21    240.001       .000
    22    240.001    144.000
    23    240.001    288.000
    24    240.001    432.000
    25    240.001    576.000
    26    300.001       .000
    27    300.001    144.000
    28    300.001    288.000
    29    300.001    432.000
    30    300.001    576.000
    31    360.002       .000
    32    360.002    144.000
    33    360.002    288.000
    34    360.002    432.000
    35    360.002    576.000
    36    420.002       .000
```

37	420.002	144.000
38	420.002	288.000
39	420.002	432.000
40	420.002	576.000
41	480.002	.000
42	480.002	144.000
43	480.002	288.000
44	480.002	432.000
45	480.002	576.000
46	540.003	.000
47	540.003	144.000
48	540.003	288.000
49	540.003	432.000
50	540.003	576.000
51	600.003	.000
52	600.003	144.000
53	600.003	288.000
54	600.003	432.000
55	600.003	576.000
56	660.003	.000
57	660.003	144.000
58	660.003	288.000
59	660.003	432.000
60	660.003	576.000
61	720.004	.000
62	720.004	144.000
63	720.004	288.000
64	720.004	432.000
65	720.004	576.000
66	780.004	.000
67	780.004	144.000
68	780.004	288.000
69	780.004	432.000
70	780.004	576.000
71	840.004	.000
72	840.004	144.000
73	840.004	288.000
74	840.004	432.000
75	840.004	576.000
76	900.005	.000
77	900.005	144.000
78	900.005	288.000
79	900.005	432.000
80	900.005	576.000
81	960.005	.000

```
     82    960.005    144.000
     83    960.005    288.000
     84    960.005    432.000
     85    960.005    576.000
     86   1020.005       .000
     87   1020.005    144.000
     88   1020.005    288.000
     89   1020.005    432.000
     90   1020.005    576.000
     91   1080.005       .000
     92   1080.005    144.000
     93   1080.005    288.000
     94   1080.005    432.000
     95   1080.005    576.000

 **QN**
  .14400E+00  .13880E+00  .00000E+00  .28250E-02  .35580E-02

   I      EE        GG
   1    .29000E+05    .11200E+05

   I      EF            EI            EJ
   1    .13700E+03    .36300E+05    .27700E+03
   2    .60000E+02    .32000E+03    .10000E-01
   3    .99600E+01    .63500E+03    .10200E+01
   4    .12600E+02    .87400E+03    .12300E+01

   I     IHL     IHR     NQQ     NM     NS
   1       1       6       1      1      1
   2       6      11       1      1      1
   3      11      16       1      1      1
   4      16      21       1      1      1
   5      21      26       1      1      1
   6      26      31       1      1      1
   7      31      36       1      1      1
   8      36      41       1      1      1
   9      41      46       1      1      1
  10      46      51       1      1      1
  11      51      56       1      1      1
  12      56      61       1      1      1
  13      61      66       1      1      1
  14      66      71       1      1      1
  15      71      76       1      1      1
  16      76      81       1      1      1
  17      81      86       1      1      1
```

18	86	91	1	1	1
19	2	7	2	1	1
20	7	12	2	1	1
21	12	17	2	1	1
22	17	22	2	1	1
23	22	27	2	1	1
24	27	32	2	1	1
25	32	37	2	1	1
26	37	42	2	1	1
27	42	47	2	1	1
28	47	52	2	1	1
29	52	57	2	1	1
30	57	62	2	1	1
31	62	67	2	1	1
32	67	72	2	1	1
33	72	77	2	1	1
34	77	82	2	1	1
35	82	87	2	1	1
36	87	92	2	1	1
37	3	8	2	1	1
38	8	13	2	1	1
39	13	18	2	1	1
40	18	23	2	1	1
41	23	28	2	1	1
42	28	33	2	1	1
43	33	38	2	1	1
44	38	43	2	1	1
45	43	48	2	1	1
46	48	53	2	1	1
47	53	58	2	1	1
48	58	63	2	1	1
49	63	68	2	1	1
50	68	73	2	1	1
51	73	78	2	1	1
52	78	83	2	1	1
53	83	88	2	1	1
54	88	93	2	1	1
55	4	9	2	1	1
56	9	14	2	1	1
57	14	19	2	1	1
58	19	24	2	1	1
59	24	29	2	1	1
60	29	34	2	1	1
61	34	39	2	1	1
62	39	44	2	1	1

63	44	49	2	1	1
64	49	54	2	1	1
65	54	59	2	1	1
66	59	64	2	1	1
67	64	69	2	1	1
68	69	74	2	1	1
69	74	79	2	1	1
70	79	84	2	1	1
71	84	89	2	1	1
72	89	94	2	1	1
73	5	10	1	1	1
74	10	15	1	1	1
75	15	20	1	1	1
76	20	25	1	1	1
77	25	30	1	1	1
78	30	35	1	1	1
79	35	40	1	1	1
80	40	45	1	1	1
81	45	50	1	1	1
82	50	55	1	1	1
83	55	60	1	1	1
84	60	65	1	1	1
85	65	70	1	1	1
86	70	75	1	1	1
87	75	80	1	1	1
88	80	85	1	1	1
89	85	90	1	1	1
90	90	95	1	1	1
91	1	2	4	1	3
92	2	3	4	1	3
93	3	4	4	1	3
94	4	5	4	1	3
95	6	7	3	1	2
96	7	8	3	1	2
97	8	9	3	1	2
98	9	10	3	1	2
99	11	12	3	1	2
100	12	13	3	1	2
101	13	14	3	1	2
102	14	15	3	1	2
103	16	17	3	1	2
104	17	18	3	1	2
105	18	19	3	1	2
106	19	20	3	1	2
107	21	22	3	1	2

108	22	23	3	1	2
109	23	24	3	1	2
110	24	25	3	1	2
111	26	27	5	1	2
112	27	28	5	1	2
113	28	29	5	1	2
114	29	30	5	1	2
115	31	32	3	1	2
116	32	33	3	1	2
117	33	34	3	1	2
118	34	35	3	1	2
119	36	37	3	1	2
120	37	38	3	1	2
121	38	39	3	1	2
122	39	40	3	1	2
123	41	42	3	1	2
124	42	43	3	1	2
125	43	44	3	1	2
126	44	45	3	1	2
127	46	47	5	1	4
128	47	48	5	1	4
129	48	49	5	1	4
130	49	50	5	1	4
131	51	52	3	1	2
132	52	53	3	1	2
133	53	54	3	1	2
134	54	55	3	1	2
135	56	57	3	1	2
136	57	58	3	1	2
137	58	59	3	1	2
138	59	60	3	1	2
139	61	62	3	1	2
140	62	63	3	1	2
141	63	64	3	1	2
142	64	65	3	1	2
143	66	67	5	1	2
144	67	68	5	1	2
145	68	69	5	1	2
146	69	70	5	1	2
147	71	72	3	1	2
148	72	73	3	1	2
149	73	74	3	1	2
150	74	75	3	1	2
151	76	77	3	1	2
152	77	78	3	1	2

```
  153     78     79     3     1     2
  154     79     80     3     1     2
  155     81     82     3     1     2
  156     82     83     3     1     2
  157     83     84     3     1     2
  158     84     85     3     1     2
  159     86     87     3     1     2
  160     87     88     3     1     2
  161     88     89     3     1     2
  162     89     90     3     1     2
  163     91     92     4     1     3
  164     92     93     4     1     3
  165     93     94     4     1     3
  166     94     95     4     1     3

 **NBC**
   1   1    2   1    3   1    4   1    5   1
  91   1   92   1   93   1   94   1   95   1
     NKD    NKS    NTN    NFV   MCAR   NCAR    ISR   NPTS  IPLOT
      5      3   1190     24      1      5      2   2048      1
   SL      SSL      VO      ST     STP      ZAA      ZAB
 .108E+04 .840E+03 .650E+02 .104E-02 .600E-02 .195E+00 .511E-03

  **FV(I,J)**
   .000   .000   .000   .000   .000   .000   .000   .000
   .000   .000

**DGX**
   .100E-01   .720E+02
 ** READ DISTRIBUTION DATA OF VARIABLES **
       1      1.050000    8.000000E-02
       2      1.050000    8.000000E-02
       3      1.050000    8.000000E-02
       4      1.050000    8.000000E-02
       5      1.000000    2.500000E-01
       6      1.150000    1.200000E-01
       7      1.150000    1.800000E-01
       8      1.150000    1.800000E-01
       9      1.000000    5.000000E-02
      10       1.000000    5.000000E-02
      11       1.000000    5.000000E-02
      12       1.000000    5.000000E-02
      13       1.000000    6.000000E-02
      14       1.000000    6.000000E-02
      15       1.120000    8.660000E-02
```

```
        16        1.000000    5.000000E-02
        17        1.000000    5.000000E-02
        18        1.000000    5.000000E-02
SUM OF THE FLEXURAL MOMENTS AT MIDSPAN  =     -93.81615

*** BETA INDEX = ***     4.022
```

APPENDIX B

USER'S MANUAL FOR THE DESIGN OF NONCOMPOSITE STEEL BRIDGES

This is a program to calculate the factored moment at midspan for interior and exterior girders of noncomposite bridges, respectively.

Follow the interactive input on the screen:

'Please enter the following data :'

' Load modifier (0.90 - 1.10) = '

' Span = (ft)'

' Beam weight = (kips/ft)'

' Spacing = '

' Moment at midspan point (kips-in) = '

' Lateral distribution factor (kips-in) = '

The results will be stored in the output file - ‘noncomp-mi.out’ for interior girders and ‘noncomp-me.out’ for exterior girders.

APPENDIX C

USER'S MANUAL FOR THE DESIGN OF COMPOSITE STEEL BRIDGES

This is a program to calculate the factored moment at midspan for interior and exterior girders of composite bridges, respectively.

Follow the interactive input on the screen:

'Please enter the following data :'

' Load modifier (0.90 - 1.10) = '

' Span = (ft)'

' Beam weight = (kips/ft)'

' Spacing = '

' Moment at midspan point (kips-in) = '

' Lateral distribution factor (kips-in) = '

The results will be stored in the output file - ‘comp-mi.out’ for interior girders and ‘comp-me.out’ for exterior girders.

APPENDIX D

DESIGN EXAMPLES

TABLE D-1. NONCOMPOSITE STEEL BRIDGES DESIGNED BY STRENGTH LIMIT I FOR FLEXURE

SPAN LENGTH (ft)	**GIRDER SPACING (ft)**	**CONTROL GIRDER**	*LOAD* **MODIFIER**	**W SHAPE**	**M_u (kip)**	**M_n (kip)**	**ERROR (%)**
30.00	4.00	EXTERIOR	0.90	W24x68	537.4367	531	1.198
30.00	4.00	EXTERIOR	0.95	W21x83	574.5125	588	-2.348
30.00	4.00	EXTERIOR	1.00	W16x100	601.6519	594	1.272
30.00	4.00	EXTERIOR	1.05	W18x97	630.7009	633	-0.365
30.00	4.00	EXTERIOR	1.10	W21x93	660.7343	663	-0.343
30.00	6.00	EXTERIOR	0.90	W18x86	558.5992	558	-0.107
30.00	6.00	EXTERIOR	0.95	W16x100	591.5028	594	0.422
30.00	6.00	EXTERIOR	1.00	W14x120	625.447	636	1.687
30.00	6.00	EXTERIOR	1.05	W21x93	652.7326	663	1.573
30.00	6.00	EXTERIOR	1.10	W24x84	682.423	672	-1.527
30.00	8.00	EXTERIOR	0.90	W24x84	675.9357	672	-0.582

30.00	8.00	EXTERIOR	0.95	W12x152	722.5721	729	0.890
30.00	8.00	EXTERIOR	1.00	W24x94	752.446	762	1.270
30.00	8.00	EXTERIOR	1.05	W18x119	793.7596	783	-1.356
30.00	8.00	EXTERIOR	1.10	W21x111	830.3203	837	0.804
30.00	10.00	INTERIOR	0.90	W18x119	797.9991	783	1.880
30.00	10.00	INTERIOR	0.95	W14x159	847.6761	861	-1.572
30.00	10.00	INTERIOR	1.00	W24x104	884.5563	867	1.985
30.00	10.00	INTERIOR	1.05	W21x122	931.4419	921	1.121
30.00	10.00	INTERIOR	1.10	W24x117	975.0229	981	-0.613
30.00	12.00	INTERIOR	0.90	W21x122	921.6889	921	0.075
30.00	12.00	INTERIOR	0.95	W18x143	975.6993	966	0.994
30.00	12.00	INTERIOR	1.00	W12x210	1036.4740	1044	-0.726
30.00	12.00	INTERIOR	1.05	W18x158	1080.6190	1068	1.168
30.00	12.00	INTERIOR	1.10	W21x147	1130.3760	1119	1.006
60.00	4.00	EXTERIOR	0.90	W33x169	1907.4030	1887	1.070

60.00	4.00	EXTERIOR	0.95	W36x170	1907.9100	2004	-5.036
60.00	4.00	EXTERIOR	1.00	W27x217	2146.3370	2124	1.041
60.00	4.00	EXTERIOR	1.05	W30x211	2250.1100	2247	0.138
60.00	4.00	EXTERIOR	1.10	W40x183	2339.9340	2343	-0.131
60.00	6.00	EXTERIOR	0.90	W30x191	1994.0790	2019	-1.250
60.00	6.00	EXTERIOR	0.95	W27x217	2007.2410	2124	-5.817
60.00	6.00	EXTERIOR	1.00	W24x250	2248.8300	2232	0.748
60.00	6.00	EXTERIOR	1.05	W36x194	2328.1970	2301	1.168
60.00	6.00	EXTERIOR	1.10	W24x279	2491.6570	2505	-0.536
60.00	8.00	EXTERIOR	0.90	W14x398	2495.8620	2403	3.721
60.00	8.00	EXTERIOR	0.95	W30x235	2513.0000	2535	-0.875
60.00	8.00	EXTERIOR	1.00	W40x211	2667.9930	2715	-1.762
60.00	8.00	EXTERIOR	1.05	W36x232	2813.7960	2808	0.206
60.00	8.00	EXTERIOR	1.10	W24x335	3011.5170	3060	-1.610
60.00	10.00	EXTERIOR	0.90	W40x211	2688.8400	2715	-0.973

60.00	10.00	EXTERIOR	0.95	W36x230	2822.0000	2829	-0.248
60.00	10.00	EXTERIOR	1.00	W40x235	2979.7250	3030	-1.687
60.00	10.00	EXTERIOR	1.05	W30x292	3162.3770	3180	-0.557
60.00	10.00	EXTERIOR	1.10	W40x249	3286.3600	3360	-2.241
60.00	12.00	INTERIOR	0.90	W40x235	2973.0690	3030	-1.915
60.00	12.00	INTERIOR	0.95	W30x292	3168.6990	3180	-0.357
60.00	12.00	INTERIOR	1.00	W44x230	3300.5980	3300	0.018
60.00	12.00	INTERIOR	1.05	W36x280	3495.1590	3510	-0.425
60.00	12.00	INTERIOR	1.10	W27x368	3716.0450	3720	-0.106
90.00	4.00	EXTERIOR	0.90	W36x300	3844.3110	3780	1.673
90.00	4.00	EXTERIOR	0.95	W40x297	4054.0000	3990	1.579
90.00	4.00	EXTERIOR	1.00	W40x331	4310.6910	4290	0.480
90.00	4.00	EXTERIOR	1.05	W36x359	4563.4350	4530	0.733
90.00	4.00	EXTERIOR	1.10	W44x335	4747.3300	4860	-2.373
90.00	6.00	EXTERIOR	0.90	W40x297	4010.8540	3990	0.520

90.00	6.00	EXTERIOR	0.95	W40x331	4292.0000	4290	0.047
90.00	6.00	EXTERIOR	1.00	W36x359	4534.9730	4530	0.110
90.00	6.00	EXTERIOR	1.05	W44x335	4729.8280	4860	-2.752
90.00	6.00	EXTERIOR	1.10	W40x372	5006.5690	5010	-0.069
90.00	8.00	EXTERIOR	0.90	W44x335	4798.2240	4860	-1.287
90.00	8.00	EXTERIOR	0.95	W40x392	5146.0000	5130	0.311
90.00	8.00	EXTERIOR	1.00	W36x439	5462.9860	5580	-2.142
90.00	8.00	EXTERIOR	1.05	W40x431	5725.5030	5850	-2.174
90.00	8.00	EXTERIOR	1.10	W40x466	6046.8730	6150	-1.705
90.00	10.00	EXTERIOR	0.90	W36x439	5431.1230	5580	-2.741
90.00	10.00	EXTERIOR	0.95	W40x431	5727.0000	5850	-2.148
90.00	10.00	EXTERIOR	1.00	W40x466	6068.7520	6150	-1.339
90.00	10.00	EXTERIOR	1.05	W40x466	6372.1900	6150	3.487
90.00	10.00	EXTERIOR	1.10	W36x527	6760.5510	6810	-0.731
90.00	12.00	EXTERIOR	0.90	W40x431	5830.7320	5850	-0.330

90.00	12.00	EXTERIOR	0.95	W40x466	6192.0000	6150	0.678
90.00	12.00	EXTERIOR	1.00	W36x527	6589.9670	6710	-1.821
90.00	12.00	EXTERIOR	1.05	W40x503	6887.5720	6900	-0.180
90.00	12.00	EXTERIOR	1.10	W40x503	7215.5510	6900	4.373

Note: Error = $((M_N - M_U)/M_U) \times 100$

TABLE D-2. COMPOSITE STEEL BRIDGES DESIGNED BY STRENGTH LIMIT I FOR FLEXURE

SPAN LENGTH (ft)	GIRDER SPACING (ft)	CONTROL GIRDER	*LOAD* MODIFIER	WIDTH OF WEB (in)	WEIGHT OF STEEL BEAM (kips/ft)	M_u (kip)	M_n (kip)	ERROR (%)
30.00	4.00	EXTERIOR	0.90	0.3672	0.03892	533.77	534.12	0.07
30.00	4.00	EXTERIOR	0.95	0.377	0.04103	563.69	566.537	0.51
30.00	4.00	EXTERIOR	1.00	0.385	0.04278	593.64	593.917	0.05
30.00	4.00	EXTERIOR	1.05	0.394	0.04481	623.61	625.7	0.33
30.00	4.00	EXTERIOR	1.10	0.4021	0.04667	653.62	653.75	0.02
30.00	6.00	EXTERIOR	0.90	0.367	0.03888	552.651	553.694	0.19
30.00	6.00	EXTERIOR	0.95	0.377	0.04103	583.621	586.823	0.55
30.00	6.00	EXTERIOR	1.00	0.380	0.04168	614.478	615.424	0.15
30.00	6.00	EXTERIOR	1.05	0.394	0.04481	645.645	646.186	0.08
30.00	6.00	EXTERIOR	1.10	0.403	0.04688	676.699	679.190	0.37
30.00	8.00	EXTERIOR	0.90	0.397	0.04549	670.999	671.947	0.14

30.00	8.00	EXTERIOR	0.95	0.407	0.04781	708.678	709.671	0.14
30.00	8.00	EXTERIOR	1.00	0.417	0.05019	746.259	748.814	0.34
30.00	8.00	EXTERIOR	1.05	0.426	0.05238	783.867	785.269	0.18
30.00	8.00	EXTERIOR	1.10	0.435	0.05462	821.658	822.900	0.15
30.00	10.00	INTERIOR	0.90	0.420	0.05092	789.39	793.44	0.51
30.00	10.00	INTERIOR	0.95	0.430	0.05337	833.52	835.51	0.24
30.00	10.00	INTERIOR	1.00	0.440	0.05588	877.81	879.12	0.15
30.00	10.00	INTERIOR	1.05	0.450	0.05845	921.99	924.28	0.25
30.00	10.00	INTERIOR	1.10	0.460	0.06108	966.36	971.02	0.48
30.00	12.00	INTERIOR	0.90	0.449	0.05819	913.59	919.69	0.67
30.00	12.00	INTERIOR	0.95	0.460	0.06108	964.75	971.02	0.65
30.00	12.00	INTERIOR	1.00	0.470	0.06376	1,015.94	1019.36	0.34
30.00	12.00	INTERIOR	1.05	0.480	0.06650	1,067.18	1069.32	0.20
30.00	12.00	INTERIOR	1.10	0.490	0.06931	1,118.31	1120.92	0.23
60.00	4.00	EXTERIOR	0.90	0.635	0.11639	1,880.57	1894.6	0.75

60.00	4.00	EXTERIOR	0.95	0.650	0.12195	1,988.26	2005	0.84
60.00	4.00	EXTERIOR	1.00	0.662	0.12650	2,095.15	2096.36	0.06
60.00	4.00	EXTERIOR	1.05	0.676	0.13190	2,203.45	2205.3	0.08
60.00	4.00	EXTERIOR	1.10	0.691	0.13782	2,312.09	2325.29	0.57
60.00	6.00	EXTERIOR	0.90	0.634	0.11602	1,956.11	1958.28	0.11
60.00	6.00	EXTERIOR	0.95	0.649	0.12158	2,067.99	2070.89	0.14
60.00	6.00	EXTERIOR	1.00	0.664	0.12726	2,179.64	2187.312	0.35
60.00	6.00	EXTERIOR	1.05	0.677	0.13229	2,291.57	2292.06	0.02
60.00	6.00	EXTERIOR	1.10	0.691	0.13782	2,404.41	2409.27	0.20
60.00	8.00	EXTERIOR	0.90	0.678	0.13269	2,361.71	2367.54	0.25
60.00	8.00	EXTERIOR	0.95	0.694	0.13902	2,496.12	2505.46	0.37
60.00	8.00	EXTERIOR	1.00	0.712	0.14633	2,631.43	2666.32	1.33
60.00	8.00	EXTERIOR	1.05	0.724	0.15130	2,765.96	2776.94	0.40
60.00	8.00	EXTERIOR	1.10	0.739	0.15763	2,902.00	2919.82	0.61
60.00	10.00	EXTERIOR	0.90	0.710	0.14550	2,636.70	2662.85	0.99

60.00	10.00	EXTERIOR	0.95	0.724	0.15130	2,785.85	2792.98	0.26
60.00	10.00	EXTERIOR	1.00	0.739	0.15763	2,936.41	2936.64	0.01
60.00	10.00	EXTERIOR	1.05	0.756	0.16497	3,087.36	3105.84	0.60
60.00	10.00	EXTERIOR	1.10	0.769	0.17069	3,238.10	3240.26	0.07
60.00	12.00	INTERIOR	0.90	0.726	0.15214	2,918.67	2930.45	0.40
60.00	12.00	INTERIOR	0.95	0.742	0.15892	3,084.56	3093.61	0.29
60.00	12.00	INTERIOR	1.00	0.759	0.16628	3,250.85	3273.14	0.69
60.00	12.00	INTERIOR	1.05	0.773	0.17247	3,416.93	3425.81	0.26
60.00	12.00	INTERIOR	1.10	0.790	0.18015	3,584.59	3617.11	0.91
90.00	4.00	EXTERIOR	0.90	0.843	0.20513	3,736.10	3789.6	1.43
90.00	4.00	EXTERIOR	0.95	0.857	0.21200	3,952.07	3952.19	0.00
90.00	4.00	EXTERIOR	1.00	0.877	0.22201	4,172.74	4193.32	0.49
90.00	4.00	EXTERIOR	1.05	0.894	0.23070	4,393.33	4406.66	0.30
90.00	4.00	EXTERIOR	1.10	0.911	0.23955	4,615.07	4627.86	0.28
90.00	6.00	EXTERIOR	0.90	0.842	0.20464	3,906.06	3921.99	0.41

90.00	6.00	EXTERIOR	0.95	0.865	0.21597	4,136.29	4195.1	1.42
90.00	6.00	EXTERIOR	1.00	0.879	0.22302	4,362.85	4368.07	0.12
90.00	6.00	EXTERIOR	1.05	0.897	0.23225	4,592.95	4598.13	0.11
90.00	6.00	EXTERIOR	1.10	0.915	0.24166	4,825.58	4836.98	0.24
90.00	8.00	EXTERIOR	0.90	0.893	0.23018	4,678.62	4684.87	0.13
90.00	8.00	EXTERIOR	0.95	0.913	0.24060	4,951.77	4952.16	0.01
90.00	8.00	EXTERIOR	1.00	0.933	0.25126	5,225.05	5230.44	0.10
90.00	8.00	EXTERIOR	1.05	0.952	0.26160	5,500.92	5505.22	0.08
90.00	8.00	EXTERIOR	1.10	0.971	0.27215	5,776.79	5790.37	0.24
90.00	10.00	EXTERIOR	0.90	0.931	0.25019	5,215.84	5241.89	0.50
90.00	10.00	EXTERIOR	0.95	0.952	0.26160	5,520.04	5547.01	0.49
90.00	10.00	EXTERIOR	1.00	0.973	0.27327	5,824.49	5864.82	0.69
90.00	10.00	EXTERIOR	1.05	0.990	0.28290	6,129.00	6131.6	0.04
90.00	10.00	EXTERIOR	1.10	1.010	0.29445	6,436.17	6456.6	0.32
90.00	12.00	EXTERIOR	0.90	0.958	0.26491	5,632.54	5636.51	0.07

90.00	12.00	EXTERIOR	0.95	0.980	0.27722	5,959.88	5973.64	0.23
90.00	12.00	EXTERIOR	1.00	1.002	0.28980	6,290.01	6325.15	0.56
90.00	12.00	EXTERIOR	1.05	1.020	0.30031	6,617.80	6623.67	0.09
90.00	12.00	EXTERIOR	1.10	1.040	0.31220	6,949.64	6967.16	0.25
120.00	4.00	EXTERIOR	0.90	1.018	0.29913	6,201.13	6210.34	0.15
120.00	4.00	EXTERIOR	0.95	1.040	0.31220	6,573.43	6578.57	0.08
120.00	4.00	EXTERIOR	1.00	1.062	0.32555	6,950.89	6961.78	0.16
120.00	4.00	EXTERIOR	1.05	1.084	0.33918	7,329.15	7356.89	0.38
120.00	4.00	EXTERIOR	1.10	1.104	0.35180	7,710.34	7726.02	0.20
120.00	6.00	EXTERIOR	0.90	1.027	0.30444	6,513.41	6532.2	0.29
120.00	6.00	EXTERIOR	0.95	1.049	0.31763	6,905.19	6909.89	0.07
120.00	6.00	EXTERIOR	1.00	1.071	0.33109	7,297.87	7303.05	0.07
120.00	6.00	EXTERIOR	1.05	1.093	0.34481	7,695.84	7712.02	0.21
120.00	6.00	EXTERIOR	1.10	1.113	0.35755	8,094.48	8097.8	0.04
120.00	8.00	EXTERIOR	0.90	1.087	0.34104	7,753.36	7769.27	0.21

120.00	8.00	EXTERIOR	0.95	1.111	0.35626	8,216.16	8232.6	0.20
120.00	8.00	EXTERIOR	1.00	1.135	0.37181	8,684.59	8715.4	0.35
120.00	8.00	EXTERIOR	1.05	1.157	0.38638	9,151.90	9175.46	0.26
120.00	8.00	EXTERIOR	1.10	1.179	0.40122	9,624.83	9652.58	0.29
120.00	10.00	EXTERIOR	0.90	1.128	0.36726	8,625.88	8632.17	0.07
120.00	10.00	EXTERIOR	0.95	1.154	0.38437	9,141.44	9174.13	0.36
120.00	10.00	EXTERIOR	1.00	1.178	0.40054	9,660.82	9695.53	0.36
120.00	10.00	EXTERIOR	1.05	1.200	0.41565	10,179.29	10191.68	0.12
120.00	10.00	EXTERIOR	1.10	1.222	0.43100	10,701.15	10705.58	0.04
120.00	12.00	EXTERIOR	0.90	1.162	0.38974	9,319.76	9345.66	0.28
120.00	12.00	EXTERIOR	0.95	1.186	0.40601	9,871.73	9873.92	0.02
120.00	12.00	EXTERIOR	1.00	1.211	0.42330	10,429.54	10446.39	0.16
120.00	12.00	EXTERIOR	1.05	1.235	0.44025	10,991.17	11017.73	0.24
120.00	12.00	EXTERIOR	1.10	1.260	0.45823	11,559.12	11636.01	0.67

Note: Error = $((M_n - M_u)/M_u)$ x 100

TABLE D-3. STEEL BRIDGES DESIGNED BY STRENGTH LIMIT I FOR SHEAR

SPAN LENGTH (ft)	**GIRDER SPACING (ft)**	**CONTROL GIRDER**	*LOAD* **MODIFIER**	**WIDTH OF WEB (in)**	**WEIGHT OF STEEL BEAM (kips/ft)**	V_u **(kip)**	V_n **(kip)**	**ERROR (%)**
30.00	4.00	EXTERIOR	0.90	0.3280	0.031054	89.80	89.85	0.056
30.00	4.00	EXTERIOR	0.95	0.3370	0.032781	94.82	94.85	0.031
30.00	4.00	EXTERIOR	1.00	0.3460	0.034556	99.85	99.99	0.139
30.00	4.00	EXTERIOR	1.05	0.3550	0.036377	104.88	105.26	0.363
30.00	4.00	EXTERIOR	1.10	0.3640	0.038244	109.91	110.66	0.684
30.00	6.00	INTERIOR	0.90	0.3390	0.033171	95.55	95.98	0.449
30.00	6.00	INTERIOR	0.95	0.3480	0.034956	100.89	101.15	0.250
30.00	6.00	INTERIOR	1.00	0.3570	0.036788	106.24	106.45	0.195
30.00	6.00	INTERIOR	1.05	0.3660	0.038666	111.59	111.88	0.263
30.00	6.00	INTERIOR	1.10	0.3750	0.040591	116.94	117.45	0.436
30.00	8.00	INTERIOR	0.90	0.3760	0.040808	117.89	118.08	0.160

30.00	8.00	INTERIOR	0.95	0.3870	0.043230	124.48	125.09	0.487
30.00	8.00	INTERIOR	1.00	0.3970	0.045493	131.08	131.64	0.427
30.00	8.00	INTERIOR	1.05	0.4060	0.047579	137.67	137.67	0.001
30.00	8.00	INTERIOR	1.10	0.4160	0.049952	144.27	144.54	0.182
30.00	10.00	INTERIOR	0.90	0.4090	0.048285	139.46	139.71	0.182
30.00	10.00	INTERIOR	0.95	0.4200	0.050917	147.25	147.33	0.051
30.00	10.00	INTERIOR	1.00	0.4320	0.053868	155.06	155.87	0.522
30.00	10.00	INTERIOR	1.05	0.4416	0.056289	162.86	162.87	0.008
30.00	10.00	INTERIOR	1.10	0.4526	0.059128	170.67	171.09	0.243
30.00	12.00	INTERIOR	0.90	0.4382	0.055426	160.26	160.37	0.070
30.00	12.00	INTERIOR	0.95	0.4510	0.058711	169.22	169.88	0.387
30.00	12.00	INTERIOR	1.00	0.4620	0.061610	178.19	178.27	0.046
30.00	12.00	INTERIOR	1.05	0.4740	0.064852	187.16	187.65	0.262
30.00	12.00	INTERIOR	1.10	0.4850	0.067897	196.13	196.46	0.166
60.00	4.00	EXTERIOR	0.90	0.3974	0.045585	131.83	131.90	0.050

60.00	4.00	EXTERIOR	0.95	0.4090	0.048285	139.26	139.71	0.329
60.00	4.00	EXTERIOR	1.00	0.4200	0.050917	146.68	147.33	0.441
60.00	4.00	EXTERIOR	1.05	0.4300	0.053371	154.11	154.43	0.204
60.00	4.00	EXTERIOR	1.10	0.4400	0.055882	161.56	161.69	0.086
60.00	6.00	EXTERIOR	0.90	0.4060	0.047579	137.60	137.67	0.050
60.00	6.00	EXTERIOR	0.95	0.4180	0.050433	145.35	145.93	0.400
60.00	6.00	EXTERIOR	1.00	0.4290	0.053123	153.10	153.71	0.399
60.00	6.00	EXTERIOR	1.05	0.4390	0.055628	160.85	160.96	0.067
60.00	6.00	EXTERIOR	1.10	0.4496	0.058347	168.63	168.83	0.120
60.00	8.00	EXTERIOR	0.90	0.4526	0.059128	170.80	171.09	0.168
60.00	8.00	EXTERIOR	0.95	0.4650	0.062412	180.41	180.59	0.102
60.00	8.00	EXTERIOR	1.00	0.4780	0.065951	190.03	190.83	0.419
60.00	8.00	EXTERIOR	1.05	0.4890	0.069021	199.66	199.71	0.029
60.00	8.00	EXTERIOR	1.10	0.5014	0.072566	209.31	209.97	0.316
60.00	10.00	EXTERIOR	0.90	0.4930	0.070155	202.97	202.99	0.011

60.00	10.00	EXTERIOR	0.95	0.5070	0.074196	214.39	214.69	0.138
60.00	10.00	EXTERIOR	1.00	0.5200	0.078050	225.82	225.84	0.008
60.00	10.00	EXTERIOR	1.05	0.5330	0.082001	237.27	237.27	0.002
60.00	10.00	EXTERIOR	1.10	0.5460	0.086050	248.73	248.99	0.102
60.00	12.00	INTERIOR	0.90	0.5300	0.081081	234.13	234.61	0.203
60.00	12.00	INTERIOR	0.95	0.5446	0.085609	247.30	247.71	0.166
60.00	12.00	INTERIOR	1.00	0.5590	0.090196	260.49	260.98	0.190
60.00	12.00	INTERIOR	1.05	0.5725	0.094005	273.69	273.74	0.020
60.00	12.00	INTERIOR	1.10	0.5862	0.099187	286.91	287.00	0.032
90.00	4.00	EXTERIOR	0.90	0.4442	0.056954	164.77	164.80	0.016
90.00	4.00	EXTERIOR	0.95	0.4566	0.060178	174.10	174.13	0.017
90.00	4.00	EXTERIOR	1.00	0.4689	0.063464	183.44	183.63	0.10
90.00	4.00	EXTERIOR	1.05	0.4806	0.066670	192.81	192.91	0.055
90.00	4.00	EXTERIOR	1.10	0.4921	0.069899	202.19	202.25	0.033
90.00	6.00	EXTERIOR	0.90	0.4510	0.058711	169.43	169.88	0.268

90.00	6.00	EXTERIOR	0.95	0.4630	0.061877	179.01	179.04	0.018
90.00	6.00	EXTERIOR	1.00	0.4753	0.065208	188.62	188.68	0.033
90.00	6.00	EXTERIOR	1.05	0.4872	0.068514	198.24	198.25	0.001
90.00	6.00	EXTERIOR	1.10	0.4990	0.071873	207.89	207.97	0.035
90.00	8.00	EXTERIOR	0.90	0.5031	0.073059	211.30	211.40	0.047
90.00	8.00	EXTERIOR	0.95	0.5172	0.077212	223.26	223.41	0.069
90.00	8.00	EXTERIOR	1.00	0.5310	0.081386	235.24	235.49	0.107
90.00	8.00	EXTERIOR	1.05	0.5446	0.085609	247.25	247.71	0.185
90.00	8.00	EXTERIOR	1.10	0.5572	0.089616	259.28	259.31	0.011
90.00	10.00	EXTERIOR	0.90	0.5500	0.087315	252.01	252.65	0.254
90.00	10.00	EXTERIOR	0.95	0.5650	0.092143	266.27	266.62	0.132
90.00	10.00	EXTERIOR	1.00	0.5796	0.096967	280.55	280.57	0.008
90.00	10.00	EXTERIOR	1.05	0.5942	0.101913	294.87	294.89	0.006
90.00	10.00	EXTERIOR	1.10	0.6090	0.107053	309.23	309.76	0.171
90.00	12.00	EXTERIOR	0.90	0.5910	0.100819	291.52	291.72	0.067

90.00	12.00	EXTERIOR	0.95	0.6076	0.106562	308.03	308.34	0.101
90.00	12.00	EXTERIOR	1.00	0.6236	0.112248	324.56	324.79	0.071
90.00	12.00	EXTERIOR	1.05	0.6392	0.117934	341.12	341.24	0.035
90.00	12.00	EXTERIOR	1.10	0.6546	0.123685	357.72	357.88	0.045
120.00	4.00	EXTERIOR	0.90	0.4842	0.067673	195.78	195.81	0.015
120.00	4.00	EXTERIOR	0.95	0.4978	0.071528	206.93	206.97	0.016
120.00	4.00	EXTERIOR	1.00	0.5116	0.075549	218.13	218.60	0.217
120.00	4.00	EXTERIOR	1.05	0.5240	0.079255	229.33	229.33	0.000
120.00	4.00	EXTERIOR	1.10	0.5367	0.083144	240.57	240.58	0.004
120.00	6.00	EXTERIOR	0.90	0.4890	0.069021	199.04	199.71	0.338
120.00	6.00	EXTERIOR	0.95	0.5020	0.072740	210.36	210.47	0.052
120.00	6.00	EXTERIOR	1.00	0.5155	0.076705	221.73	221.95	0.096
120.00	6.00	EXTERIOR	1.05	0.5286	0.080653	233.13	233.37	0.103
120.00	6.00	EXTERIOR	1.10	0.5416	0.084669	244.56	244.99	0.174
120.00	8.00	EXTERIOR	0.90	0.5466	0.086239	249.14	249.53	0.159

120.00	8.00	EXTERIOR	0.95	0.5616	0.091037	263.32	263.42	0.037
120.00	8.00	EXTERIOR	1.00	0.5766	0.095965	277.55	277.68	0.046
120.00	8.00	EXTERIOR	1.05	0.5912	0.100887	291.81	291.92	0.035
120.00	8.00	EXTERIOR	1.10	0.6060	0.106001	306.13	306.72	0.190
120.00	10.00	EXTERIOR	0.90	0.5973	0.102979	297.93	297.97	0.015
120.00	10.00	EXTERIOR	0.95	0.6142	0.108889	314.90	315.07	0.055
120.00	10.00	EXTERIOR	1.00	0.6304	0.114709	331.91	331.91	0.001
120.00	10.00	EXTERIOR	1.05	0.6465	0.120643	348.97	349.08	0.032
120.00	10.00	EXTERIOR	1.10	0.6622	0.126574	366.08	366.24	0.045
120.00	12.00	EXTERIOR	0.90	0.6432	0.119415	345.42	345.53	0.032
120.00	12.00	EXTERIOR	0.95	0.6615	0.126306	365.10	365.47	0.102
120.00	12.00	EXTERIOR	1.00	0.6789	0.133304	384.82	384.95	0.034
120.00	12.00	EXTERIOR	1.05	0.6961	0.139865	404.60	404.70	0.026
120.00	12.00	EXTERIOR	1.10	0.7130	0.146739	424.43	424.59	0.038

Note: Error = $((V_n - V_u)/V_u)$ x 100

APPENDIX E

COMPUTER PROGRAMS

RELI.FOR

This program is to perform reliability analysis.

```
C***  RELI.FOR
C     This program is to perform reliability analysis.
c     The Program Copyright 11.16.2000 by Dr. Chunhua Liu.
      PROGRAM STATIC3
      CHARACTER*1 C(12),E(12)
      CHARACTER*8 NAME0,NAME1,NAME2
      CHARACTER*12 DAT,OUT
      DIMENSION Z(120000),IZ(16500),ZS(18000),ZSG(5000),DGX(20)
      COMMON Z,IZ,ZS,Z1,ZSG
      COMMON /CONST1/ AL(11),AS(6),AD(6),AM(18)
      COMMON /CONST2/ AKSY(12),AKTY(12),ADSY(12),ADTY(12),AFY(12)
      COMMON /CONST3/ ISR,SSL/CONST4/NKS,IVD,IVS
      COMMON /DIS2/ DD(18),V(18),A(18)
      COMMON /TIME1/ T,ST,STP,VO
      COMMON /TOA/ ZAA,ZAB,NTN1,NCAR,IPLOT,MCAR,MTY,MLX
      COMMON /SSLL/ SL,NKS1
      COMMON /CONST5/ IVDEG,IVDEG2,IVDEG3,IVDEG4
      COMMON /DGXT/ DGX
      COMMON /BIYL/ IYL(20),BYL(20),AYL(20)
      COMMON /DEGA/ DE,GAMAWS
      COMMON /BVDT/ TLLA(18),VMV(18),BIAS(18),COV(18)
      COMMON /ANALN/ ITEE

      EQUIVALENCE (NAME0,C,DAT),(NAME2,E,OUT)
      NKS1=NKS
      NAME0='reli'
      NAME1=NAME0
      NAME2=NAME0
      CALL FNAME(DAT,'.DAT')
      CALL FNAME(OUT,'.OUT')
      NRL=50
      OPEN(3,FILE=DAT)
      OPEN(1,FILE='CAR.DAT')
      READ(3,*)N,M,MLX,NB,NEG,NIJ,NG,NP,NQ,NQG,NC,LX,LC,NBV,ITRA
      MTY=(M-MLX)/(2*MLX+1)
      OPEN(4,FILE=OUT,STATUS='UNKNOWN')
      READ(3,*)GG,EPS
      WRITE(4,10)N,M,MLX,MTY,NB,NEG,NIJ,NG,NP,NQ,NQG,NC,LX,LC,NBV,ITRA
 10   FORMAT(5X,'N',4X,'M',2X,'MLX',2X,'MTY',3X,'NB',2X,'NEG',2X,
     /  'NIJ',3X,'NG',3X,'NP',3X,'NQ',2X,'NQG',2X,'NC',3X,'LX',
     /   2X,'LC',2X,'NBV',2X,'ITRA'/(1X,16I5))
      WRITE(4,15)GG,EPS
      IF(ITRA.EQ.1) GG=GG/2.54
  15  FORMAT(5X,'GG',8X,'EPS'/(1X,2E12.3))
      NN=3*N
      NNB=NN-NB-NC
      N01=N+1
      N02=N01+N
      N03=N02+NG
      N04=N03+NEG*2
      N05=N04+3*NIJ
      M01=M+1
      M02=M01+M
      M03=M02+M
      M04=M03+M
      M05=M04+M
      M06=M05+NQG
      M07=M06+2*NB
      M08=M07+NQ
      M09=M08+3*NC
      M10=M09+NN
```

```
      M11=M10+NNB
      I01=1
      I03=I01+NNB
      IF(M11.GT.6500) STOP1
      CALL IOSUB(Z(1),Z(N01),Z(N02),Z(N03),Z(N04),IZ(1),IZ(M01),
    1      IZ(M02),IZ(M03),IZ(M04),IZ(M05),Z(N05),IZ(M06),IZ(M07)
    2  ,N,NC,IZ(M08),NG,NEG,NIJ,M,NB,LX,NQ,NQG,ITRA)

      CALL ADV(NN,NB,3,IZ(M06),IZ(M09),NC,IZ(M08))
      CALL DBL(3,M,N,NN,NNB,LBM,IZ(1),IZ(M01),IZ(M09),IZ(M10),LA)
      N06=N05+NQG
      N07=N06+LA
      N08=N07+NBV*LA
      N09=N08+NBV*NNB
      N10=N09+LA
      N11=N10+NNB*NBV
      N12=N11+NNB
      IF (LC.NE.0) GOTO 800
      CALL ASSEM(N,M,NEG,NIJ,NNB,NN,LA,Z(1),Z(N01),
    1     Z(N03),Z(N04),IZ(1),IZ(M01),IZ(M03),IZ(M04),
    2     IZ(M10),IZ(M09),Z(N06))
603   FORMAT(1X,'-- STIFFNESS AND MASS MATRIX HAS BEEN ASSEMBLED--')
      READ(3,*)NKD,NKS,MCAR,NCAR,ISR,NPTS,IPLOT,SL,SSL,VO,ST,STP,
    /  ZAA,ZAB
      VO1=VO*17.6
      G=386.4
      NFW=2*MCAR
      CALL CARDA(G,ITRA)
      NFV=24*MCAR
      IVD=3
      IVS=6
      IVDEG=12
      DATAL=NCAR*(AL(1)+AL(2))
      DATAL1=DATAL/NCAR
      NTN=(SL+DATAL1)/VO1/ST
      NTN1=NTN+DATAL/VO1/ST+1
      KSTP=STP/ST
      NTN2=NTN+2
      NKS1=NKS
      ITEE=10
      WRITE(4,46)NKD,NKS,NTN,NFV,MCAR,NCAR,ISR,NPTS,IPLOT,SL,SSL,
    /   VO,ST,STP,ZAA,ZAB
      IF(ITRA.EQ.1)THEN
      SL=SL/2.54
      SSL=SSL/0.3048
      VO=VO/1.609
      ENDIF
 46   FORMAT(7X,'NKD',5X,'NKS',5X,'NTN',5X,'NFV',4X,'MCAR',4X,'NCAR'
    / ,5X,'ISR',4X,'NPTS',3X,'IPLOT'/(1X,9I8)/5X,'SL',7X,'SSL',
    /  7X,'VO',7X,'ST',5X,'STP',7X,'ZAA',6X,'ZAB'/1X,7E9.3)
      J01=NKD*2+1
      J02=J01
      K01=10+1
      K02=K01+10
      K03=K02+NFV*2
      K04=K03+NFV
      K05=K04+2*NP
      K06=K05+10*NP
      K07=K06+NP*3
      K08=K07+10
      K09=K08+2*N
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      K10=K09+10
      K11=K10+6*NP
      K12=K11+NKD*3
      K13=K12+NKD*3
      K14=K13+NFV*4
      K15=K14+NKD*2
      K16=K15+4*NKD
      K17=K16+4*NKD
      K18=K17+LBM
      I04=I03+IVD*NFV
      I05=I04+NFV*2
      N7L=2*N
      CALL IOSUB1(NBV,NKD,ZS(K14),MCAR,ITRA)
      NL1=18
      N13=N12+NL1**2
      N14=N13+NL1**2
      N15=N14+NL1
      N16=N15+NL1
      N17=N16+NL1
      N18=N17+NL1
      IF(N18.GT.120000) STOP2
       DO 16 K4=1,MTY
       CC=Z(N+K4)
       DO 17 K5=1,2
       IF(K5.EQ.1) THEN
       SC=DGX(K5)-24.0
         IF(SC.LE.0.0) THEN
         IYL(K5)=0
         ENDIF
         IF(SC.LE.Z(N+K4+1).AND.SC.GE.CC) THEN
         IYL(K5)=K4
         ENDIF
       ENDIF

       IF(K5.EQ.2) THEN
       SC=DGX(K5)+24.0
         IF(SC.LE.Z(N+K4+1).AND.SC.GT.CC) THEN
         IYL(K5)=K4
         ENDIF
       ENDIF
17     CONTINUE
16     CONTINUE
       IYM=IYL(K4)
       IG1=(IYL(2)-IYL(1))+1
       LGN=MLX*IG1
       LGN4=4*LGN
       LGNWS=(MTY+1)*MLX

      K19=K18+LGN4*5
      K20=K19+M*4
      K21=K20+LGNWS*4

      IF(K21.GT.18000) STOP3

 20   CALL QQSOLV(NTN2,NFV,M,IZ(M04),IZ(M03),NIJ,Z(N04),NEG,Z(N03),
    / IZ(1),IZ(M01),N,Z(1),Z(N01),NN,IZ(M09),NNB,IZ(M10),ZSG(I01),
    / NKD,ZS(K14),LA,Z(N06),ZS(K11),ZS(K12),ZS(K13),ZS(K15),
    / ZS(K16),DATAL,ZSG(I03),IVD,NFW,LBM,ZS(K17),LGN4,ZS(K18),ZS(K19),
    / IZ(M02),NG,Z(N02),LGNWS,ZS(K20))
      CALL QQSOLV1(NFV,M,IZ(M04),IZ(M03),NIJ,Z(N04),NEG,Z(N03),
    / IZ(1),IZ(M01),N,Z(1),Z(N01),NN,IZ(M09),NNB,IZ(M10),ZSG(I01),
```

```
     / NKD,ZS(K14),LA,Z(N06),ZS(K11),ZS(K13),
     / LBM,LGN4,ZS(K18),ZS(K19),
     / NG,Z(N02),LGNWS,ZS(K20),Z(N07),Z(N08),NBV,Z(N09),
     / Z(N10),Z(N11),ZS(K17),NL1,Z(N12),Z(N13),Z(N14),Z(N15),Z(N16),
     / Z(N17))

605    FORMAT(1X,'** GET RESULTS FROM "',A11,'",THANK YOU **')
302    FORMAT(12I5)
304    FORMAT(2E13.6)
800    CONTINUE
       STOP
       END


       SUBROUTINE FNAME(C,CE)
       CHARACTER*1 C(12),CE(4)
       K=0
       DO 10 I=1,8
       IF(C(I).EQ.' ') THEN
       K=I
       GOTO 15
       ENDIF
10     CONTINUE
15     IF(K.EQ.0) K=9
       DO 20 I=K,12
20     C(I)=' '
55     DO 60 I=K,K+3
60     C(I)=CE(I-K+1)
       RETURN
       END


       SUBROUTINE IOSUB(X,Y,QN,EG,GJI,IHL,IHR,NQQ,NM,NS,NGQ,GQ,
     1      NBC,IE,N,NC,MS,NG,NEG,NIJ,M,NB,LX,NQ,NQG,ITRA)
       DIMENSION X(N),Y(N),QN(NG),EG(NEG,2),GJI(NIJ,3),IHL(M),
     1 IE(NQ),IHR(M),NQQ(M),NM(M),NS(M),NBC(NB,2),MS(NC,3),
     / NGQ(NQG),GQ(NQG)
       COMMON /IO/NRB,NR4,RW(50)
 2     READ(3,*) I,KI,X(I),Y(I)
          IF(I.EQ.N) GOTO 7
       IF(KI.EQ.0.AND.K1.EQ.0) GOTO 2
       K1=KI
       I1=I
       J1=I+KI
 4     READ(3,*) I,KI,X(I),Y(I)
          J2=I-K1
       XK=(X(I)-X(I1))/(I-I1)
       YK=(Y(I)-Y(I1))/(I-I1)
       DO 6 II=J1,J2,K1
       X(II)=X(I1)+XK*(II-I1)
 6     Y(II)=Y(I1)+YK*(II-I1)
       K1=KI
       I1=I
       J1=I+KI
       IF(I.EQ.N) GOTO 7
       IF(K1.NE.0) GOTO 4
       GOTO 2
  7    CONTINUE
       NRB=2
       WRITE(4,700)(I,X(I),Y(I),I=1,N)
700    FORMAT(6X,'I',8X,'X(I)',10X,'Y(I)'/(5X,I5,2F11.3))
```

```
      NR4=4
      IF(NG.EQ.0) GOTO 8
      READ(3,*) (QN(I),I=1,NG)
      WRITE(4,307) (QN(I),I=1,NG)
      DO 9 I=1,NG
9     QN(I)=QN(I)*1.03
 8    READ(3,*) (EG(I,1),EG(I,2),I=1,NEG)
      WRITE(4,306) (I,EG(I,1),EG(I,2),I=1,NEG)
      READ(3,*) (GJI(I,1),GJI(I,2),GJI(I,3),I=1,NIJ)
      WRITE(4,309) (I,GJI(I,1),GJI(I,2),GJI(I,3),I=1,NIJ)
      TRAN1=1.0
      TRAN2=1.0
      TRAN3=1.0
      TRAN4=1.0
      TRAN5=1.0
      IF(ITRA.EQ.1)THEN
      TRAN1=0.393701
      TRAN2=0.22482
      TRAN3=1.4503
      TRAN4=0.1550
      TRAN5=0.0240251
      ENDIF
      DO 401 I=1,N
      X(I)=X(I)*TRAN1
 401  Y(I)=Y(I)*TRAN1
      DO 402 I=1,NG
 402  QN(I)=QN(I)*TRAN2
      DO 403 I= 1,NEG
      EG(I,1)=EG(I,1)*TRAN3
 403  EG(I,2)=EG(I,2)*TRAN3
      DO 404 I=1,NIJ
      GJI(I,1)=GJI(I,1)*TRAN4
      GJI(I,2)=GJI(I,2)*TRAN5
 404  GJI(I,3)=GJI(I,3)*TRAN5
 10   READ(3,*) I,KI,IHL(I),IHR(I),NQQ(I),NM(I),NS(I)
      IF(I.EQ.M) GOTO 16
      IF(KI.EQ.0.AND.K1.EQ.0) GOTO 10
      K1=KI
      I1=I
      J1=I+1
 13   READ(3,*) I,KI,IHL(I),IHR(I),NQQ(I),NM(I),NS(I)
      J2=I-1
      DO 15 II=J1,J2
      IHL(II)=IHL(II-1)+K1
      IHR(II)=IHR(II-1)+K1
      NM(II)=NM(II-1)
      NS(II)=NS(II-1)
 15   NQQ(II)=NQQ(II-1)
      K1=KI
      I1=I
      J1=I+1
      IF(I.EQ.M) GOTO 16
      IF(K1.NE.0) GOTO 13
      GOTO 10
 16   CONTINUE
      WRITE(4,308) (I,IHL(I),IHR(I),NQQ(I),NM(I),NS(I),
     /  I=1,M)
      IF(NQG.EQ.0)GOTO 22
      READ(3,*) (NGQ(I),GQ(I),I=1,NQG)
      WRITE(4,316) (NGQ(I),GQ(I),I=1,NQG)
      DO 405 I=1,NQG
```

```
405    GQ(I)=GQ(I)*TRAN2
315    FORMAT(2(I10,E13.6))
316    FORMAT(/' ** NGQ GQ **'/(1X,I10,E13.6))
22     READ(3,*) (NBC(I,1),NBC(I,2),I=1,NB)
       WRITE(4,310) (NBC(I,1),NBC(I,2),I=1,NB)
       IF(NC.EQ.0)GOTO 20
       READ(3,*) (MS(I,1),MS(I,2),MS(I,3),I=1,NC)
       WRITE(4,314) (MS(I,1),MS(I,2),MS(I,3),I=1,NC)
 20    IF(LX.EQ.0) RETURN
       READ(3,*) (IE(I),I=1,NQ)
       WRITE(4,312) (IE(I),I=1,NQ)
304    FORMAT(/5X,1HI,9X,1HX,14X,1HY/(1X,I5,2F15.5))
306    FORMAT(/5X,1HI,8X,2HEE,8X,2HGG/(1X,I5,2E15.5))
307    FORMAT(/' **QN**'/(1X,10E12.5))
308    FORMAT(/5X,1HI,7X,3HIHL,7X,3HIHR,7X,3HNQQ,8X,2HNM,8X,
     1         2HNS/(1X,I5,5I10))
309    FORMAT(/5X,1HI,8X,2HEF,13X,2HEI,13X,2HEJ/(1X,I5,3E15.5))
310    FORMAT(/' **NBC**'/(1X,2I5,1X,2I5,1X,2I5,1X,2I5,1X,2I5))
311    FORMAT(/' **KND**'/(1X,20I5))
312    FORMAT(/' **IE(I)**'/(1X,20I5))
314    FORMAT(/' **MS**'/(1X,3I5))
       RETURN
       END


C
       SUBROUTINE DYK(K,M,NEG,NIJ,NM,NS,EG,GJI,ES,DL)
       DIMENSION  NM(M),NS(M),EG(NEG,2),GJI(NIJ,3),ES(6,6)
       CALL CLEAR2(6,6,ES)
       NMK=NM(K)
       NSK=NS(K)
       B=EG(NMK,1)*GJI(NSK,2)/DL
       A=EG(NMK,2)*GJI(NSK,3)/DL
       C=12.0*B/DL/DL
       ES(1,1)=C
       ES(4,4)=C
       ES(4,1)=-C
       C=6.0*B/DL
       ES(4,3)=C
       ES(6,1)=-C
       ES(6,4)=C
       ES(3,1)=-C
       ES(2,2)=A
       ES(5,5)=A
       ES(5,2)=-A
       ES(3,3)=4.0*B
       ES(6,6)=4.0*B
       ES(6,3)=2.0*B
       DO 20 I=1,6
       I1=I+1
       DO 20 J=I1,6
 20    ES(I,J)=ES(J,I)
       RETURN
       END

       SUBROUTINE DYK1(K,M,NEG,NIJ,NM,NS,EG,GJI,ES,DL,IBVC,I3,
     1 MTY)
       DIMENSION NM(M),NS(M),EG(NEG,2),GJI(NIJ,3),ES(6,6)
       COMMON /BVDT/ TLLA(18),VMV(18),BIAS(18),COV(18)
       CALL CLEAR2(6,6,ES)
       NMK=NM(K)
```

```
      NSK=NS(K)
      II9=9
      II10=10
      II11=11
      II16=16
      II17=17
      II18=18
      II13=13
      II14=14
      E=EG(1,1)
      G=EG(1,2)
      IF(K.LE.I3) THEN
      AI=GJI(1,2)
      AJ=GJI(1,3)
      GOTO 100
      ENDIF
      IF(((K.LE.I3+MTY).AND.(K.GE.I3+1)).OR.((K.LE.M).AND.
     1 (K.GE.M-MTY+1))) THEN
      AI=GJI(3,2)
      AJ=GJI(3,3)
      GOTO 100
      ENDIF
100   IF(IBVC.EQ.9) THEN
      IF(K.LE.I3) THEN
      B=EG(NMK,1)/DL
      ENDIF
      IF(K.GT.I3) B=0.0
      A=0.0
      C=12.0*B/DL/DL
      ES(1,1)=C
      ES(4,4)=C
      ES(4,1)=-C
      C=6.0*B/DL
      ES(4,3)=C
      ES(6,1)=-C
      ES(6,4)=C
      ES(3,1)=-C
      ES(2,2)=A
      ES(5,5)=A
      ES(5,2)=-A
      ES(3,3)=4.0*B
      ES(6,6)=4.0*B
      ES(6,3)=2.0*B
      ENDIF
      IF(IBVC.EQ.10) THEN
      B=0.0
      IF(((K.LE.I3+MTY).AND.(K.GE.I3+1)).OR.((K.LE.M).AND.
     1 (K.GE.M-MTY+1))) THEN
      B=EG(NMK,1)/DL
      ENDIF
      A=0.0
      C=12.0*B/DL/DL
      ES(1,1)=C
      ES(4,4)=C
      ES(4,1)=-C
      C=6.0*B/DL
      ES(4,3)=C
      ES(6,1)=-C
      ES(6,4)=C
      ES(3,1)=-C
      ES(2,2)=A
```

```
      ES(5,5)=A
      ES(5,2)=-A
      ES(3,3)=4.0*B
      ES(6,6)=4.0*B
      ES(6,3)=2.0*B
      ENDIF
      IF(IBVC.EQ.13) THEN
      B=GJI(NSK,2)/DL
      A=0.0
      C=12.0*B/DL/DL
      ES(1,1)=C
      ES(4,4)=C
      ES(4,1)=-C
      C=6.0*B/DL
      ES(4,3)=C
      ES(6,1)=-C
      ES(6,4)=C
      ES(3,1)=-C
      ES(2,2)=A
      ES(5,5)=A
      ES(5,2)=-A
      ES(3,3)=4.0*B
      ES(6,6)=4.0*B
      ES(6,3)=2.0*B
      ENDIF
      IF(IBVC.EQ.14) THEN
      B=0.0
      A=GJI(NSK,3)/DL
      C=12.0*B/DL/DL
      ES(1,1)=C
      ES(4,4)=C
      ES(4,1)=-C
      C=6.0*B/DL
      ES(4,3)=C
      ES(6,1)=-C
      ES(6,4)=C
      ES(3,1)=-C
      ES(2,2)=A
      ES(5,5)=A
      ES(5,2)=-A
      ES(3,3)=4.0*B
      ES(6,6)=4.0*B
      ES(6,3)=2.0*B
      ENDIF
      IF(IBVC.EQ.16) THEN
      B=0.0
      A=0.0
      IF(K.LE.I3) THEN
      A=EG(NMK,2)/DL
      ENDIF
      C=12.0*B/DL/DL
      ES(1,1)=C
      ES(4,4)=C
      ES(4,1)=-C
      C=6.0*B/DL
      ES(4,3)=C
      ES(6,1)=-C
      ES(6,4)=C
      ES(3,1)=-C
      ES(2,2)=A
      ES(5,5)=A
```

```
      ES(5,2)=-A
      ES(3,3)=4.0*B
      ES(6,6)=4.0*B
      ES(6,3)=2.0*B
      ENDIF

      DO 20 I=1,6
      I1=I+1
      DO 20 J=I1,6
20    ES(I,J)=ES(J,I)

      RETURN
      END



      SUBROUTINE CHI(K,M,N,IHL,IHR,X,Y,DL,SI,CO)
      DIMENSION IHL(M),IHR(M),X(N),Y(N)
      I=IHL(K)
      J=IHR(K)
      CO=X(J)-X(I)
      SI=Y(J)-Y(I)
      DL=SQRT(CO*CO+SI*SI)
      CO=CO/DL
      SI=SI/DL
      RETURN
      END

      SUBROUTINE FL(W1,SI,CO)
      DIMENSION W1(6,6)
      CALL CLEAR2(6,6,W1)
      W1(1,1)=1.0
      W1(2,2)=CO
      W1(3,3)=CO
      W1(2,3)=SI
      W1(3,2)=-SI
      DO 10 I=1,3
      DO 10 J=1,3
10    W1(I+3,J+3)=W1(I,J)
      RETURN
      END

      SUBROUTINE CLEAR2(M,N,C)
      DIMENSION C(M,N)
      DO 20 I=1,M
      DO 20 J=1,N
20    C(I,J)=0.0
      RETURN
      END


      SUBROUTINE CLEAR1(M,C)
      DIMENSION C(M)
      DO 20 I=1,M
20    C(I)=0.0
      RETURN
      END


      SUBROUTINE MTMULT(M,L,N,A,B,C)
      DIMENSION A(M,L),B(L,N),C(M,N)
```

```
      DO 50 I=1,M
      DO 50 K=1,N
      C(I,K)=0.0
      DO 50 J=1,L
 50   C(I,K)=C(I,K)+A(I,J)*B(J,K)
      RETURN
      END

      SUBROUTINE ADV(NN,NC,ND,LS,LO,NC2,LCC)
      DIMENSION LS(NC,2),LO(NN),LCC(NC2,3)
      DO 10 I=1,NN
10    LO(I)=1
      DO 20 I=1,NC
      K=LS(I,1)*ND-ND+LS(I,2)
20    LO(K)=0
      DO 25 I=1,NC2
      K=LCC(I,1)*ND-ND+LCC(I,3)
25    LO(K)=0
      DO 30 I=2,NN
30    LO(I)=LO(I-1)+LO(I)
      DO 40 I=1,NC
      K=LS(I,1)*ND-ND+LS(I,2)
40    LO(K)=0
      DO 50 I=1,NC2
      I1=LCC(I,1)*ND-ND+LCC(I,3)
      I2=LCC(I,2)*ND-ND+LCC(I,3)
50    LO(I1)=LO(I2)
60    CONTINUE
100   FORMAT(/1X,'**LO** '/(1X,20I5))
      END


      SUBROUTINE I0J0(K,ND,M,IHL,IHR,I0,J0)
      DIMENSION  IHL(M),IHR(M)
      I=IHL(K)-1
      J=IHR(K)-1
      I0=ND*I
      J0=ND*J
      RETURN
      END

      SUBROUTINE CIP(I,J,IP,NA,LV)
      DIMENSION LV(NA)
      IF(I.EQ.0.OR.J.EQ.0)GOTO 30
      I1=I
      J1=J
      IF(I.GT.J)GOTO 20
      I1=J
      J1=I
20    IP=LV(I1)-I1+J1
30    RETURN
      END


      SUBROUTINE SKSM(NLV,NN,NA,LO,LV,SK,I0,J0,ES)
      DIMENSION  SK(NLV),LV(NA),LO(NN),ES(6,6)
      I1=I0+1
      I3=I0+3
      J1=J0+1
      J3=J0+3
      DO 60 I=I1,I3
```

```
       IL=LO(I)
       IF(IL.EQ.0) GOTO 60
       II=I-I0
       DO 50 J=I1,I
       JL=LO(J)
       IF(JL.EQ.0)GOTO 50
       JJ=J-I0
       CALL CIP(IL,JL,IP,NA,LV)
       SK(IP)=SK(IP)+ES(II,JJ)
50     CONTINUE
 60    CONTINUE
       DO 90 I=J1,J3
       IL=LO(I)
       IF(IL.EQ.0)GOTO 90
       II=I-J0+3
       DO 70 J=I1,I3
       JL=LO(J)
       IF(JL.EQ.0)GOTO 70
       JJ=J-I0
       CALL CIP(IL,JL,IP,NA,LV)
       C=1.0
       IF(IL.EQ.JL)C=2.0
       SK(IP)=SK(IP)+ES(II,JJ)*C
 70    CONTINUE
       DO 80 J=J1,I
       JL=LO(J)
       IF(JL.EQ.0)GOTO 80
       JJ=J-J0+3
       CALL CIP(IL,JL,IP,NA,LV)
       SK(IP)=SK(IP)+ES(II,JJ)
 80    CONTINUE
 90    CONTINUE
       RETURN
       END

       SUBROUTINE ASSEM(N,M,NEG,NIJ,NNB,NN,LA,X,Y,EG,
     1     GJI,IHL,IHR,NM,NS,LV,LO,SK)
       DIMENSION X(N),Y(N),EG(NEG,2),GJI(NIJ,3),IHL(M),
     1   IHR(M),NM(M),NS(M),LV(NNB),LO(NN),SK(LA),
     2  ES(6,6),W1(6,6),W2(6,6)
       CALL CLEAR1(LA,SK)
       DO 100 K=1,M
       CALL I0J0(K,3,M,IHL,IHR,I0,J0)
       CALL CHI(K,M,N,IHL,IHR,X,Y,DL,SI,CO)
       CALL DYK(K,M,NEG,NIJ,NM,NS,EG,GJI,ES,DL)
 80    CALL FL(W1,SI,CO)
       CALL MTMULT(6,6,6,ES,W1,W2)
       W1(2,3)=-SI
       W1(5,6)=-SI
       W1(3,2)=SI
       W1(6,5)=SI
       CALL MTMULT(6,6,6,W1,W2,ES)
       CALL SKSM(LA,NN,NNB,LO,LV,SK,I0,J0,ES)
100    CONTINUE
       RETURN
       END


       SUBROUTINE ASSEM1(N,M,NEG,NIJ,NNB,NN,LA,X,Y,EG,GJI,IHL,
     1 IHR,NM,NS,LV,LO,SK,IBVC,I3,MTY)
       DIMENSION X(N),Y(N),EG(NEG,2),GJI(NIJ,3),IHL(M),
```

```
     1 IHR(M),NM(M),NS(M),LV(NNB),LO(NN),SK(LA),
     2 ES(6,6),W1(6,6),W2(6,6)
       CALL CLEAR1(LA,SK)
       DO 100 K=1,M
       CALL I0J0(K,3,M,IHL,IHR,I0,J0)
       CALL CHI(K,M,N,IHL,IHR,X,Y,DL,SI,CO)
       CALL DYK1(K,M,NEG,NIJ,NM,NS,EG,GJI,ES,DL,IBVC,I3,MTY)
 80    CALL FL(W1,SI,CO)
       CALL MTMULT(6,6,6,ES,W1,W2)
       W1(2,3)=-SI
       W1(5,6)=-SI
       W1(3,2)=SI
       W1(6,5)=SI
       CALL MTMULT(6,6,6,W1,W2,ES)
       CALL SKSM(LA,NN,NNB,LO,LV,SK,I0,J0,ES)
100    CONTINUE
       RETURN
       END


       SUBROUTINE ASSEM2(N,M,NIJ,NNB,NN,LA,X,Y,
     1 GJI,IHL,IHR,LV,LO,SK,NEG,NM,NS,EAL)
       DIMENSION X(N),Y(N),GJI(NIJ,3),IHL(M),
     1 IHR(M),LV(NNB),LO(NN),SK(LA),NM(M),NS(M),EAL(NEG,2),
     2 ES(6,6),W1(6,6),W2(6,6)
       CALL CLEAR1(LA,SK)
       DO 100 K=1,M
       CALL I0J0(K,3,M,IHL,IHR,I0,J0)
       CALL CHI(K,M,N,IHL,IHR,X,Y,DL,SI,CO)
       CALL DYK(K,M,NEG,NIJ,NM,NS,EAL,GJI,ES,DL)
 80    CALL FL(W1,SI,CO)
       CALL MTMULT(6,6,6,ES,W1,W2)
       W1(2,3)=-SI
       W1(5,6)=-SI
       W1(3,2)=SI
       W1(6,5)=SI
       CALL MTMULT(6,6,6,W1,W2,ES)
       CALL SKSM(LA,NN,NNB,LO,LV,SK,I0,J0,ES)
100    CONTINUE
       RETURN
       END


       SUBROUTINE TRNSPS(M,N,B,BT)
       DIMENSION B(M,N),BT(N,M)
       DO 20 I=1,M
       DO 20 J=1,N
       BT(J,I)=B(I,J)
 20    CONTINUE
       RETURN
       END
C
       SUBROUTINE DBL(ND,M,N,NN,NA,LBM,IHL,IHR,LO,LV,NLV)
       DIMENSION LV(NA),IHL(M),IHR(M),LO(NN)
       DO 10 I=1,NA
  10    LV(I)=1
       DO 80 I=1,N
       I3=(I-1)*ND
       DO 30 II=2,ND
       I1=LO(I3+II)
       J2=II-1
```

```
       DO 30 JJ=1,J2
       J1=LO(I3+JJ)
       IF(J1.EQ.0.OR.I1.EQ.0) GOTO 30
       JB=I1-J1
       IF(JB) 25,22,22
  22    IF(LV(I1).LT.JB+1) LV(I1)=JB+1
       GOTO 30
  25    IF(LV(J1).LT.-JB+1) LV(J1)=-JB+1
  30    CONTINUE
       DO 80 K=1,M
       IF(IHR(K)-I) 80,40,80
  40    J3=(IHL(K)-1)*ND
       DO 75 II=1,ND
       I1=LO(I3+II)
       IF(I1.EQ.0) GOTO 75
       DO 70 J=1,ND
       J1=LO(J3+J)
       IF(J1.EQ.0) GOTO 70
       JB=I1-J1
       IF(JB) 60,50,50
  50    IF(LV(I1).LT.JB+1) LV(I1)=JB+1
       GOTO 70
  60    IF(LV(J1).LT.-JB+1) LV(J1)=1-JB
  70    CONTINUE
  75    CONTINUE
  80    CONTINUE
       DO 90 I=2,NA
       IF(LBM.LT.LV(I)) LBM=LV(I)
  90    LV(I)=LV(I-1)+LV(I)
       LBM=LBM-1
       NLV=LV(NA)
 102   FORMAT(1X,'LV'/(1X,10I6))
       RETURN
       END
C
C
      SUBROUTINE IOSUB1(NBV,NKD,FV,MCAR,ITRA)
      DIMENSION FV(NKD,2),DGX(20)
      COMMON /DGXT/DGX
      COMMON /DEGA/ DE,GAMAWS
      COMMON /BVDT/ TLLA(18),VMV(18),BIAS(18),COV(18)
      COMMON /ANALN/ ITEE
      READ(3,*)((FV(I,J),J=1,2),I=1,NKD)
 20   CONTINUE
      WRITE(4,311)((FV(I,J),J=1,2),I=1,NKD)
      MN=2*MCAR
      READ(3,*)(DGX(I),I=1,MN)
24    CONTINUE
      WRITE(4,314)(DGX(I),I=1,MN)
      DE=24.0
      GAMAWS=0.000285
      WRITE(4,324)
      DO 26 I=1,NBV
      READ(3,*) ITEMP,BIAS(I),COV(I)
      WRITE(4,*) ITEMP,BIAS(I),COV(I)
26    CONTINUE
      DO 27 I=1,NBV
27    VMV(I)=0.0
      VMV(8)=0.33
      VMV(12)=2064.0
      VMV(15)=40.32
```

```
      TRAN1=1.0
      IF(ITRA.EQ.1)THEN
      TRAN1=0.393701
      DO 401 I=1,NKD
401   DGX(I)=DGX(I)*TRAN1
      DO 402 I=1,NKD
402   FV(I,2)=FV(I,2)*TRAN1
      ENDIF
314   FORMAT(/'**DGX**'/(1X,5E12.3))
311   FORMAT(/'  **FV(I,J)**'/(1X,8F8.3))
316   FORMAT(/'  De = ',F8.3,/,
     / '   WEIGHT DENSITY OF WEARING SURFACE = ', E8.3)
318   FORMAT(1X,'*** TOTAL NUMBER OF INTERMEDIATE DIAPHRAGMS ** ',I6)
320   FORMAT(1X,8I6)
324   FORMAT(1X,'** READ DISTRIBUTION DATA OF VARIABLES **')
326   FORMAT(1X,2I6,3F8.4)
C328   FORMAT(1X,' ELEMENT NO. = ',I6)
      RETURN
      END


       SUBROUTINE SETLOAD(NKS,LM,NFW,IVD,QCA)
       DIMENSION QCA(IVD,NFW)
       NKS=NKS
       N0=LM+1
       N1=LM+2
       QCA(1,N0)=4.0
       QCA(1,N1)=4.0
       QCA(2,N0)=16.0
       QCA(2,N1)=16.0
       QCA(3,N0)=16.0
       QCA(3,N1)=16.0
       RETURN
       END


        SUBROUTINE QQSOLV(MM,NFV,M,NEJF,NEAL,NJF,EJF,NEA,EAL,IHL,IHR,
     1  N,X,Y,NN,LO,NNB,LV,DP,NF,FN,LA,SK,QMNQ,QSHV,Q,SMAX,STIME,
     2  DATAL,QCA,IVD,NFW,LBM,T1,LGN4,QL,QD1,NQQ,NG,QN,LGNWS,QWS)
        DIMENSION NEJF(M),NEAL(M),EJF(NJF,3),EAL(NEA,2),IHL(M),X(N),
     1  Y(N),LO(NN),DP(NNB),LV(NNB),SMAX(NF,4),STIME(NF,4),
     2  FN(NF,2),QMNQ(NF,3),SK(LA),QSHV(NF,3),Q(NFV,4),SD(0:150),
     3  IHR(M),SY(0:100),QCA(IVD,NFW),T1(LBM),QL(LGN4,5),QD1(M,4),
     4  NQQ(M),QN(NG),QWS(LGNWS,4)
        COMMON /SSLL/SL,NKS
        COMMON /TIME1/T,ST,STP,VO
        COMMON /S000/I6,SD,SY
        COMMON /TOA/ZAA,ZAB,NTN1,NCAR,IPLOT,MCAR,MTY,MLX
        COMMON /DGXT/DGX(20)
        COMMON /BIY/IY(20),BY(20),AY(20)
        COMMON /BIYL/IYL(20),BYL(20),AYL(20)
        COMMON /LLLOC/ALL(6),ILANE
        COMMON /DEGA/DE,GAMAWS
        SD(0)=0.0
        SD(1)=0.0
        SY(0)=0.0
        CALL CLEAR2(NF,4,SMAX)
        CALL CLEAR2(NF,4,STIME)
        IPC=1
        NTC=STP/ST
        VO1=VO*17.6
```

```
        TT=DATAL/VO1
        I3=(MTY+1)*MLX
        DO 12 I=1,MTY
        I2=I3+I
        CALL CHI(I2,M,N,IHL,IHR,X,Y,DL,SI,CO)
        SY(I)=SY(I-1)+DL
12      CONTINUE
        DO 20 I=1,150
        I6=I
        CALL CHI(I,M,N,IHL,IHR,X,Y,DL,SI,CO)
        SD(I)=SD(I-1)+DL
        IF(ABS(SD(I)-SL).LT.1.0) GOTO 30
 20     CONTINUE
 30     CALL CLEAR2(NFV,4,Q)
        DO 90 K4=1,NFV
 90     Q(K4,3)=1

        CALL CLEAR2(IVD,NFW,QCA)
        DO 91 K4=1,MCAR
        LM0=2*(K4-1)
        CALL SETLOAD(NKS,LM0,NFW,IVD,QCA)
 91     CONTINUE
        NT1=2
        DO 6 K4=1,MTY
        CC=SY(K4-1)
        DO 7 K5=1,NT1
        SC=DGX(K5)
        IF(SC.LE.SY(K4).AND.SC.GT.CC) THEN
        IY(K5)=K4
        BY(K5)=SC-CC
        K3=I3+K4
        CALL CHI(K3,M,N,IHL,IHR,X,Y,DL,SI,CO)
        AY(K5)=DL-SC+CC
        ENDIF
7       CONTINUE
6       CONTINUE
        DO 16 K4=1,MTY
        CC=SY(K4-1)
        DO 17 K5=1,NT1
        IF(K5.EQ.1) THEN
        SC=DGX(K5)-24.0
          IF(SC.LT.0.0) THEN
          IYL(K5)=0
          BYL(K5)=-SC
          AYL(K5)=SY(1)
          ENDIF
          IF(SC.LE.SY(K4).AND.SC.GE.CC) THEN
          IYL(K5)=K4
          BYL(K5)=SC-CC
          K3=I3+K4
          CALL CHI(K3,M,N,IHL,IHR,X,Y,DL,SI,CO)
          AYL(K5)=DL-SC+CC
          ENDIF
        ENDIF

        IF(K5.EQ.2) THEN
        SC=DGX(K5)+24.0
          IF(SC.LE.SY(K4).AND.SC.GT.CC) THEN
          IYL(K5)=K4
          BYL(K5)=SC-CC
          K3=I3+K4
```

```
          CALL CHI(K3,M,N,IHL,IHR,X,Y,DL,SI,CO)
          AYL(K5)=DL-SC+CC
          ENDIF
        ENDIF

17      CONTINUE
16      CONTINUE

        IYM=IYL(K4)
        IG1=(IYL(2)-IYL(1))+1

        LGN=I6*IG1
        LGN4=4*LGN

        CALL LDLT(NNB,LBM,LA,LV,SK,T1)

        MM=2
        DO 100 I=2,MM
        SS=708.0
        TIME=(I-1)*ST+TT
        CALL QQDP(NFV,Q,M,NEJF,NJF,EJF,IHL,IHR,N,X,Y,NN,LO,
     1            NNB,DP,SS,SD,I6,0,IVD,NFW,QCA)
        CALL QQDPL(LGN4,QL,M,NEJF,NJF,EJF,IHL,IHR,N,X,Y,NN,LO,
     1            NNB,DP,I6)
        CALL QQDPD1(M,QD1,NEJF,NJF,EJF,IHL,IHR,N,X,Y,NN,LO,
     1            NNB,DP,NQQ,NG,QN)
        CALL QQDPWS(M,NEJF,NJF,EJF,IHL,IHR,N,X,Y,NN,LO,
     1            NNB,DP,LGNWS,QWS)
        CALL SOLVE(LBM,NNB,LA,LV,SK,DP)
        CALL QQMNQ(LGNWS,LGN4,QL,NFV,Q,M,IHL,IHR,N,X,Y,NEJF,NEAL,
     1    NJF,EJF,NEA,EAL,NF,FN,NN,LO,NNB,DP,QMNQ,QD1,QWS)
        CALL SHVSOL(NN,LO,NNB,DP,N,M,NF,FN,QSHV,IHL,IHR,X,Y)
        DO 40 K=1,NF
        DO 41 J=1,3
        IF(ABS(SMAX(K,J)).LE.ABS(QMNQ(K,J))) THEN
        SMAX(K,J)=QMNQ(K,J)
        STIME(K,J)=TIME
        ENDIF
 41     CONTINUE
        IF(ABS(SMAX(K,4)).LE.ABS(QSHV(K,1)))THEN
        SMAX(K,4)=QSHV(K,1)
        STIME(K,4)=TIME
        ENDIF
 40     CONTINUE
        IPC=0
 801    IPC=IPC+1
 100    CONTINUE
        RETURN
        END


        SUBROUTINE QQSOLV1(NFV,M,NS,NM,NIJ,GJI,NEG,EG,IHL,IHR,
     1  N,X,Y,NN,LO,NNB,LV,DP,NF,FN,LA,SK,QMNQ,Q,
     2  LBM,LGN4,QL,QD1,NG,QN,LGNWS,QWS,SM,
     3  DP1,NBV,SK1,DUDA,DKU,T1,NL1,TT1,AT1,DFDA,DGDX,DGDU,ALFA1)
        REAL KE,KE1,MNQ
        DIMENSION IHL(M),X(N),Y(N),LO(NN),DP(NNB),LV(NNB),
     1  FN(NF,2),QMNQ(NF,3),SK(LA),Q(NFV,4),UU(18),
     2  SD(0:150),IHR(M),SY(0:100),QL(LGN4,5),QD1(M,4),
     3  QN(NG),QWS(LGNWS,4),SM(NBV,LA),DP1(NBV,NNB),
     4  SK1(LA),DUDA(NBV,NNB),DKU(NNB),NM(M),NS(M),TT1(NL1,NL1),
```

```
     5  EG(NEG,2),GJI(NIJ,3),XX(18),YY(18),
     6  AT1(NL1,NL1),R1(6),R2(6),R3(6),R4(6),AL(6,6),KE(6,6),KE1(6,6),
     7  DFDA(NL1),DGDX(NL1),DGDU(NL1),ALFA1(NL1)
        COMMON /SSLL/SL,NKS
        COMMON /TIME1/T,ST,STP,VO
        COMMON /S000/I6,SD,SY
        COMMON /TOA/ZAA,ZAB,NTN1,NCAR,IPLOT,MCAR,MTY,MLX
        COMMON /DGXT/DGX(20)
        COMMON /BIY/IY(20),BY(20),AY(20)
        COMMON /BIYL/IYL(20),BYL(20),AYL(20)
        COMMON /LLLOC/ALL(6),ILANE
        COMMON /DEGA/DE,GAMAWS
        COMMON /BVDT/TLLA(18),VMV(18),BIAS(18),COV(18)
        COMMON /ANALN/ ITEE
        COMMON /RXY/RAX,RAY,RBX,RBY,MA,MB,MNQ(3)
        COMMON /CC/CX,CY,ALT(6,6)
        COMMON /SCL/SI,CO,DL

        NL1=18
        I3=(MTY+1)*MLX
        CALL CLEAR2(NBV,NNB,DP1)
        DO 200 I=1,NBV
        IF(I.EQ.1) THEN
        VMV(I)=QN(1)
        CALL CLEAR1(NNB,DKU)
        DO 10 J=1,I6
        IND=4
        CALL CHI(J,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        CALL FD(J,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,1.0)
10      CONTINUE
        DO 15 J=1,NNB
15      DP1(I,J)=DKU(J)
        DO 20 J=I3-I6+1,I3
        CALL CHI(J,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(J,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,1.0)
20      CONTINUE
        DO 30 J=1,NNB
30      DP1(I,J)=DKU(J)
        ENDIF
        IF(I.EQ.2) THEN
        VMV(I)=QN(2)
        CALL CLEAR1(NNB,DKU)
        DO 40 J=I6+1,I3-I6
        CALL CHI(J,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(J,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,1.0)
40      CONTINUE
        DO 50 J=1,NNB
50      DP1(I,J)=DKU(J)
        ENDIF
        IF(I.EQ.3) THEN
        VMV(I)=QN(4)
        CALL CLEAR1(NNB,DKU)
        DO 60 J=I3+1,I3+MTY
```

```
        CALL CHI(J,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(J,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,1.0)
60      CONTINUE
        DO 65 J=1,NNB
65      DP1(I,J)=DKU(J)
        DO 70 J=M-MTY+1,M
        CALL CHI(J,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(J,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,1.0)
70      CONTINUE
        DO 80 J=1,NNB
80      DP1(I,J)=DKU(J)
        ENDIF
        IF(I.EQ.4) THEN
        VMV(I)=QN(5)
        CALL CLEAR1(NNB,DKU)
        DO 100 J=1,NNB
100     DP1(I,J)=DKU(J)
        ENDIF
        IF(I.EQ.5) THEN
        VMV(I)=GAMAWS
        CALL CLEAR1(NNB,DKU)
        DO 120 J=1,I3
        IF(J.LE.I6.OR.J.GE.(I3-I6+1)) THEN
        ALOADWS=(DE+Y(2)/2)
        ELSE
        ALOADWS=Y(2)
        ENDIF
        L1=J
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(L1,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,ALOADWS)
120     CONTINUE
        DO 130 J=1,NNB
130     DP1(I,J)=DKU(J)
        ENDIF
        IF(I.EQ.6) THEN
        VMV(I)=0.06133
        CALL CLEAR1(NNB,DKU)
        DO 140 J=1,LGN4
        L1=QL(J,1)
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IF(L1.EQ.0) GOTO 140
        IND=QL(J,3)
        ALOADL=QL(J,2)/VMV(I)
        XQ=QL(J,4)
        ILANE=QL(I,5)
        CALL FD(L1,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,XQ,IND,ALOADL)
140     CONTINUE
        DO 150 J=1,NNB
150     DP1(I,J)=DKU(J)
        ENDIF
```

```
        IF(I.EQ.7) THEN
        VMV(I)=82.8
        CALL CLEAR1(NNB,DKU)
        DO 160 J=1,NFV
        L1=Q(J,1)
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IF(L1.EQ.0) GOTO 160
        IND=Q(J,3)
        ALOADT=Q(J,2)/VMV(I)/(1.0+VMV(8))
        XQ=Q(J,4)
        CALL FD(L1,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,XQ,IND,ALOADT)
160     CONTINUE
        DO 170 J=1,NNB
170     DP1(I,J)=DKU(J)
        ENDIF
        IF(I.EQ.8) THEN
        CALL CLEAR1(NNB,DKU)
        DO 180 J=1,NFV
        L1=Q(J,1)
        IF(L1.EQ.0) GOTO 180
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=Q(J,3)
        ALOADDLA=Q(J,2)/(1.0+VMV(8))
        XQ=Q(J,4)
        CALL FD(L1,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,XQ,IND,
     1  ALOADDLA)
180     CONTINUE
        DO 190 J=1,NNB
190     DP1(I,J)=DKU(J)
        ENDIF
        IF(I.GT.8) THEN
        DO 110 J=1,NNB
110     DP1(I,J)=0.0
        ENDIF
200     CONTINUE

        ITERATION=1
2000    CONTINUE
        DO 400 I=1,NBV
        IF(I.LE.8) THEN
        DO 410 J=1,LA
410     SM(I,J)=0.0
        ENDIF
        IF(I.EQ.12) THEN
        DO 420 J=1,LA
420     SM(I,J)=0.0
        ENDIF
        IF(I.EQ.15) THEN
        DO 430 J=1,LA
430     SM(I,J)=0.0
        ENDIF
        IF(I.EQ.9) THEN
        VMV(I)=GJI(1,2)
        IBVC=I
        CALL ASSEM1(N,M,NEG,NIJ,NNB,NN,LA,X,Y,EG,GJI,IHL,IHR,
     *  NM,NS,LV,LO,SK1,IBVC,I3,MTY)
        DO 440 J=1,LA
```

```
440     SM(I,J)=SK1(J)
        ENDIF
        IF(I.EQ.10) THEN
        VMV(I)=GJI(3,2)
        IBVC=I
        CALL ASSEM1(N,M,NEG,NIJ,NNB,NN,LA,X,Y,EG,GJI,IHL,IHR,
     *  NM,NS,LV,LO,SK1,IBVC,I3,MTY)
        DO 450 J=1,LA
450     SM(I,J)=SK1(J)
        ENDIF
        IF(I.EQ.11) THEN
        VMV(I)=GJI(4,2)
        IBVC=I
        CALL ASSEM1(N,M,NEG,NIJ,NNB,NN,LA,X,Y,EG,GJI,IHL,IHR,
     *  NM,NS,LV,LO,SK1,IBVC,I3,MTY)
        DO 460 J=1,LA
460     SM(I,J)=SK1(J)
        ENDIF
        IF(I.EQ.13) THEN
        VMV(I)=EG(1,1)
        IBVC=I
        CALL ASSEM1(N,M,NEG,NIJ,NNB,NN,LA,X,Y,EG,GJI,IHL,IHR,
     *  NM,NS,LV,LO,SK1,IBVC,I3,MTY)
        DO 470 J=1,LA
470     SM(I,J)=SK1(J)
        ENDIF
        IF(I.EQ.14) THEN
        VMV(I)=EG(1,2)
        IBVC=I
        CALL ASSEM1(N,M,NEG,NIJ,NNB,NN,LA,X,Y,EG,GJI,IHL,IHR,
     *  NM,NS,LV,LO,SK1,IBVC,I3,MTY)
        DO 480 J=1,LA
480     SM(I,J)=SK1(J)
        ENDIF
        IF(I.EQ.16) THEN
        VMV(I)=GJI(1,3)
        IBVC=I
        CALL ASSEM1(N,M,NEG,NIJ,NNB,NN,LA,X,Y,EG,GJI,IHL,IHR,
     *  NM,NS,LV,LO,SK1,IBVC,I3,MTY)
        DO 490 J=1,LA
490     SM(I,J)=SK1(J)
        ENDIF
        IF(I.EQ.17) THEN
        VMV(I)=GJI(3,3)
        IBVC=I
        CALL ASSEM1(N,M,NEG,NIJ,NNB,NN,LA,X,Y,EG,GJI,IHL,IHR,
     *  NM,NS,LV,LO,SK1,IBVC,I3,MTY)
        DO 500 J=1,LA
500     SM(I,J)=SK1(J)
        ENDIF
        IF(I.EQ.18) THEN
        VMV(I)=GJI(4,3)
        IBVC=I
        CALL ASSEM1(N,M,NEG,NIJ,NNB,NN,LA,X,Y,EG,GJI,IHL,IHR,
     *  NM,NS,LV,LO,SK1,IBVC,I3,MTY)
        DO 510 J=1,LA
510     SM(I,J)=SK1(J)
        ENDIF
400     CONTINUE
        DO 600 I=1,NBV
        DO 620 J=1,LA
```

```
620     SK1(J)=SM(I,J)
        CALL MUL(NNB,LA,LBM,LV,SK1,DP,DKU)
        DO 630 J=1,NNB
630     DKU(J)=DP1(I,J)-DKU(J)
        CALL SOLVE(LBM,NNB,LA,LV,SK,DKU)
        DO 610 J=1,NNB
        DUDA(I,J)=DKU(J)
610     CONTINUE
600     CONTINUE
        CALL I0J0(ITEE,3,M,IHL,IHR,I0,J0)
        CALL CHI(ITEE,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL DYK(ITEE,M,NEG,NIJ,NM,NS,EG,GJI,KE,DL)

        DO 240 I=1,NL1
        NVAR=I
        CALL DYK1(ITEE,M,NEG,NIJ,NM,NS,EG,GJI,KE1,DL,NVAR,I3,
     *  MTY)
        CALL CLEAR1(6,R2)
        IF(NVAR.LE.8) GOTO 270
        IF(NVAR.EQ.12) GOTO 270
        IF(NVAR.EQ.15) GOTO 270
        DO 250 J=1,3
        I1=I0+J
        J1=J0+J
        IF(LO(I1).NE.0) R2(J)=DP(LO(I1))
        IF(LO(J1).NE.0) R2(J+3)=DP(LO(J1))
250     CONTINUE
        CALL MTMULT(6,6,1,AL,R2,R1)
        CALL MTMULT(6,6,1,KE1,R1,R2)
270     CONTINUE
        CALL CLEAR1(6,R4)
        DO 260 J=1,3
        I1=I0+J
        J1=J0+J
        IF(LO(I1).NE.0) R4(J)=DUDA(NVAR,LO(I1))
        IF(LO(J1).NE.0) R4(J+3)=DUDA(NVAR,LO(J1))
260     CONTINUE
        CALL MTMULT(6,6,1,AL,R4,R3)
        CALL MTMULT(6,6,1,KE,R3,R4)
        DO 300 J=1,6
        R4(J)=-(R4(J)+R2(J))
300     CONTINUE
        DFDA(I)=R4(3)

        MNQ(3)=0.0
        IF(NVAR.EQ.7) THEN
        DO 310 J=1,NFV
        L2=Q(J,1)
        IF(L2.NE.ITEE) GOTO 310
        II=Q(J,3)
        ALOAD=Q(J,2)/VMV(NVAR)
        ALOAD=ALOAD/(1.0+VMV(8))
        CALL INFO2(L2,NS,GJI,M,NJF,FN(I,2),Q(J,4),II,ALOAD)
310     CONTINUE
        DFDA(I)=DFDA(I)+MNQ(3)
        ENDIF
        IF(NVAR.EQ.8) THEN
        DO 320 J=1,NFV
        L2=Q(J,1)
        IF(L2.NE.ITEE) GOTO 320
```

```
      II=Q(J,3)
      ALOAD=Q(J,2)
      ALOAD=ALOAD/(1.0+VMV(8))
      CALL INFO2(L2,NS,GJI,M,NJF,FN(I,2),Q(J,4),II,ALOAD)
320   CONTINUE
      DFDA(I)=DFDA(I)+MNQ(3)
      ENDIF
      IF(NVAR.EQ.6) THEN
      DO 330 J=1,LGN4
      L2=QL(J,1)
      IF(ITEE.NE.L2) GOTO 330
      II=QL(J,3)
      ALOAD=QL(J,2)/VMV(NVAR)
      CALL INFO2(L2,NS,GJI,M,NJF,FN(I,2),QL(J,4),II,ALOAD)
330   CONTINUE
      DFDA(I)=DFDA(I)+MNQ(3)
      ENDIF
      IF(NVAR.LE.2) THEN
      DO 340 J=1,M
      L2=QD1(J,1)
      IF(ITEE.NE.L2) GOTO 340
      II=QD1(J,3)
      IF((ITEE.LE.I6).OR.(ITEE.GT.(I3-I6).AND.ITEE.LE.I3)) THEN
      ALOAD=QD1(J,2)/VMV(1)
      ENDIF
      IF(ITEE.LE.(I3-I6).AND.ITEE.GT.I6) THEN
      ALOAD=QD1(J,2)/VMV(2)
      ENDIF
      CALL INFO2(L2,NS,GJI,M,NJF,FN(I,2),QD1(J,4),II,ALOAD)
340   CONTINUE
      DFDA(I)=DFDA(I)+MNQ(3)
      ENDIF
      IF(NVAR.LE.4.AND.NVAR.GE.3) GOTO 240
      IF(NVAR.EQ.5) THEN
      DO 350 J=1,LGNWS
      L2=QWS(J,1)
      IF(ITEE.NE.L2) GOTO 350
      II=QWS(J,3)
      ALOAD=QWS(J,2)/VMV(NVAR)
      CALL INFO2(L2,NS,GJI,M,NJF,FN(I,2),QWS(J,4),II,ALOAD)
350   CONTINUE
      DFDA(I)=DFDA(I)+MNQ(3)
      ENDIF
240   CONTINUE
      CALL CLEAR2(NL1,NL1,AT1)
      IF(ITERATION.EQ.1) THEN
      DO 920 I=1,NL1
      NVAR=I
      IF(I.GE.8) THEN
      XX(I)=VMV(NVAR)
      YY(I)=(XX(I)-VMV(NVAR))/(COV(NVAR)*VMV(NVAR))
      ENDIF
      IF(I.GT.8) THEN
      XX(I)=VMV(NVAR)
      ALMDA=ALOG(VMV(NVAR)/SQRT(1.0+COV(NVAR)**2))
      AKEXI=SQRT(ALOG(1.0+COV(NVAR)**2))
      YY(I)=(ALOG(XX(I))-ALMDA)/AKEXI
      ENDIF
920   CONTINUE
      DO 940 I=1,NL1
940   UU(I)=YY(I)
```

```
        ENDIF
        IGNO=1
        GLSF=XX(12)*XX(15)-QMNQ(IGNO,3)
        IF(ITERATION.EQ.1) ZFy=XX(12)*XX(15)
        DGDX(1)=-DFDA(1)
        DGDX(2)=-DFDA(2)
        DGDX(3)=-DFDA(3)
        DGDX(4)=-DFDA(4)
        DGDX(5)=-DFDA(5)
        DGDX(6)=-DFDA(6)
        DGDX(7)=-DFDA(7)
        DGDX(8)=-DFDA(8)
        DGDX(9)=-DFDA(9)
        DGDX(10)=-DFDA(10)
        DGDX(11)=-DFDA(11)
        DGDX(12)=XX(15)-DFDA(12)
        DGDX(13)=-DFDA(13)
        DGDX(14)=-DFDA(14)
        DGDX(15)=XX(12)-DFDA(15)
        DGDX(16)=-DFDA(16)
        DGDX(17)=-DFDA(17)
        DGDX(18)=-DFDA(18)
        DO 1250 I=1,NL1
        NVAR=I
        IF(I.LE.8) THEN
        DGDX(I)=DGDX(I)*VMV(NVAR)*COV(NVAR)
        ENDIF
        IF(I.GT.8) THEN
        AKEXI=SQRT(ALOG(1.0+COV(NVAR)**2))
        DGDX(I)=DGDX(I)*AKEXI*VMV(NVAR)
        ENDIF
1250    CONTINUE

        DO 1255 I=1,NL1
1255    DGDU(I)=DGDX(I)

        AMOL=0.0
        DO 950 I=1,NL1
        AMOL=AMOL+DGDU(I)**2
950     CONTINUE
        AMOL=SQRT(AMOL)

        DO 955 I=1,NL1
955     ALFA1(I)=-DGDU(I)/AMOL

        YA=0.0
        DO 960 I=1,NL1
        YA=YA+ALFA1(I)*UU(I)
960     CONTINUE

        DO 970 I=1,NL1
        UU(I)=(YA+GLSF/AMOL)*ALFA1(I)
970     CONTINUE

        BETA=0.0
        DO 975 I=1,NL1
975     BETA=BETA+UU(I)**2
        BETA=SQRT(BETA)

        DO 980 I=1,NL1
980     YY(I)=UU(I)
```

```
        DO 1000 I=1,NL1
        NVAR=I
        IF(I.LE.8) XX(I)=VMV(NVAR)*COV(NVAR)*YY(I)+VMV(NVAR)
        IF(I.GT.8) THEN
        AKEXI=SQRT(ALOG(1.0+COV(NVAR)**2))
        ALMDA=ALOG(VMV(NVAR)/SQRT(1.0+COV(NVAR)**2))
        XX(I)=AKEXI*YY(I)+ALMDA
        XX(I)=EXP(XX(I))
        ENDIF
1000    CONTINUE

        IF(ABS(GLSF/ZFy).LT.1.0e-4.AND.(ABS(BETA-BETA1).LT.0.002)) THEN
        WRITE(4,10000) BETA
        STOP
        ENDIF
        CALL CLEAR2(NL1,NL1,TT1)
        beta1=beta
        CALL CLEAR1(NNB,DP)
        CALL CLEAR1(NNB,DKU)
        DO 1200 I=1,NL1
        NVAR=I
        IF(NVAR.GT.8) GOTO 1200
        IF(I.EQ.1) THEN
        DO 1010 J=1,I6
        CALL CHI(J,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(J,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,XX(NVAR))
1010    CONTINUE
        DO 1015 J=1,NNB
1015    DP(J)=DKU(J)
        DO 1020 J=I3-I6+1,I3
        CALL CHI(J,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(J,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,XX(NVAR))
1020    CONTINUE
        DO 1030 J=1,NNB
1030    DP(J)=DKU(J)
        ENDIF
        IF(I.EQ.2) THEN
        DO 1040 J=I6+1,I3-I6
        CALL CHI(J,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(J,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,XX(NVAR))
1040    CONTINUE
        DO 1050 J=1,NNB
1050    DP(J)=DKU(J)
        ENDIF
        IF(I.EQ.3) THEN
        DO 1060 J=I3+1,I3+MTY
        CALL CHI(J,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(J,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,XX(NVAR))
1060    CONTINUE
```

```
        DO 1065 J=1,NNB
1065    DP(J)=DKU(J)
        DO 1070 J=M-MTY+1,M
        CALL CHI(J,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(J,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,XX(NVAR))
1070    CONTINUE
        DO 1080 J=1,NNB
1080    DP(J)=DKU(J)
        ENDIF
        IF(I.EQ.5) THEN
        DO 1120 J=1,I3
        IF(J.LE.I6.OR.J.GE.(I3-I6+1)) THEN
        ALOADWS=(DE+Y(2)/2)*XX(NVAR)
        ELSE
        ALOADWS=Y(2)*XX(NVAR)
        ENDIF
        L1=J
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=4
        CALL FD(L1,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,0.0,IND,ALOADWS)
1120    CONTINUE
        DO 1130 J=1,NNB
1130    DP(J)=DKU(J)
        ENDIF
        IF(I.EQ.6) THEN
        DO 1140 J=1,LGN4
        L1=QL(J,1)
        IF(L1.EQ.0) GOTO 1140
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=QL(J,3)
        ALOADL=QL(J,2)/VMV(NVAR)*XX(NVAR)
        ILANE=QL(I,5)
        CALL FD(L1,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,QL(J,4),
     /  IND,ALOADL)
1140    CONTINUE
        DO 1150 J=1,NNB
1150    DP(J)=DKU(J)
        ENDIF
        IF(I.EQ.7) THEN
        DO 1160 J=1,NFV
        L1=Q(J,1)
        IF(L1.EQ.0) GOTO 1160
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=1
        ALOADT=Q(J,2)/VMV(NVAR)*XX(NVAR)
        ALOADT=ALOADT/(1.0+VMV(8))
        XQ=Q(J,4)
        CALL FD1(L1,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,XQ,IND,ALOADT)
1160    CONTINUE
        DO 1170 J=1,NNB
1170    DP(J)=DKU(J)
        ENDIF
```

```
        IF(I.EQ.8) THEN
        DO 1180 J=1,NFV
        L1=Q(J,1)
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL,SI,CO)
        CALL TRNSPS(6,6,AL,ALT)
        IND=1
        ALOADDLA=Q(J,2)/VMV(NVAR-1)*XX(NVAR-1)
        ALOADDLA=ALOADDLA/(1.0+VMV(8))
        ALOADDLA=ALOADDLA*XX(NVAR)
        XQ=Q(J,4)
        CALL FD1(L1,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,XQ,IND,
     1  ALOADDLA)
1180    CONTINUE
        DO 1190 J=1,NNB
1190    DP(J)=DKU(J)
        ENDIF
1200    CONTINUE
        CALL ASSEM2(N,M,NIJ,NNB,NN,LA,X,Y,
     1  GJI,IHL,IHR,LV,LO,SK,NEG,NM,NS,EG)
        CALL LDLT(NNB,LBM,LA,LV,SK,T1)
        CALL SOLVE(LBM,NNB,LA,LV,SK,DP)

        CALL QQMNQ1(NEG,M,IHL,IHR,N,X,Y,NS,
     1  NJF,GJI,NF,FN,NN,LO,NNB,DP,QMNQ,
     2  EG,NIJ,NM)

        ITERATION=ITERATION+1
        IF(ITERATION.EQ.15) STOP4
        GOTO 2000
10000   FORMAT(1X,'*** BETA INDEX = ***',3X,F7.3)
        RETURN
        END


        SUBROUTINE QQDP(K,Q,M,NEJF,NJF,EJF,IHL,IHR,N,X,Y,NN,LO,
     1                  NNB,DP,SS,SD,I6,I7,IVD,NFW,QCA)
        DIMENSION Q(K,4),NEJF(M),EJF(NJF,3),IHL(M),IHR(M),X(N),Y(N),
     1            AL1(6,6),LO(NN),DP(NNB),SD(0:150),QCA(IVD,NFW)
        COMMON /CC/CX,CY,ALT(6,6)
        COMMON /IJO/IO,JO
        COMMON /SCL/SI,CO,DL
        COMMON /DGXT/DGX(20)
        COMMON /BIY/IY(20),BY(20),AY(20)
        COMMON /XAYA/XA,XB,YA,YB,PT1
        COMMON /TOA/ZAA,ZBA,NTN1,NCAR,IPLOT,MCAR,MTY,MLX
        COMMON /CONST1/AL(11),AS(6),AD(6),AM(18)

        CALL CLEAR1(NNB,DP)
        I9=8*MCAR
        IF(SS.GT.SD(I6))THEN
        I=I6
        DO 5 K5=1,I9
        Q(K5,1)=0.0
        Q(K5,4)=0.0
5       Q(K5,2)=0.0
        GOTO 250
        ENDIF
        DO 30 K5=1,I6
        CC=SD(K5-1)
        IF(CC.LE.0.0)CC=0.0
```

```
       IF(SS.LE.SD(K5).AND.SS.GT.CC)THEN
       IXM=K5
       XB=SS-CC
       CALL CHI(K5,M,N,IHL,IHR,X,Y,DL,SI,CO)
       XA=DL-XB
       I=K5
       GOTO 35
       ENDIF
30     CONTINUE
35     N08=0
       CALL SUPL(MCAR,N08,MTY,MLX,IXM,K,Q,IVD,NFW,QCA)
250    CONTINUE
       S2=SS-AL(1)
       S3=S2-AL(2)
       S4=S3-AL(3)
       S5=S4-AL(4)
       S6=S5-AL(5)
       K9=0
       DO 20 I5=I,1,-1
       IF(S2.GE.SD(I6)) THEN
       I10=2*I9
       DO 9 K8=I9+1,I10
       Q(K8,1)=0.0
       Q(K8,4)=0.0
       Q(K8,2)=0.0
9      CONTINUE
       CC=SD(I5-1)
       GOTO 251
       ENDIF
       CC=SD(I5-1)
       IF(S2.LE.SD(I5).AND.S2.GT.CC)THEN
       K9=K9+1
       IXM=I5
       XB=S2-CC
       CALL CHI(I5,M,N,IHL,IHR,X,Y,DL,SI,CO)
       XA=DL-XB
       N08=I9
       CALL SUPL(MCAR,N08,MTY,MLX,IXM,K,Q,IVD,NFW,QCA)
       IF(IVD.LT.3.AND.K9.EQ.1) GOTO 50
       ENDIF
251    CONTINUE
       IF(IVD.LT.3) GOTO20
       IF(S3.GE.SD(I6)) THEN
       I10=2*I9
       I11=3*I9
       DO 41 K8=I10+1,I11
       Q(K8,1)=0.0
       Q(K8,4)=0.0
       Q(K8,2)=0.0
 41    CONTINUE
       CC=SD(I5-1)
       GOTO 252
       ENDIF
       IF(S3.LE.SD(I5).AND.S3.GT.CC) THEN
       K9=K9+1
       IXM=I5
       XB=S3-CC
       CALL CHI(I5,M,N,IHL,IHR,X,Y,DL,SI,CO)
       XA=DL-XB
       N08=2*I9
       CALL SUPL(MCAR,N08,MTY,MLX,IXM,K,Q,IVD,NFW,QCA)
```

```
      IF(IVD.LT.4.AND.K9.EQ.2)GOTO 50
      ENDIF
 252  CONTINUE
      IF(IVD.LT.4) GOTO20
      IF(S4.GE.SD(I6)) THEN
      I10=3*I9
      I11=4*I9
      DO 42 K8=I10+1,I11
      Q(K8,1)=0.0
      Q(K8,4)=0.0
      Q(K8,2)=0.0
 42   CONTINUE
      CC=SD(I5-1)
      GOTO 253
      ENDIF
      IF(S4.LE.SD(I5).AND.S4.GT.CC) THEN
      K9=K9+1
      IXM=I5
      XB=S4-CC
      CALL CHI(I5,M,N,IHL,IHR,X,Y,DL,SI,CO)
      XA=DL-XB
      N08=3*I9
      CALL SUPL(MCAR,N08,MTY,MLX,IXM,K,Q,IVD,NFW,QCA)
      IF(IVD.LT.5.AND.K9.EQ.3)GOTO 50
      ENDIF
 253  CONTINUE
      IF(IVD.LT.5) GOTO20
      IF(S5.GE.SD(I6)) THEN
      I10=4*I9
      I11=5*I9
      DO 43 K8=I10+1,I11
      Q(K8,1)=0.0
      Q(K8,4)=0.0
      Q(K8,2)=0.0
 43   CONTINUE
      CC=SD(I5-1)
      GOTO 254
      ENDIF
      IF(S5.LE.SD(I5).AND.S5.GT.CC) THEN
      K9=K9+1
      IXM=I5
      XB=S5-CC
      CALL CHI(I5,M,N,IHL,IHR,X,Y,DL,SI,CO)
      XA=DL-XB
      N08=4*I9
      CALL SUPL(MCAR,N08,MTY,MLX,IXM,K,Q,IVD,NFW,QCA)
      IF(IVD.LT.6.AND.K9.EQ.4)GOTO 50
      ENDIF
 254  CONTINUE
      IF(IVD.LT.6) GOTO 20
      IF(S6.LE.SD(I5).AND.S6.GT.CC.AND.S6.LT.SD(I6)) THEN
      K9=K9+1
      IXM=I5
      XB=S6-CC
      CALL CHI(I5,M,N,IHL,IHR,X,Y,DL,SI,CO)
      XA=DL-XB
      N08=5*I9
      CALL SUPL(MCAR,N08,MTY,MLX,IXM,K,Q,IVD,NFW,QCA)
      IF(K9.EQ.5)GOTO 50
      ENDIF
20    CONTINUE
```

```
        IF(I7.NE.0) GOTO 80
 50     CONTINUE
80      DO 100 I=1,K
        L1=Q(I,1)
        IF(L1.EQ.0)GOTO 100
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL1,SI,CO)
        CALL TRNSPS(6,6,AL1,ALT)
        IND=Q(I,3)
        CALL FD(L1,NEJF,EJF,IHL,IHR,LO,DP,M,NN,NNB,NJF,Q(I,4),IND,
     1  Q(I,2))
100     CONTINUE

        RETURN
        END


        SUBROUTINE SUPL(MCAR,N08,MTY,MLX,IXM,K,Q,IVD,NFW,QCA)
        DIMENSION Q(K,4),QCA(IVD,NFW)
        COMMON /XAYA/XA,XB,YA,YB,PT1
        COMMON /BIY/IY(20),BY(20),AY(20)
        JM0=2*MCAR
        J1=8*MCAR
        I=1
        IF(N08.EQ.J1) I=2
        IF(N08.EQ.2*J1) I=3
        IF(N08.EQ.3*J1) I=4
        IF(N08.EQ.4*J1) I=5
        IF(N08.EQ.5*J1) I=6
        DO 6 K4=1,JM0
        YB=BY(K4)
        IYM=IY(K4)
        PT1=QCA(I,K4)
        YA=AY(K4)
        N00=(K4-1)*4+N08
        CALL CARPQ(N00,IXM,IYM,MLX,MTY,K,Q)
 6      CONTINUE
        RETURN
        END


        SUBROUTINE CARPQ(N00,IXM,IYM,MLX,MTY,K,Q)
        DIMENSION Q(K,4)
        COMMON /XAYA/XA,XB,YA,YB,PT1
        COMMON /BVDT/ TLLA(18),VMV(18),BIAS(18),COV(18)
        NB1=N00+1
        NB2=N00+2
        NB3=N00+3
        NB4=N00+4
        Q(NB1,1)=(IYM-1)*MLX+IXM
        Q(NB2,1)=Q(NB1,1)+MLX
        Q(NB3,1)=(IXM-1)*MTY+IYM+MLX*(MTY+1)
        Q(NB4,1)=Q(NB3,1)+MTY
        Q(NB1,4)=XB
        Q(NB2,4)=XB
        Q(NB3,4)=YB
        Q(NB4,4)=YB
        XY=YB+YA+XB+XA
        Q(NB1,2)=YA/XY*PT1
        Q(NB2,2)=YB/XY*PT1
        Q(NB3,2)=XA/XY*PT1
```

```
      Q(NB4,2)=XB/XY*PT1
      DLA=1+VMV(8)
      DLA=DLA*1.38
      Q(NB1,2)=YA/XY*PT1*DLA
      Q(NB2,2)=YB/XY*PT1*DLA
      Q(NB3,2)=XA/XY*PT1*DLA
      Q(NB4,2)=XB/XY*PT1*DLA
      RETURN
      END


      SUBROUTINE QQDPL(LGN4,QL,M,NEJF,NJF,EJF,IHL,IHR,N,X,Y,NN,LO,
     1                NNB,DP,I6)
      DIMENSION QL(LGN4,5),NEJF(M),EJF(NJF,3),IHL(M),IHR(M),X(N),Y(N),
     1          AL1(6,6),LO(NN),DP(NNB)
      COMMON /CC/CX,CY,ALT(6,6)
      COMMON /IJO/IO,JO
      COMMON /SCL/SI,CO,DL
      COMMON /DGXT/DGX(20)
      COMMON /BIYL/IYL(20),BYL(20),AYL(20)
      COMMON /TOA/ZAA,ZBA,NTN1,NCAR,IPLOT,MCAR,MTY,MLX
      COMMON /CONST1/AL(11),AS(6),AD(6),AM(18)
      COMMON /LLLOC/ALL(6),ILANE

      ICOUNT=0
      DO 10 I=1,I6
      IXM=I
      CALL SUPLL(LGN4,ICOUNT,MTY,MLX,IXM,QL,N,X,Y,M,IHL,IHR)
 10   CONTINUE
      DO 100 I=1,LGN4
      L1=QL(I,1)
      IF(L1.EQ.0) GOTO 100
      CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
      CALL FL(AL1,SI,CO)
      CALL TRNSPS(6,6,AL1,ALT)
      IND=QL(I,3)
      ILANE=QL(I,5)
      CALL FD(L1,NEJF,EJF,IHL,IHR,LO,DP,M,NN,NNB,NJF,QL(I,4),IND,
     1        QL(I,2))
100   CONTINUE

      RETURN
      END

      SUBROUTINE QQDPD1(M,QD1,NEJF,NJF,EJF,IHL,IHR,N,X,Y,NN,LO,
     1                NNB,DP,NQQ,NG,QN)
      DIMENSION QD1(M,4),NEJF(M),EJF(NJF,3),IHL(M),IHR(M),X(N),Y(N),
     1          AL1(6,6),LO(NN),DP(NNB),NQQ(M),QN(NG)
      COMMON /CC/CX,CY,ALT(6,6)
      COMMON /IJO/IO,JO
      COMMON /SCL/SI,CO,DL
      COMMON /DGXT/DGX(20)
      COMMON /BIYL/IYL(20),BYL(20),AYL(20)
      COMMON /TOA/ZAA,ZBA,NTN1,NCAR,IPLOT,MCAR,MTY,MLX
      COMMON /CONST1/AL(11),AS(6),AD(6),AM(18)
      COMMON /LLLOC/ALL(6),ILANE
      DO 10 I=1,M
      QD1(I,1)=I
10    CONTINUE
      DO 20 I=1,M
      II=NQQ(I)
```

```
        QD1(I,2)=QN(II)
20      CONTINUE
        DO 30 I=1,M
        QD1(I,3)=4
30      CONTINUE
        DO 40 I=1,M
        QD1(I,4)=0.0
40      CONTINUE

        DO 100 I=1,M
        L1=QD1(I,1)
        IF(L1.EQ.0) GOTO 100
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL1,SI,CO)
        CALL TRNSPS(6,6,AL1,ALT)
        IND=QD1(I,3)
        CALL FD(L1,NEJF,EJF,IHL,IHR,LO,DP,M,NN,NNB,NJF,QD1(I,4),IND,
     1          QD1(I,2))
100     CONTINUE

        RETURN
        END


        SUBROUTINE QQDPWS(M,NEJF,NJF,EJF,IHL,IHR,N,X,Y,NN,LO,
     1                  NNB,DP,LGNWS,QWS)
        DIMENSION NEJF(M),EJF(NJF,3),IHL(M),IHR(M),
     1           X(N),Y(N),AL1(6,6),LO(NN),DP(NNB),QWS(LGNWS,4)
        COMMON /CC/CX,CY,ALT(6,6)
        COMMON /IJO/IO,JO
        COMMON /SCL/SI,CO,DL
        COMMON /DGXT/DGX(20)
        COMMON /BIYL/IYL(20),BYL(20),AYL(20)
        COMMON /TOA/ZAA,ZBA,NTN1,NCAR,IPLOT,MCAR,MTY,MLX
        COMMON /CONST1/AL(11),AS(6),AD(6),AM(18)
        COMMON /DEGA/DE,GAMAWS

        DO 10 I=1,LGNWS
        IXM=I
        IF((IXM.LE.MLX).OR.(IXM.GT.MTY*MLX)) THEN
        WIDTHEQ=(DE+Y(2)/2.0)
        ENDIF
        IF(IXM.GT.MLX.AND.IXM.LE.MTY*MLX) THEN
        WIDTHEQ=Y(2)
        ENDIF
        QWS(IXM,1)=IXM
        QWS(IXM,2)=GAMAWS*WIDTHEQ
        QWS(IXM,3)=4
        QWS(IXM,4)=0.0
 10     CONTINUE

        DO 100 I=1,LGNWS
        L1=QWS(I,1)
        IF(L1.EQ.0) GOTO 100
        CALL CHI(L1,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL FL(AL1,SI,CO)
        CALL TRNSPS(6,6,AL1,ALT)
        IND=QWS(I,3)
        CALL FD(L1,NEJF,EJF,IHL,IHR,LO,DP,M,NN,NNB,NJF,QWS(I,4),IND,
     1          QWS(I,2))
100     CONTINUE
```

```
        RETURN
        END


        SUBROUTINE SUPLL(LGN4,ICOUNT,MTY,MLX,IXM,QL,N,X,Y,M,
     1   IHL,IHR)
        DIMENSION QL(LGN4,5),X(N),Y(N),IHL(M),IHR(M)
        COMMON /BIYL/IYL(20),BYL(20),AYL(20)

        DO 20 I=1,LGN4
        DO 20 J=1,5
        QL(LGN4,J)=0.0
20      CONTINUE

        K4=1
        IYM=IYL(2*(K4-1)+1)
        IG1=2
        DO 8 J4=1,IG1
        ICOUNT=ICOUNT+1
        CALL CARPQL(K4,J4,LGN4,ICOUNT,IXM,IYM,MLX,MTY,QL,N,X,Y,
     1  M,IHL,IHR)
 8      CONTINUE

        RETURN
        END


        SUBROUTINE SUPLWS(LGNWS,MTY,MLX,IXM,QWS,N,Y)
        DIMENSION QWS(LGNWS,4),Y(N)
        COMMON /BIYL/IYL(20),BYL(20),AYL(20)
        COMMON /DEGA/DE,GAMAWS
        IF((IXM.LE.MLX).OR.(IXM.GT.MTY*MLX)) THEN
        WIDTHEQ=(DE+Y(2)/2.0)
        ENDIF
        IF(IXM.GT.MLX.AND.IXM.LE.MTY*MLX) THEN
        WIDTHEQ=Y(2)
        ENDIF

        QWS(IXM,1)=IXM
        QWS(IXM,2)=GAMAWS*WIDTHEQ
        QWS(IXM,3)=4
        QWS(IXM,4)=0.0

        RETURN
        END


        SUBROUTINE CARPQL(K4,J4,LGN4,ICOUNT,IXM,IYM,MLX,MTY,QL,N,X,Y,
     1  M,IHL,IHR)
        DIMENSION QL(LGN4,5),X(N),Y(N),IHL(M),IHR(M)
        COMMON /BIYL/IYL(20),BYL(20),AYL(20)
        COMMON /SCL/SI,CO,DL
        COMMON /LLLOC/ALL(6),ILANE
        PT1L=6.133e-4

        NB1=(ICOUNT-1)*4+1
        NB2=(ICOUNT-1)*4+2
        NB3=(ICOUNT-1)*4+3
        NB4=(ICOUNT-1)*4+4
```

```
K6=2*(K4-1)+1

CALL CHI(IXM,M,N,IHL,IHR,X,Y,DL,SI,CO)
DLL=DL

  IF(J4.EQ.1) THEN
  IF(IYM.EQ.0) THEN
  QL(NB1,1)=IXM
  QL(NB2,1)=0.0
  QL(NB3,1)=0.0
  QL(NB4,1)=0.0
  QL(NB1,4)=0.0
  QL(NB2,4)=0.0
  QL(NB3,4)=0.0
  QL(NB4,4)=0.0
  QL(NB1,2)=PT1L*(DLL*BYL(K6))/DLL
  QL(NB2,2)=0.0
  QL(NB3,2)=0.0
  QL(NB4,2)=0.0
  QL(NB1,3)=4
  QL(NB2,3)=0
  QL(NB3,3)=0
  QL(NB4,3)=0
  IYM=IYM+1
  GOTO 100
  ENDIF
  IF(IYM.NE.0) THEN
  QL(NB1,1)=(IYM-1)*MLX+IXM
  QL(NB2,1)=QL(NB1,1)+MLX
  QL(NB3,1)=(IXM-1)*MTY+IYM+MLX*(MTY+1)
  QL(NB4,1)=QL(NB3,1)+MTY
  L4=QL(NB3,1)
  CALL CHI(L4,M,N,IHL,IHR,X,Y,DL,SI,CO)
  DLT=DL
  QL(NB1,4)=0.0
  QL(NB2,4)=0.0
  QL(NB3,4)=BYL(K6)
  QL(NB4,4)=BYL(K6)
  YAL=(DLT+BYL(K6))/2.0
  YBL=DLT-YAL
  XAL=DLL/2.0
  XBL=DLL/2.0
  XY=YAL+YBL+XAL+XBL
  QL(NB1,2)=YAL/XY*PT1L*(DLL*(DLT-BYL(K6)))/DLL
  QL(NB2,2)=YBL/XY*PT1L*(DLL*(DLT-BYL(K6)))/DLL
  QL(NB3,2)=XAL/XY*PT1L*(DLL*(DLT-BYL(K6)))/(DLT-BYL(K6))
  QL(NB4,2)=XBL/XY*PT1L*(DLL*(DLT-BYL(K6)))/(DLT-BYL(K6))
  QL(NB1,3)=4
  QL(NB2,3)=4
  QL(NB3,3)=2
  QL(NB4,3)=2
  IYM=IYM+1
  GOTO 100
  ENDIF
  ENDIF
  IF(J4.EQ.2) THEN
  QL(NB1,1)=(IYM-1)*MLX+IXM
  QL(NB2,1)=QL(NB1,1)+MLX
  QL(NB3,1)=(IXM-1)*MTY+IYM+MLX*(MTY+1)
  QL(NB4,1)=QL(NB3,1)+MTY
  L4=QL(NB3,1)
```

```
          CALL CHI(L4,M,N,IHL,IHR,X,Y,DL,SI,CO)
          DLT=DL
          QL(NB1,4)=0.0
          QL(NB2,4)=0.0
          QL(NB3,4)=BYL(K6+1)
          QL(NB4,4)=BYL(K6+1)
          YAL=BYL(K6+1)/2.0
          YBL=DLT-YAL
          XAL=DLL/2.0
          XBL=DLL/2.0
          XY=YAL+YBL+XAL+XBL
          QL(NB1,2)=YAL/XY*PT1L*(DLL*BYL(K6+1))/DLL
          QL(NB2,2)=YBL/XY*PT1L*(DLL*BYL(K6+1))/DLL
          QL(NB3,2)=XAL/XY*PT1L*(DLL*BYL(K6+1))/BYL(K6+1)
          QL(NB4,2)=XBL/XY*PT1L*(DLL*BYL(K6+1))/BYL(K6+1)
          QL(NB1,3)=4
          QL(NB2,3)=4
          QL(NB3,3)=3
          QL(NB4,3)=3
          GOTO 100
          ENDIF

100   CONTINUE

        RETURN
        END


        SUBROUTINE QQMNQ(LGNWS,LGN4,QL,KK,Q,M,IHL,IHR,N,X,Y,NEJF,
     1   NEAL,NJF,EJF,NEA,EAL,NF,FN,NN,LO,NNB,DP,QMNQ,QD1,QWS)
        REAL MNQ,MA,MB
        DIMENSION IHL(M),IHR(M),DP(NNB),X(N),Y(N),NEJF(M),
     1            NEAL(M),EJF(NJF,3),EAL(NEA,2),FN(NF,2),LO(NN),
     2            QMNQ(NF,3),Q(KK,4),QL(LGN4,5),QD1(M,4),QWS(LGNWS,4)
        COMMON /RXY/RAX,RAY,RBX,RBY,MA,MB,MNQ(3)
        DO 100 I=1,NF
        L1=FN(I,1)
        CALL INFO1(I,L1,IHL,IHR,DP,X,Y,LO,FN,NEJF,NEAL,EJF,EAL,M,NN,
     1  N,NJF,NEA,NF,NNB)
        DO 60 J=1,KK
        L2=Q(J,1)
        IF(L1.NE.L2) GOTO 60
        II=Q(J,3)
        CALL INFO2(L1,NEJF,EJF,M,NJF,FN(I,2),Q(J,4),II,Q(J,2))
60      CONTINUE
        DO 70 J=1,LGN4
        L2=QL(J,1)
        IF(L1.NE.L2) GOTO 70
        II=QL(J,3)
        CALL INFO2(L1,NEJF,EJF,M,NJF,FN(I,2),QL(J,4),II,QL(J,2))
70      CONTINUE
        DO 80 J=1,M
        L2=QD1(J,1)
        IF(L1.NE.L2) GOTO 80
        II=QD1(J,3)
        CALL INFO2(L1,NEJF,EJF,M,NJF,FN(I,2),QD1(J,4),II,QD1(J,2))
80      CONTINUE
        DO 90 J=1,LGNWS
        L2=QWS(J,1)
        IF(L1.NE.L2) GOTO 90
        II=QWS(J,3)
```

```
        CALL INFO2(L1,NEJF,EJF,M,NJF,FN(I,2),QWS(J,4),II,QWS(J,2))
90      CONTINUE

        DO 110 J=1,3
        QMNQ(I,J)=MNQ(J)
110     CONTINUE

100     CONTINUE
        RETURN
        END

        SUBROUTINE QQMNQ1(NEG,M,IHL,IHR,N,X,Y,NEJF,
     1  NJF,EJF,NF,FN,NN,LO,NNB,DP,QMNQ,
     2  EG,NIJ,NM)
        REAL MNQ,MA,MB
        DIMENSION IHL(M),IHR(M),DP(NNB),X(N),Y(N),NEJF(M),
     1            EJF(NJF,3),FN(NF,2),LO(NN),
     2            QMNQ(NF,3),
     3            EG(NEG,2),NM(M)
        COMMON /RXY/RAX,RAY,RBX,RBY,MA,MB,MNQ(3)
        COMMON /TOA/ ZAA,ZAB,NTN1,NCAR,IPLOT,MCAR,MTY,MLX
        COMMON /BVDT/TLLA(18),VMV(18),BIAS(18),COV(18)
        COMMON /ANALN/ ITEE
        I=1
        L1=ITEE
        CALL INFO1A(NEG,I,L1,IHL,IHR,DP,X,Y,LO,FN,M,NN,
     1  N,NF,NNB,EG,NIJ,NM,NEJF,EJF)

        DO 110 J=1,3
        QMNQ(I,J)=MNQ(J)
110     CONTINUE
        RETURN
        END


        SUBROUTINE INFO1(KNF,K,IHL,IHR,DP,X,Y,LO,FN,NEJF,NEAL,EJF,
     1       EAL,M,NN,N,NJF,NEA,NF,NNB)
        REAL MNQ,KE,MA,MB
        DIMENSION R2(6),R1(6),AL(6,6),IHL(M),IHR(M),DP(NNB),X(N),
     1    Y(N),NEJF(M),NEAL(M),EJF(NJF,3),EAL(NEA,2),
     2     LO(NN),FN(NF,2)
        COMMON /RXY/RAX,RAY,RBX,RBY,MA,MB,MNQ(3)
        COMMON /SCL/SI,CO,DL
        COMMON /KAL/KE(6,6)
        COMMON /IJO/I0,J0
        COMMON /CC/CX,CY,ALT(6,6)
        CALL I0J0(K,3,M,IHL,IHR,I0,J0)
        CALL CHI(K,M,N,IHL,IHR,X,Y,DL,SI,CO)
        CALL DYK(K,M,NEA,NJF,NEAL,NEJF,EAL,EJF,KE,DL)
        CALL FL(AL,SI,CO)
        CALL CLEAR1(6,R2)
        DO 10 J=1,3
        I1=I0+J
        J1=J0+J
        IF(LO(I1).NE.0) R2(J)=DP(LO(I1))
        IF(LO(J1).NE.0) R2(J+3)=DP(LO(J1))
10      CONTINUE
        CALL MTMULT(6,6,1,AL,R2,R1)
        CALL MTMULT(6,6,1,KE,R1,R2)
        MNQ(3)=-R2(3)-R2(1)*FN(KNF,2)
        MNQ(1)=-R2(1)
```

```
      MNQ(2)=-R2(2)
      RETURN
      END


      SUBROUTINE INFO1A(NEG,KNF,K,IHL,IHR,DP,X,Y,LO,FN,
     1 M,NN,N,NF,NNB,EAL,NIJ,NM,NS,GJI)
      REAL MNQ,KE,MA,MB
      DIMENSION R2(6),R1(6),AL(6,6),IHL(M),IHR(M),DP(NNB),X(N),
     1  Y(N),LO(NN),FN(NF,2),EAL(NEG,2),NS(M),NM(M),GJI(NIJ,3)
      COMMON /RXY/RAX,RAY,RBX,RBY,MA,MB,MNQ(3)
      COMMON /SCL/SI,CO,DL
      COMMON /KAL/KE(6,6)
      COMMON /IJO/I0,J0
      COMMON /CC/CX,CY,ALT(6,6)
      CALL I0J0(K,3,M,IHL,IHR,I0,J0)
      CALL CHI(K,M,N,IHL,IHR,X,Y,DL,SI,CO)
      CALL DYK(K,M,NEG,NIJ,NM,NS,EAL,GJI,KE,DL)
      CALL FL(AL,SI,CO)
      CALL CLEAR1(6,R2)
      DO 10 J=1,3
      I1=I0+J
      J1=J0+J
      IF(LO(I1).NE.0) R2(J)=DP(LO(I1))
      IF(LO(J1).NE.0) R2(J+3)=DP(LO(J1))
10    CONTINUE
      CALL MTMULT(6,6,1,AL,R2,R1)
      CALL MTMULT(6,6,1,KE,R1,R2)
      MNQ(3)=-R2(3)-R2(1)*FN(KNF,2)
      MNQ(1)=-R2(1)
      MNQ(2)=-R2(2)
      RETURN
      END


      SUBROUTINE INFO2(K,NEJF,EJF,M,NJF,XP,XQ,IND,G)
      REAL N2,L,N1,MB,MNQ,MA
      DIMENSION NEJF(M),EJF(NJF,3)
      COMMON /SCL/SI,CO,L
      COMMON /RXY/RAX,RAY,RBX,RBY,MA,MB,MNQ(3)
      Q2=0.0
      N2=0.0
      IF(IND.EQ.4) XQ=L
      QP=XQ-XP
      B2=0.0
      CALL FORCE(K,NEJF,EJF,M,NJF,XQ,IND,G)
      B1=-MB+RBY*(L-XP)
      N1=RBX
      Q1=-RBY
      IF(QP.LE.0.0) GOTO 70
      GOTO (10,40,30,20,50,60,70,70,70),IND
10    Q2=G
      B2=-G*QP
      GOTO 70
20    Q2=G*QP
      B2=-Q2*QP/2.0
      GOTO 70
30    N2=-G
      GOTO 70
40    N2=-G*QP
      GOTO 70
```

```
50      Q2=G*(1.0+XP/XQ)*QP/2.0
        B2=-G*QP*QP*(2.0+XP/XQ)/6.0
        GOTO 70
60      B2=-G
70      B1=B1+B2
        K1=NEJF(K)
        IF(EJF(K1,1).LT.1.0E-15) B1=0.0
        Q1=Q1+Q2
        N1=N1+N2
        MNQ(1)=MNQ(1)+Q1
        MNQ(2)=MNQ(2)+N1
        MNQ(3)=MNQ(3)+B1
        RETURN
        END



        SUBROUTINE SETG(K,NGG,GGN,M,NG,G,CXY)
        DIMENSION NGG(M),GGN(NG)
        KN=NGG(K)
        G=GGN(KN)*CXY
        RETURN
        END


        SUBROUTINE FD(K,NEJF,EJF,IHL,IHR,LO,DP,M,NN,NNB,NJF,XQ,IND,G)
        REAL MA,MB,MNQ
        DIMENSION FV1(6),FV(6),NEJF(M),EJF(NJF,3),IHL(M),IHR(M),DP(NNB)
     1           ,LO(NN)
        COMMON /CC/CX,CY,ALT(6,6)
        COMMON /RXY/RAX,RAY,RBX,RBY,MA,MB,MNQ(3)
        COMMON /LLLOC/ALL(6),ILANE
        CALL FORCE(K,NEJF,EJF,M,NJF,XQ,IND,G)
        FV1(3)=MA
        FV1(2)=RAX
        FV1(1)=RAY
        FV1(6)=MB
        FV1(5)=RBX
        FV1(4)=RBY
        CALL MTMULT(6,6,1,ALT,FV1,FV)
        CALL I0J0(K,3,M,IHL,IHR,I0,J0)
        DO 10 I=1,3
        I1=I0+I
        I1=LO(I1)
        I2=J0+I
        I2=LO(I2)
        IF(I1.NE.0) DP(I1)=DP(I1)+FV(I)
        IF(I2.NE.0) DP(I2)=DP(I2)+FV(I+3)
10      CONTINUE
        RETURN
        END

        SUBROUTINE FD1(K,NEJF,EJF,IHL,IHR,LO,DP,M,NN,NNB,NJF,XQ,IND,G)
        REAL MA,MB,MNQ,L
        DIMENSION FV1(6),FV(6),NEJF(M),EJF(NJF,3),IHL(M),IHR(M),DP(NNB)
     1           ,LO(NN)
        COMMON /CC/CX,CY,ALT(6,6)
        COMMON /RXY/RAX,RAY,RBX,RBY,MA,MB,MNQ(3)
        COMMON /LLLOC/ALL(6),ILANE
        COMMON /SCL/SI,CO,L
        CALL FORCE(K,NEJF,EJF,M,NJF,XQ,IND,G)
```

```
      FV1(3)=MA
      FV1(2)=RAX
      FV1(1)=RAY
      FV1(6)=MB
      FV1(5)=RBX
      FV1(4)=RBY
      CALL MTMULT(6,6,1,ALT,FV1,FV)
      CALL I0J0(K,3,M,IHL,IHR,I0,J0)
      DO 10 I=1,3
      I1=I0+I
      I1=LO(I1)
      I2=J0+I
      I2=LO(I2)
      IF(I1.NE.0) DP(I1)=DP(I1)+FV(I)
      IF(I2.NE.0) DP(I2)=DP(I2)+FV(I+3)
10    CONTINUE
      RETURN
      END


      SUBROUTINE FORCE(K,NEJF,EJF,M,NJF,XQ,IND,G)
      DIMENSION  NEJF(M),EJF(NJF,3)
      REAL L,MA,MB,I,J,MNQ
      COMMON /SCL/SI,CO,L
      COMMON /RXY/RAX,RAY,RBX,RBY,MA,MB,MNQ(3)
      COMMON /LLLOC/ALL(6),ILANE
      RAX=0.0
      RAY=0.0
      RBX=0.0
      RBY=0.0
      MA=0.0
      MB=0.0
      Z=XQ/L
      H=1.0-Z
      GOTO (10,20,30,40,50),IND
 10   I=H*H
      RAY=G*I*(1.0+2.0*Z)
      RBY=G-RAY
      MA=-G*XQ*I
      MB=G*H*L*Z*Z
      GOTO 100
 20   I=H*H
      J=G*(L-XQ)
      RBY=J*(1.0-I+I*H/2.0)/2.0
      MB=J*(L-XQ)*(6.0-8.0*H+3.0*I)/12.0
      RAY=J-RBY
      MA=-J*(L-XQ)**2*(4.0-3.0*H)/12.0/L
      GOTO 100
 30   I=Z*Z
      J=G*XQ
      RAY=J*(1.0-I+I*Z)/2.0
      MA=-J*XQ*(6.0-8.0*Z+3.0*I)/12.0
      RBY=J-RAY
      MB=J*XQ*Z*(4.0-3.0*Z)/12.0
      GOTO 100
 40   RAY=G*L/2.0
      MA=-G*L**2/12.0
      RBY=G*L/2.0
      MB=G*L**2/12.0
      GOTO 100
 50   CONTINUE
```

```
      XQ1=ALL(2*(ILANE-1)+1)
      XQ2=ALL(2*(ILANE-1)+2)
      Z1=XQ1/L
      H1=1.0-Z1
      I1=Z1*Z1
      J1=G*XQ1
      RAY1=J1*(1.0-I1+I1*Z1)/2.0
      MA1=-J1*XQ1*(6.0-8.0*Z1+3.0*I1)/12.0
      RBY1=J1-RAY1
      MB1=J1*XQ1*Z1*(4.0-3.0*Z1)/12.0
      Z2=XQ2/L
      H2=1.0-Z2
      I2=Z2*Z2
      J2=G*XQ2
      RAY2=J2*(1.0-I2+I2*Z2)/2.0
      MA2=-J2*XQ2*(6.0-8.0*Z2+3.0*I2)/12.0
      RBY2=J2-RAY2
      MB2=J2*XQ2*Z2*(4.0-3.0*Z2)/12.0
      RAY=RAY1-RAY2
      MA=MA1-MA2
      RBY=RBY1-RBY2
      MB=MB1-MB2
100   K1=NEJF(K)
      IF(EJF(K1,1).GE.1.0E-15) RETURN
      MA=0.0
      MB=0.0
      RETURN
      END


      SUBROUTINE SHVSOL(NN,LO,NNB,DP,N,M,NF,FN,SOLSHV,IHL,IHR,X,Y)
      DIMENSION LO(NN),DP(NNB),SOLSHV(NF,3),FN(NF,2),CC(6),IHL(M),
     / IHR(M),X(N),Y(N),CL(3,6),CT(3)
      CALL CLEAR2(NF,3,SOLSHV)
      DO 20 I=1,NF
      DO 50 K=1,6
  50  CC(K)=0.0
      I1=FN(I,1)
      CALL I0J0(I1,3,M,IHL,IHR,I0,J0)
      DO 30 J=1,3
      I2=I0+J
      J2=J0+J
      IF(LO(I2).NE.0)CC(J)=DP(LO(I2))
      IF(LO(J2).NE.0)CC(J+3)=DP(LO(J2))
 30   CONTINUE
      X1=FN(I,2)
      CALL CHI(I1,M,N,IHL,IHR,X,Y,DL,SI,CO)
      CALL CLW(CL,DL,X1)
      CALL MTMULT(3,6,1,CL,CC,CT)
      DO 10 J=1,3
      SOLSHV(I,J)=CT(J)
10    CONTINUE
20    CONTINUE
      RETURN
      END


      SUBROUTINE CLW(CL,DL,X1)
      DIMENSION CL(3,6)
      XL2=X1/DL/DL*X1
      XL3=XL2*X1/DL
```

```
        W1=1.-3.*XL2+2.*XL3
        W2=X1-2.*XL2*DL+X1*XL2
        W3=3.*XL2-2*XL3
        W4=-XL2*DL+XL3*DL
        W5=1-X1/DL
        W6=X1/DL
        CALL CLEAR2(3,6,CL)
        CL(1,3)=W2
        CL(1,1)=W1
        CL(1,6)=W4
        CL(1,4)=W3
        CL(2,2)=W5
        CL(2,5)=W6
        CL(3,3)=W5
        CL(3,6)=W6
        RETURN
        END


      SUBROUTINE CARDA(G,ITRA)
      COMMON /INOUT/ IN,IO,IP,IS
      COMMON /TIME1/ T,DT,DTPLOT,SPEED
      COMMON /CONST1/ AL(11),AS(6),AD(6),AM(18)
      COMMON /CONST2/ AKSY(12),AKTY(12),ADSY(12),ADTY(12),AFY(12)
      COMMON /CONST3/ ISR,SL
      COMMON /CONST4/ IV,NAXLE,NW
      COMMON /CONST5/ IVDEG,IVDEG2,IVDEG3,IVDEG4
      COMMON /DIS2/ D(18),V(18),A(18)
      G=G

      NAXLE=3
      IVDEG=12
      NW=NAXLE*2
      READ(1,*) (AL(I),I=1,8)
      READ(1,*) (AS(I),I=1,NAXLE),(AD(I),I=1,NAXLE)
      IF(ITRA.EQ.1)THEN
      TRAN1=0.393701
      TRAN2=0.5710432
      TRAN3=0.22482
      TRAN4=0.0885119
      DO 401 I=1,11
 401    AL(I)=AL(I)*TRAN1
      DO 402 I=1,NW
      AKSY(I)=AKSY(I)*TRAN2
      AKTY(I)=AKTY(I)*TRAN2
      ADSY(I)=ADSY(I)*TRAN2
      ADTY(I)=ADTY(I)*TRAN2
 402    AFY(I)=AFY(I)*TRAN3
      DO 403 I=1,IVDEG
      D(I)=D(I)*TRAN1
 403    V(I)=V(I)*TRAN1
      IF(IV.LE.2)THEN
      DO 404 I=4,8,2
      AM(I)=AM(I)*TRAN2
 404    AM(I+1)=AM(I+1)*TRAN4
      DO 405 I=2,3
 405    AM(I)=AM(I)*TRAN4
      AM(1)=AM(1)*TRAN2
      ELSE
      DO 406 I=7,17,2
      AM(I)=AM(I)*TRAN2
```

```
 406    AM(I+1)=AM(I+1)*TRAN4
      DO 407 I=1,4,3
      AM(I)=AM(I)*TRAN2
      AM(I+1)=AM(I+1)*TRAN4
 407    AM(I+2)=AM(I+2)*TRAN4
      ENDIF
      ENDIF
      RETURN
      END


      SUBROUTINE LDLT(N,BM,NP,V,R,T)
      INTEGER V,VI,H,VJ,VK,BM
      DIMENSION V(N),R(NP),T(BM)
      DO 80 I=2,N
      VI=V(I)
      H=I+1+V(I-1)-VI
      DO 80 J=H,I
      VJ=V(J)
      IF(J.EQ.1) L=1
      IF(J.NE.1) L=J+1+V(J-1)-VJ
      IF(L.LT.H) L=H
      S=0.D0
      J1=J-1
      IF(L.GT.J1) GOTO 55
      DO 50 K=L,J1
      IK=I-K
      VK=VJ-J+K
50      S=S+T(IK)*R(VK)
55      IF(I-J) 70,60,70
60      R(VI)=R(VI)-S
      GOTO 80
70      IJ=VI-I+J
      JI=I-J
      T(JI)=R(IJ)-S
      R(IJ)=T(JI)/R(VJ)
80      CONTINUE
      RETURN
      END


      SUBROUTINE SOLVE(BM,N,NP,V,R,B)
      INTEGER V,BM,VI,H,VJ,P
      DIMENSION V(N),R(NP),B(N)
      DO 40 I=2,N
      I1=I-1
      VI=V(I)
      H=I+1+V(I1)-VI
      DO 20 J=H,I1
      VJ=VI-I+J
      B(I)=B(I)-R(VJ)*B(J)
20      CONTINUE
40      CONTINUE
      DO 60 I=1,N
      VI=V(I)
      B(I)=B(I)/R(VI)
60      CONTINUE
      N1=N-1
      DO 100 II=1,N1
      I=N-II
      K=N
```

```
      IF(N.GT.BM+I) K=BM+I
      S=0.D0
      I1=I+1
      DO 80 J=I1,K
      P=V(J)-J+I
      IF(V(J-1).LT.P) S=S+R(P)*B(J)
80      CONTINUE
      B(I)=B(I)-S
100     CONTINUE
      RETURN
      END


      SUBROUTINE MUL(N,LA,IB,NA,R,X,B)
      DIMENSION NA(N),R(LA),X(N),B(N)
      DO 50 I=1,N
      S=0.D0
      IF(I.EQ.1) GOTO 25
      LI=NA(I)
      IH=I+1+NA(I-1)-LI
      I1=I-1
      DO 20 J=IH,I1
      LR=LI-I+J
20    S=S+R(LR)*X(J)
25    NB=I+IB
      IF(NB.GT.N) NB=N
      DO 40 J=I,NB
      LR=NA(J)-J+I
      IF(J-1)40,30,35
30    S=S+R(1)*X(1)
      GOTO 40
35    IF(NA(J-1).LT.LR) S=S+R(LR)*X(J)
40    CONTINUE
      B(I)=S
50    CONTINUE
      RETURN
      END
```

NONCOMP-ME.FOR

This program is for the calculation of ultimate moment at midspan of the exterior girder for noncomposite steel bridges.

```
C***  NONCOMP-ME.FOR
c     This is for the calculation of ultimate moment at midspan for exterior
c     girder.
c     The Program Copyright 11.16.2000 by Dr. Chunhua Liu.

      open(2,file='noncomp-me.out')

      write(*,*) 'Please enter the following data :'
      write(*,*) ' Load modifier (0.90 - 1.10) = '
      read(*,*) fai
      write(*,*) ' Span = (ft)'
      read(*,*) span
      write(*,*) ' Beam weight = (kips/ft)'
      read(*,*) wbeam
      write(*,*) ' Spacing = '
      read(*,*) S
      write(*,*) ' Moment at midspan point (kips-in) = '
      read(*,*) amtr
      write(*,*) ' Lateral distribution factor (kips-in) = '
      read(*,*) gm

      de=2.0
      tslab=8.0/12.0
      Fy=36.0
      wbarrier=0.462

      wslab=0.15*tslab*(de+S/2.0)
      w1=wbeam+wslab

      rws=0.1406
      tws=3.5/12.0
      wws=(de+S/2.0)*tws*rws

      amln=0.64*span**2/8.0
      amln=amln*12.0

      amdesign=1.75*(amtr*1.33+amln)

      amd1=w1*span**2/8.0
      amd1=amd1*12.0
      amd2=wws*span**2/8.0
      amd2=amd2*12.0

      amd3=wbarrier*span**2/8.0
      amd3=amd3*12.0

      amu=fai*(1.25*amd1+1.5*amd2+1.25*amd3+gm*amdesign)

      write(*,*) '  Mu = ',amu,'in-kips   ',amu/12.0,'ft-kips',
     * ' required Zx = ',amu/Fy

      write(2,*) '  Mu = ',amu,'in-kips   ',amu/12.0,'ft-kips',
     * ' required Zx = ',amu/Fy

      stop
      end
```

NONCOMP-MI.FOR

This program is for the calculation of ultimate moment at midspan of the interior girder for noncomposite steel bridges.

```fortran
C***  NONCOMP-MI.FOR
c     This is for the calculation of ultimate moment at midspan for interior
c     girder.
c     The Program Copyright 11.16.2000 by Dr. Chunhua Liu.

      open(2,file='noncomp-mi.out')

      write(*,*) 'Please enter the following data :'
      write(*,*) ' Load modifier (0.90 - 1.10) = '
      read(*,*) fai
      write(*,*) ' Span = (ft)'
      read(*,*) span
      write(*,*) ' Beam weight = (kips/ft)'
      read(*,*) wbeam
      write(*,*) ' Spacing = '
      read(*,*) S
      write(*,*) ' Moment at midspan point (kips-in) = '
      read(*,*) amtr
      write(*,*) ' Lateral distribution factor (kips-in) = '
      read(*,*) gm

      tslab=8.0/12.0
      Fy=36.0

      wslab=0.15*tslab*S
      w1=wbeam+wslab

      rws=0.1406
      tws=3.5/12.0
      wws=S*tws*rws

      amln=0.64*span**2/8.0
      amln=amln*12.0

      amdesign=1.75*(amtr*1.33+amln)

      amd1=w1*span**2/8.0
      amd1=amd1*12.0
      amd2=wws*span**2/8.0
      amd2=amd2*12.0

      amu=fai*(1.25*amd1+1.5*amd2+gm*amdesign)

      write(2,*) 'amd1 = ',amd1/12.0,'amd2 = ',amd2/12.0,
     * 'amdesign = ',gm*amdesign/12.0

      write(*,*) '  Mu = ',amu,'in-kips   ',amu/12.0,'ft-kips',
     * ' required Zx = ',amu/Fy

      write(2,*) '  Mu = ',amu,'in-kips   ',amu/12.0,'ft-kips',
     * ' required Zx = ',amu/Fy

      stop
      end
```

COMP-ME.FOR

This program is for the calculation of ultimate moment at midspan of the exterior girder for composite steel bridges.

```
C***  COMP-ME.FOR
c     This is for the calculation of ultimate moment at midspan for exterior
c     girder.
c     The Program Copyright 11.16.2000 by Dr. Chunhua Liu.
```

```
open(2,file='comp-me.out')

write(*,*) 'Please enter the following data :'
write(*,*) ' Load modifier (0.90 - 1.10) = '
read(*,*) fai
write(*,*) ' Span = (ft)'
read(*,*) span
write(*,*) ' Beam weight = (kips/ft)'
read(*,*) wbeam
write(*,*) ' Spacing = '
read(*,*) S
write(*,*) ' Moment at midspan point (kips-in) = '
read(*,*) amtr
write(*,*) ' Lateral distribution factor (kips-in) = '
read(*,*) gm

de=2.0
tslab=8.0/12.0
Fy=36.0
wbarrier=0.462

wslab=0.15*tslab*(de+S/2.0)
w1=wbeam+wslab

rws=0.1406
tws=3.5/12.0
wws=(de+S/2.0)*tws*rws

amln=0.64*span**2/8.0
amln=amln*12.0

amdesign=1.75*(amtr*1.33+amln)

amd1=w1*span**2/8.0
amd1=amd1*12.0
amd2=wws*span**2/8.0
amd2=amd2*12.0

amd3=wbarrier*span**2/8.0
amd3=amd3*12.0

amu=fai*(1.25*amd1+1.5*amd2+1.25*amd3+gm*amdesign)

write(2,*) '*** The follwoing is results = ***'

write(2,*) '  Mu = ',amu,'in-kips   '

stop
end
```

COMP-MI.FOR

This program is for the calculation of ultimate moment at midspan of the interior girder for composite steel bridges.

```
C***  COMP-MI.FOR
c     This is for the calculation of ultimate moment at midspan for interior
c     girder.
c     The Program Copyright 11.16.2000 by Dr. Chunhua Liu.

      open(2,file='comp-mi.out')
```

```
write(*,*) 'Please enter the following data :'
write(*,*) ' Load modifier (0.90 - 1.10) = '
read(*,*) fai
write(*,*) ' Span = (ft)'
read(*,*) span
write(*,*) ' Beam Weight = (kips/ft)'
read(*,*) wbeam
write(*,*) ' Spacing = '
read(*,*) S
write(*,*) ' Moment at midspan point (kips-in) = '
read(*,*) amtr
write(*,*) ' Lateral distribution factor (kips-in) = '
read(*,*) gm

if(span.eq.90) amtr=1339.975*12.0
if(span.eq.60) amtr=800.0*12.0
if(span.eq.30) amtr=260.0*12.0
if(span.eq.120) amtr=1879.99*12.0

write(2,*) ' span = ',span,' S = ',S
write(*,*) ' span = ',span,' S = ',S

tslab=8.0/12.0
Fy=36.0

wslab=0.15*tslab*S
w1=wbeam+wslab

rws=0.1406
tws=3.5/12.0
wws=S*tws*rws

amln=0.64*span**2/8.0
amln=amln*12.0

amdesign=1.75*(amtr*1.33+amln)

amd1=w1*span**2/8.0
amd1=amd1*12.0
amd2=wws*span**2/8.0
amd2=amd2*12.0

amu=fai*(1.25*amd1+1.5*amd2+gm*amdesign)

write(2,*) '*** The follwoing is results = ***'

write(2,*) '  Mu = ',amu,'in-kips   '

stop
end
```