FINAL REPORT

RELIABILITY VALIDATION OF HIGHWAY BRIDGES DESIGNED BY LRFD

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Reliability Validation of Highway Bridges Designed by LRFD

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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 120 ft 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.
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

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or 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

$$\eta \sum \gamma_i Q_i \leq \phi R_n$$

(1-1)

where $Q_i =$ the force effect; $R_n =$ the nominal resistance; $\gamma_i =$ the statistically based load factor applied to the force effects; $\phi =$ the statistically based resistance factor applied to nominal resistance; and $\eta =$ 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 Halder 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:

\[ g(X) = g(R(X), S(X)) = 0 \]  

(2-1)

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

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

\[ g(X) = G(Y) = 0 \]  

(2-2)

The point \( Y^* \) 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 \( \beta = \sqrt{Y^*^T Y^*} \). The following efficient formula is used to compute the design point \( Y^* \) (Madsen et al. 1986):
\[
\mathbf{Y}_{i+1} = \left[ \mathbf{Y}_i^T \alpha_i + \frac{\mathbf{G}(\mathbf{Y}_i)}{\lVert \nabla \mathbf{G}(\mathbf{Y}_i) \rVert} \right] \alpha_i
\]

(2-3)

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

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

(1) The variables \( X_i \) \((i = 1, \Lambda, n)\) are transformed into standard normal variables \( \mathbf{Z} \):

For normal variables \( X_m \),

\[
\mathbf{Z}_m = \left( X_m - \mu \right)/\sigma
\]

(2-4a)

For lognormal variables \( X_n \),

\[
\mathbf{Z}_n = \left( \ln X_n - \lambda \right)/\zeta
\]

(2-4b)

where \( \mu \) = the mean value of \( X_m \); \( \sigma \) = the standard deviation of \( X_m \); \( \lambda \) = the mean of \( \ln(X_n) \); \( \zeta \) = the standard deviation of \( \ln(X_n) \).

(2) The standard normal variables \( \mathbf{Z} \) are transformed into independent standard normal variables \( \mathbf{Y}_i \):

\[
\mathbf{Z}_i = \sum_{j=1}^{i} \alpha_{ij} Y_j
\]

(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 - $\partial U / \partial X_j$:

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

$$F = KU$$  \hspace{1cm} (2-6)

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

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

thus

$$\frac{\partial U}{\partial X_j} = K^{-1} \left[ \frac{\partial F}{\partial X_j} - \left( \frac{\partial K}{\partial X_j} \right) \cdot U \right] \hspace{1cm} j = 1, \ldots, n \hspace{1cm} (2-8)$$
2. The derivatives of nodal force vector to design variables - \( \frac{\partial \mathbf{F}}{\partial X_j} \):

For the element \( e \), the nodal forces, \( \mathbf{F}^e \), consist of two parts: \( \mathbf{F}^e_1 \) and \( \mathbf{F}^e_2 \):

\[
\mathbf{F}^e = \mathbf{F}^e_1 + \mathbf{F}^e_2
\]  

(2-9)

where \( \mathbf{F}^e_1 \) = the forces induced by displacement of the nodes, \( \mathbf{F}^e_1 = \mathbf{K}^e \mathbf{U}^e \); \( \mathbf{F}^e_2 \) = the nodal forces required to balance any distributed loads acting on the element.

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

\[
\frac{\partial \mathbf{F}^e}{\partial X_j} = \frac{\partial \mathbf{F}^e_1}{\partial X_j} + \frac{\partial \mathbf{F}^e_2}{\partial X_j} \quad j = 1, \ldots, n
\]  

(2-10)

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

\[
\frac{\partial \mathbf{F}^e_1}{\partial X_j} = \left( \frac{\partial \mathbf{K}^e}{\partial X_j} \right) \mathbf{U}^e + \frac{\partial \mathbf{U}^e}{\partial X_j} \quad j = 1, \ldots, n
\]  

(2-11)

and the second term on the right-hand side, \( \frac{\partial \mathbf{F}^e_2}{\partial X_j} \), representing partial derivative of \( \mathbf{F}^e_2 \) 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

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

Note: 1 kip = 4448 N; 1 ft = 0.3048 m
Table 2-2. Statistical Data of Loads

<table>
<thead>
<tr>
<th>Load Types</th>
<th>Dead Load $DL_i^a$</th>
<th>Wearing Surface WS</th>
<th>Lane Load $LNL$</th>
<th>Truck Load $TL$</th>
<th>Dynamic Load Allowance $IM$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias Factor</td>
<td>1.03</td>
<td>1.0</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td>COV</td>
<td>0.08</td>
<td>0.25</td>
<td>0.12</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>Distribution type</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Variables</th>
<th>Moment of Inertia $I_i^a$</th>
<th>Plastic Section Modulus $Z_x^a$</th>
<th>Modulus of Elasticity $E^a$</th>
<th>Yield Strength $F_y^b$</th>
<th>Shear Modulus of Elasticity $G^a$</th>
<th>Moment of Inertia $J_i^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias Factor</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.12</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>COV</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
<td>0.0866</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>Distribution type</td>
<td>Lognormal</td>
<td>Lognormal</td>
<td>Lognormal</td>
<td>Lognormal</td>
<td>Lognormal</td>
<td>Lognormal</td>
</tr>
</tbody>
</table>

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 $I$. 

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Final Report
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:

\[ \phi_f M_n \geq M_u \]  \hspace{1cm} (3-1)

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

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:

\[ M_u = \eta [1.25 \cdot M_{DL} + 1.5 \cdot M_{WS} + 1.75 \cdot mg \cdot M_{LL} (1.0 + IM)] \]  \hspace{1cm} (3-2)

in which \( \eta = \eta_D \cdot \eta_R \cdot \eta_I \geq 0.95 \), a load modifier; \( \eta_D \) = a factor relating to ductility; \( \eta_R \) = a factor relating to redundancy; \( \eta_I \) = 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.

\[ M_n = Z_f F_y \]  \hspace{1cm} (3-3)

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

\[ DF = 0.15 + \left( \frac{S}{3} \right)^{0.6} \left( \frac{S}{L} \right)^{0.2} \]  \hspace{1cm} (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:

$$\phi f M_n \geq M_u$$

(3-5)

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

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:

\[
M_u = \eta \left[ 1.25 \cdot M_{DL} + 1.5 \cdot M_{WS} + 1.75 \cdot mg \cdot M_{LL} (10 + IM) \right]
\]  

(3-6)

in which \( \eta = \eta_D \cdot \eta_R \cdot \eta_I \geq 0.95 \), a load modifier; \( \eta_D \) = a factor relating to ductility; \( \eta_R \) = a factor relating to redundancy; \( \eta_I \) = 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:

\[
DF = 0.15 + \left( \frac{S}{3} \right)^{0.6} \left( \frac{S}{L} \right)^{0.2}
\]  

(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: \( t_f = 1.5 \cdot t_w \), \( b_f = 15 \cdot t_w \), and \( h = 40 \cdot t_w \).
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: $P_t + P_w \geq P_c + P_s + P_{rb} + P_{rt}$

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

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

**CASE II:**

PNA in top flange

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

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

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

**CASE III:**

PNA in slab, below $P_{rb}$

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

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

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

PNA in slab, at \( P_{rb} \)

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

\[ \bar{Y} = C_{rb} \]

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

CASE V:

PNA in slab, above \( P_{rb} \)

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

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

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

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 \( M_n \) (\( \phi_f = 1.0 \)) and \( M_n \) are controlled less than \( \pm 0.03 \).
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:

\[ \phi_f V_n \geq V_u \] (3-8)

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

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:

\[
V_a = \eta \left[ 1.25 \cdot V_{DL} + 1.5 \cdot V_{WS} + 1.75 \cdot mg \cdot V_{LL} (1.0 + IM) \right]
\]

(3-9)

in which \( \eta = \eta_D \cdot \eta_R \cdot \eta_I \geq 0.95 \), a load modifier; \( \eta_D \) = a factor relating to ductility; \( \eta_R \) = a factor relating to redundancy; \( \eta_I \) = 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:

\[
DF = 0.4 + \left( \frac{S}{6} \right) - \left( \frac{S}{25} \right)^2
\]

(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

\[
\frac{D}{t_w} \leq 2.46 \sqrt[3]{\frac{E}{F_{yw}}}
\]

\[
V_n = V_p = 0.58 F_{yw} D t_w
\]

2. Web slenderness

\[
\frac{D}{t_w} \leq 3.07 \sqrt[3]{\frac{E}{F_{yw}}}
\]

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

3. Web slenderness

\[
\frac{D}{t_w} > 3.07 \sqrt[3]{\frac{E}{F_{yw}}}
\]

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

Table D-3 in Appendix D shows a set of design examples. The relative errors between $V_n$ ($\phi = 1.0$) and $V_n$ are generally controlled less than $\pm 0.03$. 
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:

\[ \delta^e = \{\delta_i, \delta_j\}^T \]  \hspace{1cm} (4-1)

where \( \delta_i = \{w_i, \theta_x, \theta_y\}^T \) = the displacement vector of the left joint; \( \delta_j = \{w_j, \theta_x, \theta_y\}^T \) = the displacement vector of the right joint; \( w \) = vertical displacement in the \( z \)-direction, and \( \theta_x \) and \( \theta_y \) = 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 (0.203 m)
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>
<thead>
<tr>
<th>Load type</th>
<th>Truck</th>
<th>Lane Load</th>
<th>Self weight&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Future surface&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computed&lt;sup&gt;a&lt;/sup&gt;</td>
<td>798.9</td>
<td>287.53</td>
<td>2234.67</td>
<td>589.56</td>
</tr>
<tr>
<td>Theoretical</td>
<td>800</td>
<td>288</td>
<td>2238.41</td>
<td>590.56</td>
</tr>
<tr>
<td>Error (%)</td>
<td>0.14</td>
<td>0.16</td>
<td>0.17</td>
<td>0.17</td>
</tr>
</tbody>
</table>

**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 $\gamma_{ws} = 2.846e - 4kips / in^3$. 
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 $X^*$. From the results obtained by the two methods shown in Tables 5-3 and 5-4, it is seen that (1) the reliability indices, $\beta$, by SFEM are slightly higher than those by AFOSM; (2) the difference in $\beta$ increases with span length; and (3) the results at design point $X^*$ 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

<table>
<thead>
<tr>
<th>Cases</th>
<th>Exterior $(\eta = 0.95)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span length $L$ (ft)</td>
<td>Girder Spacing $S$ (ft)</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>60</td>
<td>6</td>
</tr>
<tr>
<td>90</td>
<td>6</td>
</tr>
</tbody>
</table>

Note:

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

b. 1 ft = 0.3048 m

### Table 5-3. Reliability Index $\beta$

<table>
<thead>
<tr>
<th>Cases</th>
<th>SFEM</th>
<th>AFOSM With exact adjustment</th>
<th>AFOSM Without adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L$ (ft)</td>
<td>$S$ (ft)</td>
<td>$\beta$</td>
<td>Iteration No.</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
<td>3.043</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>6</td>
<td>3.475</td>
<td>9</td>
</tr>
<tr>
<td>90</td>
<td>6</td>
<td>3.693</td>
<td>14</td>
</tr>
</tbody>
</table>

Note:

a. difference = $\beta_{SFEM} - \beta_{AFOSM}$; and

b. 1 ft = 0.3048 m
The gradient, $\alpha^*_i$, 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 $\beta$ 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 $\beta$. 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 $\beta$ 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*

<table>
<thead>
<tr>
<th>Variable</th>
<th>L = 30ft, S = 6ft</th>
<th>L = 60ft, S = 6ft</th>
<th>L = 90ft, S = 6ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SFEM</td>
<td>AFORM</td>
<td>SFEM</td>
</tr>
<tr>
<td>DL</td>
<td>9.166E-02</td>
<td>9.267E-02</td>
<td>1.037E-01</td>
</tr>
<tr>
<td>TL</td>
<td>1.046E+02</td>
<td>1.065E+02</td>
<td>1.045E+02</td>
</tr>
<tr>
<td>Z_x</td>
<td>1.848E+02</td>
<td>1.843E+02</td>
<td>6.614E+02</td>
</tr>
<tr>
<td>F_y</td>
<td>3.290E+01</td>
<td>3.354E+01</td>
<td>3.167E+01</td>
</tr>
</tbody>
</table>

Note: 1 ft = 0.3048 m

Table 5-5. Sensitivities of β to Basic Variables

<table>
<thead>
<tr>
<th>Order No.</th>
<th>L = 30ft, S = 6ft</th>
<th>L = 60ft, S = 6ft</th>
<th>L = 90ft, S = 6ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>α_i</td>
<td>Variable</td>
<td>α_i</td>
</tr>
<tr>
<td>1</td>
<td>F_y</td>
<td>-0.759</td>
<td>F_y</td>
</tr>
<tr>
<td>2</td>
<td>TL</td>
<td>0.481</td>
<td>TL</td>
</tr>
<tr>
<td>3</td>
<td>Z_x</td>
<td>-0.380</td>
<td>Z_x</td>
</tr>
<tr>
<td>4</td>
<td>IM</td>
<td>0.157</td>
<td>IM</td>
</tr>
<tr>
<td>5</td>
<td>WS</td>
<td>0.088</td>
<td>WS</td>
</tr>
<tr>
<td>6</td>
<td>DL_1</td>
<td>0.084</td>
<td>LNL</td>
</tr>
<tr>
<td>7</td>
<td>LNL</td>
<td>0.082</td>
<td>DL_1</td>
</tr>
<tr>
<td>8</td>
<td>DL_2</td>
<td>0.035</td>
<td>DL_2</td>
</tr>
<tr>
<td>9</td>
<td>E</td>
<td>-0.015</td>
<td>I_1</td>
</tr>
</tbody>
</table>

Note: 1 ft = 0.3048 m
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 $\beta$ and the ratio of discrepancy in total moment on the controlling girder. The difference in $\beta$ is defined as $(\beta_{\text{SFEM}} - \beta_{\text{AFOSM}})$. The ratio of discrepancy in total moment is defined as $(M_{\text{SFEM}} - M_{\text{AFOSM}})/M_{\text{AFOSM}}$. 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 $\beta$. This study further quantifies the sensitivity of reliability index to laterally distributed moment.
Table 5-6. Design Examples

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

Note:

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

b. 1 ft = 0.3048 m
Fig. 5-3. Relationship between the Difference in $\beta$ and Ratio of Discrepancy in Total Moment

\[ y = -9.3056x - 0.0215 \]
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: $\eta = 0.95, 1.0, 1.05,$ and $1.1$. According to AASHTO LRFD Specifications (1998) commentary, the corresponding target reliability index, $\beta_T$, 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 $\eta = 0.90$ are also shown in Fig. 5-5. The extensive SFEM indicates that a load modifier, $\eta$, 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: $\eta = 0.95, 1.0, 1.05, \text{ and } 1.1$. According to AASHTO *LRFD* (1998) commentary, the corresponding target reliability index, $\beta_T$, 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 $\eta = 0.90$ are also shown in Fig. 5-7. The extensive SFEM indicates that a load modifier, $\eta$, which is 0.05 less than the specified value, achieves the same target safety level.
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: \( \eta = 0.95, 1.0, 1.05, \) and \( 1.1 \). According to AASHTO LRFD (1998) commentary, the corresponding target reliability index, \( \beta_T \), 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 \( \eta = 0.90 \) are also shown in Fig. 5-9. The results in Fig. 5-9 indicate that a load modifier, \( \eta \), 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 1 for Shear (AFOSM)
Fig. 5.9. Reliability Indices for Strength Limit 1 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, \( \beta \), 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, \( \beta \), 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, $\eta$, 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, $\eta$, 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, $\eta$, should be used for the design of steel girder bridges using Strength I limit state for shear to achieve the target safety level.
REFERENCES


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)
(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.
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386.4, 1.E-3

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NKD  NKS  NTN  NFV  MCAR  NCAR  ISR  NPTS  IPLOT
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SL  SSL  VO  ST  STP  ZAA  ZAB
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**FV(I,J)**
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  .000  .000

**DGX**
.100E-01  .720E+02
** READ DISTRIBUTION DATA OF VARIABLES **
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  2  1.050000  8.000000E-02
  3  1.050000  8.000000E-02
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  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
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 15 1.120000  8.660000E-02
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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

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Note: Error = ((M_N - M_U)/M_U) x 100
**TABLE D-2. COMPOSITE STEEL BRIDGES DESIGNED BY STRENGTH LIMIT I FOR FLEXURE**

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Note: Error = ((\(M_n-\bar{M}_n\))/\(\bar{M}_n\)) x 100
TABLE D-3. STEEL BRIDGES DESIGNED BY STRENGTH LIMIT I FOR SHEAR

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

COMPUTER PROGRAMS
RELI.FOR

This program is to perform reliability analysis.
This program is to perform reliability analysis. 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 /SSL/ 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

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NAME1=NAME0
NAME2=NAME0
CALL FNAME(DAT,'.DAT')
CALL FNAME(OUT,'.OUT')
NRL=50
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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',3X,'NQG',3X,'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 + NNB*LA
N09 = N08 + NNB*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, IPILOT, 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, IPILOT, 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
J01 = NKD*2 + 1
J02 = J01
K01 = 10 + 1
K02 = K01 + 10
K03 = K02 + NFV*2
K04 = K03 + NFV
K05 = K04 + 2*N
K06 = K05 + 10*NP
K07 = K06 + NP*3
K08 = K07 + 10
K09 = K08 + 2*N
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. 180000) STOP3

CALL QQSOLV (NTN2, NFV, M, IZ(M04), IZ(M03), NJZ, 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, NFV, LBM, ZS(K17), LGN4, ZS(K18), ZS(K19),
   / IZ(M02), NG, Z(N02), LGNWS, ZS(K20))
CALL QQSOLV1 (NFV, M, IZ(M04), IZ(M03), NJZ, Z(N04), NEG, Z(N03),
   / IZ(1), IZ(M01), N, Z(1), Z(N01), NN, IZ(M09), NNB, IZ(M10), ZSG(I01),
SUBROUTINE FNAME(C,CE)
CHARACTER*1 C(12),CE(4)
K=0
DO 10 I=1,8
   IF(C(I).EQ.' ') THEN
      K=I
   ENDIF
10     CONTINUE
15     IF(K.EQ.0) K=9
20     DO 30 I=K,12
30     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
5      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
QN(I)=QN(I)*TRAN2
DO 403 I=1, NEG
EG(I,1)=EG(I,1)*TRAN3
EG(I,2)=EG(I,2)*TRAN3
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,*) (NQQ(I), GQ(I), I=1, NQG)
WRITE (4, 316) (NQQ(I), GQ(I), I=1, NQG)
DO 405 I=1, NQG
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
   11=I+1
   DO 20 J=I+1
   20 ES(I,J)=ES(J,I)
RETURN
END

SUBROUTINE DYK1(K,M,NEG,NIJ,NM,NS,EG,GJI,ES,DL,IBVC,I3,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.11(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.11(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(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.13) 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
30    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
60     CONTINUE

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,I3
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 IOJ0(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),
SUBROUTINE ASSEM2(N,M,NIJ,NNB,NN,LA,X,Y,GJI,IHL,IHR,LV,LO,SK,NEG,NM,NS,EAL)
DIMENSION X(N),Y(N),GJI(NIJ,3),IHL(M),IHR(M),LV(NNB),LO(NN),SK(LA),NM(M),NS(M),EAL(NEG,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 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
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)
WRITE(3,326)((ITEMP,BIAS(I),COV(I),I=1,NBV)
WRITE(4,326)
WRITE(3,324)
DO 26 I=1,NBV
WRITE(3,326)
WRITE(4,326)
WRITE(3,324)
DO 27 I=1,NBV
27 VMV(I)=0.0
VMV(8)=0.33
VMV(12)=2064.0
VMV(15)=40.32
SUBROUTINE SETLOAD(NKS,LM,NFW,IVD,QCA)
DIMENSION QCA(IVD,NFW)
NKS=NKS
NO=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,SMAK,STIME,
2  DATA, QCA, IVD, NFW, LB, T, LGN4, QL, QD1, QQ, NG, QW, 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), SMAK(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(LB), QL(LGN4,5), QD1(M,4),
4  QQ(M), QN(NG), QWS(LGNWS,4)
COMMON /SSLN/ SL, NKS
COMMON /TIME1/T, ST, STP, VO
COMMON /S000/16, SD, SY
COMMON /TOA/ZAA,ZAB,NTN1,NCAR,IPLOT,MCAR,MTY,MLX
COMMON /DGXT/BGX(20)
COMMON /BIY/IX(20),BY(20),AY(20)
COMMON /BYL/YL(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,SMAK)
CALL CLEAR2(NF,4,STIME)
IPC=1
NTC=STP/ST
VO1=V0*17.6
**TT=DATAL/V01**

**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**

**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)**

**DO 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**

**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**

**ENDIF**

**ELSE**

**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**

**ELSE**

**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**

**ENDIF**

**ENDIF**
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)
IGL=(IYL(2)-IYL(1))+1
LGN=I6*IGL
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, NFV, 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, Q, 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 LB, Q, LD, QD1, NG, QN, LGNWS, QWS, SM, 3 DP1, NB, SK1, DUDA, DKU, T1, N1, N1, AT1, DFD, 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(NB, LA), DP1(NB, NNB),
4 SK1(LA), DUDA(NB, NNB), DKU(NNB), NM(M), NS(M), TT1(N1, N1),
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
   DP1(I,J)=DKU(J)
65      CONTINUE
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
   DP1(I,J)=DKU(J)
80      CONTINUE
ENDIF
IF(I.EQ.4) THEN
   VMV(I)=QN(5)
   CALL CLEAR1(NNB, DKU)
   DO 100 J=1, NNB
      DP1(I,J)=DKU(J)
100     CONTINUE
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
   DP1(I,J)=DKU(J)
130     CONTINUE
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
   DP1(I,J)=DKU(J)
150     CONTINUE
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
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,ALOADDLA)
180     CONTINUE
DO 190 J=1,NNB
DP1(I,J)=DKU(J)
ENDIF
IF (I.GT.8) THEN
DO 110 J=1,NNB
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
SM(I,J)=0.0
ENDIF
IF (I.EQ.12) THEN
DO 420 J=1,LA
SM(I,J)=0.0
ENDIF
IF (I.EQ.15) THEN
DO 430 J=1,LA
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

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
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
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
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
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
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
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
SM(I,J)=SK1(J)
ENDIF
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 IOJO(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,NS,EG,GJI,KE,DL)
DO 240 I=1,NL1
NVAR=I
CALL DYK1(ITEE,M,NEG,NIJ,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)
         almada=alog(vmv(nvar)/sqrt(1.0+cov(nvar)**2))
         akexi=sqrt(alog(1.0+cov(nvar)**2))
         yy(i)=(alog(xx(i))-almada)/akexi
      endif
920 continue
   do 940 i=1,nl1
      uu(i)=yy(i)
940 continue
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
  DGDU(I)=DGDX(I)
1255    CONTINUE
AMOL=0.0
DO 950 I=1,NL1
  AMOL=AMOL+DGDU(I)**2
950    CONTINUE
AMOL=SQRT(AMOL)
DO 955 I=1,NL1
  ALFA1(I)=-DGDU(I)/AMOL
955    CONTINUE
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
  BETA=BETA+UU(I)**2
975    BETA=SQRT(BETA)
DO 980 I=1,NL1
  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
  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
  DP(J)=DKU(J)
ENDIF
IF(I.EQ.5) THEN
  DO 1120 J=1,I3
    IF(J.LE.16.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
    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(J,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
    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
    DP(J)=DKU(J)
  ENDIF
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 TRNSFS(6,6,AL,ALT)
IND=1
ALOADL=Q(J,2)/VMV(NVAR-1)*XX(NVAR-1)
ALOADL=ALOADL/(1.0+VMV(8))
ALOADL=ALOADL*XX(NVAR)
XQ=Q(J,4)
CALL FD1(L1,NS,GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,XQ,IND,
1 ALOADL)
1180 CONTINUE
DO 1190 J=1,NNB
1190 DP(J)=DKU(J)
ENDIF
1200 CONTINUE
CALL ASSEM2(N,M,NVAR-1,NN,LA,X,Y,
1 GJI,IHL,IHR,LO,DKU,M,NN,NNB,NIJ,XX(NVAR),
2 QMNQ,IND,
3 ALOADL)
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/IX(20),BY(20),AY(20)
COMMON /XAYA/XA,XY,AY,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
Q(K5,2)=0.0
5 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=SS-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) GOTO 20
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=SS-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(1,2))
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

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)
CONTINUE
DO 100 I=1,LGN4
LI=QL(I,1)
IF (LI.EQ.0) GOTO 100
CALL CHI(LI,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(LI,NEJF,EJF,IHL,IHR,LO,DP,M,NN,NNB,NJF,QL(I,4),IND,
1          QL(I,2))
CONTINUE
DO 20 I=1,M
II=NQQ(I)
DO 10 I=1,M
II=NQQ(I)
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),
                  X(N),Y(N),ALL(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/YL(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
SUBROUTINE SUPLL(LGN4, ICOUNT, MTY, MLX, IXM, QL, N, X, Y, M, IHL, IHR)
DIMENSION QL(LGN4,5), X(N), Y(N), IHL(M), IHR(M)
COMMON /BIYL/ YL(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, M, IHL, IHR)
8 CONTINUE

RETURN
END

SUBROUTINE SUPLWS(LGNWS, MTY, MLX, IXM, QWS, N, Y)
DIMENSION QWS(LGNWS, 4), Y(N)
COMMON /BIYL/ YL(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, M, IHL, IHR)
DIMENSION QL(LGN4,5), X(N), Y(N), IHL(M), IHR(M)
COMMON /BIYL/ YL(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
\[ K_6 = 2 \cdot (K_4 - 1) + 1 \]

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
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,NEAL,NJF,EJF,NEA,EAL,NN,LO,NNB,DP,QMNQ,QD1,QWS)
REAL MNQ,MA,MB
DIMENSION IHL(M),IHR(M),DP(NNB),X(N),Y(N),NEJF(M),NEAL(M),EJF(NJF,3),EAL(NEA,2),FN(NF,2),LO(NN),QMNQ(NF,3),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,LO,NNB)
1 N,NEJF,NEA,EAL,NN)
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,NN,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,NN,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,NN,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))
CONTINUE

DO 110 J=1,3
QMNQ(I,J)=MNQ(J)
110 CONTINUE
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,N,DP,X,Y,LO,FN,M,NN,
1 N,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)
SUBROUTINE INFO1A(NEG, KNF, K, IHL, IHR, DP, X, Y, LO, FN,
               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),
               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 MTTMULT(6, 6, 1, AL, R2, R1)
CALL MTTMULT(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, 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
Q2 = G*(1.0 + XP/XQ) * QP/2.0
B2 = -G*QP*QP*(2.0 + XP/XQ)/6.0
GOTO 70

B2 = -G

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)
, 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 MMMULT(6, 6, 1, ALT, FV1, FV)
CALL I0J0(K, 3, M, IHL, IHR, I0, J0)
DO 10 I = 1, 3
I1 = I0 + I
I2 = LO(I1)
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)
, 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*I)/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*I)/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
30    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
10    SOLSHV(I,J)=CT(J)
20      CONTINUE
RETURN
END

SUBROUTINE CLW(CL,DL,X1)
DIMENSION CL(3,6)
XL2 = X1/DL/DL*X1
XL3 = XL2*X1/DL
\[
W1 = 1 - 3 \cdot XL2 + 2 \cdot XL3 \\
W2 = X1 - 2 \cdot XL2 \cdot DL + X1 \cdot XL2 \\
W3 = 3 \cdot XL2 - 2 \cdot XL3 \\
W4 = -XL2 \cdot DL + XL3 \cdot DL \\
W5 = 1 - X1 / DL \\
W6 = X1 / DL \\
\]

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 = 0.088519

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

DO 403 I = 1, IVDEG

403 AFY(I) = AFY(I) * TRAN3

DO 404 I = 1, IVDEG

D(I) = D(I) * TRAN1

404 V(I) = V(I) * TRAN1

IF (IV.LT.2) THEN

DO 405 I = 4, 8, 2

AM(I) = AM(I) * TRAN2

405 AM(I+1) = AM(I+1) * TRAN4

DO 406 I = 2, 3

406 AM(I) = AM(I) * TRAN4

AM(I) = AM(I) * TRAN2
ELSE

DO 406 I = 7, 17, 2

AM(I) = AM(I) * TRAN2
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=0.0
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
20 CONTINUE
DO 60 J=1,N
VI=V(I)
B(I)=B(I)-R(VJ)*B(J)
60 CONTINUE
N1=N-1
DO 100 II=1,N1
I=N-II
K=N
100 CONTINUE
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.LR) NB=N
DO 40 J=I,NB
LR=NA(J)-J+I
IF(J-1)40,30,35
30    S=S+R(LR)*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

This is for the calculation of ultimate moment at midspan for exterior girder.
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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.
C*** NONCOMP-MI.FOR
C This is for the calculation of ultimate moment at midspan for interior 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
wl=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=wl*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.
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.
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(2,*) ' span = ',span,' S = ',S

tslab=8.0/12.0
Fy=36.0
wslab=0.15*tslab*S
wl=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)
amdl=wl*span**2/8.0
amdl=amdl*12.0
amd2=wws*span**2/8.0
amd2=amd2*12.0
amu=fai*(1.25*amdl+1.5*amd2+gm*amdesign)
write(2,*) '*** The following is results = ***'
write(2,*) ' Mu = ',amu,'in-kips   '
stop
end