SHEAR DISTIBUTION IN CURVED COMPOSITE MULTIPLE-BOX GIRDER BRIDGES

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ABSTRACT

Horizontally curved composite box girder bridges are used in interchanges of modern highway systems. This type of structure has created design problems in estimating its live load. North Americans Codes of Practice recommends some analytical methods for design of such curved bridges. However, practical requirements arising during the design process necessitate a simple design method. On the basis of the literature review, such load distribution factors due to CHBDC truck loading are as yet unavailable. An extensive parametric study, using the finite-element modeling, was conducted, in which 225 prototype bridges were analyzed to evaluate their shear distribution factors when subjected to CHBDC truck loading conditions. The parameters considered were number of steel boxes, number of lanes, span length, and span-to-radius curvature ratio. Based of the data generated, empirical expressions for shear distribution factors were deduced. An alternative to the developed expressions was introduced using the Artificial Neural Network (ANN) application.

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TO MY FAMILY

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NOTATIONS

A	bridge width
[A]	transformation matrix from local to global coordinates
ANN	artificial neural network
B	box width
[B]	strain-displacement matrix
C	steel top flange width
C_f	correction factor as per CHBDC
D	total depth of the steel boxes
[D]	constitutive matrix or elasticity matrix
D_X	total bending stiffness divided by the width of the bridge as per CHBDC
D_{XY}	total torsional stiffness of the cross section divided by the width of the bridge as per CHBDC
E	modulus of Elasticity
F	total depth of composite bridge a width dimension that characterizes load distribution as per CHBDC
F_m	an amplification factor to account for the transverse variation in maximum longitudinal moment intensity as per CHBDC
F_V	an amplification factor to account for the transverse variation in maximum longitudinal vertical shear intensity as per CHBDC
I	moment of inertia
[K]	global stiffness matrix
[K']	element stiffness matrix
L	centre line span of simply supported bridge

M_g bending moment in box girder as per CHBDC

$M_{g\,avg}$ the average moment per box girder as per CHBDC

M_T maximum moment per design lane at the point of span under consideration as per CHBDC

n number of design lanes as per CHBDC

N number of box girders as per CHBDC

N_b number of boxes as per Johanston and Mattock

N_L number of lanes as per Johanston and Mattock

[P] applied loads vector at the nodes

R radius of curvature of center span of any curved bridge

R_L the modification factor for multilane loading as per CHBDC

RMS root mean square error

S center to center box girder spacing

t_1 thickness of steel top flange

t_2 thickness of steel web

t_3 thickness of steel bottom flange

t_4 thickness of concrete deck slab

[U] displacement vector at the nodes

V maximum shear force induced at the girder section close to the support of a straight simply supported idealized girder

V_g longitudinal vertical shear per box girder as per CHBDC

$V_{g\,avg}$ the average shear per box girder as per CHBDC

V_{max} maximum shear force induced at the girder section close to the support, obtained from the finite elements analysis

V_T	the maximum shear per lane at the point of the span under consideration as per CHBDC
W	weight vector
W1	outer web of outer box girder in any bridge model
W2	inner web of outer box girder in any bridge model
W3	outer web of inner box girder in any bridge model
W4	inner web of inner box girder in any bridge model
W_C	bridge width as per CHBDC roadway width between curbs in ft as per Johanston and Mattock
W_e	width of design lane in meters, as per CHBDC
W_E	the external virtual work
W_L	live load distribution factor for each straight box-girder as per Johanston and Mattock
W_{LC}	curved girder load distribution factor for moment as per Heins
W_I	the internal virtual work
X	input vector
α	the generalized coordinates
θ	threshold
$[\varepsilon]$	the strain matrix
$f(v)$	activation function
φ	rotation (degree of freedom)
Φ	displacement function
υ	poisson's ratio
σ	standard deviation

CHAPTER I

INTRODUCTION

1.1 General

The construction of modern highway systems and interchanges usually requires horizontally curved bridges because of some geometric restrictions of alignments and site conditions, specially, in urban areas, and densely populated cities.

Economically, box girder bridges are commonly used and highly recommended in such kind of construction, as shown in Figure 1.1, because of their light dead weight, strong flexural and torsional rigidity. In addition to these advantages, the surface inside the box girder bridges is closed and not subject to the outside environment, which is more helpful in the durability consideration of the lifetime of the structure. Moreover, these boxes can hide the required utilities to give an aesthetically pleasing scene of the bridge itself.

Box girder bridges have different methods in construction; they may be made of reinforced concrete, prestressed concrete, steel, steel box girders with orthotropic decks, or composite concrete deck-steel girders. Concrete box girder bridges may be constructed using pre-cast concrete units, which are manufactured in a production plant and then delivered to the construction site, or cast-in-place concrete, which is formed, and poured using falsework or launching frame. The prestressed concrete box girder bridges may be made using pre-tensioning or post-tensioning. When the strands are tensioned before pouring the concrete, the system is called pre-tensioning, and when they are tensioned after the concrete is poured and reaches a determined strength, the system is called post-tensioning. Tendons in concrete are usually of high tensile steel, or advanced composite-fiber. Steel box girders are usually constructed as cantilever segments. They are fabricated and lifted into final position by climbing jacks, then connected together. The decks could be of reinforced concrete or steel. A typical orthotropic deck is formed by welding longitudinal ribs to the transverse floor, which, is being supported by the main box girders. A deck plate is then welded to each component.

Curved box girder bridge is shaped by connecting curved top and bottom flange plates with cylindrical webs. Figure 1.1 shows view of tow-box girders during the construction of bridge 606 of Greater Toronto Airport Authority (GTAA). The number of boxes may vary to suit the design case and the number of traffic lanes. Curved steel plate girders may be fabricated by two different methods. One method is to prefabricate straight webs followed by either cold-bending or heat-curving to achieve the required curvature. The second method is to cut the curved flanges from straight plates and welding them to the webs, which are curved. Heat curving is typically accomplished by fabricating a straight girder in a conventional manner and then applying thermal stresses and yielding in the top and bottom flanges edges. If the temperature is high enough, the heated edges will yield resulting in residual stresses and straining that remains after the flanges cool. Cold binding may be performed by using either a press or a three-roll bender. Good control should be achieved to prevent buckling or twisting the webs. Exterior and Interior intermediate diaphragms, as shown in Figure 1.2, are used to stabilize the girders during construction.

1.2 The Problem

Design engineers usually prefer to use mathematical formulae or charts in design codes, especially, when dealing with bridges. The Canadian Highway Bridge Design Code (CHBDC 2000), specifies simple expressions for the moment and shear distribution factors for straight composite box-girder bridges and provides a specific criterion when a horizontally curved bridge is treated as straight in the structural analysis process. These load distribution expressions showed to be highly conservative in some cases and they were developed for bridges with number of boxes equal to number of lanes. Also, load distribution factors for such curved bridge are as yet unavailable for CHBDC truck loading. When subjected to moving vehicles, this type of bridges built on curved alignment, creates new design problems for engineers in estimating transverse load distribution between boxes. As such, problems arise when estimating shear forces acting on the curved resulting from different loading conditions as well as curvature effect. As a result, a practical-designed-oriented parametric study needs to be conducted to establish a database of the shear distribution factors of both straight and curved box-girder bridges when subjected to CHBDC truck loading. Then, reliable expressions for shear distribution factors can be developed for a wide range of bridge configurations.

1.3 The Objectives

The main objectives of this research work can be stated as follows:

1- Construct three-dimensional finite-element models to simulate the behavior of straight and curved composite multiple-box girder bridges, when subjected to CHBDC truck loading; from which the shear distribution among girders can be obtained.

2- Develop expressions for the shear distribution factors for both straight and curved bridges based on the data generated from the parametric study.

3- Apply the Artificial Neural Network (ANN) methodology in simulating the shear distribution factor from the database resulted from the prototypes modeling, as an alternative to the developed equations.

1.4 The Scope

The scope of this study includes:

1- A literature review on previous research work and codes of practice related to the structural behavior and load distribution of straight and curved box girder bridges;

2- Development of the finite element modeling for this type of bridges using the structural analysis program "ABAQUS";

3- A computer program written using C++ programming language to prepare the required input data for ABAQUS file to simplify the complicated geometry inputs and the locations of the truck wheel loads acting on the bridge deck slab;

4- A parametric study on different key parameters governing the shear force distribution among girders due to the CHBDC moving truck for both ultimate and fatigue limit states;

5- A comparison between the available CHBDC code equations and the results obtained from finite element analysis results for straight bridges to stand on the accuracy of the former;

6- Development of a mathematical computational model using the Artificial Neural Network to obtain shear forces for this type of bridges using the results obtained from the parametric study as a pre-processor data inputs.

1.5 The Contents and Arrangement of the Thesis

The thesis presents a literature review of previous research on box girder bridges in Chapter 2. The finite element modeling for different bridge components due to the linear static analysis is described in Chapter 3. Prototype bridges and the loading cases are provided in chapter 4. The results of the parametric study, the comparison between the obtained results and the code criterion, and the developed shear distribution factors are discussed in Chapter 5. The results of the Artificial Neural Network simulation are discussed in Chapter 6. The summary, conclusions, and recommendations for future research are presented in Chapter 7.

CHAPTER II

LITERATURE REVIEW

2.1 General

Horizontally curved composite box girder bridges gained the attention of some researchers in order to simplify the structural analysis process by developing new software programs to satisfy the design purposes. Other researchers tried to simplify the analysis by making mathematical formulas or useful charts to be used in the bridge design codes. The second approach requires a lot of effort and experience in verifying different models because of the complex geometry, the choice of the appropriate cross sections of the structural elements, the connection between the concrete deck and the steel girders, the restriction of the supports, and the different loading conditions. However, it leads to a practical design process for bridge engineers. The literature review presented in the following sections pertains to the available methods of analysis and available codes of practice for the design of straight and curved box-girder bridges. However, an extension state-of-the-art review of box girder design and analysis was presented elsewhere (88, 89).

2.2 Structural Elastic Analysis of Box Girder Bridges

Structural analysis is usually performed in a simplified manner by means of assumptions that describe the relationship between the behaviors of each element in the integrated structure. The combined response of these single elements is assumed to represent the response of the overall structure. The accuracy of such solutions depends on the validity of the assumptions made. The Canadian Highway Bridge Design Code (16) has recommended few methods of analysis for only straight box girder bridges. These methods include, Orthotropic Plate Theory, Grillage Analogy, Folded Plate, Finite-Strip, and Finite-Element methods. Several authors have applied these methods along with the thin-walled beam theory to analyze straight, and curved box girder bridges. Scordelis (84) referenced a large number of computer programs developed at the University of California, Berkely for the analysis of concrete box-girder bridges. Kirstek (59) has discussed the theoretical aspect of some of these analytical methods. Maisel (63), and, Roll and Aneja (82) have presented a comparative study of the available methods for the analysis of straight prismatic single-cell box girders. The following sections discuss these different methods and their limitations.

2.2.1 Orthotropic Plate Theory Method

In the equivalent orthotropic plate theory method, the stiffness of the diaphragms is distributed over the girder length, and the stiffness of the flanges and girders are lumped into an orthotropic plate of equivalent stiffness. However, the estimation of the flexural and torsional stiffness is considered to be a major problem in this method. The CHBDC code (16) has recommended using this method for the analysis of only straight box girder bridges of multi-spine cross section. Cheung (24) suggested this method for multiple-girder curved bridges with high torsional rigidity.

2.2.2 Grillage Analogy Method

Grillage analysis has been applied to multiple cell boxes with vertical and sloping webs and voided slabs. Hambly and Pennells (42) have applied this method to cellular bridge decks. In this method, the bridge deck is idealized as a grid assembly. The continuous curved prototype bridge is modeled as a system of discrete curved longitudinal members intersecting orthogonally with transverse grillage members. As a result of the fall-off in stress at points remote from webs due to shear lag, slab width is replaced by a reduced effective width over which the stress is assumed to be uniform. The equivalent stiffnesses of the continuum are lumped orthogonally along the grillage members.

One problem arises when using the grillage analogy method in determining the effective width of the slab to include the shear lag effects. Another difficulty of this method lies in estimating the torsional stiffness of the closed cells. Approximate technique may be used to model the torsional stiffness of closed cell by an equivalent I-beam torsional stiffness. This technique established by Evans and Shanmugam (34) provides satisfactory results.

2.2.3 Folded Plate Method

A multiple-box girder bridges can be modeled as a folded system which consists of longitudinal plate elements interconnected at joints along their longitudinal edges and simply-supported at both ends by diaphragms which are infinitely stiff in their planes and perfectly flexible perpendicular to these planes. Any arbitrary longitudinal joint loading can be resolved into harmonic component of the loading using Fourier series. Then, a direct stiffness analysis can be performed for each component. Originally, the folded plate method is limited to simply supported box-girder bridges and no intermediate diaphragms are assumed. This method produces the exact solutions for linear elastic analysis of a box girder bridges, within the scope of assumptions of the elasticity theory.

The University of California, Berkeley, was first to use this method to develop the computer program MULTPL (84, 85, 30) for simply-support straight single span bridges. Later, the method was extended to continuous span bridges with interior diaphragms (62). The method has also been applied to cellular structures by AL Rifaie and Evans (2), and Meyer and Scordelis (65). The Canadian Highway Bridge Design Code (16) restricted the use of this method to bridges with support conditions closely equivalent to line support. One of the major shortcomings of the folded plate method is the large computational effort required and the complexity.

2.2.4 Finite Strip Method

Finite strip theory discretizes the bridge into a longitudinal number of strips, running from one end support to the other. The strips are connected along their longitudinal edges by nodal lines and the stiffness matrix is then calculated for each strip based upon a displacement expansion in terms of Fourier series, rather than on the theory of elasticity. Thus, the solution converges to the exact theory of the elasticity only with mesh refinement. Similar to the folded plate method, in the finite strip method the direct stiffness harmonic analysis is performed. The finite element method is basically different from the strip method in terms of the assumed displacement interpolation functions. Unlike the finite element method, the displacement functions for the corresponding finite strip are assumed as combination of harmonics varying longitudinally and polynomials varying in the transverse direction. Therefore, the finite strip method is considered as a transition between the folded plate method and the finite element method.

The method is well suited and a powerful technique to the analysis of orthotropic and circularly curved plate elements for which direct application of the theory of elasticity becomes too involved. In 1971 Cheung and Cheung (22) applied the finite strip method for curved box girder bridges. In 1974, Kabir and Scordelis (56) developed a finite strip computer program to analyze curved continuous-span cellular bridges, with interior radial diaphragms, on supporting planar frame bents. In 1978, the method was adopted by Cheung and Chan (21) to determine the effective width of the compression flange of straight multi-spine and multi-cell box girder bridges. In 1984, Cheung (20) used a numerical technique based on the finite strip method and the force method for the analysis of continuous curved box girder bridges. In 1988, Li et al. (61) presented the application of spline finite strip method to the elasto-static analysis of circular and non-circular multi-cell box girder bridges. In 1989, Ho et al. (49) used the finite strip to analyze three different types of simply supported highway bridges, slab-on-girder, two-cell box girder, and rectangular voided slab bridges.

The basic advantage of the finite strip method is that it requires small computer storage and relatively little computation time. Although the finite strip method has broader applicability compared to folded plate method, the method is still limited to simply supported prismatic structures. For multi-span bridges, Canadian Highway Bridge Design Code (16) restricts the method to those, which have interior supports closely equivalent to line supports and isolated columns supports only permitted. In this case, the standard force method may be used. However, the method becomes very complicated and time consuming.

2.2.5 Finite Element Method

The finite element technique is being extensively applied to complicated structures and is generally the most powerful and versatile as well as accurate numerical tool of all the available methods. The finite element method has rapidly become a very popular technique for the computer solution of a box girder bridge of arbitrary plan geometry and variable cross section. In the finite element analysis the structure is modeled using suitable finite elements by subdividing its solution domain into discrete elements. A large number of elements have been developed for use in the finite element technique. These finite elements may be one-dimensional beam-type elements, two-dimensional plate or shell elements or even three-dimensional solid elements.

Since the structure is composed of several finite elements interconnected at nodal points, the individual element stiffness matrix, which approximates the behavior in the continuum, is assembled based on assumed displacement or stress patterns. Then, the nodal displacements and hence the internal stresses in the finite element is obtained by overall equilibrium equations. By using adequate mesh refinement, results obtained from finite element model usually satisfy compatibility and equilibrium conditions (13, 99).

Aneja and Roll (9) and Roll and Aneja (82) used finite element technique for horizontally curved bridge with a box cross-section using flat plate element with curved boundaries for discretizing the flanges and flat rectangular elements for the webs. The analytical results showed poor agreement with the experimental findings, because the elements used did not have sufficient degrees of freedom at their nodes to account for rotation around all axes; further the web modeling with flat rectangular element did not seem to be sufficiently accurate. In 1970, Sisodiya et al. (91) analyzed box girder bridges having one or two spans and with curved layout and skew supports using the finite element method. The curved boundaries were modeled using parallelogram elements. The agreement between the experimental and analytical results was not satisfactory and the discrepancies were suspected to be due to the mesh division. In 1971, Chapman et al. (19) conducted a finite element analysis on steel and concrete box girder bridges to investigate the effect of intermediate diaphragms on the warping and distortional stresses. In 1971, Chu and Pinjarkar (26) developed finite element formulation of curved box girder bridges consisting of horizontal sector plates and vertical cylindrical shell elements. In 1974, Bazant and El Nimeiri (12) attributed the problems associated with neglecting curvilinear boundaries is elements used to model curved box beams by the loss of continuity in elements used by model curved box beams by the loss of continuity at the end cross-section of two adjunct elements meeting at an angle. Instead of developing curvilinear element boundaries, they developed the skew-ended finite element with shear deformation using straight elements. Fam and Turkstra (36) and Fam (35) adopted the finite element method for static and free vibration analysis of box girders with orthogonal boundaries and arbitrary combination of straight and horizontally curved sections, the analysis has been shown to be reliable and efficient. Four-node plate bending annular elements were chosen to idealize the flange members and conical elements for the inclined web members. The importance of warping stresses in single-cell curved bridges was established, using the finite element method, by Truksta and Fam (92) in 1978.

Shear lag phenomena in box girders was studies by Moffatt and Dowling (67) in 1975. In 1979, Sargious et al. (83) investigated the effect of providing end-diaphragm with openings in single-cell concrete box girder bridges supported by a central pier using the finite element technique. In 1985, Ishac and Smith (51) presented approximations for the transverse moments in single-span, single cell concrete box girder bridges. In 1995, Galuta and Cheung (40) combined the boundary element with the conventional finite elemert method to analyze box girder bridges. The bending moments and vertical deflection were found to be in good agreement when compared with the finite strip solution. In 1999, Sennah and Kennedy (88) conducted an extensive parametric study on the dynamic characteristics of composite multi-cell box girder bridges using the finite element analysis. The results obtained from the finite element method were in good agreement with the experimental findings. The finite element method was also used to study the effect of temperature on box girder bridges. In 1990, Chan et al. (18) presented temperature data collected continuously in three composite box girders over a one-to-two year period. Thermal stresses in these bridges were calculated using the finite element technique. In 1996, Elbadry and Ibrahim (33) calculated the time-dependant temperature variation within the cross section and along the length of curved concrete single-cell box girder bridges using a three-dimensional finite element model.

The numerical effectiveness, accuracy as well as the flexibility of the method in linear, non-linear, static or dynamic analyses has been well established. Therefore, many investigators have been attracted to adopt the finite element method to analyze the complex mechanics of an arbitrary box girder bridges. The Canadian Highway Bridge Design Code has recommended the finite element method for analysis of all types of bridges.

2.2.6 Thin-Walled Beam Theory

Thin-walled beam theory applicable to box beams was established by Valsov (94) and, elaborated by Dabrowski (27) and numerous other researchers. The theory assumes non distortional cross-section and, hence, does not account for all warping or bending stress. The predication of shear lag or the response of deck slabs to local wheel load can not be obtained using this theory. In 1966, Kolbrunner and Hajdin (58) treated thin-walled beam structures similar to Valsov's but in more general form by including shear deformation for closed thin-walled cross sections. The load-deformation response of curved box girder, which considers bending torsion and warping deformation, as developed by Valsov was used to predict the behavior of the cross section assumed to retain their shape due to load (74, 47, 63, 69). In 1985, Hasebe et al. (43) presented a detailed analytical study based on the refined thin-walled beam theory by Kano et al. (57) including the shear deformation and shear lag in the analysis. The aim of the study was to investigate the effect of several parameters on the effective width of curved box beams. Based on Valsov's theory, several investigators (12, 66, 93, 95, 96, 38) have developed thin-walled beam finite element models that occurred by combining Valsov's thin-walled beam theory and the finite element technique. The transverse distortion and longitudinal torsional warping and in some cases shear lag effect were taken into account in the combined method. In 1985, Maisel (63) extended Valsov's thin-walled beam theory to account for torsional distortional and shear lag effects of straight, thin-walled cellular box beams. Mavaddat and Mirza (64) implemented formulations into computer programs to analyze straight concrete box beams with one, two, or three cells and side cantilevers over a simple span or two spans with symmetric mid-span loading.

Razaqpur and Li (79, 80, 81) developed a box girder finite element, which includes extension, torsion, distortion, and shear lag analysis of straight, skew, and curved multi-cell box girders using thin-walled finite element based on Valsov's theory. The exact shape functions were used to eliminate the need for dividing the box into many elements in the longitudinal direction. The results of the proposed element agreed well with those results obtained from full three-dimensional facet shell finite element analysis. In 1986, Choudhury (25) combined the thin-walled beam theory and the finite element method to develop a curved non prismatic thin-walled box beam element. The theory was incorporated into a computer program to solve linear elastic analysis and nonlinear material analysis. For both static and dynamic analyses of multi-cell box girder bridges, Valsov's thin-walled beam theory is cast in a finite element formulation and exact shape function was used by El Azab (32) to drive the stiffness matrix.

2.3 Load distribution Factors

The distribution of dead load and wheel load on highway bridges is the most important consideration in selecting member sizes. Composite girder bridges may take the form of I-girder, multi-cells, or multiple spines. Bridges of concrete deck over steel boxes are more efficient and economical than those of composite steel-concrete I-girders since they exhibit better transverse load distribution due to their superior torsional stiffness. The following paragraphs provide a summary of the research work done on load distribution in such bridge types.

In 1985, Yoo and Littrell (97) studied the effect of cross-bracing on the warping and bending stresses of curved I-girders using a full three-dimensional finite-element modeling. In 1986, Brockenbrough (15) used the finite-element modeling to derive load distribution factors, including the warping effects, of curved composite I-girder bridges as a function of the span length, radius of curvature, girder spacing, and cross-bracing spacing. In 1967, and 1968, Johanston and Mattock (55) and Fountain and Mattock (37), respectively, used a computer program for the analysis of folded plate structures to study the lateral distribution of load in simple span composite multiple-spine box girder bridges without transverse diaphragms. To verify their analysis and computer program, a one-quarter scale model of a two-lane, 24 m span bridge supported by three box girders, and one-fifth scale model of a two-lane, 30 m span bridge supported by two box girders were built and tested due to simulated concentric and eccentric AASHTO truck loadings. The results were used to develop an expression for the live load bending moment distribution factor for each box girder as a function of the roadway width, and number of boxes. Their findings formed the basis for the lateral distribution of loads for bending moment currently used by AASHTO (3) and by the Ontario Highway Bridge Design Code, OHBDC, of 1983 (76) for the multi-spine box girder bridges. This expression takes the following form:

$$W_L = 0.1 + 1.7\frac{N_L}{N_B} + \frac{0.85}{N_L} \qquad (2.1)$$

Where:

W_L is the live load distribution factor for each box-girder;

N_B is the number of box girders; and

N_L is the number of lanes calculated as $\frac{W_C}{12}$, reduced to the nearest whole number, W_C is the roadway width between curbs in feet.

The drawback of this expression is that the beneficial effect of the cross-bracing inside and between the boxes was not taken into account. Also the number of lanes to number of boxes should be between 0.5 and 1.5 inclusive, despite the fact that the expression was derived for bridges having number of spines equal to number of lanes. The AASHTO Load and Resistance Factor Design specifications (6, 7) provide similar expression to Equation 2.1. It should be noted that both AASHTO and AASHTO-LRFD (3, 6, 7) assume the applicability of Equation. 2.1 to shear force distribution among boxes although the expression was developed based on bending moments.

Heins (44) extended Equation 2.1 developed by Johanston and Mattock to curved bridges using the following equation:

$$W_{LC} = [\ \frac{1440}{R^2} + \frac{4.8}{R} + 1\ ]\ W_L \qquad (2.2)$$

Where:

W_{LC} is the curved girder load distribution factor for moment;

W_L is the straight girder load distribution factor as obtained from Equation 2.1, and

R is the centerline radius of curvature of the bridge in feet.

This equation was developed for bridges with radius of curvature ranging from 200 to 10,000 ft (60 to 3000 m).

In 1985, and 1992, Bakht and Jaeger (10, 11) presented a particular case of multiple spine bridges having at least three spines, zero transverse bending stiffness, with the load transfer between the various spines through transverse shear. Based on these simplifications, they proposed load distribution factors for bending moment and shear. These formed the basis for live load distribution used by the third edition of the OHBDC (77) for multiple-spine bridges. In 1994, Normandin and Massicotte (71) presented the results of a refined finite-element analysis to determine the distribution patterns in multiple-spine box girder bridges with different characteristics and geometry. Several parameters were considered in the analysis: the presence of the internal diaphragms, the use of external bracing, and the type of live load. The study proved that internal diaphragms, inside boxes, are essential components in a box girder bridge since they contribute largely to the reduction of the cross-sectional distortion. Also, external bracings between boxes do not significantly influence the distribution characteristics of bending moments and shear, since a fully loaded bridge usually governs the design. Results also indicate that, in some cases, both the AASHTO (3) and OHBDC (77) distribution factors underestimate the live load effects by a significant margin.

In 1980, Mukherjee and Trikha (68), using the finite-strip method, developed a set of design coefficients for twin cell curved box girder reinforced concrete bridges as an aid to practical design of such bridges. These coefficients were for moment, shear, transverse moment, and vertical deflection due to the webs. These coefficients were limited only to concrete bridges of two-lane, span length between 20 and 40 m, and radius of curvature between 45 and 150 m.

The AASHTO Guide Specification for Horizontally Curved Highway Bridges (4) pertained to both curved composite concrete deck-steel I-girder bridges and multiple-spine box girder bridges. The specifications for load distribution for both curved I-girders and multiple box girders were based on a design-oriented research work done by Heins and Jin in 1984 (46) on live load distribution of single and continuous curved composite I-girder bridges by a space frame idealization. The space frame modeling has incorporated the interaction of diaphragms (cross-bracing in the radial direction) and bottom lateral bracing in some or in all bays. Appropriate design equations were presented for use in conjunction with a plane grid solution. For both curved I-girders and curved multiple box girders, the AASHTO (Guide Specification for Horizontally Curved Highway Bridges, 1993) specifies that the moments and shears required to proportion the individual members shall be based on a rational analysis of the entire structure which takes into account the complete distribution of loads to the various members. Moreover, if the rational analysis considers the system as a plane grid and not as a space frame and bottom lateral bracing is specified in some bays or in all bays, the code modified the resulting maximum live load stresses, using Heins-Jin design equation, considering additional warping stresses beside the normal bending stresses. However, due to the lack of a better design procedure and research in this topic, this provision, as well as the load distribution factor equations, was omitted from the current AASHTO Guide Specification for horizontally curved highway bridges (4). As such, designers have to use analytical methods to analyze such bridges.

In 1981, Davis and Bon (28) presented a correction factor for curvature for load distribution in concrete and prestressed concrete multi-cell box girder bridges. For all girders except the exterior girder farthest from the centre of curvature, this factor is a ratio of the distance from the centre of curvature to the assigned girder to the centre-line radius of curvature of the bridge. For the outermost girder (farthest from the centre of curvature), they proposed straight bridge load distribution without any modifications. The drawback of this method is that the beneficial effect of the transverse diaphragms was not taken into consideration. In 1988, Nutt et al. (73) proposed a set of equations for moment distribution in straight, reinforced and prestressed concrete, multi-cell box girder bridges as a function of the number of lanes, cell width, span length, and number of cells. In 1989, Ho et al. (49) used the finite-strip method to analyze straight simply-supported, two-cell box girder and rectangular voided slab bridges without intermediate diaphragms. Empirical expressions were deduced for the ratio of the maximum longitudinal bending moment to the equivalent beam moment. This study was limited to a straight two-cell bridge section made of either steel or concrete. Also, the span lengths of the bridges considered in this study were up to 40 m in the case of two lanes, 50 m in case of three lanes, and 67 m in case of four lanes. In 1995, using the finite-strip method, Cheung and Foo (23) proposed expressions for the ratio moment distribution factor of the curved multiple-spine box girder bridge to that of the straight one as a function of span length, number of lanes, box-girder spacing, and radius of curvature. The disadvantage of this study is that it did not take into account the beneficial effect of diaphragms inside the boxes or cross-bracings between boxes. Further, the effect of the number of boxes and dead load distribution were not included.

The AASHTO specifications of 1996 (3) specified load distribution factors for bending moment in straight reinforced concrete box girder bridges, namely: S18 for one-lane traffic and S17 for two or more traffic lanes, where S is the cell width in feet. The specified load distribution factors were based on suggestions made by California design engineers in 1959. However, these distribution factors do not give the designer any indication on the behaviour of the bridge and the parameters influencing the response of the structure other than the cell width. In 1991, Zokaie et at. (98) proposed other moment and shear distribution factors for reinforced and prestressed concrete multi-cell bridges. Their findings form the load distribution factors for moment and shear currently used by the AASHTO LRFD code (6) for straight concrete multi-cell bridges. In 1996, Brighton et al. (14) described a study to determine a live load distribution factor for a new type of precast concrete double cell box girders that was proposed for a prefabricated bridge system for rapid construction of short-span bridges. In 1994 and 1996, Dean (29) and Fu et al. (39), respectively, studied torsion on multi cellular members. In 1998, Sennah and Kennedy (87) utilized the finite-element method to derive expressions for the shear distribution factors for curved composite cellular bridges. Similar study (31) was conducted for skew bridges.

Some of the aforementioned investigations on box girder bridges were confined to reinforced and prestressed concrete construction, and did not include composite concrete deck-steel construction. Others dealt with steel box girders but were limited to particular cases, or in their range of applicability of the research findings. CHBDC 2000 provided the following simplified method to be used for longitudinal bending moments in multispine bridges:

$$M_g = F_m M_{g\,avg} \tag{2.1}$$

Where

$M_{g\,avg}$ = the average moment per box girder determined by sharing equally the total moment on the bridge cross section among all box girders in the cross section

$$= \frac{nM_T R_L}{N}$$

M_T = the maximum moment per design lane at the point of the span under consideration.

n = the number of design lanes as determined from table 2.1

R_L = modification factor for multilane loading as determined from table 2.2

N = number of box girders in the bridge deck width, B.

F_m = an amplification factor to account the transverse variation in maximum longitudinal moment intensity, as compared to the average longitudinal moment intensity,

$$\frac{SN}{F\left(1+\frac{\mu C_f}{100}\right)} \geq 1.05$$

$\left[1+\frac{\mu C_f}{100}\right]$ = lane width correction factor

where

$$\mu = \frac{W_e - 3.3}{0.6} \text{ but } \leq 1.0$$

$$W_e = \frac{W_C}{n}$$

W_c = the bridge deck width, m.

S = center-to-center box girder spacing

C_f = correction factor, in % obtained from Table 2.3

F = a width dimension that characterizes load distribution for a bridge obtained from Table 2.3 depending on a factor, β

$$\beta = \pi\left[\frac{A}{L}\right]\left[\frac{D_X}{D_{XY}}\right]^{0.5}$$

A = width of the bridge for ULS and FLS; but not greater than three times the spine spacing S for FLS.

D_X = total bending stiffness, EI, of the bridge cross-section divided by the width of the bridge.

D_{XY} = total torsional stiffness, GJ, of the cross-section divided by the width of the bridge.

For bridges having more than four design lanes, the values of F shall be calculated from the following:

$$F = F_4 \frac{nR_L}{2.80}$$

where F_4 is the value of F for four design lanes obtained from table 2.3.

CHBDC of 2000 also provided the following simplified method to be used for longitudinal vertical shear in multispine bridges:

$$V_g = F_V V_{g\,avg} \qquad (2.2)$$

where

$V_{g\,avg}$ = the average shear per box girder determined by sharing equally the total shear on the bridge cross-section among all box girders in the cross-section

$$= \frac{nV_T R_L}{N}$$

V_T = the maximum shear per lane at the point of the span under consideration.

n = the number of design lanes as determined from table 2.1

R_L = modification factor for multilane loading as determined from table 2.2

N = number of box girders in the bridge deck width, B.

F_V = an amplification factor to account the transverse variation in maximum longitudinal shear intensity, as compared to the average longitudinal vertical shear intensity.

$$= \frac{SN}{F}$$

where

S = center-to-center box girder spacing, m

F = a width dimension that characterizes load distribution for a bridge, shall not exceed the value of F determined for flexure such that $F_V \geq F_m$

For bridges having more than four design lanes, the values of F shall be calculated from the following:

$$F = F_4 \frac{nR_L}{2.80}$$

where F_4 is the value of F for four design lanes obtained from table 2.5.

The Ontario Highway Bridge Design Code, OHBDC of 1992 (77), the Canadian Standard for the design of highway bridges, CAN/CSA-S6-88 (17), and CHBDC of 2000 (16) allow the treatment of a curved bridge as a straight one whenever the ratio (L^2/bR) is less than, or equal to, 1.0, where L is the span length, b is the half width of the bridge, and R is the radius of curvature of centerline of the bridge. No expressions are suggested when the ratio is more than 1.0. AASHTO Guide specifications for horizontally curved highway bridges of 2003 (5) does not include the curvature effect in calculating the bending moments when the subtended angle is not greater than 5°. Also, it does not provide any estimation for the load distribution factors. Therefore, research work on moment and shear distribution of straight and curved composite concrete deck-steel multiple-spine bridges is required.

In 2003, Androus (8) conducted a parametric study using the finite-element method, to determine the moment distribution characteristics of curved composite multiple-box girder bridges when subjected to CHBDC truck loading. The current study is a continuation of the Androus study to determine the shear distribution characteristics of such bridges.

2.4 Application of Artificial Neural Networks

Neural networks have been applied to structural engineering in recent years. The first structural engineering applications of neural network go back only to the late 1980s (1). Since then, a wide range of applications has emerged. A neural network is a non-linear system consisting of a large number of highly interconnected processing units, nodes or artificial neurons as shown in Figure 2.1. Each input signal is multiplied by the associated weight value wi and summed at a neuron. The result is put through an activation function to generate a level of activity for the neuron. This activity is the output of the neuron. When the weight value at each link and the connection pattern are determined, the neural network is trained. This process is accomplished by learning from the training set and by applying certain learning rule. The trained network can be used to generalize for those inputs that are not including in the training set.

Compared to conventional digital computing techniques, neural networks are advantageous because of their special features, such as the massively parallel processing, distributed storing of information, low sensitivity to error, their very robust operation after training, generalization and plasticity (adaptability) to new information. However, neural networks do suffer from such shortcomings such as a lack of precision and limited theory to assist in their design. Despite their limitation though, neural networks offer a powerful means of solving poorly defined problems.

2.4.1 Nodes

The counterparts of neurons in artificial neural networks or simply neural networks (NN) are often referred to as nodes, units or processing elements. Figure 2.2 illustrates a typical structure of a node.

Where: $X = \{x_1, x_2, \ldots\ldots x_N\}$ *Input vector*

$W = \{w_1, w_2, \ldots w_N\}$ *Weight vector*

θ *Threshold*

$net = \sum w_i x_i$ *Action potential*

$v = net - \theta$

$f(v)$ *Activation function*

The input vector x, which is used to simulate the stimuli, is multiplied by the weight vector, the counterpart of the synapse, along its edge to the node. The products are summed at the node. The node fires only if the sum builds to the threshold θ. Normally, the threshold is referred to as the bias, which is estimated as a trainable weight for an additional input signal attached to each node having a constant input value of $1 = x$. In this way, a node carries out the computation and the output is

$$0 = f(v) = f\left(\sum_{i=1}^{N} w_i x_i - \theta \right)$$

where f is the activation function. The different activation functions shown in Figure 2.3 are normally used as the following (44):

(a) Linear function

$f(v) = \beta$, for $\beta > 0$ where $\beta = 0$ is called the identity functions;

(b) Binary step function

$f(v) = f(\text{net} - \theta) = 1$ for net $> \theta$

$= 0$ for net $\leq \theta$

(c) Bipolar step function

$$f(v) = f(\text{net} - \theta) = 1 \text{ for net} > \theta$$
$$= -1 \text{ for net} \leq \theta$$

(d) Sigmoid function (logistic or binary sigmoid)

$$f(v) = \frac{1}{1+\exp(-\sigma v)} \quad \text{for } \sigma > 0$$

$$\frac{df}{dv} = f'(v) = \sigma f(1-f)$$

where

σ is the standard deviation

(e) Bipolar sigmoid

$$f(v) = \frac{1-\exp(-\sigma v)}{1+\exp(-\sigma v)} \quad \text{for } \sigma > 0$$

$$f'(v) = \frac{\sigma}{2} f(1-f)$$

2.4.2 Types of Artificial Neural Networks

The computational capacity of one node may have some limitations. However, when many nodes are put together to form NNs, a complex computational task can be performed. The arrangement of nodes and the pattern of connections between them are called the architecture of NN (type or structure or topology of NN). There are mainly three types of architecture: feedforward, recurrent, and cellular NN, as shown in Figure 2.4.

In the feedforward NN, signals are transmitted in one direction, only from inputs to outputs. The standard feedforward architecture consists of layers of nodes that are not connected in the same layer but connected between one layer to the subsequent layer. In the usual terminology, the set of input nodes is called the input layer, and the set of output nodes is called output layer. All other layers with no direct connections from or to the outside are called hidden layers. Recurrent networks are the networks whose partial computation is recycled through the network itself. The cycle in the topology of the network makes the storage and reuse of signals possible for a certain amount of time after they are produced. In cellular networks, the information is directly exchanged between neighboring units, so that more than one connection network can be present with different neighborhood sizes.

2.4.3 Learning the Network

A major concern in the development of the neural network is to determine an appropriate set of weights. The computational capacity of the neural network is realized by adjusting trainable weights using different learning methods, which can be classified as supervised and unsupervised learning methods. In supervised learning, the outputs of the neural network are compared with the desired outputs or target outputs, and the error is calculated. The weights are adjusted so as to minimize this error. In unsupervised learning though, the weights are determined as a result of a self-organizing process, i.e. the connections to the network weights are not performed by an external agent. The network itself decides what output is best for a given input and reorganizes accordingly. Mainly, there are two types of unsupervised learning: reinforcement and competitive learning. In the first method, each input produces a reinforcement of the network weights to enhance the reproduction of the desired output. In competitive learning, the elements of the network compete with each other for the "right" to provide the output associated with an input vector. Only one element is allowed to answer the query and this element simultaneously inhibits all other competitors.

2.4.4 Generalization

After learning, the network should extract "regularities" or "rules" from the training data and be able to generalize, i.e. to give the right answers for input not belonging to the training sets. When the network is trained with a randomly selected set of examples and tested with another set of inputs, the expected number of correct results is called generalization capability. Generalization capability can be used to evaluate the behaviour of the NN. The neural networks have extensive applications in civil engineering. In the following sections, the topologies of several types of neural networks and their applications in structural engineering are described. These include the backpropagation neural network, the counterpropagation network, the Hopefield neural network and the adaptive resonance theory neural network.

2.4.4 Backpropagation

The Backpropagation (BP) neural network is a multilayered, feedforward NN and by far the most extensively utilized due to its well-studied theory. The BP neural network approximates the non-linear relationship between the input and the output by adjusting the weight values internally instead of giving the function expression explicitly. Further, the BP neural network can be generalized for the input that is not included in the training patterns even in the noise-contained environment. Figure 2.5 shows the topology of the BP network that includes only one hidden layer. However, the BPNN can contain one hidden layer and may be extended to multi-hidden-layer neural networks.

The operation of the BP neural network can be divided into two steps: input feedforward and error backpropagation. In the forward step, an input pattern is applied as stimuli to nodes in the input layer, and its effect propagates through the network, layer by layer until an output is produced as the actual response of the network. During this process, the weights of the network are all fixed. The actual output value is then compared to the desired output, and an error signal is computed for each output node. These error signals are transmitted backwards from the output layer to each node in the intermediate layer that contributes directly to the output. However, each unit in the intermediate layer receives only a portion of the total error signal, based roughly on the relative contribution the unit made to the original output. This process repeats, layer by layer, until each node in the network has received an error signal that describes its relative contribution to the total error. Based on the error signal received, connection weights are then updated by each unit to cause the network to converge toward a state that allows all the training patterns to be encoded. The back propagation algorithm is used to train the BPNN. This algorithm looks for the minimum of the error function in weight space using the method of gradient descent. The combination of the weights that minimizes the error function is considered to be a solution to the learning problem.

2.4.5 Training Modes

In the Back Propagation training there are two methods to update the weights in the network. One is referred to as the batch update and the other as pattern update. First, presenting the whole set of data to the network once is known as an epoch. In batch mode update, after the entire set of data has been presented to the network (one epoch has been completed), a single average error is calculated for each weight, and the weights are updated once at the end of an epoch according to that average error. This is also referred as training by epoch. The other mode of update is pattern update, this type of update requires that the weight are updated after each single pattern presentation, for example if there is a hundred set of data presented to the network, then the weights will be updated one hundred times in one epoch. The pattern update is also called sample update. Each mode might prove favorable in different situation, for example it is more likely for batch mode to be trapped in a local minimum then pattern. On the other hand, the batch update mode requires less adjustment done and is consequently faster in some cases. There are advantages and disadvantages of each mode.

However, it is recommended to start with the batch mode as in general it saves the time for training the network.

2.4.6 Application of Artificial Neural Network in Structural Analysis

Engineers often deal with incomplete and noisy data, which is one area where NNs are most applicable. NNs are artificial intelligence tools which are able to learn and generalize from examples and experience to produce meaningful solutions to problems. This learning occurs even when the input data contains errors or is incomplete or fuzzy, which is often typical to the design process. These characteristics of ANNs make them a promising candidate for modeling some of the engineering problems. There are only a few applications of ANN in design optimization. The applications involve the training and a lot of data is needed to train the neural network. After a model based upon ANN is obtained, the mathematical programming methods can be used to find optimal solutions. The training data can also be from a large amount of design optimizations based upon the mathematical programming methods and the trained neural network can give different optimal designs.

In 1997, Jenkins (52) has used a so-called 'hypercube' concept for selecting training patterns for his grillage analysis model. He found that this method gives satisfactory results for small-scale problems. Jenkins argues that data representing the corner of a cube, mid-sides of the cube faces, and a number of random data from within the cube will be sufficient for training the network. He has shown that data representing only the mid-faces, upper bounds, and midpoints of the cube will be sufficient for suitable training of the network. He has used NNs generally for elastic structural analysis problems with clear linear elastic relationships.

In 1999, Jenkins (53) used the ANN for structural re-analysis. In his paper, he showed that in structural analysis, a correct solution would be one, which satisfies the conditions of equilibrium at the joint of the structure. If the forces aggregated at each joint are computed by a neural net, then the target sums are all zero and the net is then trained to produce zero total forces at each joint coordinate. Consequently, the equilibrium condition is the target in all cases. He used different illustrative examples to demonstrate that the network approach, whilst considerably slower than band-matrix processing, offers considerable advantage in convenience for the designer.

In 2001, Rafiq et al (78) have modified Jenkins's method by adding data for the mid-sides of the cube into the training pattern and used it for non-linear problems which have proved to be satisfactory for modeling reinforced concrete slabs and flanged beams to predict optimum design parameters using NNs. They showed that the batch mode, used for training the network, is very sensitive to initial weights. They recommended training the network using batch mode to start with and analyzing the network output. If the level of error after testing the network within unseen data was not satisfactory then a pattern mode should be used. They also showed in their study that it is necessary to carry out a parametric study to determine the optimum number of epochs necessary for network training. In their study, Rafiq et al. used a reinforced concrete slab example to predict the optimum design parameters for the slab. However, they considered the optimum slab depth as it is the most important which affects many other parameters and the final cost of the overall structure. They considered nine different spans of slabs with aspect ratio (1:2) and applied design load of 2.5-7.5 kN/m^2 resulting in 11 different loading cases. That combination resulted in 594 different designs. Three types of NNs were compared, namely: the multi-layer perceptron (MLP), radial basis function network (RBF), and normalized radial basis function network (NRBF). The study showed the MLP and the NRBF performed equally well. However, the RBF resulted in a poorer performance. Also, the NRBF showed the advantage of faster training. It was proved that the data selection significantly reduces the size of the training data, and the training time is considerably reduced.

In 2000, Gupta and Li (41) used several mathematical programming NN and developed a new multi-layer perceptron neural network (MPNN) for design optimization problems in mechanical motion synthesis and structural design. They considered the constrained optimization problem in the study. In their example to optimize the design of a cantilevered beam, they considered a variable cross section. The design variables were the widths and heights at each of 5 segments. The beam was subjected to load P at the free end and the constraints were (i) the limits on stresses (calculated at the left end of each segment), (ii) the maximum deflection at the tip, (iii) the cross-sectional geometry, such that the height of any segment does not exceed the width by a factor of 20, and (iv) additional side constraints on the heights and widths. The design problem had 10 design variables, and 21 constraints, 6 of which were nonlinear and 15 were linear. In their research, Gupta and Li found that a very small step size was not a good choice, which is contrary to the conventional theory of Runge-Kutta (RK) method, and it is also a peculiarity of this method. The algorithm normally converged to local optimum points near the initial point when using smaller step sizes. Larger step sizes could find better solutions, but then the approach matrix tended to become singular after a few steps. Thus, the step sizes, which were either too large or too small, did not produce good results. The range of 0.02 to 0.05 seemed to be a good range for step sizes.

In 1996, Jingui et al. (54) presented an improved strategy for genetic algorithms (GAs) in structural engineering. In their study, the improved algorithm for the GAs to solve the structural problem was stated as follows: Modeling between the response from the structures and design variables by ANNs-a global model can be achieved by training a series of patterns on the global design space. To construct fitness function, the objective function of the structural optimization problem can be mapped into the fitness function, which was used to evaluate the performance of the individual strings. Mapping the design variables with the individual strings, the design variables of the structural optimization problems correspond to the individual strings. During the procedure of initializing the population of individual strings, the constraint values at the design points, which correspond to the individual strings, were calculated by the approach to structural approximation analysis by ANNs. It can be determined whether the individual string is the feasible one, by the definition of the feasible individual strings. If the individual string is the feasible one, it will be chosen. Otherwise, it can be replaced by a new individual string chosen again, until the new individual string is the feasible one. The procedure of initializing the population of the individual strings is continued, until the number of the individual strings in the initial population is sufficient. To generate the next population of the individual strings, the individual strings are first selected from the last generation population as the mating parent's individual strings. Reproduction, or crossover, or mutation, which is one of the generating operators, is adopted to generate the individual strings in the next generation population. The approach to structural approximation analysis by ANNs was also used to determine whether the individual string generated was the feasible one. If the individual string was an infeasible one, it could be replaced by a newly generated individual string. The artificial evolution continues the generation procedure, until the artificial evolution is converged.

In 1999, Iranmanesh and Kaveh (50) presented a neurocomputing strategy which combined data processing capabilities of neural networks and numerical structural optimization. They used an improved counterpropagation neural network. The basic idea of neuro optimizer was to extend the range of applicability of ANN to structural optimization by employing counter propagation network (CPN). The strategy consisted of three phases. In the first phase, the structural design variables were generated randomly in the user-specified domain of search. The constraints and the relevant gradients were computed analytically for each set of generated design variables. In the neurocomputing phase, two CPNs were trained in such data i.e. the constraints and the relevant gradients. Weight matrices were computed automatically in the training process. In the final phase, neurocomputing models were used as fast interpolator to predict the constraints and the relevant gradients in the optimization process in order to minimize the computation time.

It was observed that selecting a larger domain of search causes reduction of accuracy of the trained ANNs, which in turn affects the results of the neuro-optimizer. However, the associated error of the objective function for training pairs above 200 was less than 7.1 percent. When the number of the design variables is high, it is appropriate to increase the domain of search and evaluate the response of the neuro-optimizer and then refine the results by decreasing the domain of search about the design variables. Furthermore, the error can be reduced either by increasing the number of training pairs in the process of training of the ANNs or by selecting a smaller value for the Kohonen units classifier, which results in a larger size ANNs. Another search was carried out to evaluate the effect of variation of the Kohonen units in the result the neuro-optimizer. Neural nets of neur-optimizer were trained based on different cases of 500 and 1000 training pairs. In each case, the Kohonen unit classifier, was varied from 1.0 to 3.5, which caused variation of the Kohonen units from 500 to about 4.

In 2001, Lee et al. (60) presented a methodology to develop a neural network based model for approximate structural analysis (NNASA). The approach was verified by modeling a stub girder system to predict its behavior. The development of approximate analytical model by using neural networks was studied in an effort to find a method to efficiently generate credible outputs that were consistent with those by Vierendeel truss girder and finite element models. The NNASA was applied to the simulation for an example of a stub-girder system. It was emphasized that the most important factors that influence the accuracy of the approximate analysis are the determination of the training patterns and the acceptable maximum errors. Both the number of hidden neurons and the initial weights influence the convergence of the NNASA.

CHAPTER III

FINITE ELEMENT ANALYSIS

3.1 General

Because of its accurate and practical results, the finite-element method is the most preferable method of analysis used today. Since more recent developments in finite-element methods have been achieved, it is now feasible to model complicated bridges in a very realistic presentation and to provide a physical appeal of its structural response within the elastic and post-plastic cases of loading. Numerically, the finite-element mesh is represented by a system of algebraic equations to be solved for unknowns at nodes. The most important advantages of the finite-element method include its ability to deal with any field problem: heat transfer, stress analysis, and magnetic fields. It has no geometric restrictions, the material properties are not restricted to isotropy, the boundary conditions and loadings are not restricted, and the components that have different behaviors, and different mathematical descriptions can be combined. Therefore, the finite-element method is very suitable for the analysis of curved composite box girder bridges. This chapter includes descriptions of modeling the different components of the composite box girder bridges. The finite element model includes the reinforced concrete deck slab, top steel flanges, steel webs, bottom steel flange, the solid end-diaphragms, the cross-bracings, and the top chords as described in subsequent sections in this chapter. The finite-element program called ABAQUS by Hibbitt et al. (53) was used in this study to model and specify the structural body system of the curved composite box girder bridges. A general illustration of this program is presented later in this chapter. The finite-element method of structural analysis described herein was also applied to perform the parametric study of the static response of both straight and curved composite box girder bridges when subjected to CHBDC truck loading.

3.2 Finite-Element Approach

The finite-element method is a numerical method for solving field problems in engineering such as heat transfer, stress analysis, and magnetic fields by means of mathematical equations. In structural problems, the methodology is typically concerned with determining stresses and displacements and will yield approximate values of the unknowns at discrete number of points (nodes) in a continuum. This numerical method of analysis starts by discretizing a model. Discretization is the process where a body is divided into an equivalent system of smaller bodies or units (elements) interconnected at nodes common to two or more elements and/or boundary lines and/or surfaces. An equation is then formulated combining all the elements to obtain a solution for one whole body. Using a displacement formulation, the stiffness matrix of each element is derived and the global stiffness matrix of the entire structure can be formulated by the direct stiffness method. This global stiffness matrix, along with the given displacement boundary conditions and applied loads is then solved, thus that the displacements and stresses for the entire system are determined. The global stiffness matrix represents the nodal force-displacement relationships and is expressed in a matrix equation form as follows:

$$[P] = [K][U] \tag{3.1}$$

Where:

[P] = nodal load vector;

[K] = the global stiffness matrix;

[U] = the nodal displacement vector;

The steps for deriving the above equation can be summarized in the following basic relationships:

(a) $\upsilon(x, y) = [\Phi(x, y)][\alpha]$ (3.2)

where:

υ = the internal displacement vector of the element.

Φ = the displacement function.

α = the generalized coordinates.

(b) $[U] = [A][\alpha]$ then, $[\alpha] = [A]^{-1}[U]$ (3.3)

where [A] is the transformation matrix from local to global coordinates,

(c) $[\varepsilon(x, y)] = [B(x, y)][\alpha] = [B(x, y)][A]^{-1}[U]$ (3.4)

where:

[B(x,y)]= the strain-displacement matrix.

[ε(x,y)]= the strain matrix.

(d) $[\sigma(x, y)] = [D][\varepsilon(x, y)] = [D][B(x, y)][A]^{-1}[U]$ (3.5)

where; [D] is the constitutive matrix or the elasticity matrix. From the principle of minimization of the local potential energy for the total external work equal to 1/2 $[U]^T[P]$, then

(e) (i) $W_E = [u']^T[P]$

(ii) $W_I = \int_{vol.}[\bar{\varepsilon}]^T[\sigma] = [u']^T[A]^{-1}[k'][A]^{-1}[U]$ (3.6)

where:

$W_E =$ the external virtual work;

$W_I =$ the internal virtual work;

$[u'] =$ the vector of virtual displacement;

$[k'] =$ the element stiffness matrix.

where

$$[k'] = \int_{vol.} [B(x,y)]^T [D][B(x,y)]$$

(f) From the principle of virtual work, $W_E = W_I$. By taking one element of virtual nodal displacement vector [u'] equal to unity successfully, the solution becomes:

$$[P] = [K][U] \tag{3.7}$$

where $[K] = \Sigma[k']$, so the global structural stiffness matrix is an assemblage of the elements stiffness matrices [k'].

(g) The solution of the resulting system of equations yields the values of nodal displacement [U] and the internal forces for each element can be obtained from Equation (3.4).

In the case of a linear (elastic) structural problem, loads are first applied on the model and the solution is obtained directly. In a nonlinear case, the analysis follows a different numerical method to obtain a solution

3.3 The Finite-Element Program 'ABAQUS'

ABAQUS is a multi-purpose finite-element program developed initially for nuclear power and offshore engineering communities, who needed a tool for studying complex, nonlinear engineering problems. Widespread adaptation across many industries during the 1980's and 1990's made ABAQUS a popular choice for demanding finite element analysis. The program is used world-wide to estimate structural responses of power plant structures due to accident and operating stresses. However, it is used on a much wider scale to solve all types of structural problems. ABAQUS runs as a batch program to assemble a data deck which describes a problem so that an analysis can be performed. A data deck for ABAQUS contains model data and history data. Model data defines a finite-element model which includes: the nodes, elements, element properties, material definitions, nodal constraints or boundary conditions, and any data that specify the model itself. Data decks for complex simulations can be large but can be managed without too many difficulties by using the convenient feature built into the program's input structure. History data defines what happens to the model such as the sequence of events or loadings in which model was subjected to. In ABAQUS, this history is divided by the user into a sequence of steps. Each step is a period of response of a particular type such as static loading or dynamic response. The definition of a step includes the procedure type, the control parameters for time integration for the non-linear solution procedures, loading, free-vibration procedure, forced vibration procedure, and output requests.

All data definitions in ABAQUS are accomplished with option blocks which are sets of data describing a part of the problem definition. The user chooses these options that are relevant for a particular application. Each option is introduced by a key word card. If the option requires data cards, they follow the key words. One of the most useful features of the ABAQUS data definition method is the availability of sets. A set can be a set of nodes or a set of elements. The user provides a name for each set. That name then provides a means of referencing all of the members of the set. Sets are the basic reference throughout ABAQUS and the use of sets is recommended. Choosing meaningful set names makes it simple to identify which data belong to which part of the model.

3.4 Finite-Element Modeling of Composite Multiple Box Bridges

A three-dimensional finite-element model was used to analyze all composite bridges considered in this study. A convergence study was conducted to choose the finite-element mesh. The finite-element mesh is usually chosen based on pilot runs and is a compromise between economy and accuracy. In the finite modeling process, the structure is first divided into several components. In this case, the bridges were divided into: concrete deck slab, steel top flanges, steel webs, steel bottom flange, steel solid-end-diaphragms and cross-bracing and top-chords. Several element types were attempted at first as trial until a suitable one is found. Also, several trial runs proved that the effect of vertical web stiffeners on the structural behavior was insignificant. Therefore, they were not included in the finite-element model. In this chapter, different element types and material used for modeling the elastic loading stage are presented.

3.4.1 Geometric Modeling

(a) Modeling of Deck Slab, Webs, Bottom Flange, and End-Diaphragms

For these components, shell elements were used. From the many types of shell elements available in the ABAQUS library, the four-node shell element named S4R was chosen. Depending on its nodes, this type of element can have either straight or curved boundaries depending on nodes definitions; this makes it suitable for curved bridges. The S4R element has six degrees of freedom at each node, these are three displacements (U_1, U_2, U_3) and three rotations (φ_1, φ_2, φ_3). A detailed diagram of the shell element S4R is shown in Figure 3.1.

(b) Modeling of Steel Top Flanges, Top-chords, and Cross-bracings

Two-node three-dimensional beam element, named B31H in ABAQUS library, was used to model the steel top flanges, top-chords, and cross-bracings. This element has two nodes with six degrees of freedom at each node, three displacements (U_1, U_2, U_3) and three rotations (φ_1, φ_2, φ_3). A detailed diagram of the beam element B31H is shown in Figure 3.2.

3.4.2 Boundary Conditions

Two different nodal constraints were used in the analysis; these were boundary constraints and multi-point constraints. For the boundary conditions, two different constraints were set in modeling the simply supported bridges. First, the roller support at one end of the bridge was restricted from both vertical and radial displacements at the lower end nodes of each web. Second, the most inner hinged support at the other end of the bridge was restricted from all possible translations at the lower end node of the web, however the rest of the end nodes were restricted only from vertical and radial translations. In summary, the boundary conditions for all end support nodes in the finite-element models were as follows: (1) one interior support fixed against tangential, radial, and vertical displacements, and, (2) all other supports were free to move tangentially but fixed against radial and vertical displacements.

The multi-point constraint option in the ABAQUS software, type BEAM, was used to model the presence of the shear studs between the shell nodes of the concrete deck and the beam element nodes of the steel top flanges. The beam type element allows for constraints between different degrees of freedom and thus, ensures full interaction between the concrete deck slab and the steel cells as intended in the design. In this type of constraint, ABAQUS software uses a linear constraint equation, where beam elements are placed between the concrete deck and the flanges acting as rigid links. This way, all forces and moments experienced by these beam elements are transferred directly to the steel flanges. In this manner, the nodal degrees of freedom of the nodes of these beam elements are transferred to those of another element node attached to. The multi-point constraints between the concrete deck and the top steel flanges, shown in Figure 3.3 were used with the proper spacing based on the comparative study between the experimental study and theoretical results (8).

3.4.3 Material modeling

It is important that material properties are defined so that ABAQUS can provide suitable properties for those elements. Also, material properties highly affect the results of the analysis. Structural material properties include elastic modulus and Poisson's ratio must be input to ABAQUS for accurately predicting the behavior of the model.

3.5 Finite-Element Analysis of the Bridge Models and the Prototype Bridges

The above mentioned finite-element method was employed to study the elastic response of the bridge models described earlier in this chapter. In the finite-element modeling, pilot runs were performed to determine the least number of possible elements in the mesh discritization without a loss in accuracy. As a result, for the elastic load verifications, it was sufficient to vertically use six elements for each side of the web and four elements between webs for the concrete slab bottom steel flanges, and 72 elements in the longitudinal direction. For the purpose of consistency, the discritization for all the finite elements models was kept the same per box girder. Figure 3.4 shows the finite-element discretization of the cross-section of four box-girder bridge. It was found that the vertical stiffeners had an insignificant effect on the structural response of the finite model, so they were omitted in the modeling. Also the steel reinforcement in the concrete deck showed no significant effect on the model elastic response, and therefore, it was also excluded in the finite-element models. The finite-element modeling was used to conduct a parametric study on the structural response of curved and straight composite box girder bridges. A list of ABAQUS input data decks used in the analysis is shown in appendix D.

Chapter IV

PARAMETRIC STUDY

4.1 General

No distinctive methodology is currently available for the design of curved box girder bridges. Apparently, in the current practice, it is common for design engineers to increase the design criterion of a straight box girder by 5% to 20% for a curved box girder. To meet the practical requirement arising during the design process of box girder bridges, the parametric study presented in this chapter was performed to help in the design and to estimate the load distribution factors in both ultimate and fatigue limit states. To generate the database required for the load distribution factors, numerous finite element prototype bridges were modeled for straight and curved box girder bridges. These bridges were loaded according to the CHBDC provisions for live loading to provide useful information for bridge designers. Accordingly, the objectives of this parametric study were to:

1. Investigate the influence of basic parameters affecting the straining actions of composite multiple-spine box-girder bridges.
2. Generate a database for the maximum load distribution factor induced in the bridges due to different truck loading conditions, for both ultimate and fatigue limit states.

4.2 Description of the Bridge Prototypes Used in the Parametric Study

To investigate the structural response of straight and curved composite multiple-box bridges, it is important to define geometric parameters that correspond to box girder bridges. These parameters include: span length, number of boxes, number of lanes, and span-to-radius of curvature ratio. In this study, 5 sets of 45 different composite concrete-deck steel box girder bridges were analyzed according to CHBDC specifications (16). The first set represents straight bridges while the remainder have different curvatures. Table 4.1 summarizes the different basic bridge prototypes of the straight box girder bridges used in this study. The symbols used in the first column in Table 4.1 represent designations of the bridge types considered: *l* stands for lane; *b* stands for box; *ss* stands for simply-supported and straight and *sc* stands for simply-supported and curved; and the number at the end of the designation represents the span length in meters. For example, *4l-4b-sc*-80 denotes a bridge of 4 lanes, 4 boxes, simply-supported and curved, and of 80 m span. Figure 4.1 shows the basic cross-sectional configurations and symbols as presented in Table 4.1.

In conducting this parametric study, the span length of the bridges varied from 20 m to 100 m and the number of lanes was taken as 2, 3, and 4. The CHBDC Code (16) recommends that each lane width for bridges and ramps of two or more lanes should be 3.75 meters. According to these recommendations plus the part of the side walk on each side of a bridge, the bridge widths were taken as : 9.30 m in the case of two-lane, 13.05 m in the case of three-lane, and 16.80 m in the case of four-lane bridges. The number of box girders ranged from 2 to 4 in the case of two-lane, 3 to 5 in the case of three-lane, 4 to 6 in the case of four-lane. To change the number of box girders for the same lane width, the thicknesses of the steel top flanges, webs, and bottom flange were changed to maintain the same shear stiffness of the webs and overall flexural stiffness of the cross-section. Appendix A shows the geometric configurations of the 45 bridges considered in this study.

The transverse geometry and the radius of curvature were also changed, for each bridge included in the parametric study to investigate their effects on the structural response. The number of cross-bracings between support lines and the top-chords was varied depending on the span length and the CHBDC recommendation of having at least 7.5 meters maximum spacing between bracing lines. Accordingly, the number of internal bracing lines between supports was maintained 3 for 20-meter spans, 5 for 40-meter spans, 7 for 60-meter spans, 11 for 80-meter spans and 17 for 100-meter spans. The number of external bracing was always taken two more than the internal ones due to the fact that a brace is placed between the box girders at the supports where there is normally a solid steel diaphragm in the case of internal bracing.

In this study, it was assumed for all curved bridges that the radii of curvature do not change and the concrete decks have constant elevations. The degree of curvature is represented by the span-to-radius curvature ratio, L/R, where L is the arc length along the centre line span of the cross-section and the radius of curvature, R, is the distance from the origin of the bridge curvature to the centre line of the cross-section. The L/R ratios considered in this study were; 0.0 in case of straight bridges and 0.4, 1.4, 1.0 and 2.0 in case of curved bridges. The higher values of L/R along with the lower value of the span length, 20 m, are theoretically possible to analyze but practically are uncommon for curved highway bridges since the Geometric Design Standards for Ontario Highways (80) only allow using curved bridges with radius of curvature ≥ 45 m. However, the inclusion in this study of a smaller radius of curvature serves to show the trend of the structural response of curved bridges within certain limits of L/R.

The ranges of the parameters considered in this study are based on an extensive survey of actual designed bridges [Johanson and Mattock (56); Chapman et al. (19); Heins (49)]. For the parametric studies, the material properties (modulus of elasticity, and Poisson's ratio) for the concrete deck, steel boxes, diaphragms, and bracing systems are taken to be the same for all the cases studied as indicated in Table 4.2.

4.3 Loading Conditions of Composite Multiple Box Girder Bridges at Service

In this section, different truck loading conditions considered on the analysis of bridges are outlined to determine their load distribution factors. The CHBDC truck loading considered in this study includes truck and lane loading. The lane loading is provided merely as a convenience to avoid the placing of more than one truck in one lane in bridges with large spans. For live loading, the Canadian Highway Bridge Design Code (16) specifies a truck with a gross weight of 625 kN (CL-625). The CHBD lane loading consists of a truck reduced to 80% of the specified gross weight and a uniformly distributed live load of 9 kN/m with impact applied centrally on a 3.0 m wide area. Figures 4.2 and 4.3 summarize the configurations of the CHBDC truck loading and lane loading.

According to CHBDC, the two types of live load (the truck loading and the equivalent lane loading) were first applied to a straight girder to determine which case produces the maximum effect in bridges of 20, 40, 60, 80, and 100 m span. When studying shear distribution in bridge prototypes, the trucks were placed close to the supports for maximum shear force results. Then, three loading cases were considered for each bridge prototype, as shown in Figure 4.4, for ultimate limit state design. These loading cases are: (i) fully loaded lanes with CHBDC truck loading; (ii) partially loaded lanes with CHBDC truck loading in the inner lane(s); and (iii) partially loaded lanes with CHBDC truck loading in the outer lane(s). In case of loading conditions for fatigue limit state design, only a truck loading was considered at the center of a traveling lane as shown in Figure 4.5. As a result, two loading cases were considered for each bridge. In the two partial loading cases of the ultimate limit state design, Figures 4.4.b and 4.4.c, the wheel loads close to the curbs were applied at a distance 0.6 m from the inside edge of the curbs. However, the only partial loading case for fatigue limit state design, Figure 4.5, the wheel loads were considered so that the truck is in the centre of the outer lanes.

4.4 Parametric Study

This parametric study examined the effects of bridge span, number of lanes, number of boxes, and curvature on the shear distribution factors for both ultimate and fatigue limit states.

The parametric study was conducted on the simply-supported curved composite concrete deck-steel box girder bridge prototypes, shown in Appendix A to:

1. Investigate the influence of major parameters affecting the shear distribution, for both ultimate and fatigue limit states throughout the bridge cross-section;
2. Generate a database for maximum shear distribution factors the different CHBDC truck live load cases.

The parametric study was based on the following assumptions:

1. The reinforced concrete slab deck had complete composite interaction with the top steel flange of the boxes (100% shear interaction);
2. The bridges were simply-supported;
3. All materials were elastic and homogenous;

4. The effect of road superelevation, outer-web-slope, and curbs were ignored;
5. Solid end-diaphragms were used in the radial direction and their material and thickness were taken to be the same as those of the webs;
6. Bridges had constant radii of curvature between support lines.

4.5 Calculation of Shear Distribution in Simply-Supported Straight and Curved Composite Multi-Box Girder Bridges

In order to determine the shear distribution factor, F_V, carried by each box girder, the maximum shear, V, was calculated in a simply-supported beam when subjected to wheel loads of a CHBDC truck with lane load as a line load per meter long of the bridge in the case of 20, 40, 60, 80 and 100m span bridges. From the finite-element modeling, the shear forces of the girder webs at the supports were obtained for different cases of loading. From these shear forces the maximum shear forces carried by each girder web, $V_{F.E,}$ were obtained for all the prototype bridges. Using the Obtained $V_{F.E}$ and the calculated V, the shear distribution factor, F_V, carried by each box girder was calculated as follows:

$$F_V = \frac{2V_{F.E}NR_L'}{nVR_L}$$

Where

N = number of box girders

n = the number of design lanes as determined from Table 2.1

R_L = modification factor for design lanes as determined from Table 2.2

R_L' = modification factor for multilane loading as determined from Table 2.2

Previous work done by Sennah et al. (90) revealed that changing the type of cross bracing system had an insignificant effect on stress distribution. In practice, X-type bracings as well as top-chords (lateral ties to the steel top flanges) are made from single or back-to-back angles. This work showed that replacing the angle cross-section by rectangular one, or changing the bracing cross-section from 25×25 mm to 150×150 mm, has no effect on load distribution. Therefore, it was decided to conduct the parametric study with X-bracings and top-chords having a 100×100 mm rectangular cross-section.

In terms of bracing effect, pervious work conducted by Nour (72) showed that having internal bracings improved the ability of the cross section to transfer loads from one girder to an adjacent one. Also, warping stresses due to torsion and distortion were significantly reduced. However, the addition of external bracing (between boxes) did not have a significant effect on the stress distribution. Based on this finding, and for consistency reasons, the current parametric study presented here, considered internal and external bracings, in accordance with the minimum spacing required by CHBDC, for all the studied bridges.

Chapter V

RESULTS FROM PARAMETRIC STUDY

5.1 General

In this chapter, the effect of different key parameters on the shear distribution factors for the straight and curved composite multiple-box girder bridges were conducted according to different cases of loadings as shown in Figure 4.4 for the Ultimate Limit State, and Figure 4.5 for the Fatigue Limit State. A total of 45 simply-supported composite multiple-box girder bridges with 5 different span lengths, were modeled and analyzed to evaluate their structural response for Ultimate Limit State, and Fatigue Limit State designs. The key parameters considered in this study were: bridge span-to-radius of curvature ratio, L/R; numbers of steel boxes, N_B; number of traffic lanes, N_L; bridge span length, L, and loading conditions. Due to the large amount of data generated for bridges considered in this study, it is not practical to graphically illustrate each observation for each one of them; thus, selected bridge configurations were used to illustrate the behavior of such bridges due to truck loading conditions.

5.2 Shear Distribution in Simply-Supported Straight and Curved Composite Multiple Box Girder Bridges for Ultimate Limit State Design

A practical-design-oriented parametric study was conducted to estimate the shear force response of the bridges box girders due to CHBDC truck loading cases for the ultimate limit sate design. Then, the shear distribution factor will be calculated as follows:

$$F_V = \frac{2V_{F.E}NR_L'}{nVR_L} \quad (5.1)$$

where:

N = number of box girders;

n = the number of design lanes as determined from Table 2.1;

R_L = modification factor for design lanes as determined from Table 2.2;

R_L' = modification factor for multilane loading as determined from Table 2.2;

V_{FE} = maximum shear force in the girder web as obtained from the finite element analysis; and

V = maximum shear force at the support of a straight simply supported idealized Girder.

To simplify the results for the shear distribution factors for box girders in bridge cross section, three box girders were only considered, namely: the outer box girder which is the farthest girder from the centre of curvature, the middle girder which is at or closest girder to, bridge centerline, and the inner girder which is the closest one to the center of curvature. The following subsections present the effects of key parameters on the shear distribution factors of the studied bridges.

5.2.1 Effect of Bridge Span Length

The influence of bridge span length on the shear load distribution carried by the innermost, intermediate, and outermost, girders was studied. Figures 5.1, 5.2, and 5.3

illustrate this effect on four-lane, four-box, girder bridges with different curvature ratio due to fully loaded lanes with CHBDC truck loading. It can be observed that for curved bridges, for inner girders, the increase of span length results in an increase in the absolute value of shear distribution. It should be noted that the rate of increase of the shear distribution factor with increase in span length increases with increase in span-to-radius of curvature ratio (L/R). This is attributed to the increasing torsional effects with the increase in bridge curvature. For central girders, the increase of span length is observed to have insignificant change in the shear distribution factor of bridges with low curvature, irrespective of the change in bridge span length. However, for bridges with high curvature, the shear distribution factor slightly decreases with increase in span length up to 60 m. Then it slightly increases with increase in span length. For example, the shear distribution factor for bridges with span-to-radius ratio of 2 decreases from 3.38 for span length of 20 m to 3.06 for span length of 60 m. Then, it increases to 4.42 for a span length of 100 m. Also, for span-to-radius of curvature ratio of 1.0, the shear distribution factor decreases from 1.92 for span length of 20 m to 1.63 for span length of 60 m. Then, it increases to 2.02 for span length 100 m.

Figures 5.4, 5.5, and 5.6 illustrate the effect of span length on shear distribution factors of the inner, central and outer girders, respectively, of four-lane, four-box, girder bridges due to inner lanes loading. It can be observed that for the inner girder, the increase of span length results in an increase in the absolute value of the shear distribution factor for bridges with span-to-radius of curvature ratio greater than 0.4. For span-to-radius of curvature ratio less than 0.4, insignificant change in the shear distribution factor is observed with increase in span length. For example, the shear distribution factor of span-to-radius ratio of 2, the shear distribution factor changes from -0.10 for span length of 20 m to -3.61 for span length of 100 m. Comparing Figure 5.1 for fully loaded lanes and Figure 5.2 for partial loading in the inner lanes, it can be observed that the case of fully loaded lanes provides the design shear distribution factor for the inner girder of bridges with high curvature. For outer girders, the increase of span length of curved bridges results in an increase in the shear distribution factor, with a rate increasing with increase in bridge curvature. For example, for L/R = 2, the shear distribution factor changes from 0.21 in the case of 20 m span to 3.67 in the case of 100 m span. However, for L/R = 0.4, it changes from -0.10 in the case of 20 m span to 0.18 in the case of 100 m span. It can be also observed that the case of inner lanes loaded with CHBDC trucks, an uplift is observed at the supports as depicted by negative values of the shear distribution factors for straight bridges and bridges with very low curvature.

Figures 5.7, 5.8, and 5.9 depict the effect of span length on the shear distribution factors of the outer girder of four-lane, four-box girder bridges due to outer lanes loading. For inner girders, it can be observed that loading the outer lanes with CHBDC trucks always causes uplift at the innermost girder for both straight and curved bridges, irrespective of the degree of curvature. This may be attributed to the increase in torsion loading effects as a result of load eccentricity to the center line of the bridge as well as the increase in bridge curvature. For example, for L/R of 2, the shear distribution factor changes from -5.22 in case of 20 m span bridge to -7.85 in case of 00 m span bridge. However, for L/R = 0.4, changes from -0.72 in the case of 20 m span bridge to -1.42 in the case of 100 m span bridge. For central girders, the increase of span length has insignificant change in the shear distribution factor for straight bridges. However, for curved bridges, the shear distribution factor decreases with increase in bridge span up to 60 m. Then, a slight change is observed for bridges with span length more than 60 m. For example, for L/R = 2, the shear distribution factor changes from 4.16 in the case of 20 m span bridge to 2.32 in the case of 60 m span bridge. However, the shear distribution factor for 100 m span bridge is 2.31. For outer girders, the increase of span length results in an increase in the shear distribution factor for curved bridges, with a rate increasing with increase in L/R ratio. For straight bridges, insignificant effect is observed. For example, for L/R = 2, the shear distribution factor changes from 5.02 in the case of 20 m span bridge to 7.6 in the case of 100 m span bridge. However, for L/R of 0.4, the shear distribution factor changes from 2.13 in the case of 20 m span bridge to 2.63 in case the of 100 m span bridge.

5.2.2 Effect of Number of Design Lanes and Number of Box Girders

The influences of the number of design lanes and the number of box girders on the shear load distribution factors for the innermost, central and outermost girders were studied due to different truck loading conditions. Figures 5.10, and 5.11 presents the shear forces and corresponding shear distribution factors for the innermost girder of bridges of 80 m span and curvature ratio of 1.0, due to fully loaded lanes with CHBDC trucks. It can be observed that for the same number of boxes, the shear force carried by the inner girder increases with the increase in number of design lanes. It can be noted that this shear forces are upward forces representing uplift at the inner support point. For example, for four-box bridges, the shear force changes from -522 kN in case of two-lane cross-section to -883 kN in the case of four-lane cross-section. On the other hand, for the same number of lanes, the value of shear force decreases with the increase in number of boxes. However, it can be observed from Figure 5.11, that for the same number of boxes, the shear distribution factor for the inner girder decreases with the increase in the number of design lanes. For example, for four-box bridges, the shear distribution factor changes from -2.47 in the case of two-lane cross-section to -2.12 in the case of four-lane cross-section. Also, it can be observed that the number of boxes have insignificant effect on the shear distribution factor.

Figure 5.12 and 5.13 present the shear forces and corresponding shear distribution factors for the outer girder of bridges of 80 m span and curvature ratio of 1.0, due to fully loaded lanes with CHBDC trucks. It can be observed that for the same number of boxes, the shear force increases with the increase of the number of design lanes. For example, for four-box bridge, the shear force increases from 758 kN in the case of two-lane cross-section to 1294 kN in the case of four-lane cross-section. On the other hand, for the same number of design lanes, the shear forces decreases with the increase in number of boxes in bridge cross-section. For example, for two-lane bridge, the shear force decreases from 1520 kN in the case of two-box section to 758 kN in the case of four-box section. However, it can be observed from Figure 5.13, that for the same number of boxes, the shear distribution factor for the outer girder decreases with the increase in the number of design lanes. For example, for four-box bridges, the shear distribution factor changes from 3.80 in the case of two-lane cross-section to 3.23 in the case of four-lane cross-section. Also, it can be observed that the number of boxes have insignificant effect on the shear distribution factor.

5.2.3 Effect of Bridge Curvature

The influence of bridge curvature on the shear distribution factor of the innermost, central, and outermost girders was studied. In this study, curvature is represented by the bridge span-to-radius of curvature ratio, L/R. Figures 5.14, 5.15, and 5.16 explain this effect for a four-lane, four-box, girder bridge of 80 m span, due to fully loaded lanes, partially loaded in the inner lanes and partially loaded in the outer lanes, respectively. It can be observed that for fully loaded lanes, the increase in the curvature ratio results in an increase in the shear distribution factor for the outer girder from 0.79 in the case of straight bridge to 7.36 in the case of bridge with curvature ratio of 2. While the increase in L/R ratio changes the shear distribution factor for the inner girder from 0.79 in the case of straight bridges to -8.05 in can of curvature ratio of 2, resulting in an uplift forces at the innermost support point. In case of the central girder, the shear distribution factor increase with increase in span-to-radius of curvature ratio but with a rate less than that for the outer girder as depicted from Figure 5.14. For example, the shear distribution factor for the central girder changes from 1.04 in can of straight bridges to 3.48 in the case of bridges with curvature ratio of 2.

For inner lanes loading, Figure 5.15 shows similar trend to the case of fully loaded lanes. However, the shear distribution factors in case of fully loaded lanes appear to be more than those in case of inner lanes loading condition, thus, they govern the design for curved bridges. In both loading cases, it can be observed that the shear force at the innermost girder changes from downward force to upward force with increase in curvature, causing uplift at the support point.

Figure 5.16 shows similar results to those for fully loaded lanes except that an uplift is observed at the inner support far away from loading location in the outer lanes in case of straight bridges of L/R = 0. In Figure 5.16, The increase of curvature results in an increase in the shear distribution factor positively from 1.47 in the straight bridge to 5.79 in curvature (L/R) of 2 for the outer girders and negatively from -0.44 in the straight bridge to -6.36 in curvature (L/R) of 2 for the inner girders. Figures 5.17, and 5.18 represent the influence of the curvature on the shear distribution factor of inner and outer girders, respectively, of four-lane bridges with 80 m span due to fully loaded lanes. It is clearly observed that the shear distribution factor increases with the increase of curvature for both the inner and the outer box girders. However, this effect is not changed with different number of boxes as described in Figures 5.11 and 5.13 previously.

5.3 Shear Distribution in Simply-Supported Straight and Curved Composite Multiple Box Girder Bridges for Fatigue Limit State Design

The following subsection present the results from the parametric study on the shear distribution factors due to fatigue loading cases that can be used for fatigue limit state design. In this case, only one lane is loaded with CHBDC truck located at the centerline of the lane. As such, the shear distribution factor for fatigue loading cases is calculated using Equation 5.1 but with a multi-lane loading factor of 1.0.

5.3.1 Effect of Bridge Span Length

The influence of bridge span length on the shear distribution factor for the innermost, central, and outermost girders was studied due to two different cases of loading, namely: truck loading in the middle lane and truck loading in the outer lane. Figures 5.19, 5.20, and

5.21 illustrate this effect due to truck loading in the middle lane of a four-lane, four-box, girder bridges with different curvatures and span lengths. It can be observed that the shear distribution factor for the inner girder decreases with increase in span length, with all shear forces causing uplift at the innermost support point. However, the shear distribution factor for the central girders decreases with the increase of span length, with downward forces at the outmost support point. For outer girders, the increase of span length is observed to have a slight decrease in the shear distribution factor. For example, the shear distribution factor for the outer girder of bridges with span-to-radius ratio of 2 decreases from 0.89 in the case of 20 m span to 0.82 in the case of 100 m span. For L/R of 1.4, the shear distribution factor changes from 0.42 in the case of 20 m span to 0.40 in the case of 100 m span.

Figures 5.22, 5.23, and 5.24 present the effect of bridge span length on shear distribution factor of the innermost, central and outmost girders of a four-lane, four-box, girder bridges due to truck loading located at the centre of the outer lane. It can observed that the shear distribution factor of the inner girder decrease with increase in span length, causing uplift at the innermost support point. Comparing the results shown in Figures 5.22 and 5.19, it can be observed that the case of truck loading in the outer lane provides the design shear distribution factor for the innermost girder for fatigue limit state design. Figure 5.23 shows the change in shear distribution factor for the central girder due to truck loading located at the center of the middle lane. Comparing Figures 5.23 and 5.20, similar trend can be observed but the values obtained from outer lane loading case provide the design shear distribution factor for fatigue design of such girder.

Figure 5.24 shows the change on the shear distribution factor for the outer girder due to truck loading located at the centre of the outer lane. In contrast to the results shown in Figure 5.21 for the outer girder, it can be observed that the shear distribution factor for the outer girder decreases with the increase in bridge span length, irrespective of the degree of curvature. Also, the case of truck loading located in the outer lane, provides the design value for fatigue design of the outer girder.

5.3.2 Effect of Number of Design Lanes and Number of Box Girders

The influences of the number of design lanes and the number of box girders in bridge cross-section on the shear distribution factors of the innermost, central, and outermost girders were studied. Figures 5.25, 5.26 show these effects in the inner girder of a four-lane, four-box, girder bridge with curvature ratio of 1.0 and span length of 80 m, due to CHBDC truck loading located at the centre of the middle lane. It can be observed that the shear force carried by the innermost girder increases with increase in number of design lanes, with the same number of boxes in bridge cross-section, causing uplift at the innermost support point as depicted from the negative sign of force. For example, the shear force carried by the innermost girder in a four-box cross-section increases from -93 kN in the case of three-lane bridge to -123 kN in the case of four-lane bridge. On the other hand, for the same number of lanes, the shear force decreases with increase in number of boxes in a bridge cross-section. However, it can be observed from Figure 5.26, that for the same number of boxes, the shear distribution factor for the inner girder decreases with the increase in the number of design lanes. For example, for four-box bridges, the shear distribution factor slightly changes from -0.32 in the case of three-lane cross-section to 0.30 in the case of four-lane cross-section.

Also, it can be observed that the shear distribution factor, slightly increases with the increase of number of boxes. For example, for four-lane bridges, the shear distribution factor slightly changes from -0.30 in the case of four-box cross-section to -0.34 in the case of six-box cross-section.

Figures 5.27 and 5.28 show the change in the shear force and the corresponding shear distribution factor of the outer girder, respectively, in a bridge with curvature ratio of 1 and span length of 80 m, due to CHBDC truck loading located at the centre of the middle lane. It can be observed that for the same number of design lanes, the shear force carried by the outer girder decreases with the increase in number of boxes. On the other hand, for the same number of boxes, the shear force increases with increase in number of design lanes. However, it can be observed from Figure 5.28, that for the same number of boxes, the shear distribution factor for the outer girder decreases with the increase in the number of design lanes. For example, for four-box bridges, the shear distribution factor slightly changes from 0.46 in the case of three-lane cross-section to 0.40 in the case of four-lane cross-section. Also, it can be observed that the shear distribution factor, slightly increases with the increase of number of boxes. For example, for four-lane bridges, the shear distribution factor slightly changes from 0.40 in the case of four-box cross-section to 0.43 in the case of six-box cross-section.

5.3.3 Effect of Bridge Curvature

The influence of bridge curvature on the shear distribution factor for the innermost, central, and outermost girders was studied due to fatigue loading cases mentioned earlier.

Figures 5.29 and 5.30 illustrate this effect in case of a four-lane, four-box, girder bridge of 80 m span due to CHBDC truck loading located at the center of the middle lane and outer lane, respectively. It can be observed that the shear distribution factors of the outer and central girders increase with increase in span-to-radius of curvature ratio. However, the shear distribution factor of the inner girder decreases with increase in curvature ratio as a result of uplift from torsion effect. Figures 5.31 and 5.32 represent the influence of the curvature on the shear distribution factor for the inner and outer girders, respectively, of a four-lane box girder bridges of 80 m span due to CHBDC truck loading located at the centre of the middle lane. It is clearly observed that the shear distribution factor increases with the increase of curvature for both the inner and the outer box girders. However, this effect is not changed with different number of boxes as described in Figures 5.26 and 5.28 previously.

5.4 Comparison between the Shear Distribution Factor from Finite-Element Analysis and CHBDC Equations

Figures 5.33 and 5.34 present a comparison between the shear distribution factors for straight bridges obtained from the current finite element analysis and from CHBDC simplified method of analysis shown in Chapter 2, for ultimate limit state and fatigue limit state, respectively. It is clearly evident that the shear distribution factors calculated from the CHBDC equations highly over estimate the design parameter. Also, CHBDC equations do not include number boxes as a variable, considering it having no effect on the shear distribution factor. As a result, empirical expressions for shear distribution factors for straight bridges are developed as shown in the following section to provide more economical and reliable design of such bridges.

5.5 Empirical Formulae for the Shear Distribution Factors for Straight Bridges

Based on the data generated from the parametric study on straight bridges, empirical equations for the shear distribution factors of the outer and middle girders are developed for ultimate and fatigue limit state designs. The Newton-Raphson technique was used to optimize the minimum square root error. These equations include the following parameters: (i) bridge span length, L; (ii) number of boxes, N_B; and (iii) number of lanes. It should be noted that the data used to derive these expressions represents the design values for the outer girder and intermediate girders. These design values are the highest values for a specific girder from all the loading cases considered in the analysis. In these expressions, the span length is considered in meters. It should be noted that cross-bracing systems, with spacing not exceeding 7.5 m is required to apply these expressions in the design process. A

The following expressions are the shear distribution factor in straight bridges due to CHBDC loading for ultimate limit state design:

1-For two-lane bridges:

D_{ss} (Outer) = $1.32\, L^{0.01}\, N_b^{-0.06}$

D_{ss} (Middle) = $1.35\, L^{0.01}\, N_b^{-0.12}$

2-For three-lane bridges:

D_{ss} (Outer) = $1.42\, L^{0.02}\, N_b^{-0.08}$

D_{ss} (Middle) = $1.35\, L^{-0.05}\, N_b^{-0.04}$

***3-For four-lane bridges*:**

D_{ss} (Outer) = 1.54 $L^{0.04}$ $N_b^{-0.09}$

D_{ss} (Middle) = 1.51 $L^{-0.08}$ $N_b^{0.01}$

The following expressions are the shear distribution factor in straight bridges due to CHBDC truck loading for fatigue limit state design:

1-For two-lane bridges:

D_{ss} (Outer) = 2.87 $L^{-0.26}$ $N_b^{-0.28}$

D_{ss} (Middle) = 1.55 $L^{-0.25}$ $N_b^{0.10}$

2-For three-lane bridges:

D_{ss} (inner and outer) = 3.44 $L^{-0.27}$ $N_b^{-0.37}$

D_{ss} (middle) = 2.12 $L^{-0.44}$ $N_b^{-0.24}$

3-For four-lane bridges:

D_{ss} (Outer) = 7.1 $L^{-0.30}$ $N_b^{-0.61}$

D_{ss} (Middle) = 3.91 $L^{-0.49}$ $N_b^{-0.25}$

Figures 5.35 and 5.36 show the correlation between the shear distribution factors from the proposed equations and the finite element analysis for ultimate limit state and fatigue limit state designs, respectively. Excellent correlation is observed. Also, comparing

Figures 5.33 and 5.34 with Figures 5.35 and 5.36, one may observe the enhancement in the correlation as a result of considering the proposed equations in design.

Chapter VI

RESULTS FROM ARTIFICIAL NEURAL NETWORK SIMULATION

6.1 General

In this chapter, the application of Artificial Neural Network (ANN) was conducted to simulate the shear distribution factors in composite multiple-box girder bridges subjected to CHBDC truck loading, with respect to the different parameters, considered in the parametric study. The database used for training and testing the ANN was obtained from an extensive parametric study using the finite-element "ABAQUS" software as shown in the previous chapter. This database included various parameters such as bridge curvature, span length, number of steel boxes, and number of traffic lanes. The methodology of the Feed Forward Network structure with the Back Propagation training was used in ANN modeling as indicated in Figure 6.1. Both batch and pattern modes have been attempted to update the weights in the Network to optimize the error between the ANN output and the target output.

6.2 Database Collection

The quality and amount of the data collected for training and testing the neural network are necessary in producing a model that can make accurate prediction. The 225 database results obtained from the finite-element analysis were divided into 180 sets for training the networks, and 45 sets for testing and verifying the best models.

6.3 ANN Models

Considering the backpropagation training using batch mode, different Neural Network Architectures were studied using the NeuralWorks Professional II/PLUS software (70). Tables 6.1 and 6.2 show the best network architectures of batch mode using one and two hidden layers, respectively, for the shear distribution factor in the outer girder due to inner-lane(s) loading. Tables 6.3 and 6.4 show the best network architectures of batch mode using one and two hidden layers, respectively, for the shear distribution factor in the outer girder due to fully-loaded lane(s). Tables 6.5 and 6.6 show the best network architectures of batch mode using one and two hidden layers, respectively, for the shear distribution factor in the outer girder due to outer-lane(s) loading. Tables 6.7 and 6.8 show the best network architectures of batch mode using one and two hidden layers, respectively, for the shear distribution factor in the inner girder due to inner-lane(s) loading. Tables 6.9 and 6.10 show the best network architectures of batch mode using one and two hidden layers, respectively, for the shear distribution factor in the inner girder due to fully-loaded lane(s). Tables 6.11 and 6.12 show the best network architectures of batch mode using one and two hidden layers, respectively, for the shear distribution factor in the inner girder due to outer-lane(s) loading. Tables 6.13 and 6.14 show the best network architectures of batch mode using one and two hidden layers, respectively, for the shear distribution factor in the outer girder due to inner-lane(s) loading. Tables 6.15 and 6.16 show the best network architectures of batch mode using one and two hidden layers, respectively, for the shear distribution factor in the outer girder due to fully-loaded lane(s). Tables 6.17 and 6.18 show the best network architectures of batch mode using one and two hidden layers, respectively, for the shear distribution factor in the outer girder due to outer-lane(s) loading.

In those tables described above, the second column represents the architecture of the attempted network. This architecture is described by 3 digits in case of one-hidden layer networks and 4 digits in case of two hidden-layer networks. The third column represents the root mean square error (RMS), and the fourth column represents the correlation (R^2). This effect does not depend on a specific variation in the number of the neurons as shown in the tables. However, different trials should be considered to obtain the best performance. The best architecture is considered the one with the minimum RMS and maximum R^2. From the results, it can be observed that the performance of the network is affected by the number of the hidden layers and the number of the neurons in each hidden layer. For example, in Table 6.7, network N54 has the best architecture 4-10-1 with ten neurons in the hidden layer, as it produced a minimum RMS of 0.03 and a maximum R^2 of 0.98.

6.4 Effect of Hidden Layers

Nine different architectures were used when considering one hidden layer, and seven different architectures were used when considering two hidden layers for inner, middle, and outer girders under inner-lane(s) loading, fully-loaded lanes and outer-lane(s) loading, respectively, with a total of 144 architectures. Figures 6.2, 6.3, and 6.4 show comparisons between the convergence of the best one-hidden layer architecture and the best two-hidden layer architecture for the shear distribution factor of the outer girder due to Inner-Lane(s) loading, fully-loaded lanes and outer-lane(s) loading, respectively. Figures 6.5, 6.6, and 6.7 show comparisons between the convergence of the best one-hidden layer architecture and the best two-hidden layer architecture for the shear distribution factor of the inner girder due to inner-lane(s) loading, fully-loaded lanes and outer-lane(s) loading, respectively. Figures 6.8, 6.9, and 6.10 show comparisons between the convergence of the best one-hidden layer architecture and the best two-hidden layer architecture for the shear distribution factor of the middle girder due to inner-lane(s) loading, fully-loaded lanes and outer-lane(s) loading, respectively. In these figures, the horizontal axis represents the number of epochs, which is the number of training cycles in the learning process, while the vertical axis represents the root mean square error (RMS). It can be observed that most of the convergence occurred when the number of epochs reached 100,000.

6.5 Effect of Number of Neurons

The performance of training using batch mode based on the root mean square (RMS) error and the correlation (R^2) was considered for the inner, middle, and outer girders under different cases of loading. Figures 6.11 and 6.12 depict the performance for the shear distribution factor of the outer box girder due to inner-lane(s) loading for one and two hidden layer(s), respectively. Figures 6.13 and 6.14 depict the performance for the shear distribution factor of the outer box girder due to fully-loaded lanes for one and two hidden layer(s), respectively. Figures 6.15 and 6.16 depict the performance for the shear distribution factor of the outer box girder due to outer-lane(s) loading for one and two hidden layer(s), respectively. Figures 6.17 to 6.22 show similar graphs for the inner girder, while Figures 6.23 to 6.28 show similar graphs for the middle girder.

From the results shown in these figures, it can be observed that for the case of inner-lane(s) loading affecting the outer box girder, the one-hidden layer architecture of 8 neurons, N5(4-8-1), showed the best results of minimum RMS error of 0.046 and highest correlation,

R^2, of 0.98. For the case of fully-loaded lanes affecting the outer box girder, the two-hidden layer architecture of 5 neurons per each hidden layer, N29(4-5-5-1), performed the best results of minimum RMS error of 0.083 and highest correlation, R^2, of 0.92. For the case of outer-lane(s) loading affecting the outer box girder, the two-hidden layer architecture of 5 neurons in the first hidden layer and 6 neurons in the second hidden layer, N46(4-5-6-1), performed the best results of minimum RMS error of 0.132 and highest correlation, R^2, of 0.96. For the case of inner-lane(s) loading affecting the inner box girder, the one-hidden layer architecture of 10 neurons, N54(4-10-1) performed the best results of minimum RMS error of 0.03 and highest correlation, R^2 ,of 0.98. For the case of fully-loaded lanes affecting the inner box girder, the two-hidden layer architecture of 5 neurons in the first hidden layer and 6 neurons in the second hidden layer, N78(4-5-6-1), performed the best results of minimum RMS error of 0.061 and highest correlation, R^2, of 0.96. For the case of outer-lane(s) loading affecting the inner box girder, the two-hidden layer architecture of 6 neurons in the first hidden layer and 8 neurons in the second hidden layer, N95(4-6-8-1), performed the best results of minimum RMS of 0.065 error and highest correlation, R^2, of 0.94. For the case of inner-lane(s) loading affecting the middle box girder, the one-hidden layer architecture of 12 neurons, N103(4-12-1), performed the best results of minimum RMS error of 0.07 and highest correlation, R^2, of 0.97. For the case of fully-loaded lanes affecting the middle box girder, the one-hidden layer architecture of 10 neurons, N118(4-10-1), performed the best results of minimum RMS error of 0.075 and highest correlation, R^2, of 0.96. For the case of outer-lane(s) loading affecting the middle box girder, the one-hidden layer architecture of 8 neurons, N133(4-8-1), performed the best results of minimum RMS error of 0.08 and highest correlation, R^2, of 0.93.

6.6 Presentation of the Best Model Results

To validate the best three models results, 45 sets of unseen data of each case of loading per each box girder were randomly chosen and used to test each model. Figures 6.29, 6.30, and 6.31 represent the correlation between the desired (FEA values) and the predicted target (ANN values) of the shear distribution factor for the inner-lane(s) loading, middle-lane(s) loading, and the outer-lane(s) loading cases affecting the outer box girders, respectively. While Figures 6.32, 6.33, and 6.34 represent the correlation between the desired and the predicted target of the shear distribution factor for the inner-lane(s) loading, middle-lane(s) loading, and the outer-lane(s) loading cases affecting the inner box girders, respectively. Figures 6.35, 6.36, and 6.37 show similar presentations for the middle girder.

Chapter VII

SUMMARY AND CONCLUSION

7.1 Summary

Because of the lack of information regarding the shear distribution factor, an extensive parametric study was conducted to examine the structural behavior and simplify the structural analysis of straight, and horizontally curved composite box-girder bridges due to the CHBDC truck live loading for both ultimate limit state and fatigue limit state. Different cases of fully and partially loading were considered, to establish the effect of different key parameters, such as the span length, the curvature, the number of box girders, and the number of traffic lanes on the shear distribution factor. The finite element software ABAQUS was used in modeling 450 models. Because it is difficult to provide empirical expressions for a wide range of parameters for a specific bridge type without overestimating some of the design parameters, the generated database was examined by using the Artificial Neural Network simulation.

7.2 Conclusion

The structural behavior of composite box-girder bridges, represented by the shear distribution factor, is affected by a range of key parameters such as bridge span length, span-to-radius of curvature ratio, number of box girders, number of traffic lanes and truck loading conditions. The following subsections summarize the conclusions drawn from this study.

7.2.1 Shear Distribution Characteristics of Composite Box-Girder Bridges

1- Bridge span length slightly affects the shear distribution factor of straight bridges. However its effect significantly increases with increase in bridge curvature.

2- Although the results show a significant change in the shear forces carried by each girder with the increase in number of boxes in a bridge cross-section, the corresponding shear distribution factors for such girders are insignificantly affected by the change in number of boxes.

3- Bridge curvature proved to be the most important parameter affecting the shear distribution factor of the outmost, middle and innermost girders, irrespective of the truck loading condition.

4- Based on the data generated from the parametric study on straight bridges, empirical expressions for the shear distribution factors for the outer and middle girders were developed. These proposed expressions proved to be more economical and reliable than the available simplified method specified in the Canadian Highway Bridge Design Code.

5- Few attempts have been made to develop similar expressions for bridges in curved alignment. However, high level of conservatism is observed. As a result, an Artificial Neural Network (ANN) approach was investigated to examine the potential of utilizing it in storing the database generated from the parametric study for curved bridges and for better predication of their shear distribution factors.

7.2.2 Shear Distribution Model using the Artificial Neural Network Simulation

1-The application of the Artificial Neural Network (ANN) can simplify the multi-dimensional structural behavior of the shear distribution in the composite multiple box-girder bridges to a one-dimensional problem with successful results.

2-Many ANN architectures should be used to obtain the best accurate model.

3-The two hidden layer architectures, generally generated better results of minimum root mean square error and maximum correlation than the one-hidden layer architectures.

4- The resulting ANN models can be easily incorporated in available bridge design software for the predication of shear distribution factors of such bridges.

7.3 Recommendations for Future Research

It is recommended that further research can be done in the following:

1- The shear distribution in curved continuous composite box girder bridges due to CHBDC truck loading.

2- Different methodologies, other than the Feedforward, in training the ANN model to simulate the shear distribution in composite box girder bridges.

3- Load distribution in straight and curved bridges at the ultimate limit state, incorporating both material and geometric nonlinearity.

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Bridge span	Type	Depth	Width of girder	No of Intermediate Diaphragms	No of Lanes	Total Width	No of girders	No of Design Lanes
m		mm	mm			mm		
25	WF-CPCI 1600	1600	2000	1	2	14000	7	3
				1	3	16000	8	4
				1	3	18000	9	5
			2200	1	2	13200	6	3
				1	3	15400	7	4
				1	3	17600	8	5
			2400	1	2	12000	5	3
				1	3	16800	7	4
				1	4	19200	8	5
25	WF-CPCI 1600	1600	2000	2	2	14000	7	3
				2	3	16000	8	4
				2	3	18000	9	5
			2200	2	2	13200	6	3
				2	3	15400	7	4
				2	3	17600	8	5
			2400	2	2	12000	5	3
				2	3	16800	7	4
				2	4	19200	8	5
30	WF-CPCI 1600	1600	2000	0	2	14000	7	3
				0	3	16000	8	4
				0	3	18000	9	5
			2200	0	2	13200	6	3
				0	3	15400	7	4
				0	3	17600	8	5
			2400	0	2	12000	5	3
				0	3	16800	7	4
				0	4	19200	8	5
30	WF-CPCI 1600	1600	2000	1	2	14000	7	3
				1	3	16000	8	4
				1	3	18000	9	5
			2200	1	2	13200	6	3
				1	3	15400	7	4
				1	3	17600	8	5
			2400	1	2	12000	5	3
				1	3	16800	7	4
				1	4	19200	8	5

Cont.

Bridge span	Type	Depth	Width of girder	No of Intermediate Diaphragms	No of Lanes	Total Width	No of girders	No of Design Lanes
m		mm	mm			mm		
30	WF-CPCI 1600	1600	2000	2	2	14000	7	3
				2	3	16000	8	4
				2	3	18000	9	5
			2200	2	2	13200	6	3
				2	3	15400	7	4
				2	3	17600	8	5
			2400	2	2	12000	5	3
				2	3	16800	7	4
				2	4	19200	8	5
35	WF-CPCI 1600	1600	2000	0	2	14000	7	3
				0	3	16000	8	4
				0	3	18000	9	5
			2200	0	2	13200	6	3
				0	3	15400	7	4
				0	3	17600	8	5
			2400	0	2	12000	5	3
				0	3	16800	7	4
				0	4	19200	8	5
35	WF-CPCI 1600	1600	2000	1	2	14000	7	3
				1	3	16000	8	4
				1	3	18000	9	5
			2200	1	2	13200	6	3
				1	3	15400	7	4
				1	3	17600	8	5
			2400	1	2	12000	5	3
				1	3	16800	7	4
				1	4	19200	8	5
35	WF-CPCI 1600	1600	2000	2	2	14000	7	3
				2	3	16000	8	4
				2	3	18000	9	5
			2200	2	2	13200	6	3
				2	3	15400	7	4
				2	3	17600	8	5
			2400	2	2	12000	5	3
				2	3	16800	7	4
				2	4	19200	8	5

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Table 2.1 Number of design lanes as determined by CHBDC 2000

W_C	n
6.0m or less	1
Over 6.0 m to 10.0 m incl.	2
Over 10.0 m to 13.5 m incl.	2 or 3
Over 13.5 m to 17.0 m incl.	4
Over 17.0 m to 20.5 m incl.	5
Over 20.5 m to 24.0 m incl.	6
Over 24.0 m to 27.5 m incl.	7
Over 27.5 m	8

Table 2.2 Modification factors for multilane loading as determined by CHBDC 2000

Number of loaded design lanes	Modification factor
1	1.00
2	0.90
3	0.80
4	0.70
5	0.60
6 or more	0.55

Table 2.3 Expressions for F and C_f for longitudinal moments in multispine bridges as determined by CHBDC 2000

Limit State	Number of design lanes	F, m	C_f %
ULS of SLS	2	$8.5-0.3\beta$	$16-2\beta$
	3	$11.5-0.5\beta$	$16-2\beta$
	4	$14.5-0.7\beta$	$16-2\beta$
FLS	2 or more	$8.5-0.9\beta$	$16-2\beta$

Table 2.4 Expressions for F for longitudinal vertical shear in multispine bridges as determined by CHBDC 2000

Limit State	Number of design lanes	F, m
ULS of SLS	2	7.2
	3	9.6
	4	11.21
FLS	2 or more	4.25

Table 4.1 Geometries of the basic prototype bridges used in the parametric study

Bridge Type	Span L (m)	No. of Lanes	No. of Boxes	Cross section dimensions (mm)								
				A	B	C	D	F	t1	t2	t3	t4
2L-2b-ss-20	20	2	2	9300	2325	300	800	1025	16	10	15	225
3L-3b-ss-20		3	3	13050	2175	300	800	1025	16	10	17	225
4L-4b-ss-20		4	4	16800	2100	300	800	1025	16	10	18	225
2L-2b-ss-40	40	2	2	9300	2325	375	1600	1825	28	14	18	225
3L-3b-ss-40		3	3	13050	2175	375	1600	1825	28	14	20	225
4L-4b-ss-40		4	4	16800	2100	375	1600	1825	28	14	21	225
2L-2b-ss-60	60	2	2	9300	2325	450	2400	2625	40	18	23	225
3L-3b-ss-60		3	3	13050	2175	450	2400	2625	40	18	25	225
4L-4b-ss-60		4	4	16800	2100	450	2400	2625	40	18	26	225
2L-2b-ss-80	80	2	2	9300	2325	530	3200	3425	52	22	26	225
3L-3b-ss-80		3	3	13050	2175	530	3200	3425	52	22	28	225
4L-4b-ss-80		4	4	16800	2100	530	3200	3425	52	22	30	225
2L-2b-ss-100	100	2	2	9300	2325	600	4000	4225	64	26	30	225
3L-3b-ss-100		3	3	13050	2175	600	4000	4225	64	26	33	225
4L-4b-ss-100		4	4	16800	2100	600	4000	4225	64	26	35	225

Note: See Figure 4.1 for symbols.

Table 4.2 Material Properties for Concrete and Steel used in the parametric Study

Material Properties	Concrete	Steel
Modulus of Elasticity, E (MPa)	27,000	200,000
Poisson's ratio, υ	0.20	0.30

Table 6.1 Neural Network Architectures of one hidden layer trained using batch mode of outer girder due to inner-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N1	4-2-1	0.078	0.963
N2	4-4-1	0.049	0.985
N3	4-5-1	0.059	0.977
N4	4-6-1	0.058	0.978
N5	4-8-1	0.046	0.987
N6	4-10-1	0.048	0.985
N7	4-12-1	0.047	0.986
N8	4-13-1	0.050	0.983
N9	4-15-1	0.050	0.984

Table 6.2 Neural Network Architectures of two hidden layers trained using batch mode of outer girder due to inner-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N10	4-2-2-1	0.064	0.974
N11	4-3-3-1	0.065	0.973
N12	4-4-4-1	0.048	0.986
N13	4-5-5-1	0.063	0.975
N14	4-5-6-1	0.051	0.983
N15	4-6-8-1	0.055	0.980
N16	4-10-10-1	0.045	0.986

Table 6.3 Neural Network Architectures of one hidden layer trained using batch mode of outer girder due to fully-loaded lanes

Network	Architecture	RMS	Correlation (R^2)
N17	4-2-1	0.113	0.837
N18	4-4-1	0.107	0.856
N19	4-5-1	0.109	0.854
N20	4-6-1	0.090	0.912
N21	4-8-1	0.089	0.927
N22	4-10-1	0.091	0.898
N23	4-12-1	0.092	0.898
N24	4-13-1	0.093	0.895
N25	4-15-1	0.094	0.894

Table 6.4 Neural Network Architectures of two hidden layers trained using batch mode of outer girder due to fully-loaded lanes

Network	Architecture	RMS	Correlation (R^2)
N26	4-2-2-1	0.092	0.901
N27	4-3-3-1	0.085	0.914
N28	4-4-4-1	0.089	0.904
N29	4-5-5-1	0.083	0.921
N30	4-5-6-1	0.087	0.915
N31	4-6-8-1	0.085	0.912
N32	4-10-10-1	0.091	0.904

Table 6.5 Neural Network Architectures of one hidden layer trained using batch mode of outer girder due to outer-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N33	4-2-1	0.148	0.880
N34	4-4-1	0.147	0.881
N35	4-5-1	0.142	0.899
N36	4-6-1	0.141	0.899
N37	4-8-1	0.144	0.893
N38	4-10-1	0.137	0.903
N39	4-12-1	0.143	0.898
N40	4-13-1	0.143	0.894
N41	4-15-1	0.146	0.888

Table 6.6 Neural Network Architectures of two hidden layers trained using batch mode of outer girder due to outer-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N42	4-2-2-1	0.146	0.89
N43	4-3-3-1	0.144	0.88
N44	4-4-4-1	0.138	0.90
N45	4-5-5-1	0.144	0.89
N46	4-5-6-1	0.132	0.96
N47	4-6-8-1	0.148	0.88
N48	4-10-10-1	0.140	0.89

Table 6.7 Neural Network Architectures of one hidden layer trained using batch mode of inner girder due to inner-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N49	4-2-1	0.125	0.80
N50	4-4-1	0.122	0.80
N51	4-5-1	0.101	0.82
N52	4-6-1	0.13	0.85
N53	4-8-1	0.14	0.88
N54	4-10-1	0.03	0.98
N55	4-12-1	0.07	0.83
N56	4-13-1	0.06	0.88
N57	4-15-1	0.08	0.84

Table 6.8 Neural Network Architectures of two hidden layers trained using batch mode of inner girder due to inner-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N58	4-2-2-1	0.102	0.935
N59	4-3-3-1	0.125	0.94
N60	4-4-4-1	0.082	0.961
N61	4-5-5-1	0.052	0.97
N62	4-5-6-1	0.073	0.95
N63	4-6-8-1	0.091	0.97
N64	4-10-10-1	0.100	0.95

Table 6.9 Neural Network Architectures of one hidden layer trained using batch mode of inner girder due to fully-loaded lanes

Network	Architecture	RMS	Correlation (R^2)
N65	4-2-1	0.152	0.82
N66	4-4-1	0.143	0.845
N67	4-5-1	0.135	0.854
N68	4-6-1	0.12	0.912
N69	4-8-1	0.105	0.901
N70	4-10-1	0.082	0.951
N71	4-12-1	0.123	0.821
N72	4-13-1	0.135	0.815
N73	4-15-1	0.13	0.83

Table 6.10 Neural Network Architectures of two hidden layers trained using batch mode of inner girder due to fully-loaded lanes

Network	Architecture	RMS	Correlation (R^2)
N74	4-2-2-1	0.145	0.901
N75	4-3-3-1	0.120	0.914
N76	4-4-4-1	0.105	0.904
N77	4-5-5-1	0.082	0.921
N78	4-5-6-1	0.061	0.96
N79	4-6-8-1	0.095	0.912
N80	4-10-10-1	0.1025	0.904

Table 6.11 Neural Network Architectures of one hidden layer trained using batch mode of inner girder due to outer-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N81	4-2-1	0.170	0.88
N82	4-4-1	0.151	0.88
N83	4-5-1	0.142	0.90
N84	4-6-1	0.112	0.90
N85	4-8-1	0.078	0.92
N86	4-10-1	0.152	0.90
N87	4-12-1	0.162	0.89
N88	4-13-1	0.175	0.89
N89	4-15-1	0.182	0.88

Table 6.12 Neural Network Architectures of two hidden layers trained using batch mode of inner girder due to outer-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N90	4-2-2-1	0.145	0.81
N91	4-3-3-1	0.144	0.82
N92	4-4-4-1	0.138	0.83
N93	4-5-5-1	0.12	0.85
N94	4-5-6-1	0.095	0.90
N95	4-6-8-1	0.065	0.94
N96	4-10-10-1	0.102	0.90

Table 6.13 Neural Network Architectures of one hidden layer trained using batch mode of middle girder due to inner-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N97	4-2-1	0.125	0.70
N98	4-4-1	0.122	0.72
N99	4-5-1	0.100	0.81
N100	4-6-1	0.130	0.82
N101	4-8-1	0.140	0.80
N102	4-10-1	0.030	0.90
N103	4-12-1	0.070	0.97
N104	4-13-1	0.060	0.85
N105	4-15-1	0.080	0.81

Table 6.14 Neural Network Architectures of two hidden layers trained using batch mode of middle girder due to inner-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N106	4-2-2-1	0.100	0.81
N107	4-3-3-1	0.120	0.84
N108	4-4-4-1	0.110	0.92
N109	4-5-5-1	0.100	0.90
N110	4-5-6-1	0.080	0.95
N111	4-6-8-1	0.090	0.90
N112	4-10-10-1	0.100	0.85

Table 6.15 Neural Network Architectures of one hidden layer trained using batch mode of middle girder due to fully-loaded lanes

Network	Architecture	RMS	Correlation (R^2)
N113	4-2-1	0.145	0.73
N114	4-4-1	0.123	0.81
N115	4-5-1	0.102	0.85
N116	4-6-1	0.093	0.91
N117	4-8-1	0.082	0.95
N118	4-10-1	0.075	0.96
N119	4-12-1	0.123	0.80
N120	4-13-1	0.1345	0.81
N121	4-15-1	0.13	0.84

Table 6.16 Neural Network Architectures of two hidden layers trained using batch mode of middle girder due to fully-loaded lanes

Network	Architecture	RMS	Correlation (R^2)
N122	4-2-2-1	0.100	0.92
N123	4-3-3-1	0.120	0.91
N124	4-4-4-1	0.105	0.93
N125	4-5-5-1	0.073	0.94
N126	4-5-6-1	0.084	0.94
N127	4-6-8-1	0.100	0.90
N128	4-10-10-1	0.140	0.87

Table 6.17 Neural Network Architectures of one hidden layer trained using batch mode of middle girder due to outer-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N129	4-2-1	0.19	0.88
N130	4-4-1	0.181	0.88
N131	4-5-1	0.162	0.89
N132	4-6-1	0.132	0.89
N133	4-8-1	0.08	0.93
N134	4-10-1	0.132	0.92
N135	4-12-1	0.152	0.91
N136	4-13-1	0.175	0.90
N137	4-15-1	0.182	0.89

Table 6.18 Neural Network Architectures of two hidden layers trained using batch mode of middle girder due to outer-lane(s) loading

Network	Architecture	RMS	Correlation (R^2)
N138	4-2-2-1	0.136	0.83
N139	4-3-3-1	0.150	0.85
N140	4-4-4-1	0.138	0.84
N141	4-5-5-1	0.12	0.85
N142	4-5-6-1	0.075	0.91
N143	4-6-8-1	0.135	0.86
N144	4-10-10-1	0.122	0.84

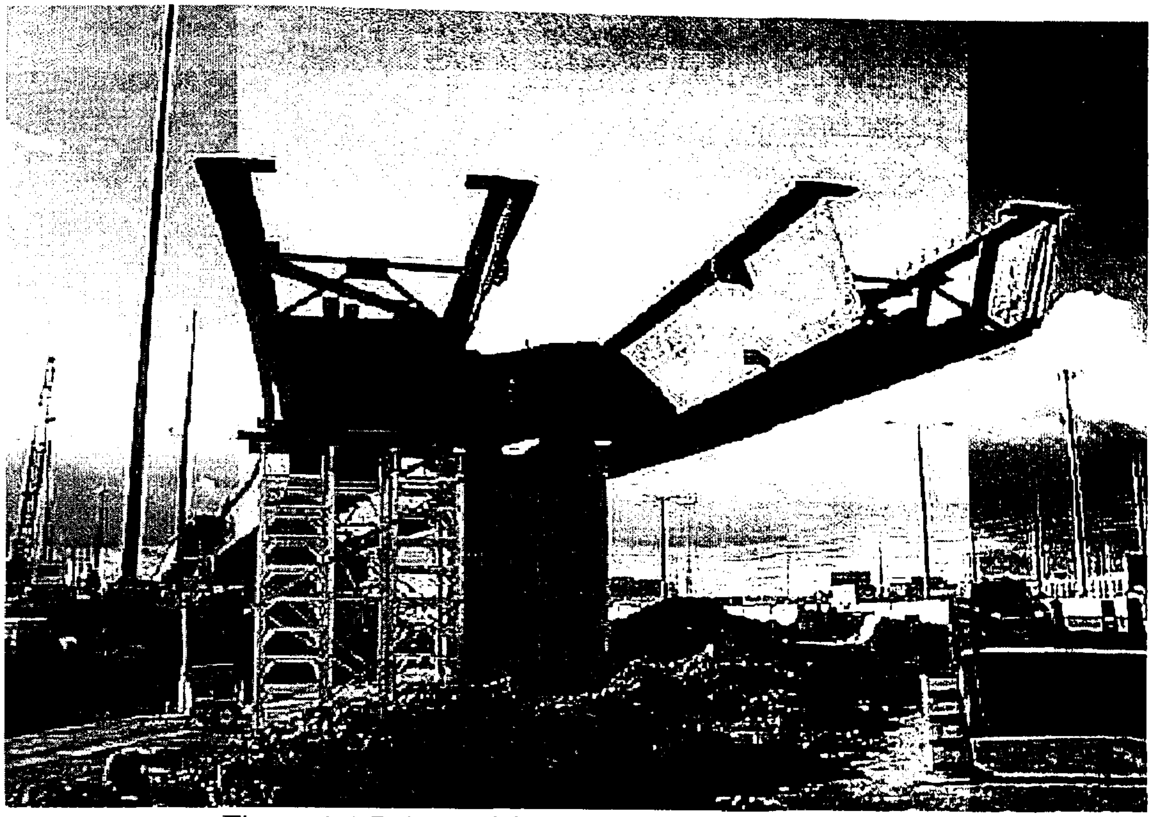


Figure 1.1 Bridge 606 during construction of GTAA.

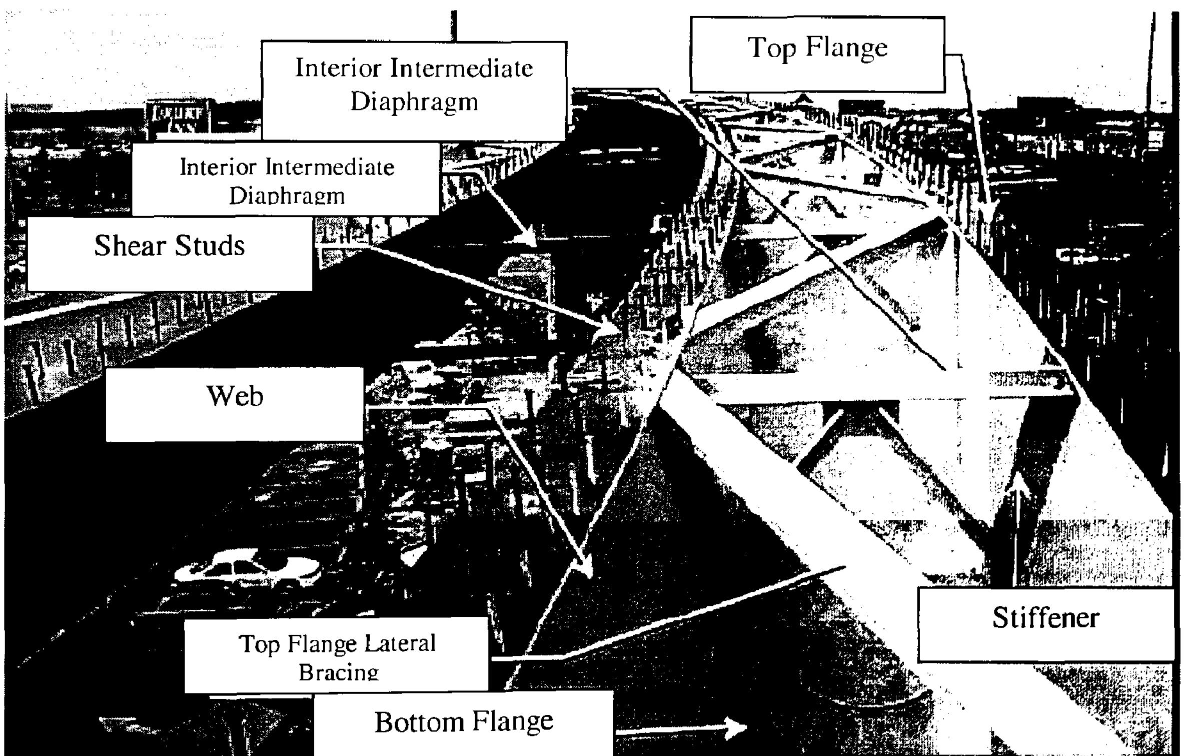


Figure 1.2 View of a curved box girder bridge during construction

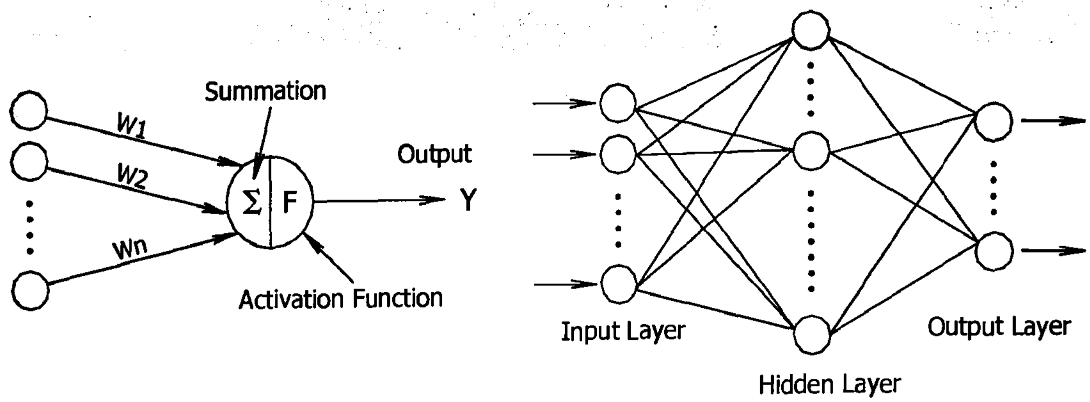


Figure 2.1 Architecture of a neural network

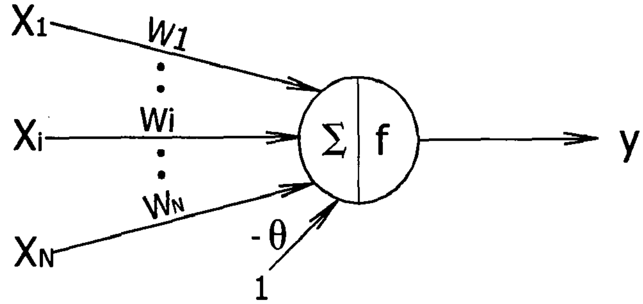


Figure 2.2 Structure of a node

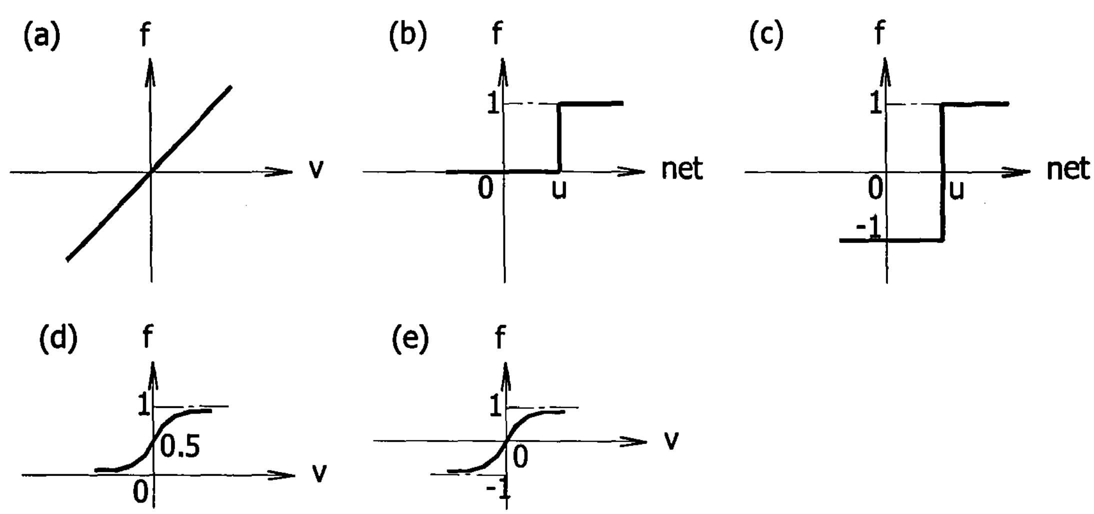


Figure 2.3 Activation functions:(a) linear, (b) binary step, (c) bipolar step, (d) binary sigmoid, and (e) bipolar sigmoid; after Haykin (44)

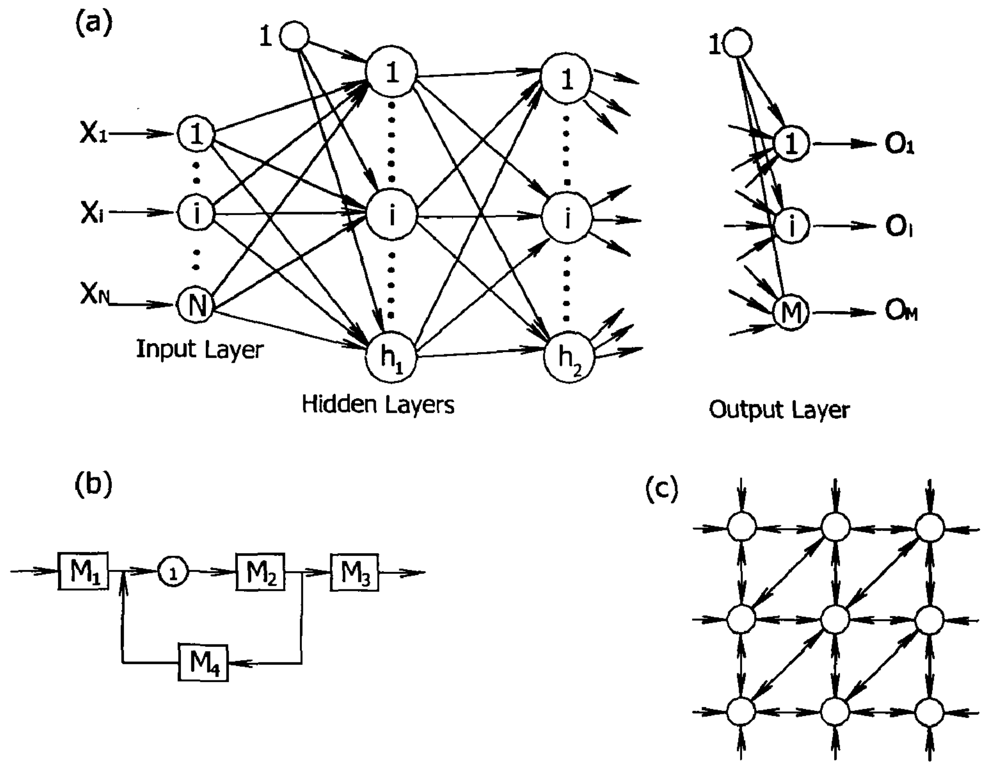


Figure 2.4 NN Architectures (a)Feedforward; (b)Recurrent; and (c)Cellular after Haykin (44)

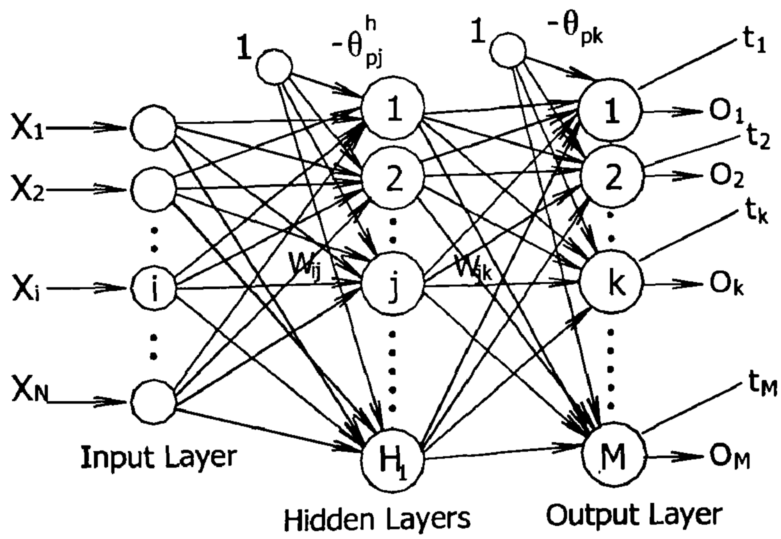
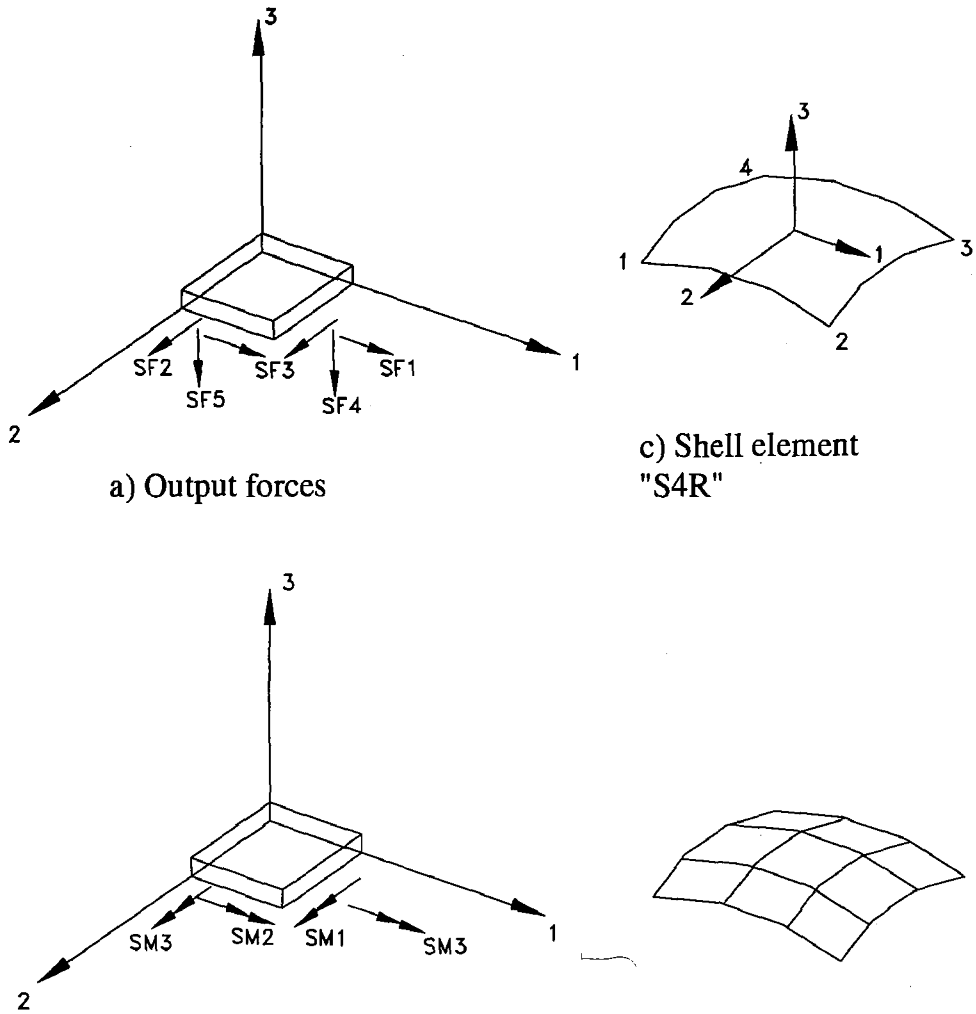


Figure 2.5 Topology of Back Propagation Artificial Neural Network after Haykin (44)



a) Output forces

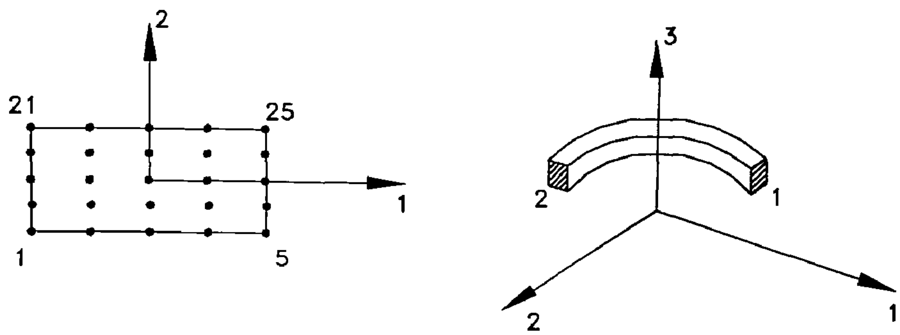
c) Shell element "S4R"

b) Output moments

d) Rebar in a shell

Note: - Four-node element1
- Degrees of freedom : U1, U2, U3, $\phi 1$, $\phi 2$, $\phi 3$.
- Output forces :SF1, SF2, SF3, SF4, SF5
- Output moments :SM1, SM2, SM3
- Stress Components :S11, S22, S12
- Strain Components :E11, E22, E12
- Rebar Option available in two directions

Figure 3.1 Shell Element S4R in ABAQUS Software



(a) Integration Points in beam element B31H for output results

(b) Element B31H in ABAQUS

Note: - two-node element
- Degrees of freedom : U1, U2, U3, $\phi1$, $\phi2$, $\phi3$.
- Output forces :SF1, SF2, SF3, SF4, SF5, SF6
- Output moments :SM1, SM2, SM3
- Stress Components :S11, S22, S12

Figure 3.2 Beam element "B31H" in space

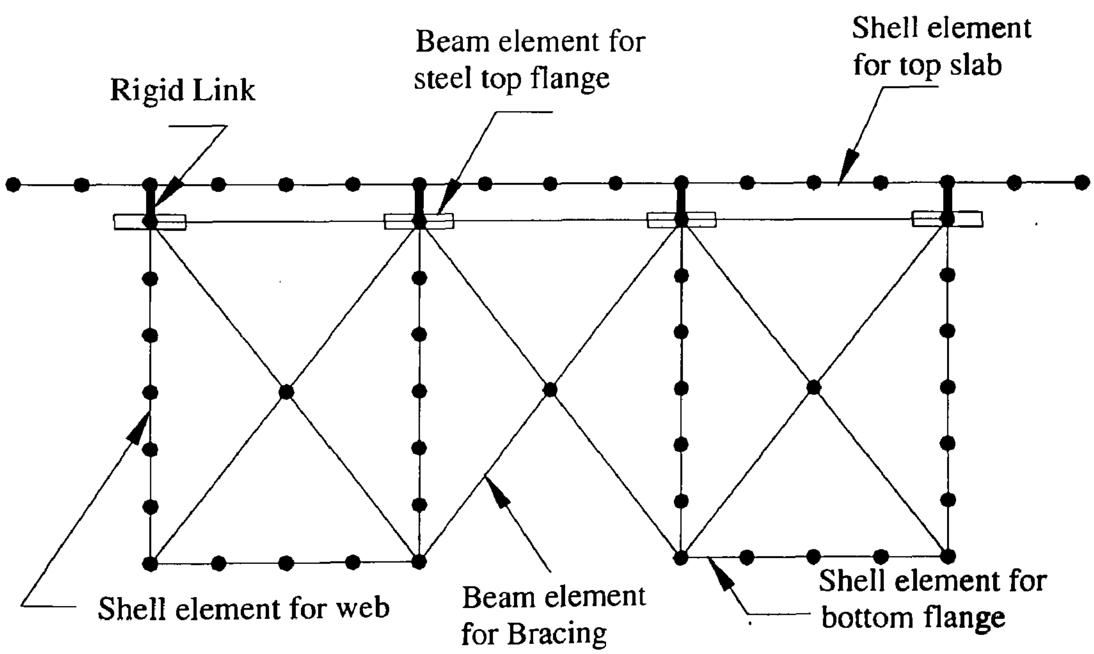


Figure 3.3 Finite element discretization of a two box girder cross section

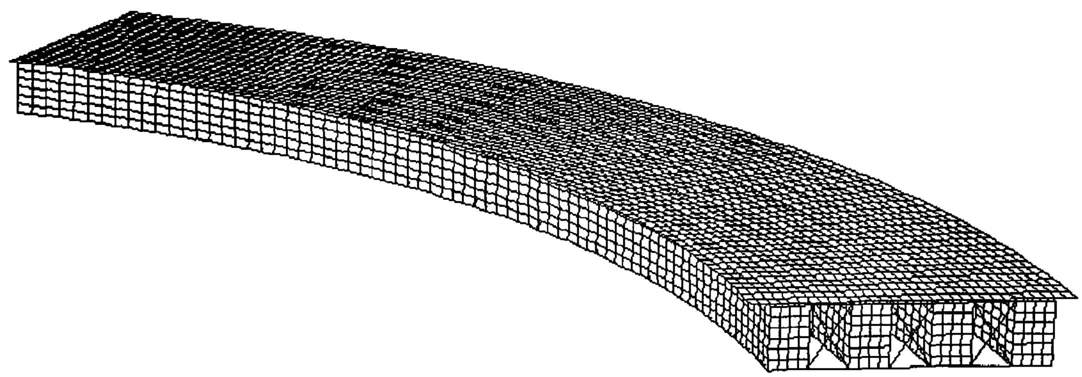


Figure 3.4 Finite Element modeling of a curved composite four-lane, four-box, girder bridge

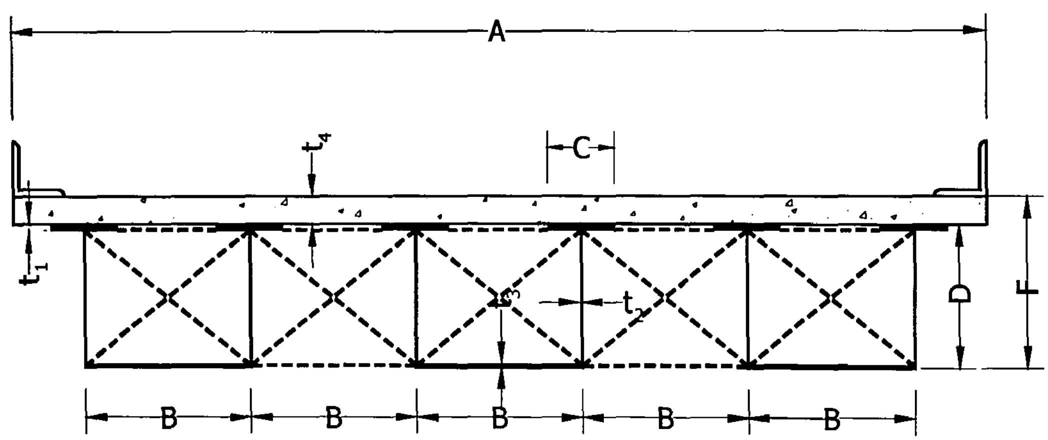


Figure 4.1 Basic cross section configurations and symbols

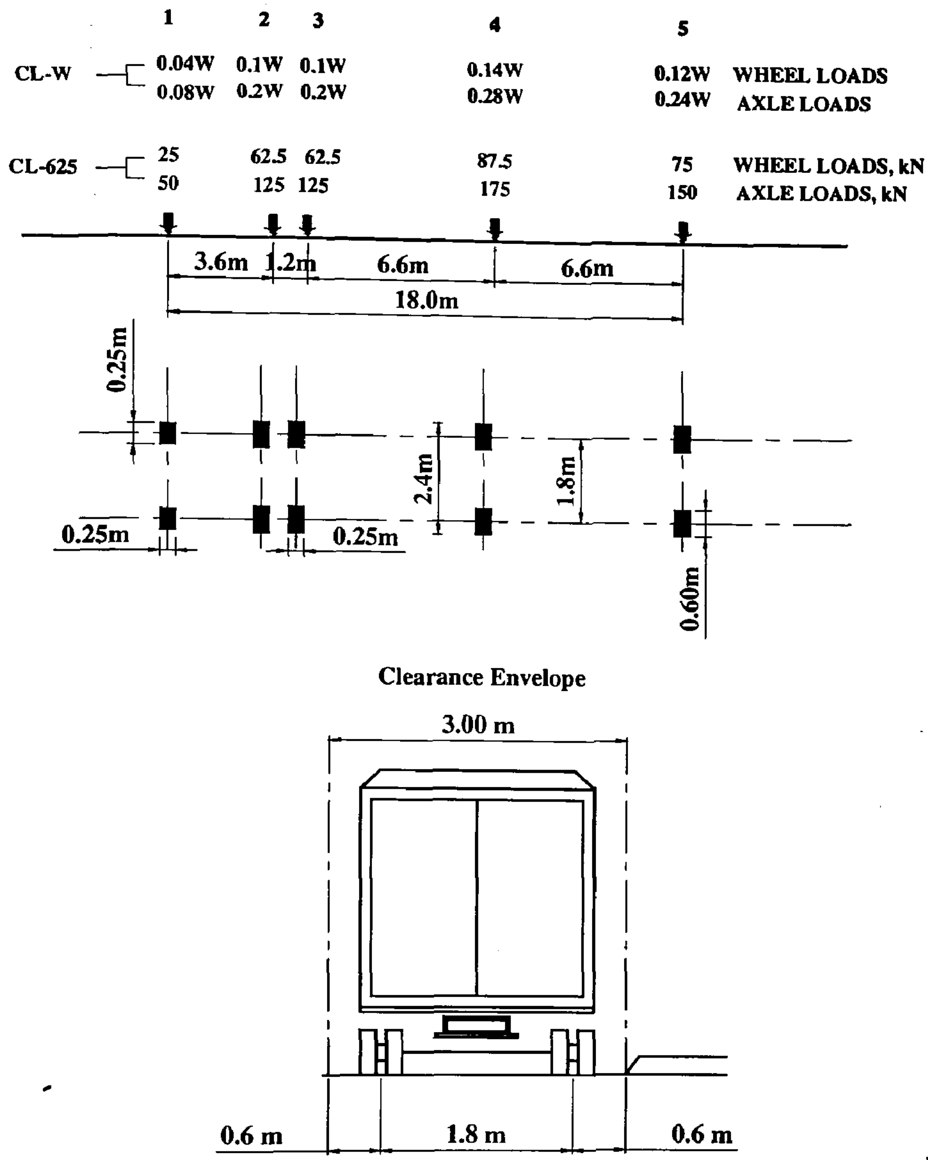


Figure 4.2 CL-W Truck Loading

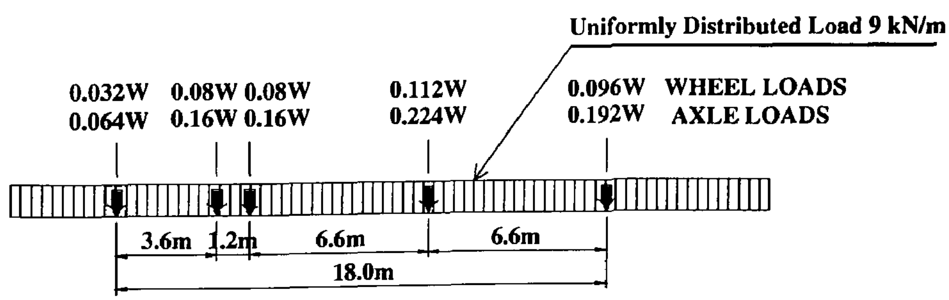


Figure 4.3 CL-W Lane Loading

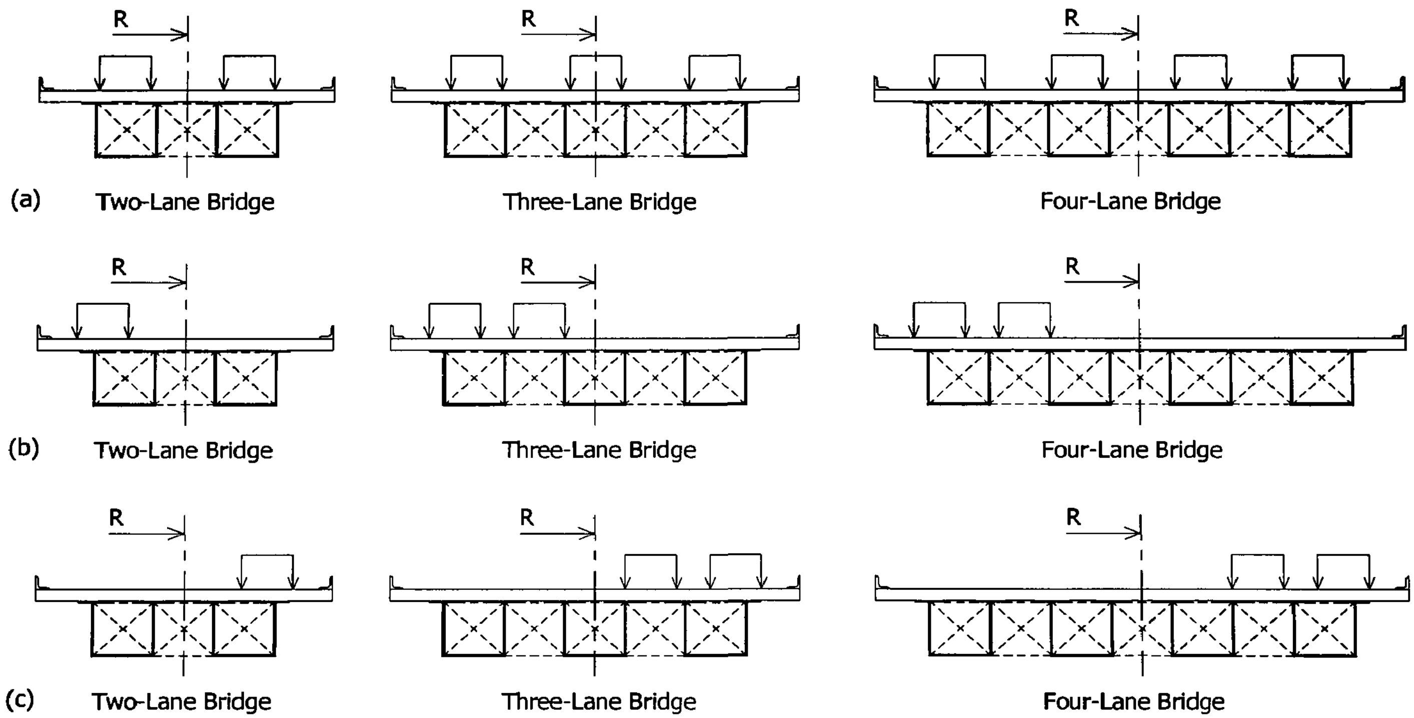


Figure 4.4 CHBDC truck loading cases considered in the parametric study for Ultimate Limit State design: (a) fully loaded bridges (b) partially loaded bridges in the inner lane(s) (c) partially loaded bridges in the outer lane(s)

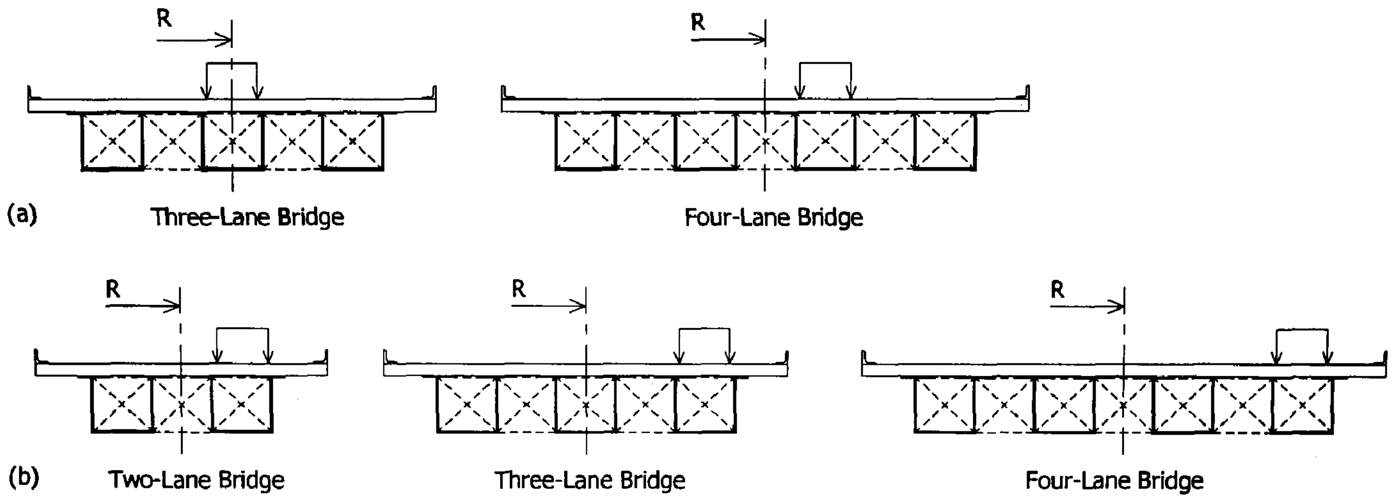


Figure 4.5 Cases of loading considered in the parametric study according to CHBDC for fatigue limit state design: (a) truck loading at the center of the middle lane (b) truck loading at the center of the outer lane

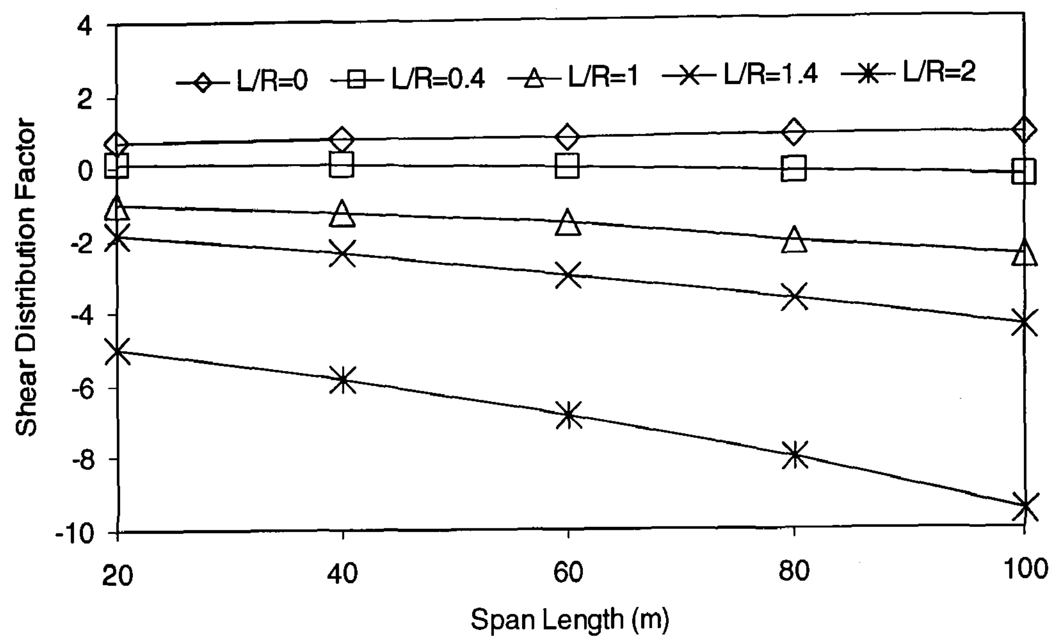


Figure 5.1 Effect of span length on the shear distribution factor for the inner girder of four-lane, four-box girder bridges due to full CHBDC truck loading

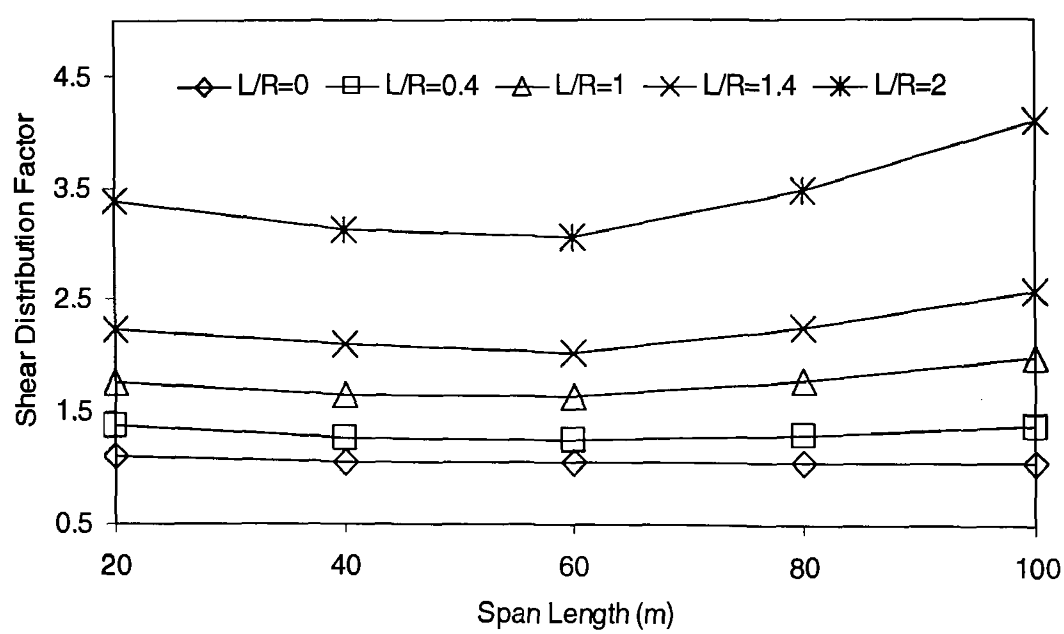


Figure 5.2 Effect of span length on the shear distribution factor for the central girder of four-lane, four-box girder bridges due to full CHBDC truck loading

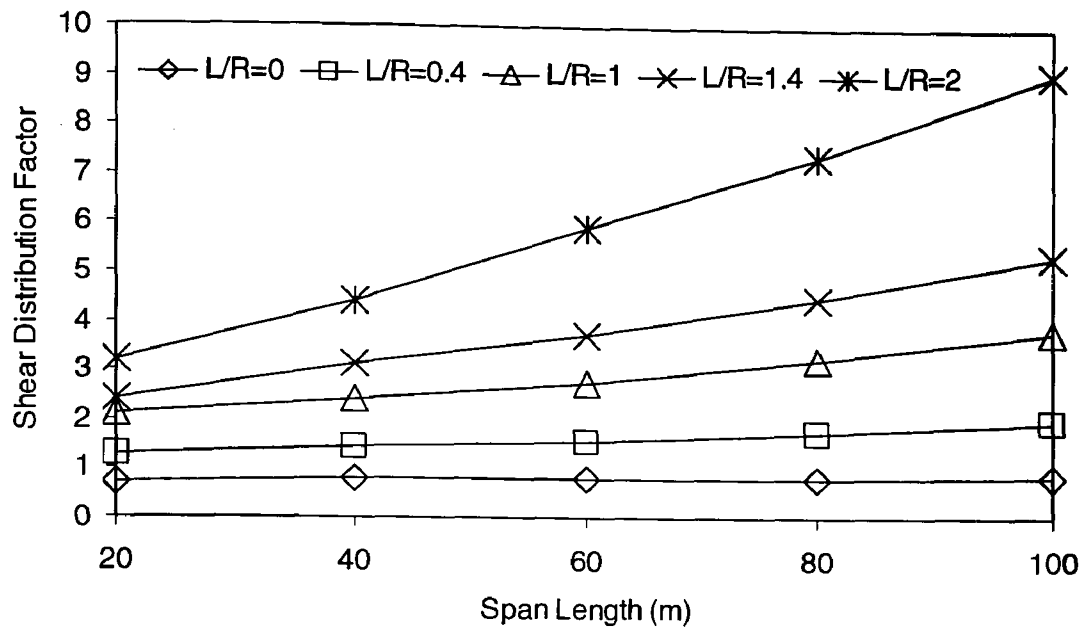


Figure 5.3 Effect of span length on the shear distribution factor for the outer girder of four-lane, four-box girder bridges due to full CHBDC truck loading

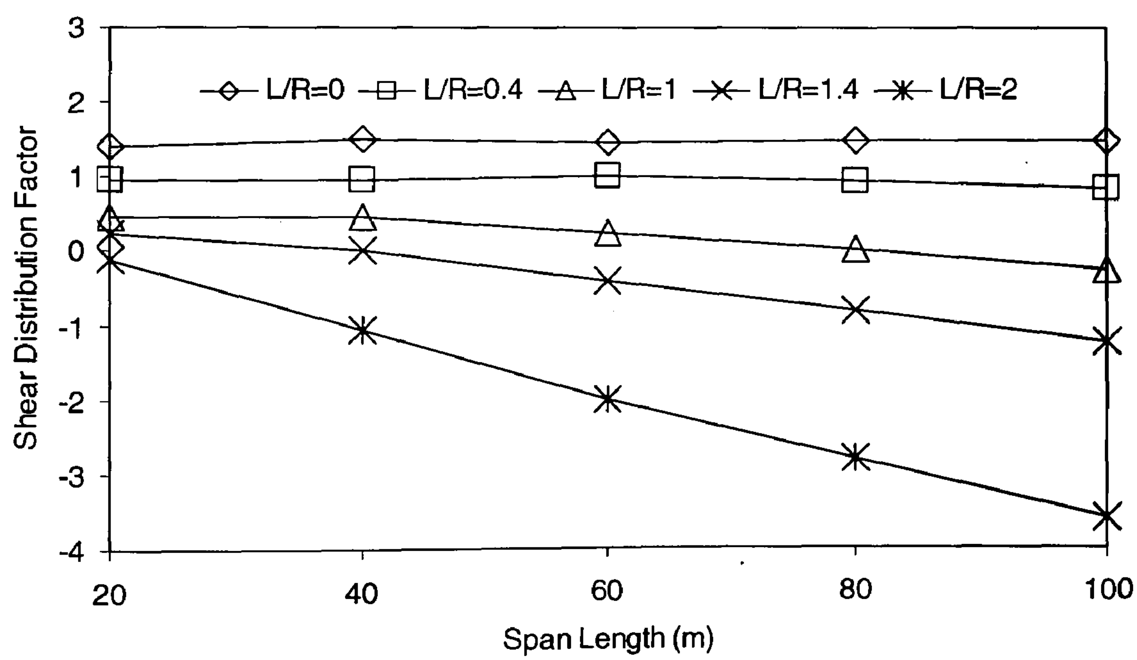


Figure 5.4 Effect of span length on the shear distribution factor for the inner girder of four-lane, four-box girder bridges due to CHBDC truck loading in the inner lanes

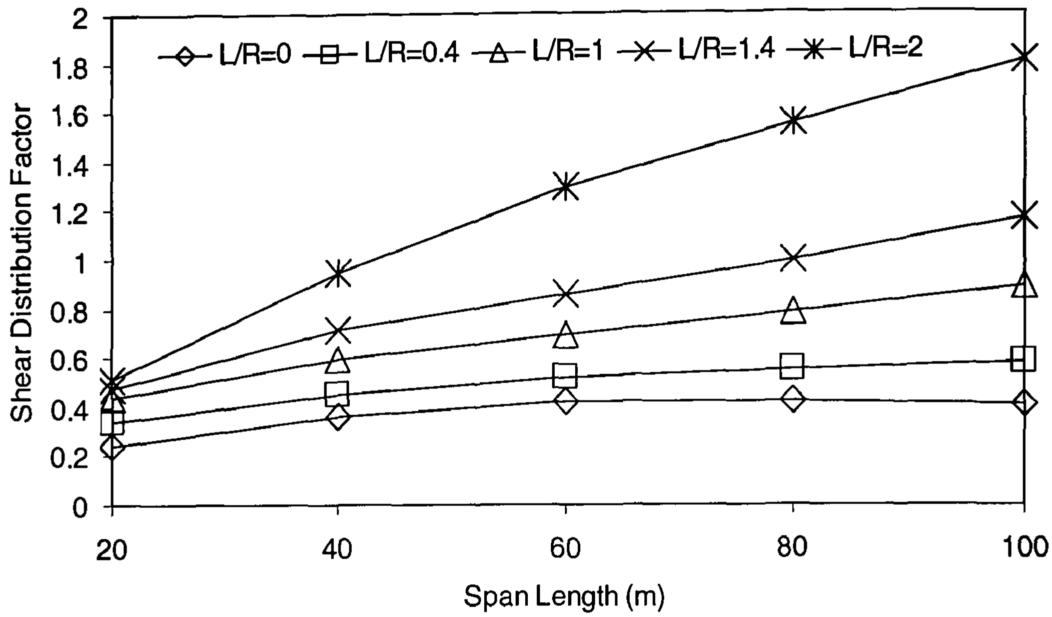


Figure 5.5 Effect of span length on the shear distribution factor for the central girder of four-lane, four-box girder bridges due to CHBDC truck loading in the inner lanes

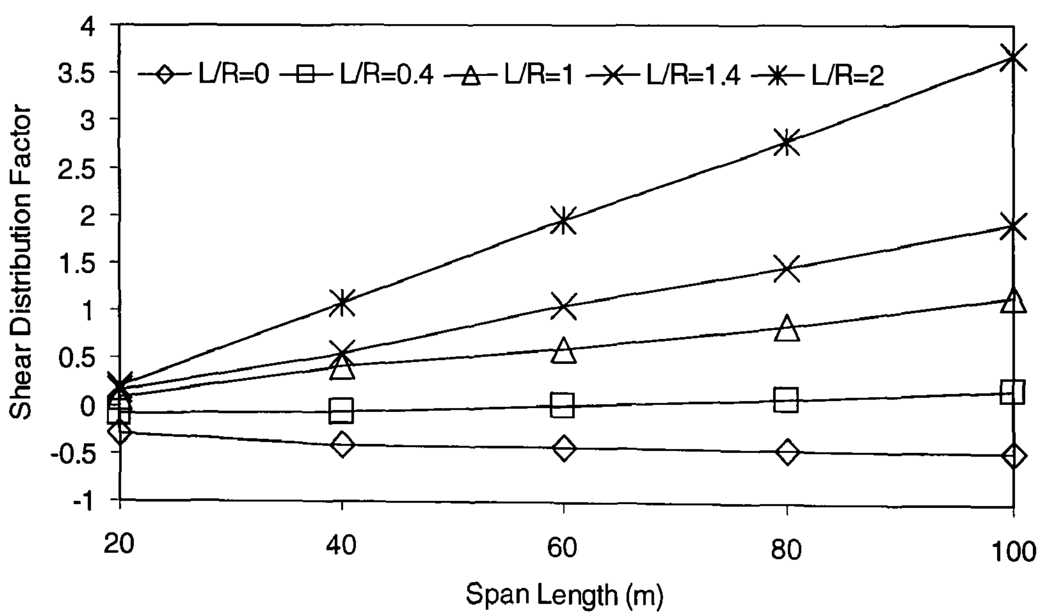


Figure 5.6 Effect of span length on the shear distribution factor for the outer girder of four-lane, four-box girder bridges due to CHBDC truck loading in the inner lanes

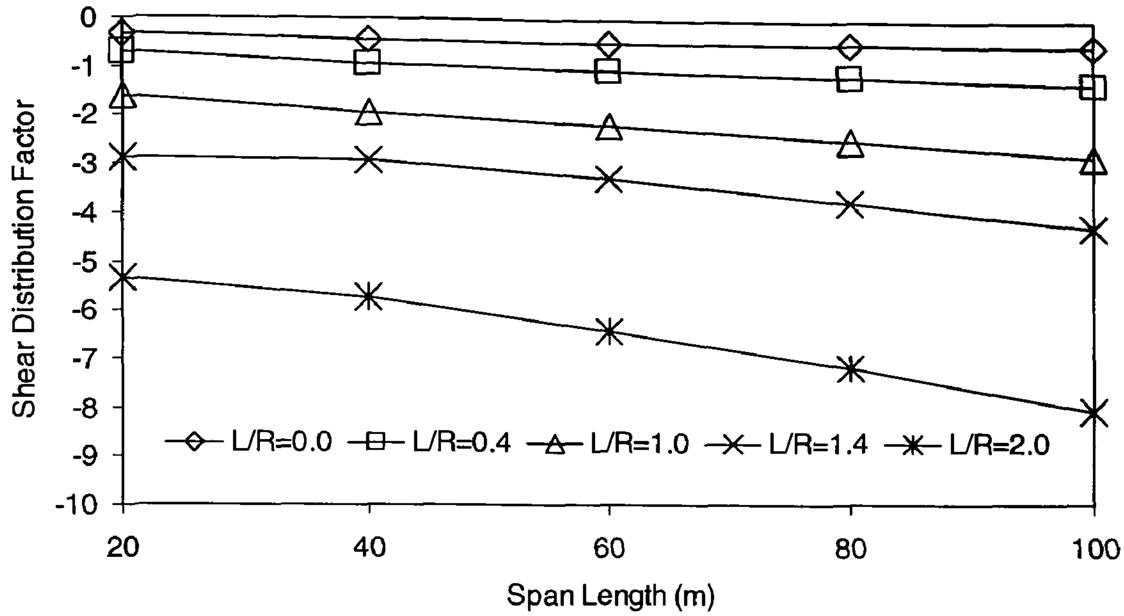


Figure 5.7 Effect of span length on the shear distribution factor for the inner girder of four-lane, four-box girder bridges due to CHBDC truck loading in the outer lanes

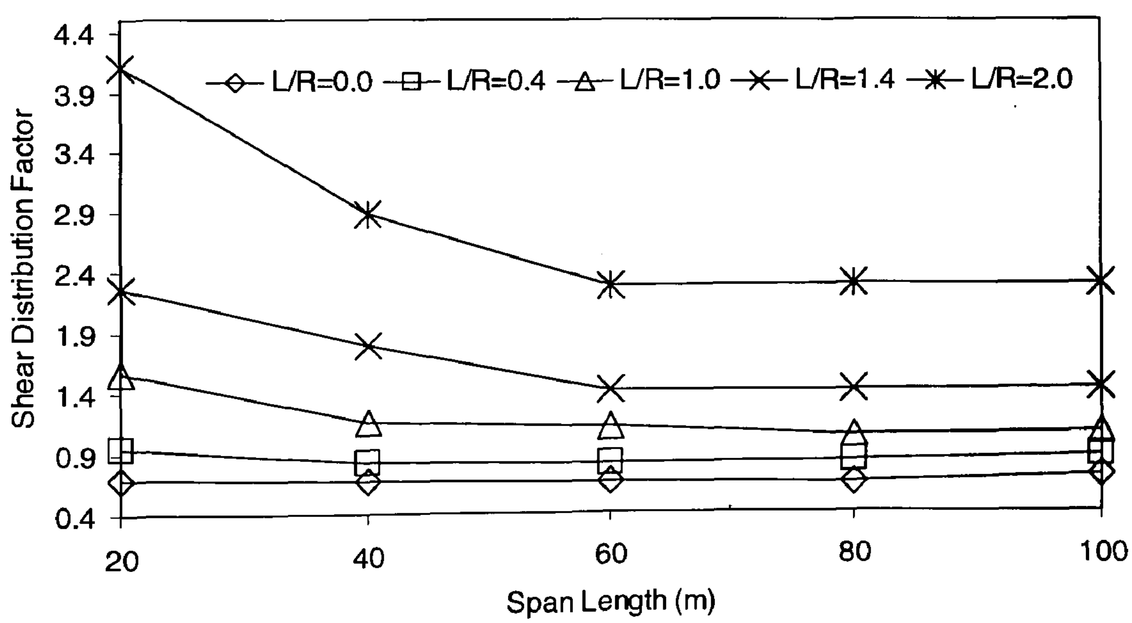


Figure 5.8 Effect of span length on the shear distribution factor for the central girder of four-lane, four-box girder bridges due to CHBDC truck loading in the outer lanes

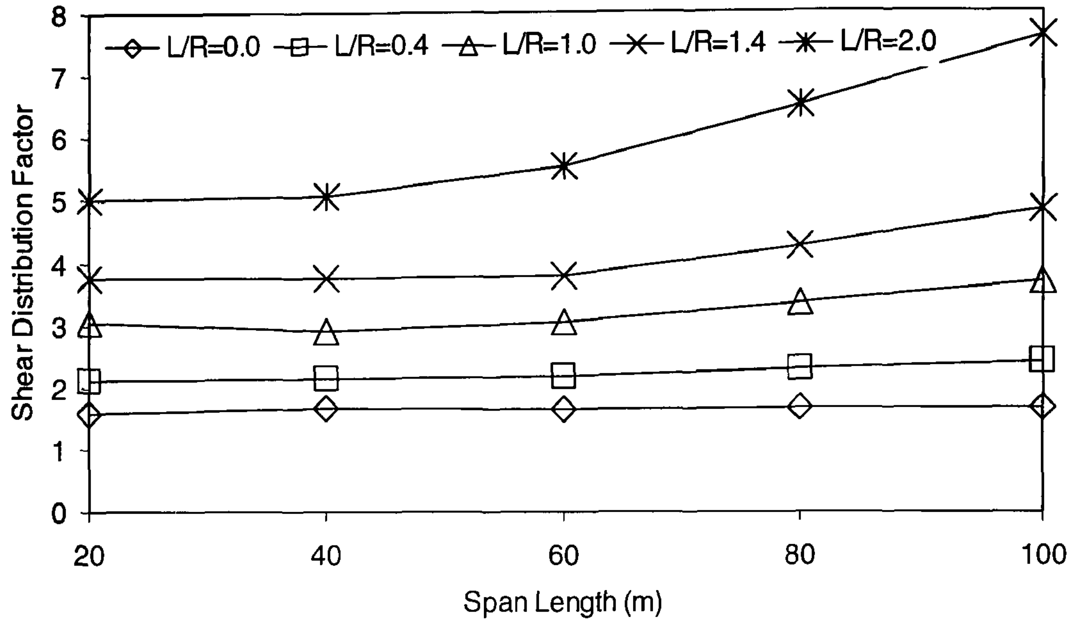


Figure 5.9 Effect of span length on the shear distribution factor for the outer girder of four-lane, four-box girder bridges due to CHBDC truck loading in the outer lanes

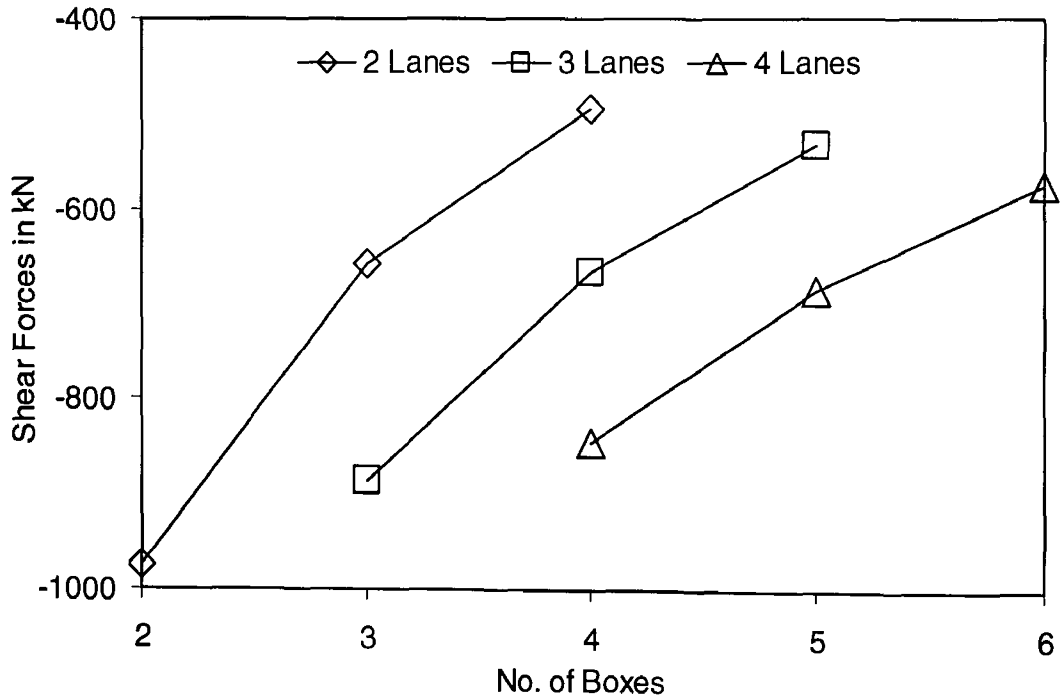


Figure 5.10 Effect of number of traffic lanes on the shear forces for the inner girder of bridges of 80 m span and L/R=1 due to full CHBDC truck loading

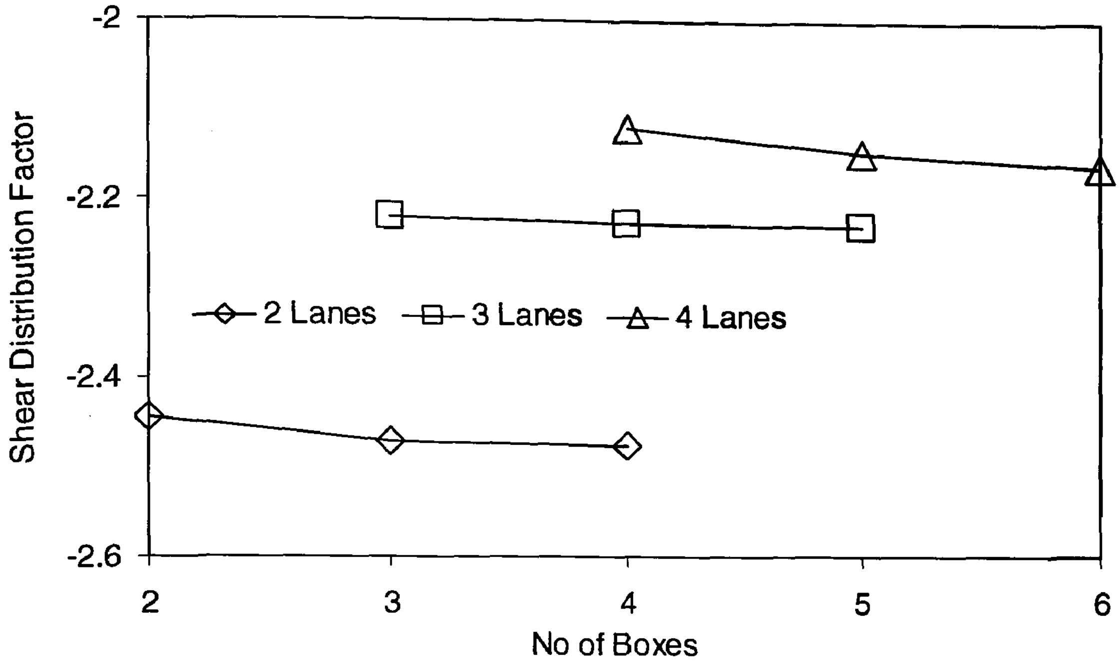


Figure 5.11 Effect of number of traffic lanes on the shear distribution factor for the inner girder of bridges of 80 m span and L/R=1 due to full CHBDC truck loading

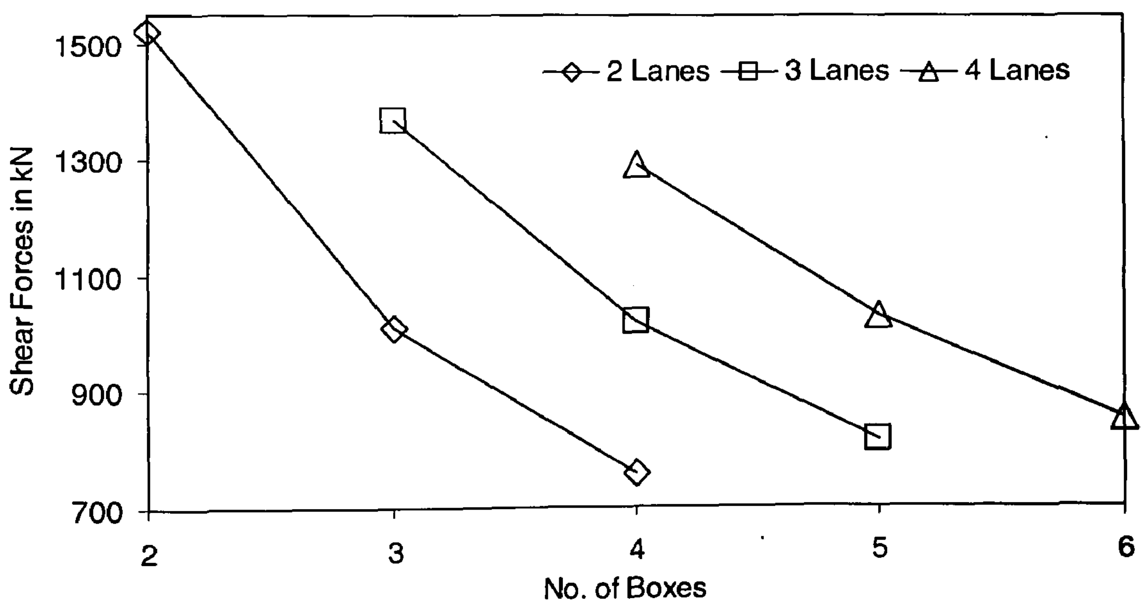


Figure 5.12 Effect of number of traffic lanes on the shear forces for the outer girder of bridges of 80 m span and L/R=1 due to full CHBDC truck loading

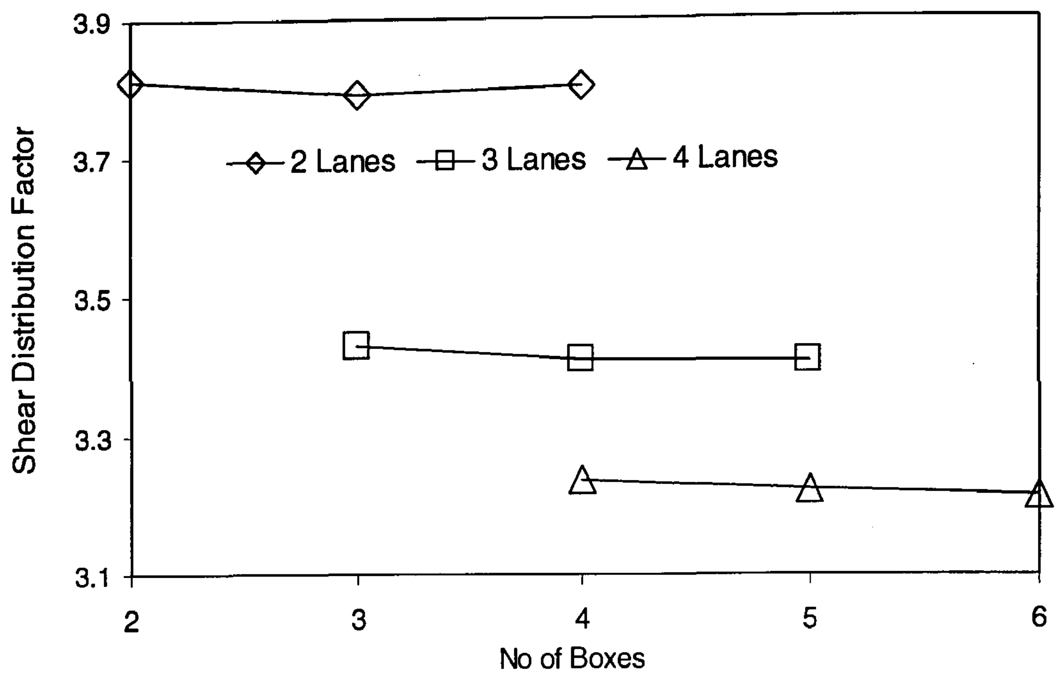


Figure 5.13 Effect of number of traffic lanes on the shear distribution factor for the outer girder of bridges of 80 m span and L/R=1 due to full CHBDC truck loading

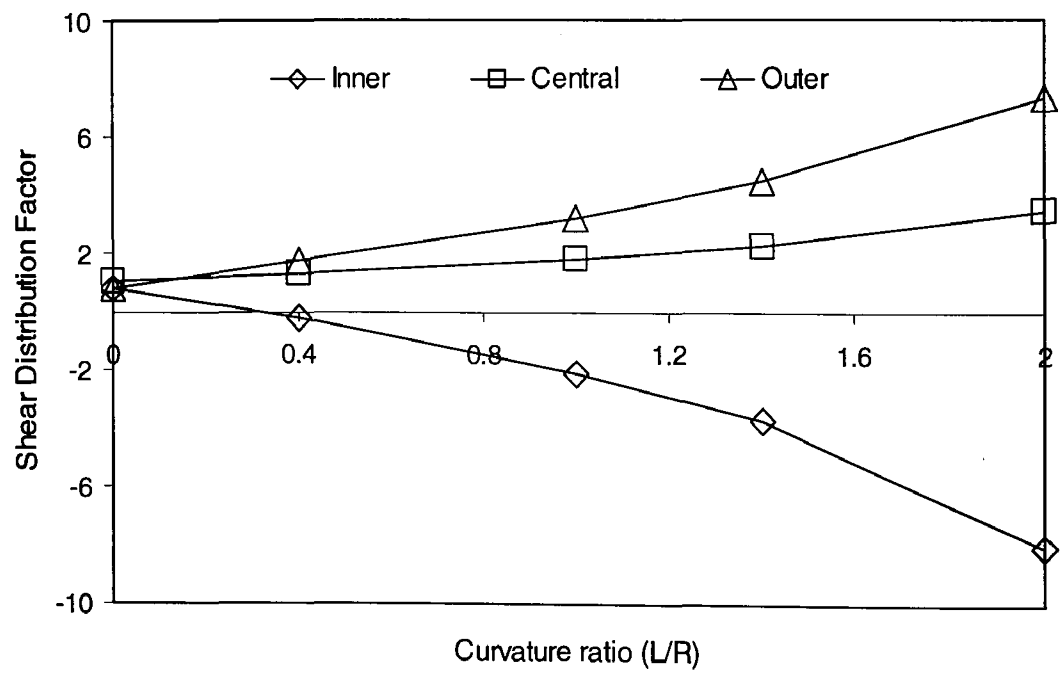


Figure 5.14 Effect of curvature on shear distribution factor for 80 m span, four-lane, four-box girder bridge due to full CHBDC truck loading

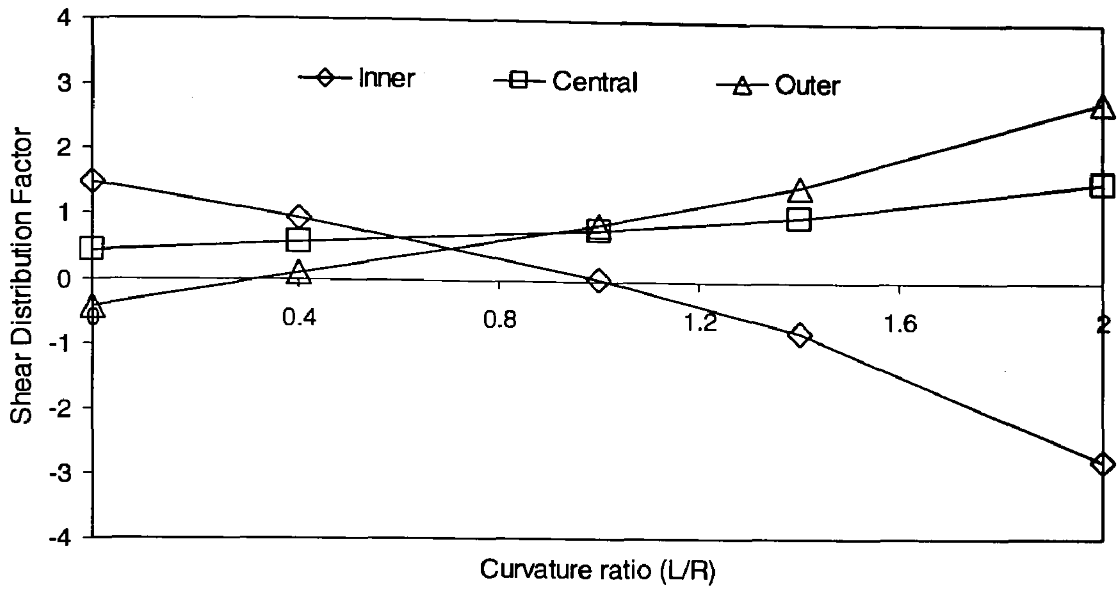


Figure 5.15 Effect of curvature on shear distribution factor for 80 m span, four-lane, four-box girder bridge due to CHBDC truck loading in the inner lanes

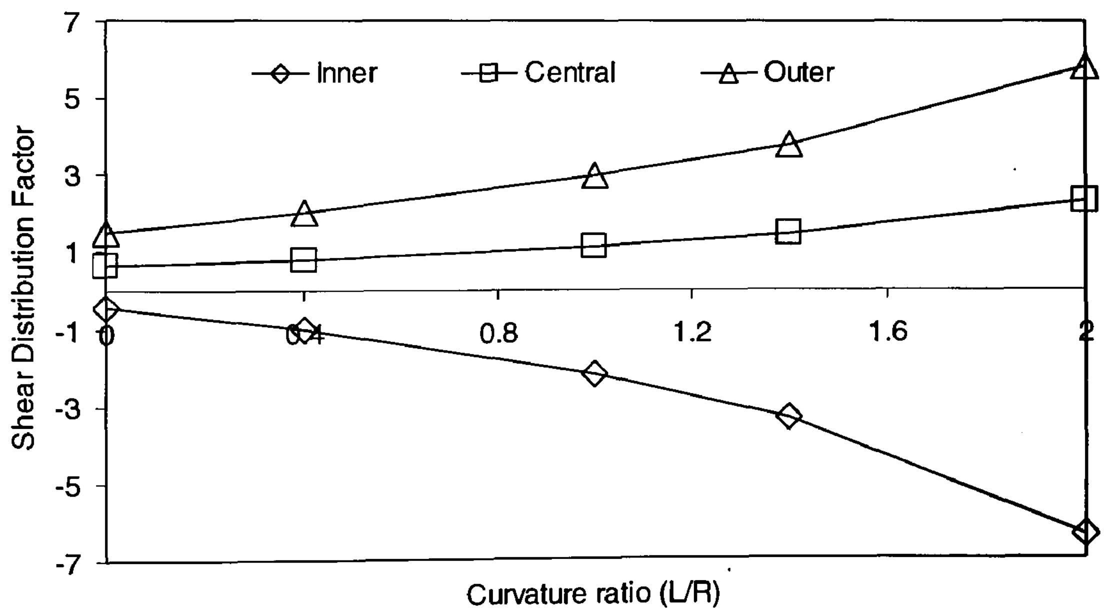


Figure 5.16 Effect of curvature on shear distribution factor for 80 m span, four-lane, four-box girder bridge due to CHBDC truck loading in the outer lanes

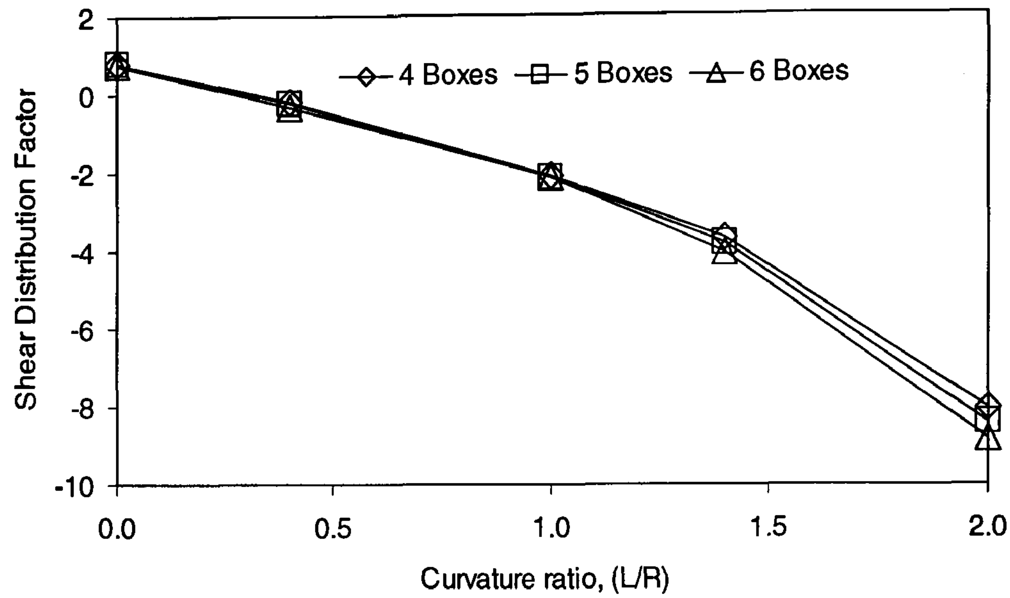


Figure 5.17 Effect of curvature on shear distribution factor for the inner girder of 80 m span, four-lane, box girder bridge due to full CHBDC truck loading

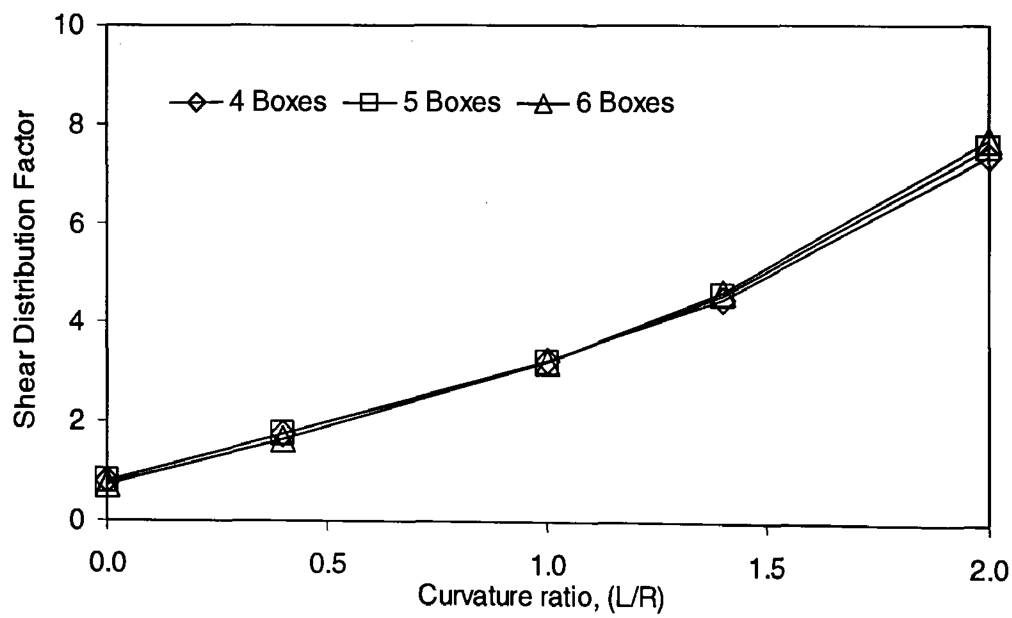


Fig 5.18 Effect of curvature on shear distribution factor for the outer girder of 80 m span, four-lane, box girder bridge due to full CHBDC truck loading

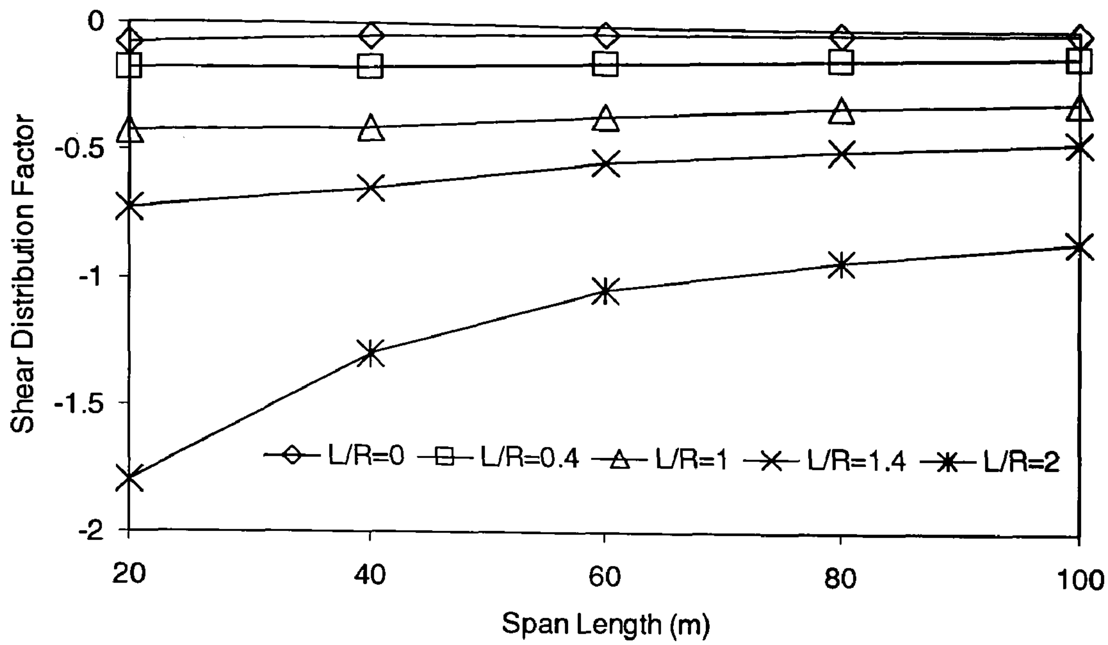


Figure 5.19 Effect of span length on the shear distribution factor for the inner girder of four-lane, four-box girder bridges due to CHBDC Fatigue truck loading in the middle lane

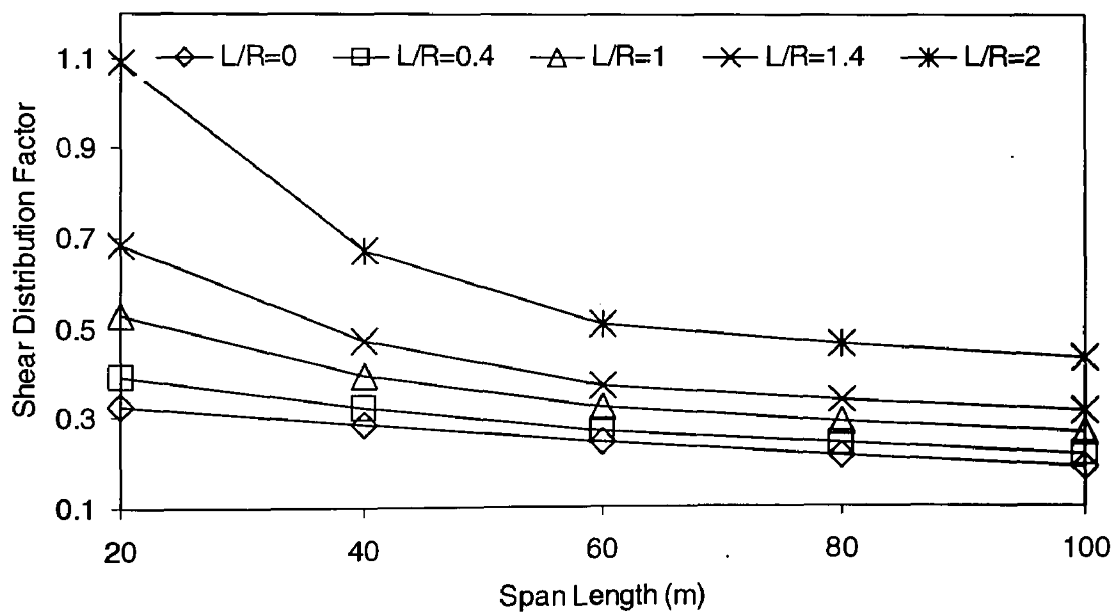


Figure 5.20 Effect of span length on the shear distribution factor for the central girder of four-lane, four-box girder bridges due to CHBDC Fatigue truck loading loading in the middle lane

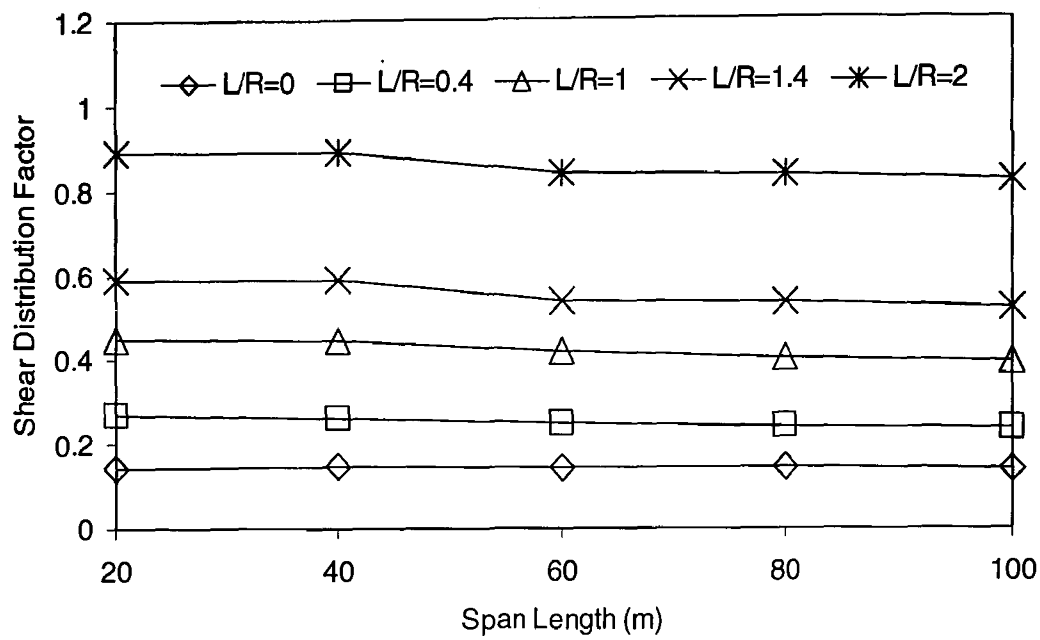


Figure 5.21 Effect of span length on the shear distribution factor for the outer girder of four-lane, four-box girder bridges due to CHBDC Fatigue truck loading loading in the middle lane

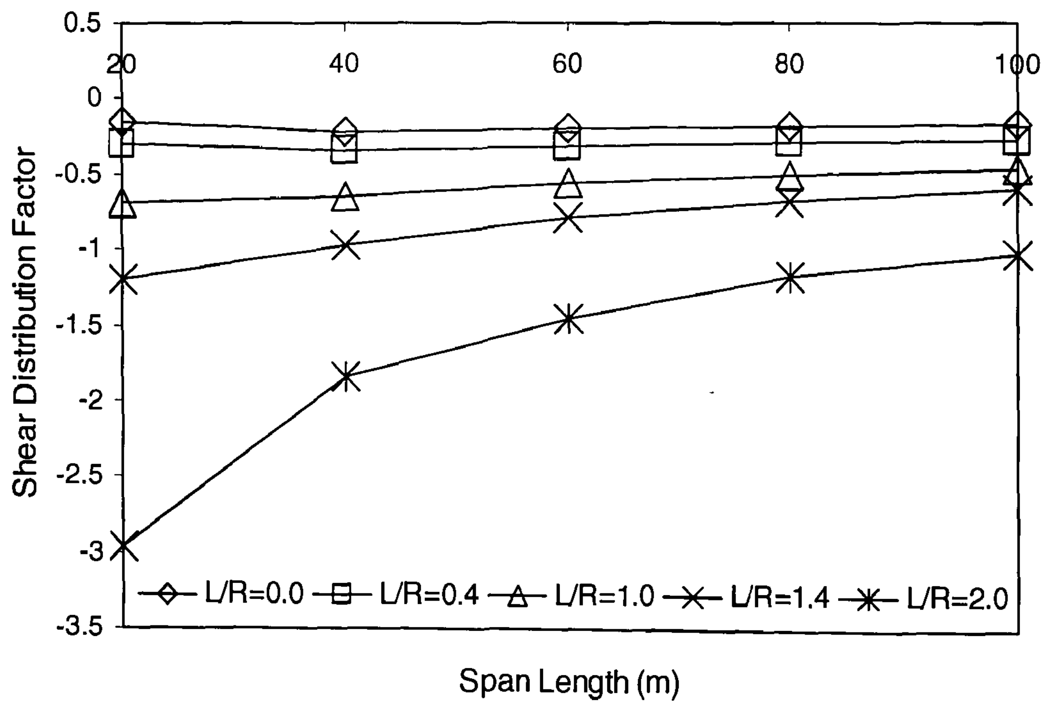


Figure 5.22 Effect of span length on the shear distribution factor for the inner girder of four-lane, four-box girder bridges due to CHBDC Fatigue truck loading in the outer lane

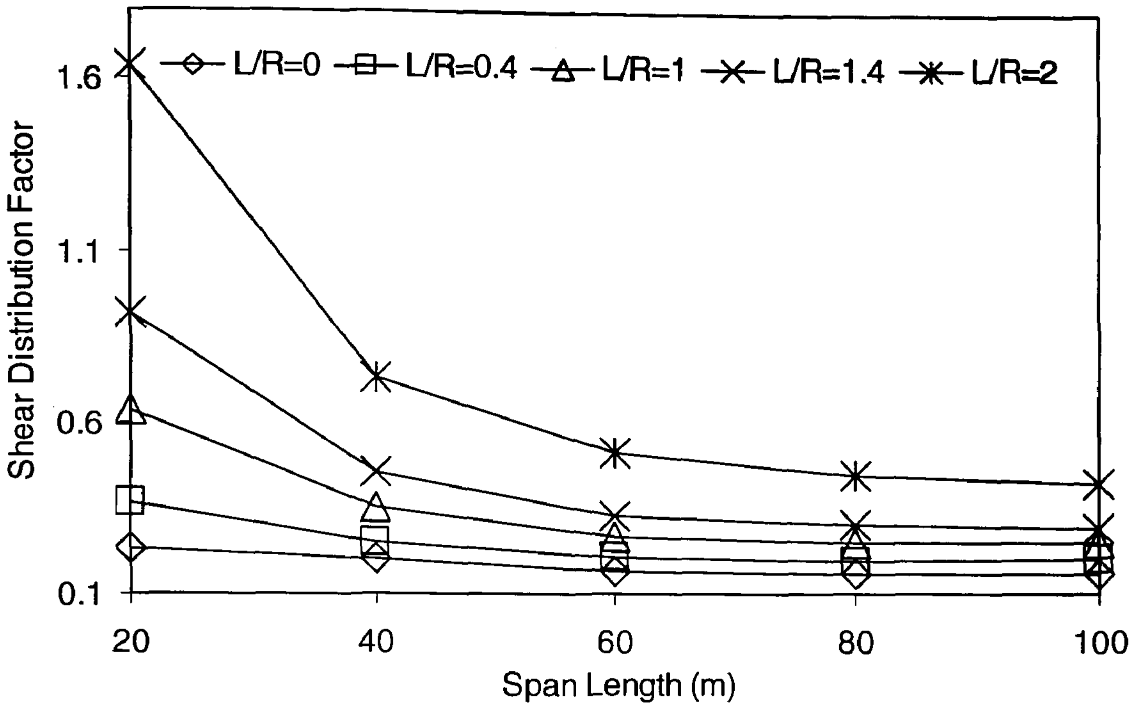


Figure 5.23 Effect of span length on the shear distribution factor for the central girder of four-lane, four-box girder bridges due to CHBDC Fatigue truck loading in the outer lane

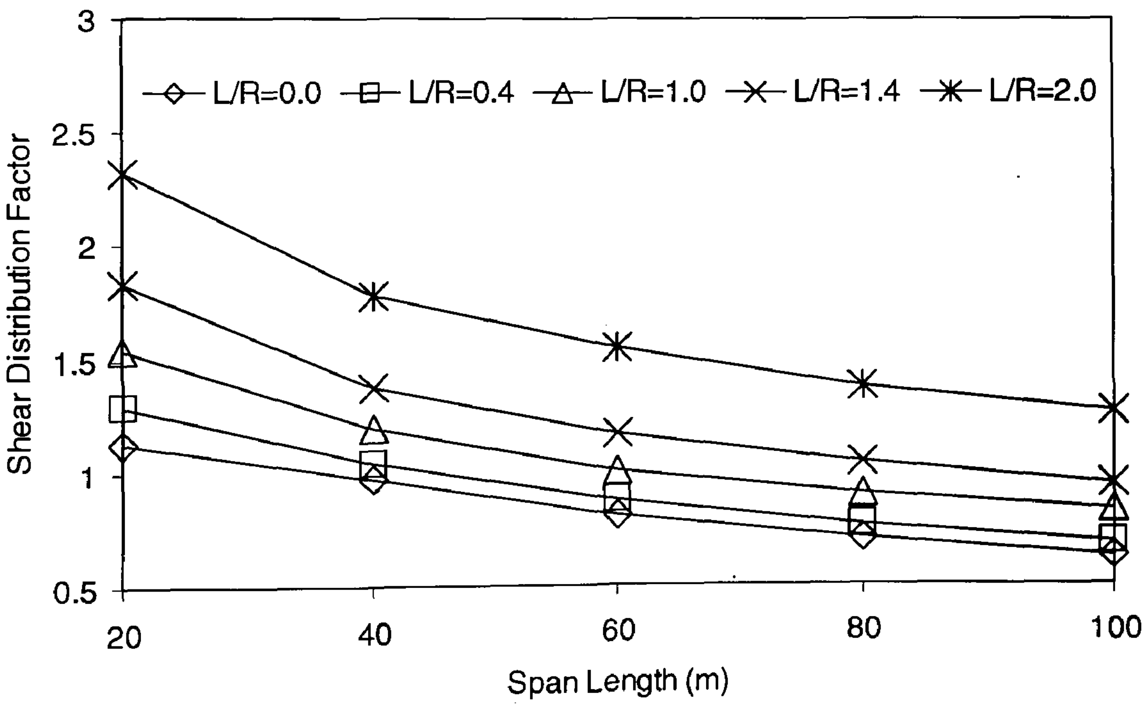


Figure 5.24 Effect of span length on the shear distribution factor for the outer girder of four-lane, four-box girder bridges due to CHBDC Fatigue truck loading in the outer lane

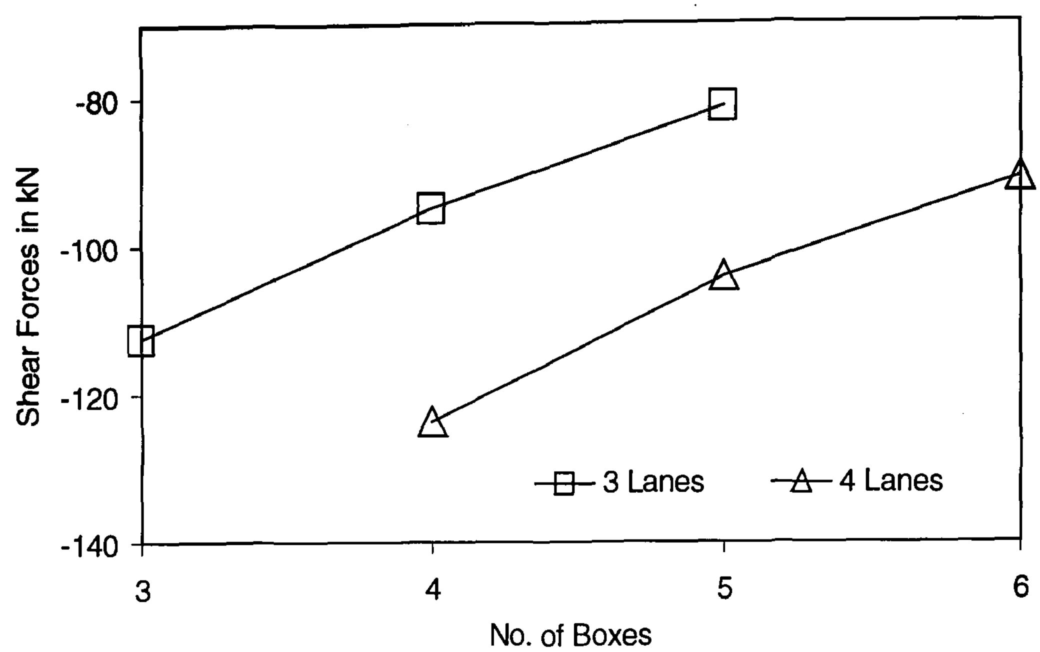


Figure 5.25 Effect of number of traffic lanes on the shear forces for the inner girder of bridges of 80 m span and L/R=1 due to CHBDC Fatigue truck loading loading in the middle lane

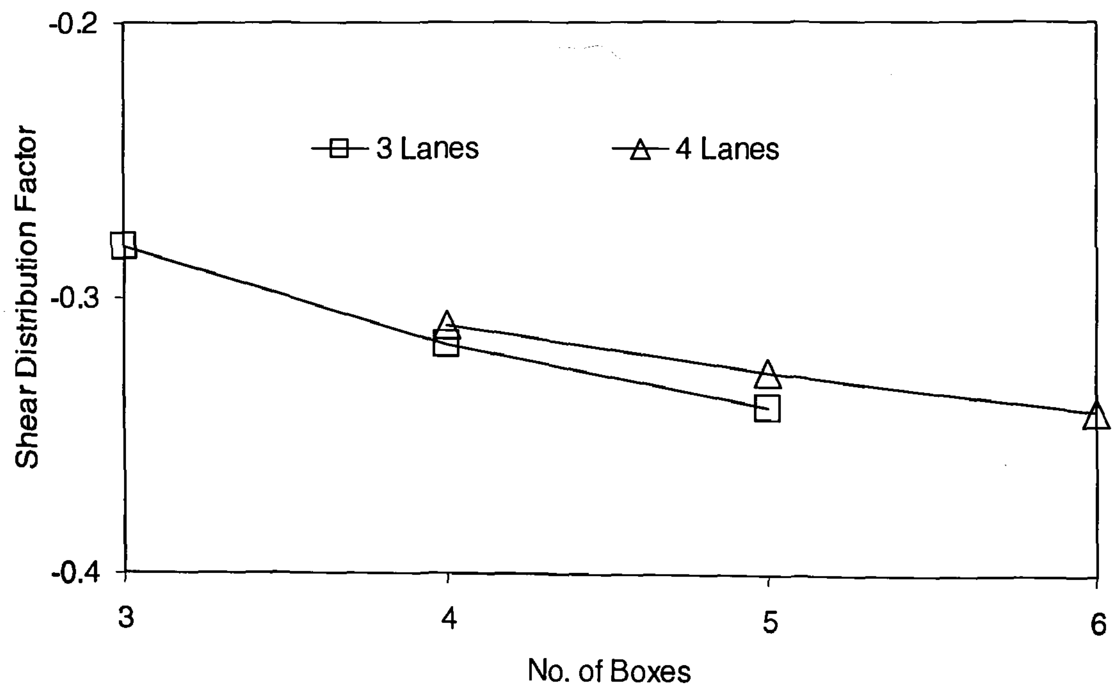


Figure 5.26 Effect of number of traffic lanes on the shear distribution factor for the inner girder of bridges of 80 m span and L/R=1 due to CHBDC Fatigue truck loading loading in the middle lane

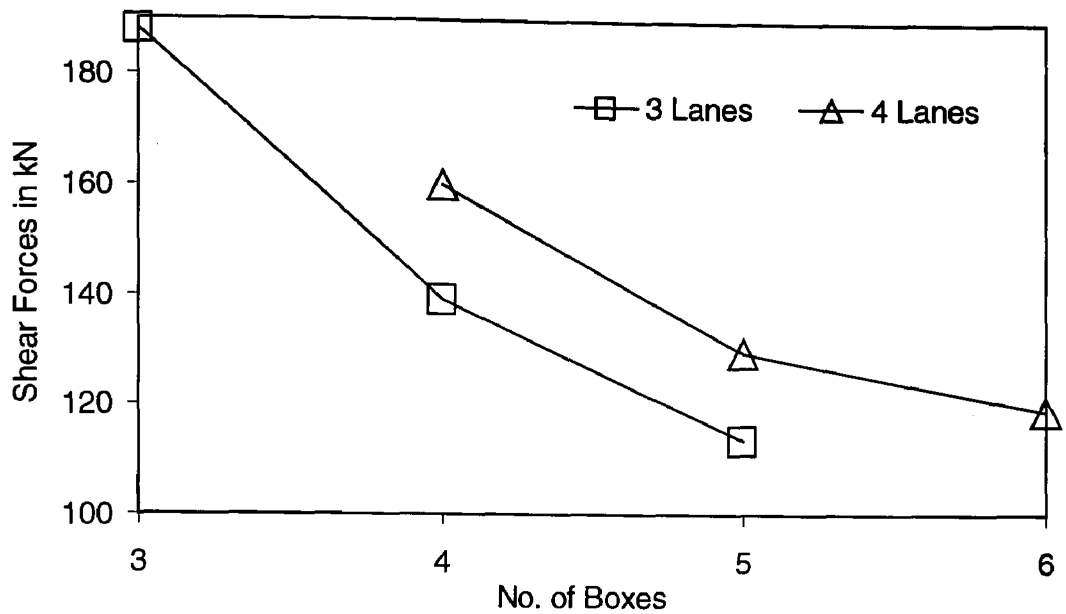


Figure 5.27 Effect of number of traffic lanes on the shear forces for the outer girder of bridges of 80 m span and L/R=1 due to CHBDC Fatigue truck loading loading in the middle lane

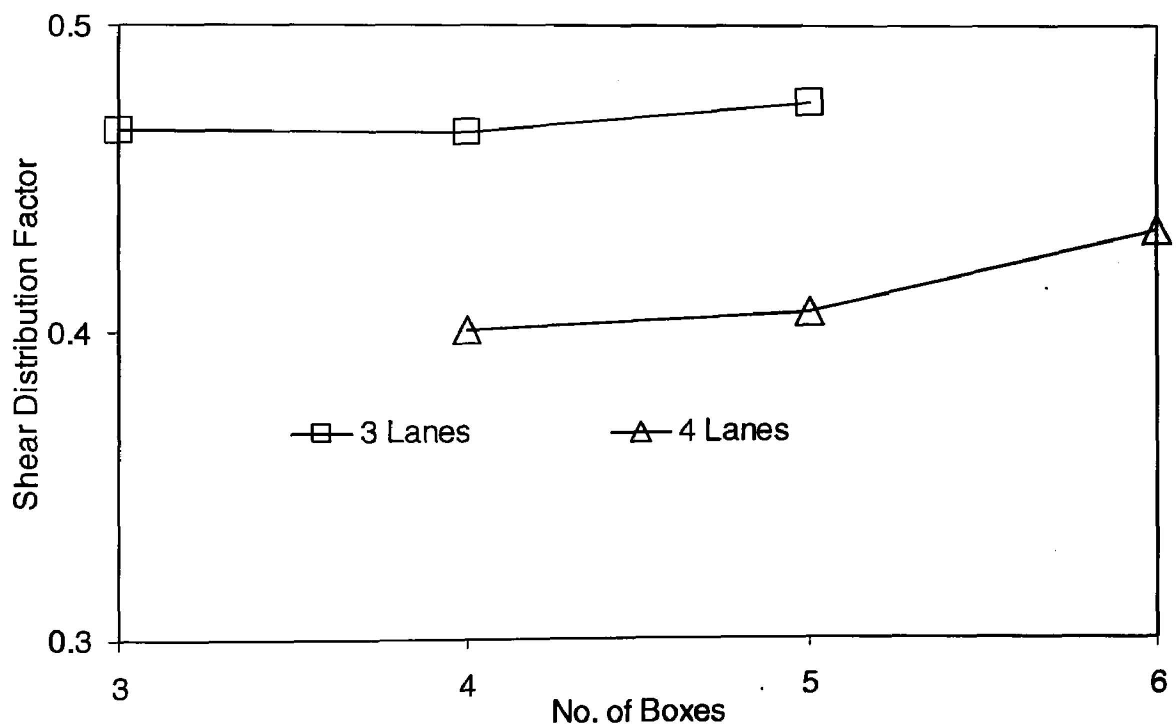


Figure 5.28 Effect of number of traffic lanes on the shear distribution factor for the outer girder of bridges of 80 m span and L/R=1 due to CHBDC Fatigue truck loading loading in the middle lane

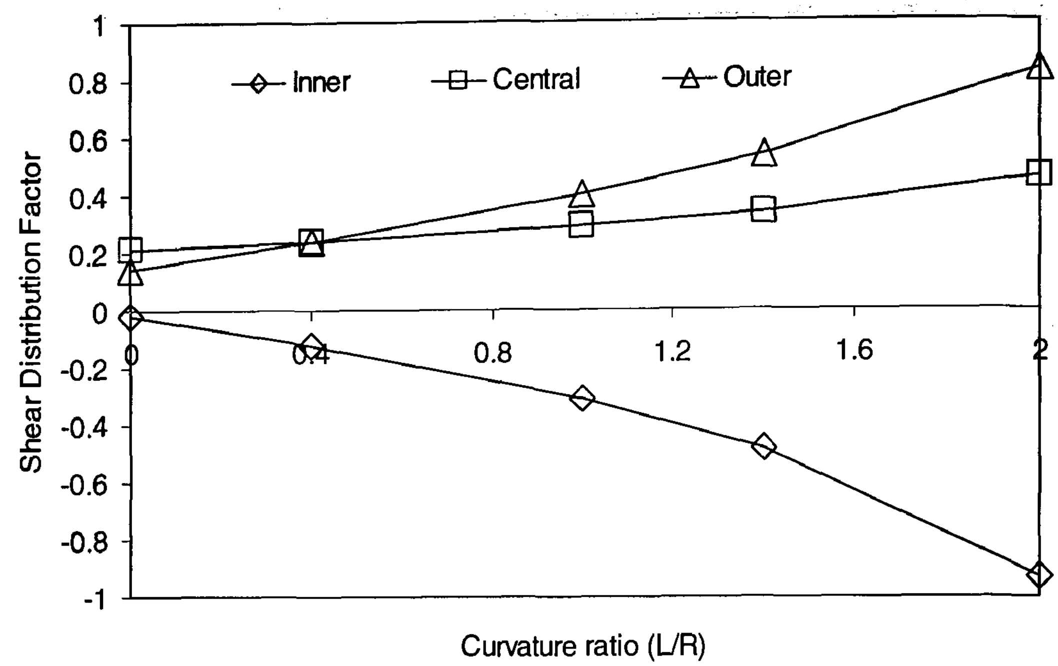


Figure 5.29 Effect of curvature on shear distribution factor for 80 m span, four-lane, four-box girder bridge due to CHBDC Fatigue truck loading loading in the middle lane

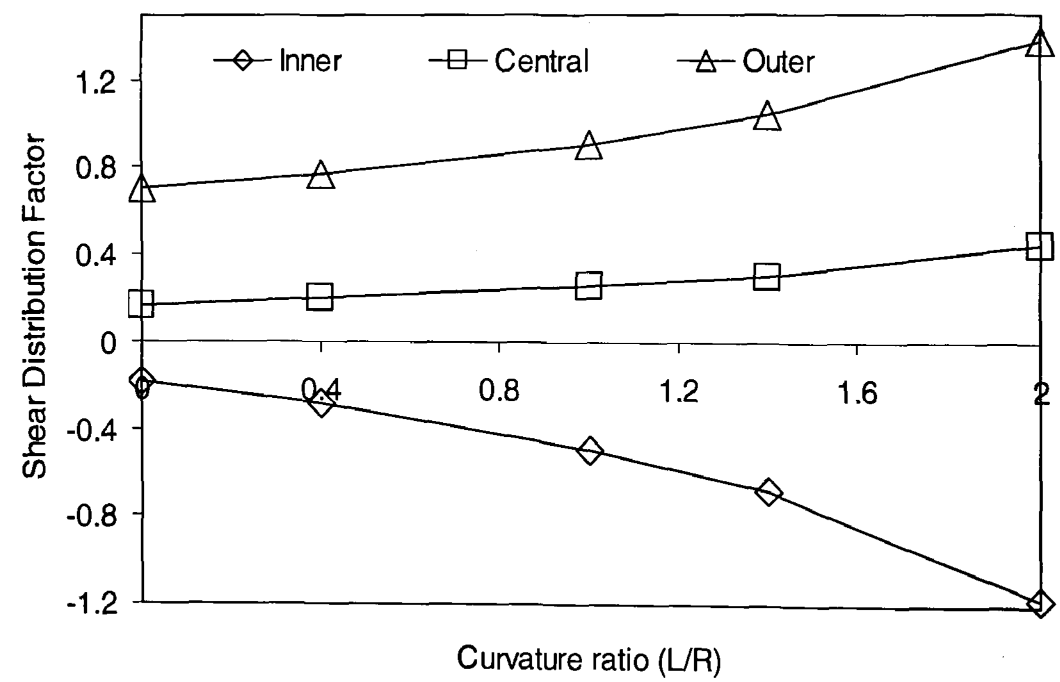


Figure 5.30 Effect of curvature on shear distribution factor for 80 m span, four-lane, four-box girder bridge due to CHBDC Fatigue truck loading in the outer lane

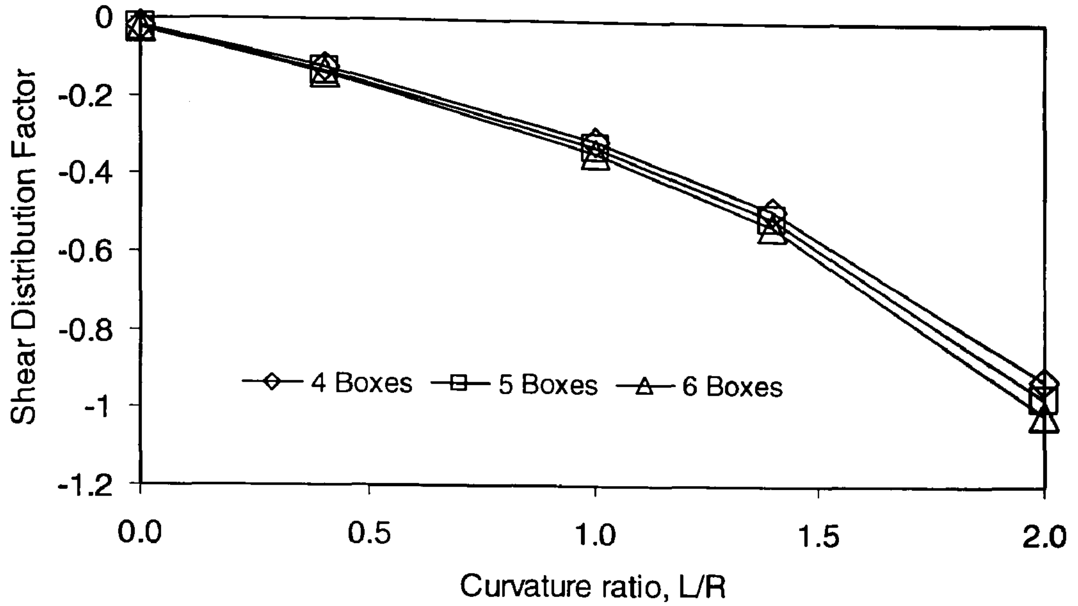


Figure 5.31 Effect of curvature on shear distribution factor for the inner girder of 80 m span, four-lane, box girder bridge due to CHBDC Fatigue truck loading loading in the middle lane

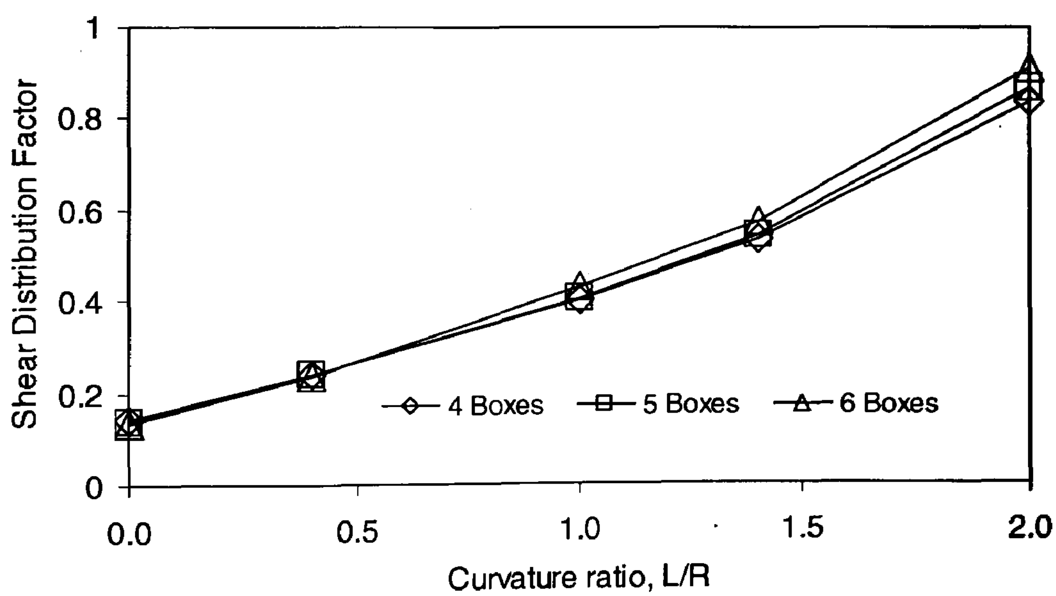


Figure 5.32 Effect of curvature on shear distribution factor for the outer girder of 80 m span, four-lane, box girder bridge due to CHBDC Fatigue truck loading loading in the middle lane

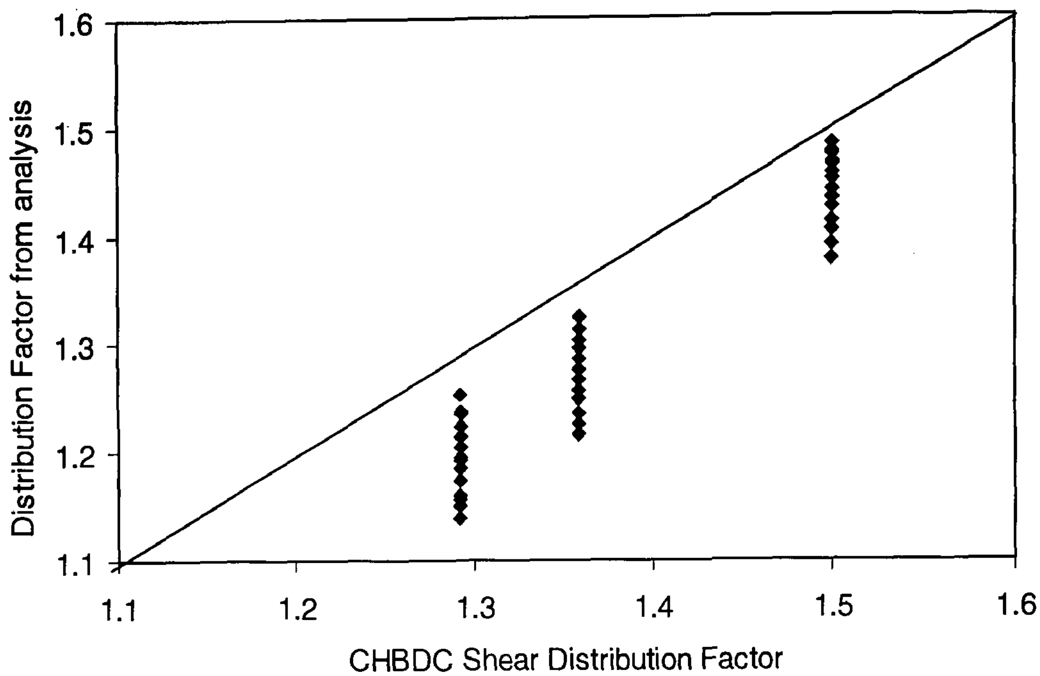


Figure 5.33 Comparison between shear distribution obtained factor from CHBDC and Finite-element analysis for the ultimate limit state

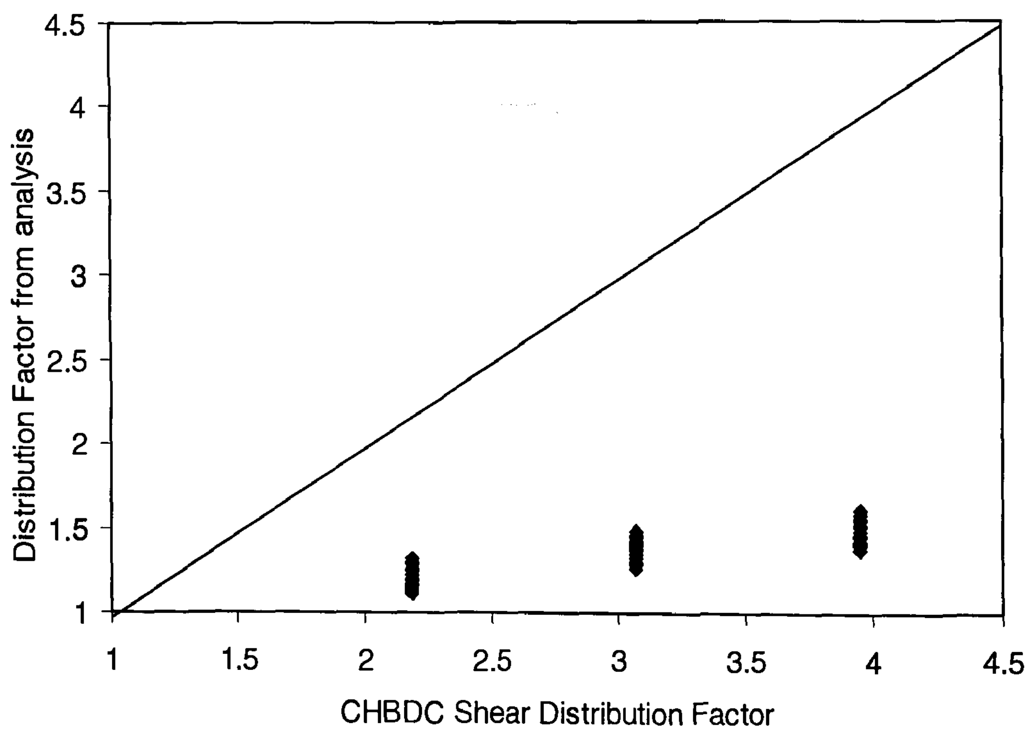


Figure 5.34 Comparison between shear distribution factor obtained from CHBDC and Finite-element analysis for the fatigue limit state

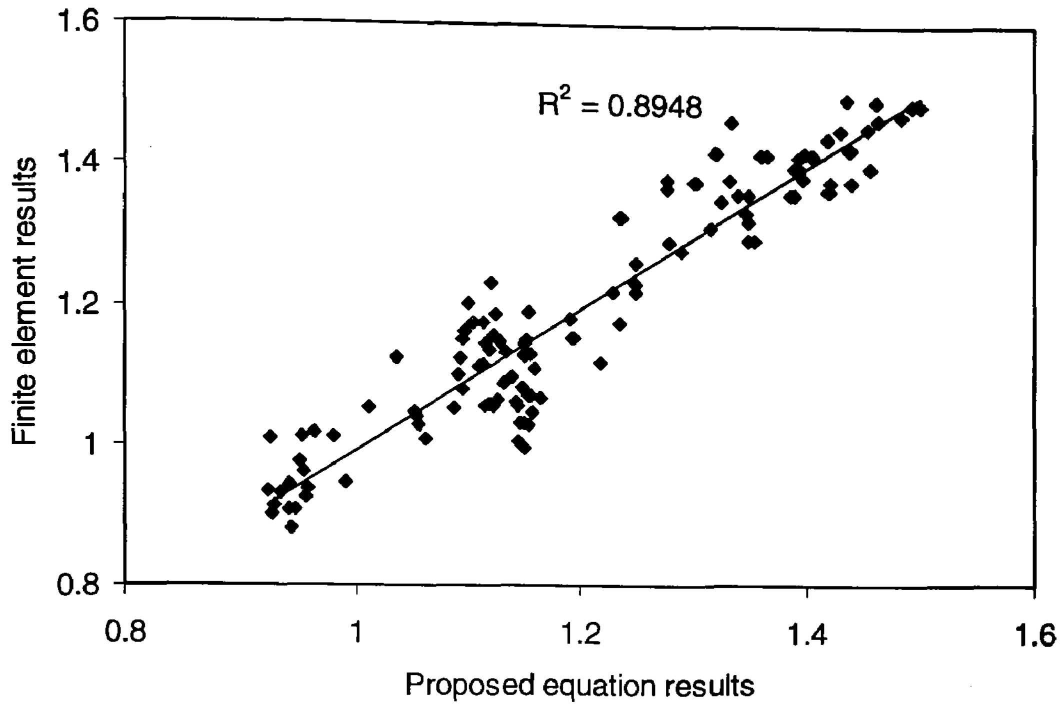


Figure 5.35 Correlation between the results from the proposed equations and those from the finite element analysis at ULS

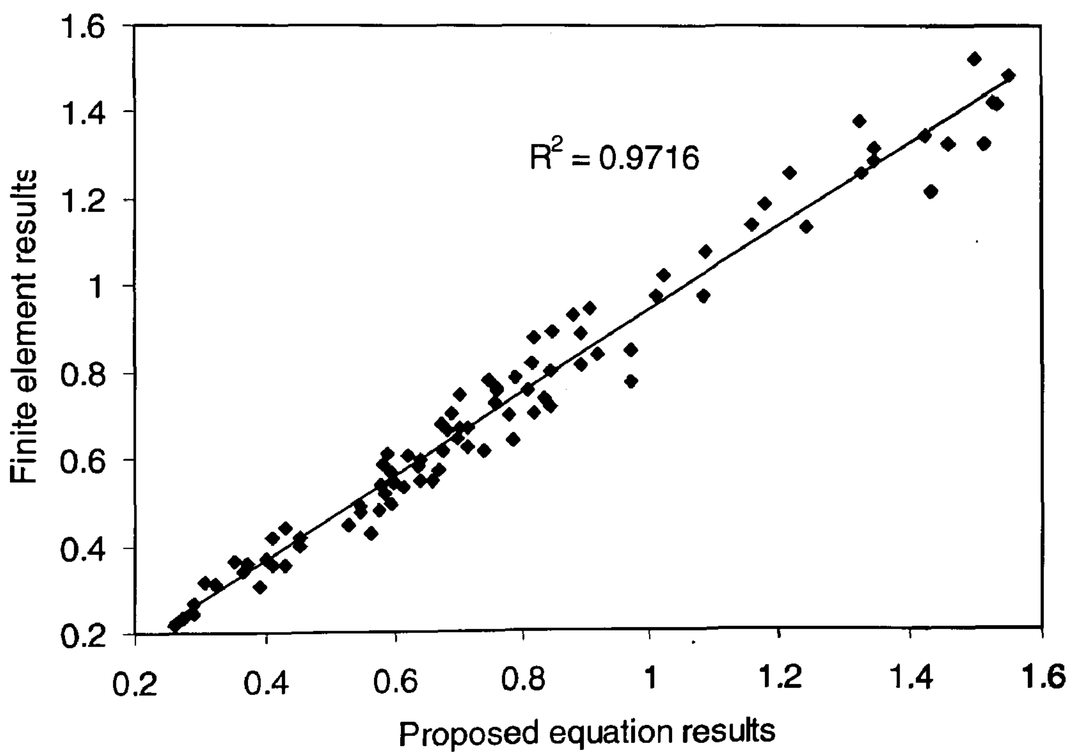


Figure 5.36 Correlation between the results from the proposed equations and those from the finite element analysis at FLS

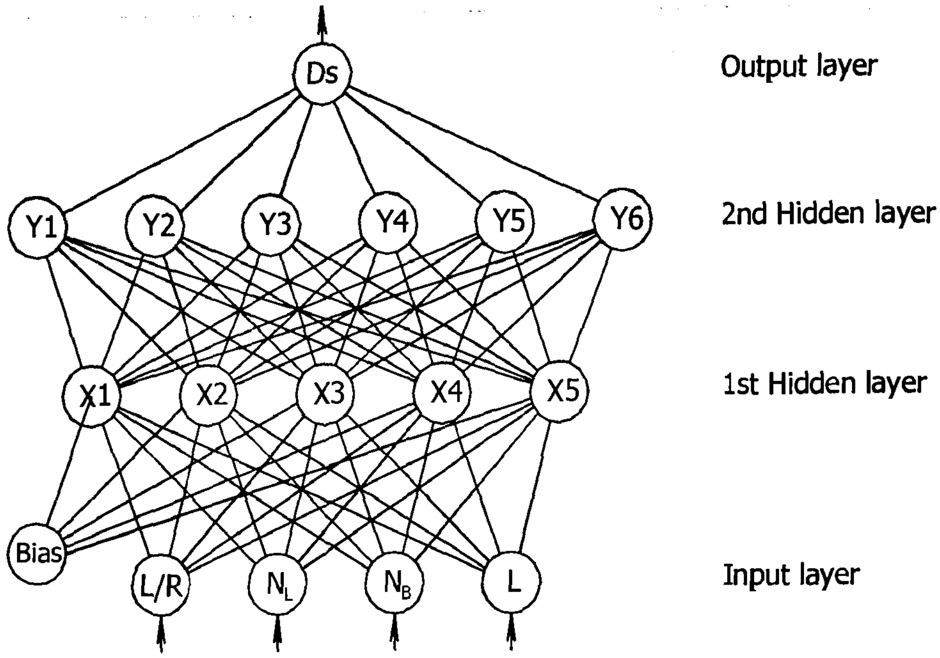


Figure 6.1 Architecture of Artificial Neural Network 4-5-6-1 predicting the shear distribution factor of curved simply supported composite box-girder bridges

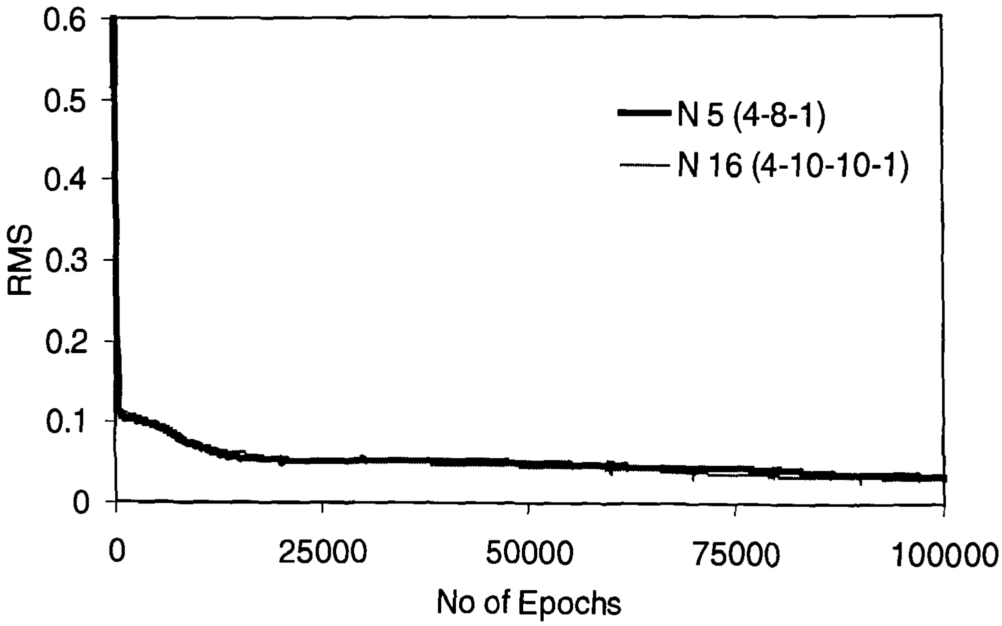


Figure 6.2 Convergence of N5 and N16 for the outer girder due to inner-lane(s) loading

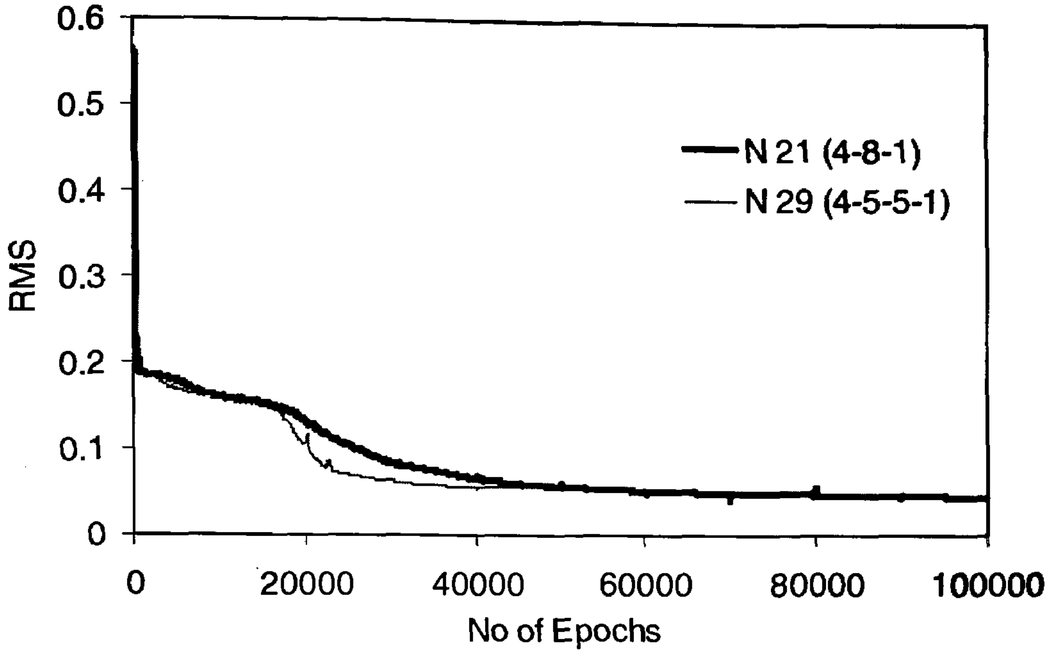


Figure 6.3 Convergence of N21 and N29 for the outer girder due to fully-loaded lanes

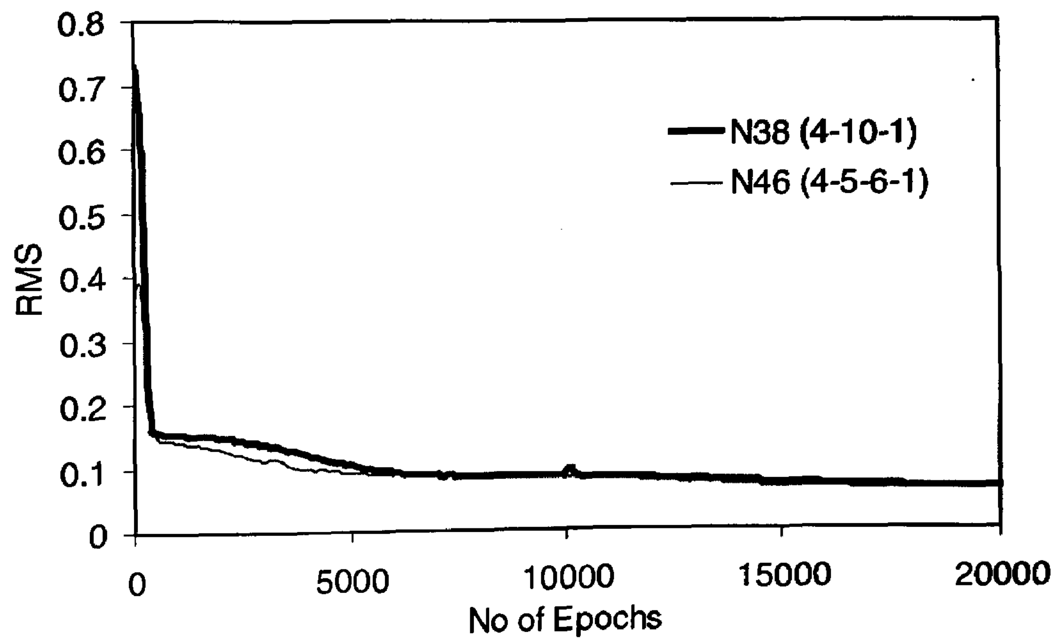


Figure 6.4 Convergence of N38 and N46 for the outer girder due to outer-lane(s) loading

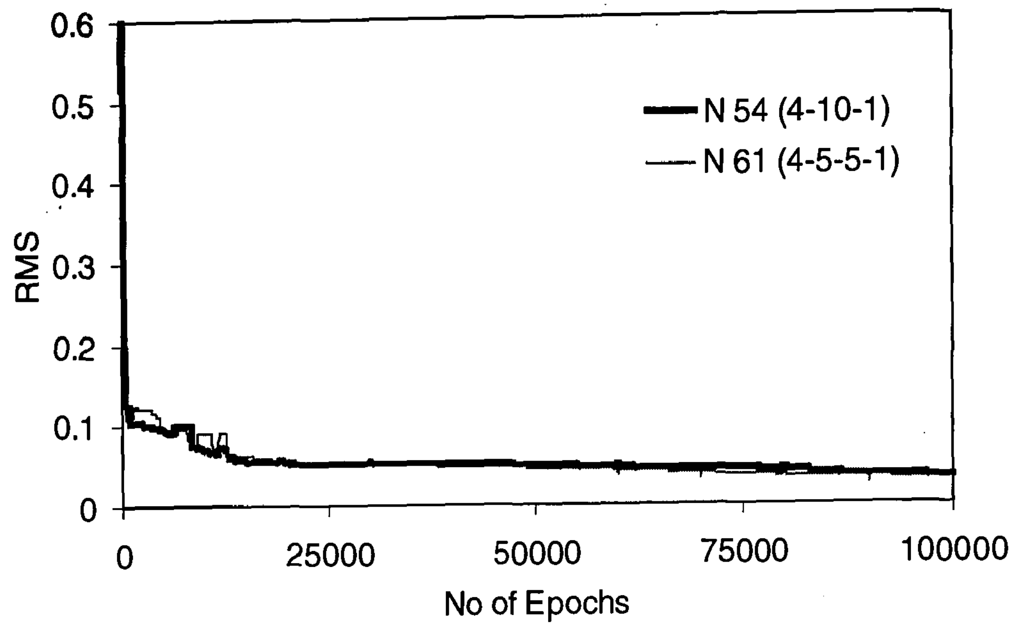


Figure 6.5 Convergence of N54 and N61 for the inner girder due to inner-lane(s) loading

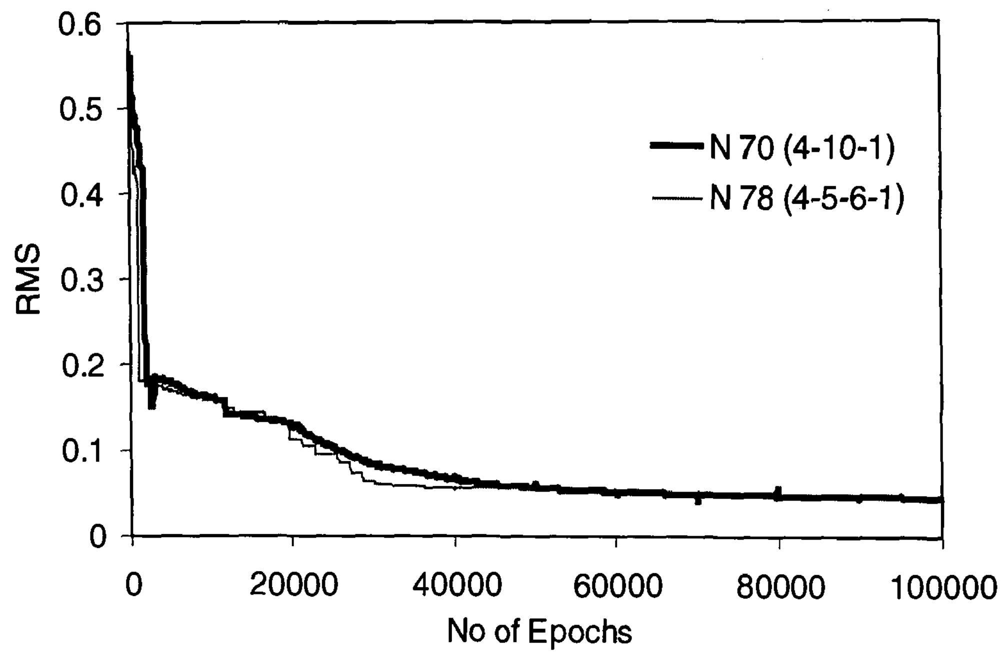


Figure 6.6 Convergence of N70 and N78 for the inner girder due to fully-loaded lanes

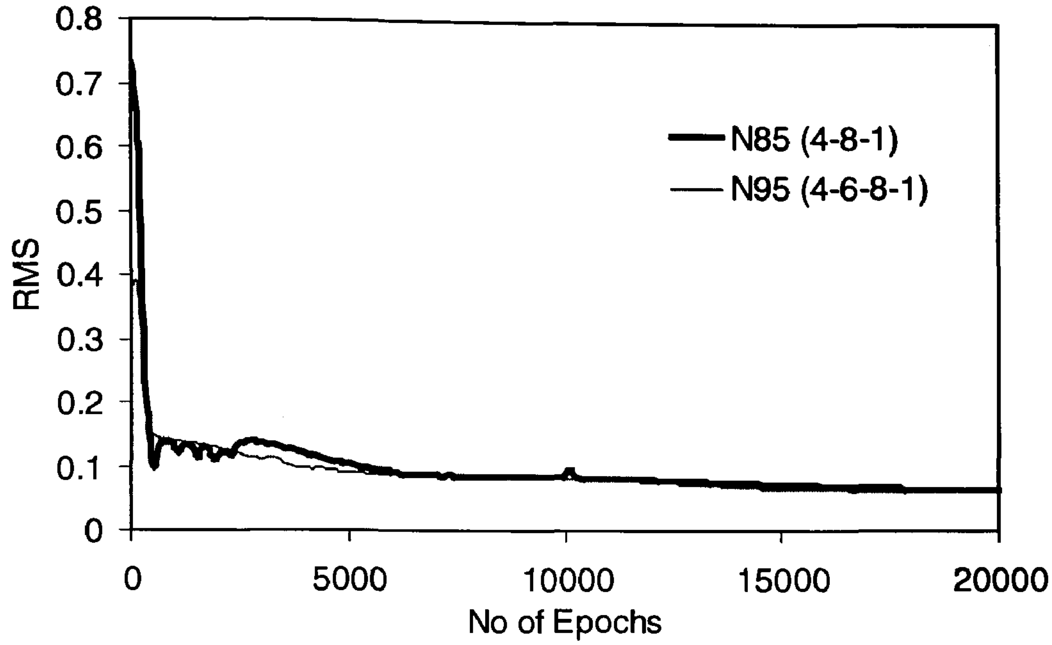


Figure 6.7 Convergence of N85 and N95 for the inner girder due to outer-lane(s) loading

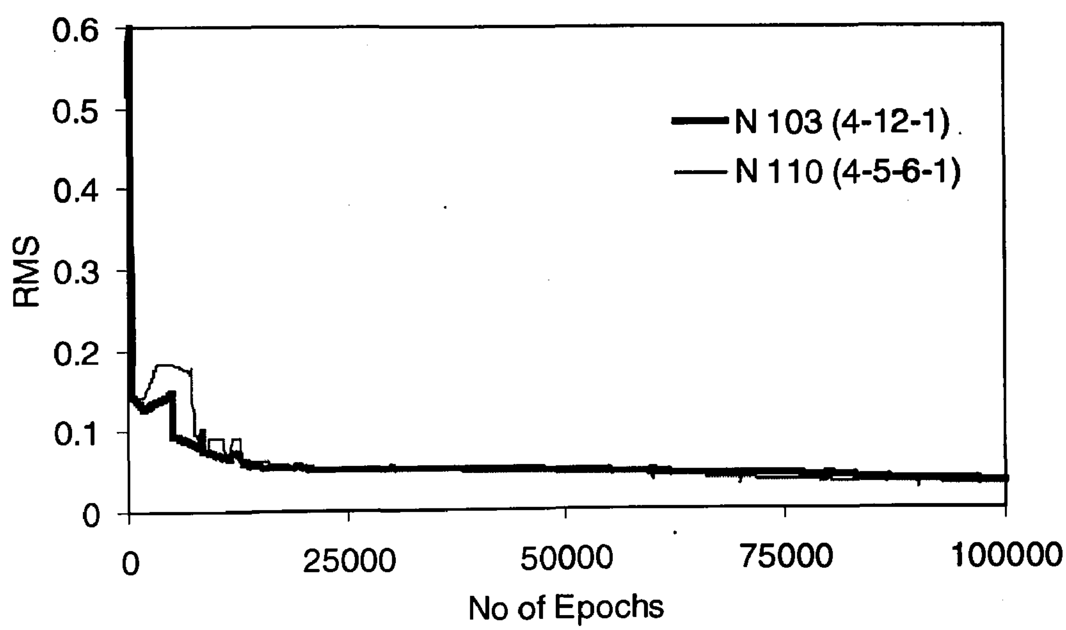


Figure 6.8 Convergence of N103 and N110 for the middle girder due to inner-lane(s) loading

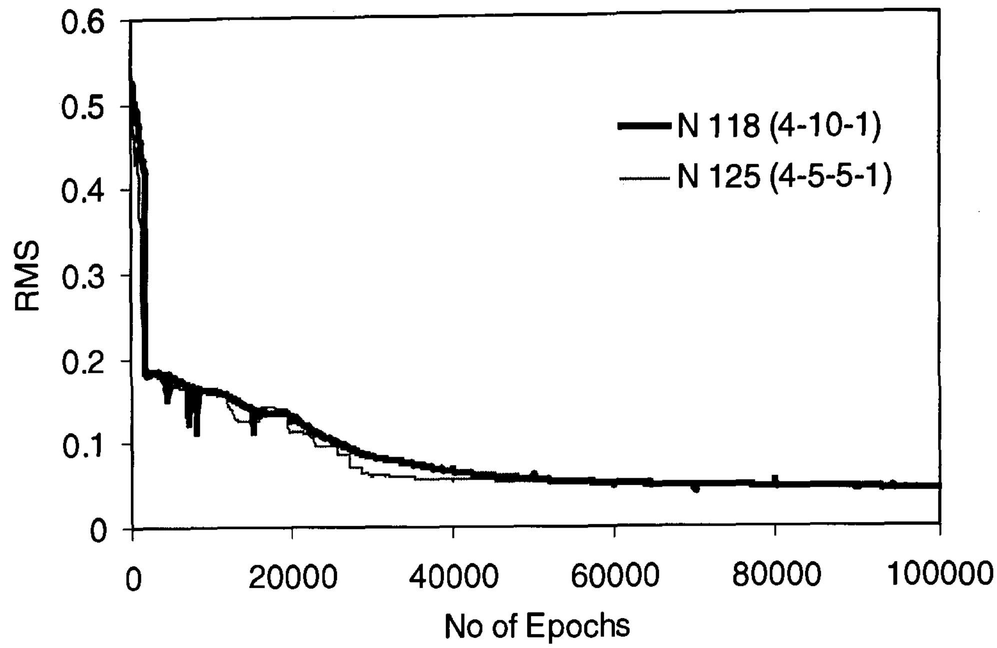


Figure 6.9 Convergence of N118 and N125 for the middle girder due to fully-loaded lanes

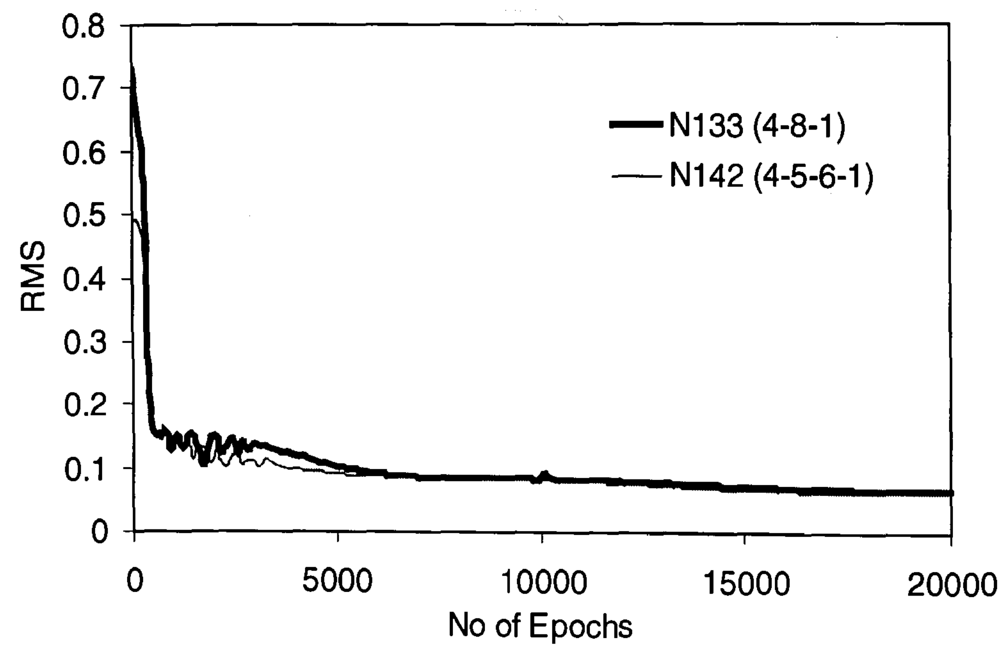


Figure 6.10 Convergence of N133 and N142 for the middle girder due to outer-lane(s) loading

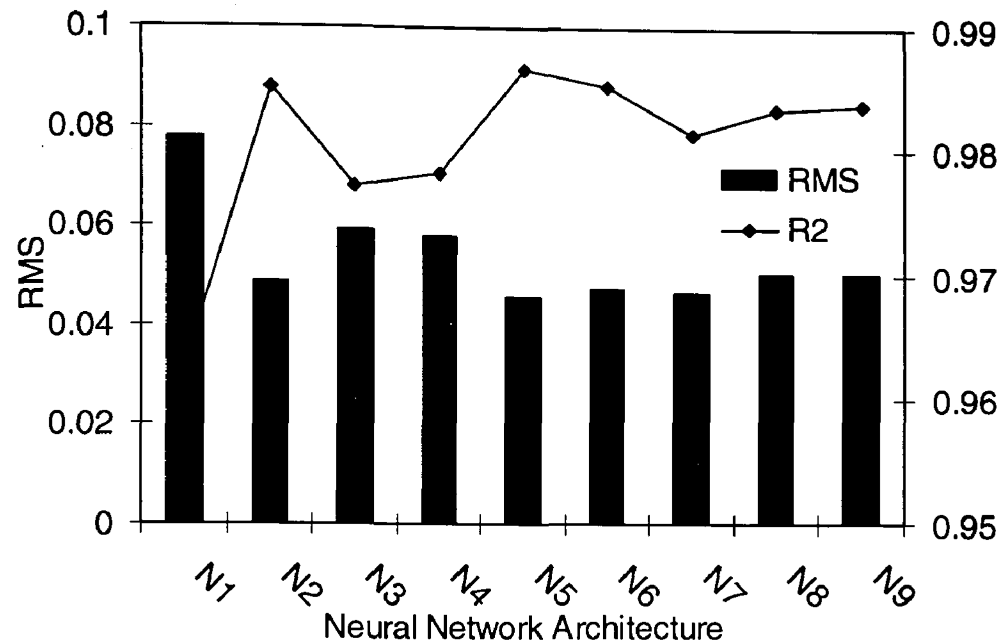


Figure 6.11 Performance of different NN architectures of the outer girder within one hidden layer due to inner-lane(s) loading

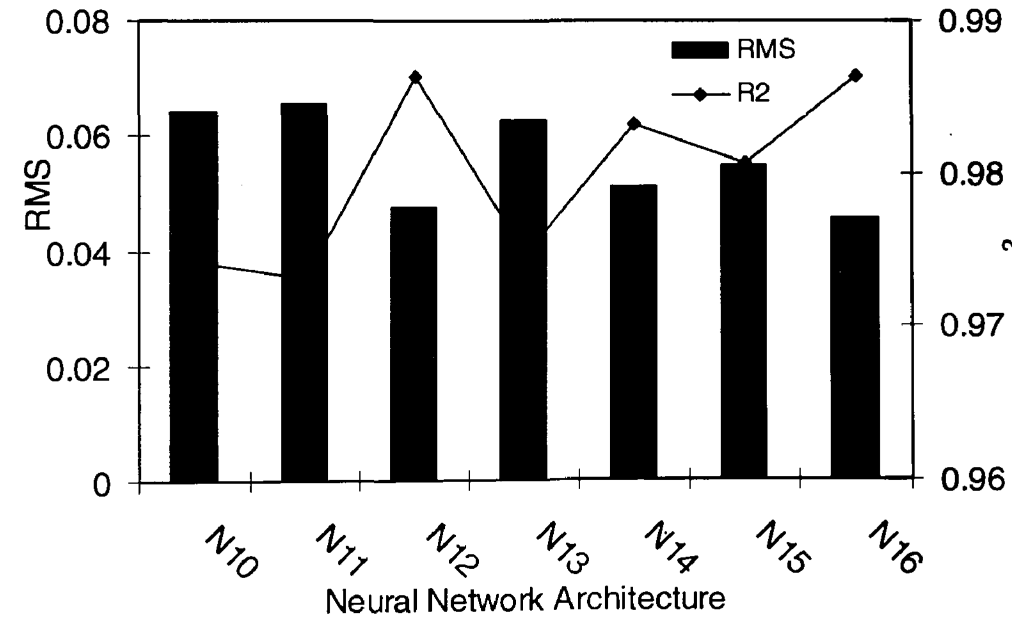


Figure 6.12 Performance of different NN architectures of the outer girder within two hidden layers due to inner-lane(s) loading

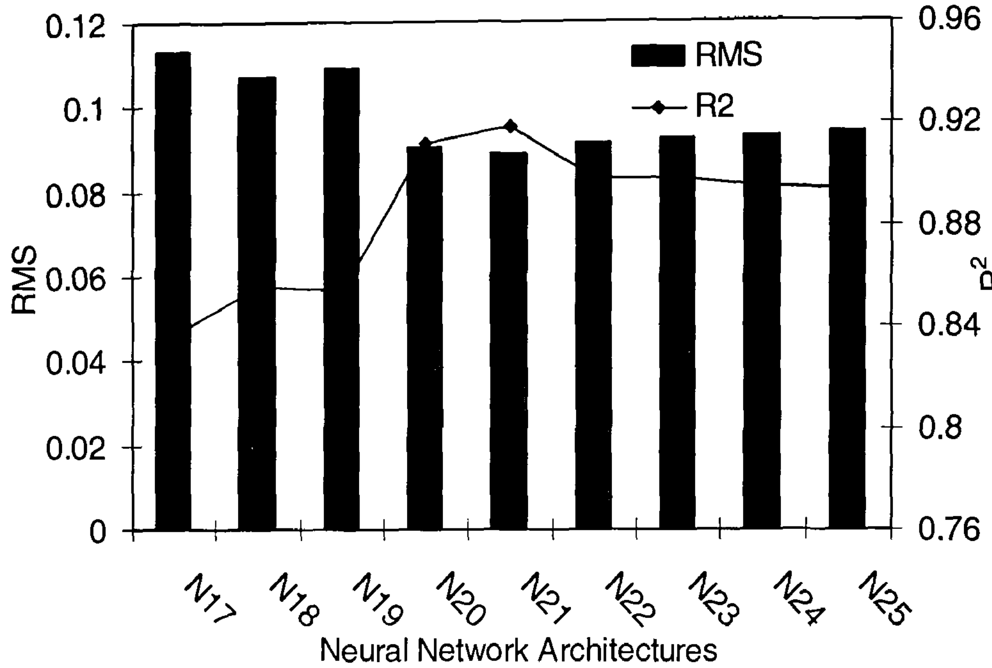


Figure 6.13 Performance of different NN architectures of the outer girder within one hidden layer due to fully-loaded lanes

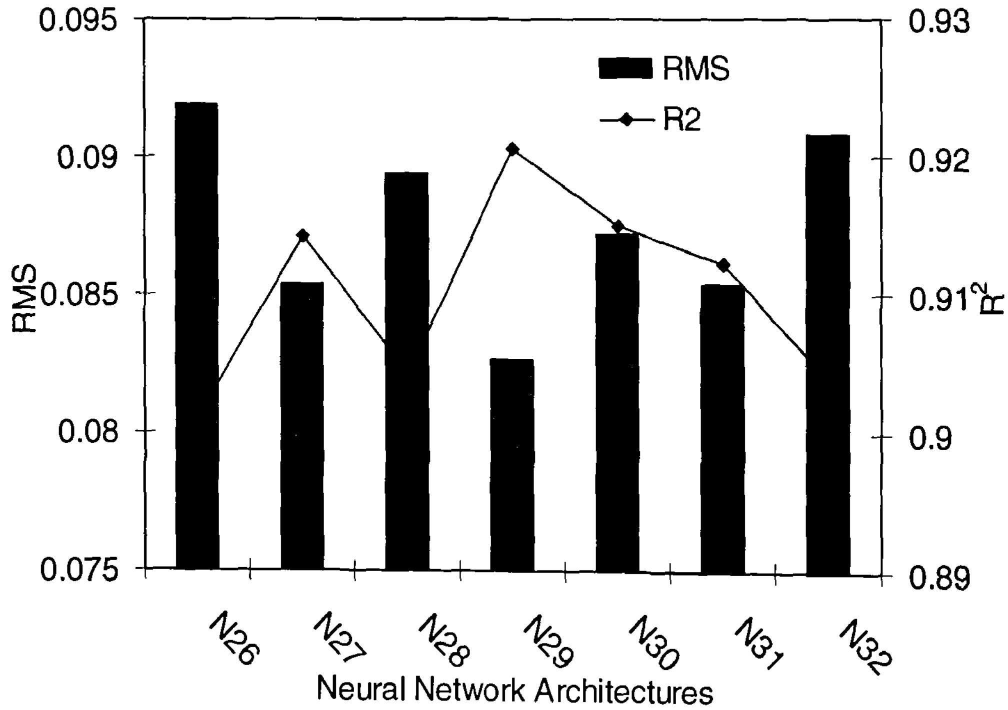


Figure 6.14 Performance of different NN architectures of the outer girder within two hidden layers due to fully-loaded lanes

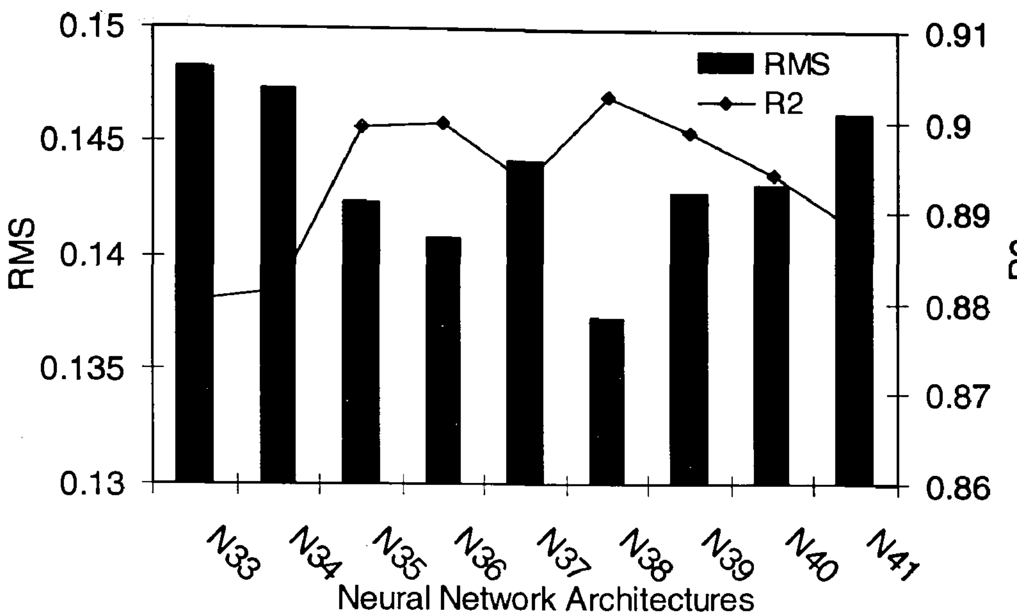


Figure 6.15 Performance of different NN architectures of the outer girder within one hidden layer due to outer-lane(s) loading

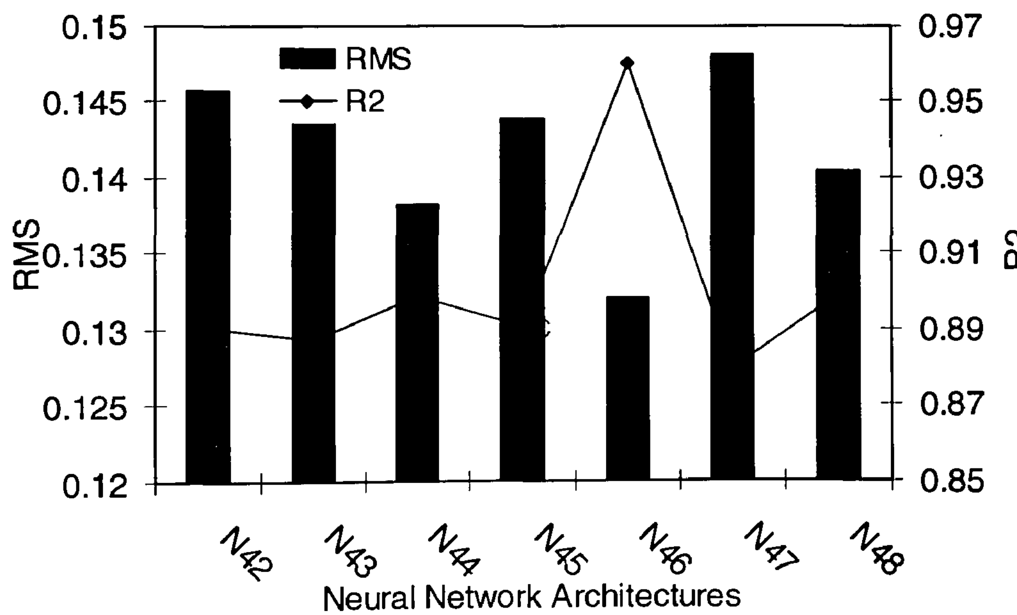


Figure 6.16 Performance of different NN architectures of the outer girder within two hidden layers due to outer-lane(s) loading

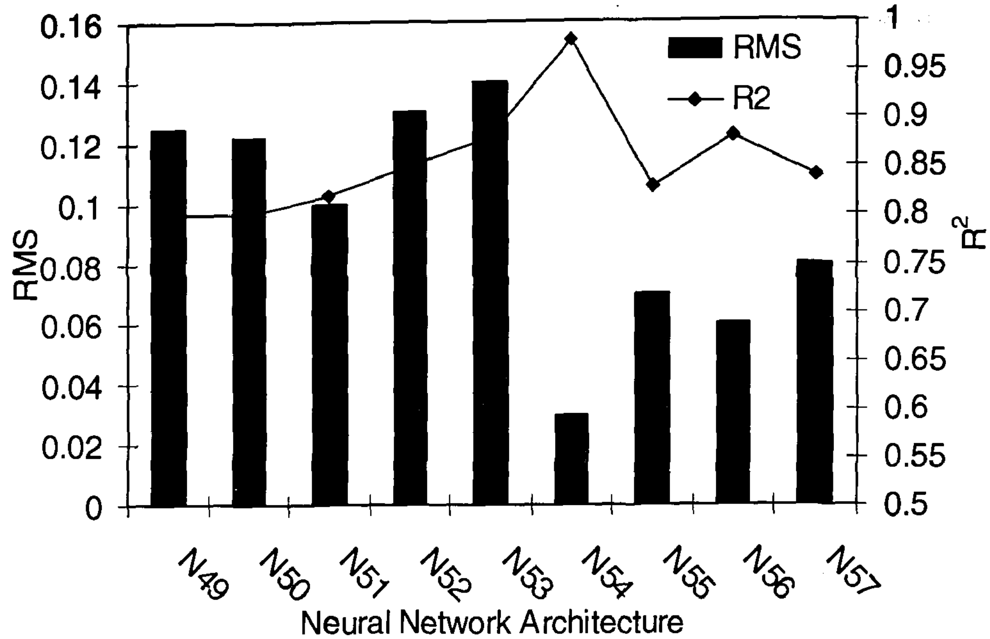


Figure 6.17 Performance of different NN architectures of the inner girder within one hidden layer due to inner-lane(s) loading

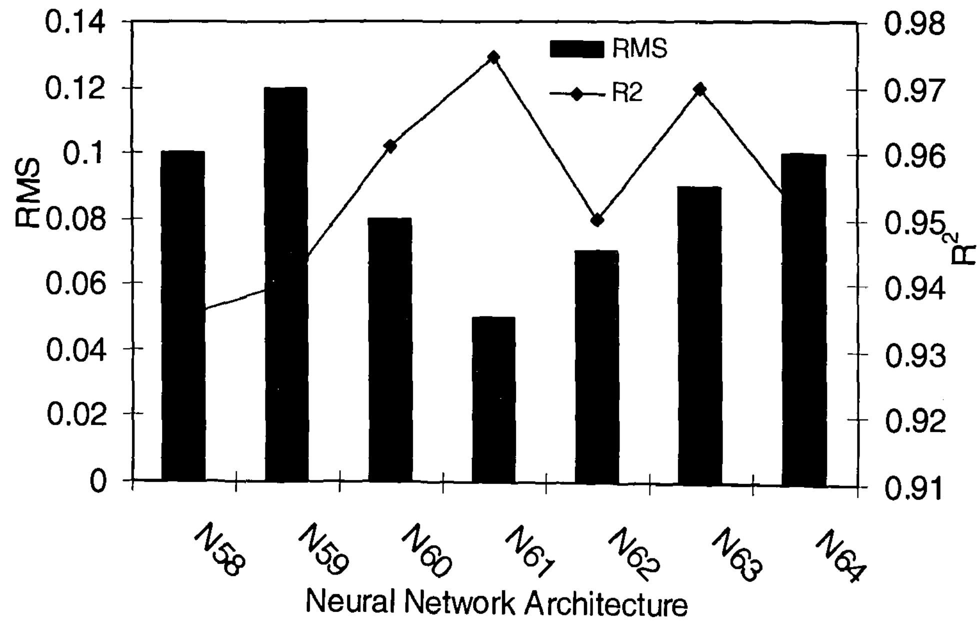


Figure 6.18 Performance of different NN architectures of the inner girder within two hidden layers due to inner-lane(s) loading

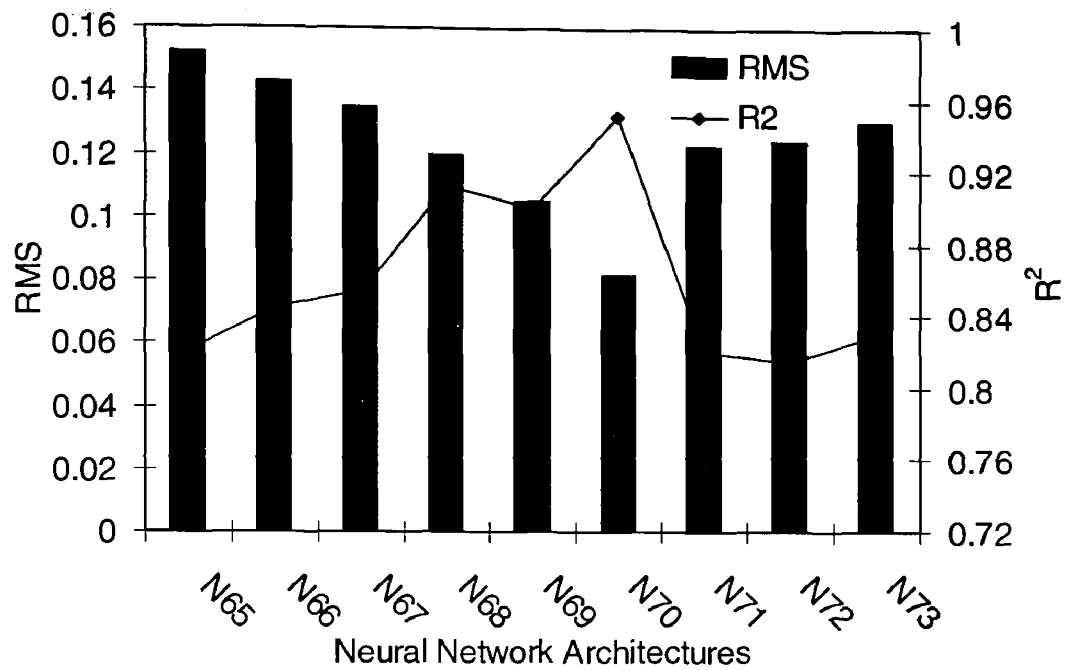


Figure 6.19 Performance of different NN architectures of the inner girder within one hidden layer due to fully-loaded lanes

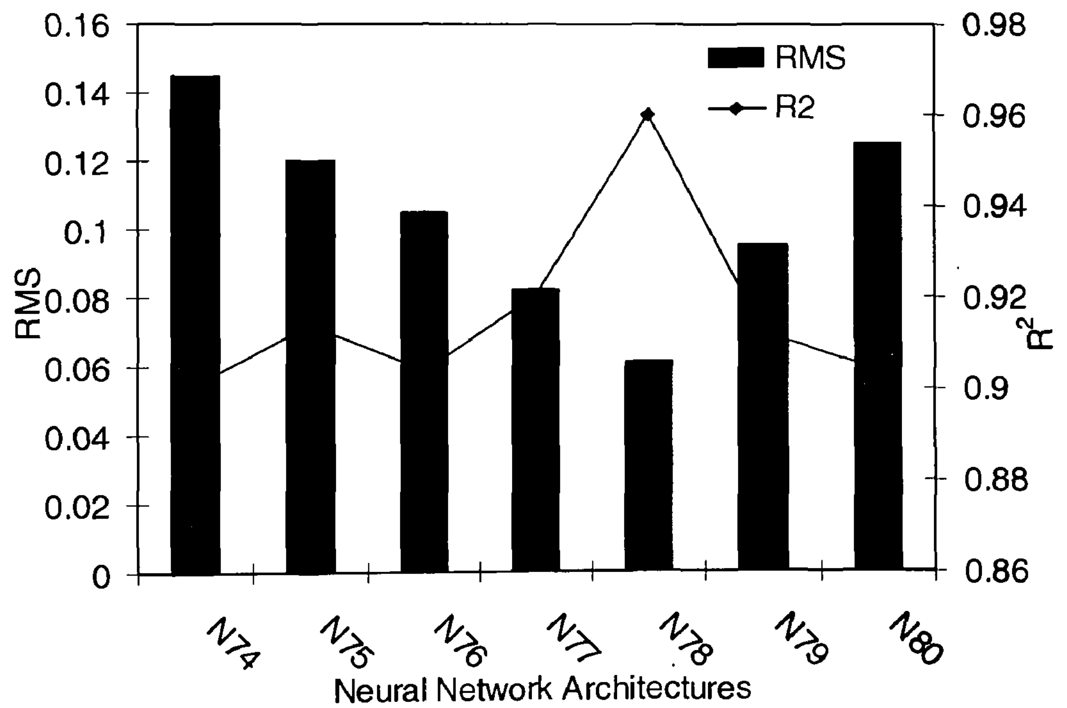


Figure 6.20 Performance of different NN architectures of the inner girder within two hidden layers due to fully-loaded lanes

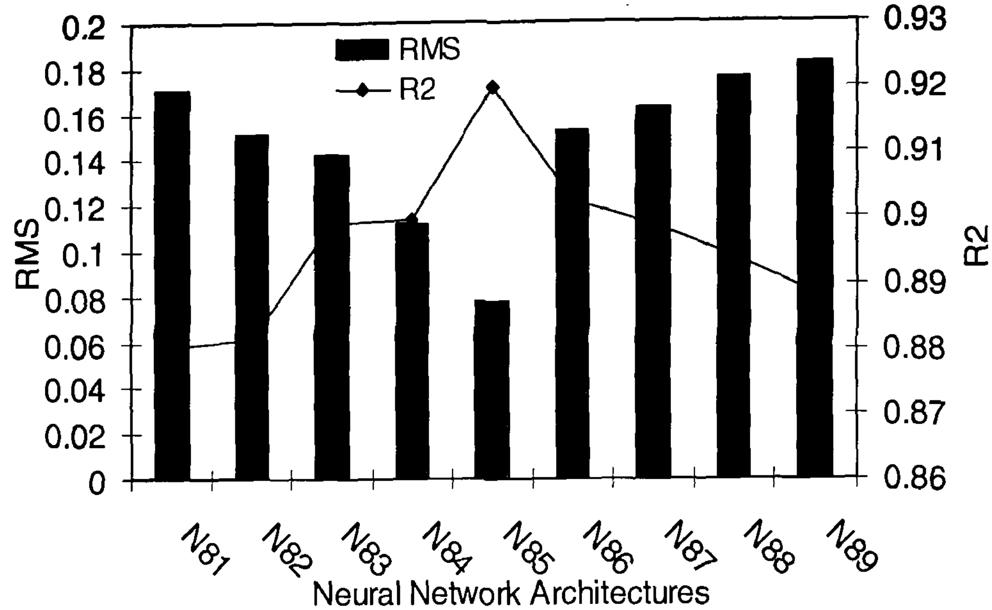


Figure 6.21 Performance of different NN architectures of the inner girder within one hidden layer due to outer-lane(s) loading

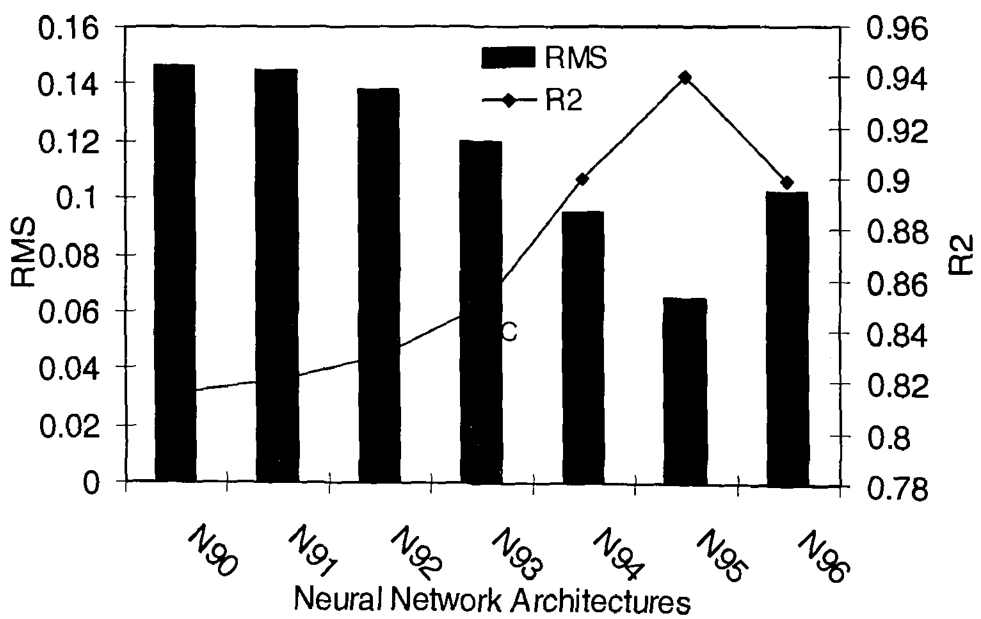


Figure 6.22 Performance of different NN architectures of the inner girder within two hidden layers due to outer-lane(s) loading

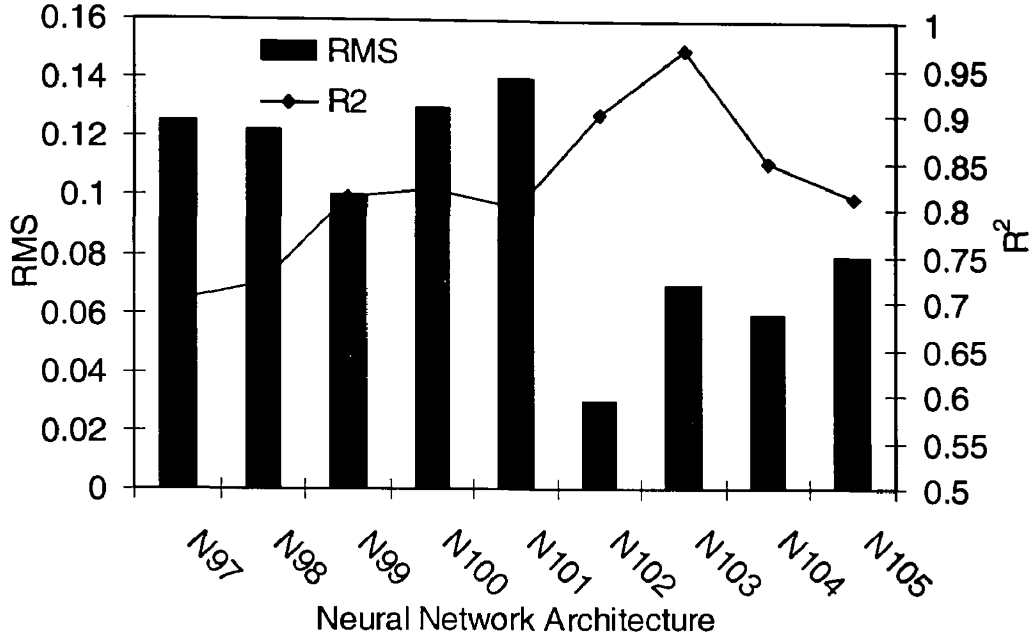


Figure 6.23 Performance of different NN architectures of the middle girder within one hidden layer due to inner-lane(s) loading

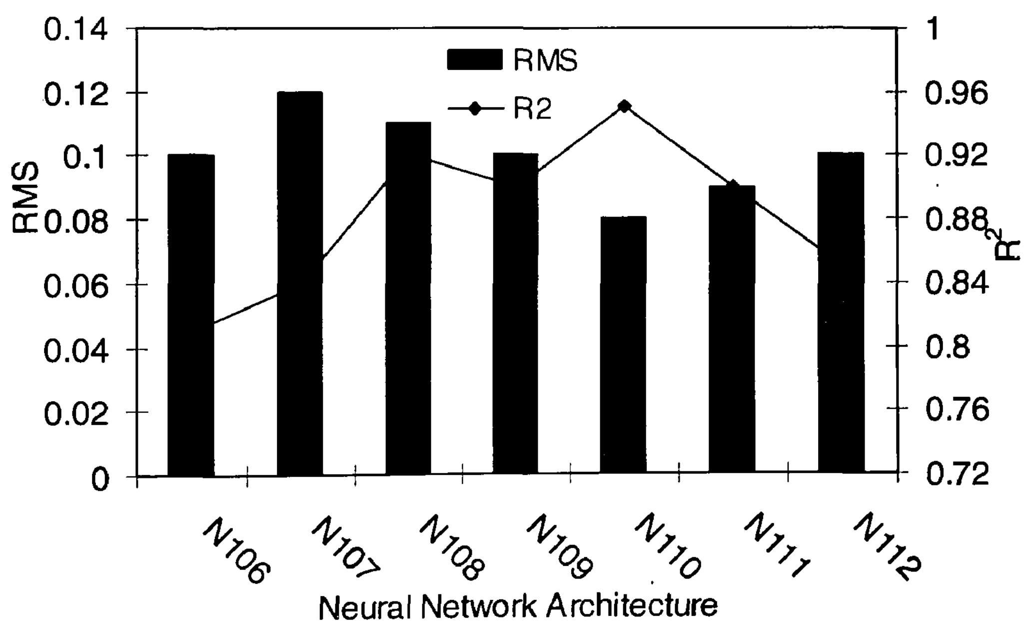


Figure 6.24 Performance of different NN architectures of the middle girder within two hidden layers due to inner-lane(s) loading

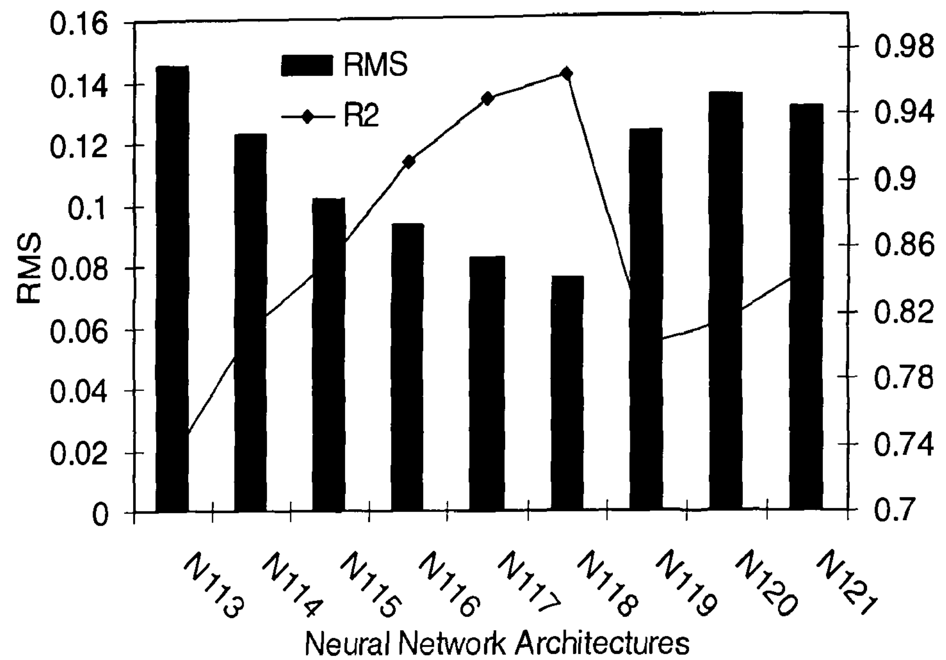


Figure 6.25 Performance of different NN architectures of the middle girder within one hidden layer due to fully-loaded lanes

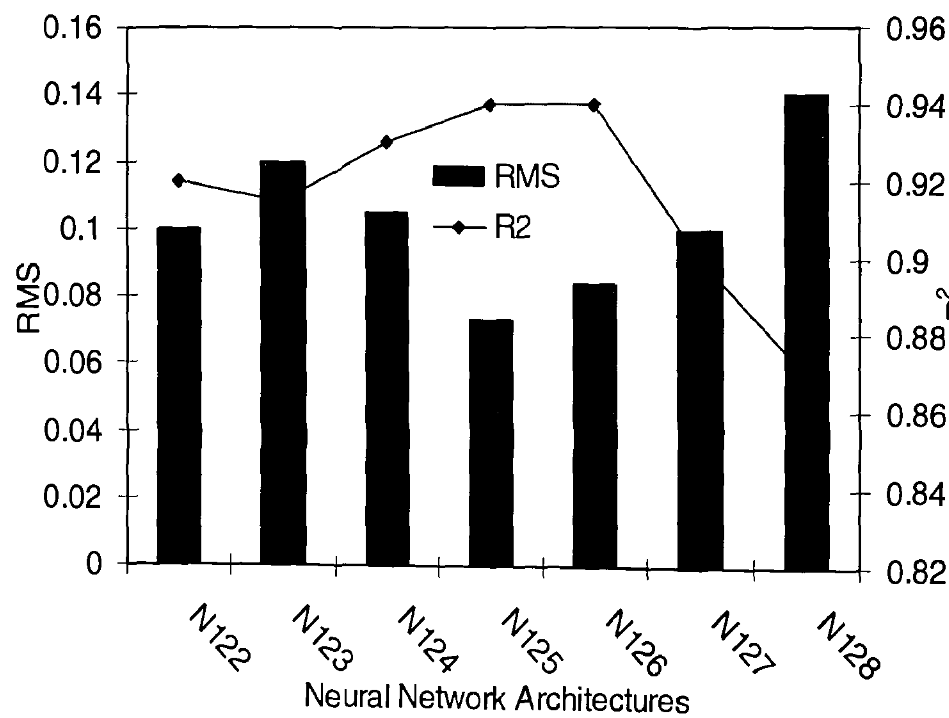


Figure 6.26 Performance of different NN architectures of the middle girder within two hidden layers due to fully-loaded lanes

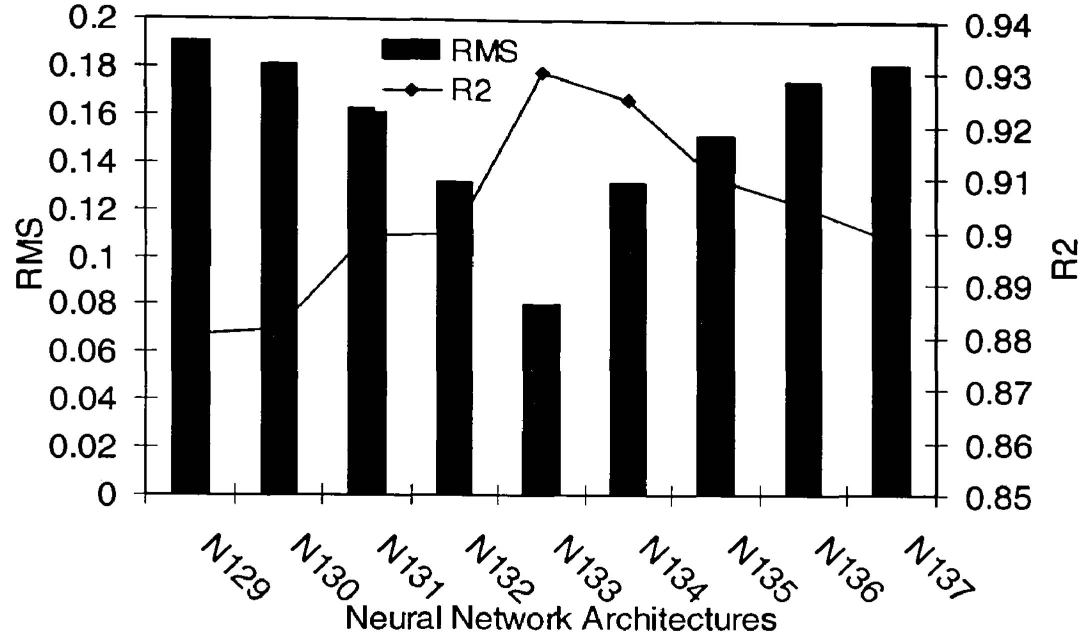


Figure 6.27 Performance of different NN architectures of the middle girder within one hidden layer due to outer-lane(s) loading

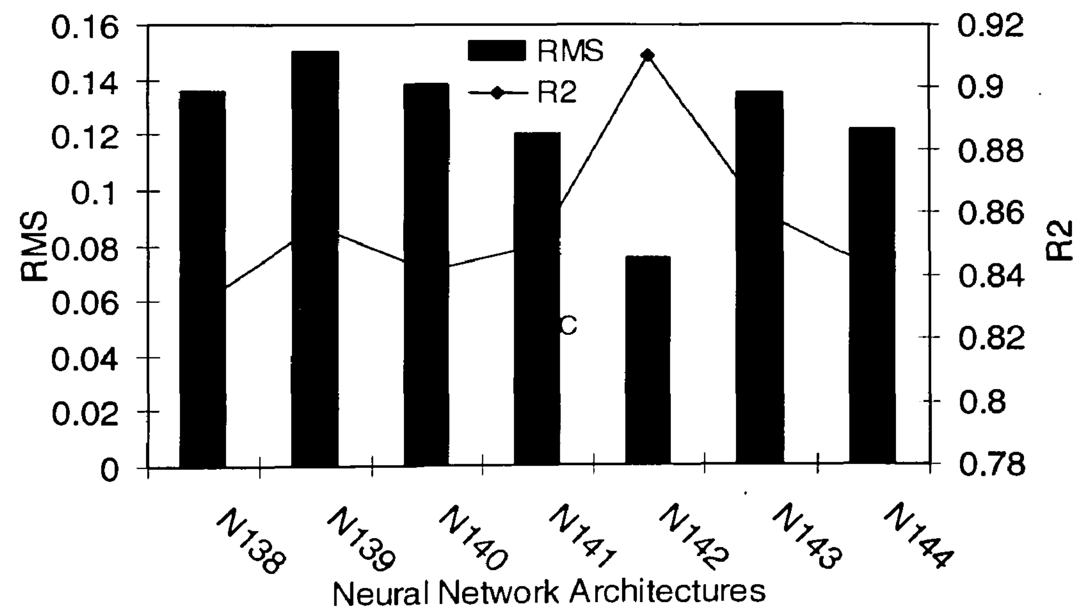


Figure 6.28 Performance of different NN architectures of the middle girder within two hidden layers due to outer-lane(s) loading

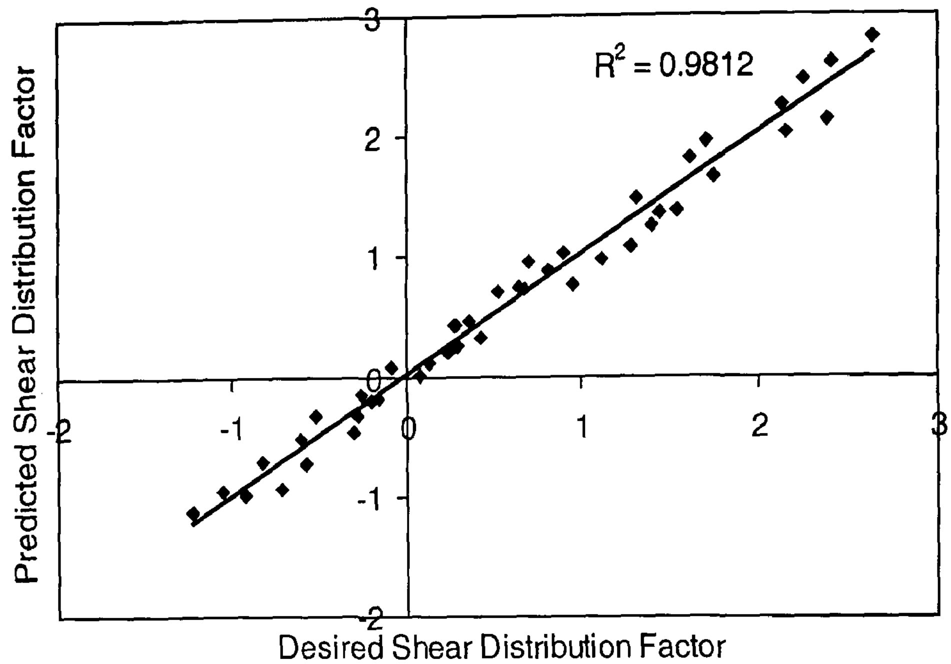


Figure 6.29 Correlation between the desired and predicted shear distribution factor for N5(4-8-1) of the outer girder due to inner-lane(s) loading

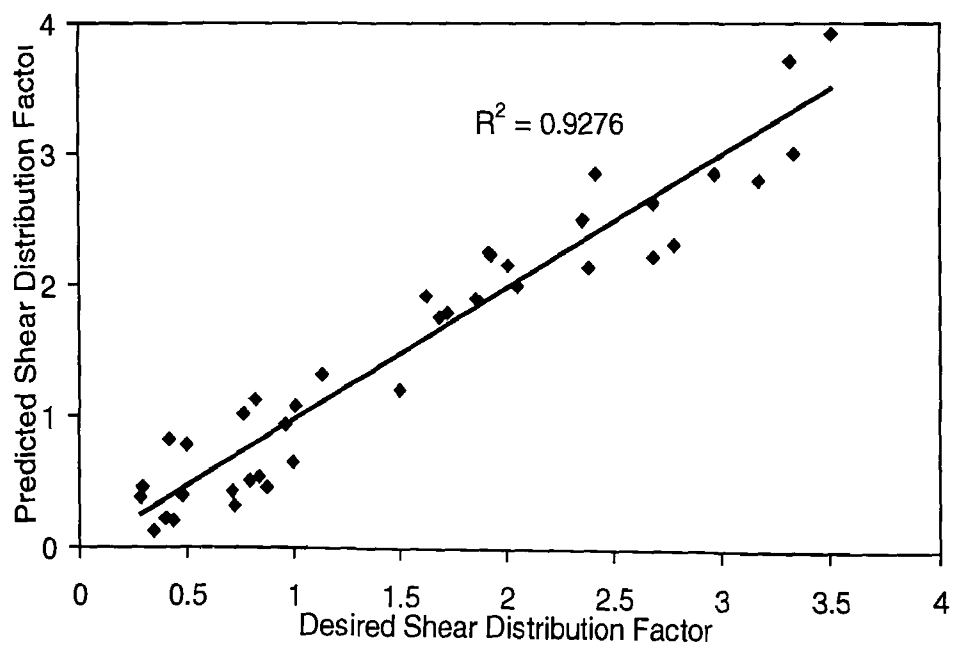


Figure 6.30 Correlation between the desired and predicted shear distribution factor for N29(4-5-5-1) of the outer girder due to fully-lane(s) loading

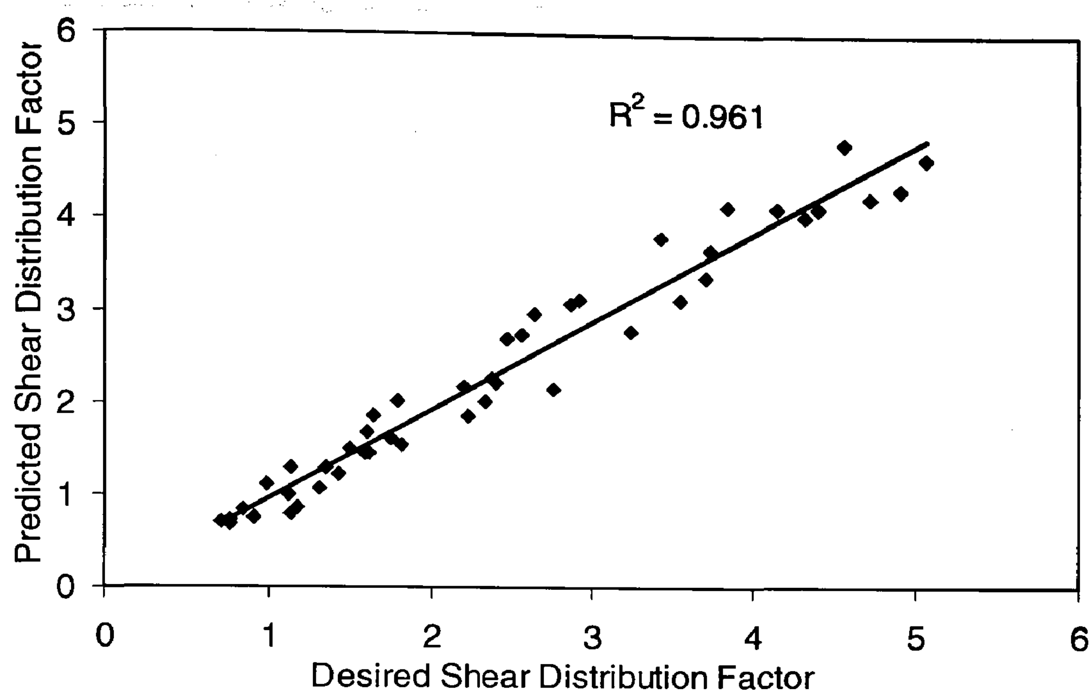


Figure 6.31 Correlation between the desired and predicted shear distribution factor for N46(4-5-6-1) of the outer girder due to outer-lane(s) loading

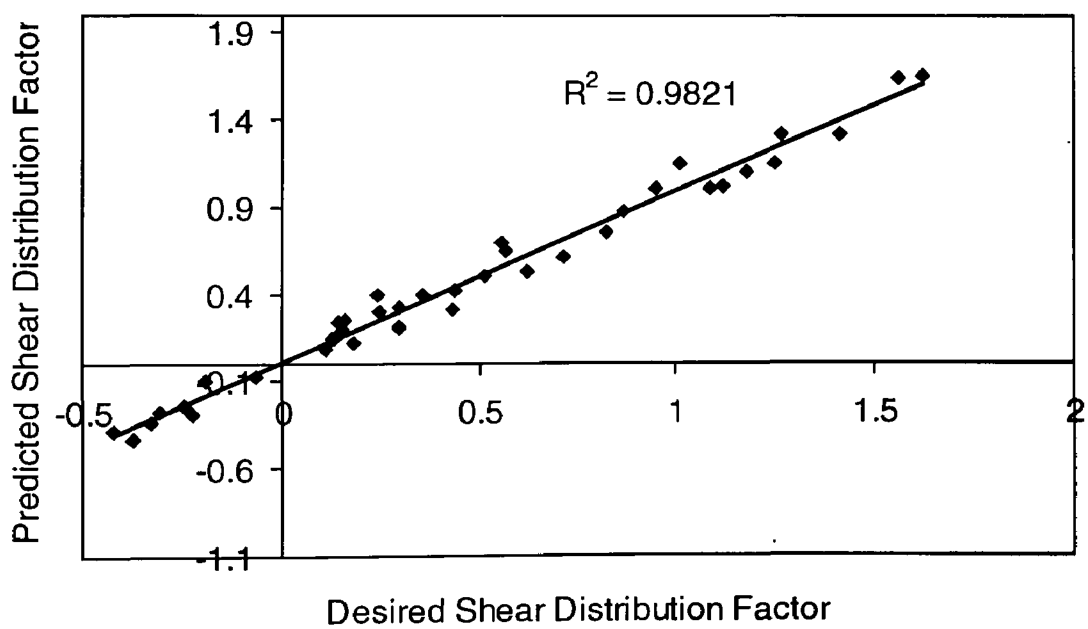


Figure 6.32 Correlation between the desired and predicted shear distribution factor for N54(4-10-1) of the inner girder due to inner-lane(s) loading

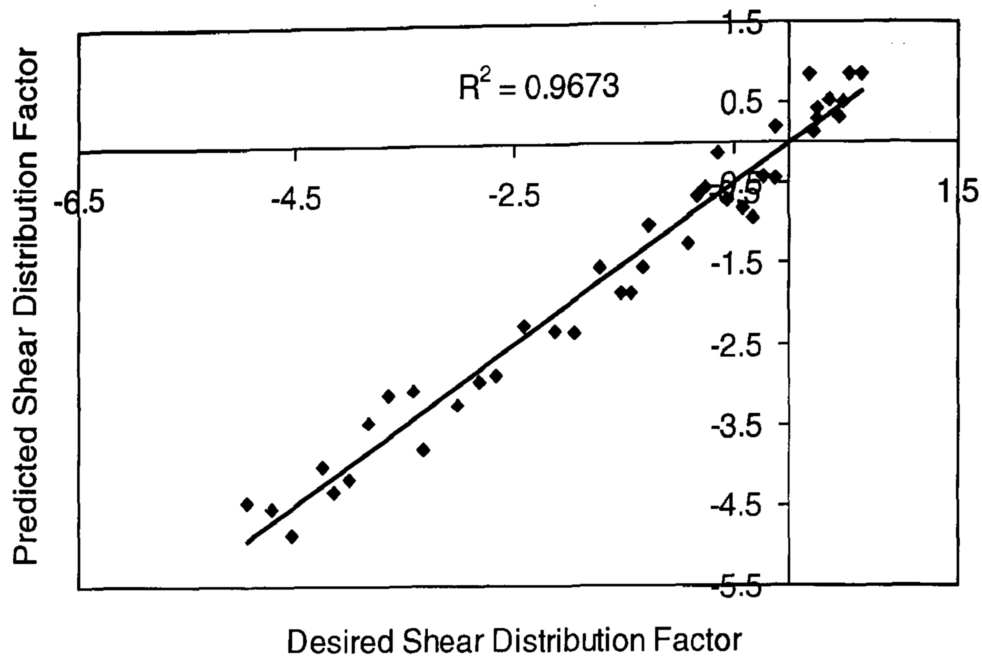


Figure 6.33 Correlation between the desired and predicted shear distribution factor for N78(4-5-6-1) of the inner girder due to fully-lane(s) loading

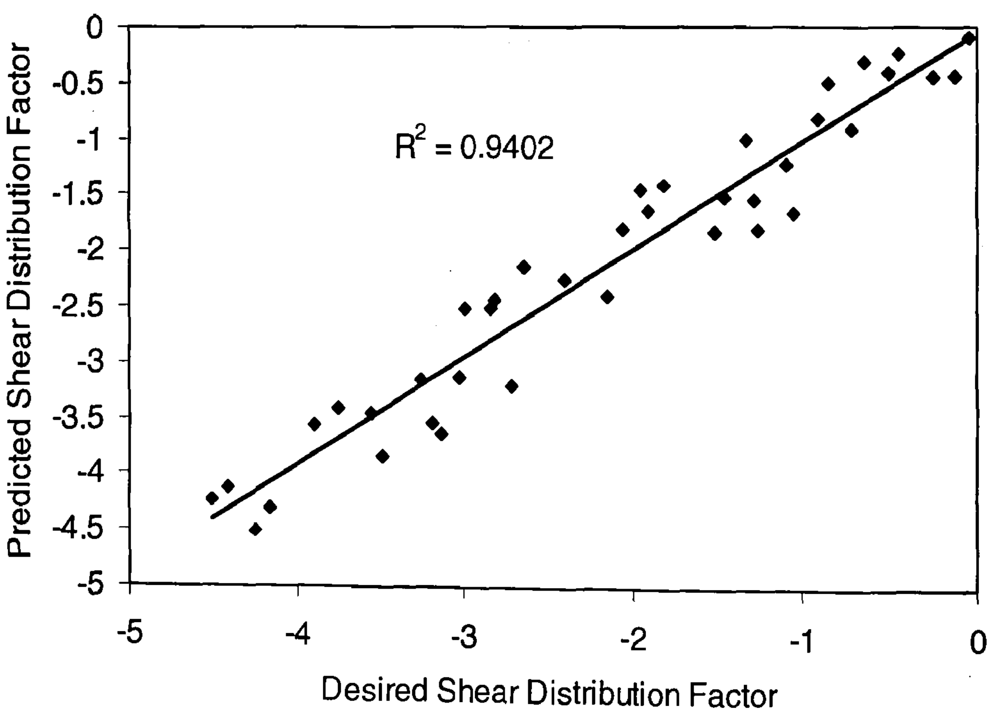


Figure 6.34 Correlation between the desired and predicted shear distribution factor for N95(4-6-8-1) of the inner girder due to outer-lane(s) loading

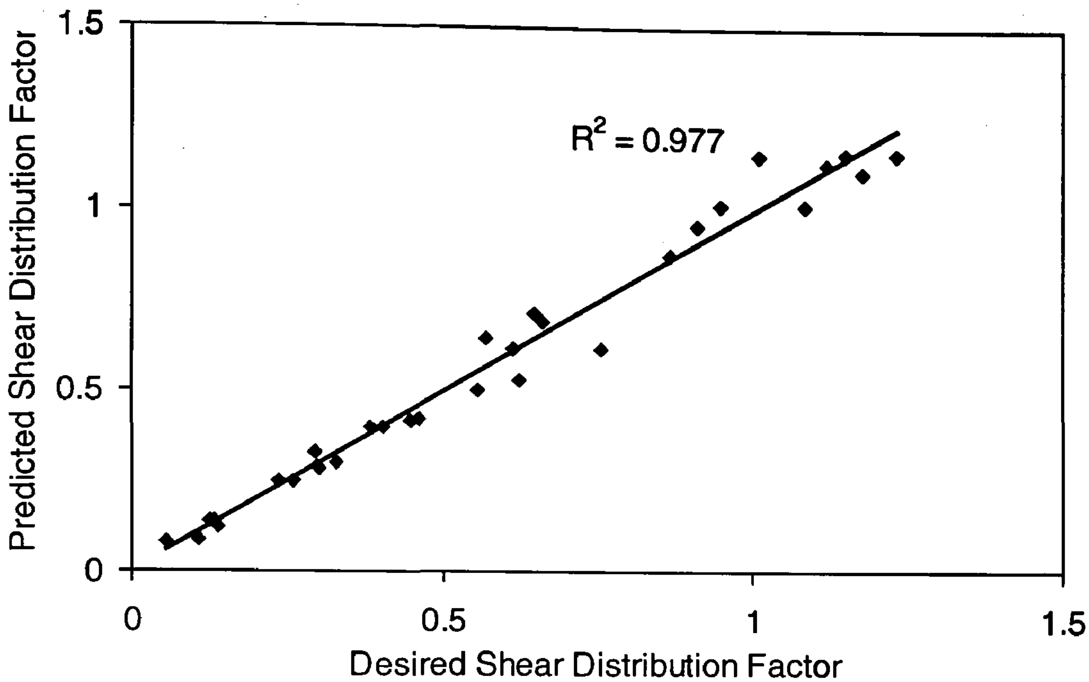


Figure 6.35 Correlation between the desired and predicted shear distribution factor for N103(4-12-1) of the middle girder due to inner-lane(s) loading

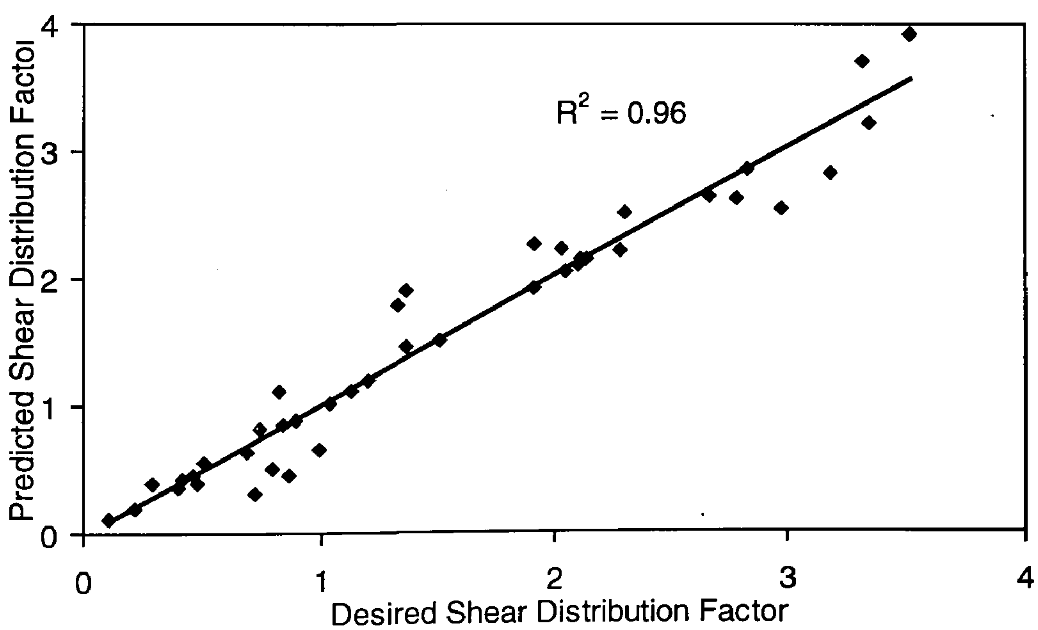


Figure 6.36 Correlation between the desired and predicted shear distribution factor for N118(4-10-1) of the middle girder due to fully-lane(s) loading

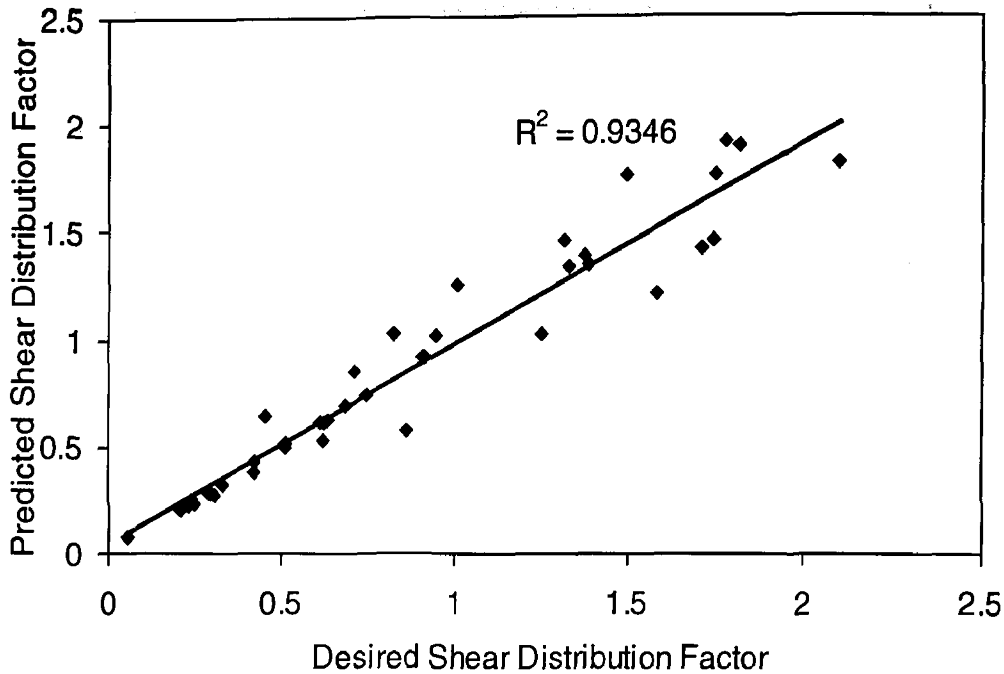


Figure 6.37 Correlation between the desired and predicted shear distribution factor for N133(4-8-1) of the middle girder due to outer-lane(s) loading

APPENDIX A

Geometries of the prototype bridges in the parametric study

Table A.1 Geometries of the prototype bridges in the parametric study

Bridge Type	Span L(m)	No. of lanes	No. of boxes	Cross-section dimensions (mm)								
				A	B	C	D	F	t_1	t_2	t_3	t_4
			2		2325				16	10	15	
2L-2b-sc-20		2	3	9300	1550	300	800	1025	11	8	15	225
			4		1160				10	8	14	
			3		2175				16	10	17	
3L-3b-sc-20	20	3	4	13050	1630	300	800	1025	12	8	16	225
			5		1305				10	8	16	
			4		2100				16	10	18	
4L-4b-sc-20		4	5	16800	1680	300	800	1025	13	10	18	225
			6		1400				11	10	18	
			2		2325				28	14	18	
2L-2b-sc-40		2	3	9300	1550	375	1600	1825	19	10	18	225
			4		1160				14	8	18	
			3		2175				28	14	20	
3L-3b-sc-40	40	3	4	13050	1630	375	1600	1825	21	11	19	225
			5		1305				17	10	18	
			4		2100				28	14	21	
4L-4b-sc-40		4	5	16800	1680	375	1600	1825	22	11	22	225
			6		1400				19	9	22	
			2		2325				40	18	23	
2L-2b-sc-60		2	3	9300	1550	450	2400	2625	27	12	22	225
			4		1160				20	10	21	
			3		2175				40	18	25	
3L-3b-sc-60	60	3	4	13050	1630	450	2400	2625	30	14	25	225
			5		1305				24	10	25	
			4		2100				40	18	26	
4L-4b-sc-60		4	5	16800	1680	450	2400	2625	32	14	27	225
			6		1400				30	12	27	
			2		2325				52	22	26	
2L-2b-sc-80		2	3	9300	1550	530	3200	3425	35	15	25	225
			4		1160				26	11	25	
			3		2175				52	22	28	
3L-3b-sc-80	80	3	4	13050	1630	530	3200	3425	40	17	28	225
			5		1305				31	13	29	
			4		2100				52	22	30	
4L-4b-sc-80		4	5	16800	1680	530	3200	3425	42	18	29	225
			6		1400				38	16	29	
			2		2325				64	26	30	
2L-2b-sc-100		2	3	9300	1550	600	4000	4225	43	18	30	225
			4		1160				32	13	30	
			3		2175				64	26	33	
3L-3b-sc-100	100	3	4	13050	1630	600	4000	4225	48	20	33	225
			5		1305				38	16	34	
			4		2100				64	26	35	
4L-4b-sc-100		4	5	16800	1680	600	4000	4225	51	21	34	225
			6		1400				42	18	34	

APPENDIX B1

Shear Forces for All Modeled Bridges Under Full CHBDC Truck Loading for Ultimate Limit State

Table B.1.1 Shear forces under CHBDC full truck load for 2-lane 2-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons			
				W1	W2	W3	W4
20	2	2	0	159980	201380	201380	159980
20	2	2	0.4	69547	260160	149040	243970
20	2	2	1	-100750	373780	71630	371860
20	2	2	1.4	-259020	484150	17628	470650
20	2	2	2	-578860	688550	-65895	610050
40	2	2	0	244340	318110	318110	244340
40	2	2	0.4	46421	381660	263170	434570
40	2	2	1	-311650	504130	187150	743820
40	2	2	1.4	-639060	626770	134300	1003400
40	2	2	2	-1484700	952170	32439	1623400
60	2	2	0	292750	396630	396630	292750
60	2	2	0.4	-13888	445060	355400	591440
60	2	2	1	-553550	543630	303340	1086500
60	2	2	1.4	-1042600	639690	271380	1511500
60	2	2	2	-2278700	891370	225440	2542400
80	2	2	0	340440	457250	457250	340440
80	2	2	0.4	-105130	510470	410760	779360
80	2	2	1	-885600	613870	346650	1520500
80	2	2	1.4	-1582800	711140	304770	2162800
80	2	2	2	-3332400	963800	229050	3737500
100	2	2	0	389220	507610	507610	389220
100	2	2	0.4	-231350	581830	442240	1005200
100	2	2	1	-1316200	717260	341100	2054800
100	2	2	1.4	-2280900	841580	266000	2970900
100	2	2	2	-4702800	1155400	108630	5237600

Table B.1.2 Shear forces under CHBDC full truck load for 2-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons					
				W1	W2	W3	W4	W5	W6
20	3	2	0	86480	129620	145270	145270	129620	86480
20	3	2	0.4	16860	146510	129550	164650	116230	150310
20	3	2	1	-117930	183370	109610	202280	97482	244510
20	3	2	1.4	-251550	225330	100270	240490	86553	317880
20	3	2	2	-536030	314690	99502	307020	71082	410120
40	3	2	0	136970	207430	218060	218060	207430	136970
40	3	2	0.4	-2008	173980	216920	225870	243850	268570
40	3	2	1	-257620	119810	227770	249830	310490	476330
40	3	2	1.4	-498710	74733	248020	278550	373810	649460
40	3	2	2	-1129000	-27997	324540	366330	537760	1052300
60	3	2	0	164630	260330	264420	264420	260330	164630
60	3	2	0.4	-45171	174490	256960	277170	347780	366750
60	3	2	1	-419280	30052	259560	309410	504400	695520
60	3	2	1.4	-763720	-98278	272730	344530	648340	974500
60	3	2	2	-1622700	-407730	328670	446650	1010500	1627500
80	3	2	0	198150	300610	298930	298930	300610	198150
80	3	2	0.4	-111710	185450	261020	341730	417350	501610
80	3	2	1	-657070	-13251	208560	422900	625430	1008600
80	3	2	1.4	-1146400	-189750	172570	499840	815680	1443700
80	3	2	2	-2373200	-629330	102770	700440	1299600	2497600
100	3	2	0	232910	334430	329490	329490	334430	232910
100	3	2	0.4	-205080	198290	239010	426120	473490	666060
100	3	2	1	-971340	-40512	92407	596850	719730	1399700
100	3	2	1.4	-1653400	-254510	-27014	751160	945300	2035600
100	3	2	2	-3367200	-796030	-305910	1141500	1524700	3601100

Table B.1.3 Shear forces under CHBDC full truck load for 2-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	2	0	58903	103780	107120	91586	91586	107120	103780	58903
20	4	2	0.4	544.4	99687	105330	98992	86768	111100	108440	111880
20	4	2	1	-114080	96141	109170	118180	83622	121010	116200	191080
20	4	2	1.4	-203380	93313	113460	128510	79154	123660	116370	222760
20	4	2	2	-486120	104830	154830	187940	93634	149630	132490	327570
40	4	2	0	93337	166210	162140	140810	140810	162140	166210	93337
40	4	2	0.4	-14247	98206	177030	124510	162180	151850	233140	194560
40	4	2	1	-215260	-24587	211660	104720	208620	140590	344810	354080
40	4	2	1.4	-406000	-135320	253280	95762	257760	134800	440490	484110
40	4	2	2	-911020	-416560	377890	90942	302580	130370	671480	784490
60	4	2	0	113010	203550	195380	177570	176990	195930	203590	112840
60	4	2	0.4	-50549	86901	197630	149740	207910	195360	318900	272170
60	4	2	1	-347070	-118280	214520	112940	274270	201490	515150	526650
60	4	2	1.4	-620420	-304540	237640	86767	342160	210320	687850	739600
60	4	2	2	-1314800	-770210	311170	35623	528140	240590	1110300	1240400
80	4	2	0	137590	2.3234	220460	207380	207380	220460	232340	137590
80	4	2	0.4	-101160	68879	198960	198960	239390	244800	244800	370930
80	4	2	1	-522070	-219580	171120	137210	305780	289170	675020	758550
80	4	2	1.4	-897390	-477680	153600	105060	373160	330340	922800	1087000
80	4	2	2	-1853900	-1135400	122460	32391	558500	435850	1545700	1891100
100	4	2	0	163250	256270	242400	235000	235000	242400	256270	163250
100	4	2	0.4	-175340	55902	172630	226830	247950	315580	456440	498060
100	4	2	1	-748930	-131250	141460	308850	299220	471450	731890	1087100
100	4	2	1.4	-1293900	-619240	-34798	209510	315510	552960	1116200	1550800
100	4	2	2	-2617400	-1431500	-254750	196150	426070	829560	1901500	2748100

Table B.1.4 Shear forces under CHBDC full truck load for 3-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons					
				W1	W2	W3	W4	W5	W6
20	3	3	0	152230	188470	201340	201340	188470	152230
20	3	3	0.4	50224	243800	148700	256040	137180	245630
20	3	3	1	-142710	352250	66289	350770	58623	379910
20	3	3	1.4	-284370	420310	14661	390290	10278	423730
20	3	3	2	-751530	727640	-77006	558860	-77520	584670
40	3	3	0	239480	296950	307240	307240	296950	239480
40	3	3	0.4	45070	346690	252720	367660	255140	421550
40	3	3	1	-322550	449180	174170	483430	193660	705670
40	3	3	1.4	-673790	555110	119560	593720	151840	933970
40	3	3	2	-1596200	849850	24903	876100	80738	1442900
60	3	3	0	286460	373910	373680	373680	373910	286460
60	3	3	0.4	-752.5	401660	304160	451140	353390	559160
60	3	3	1	-525190	460180	202790	597660	336520	995970
60	3	3	1.4	-1014300	526820	129950	735920	330050	1358300
60	3	3	2	-2271100	710700	-13046	1094300	343690	2204000
80	3	3	0	332200	436030	428270	428270	436030	332200
80	3	3	0.4	-75340	456610	313710	551060	421760	724750
80	3	3	1	-805720	502200	136650	776950	414330	1368700
80	3	3	1.4	-1472400	552080	-2671	985690	418940	1912200
80	3	3	2	-3176200	684410	-315620	1520700	461950	3218900
100	3	3	0	378780	488720	477710	477710	488720	378780
100	3	3	0.4	-178720	509650	294310	671270	475700	922470
100	3	3	1	-1168200	556630	-2706	1017300	464150	1827600
100	3	3	1.4	-2061200	603450	-247910	1331400	467670	2602600
100	3	3	2	-4313200	724390	-822170	2123400	508100	4478900

Table B.1.5 Shear forces under CHBDC full truck load for 3-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	3	0	91614	148400	153760	148280	148280	153760	148400	91614
20	4	3	0.4	10125	167720	131550	172850	126210	178590	130850	167590
20	4	3	1	-148120	209690	100050	222060	91937	221400	101130	279210
20	4	3	1.4	-272940	239430	81509	249600	69828	234510	79644	311080
20	4	3	2	-688330	390930	78243	371450	40914	305180	47915	436980
40	4	3	0	152680	231760	237900	221410	221330	237900	231760	152680
40	4	3	0.4	-685.3	210720	231380	237120	212320	250580	255590	291830
40	4	3	1	-291450	177100	233350	276800	207660	277610	294510	509830
40	4	3	1.4	-572980	151260	248400	322950	213750	306800	330110	683750
40	4	3	2	-1148800	-279130	374490	269260	382070	195800	276800	200180
60	4	3	0	188610	288470	286220	270770	270770	286220	288470	188610
60	4	3	0.4	-34556	227470	268620	285880	262830	309340	350130	399060
60	4	3	1	-442890	123480	253010	325000	265320	357430	458780	731010
60	4	3	1.4	-831670	29693	251810	371640	280690	403590	555340	1006700
60	4	3	2	-1836700	-197050	280640	511170	346090	527080	796380	1641400
80	4	3	0	225780	332020	324900	313850	313850	324900	332020	225780
80	4	3	0.4	-93563	245590	271020	346310	289010	383660	418330	532250
80	4	3	1	-666380	95134	192630	416640	264450	491870	570090	1030500
80	4	3	1.4	-1195300	-40224	135110	490060	256020	590850	706220	1451300
80	4	3	2	-2546500	-380930	15613	692710	264230	845180	1051600	2452800
100	4	3	0	263320	369200	359700	353040	353040	359700	369200	263320
100	4	3	0.4	-175900	261820	245860	418820	296450	479500	477610	690600
100	4	3	1	-956400	74668	63044	546390	214400	688360	665050	1399700
100	4	3	1.4	-1663600	-94863	-87705	668900	156340	875470	835520	2005700
100	4	3	2	-3449500	-523330	-439170	989220	42292	1343100	1269500	3466600

Table B.1.6 Shear forces under CHBDC full truck load for 3-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	3	0	61446	115740	122080	122880	119930	119930	122880	122080	115740	61446
20	5	3	0.4	-7071	115860	112910	134030	110690	130920	113230	133180	115680	126100
20	5	3	1	-140660	119700	103450	159710	98144	152790	97418	151990	112030	222850
20	5	3	1.4	-248560	122330	99944	177650	89031	161340	84249	153830	101510	254710
20	5	3	2	-624940	173230	140690	271030	96942	212030	72902	185260	97451	360480
40	5	3	0	108770	185440	189760	180190	179580	179580	180190	189760	185440	108770
40	5	3	0.4	-17180	131990	196640	178340	190880	172340	185880	187110	237200	225720
40	5	3	1	-259210	35284	221020	185420	222460	168060	200740	184840	319360	408740
40	5	3	1.4	-498690	-54376	255300	201710	261120	171310	219170	186320	387570	554360
40	5	3	2	-797430	-174220	289930	215190	295720	164400	222990	169300	412350	631910
60	5	3	0	134570	233800	229770	217860	218150	218150	217860	229770	233800	134570
60	5	3	0.4	-40790	123690	227870	201420	241550	201150	239160	235610	340270	298980
60	5	3	1	-364700	-74484	237370	183430	297420	181900	286580	251060	516600	555940
60	5	3	1.4	-675690	-260640	256460	176180	361550	172520	335940	265320	667970	767980
60	5	3	2	-1486500	-732760	331750	180850	548640	165330	472170	306080	1029100	1253800
80	5	3	0	164760	266480	260080	251920	253400	253400	251920	260080	266480	164760
80	5	3	0.4	-93789	126960	225920	243380	260240	252780	265450	297190	402470	412750
80	5	3	1	-559630	-123490	176940	238950	288050	261550	299940	363750	632750	815660
80	5	3	1.4	-990190	-353510	142460	243870	325950	276230	338420	422710	833470	1154600
80	5	3	2	-2095700	-940330	74007	273240	445420	327230	451630	572310	1325900	1960600
100	5	3	0	195810	294880	287130	283160	284430	284430	283160	287130	294880	195810
100	5	3	0.4	-166820	129800	197100	295570	255700	320340	276940	380240	457470	548670
100	5	3	1	-811640	-164020	50716	328180	220930	389990	274510	538800	733540	1134300
100	5	3	1.4	-1396500	-432900	-71366	364200	203290	457020	281950	677920	977690	1634400
100	5	3	2	-2876600	-1115500	-359110	467700	184800	633790	320310	1021400	1583200	2838400

Table B.1.7 Shear forces under CHBDC full truck load for 4-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	4	0	126460	201520	195790	198930	198930	195790	201520	126460
20	4	4	0.4	19271	249050	140040	250760	147530	253750	153580	229180
20	4	4	1	-182810	341430	47802	349730	56920	353350	68163	385200
20	4	4	1.4	-336510	411900	-6656	403830	1601	391030	20514	433180
20	4	4	2	-902720	755060	-103880	614800	-105420	523760	-70215	581330
40	4	4	0	218340	303520	306730	296270	296270	306730	303520	218340
40	4	4	0.4	22426	342510	258170	353050	245900	359630	269300	399130
40	4	4	1	-349840	424860	186360	463890	170770	457190	216360	678490
40	4	4	1.4	-478830	405900	140410	448630	126040	430290	170760	660580
40	4	4	2	-1168400	589590	88027	655120	55444	572100	119290	980310
60	4	4	0	268920	376670	372520	360560	360560	372520	376670	268920
60	4	4	0.4	-13817	394620	311940	428170	301830	438680	363820	533330
60	4	4	1	-542400	432450	221300	561720	220200	559630	354780	948230
60	4	4	1.4	-1044400	480530	157800	694510	163460	668830	352230	1283300
60	4	4	2	-2375800	621100	39511	1056800	69473	943980	364190	2037800
80	4	4	0	318480	434880	424790	417120	417120	424790	434880	318480
80	4	4	0.4	-76521	444180	319590	517020	328350	535750	429580	692140
80	4	4	1	-799940	466770	154580	710170	200250	735080	432490	1291400
80	4	4	1.4	-1473000	492290	24387	896600	106920	913520	445330	1785000
80	4	4	2	-3212400	571590	-263840	1390700	-81504	1361100	491520	2937700
100	4	4	0	366750	485310	472550	468930	468930	472550	485310	366750
100	4	4	0.4	-164180	490570	298440	617270	336430	655030	485660	874900
100	4	4	1	-1125900	507730	13284	895750	129570	973640	492200	1707100
100	4	4	1.4	-2002900	526580	-221840	1156300	-30077	1255800	510040	2402100
100	4	4	2	-4276700	577830	-781250	1843200	-385540	1968100	571660	4078600

Table B.1.8 Shear forces under CHBDC full truck load for 4-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	4	0	112450	156700	154760	154380	144490	144490	154380	154760	156700	112450
20	5	4	0.4	399130	181680	118610	184710	110000	179620	122970	193150	129710	205690
20	5	4	1	-172520	240840	58495	252270	43874	250170	59418	260800	72243	352990
20	5	4	1.4	-300290	270490	28933	285490	9247	273420	27060	279650	44534	397510
20	5	4	2	-841900	491810	716.5	467130	-55727	384930	-39114	360240	-12661	529690
40	5	4	0	180060	246640	245780	229390	223130	223130	229390	245780	246640	180060
40	5	4	0.4	39317	194640	201130	208180	181450	198270	186600	222680	228720	255440
40	5	4	1	-278550	188040	224250	288420	206200	270800	199090	293700	302070	552170
40	5	4	1.4	-582670	160150	232370	341570	212580	308420	189850	322340	328300	728190
40	5	4	2	-1436000	107530	301010	513550	262700	415160	185790	395820	391320	1094300
60	5	4	0	216390	308860	298740	280100	274800	274800	280100	298740	308860	216390
60	5	4	0.4	-10822	250010	276550	299280	265570	290290	266740	325000	366570	428420
60	5	4	1	-437910	143090	251010	347240	267710	328940	257550	375650	465710	758550
60	5	4	1.4	-849070	49952	244640	404500	284420	372220	258640	420260	548400	1023700
60	5	4	2	-1953600	-186840	261560	577770	361560	499220	287350	536500	749720	1621300
80	5	4	0	255120	355360	340390	324790	319910	319910	324790	340390	355360	255120
80	5	4	0.4	-70728	280410	278230	365980	286060	362180	291590	406090	428100	562760
80	5	4	1	-685110	145330	183140	453850	247630	449120	251030	523080	552600	1055500
80	5	4	1.4	-1229000	22065	111220	545890	231070	535680	228440	626800	661990	1458500
80	5	4	2	-2691900	-289620	-41237	806590	223330	769730	195930	883900	930380	2406200
100	5	4	0	292550	394970	378450	366430	361500	361500	366430	378450	394970	292550
100	5	4	0.4	-146250	300100	256540	434840	289720	444770	308970	504870	488640	712640
100	5	4	1	-938940	131390	57563	570440	184860	599740	224620	721210	647440	1397500
100	5	4	1.4	-1672500	-23036	-107830	706910	110590	748110	163650	910880	786180	1973500
100	5	4	2	-3568600	-423870	-500690	1074800	-38350	1136200	42287	1382100	1137900	3354100

Table B.1.9 Shear forces under CHBDC full truck load for 4-lane 6-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons											
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
20	6	4	0	260140	164056	132800	125680	128420	129180	129180	128420	125680	132800	130070	76631
20	6	4	0.4	-4907	137490	111420	141600	107470	147470	110560	150510	108810	156150	120670	158030
20	6	4	1	-168610	158660	80204	180180	69284	186960	71745	193080	71657	194780	92915	289670
20	6	4	1.4	-277730	164950	63936	199510	49345	200980	47848	205980	47255	204850	75435	332930
20	6	4	2	-782610	278370	89000	350520	27481	288620	8181	270050	8860	251480	45403	452840
40	6	4	0	132920	205890	205240	192410	193860	194680	194680	193860	192410	205240	205890	132920
40	6	4	0.4	2586	151670	209820	187950	200370	190970	200760	188650	198450	210850	260390	249260
40	6	4	1	-244730	49359	224200	191170	226010	192980	219130	187430	211660	213660	341650	435450
40	6	4	1.4	-500050	-47953	253230	207330	263080	203180	242050	191400	225400	216150	405380	81500
40	6	4	2	-1230100	-301330	373310	289500	396940	253040	314960	213130	265710	229260	543020	882240
60	6	4	0	161680	257970	251250	235720	235570	236700	236700	235570	235720	251250	257970	161680
60	6	4	0.4	-83544	180190	235370	283470	260420	291970	263880	294360	267400	334960	401980	460170
60	6	4	1	-388470	-10816	230460	231500	277100	240320	271070	234640	269320	294070	493960	614240
60	6	4	1.4	-740030	-173740	237450	245440	322640	255300	304810	242140	294830	316460	614370	836240
60	6	4	2	-1686900	-600030	284150	308910	473150	315940	414210	277990	372300	373990	892900	1329200
80	6	4	0	195990	293780	284240	272940	274150	274470	274470	274150	272940	284240	293780	195990
80	6	4	0.4	-83544	180190	235370	283470	260420	291970	263880	294360	267400	334960	401980	460170
80	6	4	1	-599410	-28729	159640	313890	254010	335350	260650	338750	267620	422810	581180	884730
80	6	4	1.4	-1082400	-222290	101910	352700	264240	384810	270170	384150	275480	498820	732730	1232000
80	6	4	2	-2352900	-722670	-19312	478310	322380	529560	317330	508090	307270	681850	1096800	2047400
100	6	4	0	195990	326030	314460	307240	308730	309190	309190	308730	307240	314460	326030	228240
100	6	4	0.4	-147570	182730	212960	332160	262540	352390	275830	363510	289570	418060	464360	588260
100	6	4	1	-827230	-76306	45377	388760	199060	439330	231660	464100	266890	592920	694550	1176600
100	6	4	1.4	-1458000	-316880	-95729	451840	159180	528540	206820	559160	253900	742490	892410	1672500
100	6	4	2	-3092500	-942800	-434390	631650	91721	771900	173150	806180	241100	1108900	1380800	2860200

APPENDIX B2

Shear Forces for All Modeled Bridges Under Outer Lanes CHBDC Truck Loading for Ultimate Limit State

Table B.2.1 Shear forces under CHBDC outer lanes truck load for 2-lane 2-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons			
				W1	W2	W3	W4
20	2	2	0	562.8	1.2891	79722	152170
20	2	2	0.4	-44452	164690	56800	198040
20	2	2	1	-118850	223060	19760	246610
20	2	2	1.4	-206530	290010	-7749	303980
20	2	2	2	-453100	473590	-66836	439670
40	2	2	0	6726	177520	146920	231290
40	2	2	0.4	-93949	212750	121860	327860
40	2	2	1	-280800	283140	86780	489780
40	2	2	1.4	-460250	352380	59721	631150
40	2	2	2	-927190	536500	7709	974990
60	2	2	0	7751	203590	198120	279920
60	2	2	0.4	-147660	230490	179360	431040
60	2	2	1	-431040	285330	155160	690270
60	2	2	1.4	-691110	339040	140820	916470
60	2	2	2	-1355600	479390	118970	1470000
80	2	2	0	-4746	334460	331030	361990
80	2	2	0.4	-217720	258930	208920	550840
80	2	2	1	-625180	315540	178120	937580
80	2	2	1.4	-988110	368670	158990	1272800
80	2	2	2	-1931100	507330	120370	2121900
100	2	2	0	8462	257630	252720	378020
100	2	2	0.4	-304770	296960	221770	688920
100	2	2	1	-864200	369500	172120	1230500
100	2	2	1.4	-1373300	436440	134030	1714300
100	2	2	2	-2667000	606090	52376	2926100

Table B.2.2 Shear forces under CHBDC outer lanes truck load for 2-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons					
				W1	W2	W3	W4	W5	W6
20	3	2	0	-6740	51516	63376	76864	70275	106070
20	3	2	0.4	-43047	63656	58216	90083	65308	141160
20	3	2	1	-103820	85402	58883	101070	52684	176200
20	3	2	1.4	-178470	111830	56438	124420	47832	217410
20	3	2	2	-395430	190190	59613	186480	40650	311390
40	3	2	0	-6505	67772	99562	111750	136800	153080
40	3	2	0.4	-78172	52069	100960	117610	156650	219670
40	3	2	1	-214200	26114	110560	133420	194440	329210
40	3	2	1.4	-347300	3189	124060	150720	229870	423280
40	3	2	2	-699520	-51905	170010	202510	323700	648210
60	3	2	0	-9666	76805	118570	139850	181960	181860
60	3	2	0.4	-116650	34439	116610	147850	227410	283840
60	3	2	1	-314560	-40279	120700	166690	311570	456230
60	3	2	1.4	-498320	-107310	129980	187060	389990	604650
60	3	2	2	-972440	-276210	163650	244170	590360	964230
80	3	2	0	-13590	91285	127660	166620	208450	217260
80	3	2	0.4	-171150	33682	109790	189490	268630	370810
80	3	2	1	-457300	-69435	84589	233560	379380	635920
80	3	2	1.4	-713730	-161200	67666	275540	481070	863880
80	3	2	2	-1383000	-399860	31567	386030	746270	1438600
100	3	2	0	-17806	107700	131070	194930	226330	254610
100	3	2	0.4	-239130	39678	86591	244880	297760	473380
100	3	2	1	-635820	-82980	12845	334700	426940	852940
100	3	2	1.4	-997780	-196200	-49258	417370	547830	1190400
100	3	2	2	-1919700	-486920	-197440	628600	861410	2032700

Table B.2.3 Shear forces under CHBDC outer lanes truck load for 2-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				9142303	W2	W3	W4	W5	W6	W7	W8
20	4	2	0	-14455	21923	31670	58477	47188	58713	74790	83075
20	4	2	0.4	-45347	21998	33214	64937	46996	62985	78930	112140
20	4	2	1	-98737	22522	39511	80174	46855	60540	78073	141540
20	4	2	1.4	-165610	25116	47986	95336	49853	68113	83066	175680
20	4	2	2	-365720	36814	80945	140650	62821	88874	96401	252190
40	4	2	0	-18684	21287	68299	61936	87001	85563	138500	118580
40	4	2	0.4	-74832	-13158	77517	55179	99644	81658	173430	169800
40	4	2	1	-183480	-77246	99814	48077	127540	77621	234160	254090
40	4	2	1.4	-291520	-138810	124980	44557	156580	75145	288060	326250
40	4	2	2	-581560	-298900	198730	44157	238490	74505	421660	497830
60	4	2	0	-25070	24797	79738	75734	105790	111110	173690	143630
60	4	2	0.4	-110040	-33674	83366	63144	122430	111860	232780	224100
60	4	2	1	-268910	-142600	94540	45550	160120	116360	338040	358320
60	4	2	1.4	-418050	-243400	108810	32795	198870	122200	432790	473460
60	4	2	2	-805870	-502490	152280	6875	304780	139560	668800	751790
80	4	2	0	-31338	31190	86460	90511	117160	132350	198850	172580
80	4	2	0.4	-153160	-51790	76623	77292	134610	145380	281870	290900
80	4	2	1	-375710	-204050	63719	56570	171590	169530	431270	494860
80	4	2	1.4	-576220	-341780	55594	40694	209130	192400	564860	670000
80	4	2	2	-1101900	702590	40413	2342	312780	250930	908220	1111300
100	4	2	0	-38482	41785	85778	110590	121920	156390	214110	204820
100	4	2	0.4	-210000	-59556	51324	107410	129670	194380	316290	374150
100	4	2	1	-556900	-172120	26858	156950	158110	285920	475950	725930
100	4	2	1.4	-800150	-416090	-55483	100520	168260	320630	666960	929170
100	4	2	2	-1520300	-858090	-173800	94422	230080	471750	1095900	1580700

Table B.2.4 Shear forces under CHBDC outer lanes truck load for 3-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons					
				W1	W2	W3	W4	W5	W6
20	3	3	0	-37525	103940	53753	238430	149240	214910
20	3	3	0.4	-103080	147500	23740	283210	115680	285570
20	3	3	1	-234470	226110	-31508	346990	55942	372510
20	3	3	1.4	-391020	333560	-76084	423560	12595	455970
20	3	3	2	-872260	664960	-164640	604050	-76007	624580
40	3	3	0	-54370	160860	125980	308010	235830	348620
40	3	3	0.4	-188330	198650	92573	352700	210200	471540
40	3	3	1	-455800	281180	42683	442760	171060	677410
40	3	3	1.4	-722330	367070	5721	529110	142810	848480
40	3	3	2	-1444800	605380	-59974	755590	90018	1245200
60	3	3	0	-59768	187230	172560	350600	309780	418370
60	3	3	0.4	-255800	209200	128740	406110	298970	602170
60	3	3	1	-629340	258050	62158	513870	290140	909920
60	3	3	1.4	-988460	309980	12351	617850	288510	1174600
60	3	3	2	-1936600	453920	-89772	891640	302360	1810000
80	3	3	0	-65711	222150	198390	395190	357170	488200
80	3	3	0.4	-343160	238800	124100	481130	350070	752560
80	3	3	1	-856090	275410	5323	643370	349000	1202300
80	3	3	1.4	-1341300	314210	-92706	797210	354450	1596000
80	3	3	2	-2601700	418140	-319170	1196400	388020	2560300
100	3	3	0	-71613	259540	214350	444460	388780	558160
100	3	3	0.4	-447810	275520	94846	578320	383960	922480
100	3	3	1	-1137000	311630	-106800	822500	379650	1550300
100	3	3	1.4	-1772900	346280	-278560	1048000	386050	2101000
100	3	3	2	-3409100	433250	-696110	1620300	413120	3462600

Table B.2.5 Shear forces under CHBDC outer lanes truck load for 3-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	3	0	-36995	53434	22358	113580	104520	175010	130580	160260
20	4	3	0.4	-90835	70577	11372	135600	92361	196960	119300	218990
20	4	3	1	-196290	102550	-5553	170700	70636	219490	92607	280710
20	4	3	1.4	-331430	151820	-15383	219240	54962	253690	76330	347490
20	4	3	2	-763750	319430	-11378	353110	28546	328620	44250	477190
40	4	3	0	-53511	64469	87644	147020	165870	222470	232090	258890
40	4	3	0.4	-159720	52256	86206	160660	162250	233560	249570	354180
40	4	3	1	-376820	32520	94210	195780	163270	256870	280430	514230
40	4	3	1.4	-596250	16212	110260	234730	170800	282120	309690	647370
40	4	3	2	-1204600	-20226	174770	352490	207710	350390	383530	953560
60	4	3	0	-67524	77737	116420	176770	200560	261280	296770	316780
60	4	3	0.4	-221240	37957	107400	189970	198040	279510	340510	458890
60	4	3	1	-519240	-34348	101430	222830	204200	316900	420570	696440
60	4	3	1.4	-809930	-101160	105020	260760	218360	352960	494040	900210
60	4	3	2	-1587000	-272690	132850	373110	273130	450220	681660	1387900
80	4	3	0	-80310	98865	126970	210890	221230	304900	335720	377160
80	4	3	0.4	-298950	41440	92978	235830	207190	346840	395700	584140
80	4	3	1	-707790	-63450	41844	289910	193870	426160	506040	936730
80	4	3	1.4	-1098400	-161510	2674	346850	190290	500330	607560	1245500
80	4	3	2	-2121200	-415730	-82579	504500	199780	693960	869720	2001400
100	4	3	0	-92777	123770	128030	249630	232480	352320	361920	438360
100	4	3	0.4	-390270	51985	53604	297190	197970	435770	437280	725480
100	4	3	1	-939900	-78187	-70849	390700	144300	584600	571400	1222300
100	4	3	1.4	-1450600	-199860	-177180	481230	105480	721380	696440	1658500
100	4	3	2	-2785800	-518060	-435910	724580	23032	1071700	1021400	2749700

Table B.2.6 Shear forces under CHBDC outer lanes truck load for 3-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	3	0	-26717	32224	27138	67175	79035	109710	101240	121560	107760	103590
20	5	3	0.4	-71203	35006	23915	77658	75153	119640	95860	131090	108160	152220
20	5	3	1	-159410	38886	18752	94627	68123	132700	82829	139530	100370	211810
20	5	3	1.4	-274500	52778	24271	125460	66973	153590	75578	153420	97678	267400
20	5	3	2	-652100	110090	70529	225030	79503	208340	66545	186330	94831	373040
40	5	3	0	-34844	36486	81860	94352	129890	136220	153350	158970	195370	173230
40	5	3	0.4	-121230	1232	88520	94994	139450	132920	158800	158560	230920	252180
40	5	3	1	-298280	-66426	110640	103930	165540	131800	171210	158040	290570	383580
40	5	3	1.4	-478040	-131110	139870	119170	196960	136190	187260	161360	342010	490640
40	5	3	2	-988920	-304530	237620	176270	295430	157700	233430	172070	463700	736460
60	5	3	0	-32750	41560	102170	111610	157240	157410	186940	193180	255440	205910
60	5	3	0.4	-152620	-32571	102760	102220	175150	147600	202950	198490	327850	315990
60	5	3	1	-384040	-172410	113120	92470	218480	136410	239170	210580	452710	495690
60	5	3	1.4	-611400	-306660	130570	89936	267810	130700	276230	221270	562700	648410
60	5	3	2	-1276900	-689755	199615	101065	431035	133613	398728	265440	873778	1058820
80	5	3	0	-38367	59862	108510	135810	172810	190320	205730	228750	281620	250270
80	5	3	0.4	-213970	-34325	86829	131540	179240	191240	216280	254710	373890	417040
80	5	3	1	-539650	-208600	55511	130990	201770	199100	242480	302270	535730	697100
80	5	3	1.4	-849500	-373380	32820	136410	231030	210640	271240	344900	680200	939760
80	5	3	2	-1659700	-801660	-13617	161210	321480	249310	355750	454630	1040700	1528400
100	5	3	0	-43218	80766	108850	164420	179310	224950	217270	265580	300070	295590
100	5	3	0.4	-287100	-30131	49668	174460	162230	250980	215150	329400	409990	531650
100	5	3	1	-733690	-233510	-49352	199210	140910	300670	215330	439890	602140	936150
100	5	3	1.4	-1149100	-424250	-134410	226240	130220	349100	221690	538880	776050	1290700
100	5	3	2	-2221700	-918520	-340740	303310	119370	478630	251460	788290	1215200	2162100

Table B.2.7 Shear forces under CHBDC outer lanes truck load for 4-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	4	0	-46980	56279	-22218	96508	38714	237160	141180	222130
20	4	4	0.4	-101417	84403	-48018	133490	9786	283800	110430	299260
20	4	4	1	-228510	163550	-107260	222460	-57124	373360	43434	431530
20	4	4	1.4	-404700	273360	-164160	320350	-117100	452350	-11276	530830
20	4	4	2	-757800	682690	-267860	579700	-231750	614830	-111950	707940
40	4	4	0	-101240	94392	17811	146890	88648	293150	216970	368370
40	4	4	0.4	-203810	118970	-4415	181040	63999	326140	201140	468320
40	4	4	1	-424550	176370	-40145	254530	23490	389690	172430	635590
40	4	4	1.4	-637310	162760	-47095	393890	8842	355060	147110	821530
40	4	4	2	-1258110	278750	-72299	631690	-28251	443740	118780	1107350
60	4	4	0	-128010	105790	43252	177560	126760	326900	284150	442450
60	4	4	0.4	-277330	118620	14929	216730	98840	364550	279830	580660
60	4	4	1	-578430	148400	-29352	298920	56894	437690	278830	814440
60	4	4	1.4	-878290	180950	-62925	381290	28420	507150	280790	1011300
60	4	4	2	-1713500	277840	-129210	614260	-28274	681100	291990	1483800
80	4	4	0	-154630	126360	50109	219540	148180	368650	323100	514210
80	4	4	0.4	-362500	134340	-847.4	276110	105950	429330	322430	706150
80	4	4	1	-767000	152240	-85856	390360	41076	544340	328000	1036000
80	4	4	1.4	-1161400	171810	-157180	504160	-9485	651230	337070	1321700
80	4	4	2	-2221100	226200	-325720	810970	-120390	925550	367510	2022500
100	4	4	0	-180620	151990	46005	267000	160090	418100	346750	584520
100	4	4	0.4	-455230	156420	-40518	346870	96581	515800	351240	843670
100	4	4	1	-982990	169890	-189730	505600	-9956	693210	359590	1294100
100	4	4	1.4	-1492200	183920	-321410	661550	-98357	858640	370170	1693800
100	4	4	2	-2812500	216780	-640460	1064800	-296950	1276900	412450	2664800

Table B.2.8 Shear forces under CHBDC outer lanes truck load for 4-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	4	0	-41397	34896	-8078	53262	840	119460	95318	180080	124180	164210
20	5	4	0.4	-82291	49807	-22327	73677	-15965	145560	77726	209510	106820	231100
20	5	4	1	-179510	90839	-49315	119170	-52842	191050	39560	244300	63690	305870
20	5	4	1.4	-303400	135810	-70337	170420	-76680	233540	14548	280830	40298	375310
20	5	4	2	-791300	351920	-88194	348080	-129430	342670	-41682	357840	-10108	496690
40	5	4	0	-82090	32993	41872	71779	62066	136760	151710	215380	222040	222470
40	5	4	0.4	-129150	14950	30390	62030	50445	120904	130380	20640	201606	374970
40	5	4	1	-343120	7964	40458	115610	59989	171690	140230	249400	257310	487990
40	5	4	1.4	-541510	-4828	51687	155570	67697	198580	135520	269130	274780	602140
40	5	4	2	-1126700	-32502	108110	281920	108320	276610	136730	322180	319110	850130
60	5	4	0	-106180	33508	58154	94972	89328	160900	179760	251430	284880	332100
60	5	4	0.4	-226500	4593	49763	108220	87604	171750	175160	267490	316810	442590
60	5	4	1	-472650	-51490	42231	141170	93638	197410	173260	299160	375300	629510
60	5	4	1.4	-719230	-104900	42287	178580	107400	226950	178750	328870	426710	785360
60	5	4	2	-1418400	-248750	61596	296110	162460	309410	197870	402560	555420	1161000
80	5	4	0	-133050	49696	54990	129280	99057	196800	191630	295430	314200	397480
80	5	4	0.4	-304720	12079	25706	154220	84808	221920	177140	331580	353080	555820
80	5	4	1	-642600	-60545	-21571	209230	68702	274650	158160	399180	424730	829400
80	5	4	1.4	-972540	-130380	-59618	267480	62582	328680	148120	461950	489520	1063700
80	5	4	2	-1866100	-316660	-146090	432860	63258	474990	131240	620060	654890	1639900
100	5	4	0	-156480	66002	45746	164560	102650	235770	199150	341930	336590	457930
100	5	4	0.4	-383780	17732	-14749	202460	69008	282060	173610	409890	387100	672170
100	5	4	1	-822810	-73241	-118920	283220	17319	372100	131700	530900	475470	1045600
100	5	4	1.4	-1249200	-161520	-211370	365920	-22140	460720	98777	641670	556970	1377900
100	5	4	2	-2378700	-397050	-439590	590460	-105770	695370	29816	923490	768210	2198300

Table B.2.9 Shear forces under CHBDC outer lanes truck load for 4-lane 6-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons											
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
20	6	4	0	-37175	19562	-843	31054	277.3	51121	32330	121990	98185	149200	114220	138680
20	6	4	0.4	-71464	25191	-8177	41846	-9255	65294	22758	140460	88788	168780	108580	204500
20	6	4	1	-161660	44759	-20974	71090	-31920	92477	-8094	168700	58849	192740	82627	293260
20	6	4	1.4	-273540	64334	-29951	107610	-44523	123140	-23224	195780	43467	217120	71859	357840
20	6	4	2	-742590	182010	974.1	259410	-59149	213550	-54796	261760	10379	262630	44966	469870
40	6	4	0	-74298	8481	37777	44782	45811	65240	86790	134930	151570	177980	213370	232460
40	6	4	0.4	-136420	-28932	48642	38000	61447	5.8093	99870	124030	163460	175590	257010	289740
40	6	4	1	-283550	-85748	63495	45586	81671	63104	113720	125660	173760	178990	306770	401720
40	6	4	1.4	-448690	-144970	87664	61265	110280	73201	130860	129440	183370	180990	347990	495420
40	6	4	2	-941860	-309860	177340	124510	206950	111670	184210	148170	213890	191290	439440	498330
60	6	4	0	-90791	-2807	53631	56146	72914	81086	116410	148400	181880	209100	279580	273180
60	6	4	0.4	-191390	-50987	50312	55746	80476	81856	122760	148380	188230	218040	327110	365380
60	6	4	1	-397710	-147440	51377	61451	104400	88894	141100	152110	204440	235500	410960	520100
60	6	4	1.4	-606960	-242610	58997	72677	134490	99600	164030	159820	222770	250390	482810	649520
60	6	4	2	-1200400	-505240	95407	118470	234680	140690	234450	182190	271910	286880	657760	956210
80	6	4	0	-113490	11242	46764	83194	74606	112900	125130	182810	191350	250750	300290	329820
80	6	4	0.4	-260070	-47263	23745	91173	70283	124510	121910	195190	189990	278130	356500	465940
80	6	4	1	-546400	-161290	-13351	112490	71730	152480	124060	222740	193010	328160	456240	698480
80	6	4	1.4	-830930	-273120	-43300	139050	80979	183790	131240	250260	198530	372840	544630	900850
80	6	4	2	-1600000	-573170	-111420	220200	121020	274920	162310	326460	218790	483740	765190	1392800
100	6	4	0	-130950	21489	37715	108340	75182	144740	131820	215940	200040	290660	320910	377740
100	6	4	0.4	-324390	-52038	-12772	122750	53574	168940	117120	246440	193560	345880	393180	561620
100	6	4	1	-698060	-193350	-100420	158380	24057	220800	96892	303930	183350	441940	518940	881080
100	6	4	1.4	-1060300	-330840	-178710	197350	4428	274490	85067	359820	177220	527850	632610	1164000
100	6	4	2	-2004500	-691200	-370390	304610	-30704	417550	69375	505510	173620	741490	917040	1848800

APPENDIX B3

Shear Forces for All Modeled Bridges Under Inner Lanes CHBDC Truck Loading for Ultimate Limit State

Table B.3.1 Shear forces under CHBDC inner lanes truck load for 2-lane 2-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons			
				W1	W2	W3	W4
20	2	2	0	184180	94054	107330	-24200
20	2	2	0.4	137320	111470	69892	9144
20	2	2	1	78658	140310	37277	48984
20	2	2	1.4	36514	163730	19363	72688
20	2	2	2	-45831	209480	-6203	108400
40	2	2	0	277630	156430	161680	-33288
40	2	2	0.4	181630	184130	131530	59983
40	2	2	1	15389	235730	90987	205150
40	2	2	1.4	-129010	286690	64517	320030
40	2	2	2	-487680	420590	17407	583530
60	2	2	0	328860	211210	185410	-36113
60	2	2	0.4	178310	232440	162780	111220
60	2	2	1	-75277	275530	134760	345040
60	2	2	1.4	-299950	317090	117400	540550
60	2	2	2	-863160	428000	91934	1010700
80	2	2	0	496000	184600	155250	-38166
80	2	2	0.4	159800	268570	188130	177970
80	2	2	1	-211130	314880	154730	530770
80	2	2	1.4	-537570	358440	132710	831290
80	2	2	2	-1341400	471780	94656	1554200
100	2	2	0	429390	265450	242160	-40168
100	2	2	0.4	120500	300100	206950	266070
100	2	2	1	-401070	363160	155870	771020
100	2	2	1.4	-854480	420200	118890	1201400
100	2	2	2	-1976000	563530	43360	2250300

Table B.3.2 Shear forces under CHBDC inner lanes truck load for 2-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons					
				W1	W2	W3	W4	W5	W6
20	3	2	0	125800	87610	105600	26750	39774	-24170
20	3	2	0.4	88731	89773	91113	28006	26614	3554
20	3	2	1	43152	96345	78900	35991	16610	34159
20	3	2	1.4	9160	103600	73384	42904	11579	51586
20	3	2	2	-59841	119960	67571	56481	5402	76181
40	3	2	0	182000	164860	127620	77702	43051	-32783
40	3	2	0.4	115040	146850	124470	79106	59104	32381
40	3	2	1	-2512	118440	124830	86652	87947	131050
40	3	2	1.4	-106460	97818	131660	97363	113860	206770
40	3	2	2	-368570	52783	160260	131500	180420	375620
60	3	2	0	214220	212660	151900	100990	48784	-39179
60	3	2	0.4	111830	169320	146240	105570	90561	60917
60	3	2	1	-62330	100500	144570	118340	161880	216240
60	3	2	1.4	-217710	41411	148400	132800	225720	343210
60	3	2	2	-609580	-102320	169490	176020	388560	643360
80	3	2	0	253960	236170	176900	111430	66192	-46955
80	3	2	0.4	101960	178750	156720	131290	122590	102820
80	3	2	1	-155720	83786	129420	168100	219240	343540
80	3	2	1.4	-382670	942.6	110820	202570	306140	545780
80	3	2	2	-942200	-200610	76540	292110	524540	1026900
100	3	2	0	294820	250050	204580	115350	86382	-54351
100	3	2	0.4	77164	181470	157850	161810	153970	161020
100	3	2	1	-289810	66724	85729	242420	270160	512860
100	3	2	1.4	-608140	-33433	28713	313590	374160	809810
100	3	2	2	-1394500	-282440	-101130	491330	637990	1527900

Table B.3.3 Shear forces under CHBDC inner lanes truck load for 2-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	2	0	95969	89560	87415	43467	34037	18965	17133	-25164
20	4	2	0.4	64950	83397	81925	41534	25596	16121	15375	-1100
20	4	2	1	27711	78122	78637	43679	20888	16405	15589	24175
20	4	2	1.4	-416.6	76021	78696	46929	19291	17460	15975	38338
20	4	2	2	-58993	73673	82361	55281	18884	19998	16845	57758
40	4	2	0	136850	167250	103350	85725	41890	57054	4947	-34579
40	4	2	0.4	76807	120640	97182	65183	40586	39931	26349	8964
40	4	2	1	-5093	76102	120940	63734	68474	43236	87427	90566
40	4	2	1.4	-85706	28216	136760	58119	87726	39566	127790	147070
40	4	2	2	-290630	-87730	184550	53503	141850	36193	221380	270750
60	4	2	0	163140	203580	129450	107700	57590	65048	5041	-42126
60	4	2	0.4	84672	145170	127770	92243	71737	64703	62010	35759
60	4	2	1	-51875	49717	133060	73090	100100	66213	152280	155580
60	4	2	1.4	-174070	-34320	141550	59885	128810	69228	229090	252170
60	4	2	2	-482970	-243180	170730	34488	208720	81305	416770	477430
80	4	2	0	194770	225680	150120	122390	75108	68741	11193	-50257
80	4	2	0.4	77798	145210	138350	107610	89556	80107	90295	64847
80	4	2	1	-119920	9531	123230	86389	118670	100380	221050	248020
80	4	2	1.4	-293560	-110170	113560	70309	148210	118740	334580	400420
80	4	2	2	-721120	-404420	97957	36453	229110	165080	611590	760350
100	4	2	0	228750	237560	174910	128530	98294	65525	22530	-59197
100	4	2	0.4	60520	137830	139060	123240	103290	100970	120960	107070
100	4	2	1	-163000	63207	133700	156340	123240	160780	237750	346940
100	4	2	1.4	-465580	-178930	38991	113430	132100	211870	428590	602740
100	4	2	2	-1066200	-547320	-62293	106370	180450	336800	783180	1146000

Table B.3.4 Shear forces under CHBDC inner lanes truck load for 3-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons					
				W1	W2	W3	W4	W5	W6
20	3	3	0	214910	149240	238430	53753	103940	-37525
20	3	3	0.4	143510	170930	193800	72193	61689	9282
20	3	3	1	54780	207530	151190	102470	24222	61055
20	3	3	1.4	-12899	238250	126000	124120	2816	89738
20	3	3	2	-168680	327820	90040	172590	-29769	141200
40	3	3	0	348620	235830	308010	125980	160860	-54370
40	3	3	0.4	202910	233640	238770	132270	104020	38909
40	3	3	1	5690	318850	217290	225620	89218	235490
40	3	3	1.4	-191940	372940	182190	284320	62820	365540
40	3	3	2	-693150	526060	124400	433120	18794	644270
60	3	3	0	418370	309780	350600	172560	187230	-59768
60	3	3	0.4	232840	324730	302390	219710	170880	118850
60	3	3	1	-93587	355470	233890	306630	154730	393880
60	3	3	1.4	-382740	391490	187370	386180	148840	610290
60	3	3	2	-1109200	493310	99669	589560	152830	1100800
80	3	3	0	488200	357170	395190	198390	222150	-65711
80	3	3	0.4	223500	367770	317300	275540	210510	192250
80	3	3	1	-234700	392050	200960	413290	201740	599060
80	3	3	1.4	-637400	419600	113500	537000	202330	929190
80	3	3	2	-1653500	493860	-77473	853160	223600	1709700
100	3	3	0	558160	388780	444460	214350	259540	-71613
100	3	3	0.4	191950	400370	320300	338280	247130	287680
100	3	3	1	599060	426460	127170	553920	236660	864160
100	3	3	1.4	-984630	453220	-26904	745000	236610	1342600
100	3	3	2	-2303300	523800	-367660	1203200	253450	2440500

Table B.3.5 Shear forces under CHBDC inner lanes truck load for 3-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**
20	4	3	0	160260	130580	175010	104520	113580	22358	53434	-36995
20	4	3	0.4	95144	133280	149190	113090	92223	29777	36172	4276
20	4	3	1	23306	143930	129000	125880	72714	41911	20736	47288
20	4	3	1.4	-32955	155040	118390	137550	61650	50378	11373	70863
20	4	3	2	-170710	197720	112250	171180	47459	70367	-1698	111970
40	4	3	0	256540	231790	223150	167770	148830	88609	64658	-56419
40	4	3	0.4	158050	216440	216290	175350	140170	93559	77142	33863
40	4	3	1	-11995	192350	212090	194150	133840	106840	98429	163690
40	4	3	1.4	-166770	174040	215730	215740	134170	120880	116710	260900
40	4	3	2	-563920	141120	246840	283360	150160	160350	161820	465360
60	4	3	0	316780	296770	261280	200560	176770	116420	77737	-67524
60	4	3	0.4	173370	255560	246980	207590	168810	128910	115950	70591
60	4	3	1	-77017	188250	232070	227570	165680	154550	179390	278260
60	4	3	1.4	-303030	130490	227520	252260	172360	180370	234810	440680
60	4	3	2	-866140	902.5	239320	326970	205240	247090	367600	798700
80	4	3	0	377160	335720	304900	221230	210890	126970	98865	-80310
80	4	3	0.4	170520	278030	267090	239510	191910	163390	153900	120890
80	4	3	1	-185970	181470	213130	279010	172160	228360	246080	433960
80	4	3	1.4	-498000	100480	176460	320010	164660	285660	325300	684240
80	4	3	2	-1283500	-100390	102800	434350	165630	431200	523530	1268400
100	4	3	0	438360	361920	352320	232480	249630	128030	123770	-92777
100	4	3	0.4	150580	290450	275020	272780	208950	204160	192830	189330
100	4	3	1	-339570	170960	155590	348970	153320	333760	308850	637400
100	4	3	1.4	-767730	67428	61636	420850	115610	445950	410590	1005600
100	4	3	2	-1826900	-187820	-150250	608020	44175	721140	664710	1873100

Table B.3.6 Shear forces under CHBDC inner lanes truck load for 3-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	3	0	103590	107760	121560	101240	109710	79035	67175	27138	32224	-26717
20	5	3	0.4	56114	101240	108740	101130	96819	79226	53514	26406	26382	6703
20	5	3	1	-6142	98582	100190	107850	88149	84505	43826	31470	22876	45994
20	5	3	1.4	-58485	98406	96857	115340	83250	89134	37450	34911	19856	68850
20	5	3	2	-200850	113780	108440	145600	82687	104570	29939	44806	16882	109360
40	5	3	0	173230	195370	158970	153350	136220	129890	94352	81860	36486	-34844
40	5	3	0.4	92301	159990	161610	150520	141890	123410	95878	78025	68522	41199
40	5	3	1	-52098	99481	171920	151170	157700	118590	102940	75627	117590	152680
40	5	3	1.4	-188320	46290	188170	157750	177470	118800	112150	75725	156330	237100
40	5	3	2	-549730	-81863	249740	191390	241650	130070	141900	81390	242800	415300
60	5	3	0	205910	255440	193180	186940	157410	157240	111610	102170	41560	-32752
60	5	3	0.4	93002	183550	190010	174470	170450	144410	123810	104660	110310	75548
60	5	3	1	-107800	59404	192860	160830	202230	130180	150460	111800	219170	238620
60	5	3	1.4	-293450	-53390	201290	154380	238360	123500	178840	120130	309950	367310
60	5	3	2	-768080	-331220	242110	154380	344610	117230	256460	142920	520890	654090
80	5	3	0	250270	281620	228750	205730	190320	172810	135810	108510	59862	-38367
80	5	3	0.4	82044	190070	204710	198450	192860	170960	143270	132110	148520	124660
80	5	3	1	-211200	31779	171120	193220	207380	174550	162720	173080	292730	380390
80	5	3	1.4	-474070	-109380	148100	194430	228530	182380	185020	208890	414980	588590
80	5	3	2	-1139500	-463850	104010	209680	298090	211630	251030	297840	710550	1075400
100	5	3	0	295590	300070	265580	217270	224950	179310	164420	108850	80766	-43218
100	5	3	0.4	56947	191260	205010	223920	204000	201100	158280	168900	186990	190080
100	5	3	1	-353450	3930	109320	242320	178950	243800	154950	269640	362130	564410
100	5	3	1.4	-716850	-163340	31833	263230	166080	284430	158300	355870	513150	875840
100	5	3	2	-1623000	-581440	-146270	324960	152530	391330	179350	564910	882120	1613900

Table B.3.7 Shear forces under CHBDC inner lanes truck load for 4-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	4	0	222130	141180	237160	38714	96508	-22218	56279	-46980
20	4	4	0.4	150490	157260	193100	54057	60790	-4243	32155	-13035
20	4	4	1	74524	169300	151610	68671	31459	12283	11446	15231
20	4	4	1.4	38420	175980	134910	75607	18145	20165	2007	27259
20	4	4	2	-16724	181340	112560	81671	2042	24967	-7494	33025
40	4	4	0	368370	216970	293150	88648	146890	17811	94392	-101240
40	4	4	0.4	236880	209740	235210	96994	96156	28610	57800	-17509
40	4	4	1	113810	257790	225920	152120	83151	75828	50196	99227
40	4	4	1.4	11934	252250	188170	156870	51633	80953	28095	135450
40	4	4	2	-263380	316530	158000	233200	20201	135970	6268	264230
60	4	4	0	442450	284150	326900	126760	177560	43252	105790	-128010
60	4	4	0.4	305830	288540	293070	155750	145690	72374	96874	665
60	4	4	1	74538	298350	246980	209380	105230	121920	88067	184300
60	4	4	1.4	-127030	312960	216310	259070	79201	163840	84534	320080
60	4	4	2	-636730	358370	160590	390090	36580	266710	86881	613040
80	4	4	0	514210	323100	368650	148180	219540	50109	126360	-154630
80	4	4	0.4	325050	324940	313950	192470	172270	100960	121220	28775
80	4	4	1	3441	329630	233480	272820	109190	186550	118500	299340
80	4	4	1.4	-282630	334400	172220	347670	65893	261230	121300	511710
80	4	4	2	-975280	362120	51460	539480	-14835	436300	135500	972800
100	4	4	0	584520	346750	418100	160090	267000	46005	151990	-180620
100	4	4	0.4	326820	347380	328980	228060	196160	131520	148220	71378
100	4	4	1	-107680	351450	193440	348580	96044	273080	147410	452870
100	4	4	1.4	-484580	357320	87979	457340	23223	392840	151530	753950
100	4	4	2	-1420400	373750	-148560	734620	-128100	683530	173700	1445500

Table B.3.8 Shear forces under CHBDC inner lanes truck load for 4-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	4	0	164210	124180	180080	95318	119460	840.1	53262	-8078	34896	-41397
20	5	4	0.4	96292	128790	147930	105080	94668	11443	34604	2370	21782	-11696
20	5	4	1	32708	122750	111850	73732	19854	18267	12006	9363	14887	20636
20	5	4	1.4	2120	136260	111320	114970	61947	25654	9768	17548	3253	26478
20	5	4	2	-58374	143040	98294	121780	46996	31406	-1143	22188	-4362	36387
40	5	4	0	272470	222040	215380	151710	136760	62066	71779	41872	32993	-82090
40	5	4	0.4	159360	182690	182850	142870	114300	56029	50364	36673	31702	-12185
40	5	4	1	69210	187240	194480	167870	121590	76755	53663	57146	53511	77584
40	5	4	1.4	-40980	172060	191660	182150	120320	87708	48438	65962	62134	141310
40	5	4	2	-323690	145750	203690	229730	129920	119220	43912	88027	81487	264750
60	5	4	0	332100	284880	251430	179760	160900	89328	94972	58154	33508	-106180
60	5	4	0.4	223530	254530	237500	186050	153370	94188	86033	68490	59609	-3224
60	5	4	1	37389	202330	218960	201460	149160	107980	78751	87988	100040	142960
60	5	4	1.4	-124310	163030	212410	220790	152600	122910	76993	104370	131440	249020
60	5	4	2	-540530	68002	210150	278990	175570	167240	84020	146650	206550	477990
80	5	4	0	397480	314200	295430	191630	196800	99057	129280	54990	49696	-133050
80	5	4	0.4	241710	276570	262350	208230	176970	116570	110310	84750	83813	17671
80	5	4	1	-22728	213540	214170	241750	154500	151510	88440	134520	137080	238960
80	5	4	1.4	-256370	158840	179340	276110	143780	185560	76523	176880	181430	409950
80	5	4	2	-834790	31908	112890	373700	135660	274910	60201	276840	285630	786900
100	5	4	0	457930	336590	341930	199150	235770	102650	164560	45746	66002	-156480
100	5	4	0.4	244950	289450	279650	229240	196490	139670	132270	104880	109900	51336
100	5	4	1	-113770	211190	184360	286140	143700	206770	89699	201070	179200	365070
100	5	4	1.4	-424350	144370	110730	340620	108600	267420	61337	280710	236960	611230
100	5	4	2	-1199100	-22665	-55508	485660	42684	422850	8388	472020	378880	1177100

Table B.3.9 Shear forces under CHBDC inner lanes truck load for 4-lane 6-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons											
				W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**
20	6	4	0	142800	114220	149200	98185	121990	32330	51121	277.3	31054	-843	19562	-37175
20	6	4	0.4	91857	111620	130480	98818	102020	31317	33743	4796	19911	3666	13057	-12465
20	6	4	1	34125	106380	110960	98995	85075	33037	20883	9402	10643	8393	7205	9494
20	6	4	1.4	8148	103200	102960	99012	76995	34947	14637	12484	6232	10930	4285	18726
20	6	4	2	-33906	96034	92893	98225	65619	34406	5678	13023	424.1	11159	286.4	23403
40	6	4	0	232460	213370	177980	151570	134930	86790	65240	45811	44782	37777	8481	-74298
40	6	4	0.4	159970	197420	170760	153930	126320	91436	59444	51701	39038	44352	21556	-15328
40	6	4	1	56798	150440	169690	148480	131140	88151	63818	49324	42892	44393	54053	60467
40	6	4	1.4	-34803	111930	174950	149780	140870	89211	69868	49227	46633	44591	76647	113230
40	6	4	2	-276030	21647	205080	168100	177780	100700	90599	54490	58281	47196	121750	167010
60	6	4	0	273180	279580	209100	181880	148400	116410	81086	72914	56146	53631	-2807	-90791
60	6	4	0.4	181860	232660	200370	176740	149910	112940	82839	69464	59030	59070	39412	-4891
60	6	4	1	25210	153540	190580	172750	159390	112870	91397	68737	67340	69308	101790	117460
60	6	4	1.4	-115680	85960	188310	173320	172730	115860	102780	71036	76882	78296	150650	209090
60	6	4	2	-477860	-80799	199740	192370	225010	135590	140530	81983	104070	99545	257360	400970
80	6	4	0	329820	300280	250750	191350	182810	125130	112900	74606	83194	46764	11242	-113490
80	6	4	0.4	195780	245050	224890	194210	173580	131390	105410	82476	78751	70009	63211	15420
80	6	4	1	-33404	150260	186200	203470	166180	147580	100730	100350	76719	107990	142160	206240
80	6	4	1.4	-239520	64954	156790	215670	166610	166110	102540	118720	78751	140010	206720	356570
80	6	4	2	-747910	-137060	103910	261810	185840	221010	118480	166550	89404	212180	351350	684370
100	6	4	0	377740	320910	290660	200040	215940	131820	144740	75182	108340	37715	21489	-130950
100	6	4	0.4	194830	251010	239230	210080	190470	150220	125220	99321	96938	86606	88353	46745
100	6	4	1	-114760	132460	159000	232390	157410	187110	101940	143530	83922	164900	191820	316950
100	6	4	1.4	-385170	28696	95652	256690	137170	223160	88922	183200	77039	228900	276310	531100
100	6	4	2	-1062200	-232330	-49080	326920	105040	320940	72006	284070	69976	380140	477470	1023900

APPENDIX B4

Shear Distribution Factors for All Modeled Bridges Under Full CHBDC Truck Loading for Ultimate Limit State

Table B.4.1 Shear Distribution factors under CHBDC full truck load for 2-lane 2-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder			
				W1	W2	W3	W4
20	2	2	0	0.8817834	1.1099734	1.1099734	0.8817834
20	2	2	0.4	0.3833316	1.433959	0.8214839	1.3447224
20	2	2	1	-0.555317	2.0602137	0.3948128	2.049631
20	2	2	1.4	-1.427676	2.668555	0.0971626	2.5941452
20	2	2	2	-3.190581	3.7951741	-0.363202	3.362495
40	2	2	0	0.8680614	1.1301425	1.1301425	0.8680614
40	2	2	0.4	0.1649189	1.3559152	0.9349584	1.5438874
40	2	2	1	-1.107192	1.7910117	0.6648837	2.6425532
40	2	2	1.4	-2.270375	2.2267122	0.4771247	3.5647574
40	2	2	2	-5.274662	3.3827537	0.1152453	5.767418
60	2	2	0	0.8489745	1.1502264	1.1502264	0.8489745
60	2	2	0.4	-0.040275	1.2906733	1.0306594	1.715175
60	2	2	1	-1.605294	1.5765261	0.8796855	3.1508482
60	2	2	1.4	-3.023538	1.8551	0.7870016	4.3833476
60	2	2	2	-6.608226	2.5849716	0.6537756	7.3729559
80	2	2	0	0.8532271	1.145982	1.145982	0.8532271
80	2	2	0.4	-0.263482	1.2793645	1.0294665	1.9532696
80	2	2	1	-2.219533	1.5385106	0.8687909	3.8107504
80	2	2	1.4	-3.96689	1.7822934	0.7638293	5.4205136
80	2	2	2	-8.351822	2.415522	0.5740562	9.3671027
100	2	2	0	0.8658805	1.1292574	1.1292574	0.8658805
100	2	2	0.4	-0.514674	1.2943714	0.9838317	2.2362238
100	2	2	1	-2.928092	1.5956565	0.75883	4.5712223
100	2	2	1.4	-5.074217	1.8722257	0.5917584	6.6092294
100	2	2	2	-10.46211	2.5703671	0.2416643	11.651856

Table B.4.2 Shear Distribution factors under CHBDC full truck load for 2-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder					
				W1	W2	W3	W4	W5	W6
20	3	2	0	0.7149953	1.0716661	1.2010564	1.2010564	1.0716661	0.7149953
20	3	2	0.4	0.1393943	1.2113084	1.0710874	1.3612855	0.9609609	1.2427259
20	3	2	1	-0.975016	1.5160578	0.9062284	1.672401	0.8059571	2.0215482
20	3	2	1.4	-2.079753	1.8629727	0.8290076	1.9883118	0.7155988	2.6281532
20	3	2	2	-4.431763	2.6017791	0.8226579	2.5383654	0.5876884	3.3907707
40	3	2	0	0.7299155	1.1053981	1.1620456	1.1620456	1.1053981	0.7299155
40	3	2	0.4	-0.010701	0.9271425	1.1559705	1.2036652	1.2994809	1.4312142
40	3	2	1	-1.372861	0.6384696	1.2137903	1.3313484	1.6546066	2.5383709
40	3	2	1.4	-2.657634	0.3982535	1.3217029	1.4843978	1.99204	3.4609837
40	3	2	2	-6.016461	-0.149197	1.7294793	1.952179	2.8657324	5.6077251
60	3	2	0	0.7161401	1.1324349	1.1502264	1.1502264	1.1324349	0.7161401
60	3	2	0.4	-0.196494	0.7590311	1.1177754	1.2056888	1.5128422	1.5953616
60	3	2	1	-1.823867	0.1307261	1.1290854	1.3459328	2.1941388	3.0255103
60	3	2	1.4	-3.32218	-0.427509	1.1863748	1.4987047	2.8202774	4.2390726
60	3	2	2	-7.058741	-1.773625	1.4297137	1.9429264	4.3956726	7.0796211
80	3	2	0	0.7449196	1.1301049	1.1237892	1.1237892	1.1301049	0.7449196
80	3	2	0.4	-0.419959	0.6971756	0.9812714	1.2846903	1.568974	1.8857388
80	3	2	1	-2.470171	-0.049815	0.7840547	1.5898386	2.3512242	3.7917029
80	3	2	1.4	-4.309744	-0.713341	0.6487549	1.8790847	3.0664448	5.4274058
80	3	2	2	-8.921742	-2.365886	0.3863507	2.6332148	4.8856803	9.3894083
100	3	2	0	0.7772168	1.1159874	1.0995027	1.0995027	1.1159874	0.7772168
100	3	2	0.4	-0.684349	0.6616904	0.7975724	1.4219554	1.5800283	2.2226312
100	3	2	1	-3.241345	-0.135188	0.3083606	1.9916786	2.4017271	4.6707757
100	3	2	1.4	-5.517368	-0.849296	-0.090145	2.5066085	3.1544504	6.7927634
100	3	2	2	-11.23629	-2.656339	-1.020817	3.8091666	5.0878986	12.016811

Table B.4.3 Shear Distribution factors under CHBDC full truck load for 2-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	2	0	0.6493272	1.1440365	1.1808556	1.0096139	1.0096139	1.1808556	1.1440365	0.6493272
20	4	2	0.4	0.0060013	1.0989166	1.1611232	1.0912552	0.9565018	1.2247298	1.1954068	1.2333282
20	4	2	1	-1.25758	1.0598267	1.2034541	1.3027774	0.9218214	1.3339743	1.2809505	2.1064029
20	4	2	1.4	-2.241994	1.0286517	1.2507456	1.4166519	0.8725676	1.3631871	1.2828245	2.4556328
20	4	2	2	-5.358827	1.1556114	1.7067949	2.0717886	1.0321903	1.6494718	1.4605261	3.6110237
40	4	2	0	0.6631927	1.1809813	1.1520625	1.0005053	1.0005053	1.1520625	1.1809813	0.6631927
40	4	2	0.4	-0.10123	0.6977887	1.2578613	0.884688	1.1523467	1.0789484	1.6565428	1.3824182
40	4	2	1	-1.529499	-0.174699	1.5039198	0.7440729	1.4823195	0.9989421	2.449998	2.5158647
40	4	2	1.4	-2.884775	-0.961497	1.7996447	0.6804232	1.8314767	0.9578021	3.1298386	3.4397742
40	4	2	2	-6.473122	-2.959807	2.6850432	0.6461753	2.1499388	0.9263253	4.7711049	5.5740812
60	4	2	0	0.6554576	1.1805893	1.1332034	1.0299054	1.0265414	1.1363934	1.1808213	0.6544716
60	4	2	0.4	-0.293184	0.5040255	1.1462534	0.8684915	1.2058773	1.1330874	1.849619	1.5785851
60	4	2	1	-2.013005	-0.686024	1.2442153	0.6550516	1.5907651	1.1686414	2.9878683	3.0545683
60	4	2	1.4	-3.598434	-1.766331	1.3783112	0.5032483	1.9845269	1.2198553	3.9895278	4.2896776
60	4	2	2	-7.625836	-4.467216	1.804785	0.2066133	3.0632103	1.3954212	6.4397364	7.194316
80	4	2	0	0.6896694	1.165E-05	1.105055	1.0394915	1.0394915	1.105055	1.1646034	0.6896694
80	4	2	0.4	-0.507064	0.3452557	0.9972863	0.9972863	1.1999415	1.2270591	1.2270591	1.8592853
80	4	2	1	-2.616874	-1.100644	0.8577384	0.6877646	1.5327212	1.4494636	3.3835353	3.8022292
80	4	2	1.4	-4.498164	-2.394369	0.7699195	0.5266129	1.8704632	1.6558281	4.6255317	5.4485836
80	4	2	2	-9.292667	-5.691188	0.6138303	0.1623598	2.7994793	2.1846966	7.7478157	9.479132
100	4	2	0	0.7263501	1.140225	1.078513	1.0455881	1.0455881	1.078513	1.140225	0.7263501
100	4	2	0.4	-0.780142	0.2487254	0.7680846	1.0092373	1.1032067	1.4041136	2.0308436	2.2160239
100	4	2	1	-3.332223	-0.583972	0.6293996	1.3741698	1.3313229	2.0976278	3.2564064	4.8368462
100	4	2	1.4	-5.756964	-2.755191	-0.154827	0.9321752	1.4038022	2.4602911	4.9663212	6.8999918
100	4	2	2	-11.64563	-6.369189	-1.133462	0.8727324	1.895718	3.6909706	8.4603653	12.227152

Table B.4.4 Shear Distribution factors under CHBDC full truck load for 3-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder					
				W1	W2	W3	W4	W5	W6
20	3	3	0	0.8390667	1.0388156	1.1097529	1.1097529	1.0388156	0.8390667
20	3	3	0.4	0.2768264	1.3437854	0.8196099	1.4112503	0.7561135	1.3538721
20	3	3	1	-0.786594	1.9415439	0.365374	1.9333864	0.3231203	2.0940013
20	3	3	1.4	-1.567401	2.3166794	0.080809	2.1512141	0.0566506	2.3355299
20	3	3	2	-4.142309	4.0106317	-0.424444	3.0803442	-0.427277	3.2226046
40	3	3	0	0.8507954	1.0549678	1.0915249	1.0915249	1.0549678	0.8507954
40	3	3	0.4	0.1601192	1.231678	0.8978329	1.3061777	0.9064303	1.4976315
40	3	3	1	-1.145916	1.595792	0.61877	1.7174713	0.6880117	2.5070185
40	3	3	1.4	-2.393759	1.9721273	0.4247582	2.1092962	0.5394387	3.318095
40	3	3	2	-5.670785	3.0192437	0.0884723	3.1125015	0.2868361	5.1261596
60	3	3	0	0.8307335	1.0843384	1.0836714	1.0836714	1.0843384	0.8307335
60	3	3	0.4	-0.002182	1.1648134	0.8820635	1.3083053	1.0248304	1.6215631
60	3	3	1	-1.52305	1.3345213	0.5880907	1.733213	0.9759075	2.8883114
60	3	3	1.4	-2.941468	1.5277772	0.3768548	2.1341668	0.9571445	3.9390678
60	3	3	2	-6.586186	2.0610289	-0.037833	3.1734682	0.9967004	6.3915964
80	3	3	0	0.8325757	1.0927994	1.0733509	1.0733509	1.0927994	0.8325757
80	3	3	0.4	-0.188821	1.144378	0.7862351	1.3810931	1.0570352	1.8164034
80	3	3	1	-2.019334	1.2586379	0.3424788	1.9472296	1.0384138	3.4303019
80	3	3	1.4	-3.6902	1.3836495	-0.006694	2.4703838	1.0499676	4.7924478
80	3	3	2	-7.960346	1.7153013	-0.791022	3.8112517	1.1577614	8.0673624
100	3	3	0	0.8426551	1.0872337	1.0627402	1.0627402	1.0872337	0.8426551
100	3	3	0.4	-0.39759	1.1337957	0.6547384	1.4933446	1.0582687	2.0521781
100	3	3	1	-2.598843	1.2383101	-0.00602	2.2631422	1.0325739	4.0657806
100	3	3	1.4	-4.58546	1.3424684	-0.551514	2.9619065	1.0404047	5.7898887
100	3	3	2	-9.595385	1.6115183	-1.829045	4.7238337	1.1303475	9.96401

Table B.4.5 Shear Distribution factors under CHBDC full truck load for 3-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	3	0	0.6732817	1.0906084	1.1299997	1.0897266	1.0897266	1.1299997	1.0906084	0.6732817
20	4	3	0.4	0.0744098	1.2325933	0.9667759	1.2702943	0.9275316	1.3124782	0.9616315	1.2316379
20	4	3	1	-1.088551	1.5410356	0.7352788	1.6319441	0.6756554	1.6270937	0.7432158	2.051946
20	4	3	1.4	-2.005867	1.7595982	0.5990189	1.8343387	0.5131739	1.7234406	0.5853128	2.2861622
20	4	3	2	-5.058615	2.8729889	0.5750167	2.7298282	0.3006816	2.2428025	0.3521328	3.2114156
40	4	3	0	0.7232306	1.097825	1.1269096	1.048798	1.0484191	1.1269096	1.097825	0.7232306
40	4	3	0.4	-0.003246	0.9981605	1.0960249	1.1232148	1.0057395	1.1869735	1.2107054	1.3823708
40	4	3	1	-1.380571	0.8389058	1.1053566	1.3111751	0.9836656	1.315012	1.3950657	2.415016
40	4	3	1.4	-2.714152	0.7165042	1.1766471	1.5297833	1.0125133	1.4532823	1.5636995	3.2388584
40	4	3	2	-5.441756	-1.322212	1.7739233	1.2754589	1.8098291	0.9274859	1.3111751	0.9482335
60	4	3	0	0.7292916	1.1154167	1.1067167	1.0469768	1.0469768	1.1067167	1.1154167	0.7292916
60	4	3	0.4	-0.133616	0.8795502	1.0386634	1.1054021	1.0162754	1.196114	1.3538352	1.5430311
60	4	3	1	-1.712507	0.4774557	0.9783048	1.256666	1.0259034	1.3820619	1.7739483	2.8265704
60	4	3	1.4	-3.215789	0.1148129	0.9736648	1.4370072	1.0853341	1.5605471	2.1473135	3.8925712
60	4	3	2	-7.101903	-0.761926	1.0851407	1.9765229	1.3382139	2.0380415	3.0793343	6.3467431
80	4	3	0	0.754481	1.1094994	1.0857067	1.0487813	1.0487813	1.0857067	1.1094994	0.754481
80	4	3	0.4	-0.312656	0.8206793	0.9056579	1.1572518	0.9657744	1.2820629	1.3979184	1.7786008
80	4	3	1	-2.226818	0.3179059	0.6437048	1.392271	0.8837031	1.6436644	1.9050494	3.443585
80	4	3	1.4	-3.994291	-0.134415	0.4514923	1.637616	0.8555329	1.9744223	2.3599502	4.8497574
80	4	3	2	-8.509548	-1.27294	0.0521734	2.3148043	0.882968	2.8243078	3.5140942	8.1964342
100	4	3	0	0.7810618	1.0951238	1.0669448	1.0471899	1.0471899	1.0669448	1.0951238	0.7810618
100	4	3	0.4	-0.521756	0.7766124	0.7292718	1.242307	0.8793322	1.4222965	1.4166904	2.0484629
100	4	3	1	-2.836881	0.2214808	0.1870016	1.6207061	0.6359549	2.0418186	1.9726763	4.1518006
100	4	3	1.4	-4.934583	-0.281383	-0.260151	1.9840962	0.4637369	2.5968257	2.4783257	5.9493223
100	4	3	2	-10.23193	-1.552305	-1.302669	2.9342318	0.1254468	3.9839133	3.7656004	10.282655

Table B.4.6 Shear Distribution factors under CHBDC full truck load for 3-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	3	0	0.564467	1.063233	1.1214747	1.1288238	1.101724	1.101724	1.1288238	1.1214747	1.063233	0.564467
20	5	3	0.4	-0.064957	1.0643354	1.0372355	1.2312521	1.0168417	1.2026824	1.0401752	1.2234437	1.0626818	1.158404
20	5	3	1	-1.292158	1.0996111	0.9503322	1.4671586	0.9015892	1.4035888	0.8949199	1.3962397	1.0291515	2.0471874
20	5	3	1.4	-2.28337	1.1237713	0.9181248	1.6319625	0.8178737	1.4821325	0.7739443	1.4131427	0.9325106	2.3398659
20	5	3	2	-5.740944	1.5913587	1.2924335	2.4897878	0.8905472	1.9477907	0.6697063	1.701871	0.8952231	3.3115105
40	5	3	0	0.6440414	1.0980144	1.1235937	1.0669285	1.0633166	1.0633166	1.0669285	1.1235937	1.0980144	0.6440414
40	5	3	0.4	-0.101725	0.78153	1.1643311	1.0559744	1.1302254	1.0204476	1.1006197	1.1079027	1.4044922	1.3365176
40	5	3	1	-1.534816	0.2089212	1.3086883	1.097896	1.3172147	0.9951052	1.1886077	1.0944618	1.8909722	2.4202029
40	5	3	1.4	-2.952809	-0.321967	1.5116646	1.1943512	1.5461256	1.0143489	1.2977342	1.103225	2.2948526	3.2824379
40	5	3	2	-4.721687	-1.031579	1.7167134	1.2741681	1.7509967	0.9734339	1.3203529	1.0024474	2.4415782	3.7416216
60	5	3	0	0.6504213	1.1300327	1.1105544	1.0529894	1.0543911	1.0543911	1.0529894	1.1105544	1.1300327	0.6504213
60	5	3	0.4	-0.197152	0.5978347	1.1013711	0.9735295	1.167491	0.9722245	1.1559394	1.138781	1.6446374	1.4450692
60	5	3	1	-1.762716	-0.360006	1.1472877	0.8865778	1.4375292	0.8791828	1.3851359	1.213456	2.4968986	2.6870418
60	5	3	1.4	-3.265833	-1.259759	1.239556	0.8515362	1.7474907	0.8338462	1.6237091	1.2823793	3.2285199	3.7119013
60	5	3	2	-7.184746	-3.541671	1.6034574	0.8741078	2.6517585	0.7990946	2.2821537	1.4793858	4.9739806	6.06003
80	5	3	0	0.6882158	1.1131084	1.0863751	1.0522901	1.0584722	1.0584722	1.0522901	1.0863751	1.1131084	0.6882158
80	5	3	0.4	-0.391764	0.5303221	0.943686	1.0166178	1.0870434	1.0558824	1.108806	1.2413865	1.6811495	1.7240899
80	5	3	1	-2.337619	-0.515828	0.7390926	0.9981134	1.203208	1.0925154	1.2528735	1.519413	2.6430476	3.4070774
80	5	3	1.4	-4.136103	-1.47664	0.5950669	1.0186646	1.3615193	1.1538349	1.4136075	1.7656936	3.4814712	4.822857
80	5	3	2	-8.753907	-3.927834	0.3091332	1.1413454	1.8605551	1.366866	1.8864948	2.3905849	5.5383908	8.1895838
100	5	3	0	0.7260164	1.0933441	1.0646089	1.0498891	1.054598	1.054598	1.0498891	1.0646089	1.0933441	0.7260164
100	5	3	0.4	-0.618528	0.4812672	0.7307994	1.0959024	0.9480741	1.1877436	1.0268269	1.4098384	1.6961887	2.0343363
100	5	3	1	-3.009366	-0.608147	0.1880427	1.2168125	0.8191553	1.4459891	1.017817	1.9977407	2.7197898	4.2057114
100	5	3	1.4	-5.177886	-1.605089	-0.264608	1.350366	0.7537504	1.6945202	1.0454027	2.5135642	3.6250392	6.0599619
100	5	3	2	-10.66574	-4.136006	-1.331493	1.734119	0.6851939	2.3499408	1.1876324	3.7871054	5.8701246	10.524104

Table B.4.7 Shear Distribution factors under CHBDC full truck load for 4-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	4	0	0.6970267	1.110745	1.0791622	1.0964694	1.0964694	1.0791622	1.110745	0.6970267
20	4	4	0.4	0.1062186	1.3727225	0.7718774	1.3821478	0.813161	1.3986282	0.8465076	1.2632024
20	4	4	1	-1.007619	1.8819059	0.2634767	1.9276541	0.3137337	1.9476069	0.3757032	2.1231589
20	4	4	1.4	-1.854788	2.2703249	-0.036687	2.2258444	0.0088244	2.1552929	0.1130698	2.3876167
20	4	4	2	-4.975644	4.1617662	-0.572569	3.3886762	-0.581058	2.8868788	-0.387014	3.2041951
40	4	4	0	0.7756918	1.0783089	1.089713	1.052552	1.052552	1.089713	1.0783089	0.7756918
40	4	4	0.4	0.0796724	1.2168279	0.917195	1.2542731	0.8736036	1.2776497	0.9567363	1.4179805
40	4	4	1	-1.242869	1.5093909	0.6620771	1.6480519	0.6066909	1.624249	0.7686575	2.4104567
40	4	4	1.4	-2.2501129	1.4420321	0.4988316	2.1838381	0.4477796	1.528682	0.6066554	3.0368282
40	4	4	2	-5.950949	2.0946236	0.3127316	3.1674306	0.1969747	2.0324873	0.423799	4.3827261
60	4	4	0	0.7798676	1.0923424	1.0803074	1.0456234	1.0456234	1.0803074	1.0923424	0.7798676
60	4	4	0.4	-0.040069	1.1443974	0.9046255	1.2416923	0.8753065	1.2721713	1.0550774	1.5466561
60	4	4	1	-1.572959	1.2541043	0.6417696	1.6289871	0.6385796	1.6229261	1.0288614	2.7498655
60	4	4	1.4	-3.028758	1.3935362	0.4576197	2.0140779	0.4740337	1.9396059	1.0214664	3.7215679
60	4	4	2	-6.889816	1.801189	0.1145818	3.0647183	0.2014716	2.7375405	1.0561504	5.9096167
80	4	4	0	0.7981899	1.0899172	1.0646292	1.0454063	1.0454063	1.0646292	1.0899172	0.7981899
80	4	4	0.4	-0.191781	1.1132253	0.8009719	1.2957805	0.8229266	1.3427225	1.0766341	1.7346746
80	4	4	1	-2.004848	1.1698415	0.3874158	1.7798623	0.5018762	1.8422929	1.0839273	3.2365689
80	4	4	1.4	-3.691704	1.2338009	0.0611199	2.2471022	0.2679681	2.2895079	1.1161075	4.4736531
80	4	4	2	-8.051072	1.4325464	-0.661249	3.4854394	-0.204269	3.4112544	1.2318711	7.3626054
100	4	4	0	0.8158924	1.0796476	1.051261	1.0432078	1.0432078	1.051261	1.0796476	0.8158924
100	4	4	0.4	-0.365244	1.0913493	0.6639262	1.3732132	0.7484409	1.4572162	1.0804262	1.9463512
100	4	4	1	-2.50474	1.1295244	0.0295523	1.9927353	0.2882486	2.1660137	1.0949755	3.7977096
100	4	4	1.4	-4.455763	1.1714592	-0.493518	2.7223693	-0.066911	2.7937225	1.1346633	5.3438452
100	4	4	2	-9.514185	1.2854728	-1.738012	4.1004852	-0.857694	4.3783447	1.2717466	9.0734804

Table B.4.8 Shear Distribution factors under CHBDC full truck load for 4-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	4	0	0.7747573	1.0796307	1.0662645	1.0636464	0.9955063	0.9955063	1.0636464	1.0662645	1.0796307	0.7747573
20	5	4	0.4	2.7499234	1.2517378	0.8171985	1.2726138	0.7578773	1.2375448	0.847238	1.3307637	0.8936752	1.4171617
20	5	4	1	-1.188627	1.659338	0.4030185	1.7380883	0.3022828	1.7236197	0.4093778	1.7968583	0.4977394	2.4320284
20	5	4	1.4	-2.068936	1.8636204	0.1993424	1.9669673	0.0637099	1.8838075	0.1864378	1.9267309	0.3068301	2.738762
20	5	4	2	-5.800518	3.3884695	0.0049365	3.2184294	-0.383948	2.6520884	-0.269487	2.4819794	-0.087232	3.6494549
40	5	4	0	0.7996191	1.0952907	1.0914716	1.0186861	0.9908864	0.9908864	1.0186861	1.0914716	1.0952907	0.7996191
40	5	4	0.4	0.1746008	0.8643666	0.8931877	0.9244957	0.8057919	0.8804869	0.8286622	0.988888	1.0157107	1.1343702
40	5	4	1	-1.236998	0.835057	0.9958601	1.2808294	0.9157028	1.2025816	0.8841284	1.304277	1.3414469	2.452103
40	5	4	1.4	-2.587549	0.7112018	1.0319198	1.5168604	0.9440354	1.3696463	0.843095	1.4314629	1.4579304	3.233781
40	5	4	2	-6.377058	0.4775244	1.3367396	2.2805974	1.1666107	1.8436624	0.8250651	1.7577764	1.7377926	4.8596199
60	5	4	0	0.7844133	1.1196169	1.0829319	1.0153619	0.9961494	0.9961494	1.0153619	1.0829319	1.1196169	0.7844133
60	5	4	0.4	-0.03923	0.9062857	1.0024932	1.0848894	0.9626907	1.0523007	0.966932	1.1781243	1.3288155	1.5530216
60	5	4	1	-1.587423	0.518701	0.9099107	1.2587443	0.9704482	1.1924068	0.9336182	1.3617305	1.6881978	2.7497422
60	5	4	1.4	-3.077877	0.1810759	0.8868195	1.4663117	1.0310219	1.3492968	0.9375695	1.5234417	1.9879489	3.7109104
60	5	4	2	-7.081796	-0.677295	0.9481545	2.0944151	1.3106543	1.8096715	1.0416432	1.9448114	2.7177335	5.8772092
80	5	4	0	0.7992426	1.1132755	1.0663773	1.0175054	1.0022173	1.0022173	1.0175054	1.0663773	1.1132755	0.7992426
80	5	4	0.4	-0.221577	0.8784713	0.8716418	1.1465459	0.8961717	1.1346412	0.9134961	1.2722029	1.3411561	1.7630203
80	5	4	1	-2.14632	0.4552913	0.5737429	1.4218259	0.7757778	1.4070077	0.7864294	1.6387104	1.731191	3.3066812
80	5	4	1.4	-3.850224	0.0691255	0.3484312	1.7101698	0.7238985	1.6781838	0.7156592	1.9636455	2.0738891	4.5692038
80	5	4	2	-8.433212	-0.907325	-0.129188	2.5268934	0.6996505	2.411418	0.6138115	2.769091	2.914704	7.5381681
100	5	4	0	0.8135287	1.0983403	1.0524011	1.0189757	1.0052663	1.0052663	1.0189757	1.0524011	1.0983403	0.8135287
100	5	4	0.4	-0.406695	0.8345239	0.7133914	1.2092116	0.805659	1.2368251	0.8591898	1.4039523	1.3588196	1.9817232
100	5	4	1	-2.611023	0.3653719	0.1600723	1.5862907	0.5140623	1.6677687	0.6246277	2.0055548	1.8004138	3.8861953
100	5	4	1.4	-4.650921	-0.064059	-0.299856	1.9657891	0.3075308	2.0803589	0.4550811	2.5329929	2.1862247	5.4879473
100	5	4	2	-9.923633	-1.178706	-1.392329	2.9888248	-0.106644	3.1595671	0.1175925	3.8433706	3.1642945	9.3271467

Table B.4.9 Shear Distribution factors under CHBDC full truck load for 4-lane 6-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder											
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
20	6	4	0	2.150773	1.356374	1.097958	1.03909	1.06174	1.06802	1.06802	1.06174	1.03909	1.09795	1.07538	0.63356
20	6	4	0.4	-0.04057	1.136733	0.921193	1.17071	0.88853	1.21924	0.91408	1.24437	0.89961	1.29101	0.99767	1.30655
20	6	4	1	-1.39402	1.311762	0.663107	1.48968	0.57282	1.54573	0.59317	1.59633	0.59244	1.61039	0.76819	2.39492
20	6	4	1.4	-2.29620	1.363766	0.528607	1.64949	0.40797	1.66165	0.39559	1.70299	0.39069	1.69364	0.62367	2.75258
20	6	4	2	-6.47042	2.301494	0.73583	2.89801	0.22720	2.38623	0.06763	2.23270	0.07325	2.07917	0.37538	3.74396
40	6	4	0	0.708333	1.567416	1.562468	1.46479	1.47583	1.48207	1.48207	1.47583	1.46479	1.56246	1.56741	1.01190
40	6	4	0.4	0.013781	0.808252	1.118134	1.00158	1.06777	1.01768	1.06985	1.00531	1.05754	1.12362	1.38762	1.32831
40	6	4	1	-1.30417	0.263035	1.194766	1.01874	1.20441	1.02839	1.16774	0.99881	1.12794	1.13859	1.82065	2.32052
40	6	4	1.4	-2.66477	-0.25554	1.349467	1.10486	1.40195	1.08275	1.28988	1.01997	1.20116	1.15186	2.16027	0.43431
40	6	4	2	-6.55522	-1.60579	1.989376	1.54275	2.1153	1.34845	1.67842	1.13577	1.41597	1.22173	2.89376	4.70147
60	6	4	0	0.703308	1.122169	1.092937	1.02538	1.02472	1.02964	1.02964	1.02472	1.02538	1.09293	1.12216	0.70330
60	6	4	0.4	-0.36341	0.783826	1.023859	1.23309	1.13282	1.27006	1.14787	1.28046	1.16318	1.45707	1.74861	2.00173
60	6	4	1	-1.68984	-0.04705	1.0025	1.00702	1.20538	1.04539	1.17915	1.02068	1.17154	1.27920	2.14872	2.67194
60	6	4	1.4	-3.21912	-0.75576	1.032907	1.06766	1.40348	1.11055	1.32592	1.05330	1.28251	1.3766	2.67250	3.63764
60	6	4	2	-7.33801	-2.61012	1.236052	1.34375	2.05820	1.37433	1.80181	1.20925	1.61950	1.62685	3.88411	5.78201
80	6	4	0	0.736799	1.104428	1.068564	1.02608	1.03063	1.03183	1.03183	1.03063	1.02608	1.06856	1.10442	0.73679
80	6	4	0.4	-0.31407	0.677401	0.884843	1.06566	0.97901	1.09762	0.99202	1.10660	1.00525	1.25923	1.51119	1.72995
80	6	4	1	-2.25340	-0.10800	0.600146	1.18002	0.95491	1.26070	0.97988	1.27348	1.00608	1.5895	2.18487	3.32602
80	6	4	1.4	-4.06914	-0.83567	0.383118	1.32593	0.99337	1.44664	1.01567	1.44416	1.03563	1.87525	2.75460	4.63154
80	6	4	2	-8.84542	-2.71678	-0.07260	1.79814	1.21194	1.99081	1.19296	1.91009	1.15514	2.56332	4.12328	7.69693
100	6	4	0	0.654015	1.087957	1.049348	1.02525	1.03022	1.03176	1.03176	1.03022	1.02525	1.04934	1.08795	0.76163
100	6	4	0.4	-0.49243	0.609767	0.710644	1.10841	0.87609	1.17592	0.92044	1.21302	0.96629	1.39505	1.54956	1.96301
100	6	4	1	-2.76045	-0.25463	0.151422	1.29728	0.66426	1.46603	0.77304	1.54869	0.89060	1.97856	2.31770	3.92629
100	6	4	1.4	-4.86532	-1.05742	-0.31944	1.50778	0.53118	1.76372	0.69015	1.86590	0.84726	2.47767	2.97795	5.58110
100	6	4	2	-10.3196	-3.14610	-1.44955	2.10780	0.30607	2.57581	0.57779	2.69020	0.80454	3.70038	4.60770	9.54444

APPENDIX B5

Shear Distribution Factors for All Modeled Bridges Under Outer CHBDC Truck Loading for Ultimate Limit State

Table B.5.1 Shear Distribution factors under CHBDC outer lanes truck load for 2-lane 2-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder			
				W1	W2	W3	W4
20	2	2	0	0.003447	7.89E-06	0.488238	0.931929
20	2	2	0.4	-0.27223	1.008605	0.347858	1.212849
20	2	2	1	-0.72786	1.366078	0.121015	1.510304
20	2	2	1.4	-1.26484	1.776097	-0.04745	1.861653
20	2	2	2	-2.77490	2.900389	-0.40932	2.692654
40	2	2	0	0.02655	0.700746	0.579955	0.912999
40	2	2	0.4	-0.37085	0.839814	0.481033	1.294201
40	2	2	1	-1.10843	1.117673	0.342557	1.933368
40	2	2	1.4	-1.8168	1.390992	0.235744	2.491414
40	2	2	2	-3.66001	2.117791	0.030431	3.848695
60	2	2	0	0.024975	0.656012	0.638386	0.901964
60	2	2	0.4	-0.47579	0.74269	0.577937	1.388906
60	2	2	1	-1.38890	0.919396	0.49996	2.224202
60	2	2	1.4	-2.22691	1.092462	0.453753	2.953068
60	2	2	2	-4.36804	1.5447	0.383348	4.736664
80	2	2	0	-0.01321	0.931378	0.921826	1.008041
80	2	2	0.4	-0.60629	0.721048	0.581784	1.533935
80	2	2	1	-1.74095	0.878691	0.496014	2.610898
80	2	2	1.4	-2.75161	1.026643	0.442743	3.544392
80	2	2	2	-5.37757	1.412772	0.335197	5.908898
100	2	2	0	0.020917	0.63682	0.624683	0.934405
100	2	2	0.4	-0.75334	0.734037	0.54818	1.7029
100	2	2	1	-2.13616	0.913345	0.425453	3.041599
100	2	2	1.4	-3.39458	1.07881	0.331301	4.237475
100	2	2	2	-6.59237	1.498157	0.129465	7.23285

Table B.5.2 Shear Distribution factors under CHBDC outer lanes truck load for 2-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder					
				W1	W2	W3	W4	W5	W6
20	3	2	0	-0.06192	0.473246	0.582197	0.706103	0.645574	0.974401
20	3	2	0.4	-0.39545	0.584769	0.534795	0.827538	0.599945	1.296751
20	3	2	1	-0.95373	0.784536	0.540922	0.928469	0.483976	1.618642
20	3	2	1.4	-1.63949	1.027314	0.518462	1.142971	0.439403	1.997213
20	3	2	2	-3.63257	1.74716	0.547628	1.713078	0.373427	2.860551
40	3	2	0	-.038517	0.401287	0.58952	0.661686	0.810011	0.906407
40	3	2	0.4	-0.46286	0.308307	0.597797	0.696384	0.927545	1.300695
40	3	2	1	-1.26830	0.154624	0.65464	0.789997	1.151305	1.949295
40	3	2	1.4	-2.05641	0.018882	0.734575	0.892433	1.36109	2.506296
40	3	2	2	-4.14196	-0.30733	1.006651	1.199088	1.91667	3.838136
60	3	2	0	-0.04672	0.371224	0.573088	0.675941	0.879473	0.87899
60	3	2	0.4	-0.56381	0.166455	0.563615	0.714608	1.099148	1.371893
60	3	2	1	-1.52037	-0.19468	0.583383	0.805668	1.505921	2.20511
60	3	2	1.4	-2.40854	-0.51866	0.628236	0.904123	1.884951	2.922473
60	3	2	2	-4.70012	-1.33501	0.790975	1.180154	2.853405	4.660442
80	3	2	0	-0.05677	0.381305	0.533246	0.695985	0.870712	0.907512
80	3	2	0.4	-0.71491	0.140692	0.458602	0.791515	1.122089	1.548903
80	3	2	1	-1.91018	-0.29003	0.353335	0.975599	1.584701	2.656289
80	3	2	1.4	-2.98131	-0.67335	0.282646	1.150953	2.009468	3.608496
80	3	2	2	-5.77690	-1.67024	0.131858	1.612478	3.11723	6.009148
100	3	2	0	-0.06602	0.399326	0.485976	0.722754	0.839177	0.944033
100	3	2	0.4	-0.88663	0.147116	0.321059	0.907956	1.104022	1.755179
100	3	2	1	-2.35746	-0.30767	0.047626	1.240987	1.582991	3.162496
100	3	2	1.4	-3.69952	-0.72746	-0.18263	1.547508	2.031222	4.413717
100	3	2	2	-7.11778	-1.80538	-0.73206	2.330698	3.193901	7.536762

Table B.5.3 Shear Distribution factors under CHBDC outer lanes truck load for 2-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	2	0	-0.17705	0.268524	0.387911	0.716257	0.577983	0.719148	0.916067	1.017546
20	4	2	0.4	-0.55543	0.269443	0.406822	0.795382	0.575632	0.771473	0.966776	1.373549
20	4	2	1	-1.20938	0.275861	0.483951	0.982013	0.573905	0.741526	0.956279	1.733656
20	4	2	1.4	-2.02847	0.307634	0.587758	1.167725	0.610626	0.834284	1.017436	2.15182
20	4	2	2	-4.47953	0.450917	0.991457	1.722755	0.769464	1.088575	1.18077	3.088955
40	4	2	0	-0.14750	0.168057	0.53921	0.488975	0.686859	0.675506	1.093435	0.93617
40	4	2	0.4	-0.59078	-0.10388	0.611984	0.435629	0.786674	0.644677	1.369202	1.340544
40	4	2	1	-1.44854	-0.60984	0.788016	0.37956	1.006908	0.612805	1.848656	2.006
40	4	2	1.4	-2.30150	-1.09588	0.986697	0.35177	1.236174	0.593258	2.274188	2.575692
40	4	2	2	-4.59132	-2.35976	1.568942	0.348612	1.882841	0.588205	3.328939	3.930289
60	4	2	0	-0.16156	0.159803	0.513867	0.488063	0.681757	0.716042	1.119335	0.925615
60	4	2	0.4	-0.70914	-0.21701	0.537247	0.406928	0.788993	0.720875	1.500137	1.444199
60	4	2	1	-1.73297	-0.91897	0.609257	0.293544	1.031884	0.749875	2.178479	2.309172
60	4	2	1.4	-2.6941	-1.56857	0.70122	0.211345	1.281606	0.787511	2.78909	3.051185
60	4	2	2	-5.19338	-3.23826	0.981359	0.044306	1.964137	0.899386	4.310042	4.844866
80	4	2	0	-0.17453	0.173711	0.481534	0.504096	0.652516	0.737115	1.107483	0.961174
80	4	2	0.4	-0.85301	-0.28844	0.426747	0.430473	0.749702	0.809685	1.569858	1.62015
80	4	2	1	-2.09249	-1.13644	0.354879	0.315063	0.95566	0.944187	2.401933	2.756093
80	4	2	1.4	-3.20922	-1.90352	0.309627	0.226643	1.164737	1.07156	3.145954	3.731525
80	4	2	2	-6.13696	3.913033	0.225078	0.013044	1.74201	1.39754	5.058277	6.189319
100	4	2	0	-0.19024	0.206572	0.424059	0.546721	0.602733	0.773142	1.058491	1.012564
100	4	2	0.4	-1.0381	-0.29442	0.253729	0.531001	0.641047	0.960952	1.563636	1.849678
100	4	2	1	-2.75313	-0.85090	0.132777	0.77591	0.781645	1.413497	2.352944	3.588765
100	4	2	1.4	-3.95568	-2.05701	-0.27429	0.496939	0.831823	1.585092	3.297236	4.593518
100	4	2	2	-7.51587	-4.24212	-0.85921	0.466792	1.137442	2.332181	5.417778	7.814474

Table B.5.4 Shear Distribution factors under CHBDC outer lanes truck load for 3-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder					
				W1	W2	W3	W4	W5	W6
20	3	3	0	-0.23268	0.644513	0.333312	1.47846	0.92541	1.332617
20	3	3	0.4	-0.63918	0.91462	0.147207	1.756133	0.71731	1.770767
20	3	3	1	-1.45390	1.402066	-0.19537	2.151621	0.346886	2.309865
20	3	3	1.4	-2.42464	2.068344	-0.47178	2.626417	0.078099	2.827385
20	3	3	2	-5.40872	4.123294	-1.02090	3.745602	-0.47130	3.872905
40	3	3	0	-0.21730	0.642919	0.503512	1.231043	0.942557	1.393352
40	3	3	0.4	-0.75271	0.793957	0.369992	1.409658	0.84012	1.884634
40	3	3	1	-1.82172	1.12381	0.170594	1.769607	0.683686	2.707447
40	3	3	1.4	-2.88698	1.467092	0.022865	2.114727	0.570778	3.391174
40	3	3	2	-5.77452	2.41956	-0.23970	3.019914	0.359781	4.976769
60	3	3	0	-0.19499	0.610838	0.562977	1.143832	1.010657	1.364931
60	3	3	0.4	-0.83454	0.682515	0.420014	1.324933	0.975389	1.964579
60	3	3	1	-2.05322	0.841888	0.20279	1.6765	0.946581	2.968612
60	3	3	1.4	-3.22484	1.011309	0.040295	2.015735	0.941263	3.83213
60	3	3	2	-6.31815	1.480913	-0.29288	2.908974	0.986449	5.905122
80	3	3	0	-0.18527	0.626358	0.559366	1.11425	1.007051	1.376494
80	3	3	0.4	-0.96755	0.673304	0.349904	1.35656	0.987033	2.121865
80	3	3	1	-2.41377	0.776527	0.015008	1.814001	0.984016	3.38992
80	3	3	1.4	-3.78183	0.885924	-0.26138	2.247757	0.999382	4.499969
80	3	3	2	-7.33556	1.178958	-0.89990	3.373285	1.094034	7.218841
100	3	3	0	-0.17922	0.649561	0.536462	1.112367	0.973014	1.396928
100	3	3	0.4	-1.12075	0.689554	0.237375	1.447383	0.960951	2.308725
100	3	3	1.	-2.84561	0.779928	-0.26729	2.058502	0.950164	3.879994
100	3	3	1.4	-4.43710	0.866648	-0.69716	2.622869	0.966182	5.258252
100	3	3	2	-8.53208	1.084311	-1.74218	4.055186	1.033931	8.665979

Table B.5.5 Shear Distribution factors under CHBDC outer lanes truck load for 3-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	3	0	-0.30586	0.441779	0.18485	0.939051	0.864146	1.446939	1.079603	1.32499
20	4	3	0.4	-0.75100	0.583513	0.094021	1.121107	0.763618	1.628417	0.986343	1.810555
20	4	3	1	-1.62287	0.847858	-0.04591	1.411305	0.584001	1.814689	0.765652	2.320841
20	4	3	1.4	-2.74018	1.25521	-0.12718	1.812622	0.454412	2.097446	0.631078	2.872961
20	4	3	2	-6.31449	2.640968	-0.09407	2.919426	0.236011	2.716949	0.365848	3.945289
40	4	3	0	-0.28516	0.343556	0.467056	0.783472	0.883924	1.185547	1.236812	1.379629
40	4	3	0.4	-0.85115	0.278473	0.459393	0.85616	0.864633	1.244645	1.329963	1.887431
40	4	3	1	-2.00808	0.1733	0.502047	1.043315	0.870069	1.368865	1.494416	2.740341
40	4	3	1.4	-3.17742	0.086394	0.587577	1.25088	0.910196	1.503422	1.650343	3.449846
40	4	3	2	-6.41933	-0.10778	0.931352	1.878425	1.10689	1.867234	2.043838	5.081538
60	4	3	0	-0.29372	0.338156	0.506427	0.768949	0.872436	1.136567	1.290949	1.377992
60	4	3	0.4	-0.96239	0.165113	0.46719	0.826369	0.861474	1.215868	1.481218	1.99617
60	4	3	1	-2.25869	-0.14941	0.44122	0.96931	0.88827	1.378514	1.829478	3.029512
60	4	3	1.4	-3.52319	-0.44004	0.456837	1.134305	0.949865	1.535375	2.149073	3.915911
60	4	3	2	-6.90344	-1.18620	0.577897	1.623028	1.188115	1.958456	2.965219	6.037362
80	4	3	0	-0.30191	0.37167	0.477328	0.792814	0.831686	1.146233	1.262096	1.417885
80	4	3	0.4	-1.12386	0.155788	0.349539	0.886573	0.778904	1.303901	1.487584	2.19623
80	4	3	1	-2.66084	-0.23853	0.157307	1.08988	0.72883	1.602094	1.902393	3.521517
80	4	3	1.4	-4.12929	-0.60717	0.010053	1.303938	0.715371	1.880927	2.284044	4.682298
80	4	3	2	-7.97438	-1.56288	-0.31044	1.896603	0.751047	2.608854	3.269601	7.524008
100	4	3	0	-0.30959	0.413018	0.427234	0.833011	0.775782	1.175686	1.207721	1.4628
100	4	3	0.4	-1.30232	0.17347	0.178876	0.991718	0.660623	1.454157	1.459196	2.420915
100	4	3	1	-3.13643	-0.26090	-0.23642	1.303759	0.481527	1.950801	1.906752	4.078795
100	4	3	1.4	-4.84062	-0.66693	-0.59124	1.605857	0.351985	2.407233	2.324009	5.534387
100	4	3	2	-9.29616	-1.72875	-1.45462	2.417911	0.076857	3.576245	3.408395	9.175703

Table B.5.6 Shear Distribution factors
under CHBDC outer lanes truck load for 3-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	3	0	-0.27611	0.333025	0.280463	0.694233	0.816802	1.133819	1.046284	1.256285	1.113666	1.070571
20	5	3	0.4	-0.73586	0.361776	0.247154	0.802571	0.776683	1.236442	0.990683	1.354775	1.1178	1.573147
20	5	3	1	-1.64745	0.401875	0.193796	0.977941	0.70403	1.371413	0.856012	1.441999	1.037293	2.188991
20	5	3	1.4	-2.83687	0.545444	0.250833	1.29659	0.692145	1.587305	0.781075	1.585548	1.009472	2.763496
20	5	3	2	-6.73925	1.137746	0.728895	2.325615	0.821639	2.153129	0.687722	1.925663	0.980049	3.855253
40	5	3	0	-0.23210	0.243043	0.545292	0.628504	0.865233	0.907398	1.021506	1.058942	1.301413	1.153932
40	5	3	0.4	-0.80754	0.008207	0.589656	0.632781	0.928914	0.885416	1.05781	1.056211	1.538221	1.67984
40	5	3	1	-1.98692	-0.44248	0.737003	0.692306	1.102707	0.877956	1.140476	1.052747	1.935566	2.555131
40	5	3	1.4	-3.18435	-0.87335	0.931712	0.793824	1.312004	0.907199	1.24739	1.074863	2.278222	3.268286
40	5	3	2	-6.58746	-2.02855	1.582851	1.174182	1.96794	1.050483	1.554941	1.146205	3.088832	4.90576
60	5	3	0	-0.17807	0.22598	0.555549	0.606879	0.854992	0.855916	1.016486	1.050416	1.388954	1.119635
60	5	3	0.4	-0.82987	-0.17710	0.558757	0.555821	0.952378	0.802575	1.10354	1.079289	1.782683	1.718195
60	5	3	1	-2.08821	-0.93747	0.61509	0.502805	1.187984	0.741729	1.300486	1.145028	2.461609	2.695313
60	5	3	1.4	-3.32448	-1.66746	0.709974	0.489027	1.456216	0.710681	1.502	1.203155	3.05968	3.525727
60	5	3	2	-6.94314	-3.75054	1.085406	0.549541	2.343752	0.72652	2.168082	1.443329	4.751165	5.757331
80	5	3	0	-0.18029	0.281304	0.509912	0.6382	0.812071	0.894355	0.96677	1.074946	1.323393	1.176073
80	5	3	0.4	-1.00549	-0.16130	0.408028	0.618135	0.842287	0.898678	1.016346	1.196937	1.75699	1.959761
80	5	3	1	-2.53593	-0.98025	0.260858	0.61555	0.948161	0.935614	1.139466	1.420432	2.517511	3.275823
80	5	3	1.4	-3.99198	-1.75459	0.154228	0.64102	1.08566	0.989843	1.274615	1.620759	3.196406	4.416135
80	5	3	2	-7.79928	-3.76717	-0.06398	0.757561	1.510704	1.171561	1.671746	2.136404	4.890473	7.182281
100	5	3	0	-0.18027	0.336894	0.454038	0.685834	0.747943	0.938318	0.906283	1.107795	1.251661	1.232974
100	5	3	0.4	-1.19756	-0.12568	0.207177	0.727713	0.676699	1.046895	0.89744	1.374003	1.710162	2.217634
100	5	3	1	-3.06038	-0.97402	-0.20585	0.830951	0.587768	1.254164	0.898191	1.834882	2.511664	3.904896
100	5	3	1.4	-4.79316	-1.76964	-0.56065	0.943699	0.543177	1.456176	0.92472	2.247792	3.237082	5.383806
100	5	3	2	-9.26722	-3.83135	-1.42130	1.265176	0.49792	1.996475	1.048897	3.288138	5.068878	9.018615

Table B.5.7 Shear Distribution factors under CHBDC outer lanes truck load for 4-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	4	0	-0.29593	0.354515	-0.13995	0.607927	0.243869	1.493928	0.889327	1.39925
20	4	4	0.4	-0.72885	0.531675	-0.30247	0.980886	0.061644	1.787724	0.695625	2.135111
20	4	4	1	-1.73943	1.030241	-0.67565	1.711329	-0.35983	2.351884	0.273601	3.138311
20	4	4	1.4	-2.91930	1.72196	-1.03408	2.327962	-0.73764	2.849461	-0.07103	3.823826
20	4	4	2	-5.27356	4.300428	-1.68731	4.165167	-1.45984	3.872962	-0.7052	5.029484
40	4	4	0	-0.41105	0.383251	0.072316	0.596403	0.359929	1.190249	0.880942	1.495657
40	4	4	0.4	-0.82751	0.483042	-0.01792	0.835059	0.259849	1.324195	0.816669	2.161475
40	4	4	1	-2.02376	0.716098	-0.16299	1.203444	0.095374	1.582221	0.700101	3.100625
40	4	4	1.4	-2.94760	0.660839	-0.19121	1.93274	0.0359	1.441616	0.597297	3.835579
40	4	4	2	-5.60818	1.131782	-0.29354	2.81479	-0.11470	1.801675	0.482271	5.136067
60	4	4	0	-0.92426	0.350618	0.143349	0.588484	0.420119	1.083439	0.941754	1.466405
60	4	4	0.4	-0.94915	0.39314	0.049479	0.828305	0.327584	1.208222	0.927436	2.234472
60	4	4	1	-2.51708	0.49184	-0.09728	1.190706	0.188563	1.450629	0.924122	3.219285
60	4	4	1.4	-3.21090	0.59972	-0.20855	1.533703	0.094192	1.680839	0.930618	3.941735
60	4	4	2	-6.27902	0.920841	-0.42823	2.325832	-0.09370	2.257359	0.967738	5.417734
80	4	4	0	-0.44290	0.361931	0.143526	0.628825	0.42443	1.055918	0.92545	1.472843
80	4	4	0.4	-1.31830	0.384788	-0.00242	0.830857	0.303471	1.229723	0.923531	2.412614
80	4	4	1	-2.72690	0.436059	-0.24591	1.181102	0.117653	1.559144	0.939485	3.567398
80	4	4	1.4	-3.36657	0.492113	-0.45020	1.524057	-0.02716	1.865307	0.965464	4.315724
80	4	4	2	-6.92186	0.647901	-0.93295	2.322848	-0.34483	2.651038	1.052653	6.393014
100	4	4	0	-0.45922	0.386429	0.116966	0.678838	0.407023	1.063004	0.881599	1.486121
100	4	4	0.4	-1.46740	0.397692	-0.10301	0.821904	0.245554	1.311403	0.893015	2.6325
100	4	4	1	-2.98921	0.431939	-0.48238	1.19547	-0.02531	1.762461	0.914244	3.870202
100	4	4	1.4	-3.92386	0.46761	-0.81717	1.511967	-0.25006	2.183061	0.941144	4.786425
100	4	4	2	-7.85067	0.551155	-1.62834	2.317215	-0.75498	3.246472	1.048639	7.675157

Table B.5.8 Shear Distribution factors under CHBDC outer lanes truck load for 4-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	4	0	-0.32596	0.274773	-0.06360	0.419388	0.006614	0.940634	0.750539	1.417959	0.9778	1.292998
20	5	4	0.4	-0.64796	0.392183	-0.17580	0.580136	-0.12570	1.146147	0.612018	1.649692	0.841106	1.819693
20	5	4	1	-1.41347	0.715271	-0.38830	0.938351	-0.41608	1.504337	0.311497	1.92363	0.501498	2.408436
20	5	4	1.4	-2.38898	1.069375	-0.55383	1.341896	-0.60378	1.838906	0.114552	2.21127	0.317308	2.95521
20	5	4	2	-6.23073	2.771036	-0.69444	2.740799	-1.01913	2.698201	-0.32820	2.81765	-0.07959	3.910962
40	5	4	0	-0.41662	0.20931	0.265639	0.455371	0.393751	0.867615	0.962459	1.366385	1.408637	1.411365
40	5	4	0.4	-0.65546	0.075875	0.154237	0.314818	0.256021	0.613619	0.661712	0.104753	1.023202	1.903068
40	5	4	1	-1.74142	0.040419	0.205335	0.58675	0.304459	0.87137	0.711703	1.265769	1.305914	2.476674
40	5	4	1.4	-2.74830	-0.02450	0.262325	0.789557	0.34358	1.007844	0.687799	1.365903	1.394579	3.056014
40	5	4	2	-5.71829	-0.16495	0.548686	1.430816	0.549752	1.403866	0.69394	1.635146	1.619565	4.314626
60	5	4	0	-0.43988	0.138819	0.240924	0.393455	0.370073	0.666585	0.74472	1.041638	1.180216	1.375842
60	5	4	0.4	-0.93835	0.019028	0.206161	0.44834	0.362931	0.711535	0.725662	1.108172	1.312498	1.833586
60	5	4	1	-1.95812	-0.21331	0.174957	0.584847	0.387929	0.817841	0.717791	1.239376	1.554813	2.607969
60	5	4	1.4	-2.97966	-0.43458	0.175189	0.739831	0.444943	0.940221	0.740535	1.362461	1.767798	3.253632
60	5	4	2	-5.87622	-1.03053	0.255183	1.226741	0.673048	1.281841	0.819747	1.667748	2.301024	4.809854
80	5	4	0	-0.47636	0.177929	0.196884	0.462868	0.354659	0.704614	0.686103	1.057744	1.124947	1.423119
80	5	4	0.4	-1.09100	0.043247	0.092037	0.552162	0.303643	0.794552	0.634224	1.187174	1.264152	1.990033
80	5	4	1	-2.30073	-0.21677	-0.07723	0.749118	0.245978	0.983344	0.566269	1.429206	1.520684	2.969546
80	5	4	1.4	-3.48203	-0.46680	-0.21345	0.957673	0.224066	1.176791	0.530322	1.653945	1.752655	3.808423
80	5	4	2	-6.6813	-1.13375	-0.52305	1.549792	0.226486	1.700633	0.469886	2.220035	2.344738	5.871423
100	5	4	0	-0.49730	0.20976	0.145384	0.522985	0.32623	0.749296	0.632915	1.086681	1.06971	1.455338
100	5	4	0.4	-1.21968	0.056354	-0.04687	0.643434	0.219313	0.896409	0.551746	1.302663	1.230235	2.13621
100	5	4	1	-2.61495	-0.23276	-0.37793	0.900096	0.055041	1.182563	0.418553	1.687242	1.511081	3.323
100	5	4	1.4	-3.97005	-0.51332	-0.67175	1.162923	-0.07036	1.464205	0.313921	2.039278	1.770095	4.379076
100	5	4	2	-7.55969	-1.26185	-1.39705	1.876529	-0.33614	2.209941	0.094758	2.934925	2.441432	6.986372

Table B.5.9 Shear Distribution factors under CHBDC outer lanes truck load for 4-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder											
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
20	6	4	0	-0.3512	0.18483	-0.0079	0.29342	0.00262	0.4830	0.3054	1.1526	0.9277	1.4097	1.0792	1.3103
20	6	4	0.4	-0.6752	0.23802	-0.0772	0.39539	-0.0874	0.6169	0.2150	1.3271	0.8389	1.5947	1.0259	1.9322
20	6	4	1	-1.5275	0.42292	-0.1981	0.67171	-0.3016	0.8738	-0.076	1.5940	0.5560	1.8211	0.7807	2.7709
20	6	4	1.4	-2.5846	0.60788	-0.2830	1.01679	-0.4206	1.1635	-0.219	1.8498	0.4107	2.0515	0.6789	3.3811
20	6	4	2	-7.0166	1.71978	0.00920	2.45112	-0.5588	2.0178	-0.517	2.4733	0.0980	2.4815	0.4248	4.4397
40	6	4	0	-0.4524	0.05165	0.23007	0.27273	0.27900	0.3973	0.5285	0.8217	0.9231	1.0839	1.2994	1.4157
40	6	4	0.4	-0.8308	-0.1762	0.29624	0.23143	0.37423	3.54E-5	0.6082	0.7553	0.9955	1.0693	1.5652	1.7646
40	6	4	1	-1.7269	-0.5222	0.38670	0.27763	0.49740	0.3843	0.6925	0.7653	1.0582	1.0901	1.8683	2.4465
40	6	4	1.4	-2.7326	-0.8829	0.53390	0.37312	0.67163	0.4458	0.7969	0.7883	1.1167	1.1022	2.1193	3.0172
40	6	4	2	-5.7362	-1.8871	1.08005	0.75830	1.26038	0.6801	1.1218	0.9024	1.3026	1.1650	2.6763	3.0349
60	6	4	0	-0.4513	-0.0139	0.26662	0.27912	0.36248	0.4031	0.5787	0.7377	0.9042	1.0395	1.3899	1.3580
60	6	4	0.4	-0.9514	-0.2534	0.25012	0.27713	0.40008	0.4069	0.6102	0.7376	0.9357	1.0839	1.6262	1.8164
60	6	4	1	-1.9771	-0.7329	0.25541	0.30549	0.51901	0.4419	0.7014	0.7562	1.0163	1.1707	2.0430	2.5856
60	6	4	1.4	-3.0174	-1.2061	0.29329	0.36130	0.66860	0.4951	0.8154	0.7945	1.1074	1.2447	2.4002	3.2290
60	6	4	2	-5.9677	-2.5117	0.47430	0.58896	1.16669	0.6994	1.1655	0.9057	1.3517	1.4262	3.2700	4.7537
80	6	4	0	-0.4876	0.0483	0.20091	0.35743	0.32053	0.4850	0.5376	0.7854	0.8221	1.0773	1.2901	1.4170
80	6	4	0.4	-1.1173	-0.2030	0.10201	0.39171	0.30196	0.5349	0.5237	0.8386	0.8162	1.1949	1.5316	2.0018
80	6	4	1	-2.3475	-0.6929	-0.0573	0.48330	0.30818	0.6551	0.5330	0.9569	0.8292	1.4099	1.9602	3.0009
80	6	4	1.4	-3.5700	-1.1734	-0.1860	0.59741	0.34792	0.7896	0.5638	1.0752	0.8529	1.6018	2.3399	3.8704
80	6	4	2	-6.8742	-2.4625	-0.4787	0.94607	0.51995	1.1811	0.6973	1.4026	0.9400	2.0783	3.2875	5.9840
100	6	4	0	-0.4994	0.08195	0.14383	0.41317	0.28672	0.5519	0.5027	0.8235	0.7628	1.1084	1.2238	1.4405
100	6	4	0.4	-1.2371	-0.1984	-0.0487	0.46813	0.20431	0.6442	0.4466	0.9398	0.7381	1.3190	1.4994	2.1418
100	6	4	1	-2.6621	-0.7373	-0.3829	0.60401	0.09174	0.8420	0.3695	1.1590	0.6992	1.6854	1.9790	3.3601
100	6	4	1.4	-4.0436	-1.2617	-0.6815	0.75263	0.01688	1.0468	0.3244	1.3722	0.6758	2.0130	2.4125	4.4391
100	6	4	2	-7.6445	-2.6360	-1.4125	1.16169	-0.1170	1.5924	0.2645	1.9278	0.6621	2.8278	3.4973	7.0507

APPENDIX B6

Shear Distribution Factors for All Modeled Bridges Under Inner CHBDC Truck Loading for Ultimate Limit State

Table B.6.1 Shear Distribution factors under CHBDC inner lanes truck load for 2-lane 2-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder			
				W1	W2	W3	W4
20	2	2	0	1.127966	0.576011	0.657317	-0.14820
20	2	2	0.4	0.840984	0.682671	0.428037	0.056
20	2	2	1	0.481722	0.859295	0.228294	0.299991
20	2	2	1.4	0.223621	1.002725	0.118584	0.44516
20	2	2	2	-0.28068	1.28291	-0.03798	0.66387
40	2	2	0	1.095922	0.617495	0.638219	-0.13140
40	2	2	0.4	0.71697	0.726839	0.519204	0.236778
40	2	2	1	0.060747	0.930525	0.359164	0.809813
40	2	2	1.4	-0.50925	1.131686	0.254676	1.263293
40	2	2	2	-1.92507	1.660246	0.068713	2.303438
60	2	2	0	1.059659	0.680565	0.597432	-0.11636
60	2	2	0.4	0.574554	0.748973	0.524513	0.358375
60	2	2	1	-0.24255	0.887818	0.434226	1.111795
60	2	2	1.4	-0.96650	1.021734	0.378289	1.741771
60	2	2	2	-2.78129	1.37911	0.296232	3.256698
80	2	2	0	1.381221	0.514059	0.432328	-0.10628
80	2	2	0.4	0.444998	0.747892	0.523889	0.495597
80	2	2	1	-0.58793	0.876853	0.43088	1.478046
80	2	2	1.4	-1.49698	0.998155	0.36956	2.31491
80	2	2	2	-3.73542	1.313775	0.26359	4.328012
100	2	2	0	1.061383	0.65615	0.598581	-0.09928
100	2	2	0.4	0.297857	0.741799	0.511547	0.657682
100	2	2	1	-0.99138	0.897673	0.385286	1.905838
100	2	2	1.4	-2.11213	1.038667	0.293877	2.969668
100	2	2	2	-4.88435	1.392956	0.107179	5.562381

Table B.6.2 Shear Distribution factors under CHBDC inner lanes truck load for 2-lane 3-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder					
				W1	W2	W3	W4	W5	W6
20	3	2	0	1.155648	0.80482	0.970083	0.245736	0.36538	-0.22203
20	3	2	0.4	0.815118	0.82469	0.837	0.257274	0.244487	0.032648
20	3	2	1	0.396411	0.885063	0.724806	0.330627	0.152586	0.313798
20	3	2	1.4	0.084147	0.95171	0.674134	0.394133	0.106369	0.473889
20	3	2	2	-0.54972	1.102	0.620734	0.518857	0.049625	0.699829
40	3	2	0	1.077646	0.976158	0.755655	0.460084	0.254911	-0.19411
40	3	2	0.4	0.681167	0.869518	0.737003	0.468397	0.349962	0.191732
40	3	2	1	-0.01487	0.701299	0.739135	0.513078	0.520746	0.775964
40	3	2	1.4	-0.63036	0.579193	0.779576	0.576499	0.67418	1.224312
40	3	2	2	-2.18235	0.312535	0.94892	0.778629	1.06829	2.224095
60	3	2	0	1.035396	1.027856	0.734183	0.488118	0.235789	-0.18936
60	3	2	0.4	0.540511	0.81838	0.706826	0.510255	0.437711	0.294432
60	3	2	1	-0.30126	0.48575	0.698755	0.571976	0.78242	1.045159
60	3	2	1.4	-1.05226	0.200153	0.717266	0.641866	1.090979	1.658847
60	3	2	2	-2.94630	-0.49454	0.819201	0.850763	1.878039	3.109572
80	3	2	0	1.060811	0.986501	0.738926	0.465452	0.276489	-0.19613
80	3	2	0.4	0.425895	0.746653	0.654632	0.548409	0.512068	0.429487
80	3	2	1	-0.65045	0.349981	0.540598	0.702167	0.915783	1.434994
80	3	2	1.4	-1.59844	0.003937	0.462904	0.846151	1.278771	2.279767
80	3	2	2	-3.93564	-0.83796	0.319714	1.220167	2.191046	4.289444
100	3	2	0	1.093122	0.927125	0.758533	0.42769	0.320284	-0.20152
100	3	2	0.4	0.286106	0.672847	0.58527	0.599953	0.570884	0.597023
100	3	2	1	-1.07454	0.247397	0.317863	0.898835	1.001688	1.901561
100	3	2	1.4	-2.25483	-0.12396	0.106461	1.162716	1.387295	3.002581
100	3	2	2	-5.17047	-1.04722	-0.37496	1.821733	2.365513	5.665086

Table B.6.3 Shear Distribution factors under CHBDC inner lanes truck load for 2-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	2	0	1.175478	1.096978	1.070705	0.532407	0.416903	0.232293	0.209854	-0.30822
20	4	2	0.4	0.795542	1.02149	1.00346	0.50873	0.313513	0.197458	0.188321	-0.01347
20	4	2	1	0.339419	0.956879	0.963187	0.535003	0.255847	0.200937	0.190942	0.296108
20	4	2	1.4	-0.00510	0.931145	0.96391	0.574811	0.236286	0.213859	0.19567	0.469584
20	4	2	2	-0.72257	0.902385	1.008801	0.677111	0.231301	0.244946	0.206326	0.70745
40	4	2	0	1.080409	1.320412	0.815932	0.676785	0.330715	0.450432	0.039056	-0.27299
40	4	2	0.4	0.606379	0.952434	0.767236	0.514609	0.32042	0.315249	0.208021	0.070769
40	4	2	1	-0.04020	0.600813	0.954802	0.50317	0.540591	0.341341	0.690222	0.715004
40	4	2	1.4	-0.67663	0.222761	1.079698	0.45884	0.692583	0.312367	1.008882	1.161094
40	4	2	2	-2.29447	-0.69261	1.456993	0.422398	1.119883	0.285738	1.74776	2.137528
60	4	2	0	1.051346	1.311959	0.834233	0.694066	0.371135	0.419198	0.032486	-0.27147
60	4	2	0.4	0.545664	0.935539	0.823406	0.594455	0.462305	0.416975	0.39962	0.230447
60	4	2	1	-0.33430	0.320398	0.857497	0.471024	0.645089	0.426706	0.981359	1.002626
60	4	2	1.4	-1.12178	-0.22117	0.912211	0.385925	0.830108	0.446136	1.476357	1.625095
60	4	2	2	-3.11247	-1.56715	1.100259	0.222256	1.345084	0.523965	2.68585	3.076769
80	4	2	0	1.08476	1.256911	0.836084	0.681644	0.41831	0.382849	0.062339	-0.27990
80	4	2	0.4	0.433291	0.808738	0.770532	0.599327	0.498777	0.446151	0.502893	0.361162
80	4	2	1	-0.66788	0.053082	0.686322	0.481138	0.660926	0.55906	1.231125	1.381333
80	4	2	1.4	-1.63496	-0.61358	0.632466	0.391582	0.825447	0.661315	1.863423	2.230115
80	4	2	2	-4.01623	-2.25239	0.545566	0.203023	1.276015	0.919403	3.406214	4.234724
100	4	2	0	1.130867	1.17442	0.864699	0.635411	0.485934	0.323935	0.111381	-0.29265
100	4	2	0.4	0.299191	0.681387	0.687468	0.609259	0.510633	0.499163	0.597987	0.52932
100	4	2	1	-0.80582	0.312475	0.66097	0.772895	0.609259	0.794845	1.17536	1.71516
100	4	2	1.4	-2.30167	-0.88457	0.192759	0.560762	0.65306	1.047417	2.118811	2.979753
100	4	2	2	-5.27095	-2.70577	-0.30795	0.525859	0.892087	1.665031	3.871791	5.665456

Table B.6.4 Shear Distribution factors under CHBDC inner lanes truck load for 3-lane 3-box bridges for ULS

Span	**No of Boxes**	**No of Lanes**	**L/R**	**Shear Distribution Factor / box girder**					
				W1	**W2**	**W3**	**W4**	**W5**	**W6**
20	3	3	0	1.332617	0.92541	1.47846	0.333312	0.644513	-0.23268
20	3	3	0.4	0.889879	1.059905	1.201718	0.447655	0.382522	0.057556
20	3	3	1	0.339681	1.286855	0.937501	0.635397	0.150196	0.378591
20	3	3	1.4	-0.07998	1.477344	0.781303	0.769645	0.017461	0.556449
20	3	3	2	-1.04595	2.032751	0.558321	1.070199	-0.18459	0.875555
40	3	3	0	1.393352	0.942557	1.231043	0.503512	0.642919	-0.21730
40	3	3	0.4	0.810983	0.933804	0.954307	0.528652	0.415743	0.15551
40	3	3	1	0.022742	1.274368	0.868457	0.90175	0.356583	0.941198
40	3	3	1.4	-0.76713	1.490553	0.72817	1.13636	0.251077	1.460977
40	3	3	2	-2.77035	2.102537	0.497197	1.731078	0.075115	2.574995
60	3	3	0	1.364931	1.010657	1.143832	0.562977	0.610838	-0.19499
60	3	3	0.4	0.75964	1.059431	0.986547	0.716803	0.557496	0.387748
60	3	3	1	-0.30532	1.15972	0.763066	1.00038	0.504806	1.285033
60	3	3	1.4	-1.24868	1.277235	0.611294	1.259912	0.48559	1.99107
60	3	3	2	-3.61876	1.609423	0.32517	1.923438	0.498608	3.591358
80	3	3	0	1.376494	1.007051	1.11425	0.559366	0.626358	-0.18527
80	3	3	0.4	0.630165	1.036938	0.894637	0.776893	0.593539	0.542054
80	3	3	1	-0.66174	1.105396	0.566613	1.165283	0.568812	1.689067
80	3	3	1.4	-1.79716	1.183074	0.320017	1.514087	0.570475	2.619878
80	3	3	2	-4.66209	1.392453	-0.21843	2.40551	0.630447	4.820549
100	3	3	0	1.396928	0.973014	1.112367	0.536462	0.649561	-0.17922
100	3	3	0.4	0.4804	1.002021	0.801627	0.846626	0.618502	0.719988
100	3	3	1	1.49929	1.067317	0.318273	1.386316	0.592298	2.162766
100	3	3	1,4	-2.46427	1.134291	-0.06733	1.864539	0.592173	3.360175
100	3	3	2	-5.76455	1.310934	-0.92015	3.011294	0.634319	6.107931

Table B.6.5 Shear Distribution factors under CHBDC inner lanes truck load for 3-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	3	0	1.32499	1.079603	1.446939	0.864146	0.939051	0.18485	0.441779	-0.30586
20	4	3	0.4	0.786627	1.101926	1.233466	0.935	0.762477	0.246189	0.299061	0.035353
20	4	3	1	0.192688	1.189978	1.06654	1.040745	0.601181	0.34651	0.17144	0.390965
20	4	3	1.4	-0.27246	1.281832	0.978819	1.137229	0.509707	0.416513	0.094029	0.585878
20	4	3	2	-1.41138	1.6347	0.928055	1.415274	0.392379	0.581777	-0.01403	0.92574
40	4	3	0	1.367106	1.235213	1.18917	0.894049	0.793118	0.472199	0.344564	-0.30065
40	4	3	0.4	0.842251	1.153413	1.152613	0.934443	0.746968	0.498578	0.411091	0.180457
40	4	3	1	-0.06392	1.025037	1.130231	1.034629	0.713236	0.569352	0.52453	0.872307
40	4	3	1.4	-0.88872	0.927462	1.149629	1.149682	0.714994	0.644172	0.62195	1.390341
40	4	3	2	-3.00514	0.752031	1.315415	1.51003	0.800205	0.854508	0.862342	2.479912
60	4	3	0	1.377992	1.290949	1.136567	0.872436	0.768949	0.506427	0.338156	-0.29372
60	4	3	0.4	0.754159	1.111685	1.074362	0.903016	0.734323	0.560758	0.504382	0.307071
60	4	3	1	-0.33502	0.818887	1.009504	0.989929	0.720708	0.672292	0.780346	1.21043
60	4	3	1.4	-1.31818	0.567631	0.989711	1.09733	0.749766	0.784609	1.021423	1.916957
60	4	3	2	-3.76770	0.003926	1.041041	1.422319	0.892794	1.074841	1.599059	3.474343
80	4	3	0	1.417885	1.262096	1.146233	0.831686	0.792814	0.477328	0.37167	-0.30191
80	4	3	0.4	0.641048	1.045218	1.004091	0.900407	0.721461	0.614244	0.578567	0.454471
80	4	3	1	-0.69913	0.682213	0.801235	1.048902	0.647214	0.85849	0.925106	1.631417
80	4	3	1.4	-1.87216	0.377742	0.663379	1.203037	0.619018	1.073902	1.222924	2.572313
80	4	3	2	-4.82515	-0.37740	0.386463	1.632883	0.622665	1.621041	1.968144	4.768388
100	4	3	0	1.4628	1.207721	1.175686	0.775782	0.833011	0.427234	0.413018	-0.30959
100	4	3	0.4	0.502483	0.969227	0.917737	0.910262	0.697263	0.681279	0.643471	0.631791
100	4	3	1	-1.13313	0.570491	0.519201	1.164507	0.511626	1.113752	1.030627	2.126993
100	4	3	1.4	-2.56190	0.225006	0.205678	1.404369	0.385789	1.488128	1.370132	3.355671
100	4	3	2	-6.09633	-0.62675	-0.50138	2.028953	0.147411	2.406432	2.218126	6.250504

Table B.6.6 Shear Distribution factors under CHBDC inner lanes truck load for 3-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	3	0	1.070571	1.113666	1.256285	1.046284	1.133819	0.816802	0.694233	0.280463	0.333025	-0.27611
20	5	3	0.4	0.579921	1.046284	1.123794	1.045147	1.000594	0.818776	0.553051	0.272898	0.27265	0.069273
20	5	3	1	-0.06347	1.018814	1.035433	1.114596	0.910993	0.873333	0.452928	0.325233	0.236416	0.475334
20	5	3	1.4	-0.60442	1.016996	1.000987	1.192003	0.860363	0.921172	0.387034	0.360794	0.205206	0.711543
20	5	3	2	-2.07572	1.175881	1.120694	1.504731	0.854545	1.080699	0.30941	0.463056	0.17447	1.130202
40	5	3	0	1.153932	1.301413	1.058942	1.021506	0.907398	0.865233	0.628504	0.545292	0.243043	-0.23210
40	5	3	0.4	0.614842	1.065737	1.076528	1.002655	0.945168	0.822068	0.638669	0.519746	0.456444	0.274438
40	5	3	1	-0.34703	0.66267	1.145206	1.006984	1.050483	0.78996	0.685711	0.503772	0.783299	1.017043
40	5	3	1.4	-1.25445	0.30835	1.253452	1.050816	1.182176	0.791359	0.747062	0.504425	1.041357	1.579388
40	5	3	2	-3.66190	-0.54531	1.663586	1.274901	1.609696	0.866432	0.945234	0.542161	1.617357	2.766426
60	5	3	0	1.119635	1.388954	1.050416	1.016486	0.855916	0.854992	0.606879	0.555549	0.225982	-0.17808
60	5	3	0.4	0.505698	0.998053	1.033179	0.94868	0.926821	0.785229	0.673217	0.569088	0.59981	0.410792
60	5	3	1	-0.58616	0.323009	1.048676	0.874513	1.099625	0.707853	0.818126	0.607912	1.191736	1.297496
60	5	3	1.4	-1.59563	-0.29030	1.094514	0.839441	1.296082	0.671531	0.972442	0.653207	1.685352	1.997247
60	5	3	2	-4.17643	-1.80100	1.316472	0.839441	1.873816	0.637438	1.3945	0.777127	2.832338	3.556612
80	5	3	0	1.176073	1.323393	1.074946	0.96677	0.894355	0.812071	0.6382	0.509912	0.281304	-0.18029
80	5	3	0.4	0.385542	0.89318	0.961976	0.932559	0.906291	0.803378	0.673257	0.620813	0.697927	0.585804
80	5	3	1	-0.99247	0.149336	0.80413	0.907982	0.974523	0.820248	0.764656	0.81334	1.375601	1.787535
80	5	3	1.4	-2.22775	-0.514	0.695954	0.913668	1.073912	0.857043	0.869449	0.981619	1.95008	2.765911
80	5	3	2	-5.35475	-2.17973	0.488765	0.985331	1.400789	0.994495	1.179644	1.399614	3.339028	5.053536
100	5	3	0	1.232974	1.251661	1.107795	0.906283	0.938318	0.747943	0.685834	0.454038	0.336894	-0.18027
100	5	3	0.4	0.237539	0.797789	0.855144	0.934022	0.850931	0.838834	0.660222	0.704521	0.779978	0.792867
100	5	3	1	-1.47432	0.016393	0.455999	1.010772	0.746441	1.016946	0.646332	1.12473	1.510527	2.354284
100	5	3	1.4	-2.99014	-0.68132	0.132783	1.097993	0.692758	1.186423	0.660306	1.484415	2.140466	3.653329
100	5	3	2	-6.76990	-2.42532	-0.61012	1.355483	0.636238	1.632327	0.74811	2.356369	3.679525	6.731947

Table B.6.7 Shear Distribution factors under CHBDC inner lanes truck load for 4-lane 4-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	4	0	1.39925	0.889327	1.493928	0.243869	0.607927	-0.139957	0.354515	-0.295938
20	4	4	0.4	0.947973	0.990619	1.216383	0.340518	0.382931	-0.026728	0.202552	-0.082111
20	4	4	1	0.469445	1.066461	0.955028	0.432575	0.198168	0.077374	0.072101	0.095944
20	4	4	1.4	0.242017	1.10854	0.84983	0.476267	0.1143	0.127024	0.012643	0.171711
20	4	4	2	-0.105348	1.142304	0.709042	0.514465	0.012863	0.157273	-0.047207	0.208032
40	4	4	0	1.495657	0.880942	1.190249	0.359929	0.596403	0.072316	0.383251	-0.411055
40	4	4	0.4	0.961781	0.851587	0.955001	0.393815	0.390413	0.116162	0.23468	-0.07109
40	4	4	1	0.462092	1.04668	0.917281	0.617638	0.33761	0.307877	0.203806	0.402882
40	4	4	1.4	0.048454	1.024186	0.764009	0.636924	0.209641	0.328686	0.114071	0.549955
40	4	4	2	-1.069376	1.285176	0.641512	0.94684	0.08202	0.552066	0.025449	1.072828
60	4	4	0	1.466405	0.941754	1.083439	0.420119	0.588484	0.143349	0.350618	-0.424261
60	4	4	0.4	1.013607	0.956303	0.971317	0.5162	0.482858	0.239868	0.321068	0.002204
60	4	4	1	.24704	0.988817	0.818562	0.693945	0.348762	0.404077	0.291879	0.610823
60	4	4	1.4	-0.421013	1.037238	0.716913	0.858632	0.262495	0.543012	0.28017	1.060836
60	4	4	2	-2.110304	1.18774	0.532241	1.292869	0.121237	0.883953	0.287948	2.031789
80	4	4	0	1.472843	0.92545	1.055918	0.42443	0.628825	0.143526	0.361931	-0.442904
80	4	4	0.4	0.931035	0.93072	0.899242	0.551289	0.49343	0.289178	0.347208	0.08242
80	4	4	1	0.009856	0.944154	0.668753	0.781434	0.312751	0.534332	0.339418	0.857395
80	4	4	1.4	-0.809532	0.957816	0.493287	0.995826	0.188736	0.748237	0.347438	1.465683
80	4	4	2	-2.793479	1.037214	0.147396	1.545224	-0.042492	1.249687	0.38811	2.786375
100	4	4	0	1.486121	0.881599	1.063004	0.407023	0.678838	0.116966	0.386429	-0.45922
100	4	4	0.4	0.830928	0.883201	0.83642	0.579834	0.49873	0.334385	0.376844	0.181476
100	4	4	1	-0.273772	0.893549	0.491814	0.886252	0.244188	0.694296	0.374785	1.151405
100	4	4	1.4	-1.232027	0.908473	0.223683	1.16277	0.059044	0.998781	0.38526	1.91689
100	4	4	2	-3.611315	0.950246	-0.377708	1.867745	-0.32569	1.73785	0.441626	3.675131

Table B.6.8 Shear Distribution factors under CHBDC inner lanes truck load for 4-lane 5-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	4	0	1.292998	0.9778	1.417959	0.750539	0.940634	0.006615	0.419388	-0.06360	0.274773	-0.32596
20	5	4	0.4	0.758208	1.014099	1.164808	0.827405	0.745421	0.090103	0.272474	0.018661	0.171513	-0.09209
20	5	4	1	0.257544	0.96654	0.880713	0.580569	0.156331	0.143835	0.094536	0.073725	0.117221	0.162489
20	5	4	1.4	0.016693	1.072918	0.876539	0.90528	0.487774	0.202001	0.076914	0.138174	0.025614	0.208489
20	5	4	2	-0.45964	1.126304	0.773972	0.958902	0.370049	0.247292	-0.009	0.174709	-0.03434	0.286513
40	5	4	0	1.382855	1.408637	1.366385	0.962459	0.867615	0.393751	0.455371	0.265639	0.20931	-0.52078
40	5	4	0.4	0.808793	0.927198	0.92801	0.725102	0.580102	0.284361	0.25561	0.186125	0.160896	-0.06184
40	5	4	1	0.351258	0.950291	0.987036	0.851983	0.6171	0.389551	0.272353	0.290031	0.271582	0.393759
40	5	4	1.4	-0.20798	0.873248	0.972723	0.924458	0.610655	0.44514	0.245835	0.334774	0.315346	0.717184
40	5	4	2	-1.64280	0.739718	1.033779	1.165938	0.659377	0.605072	0.222865	0.446759	0.413567	1.343674
60	5	4	0	1.375842	1.180216	1.041638	0.74472	0.666585	0.370073	0.393455	0.240924	0.138819	-0.43988
60	5	4	0.4	0.926052	1.054481	0.983928	0.770778	0.63539	0.390207	0.356422	0.283744	0.246951	-0.01335
60	5	4	1	0.154897	0.838224	0.907119	0.83462	0.617948	0.447345	0.326254	0.364522	0.414451	0.592263
60	5	4	1.4	-0.51499	0.67541	0.879984	0.914701	0.6322	0.509198	0.318971	0.43239	0.544537	1.031654
60	5	4	2	-2.23933	0.281722	0.870621	1.155815	0.727361	0.692851	0.348083	0.60755	0.855707	1.980243
80	5	4	0	1.423119	1.124947	1.057744	0.686103	0.704614	0.354659	0.462868	0.196884	0.177929	-0.47636
80	5	4	0.4	0.865408	0.990219	0.939306	0.745537	0.633615	0.417362	0.394949	0.303435	0.30008	0.063268
80	5	4	1	-0.08137	0.764549	0.766805	0.865551	0.553165	0.54246	0.316647	0.481629	0.490795	0.855562
80	5	4	1.4	-0.91789	0.568704	0.642101	0.988572	0.514783	0.664371	0.273979	0.633293	0.649584	1.467766
80	5	4	2	-2.98884	0.114242	0.404186	1.337979	0.485711	0.984275	0.215541	0.991185	1.022657	2.817381
100	5	4	0	1.455338	1.06971	1.086681	0.632915	0.749296	0.32623	0.522985	0.145384	0.20976	-0.49730
100	5	4	0.4	0.778471	0.919895	0.88875	0.728543	0.624461	0.443882	0.420365	0.333317	0.349271	0.16315
100	5	4	1	-0.36157	0.671179	0.585911	0.909376	0.45669	0.657131	0.285071	0.639016	0.569512	1.160221
100	5	4	1.4	-1.34861	0.458819	0.351909	1.082517	0.345139	0.849882	0.194934	0.892119	0.753078	1.942537
100	5	4	2	-3.81083	-0.07203	-0.17640	1.543466	0.135653	1.343851	0.026658	1.500117	1.204111	3.740917

Table B.6.9 Shear Distribution factors under CHBDC inner lanes truck load for 4-lane 6-box bridges for ULS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder											
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
20	6	4	0	1.3492	1.0792	1.4097	0.9277	1.1526	0.3054	0.4830	0.0026	0.2934	-0.0079	0.1848	-0.3512
20	6	4	0.4	0.8679	1.0546	1.2328	0.9337	0.9639	0.2959	0.3188	0.0453	0.1881	0.03464	0.1233	-0.1177
20	6	4	1	0.3224	1.0051	1.0484	0.9353	0.8038	0.3121	0.1973	0.0888	0.1005	0.07930	0.0680	0.08970
20	6	4	1.4	0.0769	0.9751	0.9728	0.9355	0.7275	0.3302	0.1383	0.1179	0.0588	0.10327	0.0404	0.17693
20	6	4	2	-0.320	0.9074	0.8777	0.9281	0.6200	0.3250	0.0536	0.1230	0.0040	0.10544	0.0027	0.22113
40	6	4	0	1.4157	1.2994	1.0839	0.9231	0.8217	0.5285	0.3973	0.2790	0.2727	0.23007	0.0516	-0.4524
40	6	4	0.4	0.9742	1.2023	1.0399	0.9374	0.7693	0.5568	0.3620	0.3148	0.2377	0.27011	0.1312	-0.0933
40	6	4	1	0.3459	0.9162	1.0334	0.9042	0.7986	0.5368	0.3886	0.3003	0.2612	0.27036	0.3291	0.36826
40	6	4	1.4	-0.211	0.6816	1.0654	0.9122	0.8579	0.5433	0.4255	0.2998	0.2840	0.27157	0.4668	0.68960
40	6	4	2	-1.681	0.1318	1.249	1.0237	1.0827	0.6132	0.5517	0.3318	0.3549	0.28743	0.7414	1.01714
60	6	4	0	1.3580	1.3899	1.0395	0.9042	0.7377	0.5787	0.4031	0.3624	0.2791	0.26662	-0.013	-0.4513
60	6	4	0.4	0.9041	1.1566	0.9961	0.8786	0.7452	0.5614	0.4118	0.3453	0.2934	0.29366	0.1959	-0.0243
60	6	4	1	0.1253	0.7633	0.9474	0.8588	0.7923	0.5611	0.4543	0.3417	0.3347	0.34456	0.5060	0.58394
60	6	4	1.4	-0.575	0.4273	0.9361	0.8616	0.8587	0.5759	0.5109	0.3531	0.3822	0.38924	0.7489	1.03947
60	6	4	2	-2.375	-0.401	0.9929	0.9563	1.1186	0.6740	0.6986	0.4075	0.5173	0.49488	1.2794	1.99339
80	6	4	0	1.4170	1.2901	1.0773	0.8221	0.7854	0.5376	0.4850	0.3205	0.3574	0.20091	0.0483	-0.4876
80	6	4	0.4	0.8411	1.0528	0.9662	0.8344	0.7457	0.5645	0.4528	0.3543	0.3383	0.30078	0.2715	0.06625
80	6	4	1	-0.143	0.6455	0.7999	0.8741	0.7139	0.6340	0.4327	0.4311	0.3296	0.46397	0.6107	0.88609
80	6	4	1.4	-1.029	0.2790	0.6736	0.9266	0.7158	0.7136	0.4405	0.5100	0.3383	0.60154	0.8881	1.53197
80	6	4	2	-3.213	-0.588	0.4464	1.1248	0.7984	0.9495	0.5090	0.7155	0.3841	0.91161	1.5095	2.94034
100	6	4	0	1.4405	1.2238	1.1084	0.7628	0.8235	0.5027	0.5519	0.2867	0.4131	0.14383	0.0819	-0.4994
100	6	4	0.4	0.7430	0.9572	0.9123	0.8011	0.7263	0.5728	0.4775	0.3787	0.3696	0.33028	0.3369	0.17827
100	6	4	1	-0.437	0.5051	0.6063	0.8862	0.6003	0.7135	0.3887	0.5473	0.3200	0.62887	0.7315	1.20875
100	6	4	1.4	-1.468	0.1094	0.3647	0.9789	0.5231	0.8510	0.3391	0.6986	0.2938	0.87295	1.0537	2.02545
100	6	4	2	-4.050	-0.886	-0.187	1.2467	0.4005	1.2239	0.2746	1.0833	0.2668	1.44973	1.8209	3.90484

APPENDIX C1

Shear Forces for All Modeled Bridges Under Full CHBDC Truck Loading for Fatigue Limit State

Table C.1.1 Shear forces under CHBDC full truck load for 3-lane 3-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons					
				W1	W2	W3	W4	W5	W6
20	3	3	0	10698	54919	104000	104000	54919	10698
20	3	3	0.4	-20158	66577	83679	133660	42803	38059
20	3	3	1	-69466	95379	64102	154710	20066	73154
20	3	3	1.4	-116550	134970	59748	162410	4556	98091
20	3	3	2	-264650	232940	31975	212640	-24953	149550
40	3	3	0	30330	81261	127470	127470	81261	30330
40	3	3	0.4	-24724	87918	107650	153930	73072	79993
40	3	3	1	-111850	112790	89708	180710	58262	148480
40	3	3	1.4	-184180	142940	84713	193150	45769	195950
40	3	3	2	-393900	210770	65134	259450	30190	312900
60	3	3	0	36674	89613	135870	135870	89613	36674
60	3	3	0.4	-25163	88570	117910	160330	89482	93940
60	3	3	1	-119540	99077	99603	186150	86061	173990
60	3	3	1.4	-194640	115930	92205	199380	81827	230910
60	3	3	2	-411230	146990	66994	260710	83801	379110
80	3	3	0	43843	92981	136790	136790	92981	43843
80	3	3	0.4	-23565	89797	116380	163010	94937	106720
80	3	3	1	-112290	100620	96517	183930	90814	187920
80	3	3	1.4	-200680	106480	77681	211360	91585	261400
80	3	3	2	-418530	122770	37175	279660	96621	430850
100	3	3	0	49730	93679	135930	135930	93679	49730
100	3	3	0.4	-24257	90279	111980	165640	95243	119150
100	3	3	1	-132490	94200	79367	202980	94840	219420
100	3	3	1.4	-212060	103100	57634	226540	93193	291030
100	3	3	2	-443370	114310	-2111	307510	96921	486010

Table C.1.2 Shear forces under CHBDC full truck load for 3-lane 4-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	3	0	4631	30241	39725	95020	95020	39725	30241	4631
20	4	3	0.4	-16128	36691	36003	101860	90914	45522	25615	24131
20	4	3	1	-56197	47806	29334	112220	81362	54291	16244	52868
20	4	3	1.4	-101480	63950	26492	127110	75968	64828	10132	76229
20	4	3	2	-233770	113190	27323	163910	65688	85758	-1438	116830
40	4	3	0	18249	44308	66365	109780	109700	67446	44998	17287
40	4	3	0.4	-18064	39420	64931	113270	107570	70026	50231	50429
40	4	3	1	-86185	31855	65646	122110	106440	76148	59434	102530
40	4	3	1.4	151930	26119	69417	132550	107710	82685	67629	144040
40	4	3	2	-322930	14571	86505	165010	118360	102160	88523	232040
60	4	3	0	23047	53786	76486	108830	108830	76486	53786	23047
60	4	3	0.4	-17345	42368	73078	111280	107490	80717	65312	61443
60	4	3	1	-90782	23064	69908	117840	107810	89012	85185	122480
60	4	3	1.4	-158020	6643	69695	125670	110470	97037	102530	171420
60	4	3	2	-330880	-33107	74211	148960	121400	118010	144630	282780
80	4	3	0	27195	58481	81373	106560	106560	81373	58481	27195
80	4	3	0.4	-16967	45966	73546	110670	103290	89763	71024	69966
80	4	3	1	-94939	24607	62162	119500	99815	104620	92441	139230
80	4	3	1.4	-164600	6090	54066	128690	98613	117830	110980	196010
80	4	3	2	-337320	-38391	38197	154050	99341	150360	155650	155650
100	4	3	0	31364	61495	83908	102570	102570	83908	61495	31364
100	4	3	0.4	-17468	48858	70782	109220	96163	97220	74016	79225
100	4	3	1	-99149	28353	51516	122560	88512	119850	94886	154110
100	4	3	1.4	-176600	8756	33743	134680	81183	140130	114110	222430
100	4	3	2	-357590	-35985	-2628	166610	69575	187800	158820	372380

Table C.1.3 Shear forces under CHBDC full truck load for 3-lane 5-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	3	0	136	19296	19112	44602	75728	80262	53853	20421	3178	-1346
20	5	3	0.4	-17504	20377	17955	48392	74718	83199	51905	25321	20243	19997
20	5	3	1	-51763	21954	16331	54310	71412	86896	46349	28879	18064	45507
20	5	3	1.4	-89618	27208	21308	71671	69102	86902	42125	33263	16967	64346
20	5	3	2	-210790	44579	35695	101020	71588	101790	37066	42527	14898	99251
40	5	3	0	10623	29484	39025	61009	86293	90382	69750	42917	33088	15554
40	5	3	0.4	-19239	16829	40564	60594	89007	88462	70805	42100	45202	43478
40	5	3	1	-76363	-5903	46350	62251	96363	86994	74050	41631	64913	87639
40	5	3	1.4	-129210	-24262	57828	71806	104070	82092	74971	41379	79506	119900
40	5	3	2	-277210	-75621	85022	87657	132750	88891	89050	44935	115480	192970
60	5	3	0	17605	39914	48415	69626	91886	95635	77725	53214	45261	23218
60	5	3	0.4	-16087	15670	43516	62435	91994	88658	77524	50354	60436	50523
60	5	3	1	-74332	-20570	44724	58791	101780	84855	85868	53117	92992	97928
60	5	3	1.4	-125450	-50172	51733	62037	111780	78221	90942	54966	118030	133210
60	5	3	2	-264970	-132190	64135	62312	143690	76429	114340	62061	181380	218500
80	5	3	0	17626	38824	46424	65235	92262	95465	72309	52529	43701	22847
80	5	3	0.4	-18047	19051	41077	63663	92957	95326	74339	58284	63126	57472
80	5	3	1	-81333	-15820	33569	62355	96257	96136	79015	68019	68019	113630
80	5	3	1.4	-135050	-43631	33339	66940	99088	92890	81288	75088	120820	156770
80	5	3	2	-276220	-119560	23810	70181	113960	98986	95517	94584	184880	261820
100	5	3	0	20376	41275	47456	64743	92424	95368	70629	54485	46002	25922
100	5	3	0.4	-19787	22370	36800	65493	88849	99034	69945	65224	64635	65452
100	5	3	1	-89704	-10584	19971	68108	84566	106230	69909	83376	95962	130320
100	5	3	1.4	-147950	-36542	12079	75057	80307	108110	68566	97080	120570	181050
100	5	3	2	-238160	-85563	-14427	67810	62446	100640	57965	106040	146420	243820

Table C.1.4 Shear forces under CHBDC full truck load for 4-lane 4-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	4	0	-13996	31038	1258	59336	105630	98961	43359	13656
20	4	4	0.4	-32787	41846	-6659	70981	98508	109540	33406	35134
20	4	4	1	-76824	67422	-23336	95560	80594	131910	13164	73209
20	4	4	1.4	-132540	101980	-39214	124330	64664	153660	-3715	103290
20	4	4	2	-325650	226100	-67565	197840	31035	197250	-35271	155680
40	4	4	0	-13508	40488	25003	80579	118070	121110	64708	41672
40	4	4	0.4	-47850	47928	17239	91047	110140	130470	58791	73912
40	4	4	1	-115110	63771	5149	110740	96862	148270	48444	125750
40	4	4	1.4	-181950	81209	-2520	132810	89250	164480	41066	165320
40	4	4	2	-365730	132290	-14356	189040	73022	203980	27869	250010
60	4	4	0	-10567	40642	33761	84408	124140	128580	74298	49042
60	4	4	0.4	-48720	42833	25710	93242	116310	137320	73037	85370
60	4	4	1	-121180	48462	13635	111080	104400	153190	71373	144460
60	4	4	1.4	-183240	53257	5473	127360	99893	170210	72477	185740
60	4	4	2	-359270	72171	-9939	174830	85506	205670	73678	289380
80	4	4	0	-7652	42559	37247	85597	123750	131030	78022	56664
80	4	4	0.4	-48545	42982	26308	95550	114750	142360	78058	95859
80	4	4	1	-123680	44750	9143	115110	101040	162620	78663	159970
80	4	4	1.4	-193070	47122	-4335	134110	90880	180830	79723	212700
80	4	4	2	-369640	54609	-33638	184040	70623	225880	83919	332970
100	4	4	0	-4997	44739	38084	85504	120850	132850	78808	62842
100	4	4	0.4	-49284	44583	23407	97261	109710	147590	79120	105690
100	4	4	1	-128940	44951	-245.2	119790	92546	173670	80463	176140
100	4	4	1.4	-200140	45700	-19360	140750	79411	196510	82178	233990
100	4	4	2	-378270	48631	-63232	194300	50951	252260	87129	368020

Table C.1.5 Shear forces under CHBDC full truck load for 4-lane 5-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	4	0	-14088	20376	2659	31142	26380	93997	87891	50472	30835	9572
20	5	4	0.4	-31060	25747	-2920	37092	13745	98375	92834	60247	25291	30984
20	5	4	1	-71906	44005	-12380	57055	9398	118170	70370	72091	11069	63926
20	5	4	1.4	-118430	60871	-19042	75431	1813	132670	60783	85788	1762	90895
20	5	4	2	-301910	141830	-24223	139800	-16943	169990	39017	112520	-18049	137510
40	5	4	0	-12097	20702	24572	38510	53476	99499	99269	72205	48408	33581
40	5	4	0.4	-39418	17134	22816	41730	51781	101410	96492	74538	51834	59870
40	5	4	1	-93757	11036	22073	49899	51037	107870	94624	81054	58084	101890
40	5	4	1.4	-148430	6576	24521	60652	53888	116120	93915	86201	62437	133610
40	5	4	2	-302780	-2170	38234	92418	63404	136230	94470	100530	73955	201410
60	5	4	0	-10016	21402	28013	43510	61975	101090	101480	79593	57634	39623
60	5	4	0.4	-40531	13252	25057	45995	60778	102930	99764	83251	65950	68633
60	5	4	1	-99059	-1338	21971	21971	60759	107360	97907	89689	79901	115730
60	5	4	1.4	-149480	-13745	20726	58670	62697	113870	100980	97418	91333	148510
60	5	4	2	-295070	-45131	23562	81801	72743	129500	103390	111940	118610	230310
80	5	4	0	-8777	24243	27311	47951	65467	100560	99003	85496	61304	44669
80	5	4	0.4	-42305	16004	20715	51867	61898	104560	95730	92497	69416	76919
80	5	4	1	-104280	1351	10807	60593	57551	112840	91219	104680	83043	129750
80	5	4	1.4	-161940	-11762	3379	69915	55450	121280	88418	115350	94611	173130
80	5	4	2	-309820	-44054	-11988	96207	54209	144350	84369	141290	122120	271770
100	5	4	0	-52487	6527	1597	35438	15876	56299	53475	120550	142330	179070
100	5	4	0.4	-43541	18101	16208	56407	60357	104350	89981	99779	71424	84994
100	5	4	1	-109260	3066	-464.5	67203	51467	116710	82923	117920	85440	143300
100	5	4	1.4	-168260	-10245	-13965	77817	45271	128410	77945	133460	97351	191130
100	5	4	2	-316630	-42831	-44866	106250	33167	158420	68019	170650	125580	301760

Table C.1.6 Shear forces under CHBDC full truck load for 4-lane 6-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons											
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
20	6	4	0	-17787	6831	-2524	11253	-3383	17982	-948.9	32434	31469	94219	75838	93854
20	6	4	0.4	-27705	15502	2053	23666	5251	42922	64008	90761	61174	29579	20176	23286
20	6	4	1	-64031	23793	-1940	35452	-1623	53474	56634	100580	3074	38066	13000	55281
20	6	4	1.4	-104940	30956	-4449	48481	-5160	63688	51890	109690	46841	46807	8694	79991
20	6	4	2	-276890	73997	7968	102970	-9679	94068	40115	130770	33431	62278	-1685	122090
40	6	4	0	-11120	13096	21348	24639	29354	54956	81028	88601	72019	44494	35349	24361
40	6	4	0.4	-33323	545.3	23629	21316	30644	49083	78082	89836	77213	45500	47127	48513
40	6	4	1	-77786	-17519	26894	22480	35609	49474	81878	90267	80465	46454	62249	83242
40	6	4	1.4	-124040	-34851	32885	26219	43306	52582	87610	91753	83221	46841	73704	110070
40	6	4	2	-257070	-80466	55937	42027	68349	61692	101660	97003	91809	49348	98846	166150
60	6	4	0	-7748	13244	24456	27375	35438	58212	82978	89993	75317	51234	44066	29740
60	6	4	0.4	-34969	-890.9	22090	25234	33920	54412	82353	93431	80226	54392	58522	56332
60	6	4	1	-280800	-83339	75752	98716	156840	211020	285990	303670	294980	225250	293980	321990
60	6	4	1.4	-129370	-46449	21851	26927	44474	56691	90236	94779	87566	61389	96235	125280
60	6	4	2	-253430	-102650	28216	35011	63991	63479	104360	99672	98522	68927	133570	191670
80	6	4	0	-7022	16131	22471	31290	36707	59370	85187	93124	73928	56567	46592	32878
80	6	. 4	0.4	-37454	2757	16115	30643	31541	58334	83339	98980	76241	63502	60207	63073
80	6	4	1	-120820	-27771	10647	43588	45338	193570	437780	525090	338930	192200	117030	123170
80	6	4	1.4	-140410	-39813	2152	37304	31479	66846	83044	106960	76384	80982	96215	146550
80	6	4	2	-269190	-91331	-10295	49859	37157	81031	87207	118730	78986	99736	134160	232160
100	6	4	0	-5174	18212	21395	33810	37247	59534	83586	92649	71780	60166	48928	36549
100	6	4	0.4	-38139	4547	11401	34016	29152	60821	80791	100520	72258	70317	62730	69633
100	6	4	1	-94234	-17863	-2802	38155	23709	67507	76832	108340	70314	85321	82961	119990
100	6	4	1.4	-144830	-38006	-14463	42774	20321	20321	74622	115720	69306	97852	99824	161330
100	6	4	2	-272760	-88203 .	-41367	56347	14778	92899	71516	134610	68034	127110	139280	257010

APPENDIX C2

Shear Forces for All Modeled Bridges Under Outer Lanes CHBDC Truck Loading for Fatigue Limit State

Table C.2.1 Shear forces under CHBDC outer lanes truck load for 2-lane 2-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons			
				W1	W2	W3	W4
20	2	2	0	-24430	96107	91870	175690
20	2	2	0.4	-66920	129190	71051	216960
20	2	2	1	-158940	198340	33631	288650
20	2	2	1.4	-256440	272720	4058	352130
20	2	2	2	-523530	468390	-59257	493950
40	2	2	0	-32041	131750	138830	239590
40	2	2	0.4	-106850	156950	119450	308790
40	2	2	1	-244110	207110	93412	427880
40	2	2	1.4	-369300	256580	77015	525970
40	2	2	2	-686890	380670	42106	761120
60	2	2	0	-32307	132980	170030	253600
60	2	2	0.4	-118690	147440	159570	336920
60	2	2	1	-240810	155400	136700	427590
60	2	2	1.4	525970	200770	140790	591110
60	2	2	2	-591920	217030	102410	698960
80	2	2	0	12986	114160	159230	260850
80	2	2	0.4	-127340	147400	170910	356470
80	2	2	1	-295110	169860	158000	515270
80	2	2	1.4	-387910	167320	139690	578130
80	2	2	2	-807630	243510	134210	979720
100	2	2	0	-30689	138640	179610	271120
100	2	2	0.4	-132320	150910	171480	372290
100	2	2	1	-321260	174060	152540	553400
100	2	2	1.4	-480890	194530	140830	705160
100	2	2	2	-869260	244600	116550	1068900

Table C.2.2 Shear forces under CHBDC outer lanes truck load for 2-lane 3-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons					
				W1	W2	W3	W4	W5	W6
20	3	2	0	-15922	36388	33398	106430	86795	92151
20	3	2	0.4	-49484	47610	28814	118900	82944	123620
20	3	2	1	-127930	70546	12908	141020	83431	181760
20	3	2	1.4	-209720	99503	10101	166800	78989	226860
20	3	2	2	-449380	186500	14558	236930	73226	331200
40	3	2	0	-17280	39856	71948	118720	137210	127680
40	3	2	0.4	-69922	27768	72277	122040	150730	175360
40	3	2	1	-174440	3332	71862	132250	186280	261740
40	3	2	1.4	-266070	-12300	81996	145560	212570	328020
40	3	2	2	-501310	-50395	112070	180480	276310	478910
60	3	2	0	-17901	41304	82087	125720	156840	136260
60	3	2	0.4	-76994	17331	80635	129900	181910	192350
60	3	2	1	-191110	-30114	75942	138810	236490	295510
60	3	2	1.4	-279340	-64100	79659	149940	149940	367880
60	3	2	2	-516230	-149710	95791	177700	377490	547760
80	3	2	0	-18452	47709	83039	129320	157910	147690
80	3	2	0.4	-84727	22878	75111	138760	183200	212130
80	3	2	1	-208610	-25574	57648	155630	237050	331580
80	3	2	1.4	-312550	-63568	50140	172170	277960	423960
80	3	2	2	-567970	-155840	35794	214160	379290	643490
100	3	2	0	-7599	60893	83698	128670	146230	146790
100	3	2	0.4	-90070	31132	66333	148690	177580	228610
100	3	2	1	-230740	-15826	33493	176770	227270	367520
100	3	2	1.4	-344300	-52229	13727	202780	265630	473610
100	3	2	2	-617630	-139760	-30550	265440	359090	723430

Table C.2.3 Shear forces under CHBDC outer lanes truck load for 2-lane 4-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	2	0	-19023	16155	17612	34310	50344	84455	83135	72249
20	4	2	0.4	-44645	16623	19773	45017	55810	80781	82462	94483
20	4	2	1	-107040	17373	24611	57904	56380	87693	88016	136760
20	4	2	1.4	-174820	20056	33113	73291	59611	95720	93542	171990
20	4	2	2	-375250	31807	65926	118630	75359	122230	103330	237450
40	4	2	0	-22006	7519	45405	42243	77223	94351	134600	98795
40	4	2	0.4	-59561	-15085	52668	42873	88515	87948	152490	131820
40	4	2	1	-135260	-60630	66923	36448	106870	84095	194610	190760
40	4	2	1.4	-209600	-103320	84302	34734	127960	83092	232110	240160
40	4	2	2	-398000	-208420	131290	33490	181040	83224	320380	352420
60	4	2	0	-22635	7790	44646	49859	85183	105950	147990	105520
60	4	2	0.4	-66003	-21152	48180	47531	95632	102490	172360	146060
60	4	2	1	-151460	-80692	53461	37173	115460	104250	228970	218180
60	4	2	1.4	-221560	-129590	58980	30243	134030	109150	276520	273220
60	4	2	2	-409200	-256070	79620	17822	186480	117350	390260	406510
80	4	2	0	-23567	10971	42527	55408	88502	110090	148220	115070
80	4	2	0.4	-70411	-20514	39840	52936	95990	113540	176560	159370
80	4	2	1	-160500	-83226	33596	43820	110720	123240	237540	242370
80	4	2	1.4	-240640	-139050	29588	36815	125400	132040	291060	312610
80	4	2	2	-438130	-275880	22885	21772	164220	153920	420660	478920
100	4	2	0	-24374	15840	37463	61821	86725	114430	143150	123630
100	4	2	0.4	-77506	-15219	27852	62302	88897	124950	172000	174800
100	4	2	1	-145590	-37501	17745	68196	90560	139080	191020	234850
100	4	2	1.4	-264490	-130400	-7619	58899	101200	165280	284620	351430
100	4	2	2	-475870	-261730	-43317	56377	119530	209850	411490	543150

Table C.2.4 Shear forces under CHBDC outer lanes truck load for 3-lane 3-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons					
				W1	W2	W3	W4	W5	W6
20	3	3	0	-31198	44242	-14400	99489	76532	164570
20	3	3	0.4	-64141	67189	-30219	125290	59887	202200
20	3	3	1	-142600	120400	-61799	173160	28125	266470
20	3	3	1.4	-234180	183830	-88884	218490	2240	314810
20	3	3	2	-511800	-511800	-140960	327240	-46756	417370
40	3	3	0	-51603	56994	13048	122140	114490	223060
40	3	3	0.4	-100630	70428	563.6	138360	105330	269710
40	3	3	1	-200440	101500	-17731	173150	89855	342210
40	3	3	1.4	-296830	132510	-31225	204900	78434	405570
40	3	3	2	-541640	212830	-54042	282480	63562	539860
60	3	3	0	-54812	52162	26307	125410	143810	231420
60	3	3	0.4	-109750	58151	14053	140690	139990	282130
60	3	3	1	-206770	69203	-4193	167890	138930	366200
60	3	3	1.4	-296470	81294	-16025	197300	140280	429650
60	3	3	2	-528350	115730	-41728	263070	143280	586510
80	3	3	0	-58630	53467	30653	131120	154010	236600
80	3	3	0.4	-117450	56576	14935	149300	152110	292000
80	3	3	1	-225440	63809	-10060	183310	150480	385960
80	3	3	1.4	-307300	67689	-27650	208710	155150	457360
80	3	3	2	-540480	86290	-69695	282840	159680	636460
100	3	3	0	-61233	57013	30222	136480	154770	241430
100	3	3	0.4	-125300	59374	9730	158810	153090	302510
100	3	3	1	-239670	64397	-23526	199490	152100	406330
100	3	3	1.4	-319930	65460	-46041	227590	157650	480590
100	3	3	2	-517140	73542	-94192	299740	165280	644440

Table C.2.5 Shear forces under CHBDC outer lanes truck load for 3-lane 4-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	3	0	-25820	21386	688.4	32879	13307	105130	90334	101330
20	4	3	0.4	-51634	29755	-4802	44269	7345	117320	85773	130810
20	4	3	1	-116810	52008	-14674	70690	-5127	140010	75178	182450
20	4	3	1.4	-194770	80658	-20727	99318	-14677	159740	65701	221000
20	4	3	2	-441840	176560	-19181	178030	-28872	206780	49465	299780
40	4	3	0	-37926	17307	24361	37036	44360	113760	136220	143000
40	4	3	0.4	-76292	12426	23590	41720	42679	117840	143390	178310
40	4	3	1	-153520	4857	26212	54233	43204	126520	153980	233970
40	4	3	1.4	-236180	-1996	31462	67250	41743	126050	159620	302000
40	4	3	2	-430690	-13900	52848	106360	57490	158980	189350	381720
60	4	3	0	-42397	13900	28117	45029	58011	117750	151430	152460
60	4	3	0.4	-84660	2438	25391	48369	57092	122520	163330	191560
60	4	3	1	-160870	-17446	23080	55621	57715	132220	186140	254510
60	4	3	1.4	-227810	-34220	23276	63767	61938	143490	205480	300850
60	4	3	2	-415540	-76536	29918	90419	74476	165710	249890	419340
80	4	3	0	-44513	15608	24629	52958	62504	121810	152440	161780
80	4	3	0.4	-90414	2959	17272	58012	59323	130380	164710	205160
80	4	3	1	-172150	-19337	6605	68384	56187	146180	187170	276850
80	4	3	1.4	-239490	-37895	-981.7	77254	55007	159800	207450	332420
80	4	3	2	-423900	-84904	-16495	105640	55979	194130	254040	469910
100	4	3	0	-46530	19053	19673	61117	62853	125150	147550	169810
100	4	3	0.4	-93921	6206	7081	68129	57817	139580	161120	216300
100	4	3	1	-186670	-16264	-13625	83820	47702	162940	181500	299480
100	4	3	1.4	-249650	-33842	-27892	93523	42831	181660	201500	356840
100	4	3	2	-404850	-73848	-58454	121570	35971	225260	241990	483450

Table C.2.6 Shear forces under CHBDC outer lanes truck load for 3-lane 5-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	3	0	-22827	9728	5034	17588	6262	29473	38364	94202	84170	77243
20	5	3	0.4	-44893	11308	3565	23572	4479	36098	36576	100820	86013	103890
20	5	3	1	-100500	16201	2468	38453	1152	48812	31267	111090	85846	148910
20	5	3	1.4	-169930	24711	5707	57733	460.2	62300	27522	120040	84649	182960
20	5	3	2	-413490	62009	35120	124120	9421	100920	23386	141090	81934	248070
40	5	3	0	-35961	-209.9	25861	20158	30776	33971	64038	97450	130280	111760
40	5	3	0.4	-67639	-13332	28243	20334	34186	32536	65877	97318	144360	141740
40	5	3	1	-132800	-38351	36641	23880	44015	32677	71176	97227	165840	189000
40	5	3	1.4	-196370	-61488	46957	29144	54897	33555	76398	98730	185250	227950
40	5	3	2	-373950	-122120	81241	49267	89500	41660	93467	102810	227260	312470
60	5	3	0	-35374	-6979	25857	20629	38008	40161	74948	104390	147940	114730
60	5	3	0.4	-69098	-28081	25996	18017	43177	37310	79323	105400	167870	145210
60	5	3	1	-129610	-65791	27975	14679	54183	33473	88693	110040	203610	193530
60	5	3	1.4	-183590	-98769	31497	13476	66101	33000	99478	114710	231510	229040
60	5	3	2	-335980	-187860	46540	14888	102490	31436	125340	121140	299220	319870
80	5	3	0	-37567	-3250	-3250	26280	35316	49324	78535	110280	144070	124760
80	5	3	0.4	-74665	-23657	14592	25233	36590	49487	80659	115580	163460	160070
80	5	3	1	-143360	-61294	7717	24965	41343	50899	85740	124840	197380	219410
80	5	3	1.4	-195690	-90734	2714	24785	45577	52419	90907	134110	225610	263610
80	5	3	2	-346950	-171840	-6356	29292	62443	59389	106040	153780	293230	374890
100	5	3	0	-39691	1087	12883	32730	31124	58154	77820	114730	136750	133090
100	5	3	0.4	-81062	-18310	2555	34120	28023	62301	77138	125150	155060	173130
100	5	3	1	-175280	-59558	-15489	43564	28129	72028	59934	131330	196070	267640
100	5	3	1.4	-206820	-79293	-26226	39541	22522	76006	78861	158330	213540	288280
100	5	3	2	-335310	-141130	-52034	47667	21581	92687	85323	190790	268470	392620

Table C.2.7 Shear forces under CHBDC outer lanes truck load for 4-lane 4-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	4	0	-24817	21803	-16091	36854	-21056	86759	76182	179600
20	4	4	0.4	-47313	36464	-27824	57474	-31740	124520	79682	179700
20	4	4	1	-109910	73401	-56951	100330	-65615	169090	47972	244760
20	4	4	1.4	-190670	123570	-83647	145560	-94508	205790	22561	291330
20	4	4	2	-469690	303880	-129340	259710	-146560	278360	-21045	368770
40	4	4	0	-54229	32678	-3717	49053	-2315	104800	112390	239460
40	4	4	0.4	-85566	41194	-9173	62197	-3348	130280	117500	234810
40	4	4	1	-160430	59987	-21800	86617	-19535	149950	106620	293670
40	4	4	1.4	-238030	81008	-30693	112140	-30922	170580	98938	338410
40	4	4	2	-455090	142910	-43721	180550	-51668	215480	82414	437940
60	4	4	0	-59974	27427	2331	50081	10655	107370	141630	244790
60	4	4	0.4	-93804	31275	-2519	61968	11695	129440	144390	244550
60	4	4	1	-166070	36452	-14477	80313	311.3	149180	146200	303470
60	4	4	1.4	-238060	43787	-22715	99931	-8405	163950	146150	352520
60	4	4	2	-436780	66354	-38840	155730	-23584	4180	145350	466040
80	4	4	0	-64841	26454	720.5	56063	17004	114170	151860	245790
80	4	4	0.4	-100830	28977	-6143	69478	17644	135450	150840	252040
80	4	4	1	-173430	29833	-22509	88325	4034	156000	154650	316470
80	4	4	1.4	-237990	31311	-34816	106560	-3999	175980	156650	364360
80	4	4	2	-410390	38808	-62504	156290	-23974	219870	160990	481250
100	4	4	0	-68896	27997	-3448	63649	19051	121030	152250	247050
100	4	4	0.4	-107080	30007	-13242	78343	18092	142550	149780	259760
100	4	4	1	-179660	28596	-35044	98050	2299	167980	155230	327330
100	4	4	1.4	-236310	27394	-50524	114070	-6629	189050	160130	373420
100	4	4	2	-404700	30411	-91118	165970	-33338	242320	162980	499040

Table C.2.8 Shear forces under CHBDC outer lanes truck load for 4-lane 5-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	4	0	-20759	13004	-7057	20034	-8777	34413	4277	105660	75171	123270
20	5	4	0.4	-39949	19834	-14372	29826	-18190	48118	-6068	122060	66179	159750
20	5	4	1	-99708	45768	-32091	60771	-42926	82253	-32125	154880	43056	223180
20	5	4	1.4	-168800	70741	-44488	89611	-57195	106560	-46107	175490	30842	263350
20	5	4	2	-437400	189820	-54868	188150	-87284	167660	-77389	219490	3432	332160
40	5	4	0	-41664	7344	10920	22706	13957	33126	37419	104100	127650	162560
40	5	4	0.4	-69689	3504	9232	26180	12332	36395	35549	109330	134000	192240
40	5	4	1	-131180	-2342	9653	36792	11872	43815	30763	114720	39890	240930
40	5	4	1.4	-195700	-7011	13106	49603	14052	52509	29349	122490	145610	277110
40	5	4	2	-379860	-16329	30825	89272	26306	76462	27827	137630	158370	357600
60	5	4	0	-46022	2843	12338	24879	19540	37854	48452	109840	146570	168020
60	5	4	0.4	-78710	-5448	9828	28191	18836	40472	46422	113200	154080	198330
60	5	4	1	-134560	-20059	6759	33794	18787	44635	45589	123780	172470	245220
60	5	4	1.4	-195810	-33707	6760	43075	21966	51206	45265	129470	183690	284930
60	5	4	2	-361270	-68609	11244	70762	34824	70312	48507	145120	212190	374750
80	5	4	0	-49756	4855	7118	30228	17906	47462	51817	116150	146320	175130
80	5	4	0.4	-85099	-3528	800.7	35039	14704	52475	48130	123160	153500	208240
80	5	4	1	-144950	-18322	-8660	43298	10613	60573	43002	135700	169510	262480
80	5	4	1.4	-195600	-30726	-15336	51135	9015	68974	42864	148190	181010	299490
80	5	4	2	-344230	-62861	-29876	78660	8704	93325	38240	173600	206710	397640
100	5	4	0	-7121	26563	26555	51182	66522	98042	94847	89319	63203	49567
100	5	4	0.4	-90563	-2088	-8600	41621	10100	63800	48324	131170	149550	214860
100	5	4	1	-150170	-17065	-24077	50527	1797	74775	41544	149290	166110	271930
100	5	4	1.4	-197270	-29044	-35267	58119	-3069	84695	40330	164800	177620	309490
100	5	4	2	-338000	-59914	-63871	85891	-13671	114100	30405	199760	202790	413710

Table C.2.9 Shear forces under CHBDC outer lanes truck load for 4-lane 6-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Forces in Webs(Max) in Newtons											
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
20	6	4	0	138680	109790	144400	93427	114520	26024	43488	-997.6	27097	-1310	17105	-33751
20	6	4	0.4	-33804	9388	-6338	16295	-8494	24977	-6612	41899	25835	104540	73063	126420
20	6	4	1	-85801	21416	-13627	34769	-21277	44986	-21649	63688	11229	123620	62075	183570
20	6	4	1.4	-146390	32023	-18780	-28530	-28530	61940	-30290	78596	2836	136960	56552	220260
20	6	4	2	-397350	95035	-2463	136180	-36604	110800	-48094	113900	-14447	162660	42438	281210
40	6	4	0	-36058	-1736	10994	13707	13669	18261	20130	34638	56591	96320	123080	128530
40	6	4	0.4	-57236	-16258	14744	10180	19637	14154	26107	30134	62213	95683	142190	147470
40	6	4	1	-108080	-36168	19732	12619	26434	15381	29968	28954	63760	94772	159290	188050
40	6	4	1.4	-162540	-56068	27498	17573	35754	18473	35430	30410	67659	95763	172590	218240
40	6	4	2	-320820	-109530	56216	37784	66876	30616	51886	34753	75672	97515	202240	284210
60	6	4	0	-38698	-8965	12553	13494	19963	19160	27629	38439	66542	102820	141630	129730
60	6	4	0.4	-65728	-22352	11315	13015	21759	19005	29042	37895	67758	104580	154400	155320
60	6	4	1	-113380	-46016	10390	12977	26284	19150	32457	38181	72526	111410	178200	194050
60	6	4	1.4	-165680	-70242	12185	15655	33963	21682	37910	38876	75866	113460	195590	227290
60	6	4	2	-308370	-134220	20771	26403	58204	31161	54719	43087	86583	120080	236850	302070
80	6	4	0	-41867	-5382	6446	18330	15700	26151	25255	48085	68462	110050	137480	138510
80	6	4	0.4	-72007	-17962	1357	19631	14573	28342	24241	50362	67599	115180	148740	167320
80	6	4	1	-126280	-40883	-6468	22812	14243	33039	23963	55250	67692	124980	168820	214370
80	6	4	1.4	-166790	-58378	-11743	25310	14578	36270	24004	59058	70047	134720	185450	246260
80	6	4	2	-295950	-109860	-23509	38777	21148	51552	28621	71345	71875	152110	221890	331510
100	6	4	0	-43486	-3943	1256	21735	12595	31867	24142	55569	69344	114030	133160	142410
100	6	4	0.4	-75879	-16782	-7393	23930	8937	35800	21357	60293	67467	122490	144490	173410
100	6	4	1	-126560	-38120	-20634	26961	3772	41396	17481	67317	65773	137820	137820	222830
100	6	4	1.4	-166830	-55212	-30351	29884	833.3	46537	16129	74758	68083	150420	181160	254770
100	6	4	2	-287880	-102770	-55291	43322	-3682	64927	13629	93045	66136	177100	217330	344940

APPENDIX C3

Shear Distribution Factors for All Modeled Bridges Under Full CHBDC Truck Loading for Fatigue Limit State

Table C.3.1 Shear Distribution factors under CHBDC full truck load for 3-lane 3-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder					
				W1	W2	W3	W4	W5	W6
20	3	3	0	0.058966	0.302704	0.573231	0.573231	0.302704	0.058966
20	3	3	0.4	-0.11110	0.366961	0.461225	0.736712	0.235923	0.209775
20	3	3	1	-0.38288	0.525713	0.35332	0.852736	0.1106	0.403213
20	3	3	1.4	-0.64240	0.743932	0.329321	0.895177	0.025112	0.540661
20	3	3	2	-1.45870	1.283927	0.176241	1.172037	-0.13753	0.824295
40	3	3	0	0.107753	0.288694	0.45286	0.45286	0.288694	0.107753
40	3	3	0.4	-0.08783	0.312344	0.382446	0.546864	0.259601	0.284189
40	3	3	1	-0.39736	0.400707	0.318704	0.642005	0.206986	0.527502
40	3	3	1.4	-0.65433	0.50782	0.300958	0.6862	0.162603	0.696147
40	3	3	2	-1.3994	0.748798	0.2314	0.921742	0.107255	1.111633
60	3	3	0	0.106355	0.259878	0.394023	0.394023	0.259878	0.106355
60	3	3	0.4	-0.07297	0.256853	0.341939	0.464957	0.259498	0.272426
60	3	3	1	-0.34666	0.287323	0.288849	0.539835	0.249577	0.504571
60	3	3	1.4	-0.56445	0.336197	0.267394	0.578202	0.237298	0.669639
60	3	3	2	-1.19256	0.426271	0.194282	0.756059	0.243023	1.099418
80	3	3	0	0.109881	0.233033	0.34283	0.34283	0.233033	0.109881
80	3	3	0.4	-0.05906	0.225054	0.291677	0.408544	0.237936	0.267467
80	3	3	1	-0.28142	0.252179	0.241896	0.460974	0.227602	0.470974
80	3	3	1.4	-0.50295	0.266865	0.194688	0.529721	0.229535	0.655133
80	3	3	2	-1.04894	0.307692	0.09317	0.700897	0.242156	1.079817
100	3	3	0	0.110632	0.208404	0.302397	0.302397	0.208404	0.110632
100	3	3	0.4	-0.05396	0.20084	0.249117	0.368492	0.211883	0.265068
100	3	3	1	-0.29474	0.209563	0.176564	0.451561	0.210986	0.488134
100	3	3	1.4	-0.47176	0.229362	0.128216	0.503973	0.207322	0.647442
100	3	3	2	-0.98634	0.2543	-0.00469	0.684104	0.215616	1.081205

Table C.3.2 Shear Distribution factors under CHBDC full truck load for 3-lane 4-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	3	0	0.034034	0.222245	0.291944	0.698313	0.698313	0.291944	0.222245	0.034034
20	4	3	0.4	-0.11852	0.269646	0.26459	0.748581	0.668137	0.334546	0.188248	0.177341
20	4	3	1	-0.41299	0.351332	0.215579	0.824718	0.597939	0.398991	0.119379	0.388533
20	4	3	1.4	-0.74578	0.469976	0.194693	0.934146	0.558297	0.476428	0.074461	0.560216
20	4	3	2	-1.71800	0.831846	0.2008	1.204593	0.482749	0.630245	-0.01056	0.858597
40	4	3	0	0.086444	0.209883	0.314365	0.520017	0.519638	0.319485	0.213151	0.081887
40	4	3	0.4	-0.08556	0.186729	0.307572	0.536549	0.509549	0.331706	0.237939	0.238877
40	4	3	1	-0.40825	0.150894	0.310959	0.578423	0.504196	0.360706	0.281533	0.485675
40	4	3	1.4	0.719678	0.123723	0.328822	0.627877	0.510212	0.391671	0.320352	0.682304
40	4	3	2	-1.52968	0.069021	0.409766	0.781637	0.56066	0.483922	0.419325	1.099151
60	4	3	0	0.089115	0.207972	0.295746	0.420809	0.420809	0.295746	0.207972	0.089115
60	4	3	0.4	-0.06706	0.163823	0.282568	0.430282	0.415628	0.312106	0.25254	0.237579
60	4	3	1	-0.35102	0.089181	0.270311	0.455648	0.416865	0.34418	0.329382	0.473589
60	4	3	1.4	-0.61101	0.025686	0.269487	0.485924	0.42715	0.37521	0.396449	0.662824
60	4	3	2	-1.27940	-0.12801	0.286949	0.575978	0.469413	0.456305	0.559236	1.093415
80	4	3	0	0.090877	0.195424	0.271921	0.356088	0.356088	0.271921	0.195424	0.090877
80	4	3	0.4	-0.05669	0.153603	0.245766	0.369822	0.345161	0.299958	0.237338	0.233803
80	4	3	1	-0.31725	0.082228	0.207725	0.399329	0.333548	0.349605	0.308907	0.46526
80	4	3	1.4	-0.55003	0.020351	0.18067	0.430039	0.329532	0.393748	0.370858	0.655
80	4	3	2	-1.12721	-0.12829	0.127642	0.514783	0.331964	0.502453	0.52013	0.52013
100	4	3	0	0.093032	0.182407	0.248889	0.304244	0.304244	0.248889	0.182407	0.093032
100	4	3	0.4	-0.05181	0.144923	0.209954	0.323969	0.285239	0.288375	0.219547	0.234998
100	4	3	1	-0.29409	0.084101	0.152807	0.363538	0.262545	0.3555	0.281452	0.457122
100	4	3	1.4	-0.52383	0.025972	0.100089	0.399489	0.240806	0.415655	0.338474	0.659774
100	4	3	2	-1.06068	-0.10673	-0.00779	0.4942	0.206374	0.557054	0.471093	1.104556

Table C.3.3 Shear Distribution factors under CHBDC full truck load for 3-lane 5-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	3	0	0.001249	0.177261	0.17557	0.409731	0.695667	0.737318	0.494715	0.187595	0.029194	-0.01237
20	5	3	0.4	-0.1608	0.187191	0.164942	0.444548	0.686389	0.764299	0.47682	0.232609	0.18596	0.1837
20	5	3	1	-0.47551	0.201678	0.150023	0.498913	0.656019	0.798261	0.42578	0.265294	0.165943	0.418045
20	5	3	1.4	-0.82326	0.249943	0.195744	0.658398	0.634798	0.798316	0.386977	0.305567	0.155866	0.591108
20	5	3	2	-1.9364	0.40952	0.327908	0.928009	0.657635	0.935083	0.340503	0.39067	0.136859	0.911759
40	5	3	0	0.0629	0.174579	0.231072	0.361242	0.510952	0.535164	0.412999	0.254117	0.195918	0.092097
40	5	3	0.4	-0.11391	0.099647	0.240185	0.358785	0.527022	0.523795	0.419246	0.24928	0.267647	0.257439
40	5	3	1	-0.45215	-0.03495	0.274444	0.368596	0.570578	0.515103	0.43846	0.246503	0.384358	0.518922
40	5	3	1.4	-0.76506	-0.14365	0.342407	0.425173	0.616212	0.486077	0.443913	0.24501	0.470765	0.709944
40	5	3	2	-1.64139	-0.44776	0.503426	0.519029	0.78603	0.526335	0.527277	0.266066	0.683772	1.142601
60	5	3	0	0.085091	0.192918	0.234006	0.336525	0.444115	0.462236	0.375671	0.257201	0.218761	0.11222
60	5	3	0.4	-0.07775	0.075738	0.210327	0.301769	0.444637	0.428513	0.374699	0.243378	0.292107	0.244194
60	5	3	1	-0.35927	-0.09942	0.216166	0.284156	0.491936	0.410132	0.415028	0.256732	0.449461	0.473318
60	5	3	1.4	-0.60634	-0.24249	0.250043	0.299845	0.54027	0.378068	0.439553	0.265669	0.570478	0.643848
60	5	3	2	-1.28068	-0.63891	0.309986	0.301174	0.694501	0.369407	0.552643	0.299961	0.87667	1.056083
80	5	3	0	0.073625	0.162171	0.193917	0.272492	0.385386	0.398765	0.302041	0.219418	0.182543	0.095434
80	5	.3	0.4	-0.07538	0.079578	0.171582	0.265925	0.388289	0.398184	0.31052	0.243457	0.263682	0.240065
80	5	3	1	-0.33973	-0.06608	0.14022	0.260462	0.402073	0.401568	0.330052	0.284121	0.284121	0.474642
80	5	3	1.4	-0.56411	-0.18225	0.13926	0.279614	0.413899	0.388009	0.339547	0.313649	0.504675	0.654841
80	5	3	2	-1.15379	-0.49941	0.099456	0.293152	0.47602	0.413472	0.398982	0.395085	0.772259	1.093643
100	5	3	0	0.075549	0.153038	0.175955	0.240051	0.342686	0.353602	0.261875	0.202017	0.170564	0.096113
100	5	3	0.4	-0.07336	0.082943	0.136446	0.242832	0.329431	0.367194	0.259339	0.241835	0.239651	0.24268
100	5	3	1	-0.33260	-0.03924	0.074048	0.252528	0.31355	0.393875	0.259206	0.309138	0.355804	0.483195
100	5	3	1.4	-0.54856	-0.13548	0.044786	0.278293	0.297759	0.400846	0.254226	0.359949	0.447045	0.67129
100	5	3	2	-0.88304	-0.31724	-0.05349	0.251423	0.231535	0.373149	0.21492	0.393171	0.54289	0.904026

Table C.3.4 Shear Distribution factors under CHBDC full truck load for 4-lane 4-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	4	0	-0.07714	0.171076	0.006934	0.32705	0.582215	0.545457	0.238988	0.07527
20	4	4	0.4	-0.18071	0.230648	-0.03670	0.391236	0.54296	0.603766	0.184128	0.193653
20	4	4	1	-0.42344	0.371619	-0.12862	0.526711	0.444221	0.727066	0.072558	0.403516
20	4	4	1.4	-0.73054	0.562097	-0.21614	0.685286	0.356417	0.846949	-0.02047	0.569317
20	4	4	2	-1.79493	1.246226	-0.37241	1.090461	0.17106	1.087209	-0.19441	0.858082
40	4	4	0	-0.04799	0.143841	0.088828	0.286271	0.419465	0.430265	0.229887	0.148047
40	4	4	0.4	-0.16999	0.170273	0.061245	0.323461	0.391292	0.463518	0.208866	0.262586
40	4	4	1	-0.40894	0.226558	0.018293	0.393424	0.34412	0.526756	0.172106	0.446749
40	4	4	1.4	-0.64641	0.288509	-0.00895	0.471831	0.317077	0.584345	0.145894	0.587329
40	4	4	2	-1.29932	0.469984	-0.05100	0.671598	0.259424	0.724675	0.09901	0.888205
60	4	4	0	-0.03064	0.117862	0.097907	0.244783	0.360006	0.372882	0.215464	0.142222
60	4	4	0.4	-0.14128	0.124216	0.074559	0.270402	0.337299	0.398228	0.211807	0.247573
60	4	4	1	-0.35142	0.14054	0.039541	0.322132	0.30276	0.444251	0.206982	0.418934
60	4	4	1.4	-0.53139	0.154445	0.015872	0.369344	0.28969	0.493609	0.210183	0.538646
60	4	4	2	-1.04188	0.209296	-0.02882	0.507007	0.247967	0.596443	0.213666	0.839202
80	4	4	0	-0.01917	0.106663	0.09335	0.214527	0.310148	0.328394	0.195542	0.142014
80	4	4	0.4	-0.12166	0.107724	0.065934	0.239472	0.287592	0.356789	0.195633	0.240246
80	4	4	1	-0.30997	0.112155	0.022915	0.288494	0.253231	0.407566	0.197149	0.400925
80	4	4	1.4	-0.48388	0.118099	-0.01086	0.336113	0.227768	0.453205	0.199806	0.533079
80	4	4	2	-0.92641	0.136864	-0.08430	0.46125	0.176999	0.566111	0.210322	0.834505
100	4	4	0	-0.01111	0.099529	0.084724	0.190217	0.26885	0.295545	0.175321	0.139802
100	4	4	0.4	-0.10964	0.099182	0.052073	0.216372	0.244067	0.328337	0.176015	0.235124
100	4	4	1	-0.28684	0.1	-0.00054	0.266491	0.205883	0.386356	0.179002	0.391851
100	4	4	1.4	-0.44524	0.101667	-0.04306	0.31312	0.176662	0.437167	0.182818	0.520547
100	4	4	2	-0.84152	0.108187	-0.14066	0.432251	0.113348	0.561192	0.193832	0.818718

Table C.3.5 Shear Distribution factors under CHBDC full truck load for 4-lane 5-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	4	0	-0.09706	0.140386	0.01832	0.214562	0.181753	0.64762	0.605551	0.347742	0.212447	0.065949
20	5	4	0.4	-0.21399	0.177392	-0.02011	0.255556	0.0947	0.677783	0.639607	0.415089	0.17425	0.213473
20	5	4	1	-0.49541	0.303185	-0.08529	0.393097	0.06475	0.814167	0.484835	0.496692	0.076263	0.440437
20	5	4	1.4	-0.81595	0.419389	-0.13119	0.519704	0.012491	0.914069	0.418782	0.591062	0.01214	0.626248
20	5	4	2	-2.08009	0.977179	-0.16689	0.963193	-0.11673	1.171196	0.268819	0.77524	-0.12435	0.947416
40	5	4	0	-0.05372	0.091934	0.109121	0.171017	0.237479	0.44186	0.440839	0.320651	0.214973	0.149128
40	5	4	0.4	-0.17504	0.076089	0.101322	0.185317	0.229952	0.450346	0.428506	0.331012	0.230187	0.265874
40	5	4	1	-0.41636	0.049009	0.098023	0.221594	0.226648	0.479034	0.420211	0.359948	0.257942	0.452478
40	5	4	1.4	-0.65915	0.029203	0.108894	0.269346	0.239308	0.515671	0.417062	0.382806	0.277273	0.593342
40	5	4	2	-1.3446	-0.00963	0.169791	0.410414	0.281568	0.604977	0.419527	0.446438	0.328423	0.894431
60	5	4	0	-0.03630	0.077582	0.101547	0.157724	0.224659	0.366451	0.367865	0.288524	0.208923	0.143633
60	5	4	0.4	-0.14692	0.048038	0.090832	0.166732	0.22032	0.373121	0.361644	0.301785	0.239069	0.248794
60	5	4	1	-0.35908	-0.00485	0.079645	0.079645	0.220251	0.38918	0.354913	0.325122	0.289641	0.419521
60	5	4	1.4	-0.54186	-0.04982	0.075132	0.212679	0.227276	0.412779	0.366052	0.35314	0.331082	0.538348
60	5	4	2	-1.06962	-0.1636	0.085412	0.296528	0.263693	0.469437	0.374789	0.405782	0.429961	0.834873
80	5	4	0	-0.02749	0.075949	0.08556	0.150221	0.205096	0.315035	0.310158	0.267843	0.192054	0.13994
80	5	4	0.4	-0.13253	0.050137	0.064896	0.162489	0.193915	0.327567	0.299904	0.289776	0.217467	0.240973
80	5	4	1	-0.32668	0.004232	0.033856	0.189826	0.180296	0.353506	0.285772	0.327943	0.260158	0.406482
80	5	4	1.4	-0.50732	-0.03684	0.010586	0.21903	0.173714	0.379947	0.276997	0.36137	0.296398	0.542383
80	5	4	2	-0.97060	-0.13801	-0.03755	0.301398	0.169827	0.452221	0.264312	0.442635	0.382579	0.851404
100	5	4	0	-0.14595	0.01815	0.004441	0.098547	0.044148	0.156557	0.148704	0.335228	0.395794	0.497961
100	5	4	0.4	-0.12108	0.050336	0.045072	0.156858	0.167842	0.290179	0.250221	0.277467	0.198617	0.236353
100	5	4	1	-0.30383	0.008526	-0.00129	0.186879	0.14312	0.324549	0.230594	0.327914	0.237593	0.398491
100	5	4	1.4	-0.46790	-0.02848	-0.03883	0.216395	0.12589	0.357085	0.216751	0.371128	0.270716	0.531498
100	5	4	2	-0.88049	-0.11910	-0.12476	0.295462	0.092231	0.440537	0.189149	0.474547	0.349215	0.83914

Table C.3.6 Shear Distribution factors under CHBDC full truck load for 4-lane 6-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder											
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
20	6	4	0	-0.1470	0.05647	-0.0208	0.09303	-0.0279	0.14867	-0.0078	0.26815	0.26017	0.77897	0.6270	0.7759
20	6	4	0.4	-0.2290	0.12816	0.01697	0.19566	0.04341	0.35486	0.52920	0.75039	0.50577	0.24455	0.1668	0.1925
20	6	4	1	-0.5293	0.19671	-0.0160	0.29310	-0.0134	0.44211	0.46823	0.83157	0.02541	0.31472	0.1074	0.4570
20	6	4	1.4	-0.8676	0.25593	-0.0367	0.40082	-0.0426	0.52655	0.42901	0.90689	0.38727	0.38698	0.0718	0.6613
20	6	4	2	-2.2892	0.61178	0.06587	0.85133	-0.0800	0.77773	0.33166	1.08117	0.27639	0.51489	-0.013	1.0094
40	6	4	0	-0.0592	0.09969	0.16252	0.18757	0.22346	0.41837	0.61685	0.67450	0.54827	0.33872	0.2691	0.1854
40	6	4	0.4	-0.1775	0.00290	0.12591	0.11359	0.16330	0.26156	0.4161	0.47873	0.41146	0.24247	0.2511	0.2585
40	6	4	1	-0.4145	-0.0933	0.14331	0.11979	0.18976	0.26364	0.43632	0.48103	0.42879	0.24755	0.3317	0.4435
40	6	4	1.4	-0.6610	-0.1857	0.17524	0.13972	0.23077	0.28021	0.46687	0.48895	0.44348	0.24961	0.3927	0.5865
40	6	4	2	-1.3699	-0.4288	0.29808	0.22396	0.36423	0.32875	0.54174	0.51693	0.48925	0.26297	0.5267	0.8854
60	6	4	0	-0.0337	0.05761	0.10638	0.11908	0.15415	0.25322	0.36095	0.39146	0.32762	0.22286	0.1916	0.1293
60	6	4	0.4	-0.1521	-0.0038	0.09609	0.10976	0.14755	0.23669	0.35823	0.40642	0.34898	0.23660	0.2545	0.2450
60	6	4	1	-1.2214	-0.3625	0.32952	0.42941	0.68225	0.91793	1.24405	1.32096	1.28316	0.97983	1.2788	1.4006
60	6	4	1.4	-0.5627	-0.2020	0.09505	0.11713	0.19346	0.24660	0.39252	0.41228	0.38091	0.26704	0.4186	0.5449
60	6	4	2	-1.1024	-0.4465	0.12274	0.15229	0.27836	0.27613	0.45396	0.43357	0.42857	0.29983	0.5810	0.8337
80	6	4	0	-0.0263	0.06064	0.08447	0.11763	0.13799	0.22319	0.32025	0.35008	0.27792	0.21265	0.1751	0.1236
80	6	4	0.4	-0.1408	0.01036	0.06058	0.11519	0.11857	0.21929	0.31330	0.37210	0.28661	0.23872	0.2263	0.2371
80	6	4	1	-0.4542	-0.1044	0.04002	0.16386	0.17044	0.72770	1.64577	1.97400	1.27416	0.72255	0.4399	0.4630
80	6	4	1.4	-0.5278	-0.1496	0.00809	0.14024	0.11834	0.25129	0.31219	0.40210	0.28715	0.30444	0.3617	0.5509
80	6	4	2	-1.0119	-0.3433	-0.0387	0.18743	0.13968	0.30462	0.32784	0.44635	0.29693	0.37494	0.5043	0.8727
100	6	4	0	-0.0172	0.06077	0.07139	0.11282	0.12429	0.19866	0.27892	0.30916	0.23952	0.20077	0.1632	0.1219
100	6	4	0.4	-0.1272	0.01517	0.03804	0.11351	0.09728	0.20295	0.26959	0.33543	0.24112	0.23464	0.2093	0.2323
100	6	4	1	-0.3144	-0.0596	-0.0093	0.12732	0.07911	0.22527	0.25638	0.36152	0.23463	0.28471	0.2768	0.4004
100	6	4	1.4	-0.4832	-0.1268	-0.0482	0.14273	0.06781	0.06781	0.24901	0.38615	0.23127	0.32653	0.3331	0.5383
100	6	4	2	-0.9101	-0.2943	-0.1380	0.18802	0.04931	0.31000	0.23864	0.44919	0.22702	0.42416	0.4647	0.8576

APPENDIX C4

Shear Distribution Factors for All Modeled Bridges Under Outer Lanes CHBDC Truck Loading for Fatigue Limit State

Table C.4.1 Shear Distribution Factors under CHBDC outer lanes truck load for 2-lanes 2-boxes bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder			
				W1	W2	W3	W4
20	2	2	0	-0.14961	0.588584	0.562636	1.075971
20	2	2	0.4	-0.40983	0.791193	0.435135	1.32872
20	2	2	1	-0.97339	1.214686	0.205965	1.767768
20	2	2	1.4	-1.57050	1.670209	0.024852	2.156536
20	2	2	2	-3.20623	2.868543	-0.36290	3.025079
40	2	2	0	-0.12647	0.520073	0.54802	0.945762
40	2	2	0.4	-0.42178	0.619548	0.471519	1.218924
40	2	2	1	-0.96360	0.81755	0.368736	1.689022
40	2	2	1.4	-1.45778	1.012829	0.304011	2.076225
40	2	2	2	-2.71144	1.502665	0.16621	3.004461
60	2	2	0	-0.1041	0.428491	0.547874	0.817155
60	2	2	0.4	-0.38244	0.475084	0.51417	1.085631
60	2	2	1	-0.77594	0.500733	0.440478	1.377789
60	2	2	1.4	1.694791	0.646925	0.453656	1.904687
60	2	2	2	-1.90729	0.699319	0.329988	2.252203
80	2	2	0	0.036162	0.317904	0.443411	0.726394
80	2	2	0.4	-0.35460	0.410468	0.475937	0.992669
80	2	2	1	-0.82179	0.473013	0.439986	1.434883
80	2	2	1.4	-1.08022	0.465939	0.388998	1.60993
80	2	2	2	-2.24902	0.678107	0.373737	2.728246
100	2	2	0	-0.07585	0.342696	0.443967	0.670165
100	2	2	0.4	-0.32707	0.373025	0.423871	0.920241
100	2	2	1	-0.79410	0.430248	0.377054	1.367916
100	2	2	1.4	-1.18868	0.480847	0.348109	1.743042
100	2	2	2	-2.14867	0.604612	0.288093	2.642149

Table C.4.2 Shear Distribution factors under CHBDC outer lanes truck load for 2-lane 3-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder					
				W1	W2	W3	W4	W5	W6
20	3	2	0	-0.14626	0.334274	0.306807	0.977708	0.797333	0.846535
20	3	2	0.4	-0.45457	0.437364	0.264697	1.092262	0.761956	1.135622
20	3	2	1	-1.17521	0.648063	0.118578	1.295465	0.76643	1.669719
20	3	2	1.4	-1.92657	0.914074	0.092792	1.53229	0.725624	2.084025
20	3	2	2	-4.12818	1.713262	0.133735	2.176532	0.672683	3.042533
40	3	2	0	-0.10231	0.235993	0.426014	0.702957	0.812438	0.75601
40	3	2	0.4	-0.41401	0.164418	0.427962	0.722615	0.892492	1.038329
40	3	2	1	-1.03288	0.019729	0.425504	0.78307	1.102988	1.549797
40	3	2	1.4	-1.57543	-0.07283	0.485509	0.86188	1.258655	1.942249
40	3	2	2	-2.96832	-0.29839	0.663581	1.068646	1.636068	2.835689
60	3	2	0	-0.08652	0.199636	0.396754	0.607646	0.75806	0.65859
60	3	2	0.4	-0.37213	0.083766	0.389736	0.62785	0.879231	0.929691
60	3	2	1	-0.92369	-0.14555	0.367053	0.670915	1.143034	1.428298
60	3	2	1.4	-1.35014	-0.30981	0.385018	0.72471	0.72471	1.778086
60	3	2	2	-2.49511	-0.72359	0.46299	0.858883	1.824534	2.647505
80	3	2	0	-0.07707	0.199284	0.346861	0.54018	0.659603	0.616913
80	3	2	0.4	-0.35391	0.095563	0.313745	0.579612	0.765241	0.886084
80	3	2	1	-0.87138	-0.10682	0.2408	0.650079	0.990177	1.385036
80	3	2	1.4	-1.30554	-0.26552	0.209439	0.719168	1.161061	1.770915
80	3	2	2	-2.37245	-0.65095	0.149514	0.894564	1.584325	2.687909
100	3	2	0	-0.02817	0.225777	0.310332	0.477077	0.542186	0.544262
100	3	2	0.4	-0.33395	0.11543	0.245947	0.551307	0.658424	0.847631
100	3	2	1	-0.85552	-0.05867	0.124184	0.655421	0.842662	1.362676
100	3	2	1.4	-1.27658	-0.19365	0.050896	0.751859	0.984892	1.756032
100	3	2	2	-2.29002	-0.51819	-0.11327	0.984188	1.331419	2.682304

Table C.4.3 Shear Distribution factors under CHBDC outer lanes truck load for 2-lane 4-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	2	0	-0.23300	0.197875	0.215721	0.420247	0.61664	1.034449	1.018281	0.884944
20	4	2	0.4	-0.54683	0.203607	0.24219	0.551392	0.68359	0.989448	1.010038	1.157277
20	4	2	1	-1.31108	0.212794	0.301448	0.709238	0.690572	1.07411	1.078066	1.675108
20	4	2	1.4	-2.14128	0.245656	0.405585	0.897706	0.730147	1.172429	1.145751	2.106623
20	4	2	2	-4.59625	0.389589	0.807496	1.453042	0.923036	1.497137	1.26564	2.908412
40	4	2	0	-0.17373	0.059361	0.358465	0.333502	0.609663	0.744886	1.062646	0.779971
40	4	2	0.4	-0.47022	-0.11909	0.415805	0.338476	0.698812	0.694335	1.203884	1.040698
40	4	2	1	-1.06785	-0.47866	0.528346	0.287751	0.843722	0.663917	1.536415	1.50602
40	4	2	1.4	-1.65475	-0.81569	0.665551	0.274219	1.010224	0.655998	1.832471	1.896025
40	4	2	2	-3.14214	-1.64544	1.036514	0.264398	1.429282	0.65704	2.529349	2.7823
60	4	2	0	-0.14587	0.050202	0.287719	0.321313	0.548957	0.682789	0.953713	0.680017
60	4	2	0.4	-0.42535	-0.13631	0.310493	0.306311	0.616295	0.660491	1.110764	0.941275
60	4	2	1	-0.97607	-0.52001	0.344526	0.239559	0.744075	0.671833	1.475584	1.406048
60	4	2	1.4	-1.42783	-0.83513	0.380093	0.194899	0.863748	0.703411	1.782017	1.76075
60	4	2	2	-2.63706	-1.65022	0.513106	0.114853	1.201759	0.756255	2.515007	2.61973
80	4	2	0	-0.13125	0.061102	0.236852	0.308592	0.492907	0.61314	0.825502	0.640876
80	4	2	0.4	-0.39215	-0.11425	0.221887	0.294824	0.534611	0.632354	0.98334	0.887602
80	4	2	1	-0.89389	-0.46352	0.187111	0.244053	0.616648	0.686378	1.322965	1.349865
80	4	2	1.4	-1.34023	-0.77443	0.164789	0.205039	0.698408	0.735389	1.621041	1.741063
80	4	2	2	-2.44013	-1.53649	0.127457	0.121258	0.914614	0.857248	2.342841	2.667316
100	4	2	0	-0.12049	0.078308	0.185205	0.305623	0.428741	0.565705	0.707688	0.611187
100	4	2	0.4	-0.38316	-0.07523	0.137691	0.308001	0.439478	0.617713	0.850313	0.864155
100	4	2	1	-0.71975	-0.18539	0.087726	0.337139	0.4477	0.687567	0.944342	1.161023
100	4	2	1.4	-1.30755	-0.64465	-0.03766	0.291178	0.5003	0.817091	1.40707	1.737357
100	4	2	2	-2.35254	-1.29390	-0.21414	0.27871	0.590918	1.037431	2.034275	2.685159

Table C.4.4 Shear Distribution factors under CHBDC outer lanes truck load for 3-lane 3-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder					
				W1	W2	W3	W4	W5	W6
20	3	3	0	-0.19345	0.274336	-0.08929	0.616913	0.474561	1.020468
20	3	3	0.4	-0.39772	0.416627	-0.18738	0.7769	0.371348	1.253805
20	3	3	1	-0.88423	0.746578	-0.38320	1.073733	0.174398	1.652331
20	3	3	1.4	-1.45210	1.139896	-0.55115	1.354816	0.01389	1.952078
20	3	3	2	-3.17357	-3.17357	-0.87406	2.029155	-0.28992	2.588034
40	3	3	0	-0.20624	0.227792	0.05215	0.488165	0.457589	0.891518
40	3	3	0.4	-0.40219	0.281484	0.002253	0.552992	0.420979	1.077967
40	3	3	1	-0.80111	0.405671	-0.07086	0.69204	0.359129	1.367732
40	3	3	1.4	-1.18635	0.529611	-0.12479	0.818937	0.313482	1.620967
40	3	3	2	-2.16480	0.850631	-0.21599	1.129006	0.254042	2.157693
60	3	3	0	-0.17882	0.170178	0.085827	0.40915	0.46918	0.755007
60	3	3	0.4	-0.35805	0.189718	0.045848	0.459001	0.456717	0.920449
60	3	3	1	-0.67458	0.225775	-0.01368	0.547741	0.453259	1.194727
60	3	3	1.4	-0.96723	0.265222	-0.05228	0.643691	0.457663	1.401732
60	3	3	2	-1.72374	0.377569	-0.13613	0.858265	0.467451	1.913488
80	3	3	0	-0.16530	0.150752	0.086427	0.369697	0.434236	0.667101
80	3	3	0.4	-0.33115	0.159518	0.04211	0.420956	0.428879	0.823303
80	3	3	1	-0.63563	0.179911	-0.02836	0.516848	0.424283	1.088226
80	3	3	1.4	-0.86644	0.190851	-0.07796	0.588464	0.43745	1.28954
80	3	3	2	-1.52389	0.243297	-0.19650	0.797476	0.450222	1.794518
100	3	3	0	-0.15325	0.142689	0.075638	0.341574	0.387349	0.604236
100	3	3	0.4	-0.31359	0.148598	0.024352	0.39746	0.383144	0.757103
100	3	3	1	-0.59983	0.161169	-0.05887	0.499271	0.380666	1.016937
100	3	3	1.4	-0.80070	0.163829	-0.11522	0.569598	0.394557	1.202791
100	3	3	2	-1.29426	0.184056	-0.23573	0.750171	0.413652	1.612864

Table C.4.5 Shear Distribution factors under CHBDC outer lanes truck load for 3-lane 4-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	3	0	-0.213473	0.176814	0.005692	0.271835	0.110019	0.869189	0.746859	0.837771
20	4	3	0.4	-0.426897	0.246007	-0.039702	0.366005	0.060727	0.969973	0.70915	1.081505
20	4	3	1	-0.965756	0.429989	-0.121321	0.584447	-0.042389	1.157568	0.621553	1.508451
20	4	3	1.4	-1.61031	0.66686	-0.171366	0.821137	-0.121346	1.320691	0.5432	1.827173
20	4	3	2	-3.653024	1.459754	-0.158584	1.471908	-0.238707	1.709606	0.408964	2.478507
40	4	3	0	-0.202108	0.092229	0.12982	0.197365	0.236395	0.606229	0.725919	0.76205
40	4	3	0.4	-0.406561	0.066218	0.125712	0.222327	0.227437	0.627971	0.764128	0.950217
40	4	3	1	-0.818111	0.025883	0.139684	0.289009	0.230235	0.674227	0.820562	1.24683
40	4	3	1.4	-1.258607	-0.010637	0.167662	0.358376	0.222449	0.671723	0.850618	1.609363
40	4	3	2	-2.295155	-0.074073	0.281628	0.566794	0.306365	0.847207	1.009049	2.034193
60	4	3	0	-0.184427	0.060465	0.122309	0.195876	0.252348	0.512212	0.65872	0.663201
60	4	3	0.4	-0.368271	0.010605	0.110451	0.210405	0.24835	0.532962	0.710485	0.833286
60	4	3	1	-0.699784	-0.07589	0.100398	0.241951	0.25106	0.575157	0.809709	1.107118
60	4	3	1.4	-0.990973	-0.148857	0.101251	0.277386	0.26943	0.624181	0.893838	1.308697
60	4	3	2	-1.807598	-0.332931	0.130143	0.393322	0.32397	0.720838	1.087021	1.824128
80	4	3	0	-0.167341	0.058676	0.09259	0.199089	0.234976	0.457929	0.573079	0.608191
80	4	3	0.4	-0.3399	0.011124	0.064932	0.218089	0.223017	0.490147	0.619206	0.771273
80	4	3	1	-0.647176	-0.072695	0.024831	0.257081	0.211228	0.549545	0.703642	1.040782
80	4	3	1.4	-0.900332	-0.142461	-0.003691	0.290427	0.206792	0.600748	0.779882	1.249691
80	4	3	2	-1.593598	-0.319186	-0.062011	0.39714	0.210446	0.729807	0.955031	1.766567
100	4	3	0	-0.15527	0.06358	0.065648	0.203946	0.209739	0.417623	0.492372	0.566653
100	4	3	0.4	-0.313413	0.020709	0.023629	0.227345	0.192934	0.465776	0.537655	0.72179
100	4	3	1	-0.622915	-0.054273	-0.045466	0.279706	0.159181	0.543728	0.605662	0.99936
100	4	3	1.4	-0.833078	-0.11293	-0.093075	0.312085	0.142926	0.606196	0.672402	1.190769
100	4	3	2	-1.350978	-0.24643	-0.19506	0.405677	0.120035	0.751689	0.807517	1.613265

Table C.4.6 Shear Distribution factors under CHBDC outer lanes truck load for 3-lane 5-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder									
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
20	5	3	0	-0.23591	0.100536	0.052025	0.181767	0.064716	0.304594	0.39648	0.973549	0.869871	0.798283
20	5	3	0.4	-0.46395	0.116865	0.036843	0.243609	0.046289	0.373062	0.378002	1.041944	0.888918	1.073671
20	5	3	1	-1.03863	0.167432	0.025506	0.3974	0.011906	0.504457	0.323135	1.148081	0.887192	1.538939
20	5	3	1.4	-1.75617	0.255381	0.05898	0.596653	0.004756	0.643851	0.284431	1.240576	0.874821	1.890835
20	5	3	2	-4.27329	0.640844	0.362954	1.282742	0.097363	1.042977	0.241687	1.458122	0.846763	2.563727
40	5	3	0	-0.23954	-0.00139	0.172267	0.134278	0.205007	0.22629	0.426575	0.649141	0.86783	0.744464
40	5	3	0.4	-0.45056	-0.08880	0.188134	0.13545	0.227722	0.216731	0.438825	0.648262	0.961621	0.944169
40	5	3	1	-0.88461	-0.25546	0.244076	0.159071	0.293196	0.21767	0.474123	0.647655	1.104705	1.25898
40	5	3	1.4	-1.30807	-0.40958	0.312793	0.194136	0.365684	0.223519	0.508908	0.657667	1.234001	1.518437
40	5	3	2	-2.49098	-0.81347	0.541168	0.328181	0.596184	0.277509	0.622609	0.684845	1.513841	2.081448
60	5	3	0	-0.19234	-0.03794	0.140597	0.11217	0.206668	0.218375	0.40753	0.56762	0.804423	0.623844
60	5	3	0.4	-0.37572	-0.15269	0.141353	0.097967	0.234775	0.202873	0.431319	0.573112	0.912793	0.789579
60	5	3	1	-0.70475	-0.35773	0.152114	0.079817	0.29462	0.182009	0.482268	0.598342	1.107129	1.052319
60	5	3	1.4	-0.99827	-0.53705	0.171265	0.073276	0.359424	0.179437	0.540911	0.623735	1.258835	1.245404
60	5	3	2	-1.82689	-1.02148	0.253061	0.080953	0.557289	0.170933	0.681536	0.658698	1.627008	1.739292
80	5	3	0	-0.17653	-0.01527	-0.01527	0.123495	0.165957	0.231784	0.369053	0.518229	0.677016	0.586274
80	5	3	0.4	-0.35086	-0.11116	0.068571	0.118575	0.171944	0.23255	0.379034	0.543135	0.768134	0.752203
80	5	3	1	-0.67368	-0.28803	0.036264	0.117316	0.19428	0.239185	0.402911	0.58665	0.927531	1.031055
80	5	3	1.4	-0.91958	-0.42637	0.012754	0.11647	0.214176	0.246328	0.427192	0.630212	1.06019	1.23876
80	5	3	2	-1.63039	-0.80751	-0.02986	0.137649	0.293433	0.279082	0.498305	0.722645	1.377951	1.761689
100	5	3	0	-0.16556	0.004534	0.053738	0.136524	0.129825	0.242574	0.324605	0.478565	0.570416	0.555149
100	5	3	0.4	-0.33812	-0.07637	0.010657	0.142322	0.11689	0.259872	0.32176	0.522029	0.646791	0.722165
100	5	3	1	-0.73113	-0.24843	-0.06460	0.181715	0.117333	0.300445	0.249998	0.547808	0.817853	1.116388
100	5	3	1.4	-0.86269	-0.33074	-0.10939	0.164935	0.093944	0.317038	0.328947	0.660431	0.890724	1.202482
100	5	3	2	-1.39865	-0.58868	-0.21704	0.19883	0.090019	0.386619	0.355902	0.795829	1.11985	1.637708

Table C.4.7 Shear Distribution factors under CHBDC outer lanes truck load for 4-lane 4-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder							
				W1	W2	W3	W4	W5	W6	W7	W8
20	4	4	0	-0.15632	0.137342	-0.10136	0.232152	-0.13263	0.546516	0.479889	1.131344
20	4	4	0.4	-0.29803	0.229695	-0.17527	0.362043	-0.19993	0.784381	0.501936	1.131973
20	4	4	1	-0.69234	0.462371	-0.35874	0.632003	-0.41332	1.065139	0.302187	1.541802
20	4	4	1.4	-1.20107	0.778397	-0.52691	0.916917	-0.59532	1.296321	0.142117	1.835158
20	4	4	2	-2.95869	1.914213	-0.81474	1.635976	-0.92321	1.753456	-0.13256	2.322971
40	4	4	0	-0.22018	0.132679	-0.01509	0.199165	-0.00939	0.425509	0.456326	0.972256
40	4	4	0.4	-0.34741	0.167256	-0.03724	0.252532	-0.01359	0.528963	0.477074	0.953376
40	4	4	1	-0.65137	0.243559	-0.08851	0.351683	-0.07931	0.608828	0.432899	1.19236
40	4	4	1.4	-0.96645	0.328909	-0.12462	0.455311	-0.12555	0.69259	0.401708	1.374014
40	4	4	2	-1.84775	0.580244	-0.17751	0.73307	-0.20978	0.874893	0.334618	1.778126
60	4	4	0	-0.19877	0.090901	0.007726	0.165983	0.035314	0.355855	0.469402	0.811304
60	4	4	0.4	-0.31089	0.103654	-0.00834	0.20538	0.038761	0.429001	0.478549	0.810508
60	4	4	1	-0.55040	0.120812	-0.04798	0.26618	0.001032	0.494425	0.484548	1.005786
60	4	4	1.4	-0.78899	0.145123	-0.07528	0.3312	-0.02785	0.543377	0.484383	1.168351
60	4	4	2	-1.44761	0.219916	-0.12872	0.516133	-0.07816	0.013854	0.481731	1.544589
80	4	4	0	-0.18572	0.075772	0.002064	0.16058	0.048704	0.327015	0.43497	0.704012
80	4	4	0.4	-0.28880	0.082998	-0.01759	0.199005	0.050537	0.387967	0.432049	0.721914
80	4	4	1	-0.49675	0.08545	-0.06447	0.252988	0.011555	0.446828	0.442961	0.90646
80	4	4	1.4	-0.68167	0.089684	-0.09972	0.305218	-0.01145	0.504057	0.44869	1.04363
80	4	4	2	-1.17547	0.111157	-0.17902	0.447659	-0.06866	0.62977	0.461121	1.378437
100	4	4	0	-0.17516	0.071181	-0.00876	0.161825	0.048436	0.307714	0.38709	0.628116
100	4	4	0.4	-0.27224	0.076292	-0.03366	0.199184	0.045998	0.362428	0.38081	0.66043
100	4	4	1	-0.45677	0.072704	-0.08909	0.249289	0.005845	0.427083	0.394667	0.832225
100	4	4	1.4	-0.60081	0.069648	-0.12845	0.290019	-0.01685	0.480653	0.407125	0.949407
100	4	4	2	-1.02893	0.077319	-0.23166	0.421973	-0.08476	0.61609	0.414371	1.268791

Table C.4.8 Shear Distribution factors under CHBDC outer lanes truck load for 4-lane 5-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder									
				W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**
20	5	4	0	-0.16345	0.102394	-0.05556	0.157749	-0.06911	0.27097	0.033677	0.831972	0.5919	0.970634
20	5	4	0.4	-0.31456	0.156174	-0.11316	0.234851	-0.14322	0.378884	-0.04778	0.961107	0.521097	1.25788
20	5	4	1	-0.78510	0.36038	-0.25268	0.478514	-0.33800	0.647664	-0.25295	1.219533	0.339025	1.757331
20	5	4	1.4	-1.32914	0.557018	-0.35030	0.705602	-0.45035	0.839059	-0.36304	1.381817	0.242851	2.073631
20	5	4	2	-3.44411	1.494652	-0.43203	1.481503	-0.68727	1.320163	-0.60936	1.728275	0.027024	2.615445
40	5	4	0	-0.21145	0.046591	0.069277	0.144048	0.088544	0.210154	0.237389	0.660418	0.80982	1.031292
40	5	4	0.4	-0.35368	0.017784	0.046855	0.13287	0.062588	0.184714	0.18042	0.554878	0.680084	0.975667
40	5	4	1	-0.66577	-0.01188	0.048991	0.186729	0.060253	0.222372	0.15613	0.582233	0.202452	1.222781
40	5	4	1.4	-0.99322	-0.03558	0.066516	0.251748	0.071317	0.266497	0.148954	0.621668	0.739008	1.406404
40	5	4	2	-1.92788	-0.08287	0.156445	0.453078	0.13351	0.388064	0.141229	0.698507	0.803768	1.814911
60	5	4	0	-0.19066	0.011778	0.051115	0.10307	0.080951	0.156824	0.20073	0.455051	0.607218	0.696082
60	5	4	0.4	-0.32608	-0.02257	0.040716	0.116791	0.078035	0.16767	0.19232	0.468971	0.638331	0.821652
60	5	4	1	-0.55746	-0.08310	0.028002	0.140004	0.077832	0.184916	0.188869	0.512803	0.714518	1.015911
60	5	4	1.4	-0.81121	-0.13964	0.028006	0.178453	0.091002	0.212139	0.187526	0.536375	0.761001	1.180424
60	5	4	2	-1.49668	-0.28423	0.046582	0.293157	0.144271	0.291292	0.200957	0.601211	0.879072	1.552535
80	5	4	0	-0.17814	0.017383	0.025485	0.108227	0.06411	0.169931	0.185523	0.415858	0.523877	0.627028
80	5	4	0.4	-0.30468	-0.01263	0.002867	0.125452	0.052646	0.187879	0.172322	0.440956	0.549584	0.745573
80	5	4	1	-0.51897	-0.06559	-0.03100	0.155022	0.037998	0.216873	0.153962	0.485854	0.606906	0.939771
80	5	4	1.4	-0.70031	-0.11001	-0.05490	0.183081	0.032277	0.246951	0.153468	0.530573	0.64808	1.07228
80	5	4	2	-1.23246	-0.22506	-0.10696	0.281631	0.031163	0.334137	0.136913	0.62155	0.740095	1.423692
100	5	4	0	-0.02263	0.084419	0.084394	0.16266	0.211412	0.311585	0.301431	0.283863	0.200864	0.157528
100	5	4	0.4	-0.28781	-0.00663	-0.02733	0.132275	0.032099	0.202761	0.153578	0.416869	0.475282	0.682842
100	5	4	1	-0.47725	-0.05423	-0.07651	0.160579	0.005711	0.237641	0.13203	0.474455	0.527911	0.864215
100	5	4	1.4	-0.62694	-0.09230	-0.11208	0.184707	-0.00975	0.269167	0.128172	0.523747	0.56449	0.983584
100	5	4	2	-1.07419	-0.19041	-0.20298	0.272968	-0.04344	0.362619	0.09663	0.634853	0.644483	1.314803

Table C.4.9 Shear Distribution factors under CHBDC outer lanes truck load for 4-lane 6-box bridges for FLS

Span	No of Boxes	No of Lanes	L/R	Shear Distribution Factor / box girder											
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
20	6	4	0	1.31036	1.03739	1.36441	0.88277	1.08208	0.24589	0.41091	-0.0094	0.25603	-0.0123	0.16162	-0.3189
20	6	4	0.4	-0.3194	0.08870	-0.0598	0.15396	-0.0802	0.23600	-0.0624	0.39589	0.24411	0.98778	0.69036	1.19452
20	6	4	1	-0.8107	0.20235	-0.1287	0.32852	-0.2010	0.42506	-0.2045	0.60177	0.10610	1.16806	0.58653	1.73452
20	6	4	1.4	-1.3832	0.30258	-0.1774	-0.2695	-0.2695	0.58526	-0.2862	0.74264	0.02679	1.29411	0.53435	2.08120
20	6	4	2	-3.7545	0.89797	-0.0232	1.28674	-0.3458	1.04693	-0.4544	1.07622	-0.1365	1.53695	0.40099	2.65711
40	6	4	0	-0.2196	-0.0105	0.06695	0.08348	0.08324	0.11121	0.12259	0.21095	0.34465	0.58661	0.74959	0.78278
40	6	4	0.4	-0.3485	-0.0990	0.08979	0.06199	0.11959	0.08620	0.159	0.18352	0.37889	0.58273	0.86598	0.89813
40	6	4	1	-0.6582	-0.2202	0.12017	0.07685	0.16099	0.09367	0.18251	0.17633	0.38831	0.57719	0.97012	1.14528
40	6	4	1.4	-0.9899	-0.3414	0.16747	0.10702	0.21775	0.11250	0.21578	0.18520	0.41206	0.58322	1.05112	1.32914
40	6	4	2	-1.9538	-0.6670	0.34237	0.23011	0.40729	0.18646	0.31600	0.21165	0.46086	0.59389	1.23170	1.73092
60	6	4	0	-0.1923	-0.0445	0.06240	0.06708	0.09924	0.09525	0.13735	0.19109	0.33080	0.51116	0.70410	0.64494
60	6	4	0.4	-0.3267	-0.1111	0.05625	0.06470	0.10817	0.09448	0.14438	0.18839	0.33685	0.51991	0.76758	0.77216
60	6	4	1	-0.5636	-0.2287	0.05165	0.06451	0.13066	0.09520	0.16135	0.18981	0.36055	0.55386	0.88590	0.96470
60	6	4	1.4	-0.8236	-0.3492	0.06057	0.07782	0.16884	0.10779	0.18846	0.19326	0.37716	0.56405	0.97236	1.12995
60	6	4	2	-1.5330	-0.6672	0.10326	0.13126	0.28935	0.15491	0.27203	0.21420	0.43044	0.59696	1.17748	1.50171
80	6	4	0	-0.1798	-0.0231	0.02769	0.07875	0.06745	0.11235	0.10850	0.20659	0.29414	0.47282	0.59067	0.59509
80	6	4	0.4	-0.3093	-0.0771	0.00583	0.08434	0.06261	0.12176	0.10415	0.21637	0.29043	0.49486	0.63905	0.71887
80	6	4	1	-0.5425	-0.1756	-0.0277	0.09801	0.06119	0.14195	0.10295	0.23737	0.29083	0.53696	0.72532	0.92102
80	6	4	1.4	-0.7166	-0.2508	-0.0504	0.10874	0.06263	0.15583	0.10313	0.25373	0.30095	0.57881	0.79677	1.05803
80	6	4	2	-1.2715	-0.4720	-0.1010	0.16660	0.09086	0.22148	0.12296	0.30652	0.30880	0.65352	0.95333	1.42430
100	6	4	0	-0.1658	-0.0150	0.00479	0.08289	0.04803	0.12153	0.09207	0.21192	0.26445	0.43487	0.50783	0.54310
100	6	4	0.4	-0.2893	-0.0640	-0.0281	0.09126	0.03408	0.13653	0.08144	0.22993	0.25729	0.46714	0.55104	0.66133
100	6	4	1	-0.4826	-0.1453	-0.0786	0.10282	0.01438	0.15787	0.06666	0.25672	0.25083	0.52560	0.52560	0.84980
100	6	4	1.4	-0.6362	-0.2105	-0.1157	0.11396	0.00317	0.17747	0.06151	0.28510	0.25964	0.57365	0.69088	0.97161
100	6	4	2	-1.0978	-0.3919	-0.2108	0.16521	-0.0140	0.24761	0.05197	0.35484	0.25222	0.67540	0.82883	1.31549

APPENDIX D

Finite Element ABAQUS Input File for four-lane, four-box, bridge of curvature ratio L/R of 1.0 and a span length of 60 m

```
*HEADING
4 BOX CURVED SIMPLY SUPPORTED LINEAR CASE
**DATA CHECK
*PREPRINT,ECHO=YES,MODEL=NO,HISTORY=NO
*Restart,write
***REFERENCE NODE COORDINATES 4L4b60sc inside between-boxes bracings
along the bridge**
*NODE
1,0,0,0
8001,0,0,-0.132500
56001,0,0,-2.499500
2,-24.738356,45.283260,0.000000
66,-32.792706,60.026649,0.000000
7202,24.738356,45.283260,0.000000
7266,32.792706,60.026649,0.000000
8006,-25.241751,46.204720,-0.132500
56006,-25.241751,46.204720,-2.499500
15206,25.241751,46.204720,-0.132500
63206,25.241751,46.204720,-2.499500
8062,-32.289307,59.105186,-0.132500
56062,-32.289307,59.105186,-2.499500
15262,32.289307,59.105186,-0.132500
63262,32.289307,59.105186,-2.499500
*********NODE GENERATION FOR END DIAPHRAM************
*NGEN,NSET=ORIGIN
8001,56001,8000
*NGEN,NSET=NEND
***left end****
2,66,2
8006,56006,8000
8062,56062,8000
8006,8062,2
16006,16062,2
24006,24062,2
32006,32062,2
40006,40062,2
48006,48062,2
56006,56062,2
***right end****
7202,7266,2
15206,63206,8000
15262,63262,8000
15206,15262,2
23206,23262,2
31206,31262,2
39206,39262,2
```

```
47206,47262,2
55206,55262,2
63206,63262,2
************************
*NSET,NSET=LEFT7
56014,56022,56030,56038,56046,56054,56062
*NSET,NSET=RIGHT7
63214,63222,63230,63238,63246,63254,63262
*******************************NODE GEN. FOR TOP SLAB ************
*NGEN,NSET=NPLATET,LINE=C
2,7202,100,1
4,7204,100,1
6,7206,100,1
8,7208,100,1
10,7210,100,1
12,7212,100,1
14,7214,100,1
16,7216,100,1
18,7218,100,1
20,7220,100,1
22,7222,100,1
24,7224,100,1
26,7226,100,1
28,7228,100,1
30,7230,100,1
32,7232,100,1
34,7234,100,1
36,7236,100,1
38,7238,100,1
40,7240,100,1
42,7242,100,1
44,7244,100,1
46,7246,100,1
48,7248,100,1
50,7250,100,1
52,7252,100,1
54,7254,100,1
56,7256,100,1
58,7258,100,1
60,7260,100,1
62,7262,100,1
64,7264,100,1
66,7266,100,1
*******************************NODE GEN FOR TOP FLANGE
**************
*NGEN,NSET=NTOPFLNG,LINE=C
```

```
8006,15206,100,8001
8014,15214,100,8001
8022,15222,100,8001
8030,15230,100,8001
8038,15238,100,8001
8046,15246,100,8001
8054,15254,100,8001
8062,15262,100,8001
*******************************NODE GEN. FOR WEBS *******************
*NGEN,NSET=NWEB,LINE=C
16006,23206,100,16001
16014,23214,100,16001
16022,23222,100,16001
16030,23230,100,16001
16038,23238,100,16001
16046,23246,100,16001
16054,23254,100,16001
16062,23262,100,16001
**************************
24006,31206,100,24001
24014,31214,100,24001
24022,31222,100,24001
24030,31230,100,24001
24038,31238,100,24001
24046,31246,100,24001
24054,31254,100,24001
24062,31262,100,24001
**************************
32006,39206,100,32001
32014,39214,100,32001
32022,39222,100,32001
32030,39230,100,32001
32038,39238,100,32001
32046,39246,100,32001
32054,39254,100,32001
32062,39262,100,32001
***************************
40006,47206,100,40001
40014,47214,100,40001
40022,47222,100,40001
40030,47230,100,40001
40038,47238,100,40001
40046,47246,100,40001
40054,47254,100,40001
40062,47262,100,40001
***********************
```

```
48006,55206,100,48001
48014,55214,100,48001
48022,55222,100,48001
48030,55230,100,48001
48038,55238,100,48001
48046,55246,100,48001
48054,55254,100,48001
48062,55262,100,48001
****************************
56006,63206,100,56001
56014,63214,100,56001
56022,63222,100,56001
56030,63230,100,56001
56038,63238,100,56001
56046,63246,100,56001
56054,63254,100,56001
56062,63262,100,56001
****************************NODE GEN FOR BOTTOM FLANGE
******************
*NGEN,NSET=NPLATEB,LINE=C
56008,63208,100,56001
56010,63210,100,56001
56012,63212,100,56001
56014,63214,100,56001
56016,63216,100,56001
56018,63218,100,56001
56020,63220,100,56001
56022,63222,100,56001
56024,63224,100,56001
56026,63226,100,56001
56028,63228,100,56001
56030,63230,100,56001
56032,63232,100,56001
56034,63234,100,56001
56036,63236,100,56001
56038,63238,100,56001
56040,63240,100,56001
56042,63242,100,56001
56044,63244,100,56001
56046,63246,100,56001
56048,63248,100,56001
56050,63250,100,56001
56052,63252,100,56001
56054,63254,100,56001
56056,63256,100,56001
56058,63258,100,56001
```

```
56060,63260,100,56001
****************************ELEMENT GEN FOR TOP SLAB
*********************
*ELEMENT,TYPE=S4R
1,2,102,104,4
*ELGEN,ELSET=ESLABT
1,72,100,32,32,2,1
*************************ELEMENT GEN FOR BOTTOM FLANGE
*****************
*ELEMENT,TYPE=S4R
2305,56006,56106,56108,56008
2593,56022,56122,56124,56024
2881,56038,56138,56140,56040
3169,56054,56154,56156,56056
*ELGEN,ELSET=FLANGEB
2305,72,100,4,4,2,1
2593,72,100,4,4,2,1
2881,72,100,4,4,2,1
3169,72,100,4,4,2,1
**************************ELEMENT GEN FOR TOP FLANGE
******************
*ELEMENT,TYPE=B31H
3457,8006,8106
3529,8014,8114
3601,8022,8122
3673,8030,8130
3745,8038,8138
3817,8046,8146
3889,8054,8154
3961,8062,8162
*ELGEN,ELSET=TOPFL
3457,72,100,1
3529,72,100,1
3601,72,100,1
3673,72,100,1
3745,72,100,1
3817,72,100,1
3889,72,100,1
3961,72,100,1
************************ELEMENT GEN FOR WEBS ********************
*ELEMENT,TYPE=S4R
4033,16006,16106,8106,8006
4465,16014,16114,8114,8014
4897,16022,16122,8122,8022
5329,16030,16130,8130,8030
5761,16038,16138,8138,8038
```

```
6193,16046,16146,8146,8046
6625,16054,16154,8154,8054
7057,16062,16162,8162,8062
*ELGEN,ELSET=WEB
4033,72,100,6,6,8000,1
4465,72,100,6,6,8000,1
4897,72,100,6,6,8000,1
5329,72,100,6,6,8000,1
5761,72,100,6,6,8000,1
6193,72,100,6,6,8000,1
6625,72,100,6,6,8000,1
7057,72,100,6,6,8000,1
**************************ELEMENT GEN FOR END DIAPHRAGM
***************
*ELEMENT,TYPE=S4R
7489,16006,16008,8008,8006
7513,16022,16024,8024,8022
7537,16038,16040,8040,8038
7561,16054,16056,8056,8054
7585,23206,23208,15208,15206
7609,23222,23224,15224,15222
7633,23238,23240,15240,15238
7657,23254,23256,15256,15254
*ELGEN,ELSET=DIAPH
7489,4,2,6,6,8000,1
7513,4,2,6,6,8000,1
7537,4,2,6,6,8000,1
7561,4,2,6,6,8000,1
7585,4,2,6,6,8000,1
7609,4,2,6,6,8000,1
7633,4,2,6,6,8000,1
7657,4,2,6,6,8000,1
****************************END FLANGE ELEMENTS *****************
*ELEMENT,TYPE=B31H
7681,8006,8008
7685,8022,8024
7689,8038,8040
7693,8054,8056
7697,15206,15208
7701,15222,15224
7705,15238,15240
7709,15254,15256
*ELGEN,ELSET=ENDFL
7681,4,2,1
7685,4,2,1
7689,4,2,1
```

```
7693,4,2,1
7697,4,2,1
7701,4,2,1
7705,4,2,1
7709,4,2,1
******************************ELEMENT GEN FOR TRUSS ELEMENTS
***********
*NGEN,NSET=XBP,LINE=C
32010,39210,100,32001
32018,39218,100,32001
32026,39226,100,32001
32034,39234,100,32001
32042,39242,100,32001
32050,39250,100,32001
32058,39258,100,32001
*******************************
*ELEMENT,TYPE=B31H
7713,8906,8914
7714,8906,32910
7715,32910,56914
7716,8914,32910
7717,32910,56906
*ELGEN,ELSET=XBRAC
7713,7,900,20,4,16,5
7714,7,900,20,4,16,5
7715,7,900,20,4,16,5
7716,7,900,20,4,16,5
7717,7,900,20,4,16,5
************************ELEMENT GEN FOR TRUSSES ELEMENTS
BETWEEN BOXES *****
*ELEMENT,TYPE=B31H
20001,8014,8022
20002,8014,32018
20003,32018,56022
20004,8022,32018
20005,32018,56014
20006,56014,56022
*ELGEN,ELSET=XBRAC
20001,9,900,18,3,16,6
20002,9,900,18,3,16,6
20003,9,900,18,3,16,6
20004,9,900,18,3,16,6
20005,9,900,18,3,16,6
20006,9,900,18,3,16,6
*********************************
*NSET,NSET=REACT
```

```
56006,LEFT7,63206,RIGHT7
**********************************MATERIAL PROPERTIES ****************
*BEAM SECTION,SECTION=RECT,ELSET=XBRAC,MATERIAL=STEEL
.1,.1
5,5
*SHELL SECTION,ELSET=WEB,MATERIAL=STEEL
.018,5
*BEAM SECTION,SECTION=RECT,ELSET=TOPFL,MATERIAL=STEEL
.040,.45
5,5
*BEAM SECTION,SECTION=RECT,ELSET=ENDFL,MATERIAL=STEEL
.040,.45
5,5
***********************************************
*SHELL SECTION,ELSET=DIAPH,MATERIAL=STEEL
.018,5
*SHELL SECTION,ELSET=FLANGEB,MATERIAL=STEEL
.026,5
*MATERIAL,NAME=STEEL
*DENSITY
7800
*ELASTIC
200000E6,.3
*SHELL SECTION,ELSET=ESLABT,MATERIAL=CON
.225,5
*MATERIAL,NAME=CON
*DENSITY
2400
*ELASTIC
27000E6,.20
******************MULTIPOINT CONSTRAINT ****************
*NGEN,NSET=SLABN6,LINE=C
6,7206,100,1
*NGEN,NSET=FLANGEN6,LINE=C
8006,15206,100,8001
*NGEN,NSET=SLABN14,LINE=C
14,7214,100,1
*NGEN,NSET=FLANGEN14,LINE=C
8014,15214,100,8001
*NGEN,NSET=SLABN22,LINE=C
22,7222,100,1
*NGEN,NSET=FLANGEN22,LINE=C
8022,15222,100,8001
*NGEN,NSET=SLABN30,LINE=C
30,7230,100,1
*NGEN,NSET=FLANGEN30,LINE=C
```

```
8030,15230,100,8001
*NGEN,NSET=SLABN38,LINE=C
38,7238,100,1
*NGEN,NSET=FLANGEN38,LINE=C
8038,15238,100,8001
*NGEN,NSET=SLABN46,LINE=C
46,7246,100,1
*NGEN,NSET=FLANGEN46,LINE=C
8046,15246,100,8001
*NGEN,NSET=SLABN54,LINE=C
54,7254,100,1
*NGEN,NSET=FLANGEN54,LINE=C
8054,15254,100,8001
*NGEN,NSET=SLABN62,LINE=C
62,7262,100,1
*NGEN,NSET=FLANGEN62,LINE=C
8062,15262,100,8001
****************************************
*NSET,NSET=LTOP1
8,10,12
*NSET,NSET=LTOP2
24,26,28
*NSET,NSET=LTOP3
40,42,44
*NSET,NSET=LTOP4
56,58,60
*NSET,NSET=LBOT1
8008,8010,8012
*NSET,NSET=LBOT2
8024,8026,8028
*NSET,NSET=LBOT3
8040,8042,8044
*NSET,NSET=LBOT4
8056,8058,8060
*NSET,NSET=RTOP1
7208,7210,7212
*NSET,NSET=RTOP2
7224,7226,7228
*NSET,NSET=RTOP3
7240,7242,7244
*NSET,NSET=RTOP4
7256,7258,7260
*NSET,NSET=RBOT1
15208,15210,15212
*NSET,NSET=RBOT2
15224,15226,15228
```

```
*NSET,NSET=RBOT3
15240,15242,15244
*NSET,NSET=RBOT4
15256,15258,15260
*MPC
BEAM,SLABN6,FLANGEN6
BEAM,SLABN14,FLANGEN14
BEAM,SLABN22,FLANGEN22
BEAM,SLABN30,FLANGEN30
BEAM,SLABN38,FLANGEN38
BEAM,SLABN46,FLANGEN46
BEAM,SLABN54,FLANGEN54
BEAM,SLABN62,FLANGEN62
BEAM,LBOT1,LTOP1
BEAM,LBOT2,LTOP2
BEAM,LBOT3,LTOP3
BEAM,LBOT4,LTOP4
BEAM,RBOT1,RTOP1
BEAM,RBOT2,RTOP2
BEAM,RBOT3,RTOP3
BEAM,RBOT4,RTOP4
*****************************************************************
*BOUNDARY
56006,1,3
LEFT7,3
63206,2,3
RIGHT7,3
************************************DEAD LOAD***********************
*STEP
*STATIC
*ELSET,ELSET=LANE,GENERATE
1,2273,32
2,2274,32
3,2275,32
4,2276,32
5,2277,32
6,2278,32
7,2279,32
8,2280,32
9,2281,32
10,2282,32
11,2283,32
12,2284,32
13,2285,32
14,2286,32
15,2287,32
```

```
16,2288,32
17,2289,32
18,2290,32
19,2291,32
20,2292,32
21,2293,32
22,2294,32
23,2295,32
24,2296,32
25,2297,32
26,2298,32
27,2299,32
28,2300,32
29,2301,32
30,2302,32
31,2303,32
32,2304,32
*DLOAD
LANE,GRAV,9.81,0,0,-1
FLANGEB,GRAV,9.81,0,0,-1
TOPFL,GRAV,9.81,0,0,-1
WEB,GRAV,9.81,0,0,-1
****************REACTIONS***********
*NSET,NSET=REACT
56006,LEFT7,63206,RIGHT7
*NODEPRINT,NSET=REACT,TOTALS=YES
RF3
*ENDSTEP
*STEP
*STATIC
************************************CONCNTRIC TRUCK LOADING
*************
*ELSET,ELSET=CTRUCK,GENERATE
3,2275,32
4,2276,32
5,2277,32
6,2278,32
7,2279,32
8,2280,32
9,2281,32
10,2282,32
11,2283,32
12,2284,32
13,2285,32
14,2286,32
15,2287,32
```

```
16,2288,32
17,2289,32
18,2290,32
19,2291,32
20,2292,32
21,2293,32
22,2294,32
23,2295,32
24,2296,32
25,2297,32
26,2298,32
27,2299,32
28,2300,32
29,2301,32
30,2302,32
*DLOAD,OP=NEW
CTRUCK,P,-2448
*NSET,NSET=C1TRUCK
110,116,124,130,138,144,152,158
*NSET,NSET=C2TRUCK
1010,1016,924,930,938,944,852,858
*NSET,NSET=C3TRUCK
1910,1916,1724,1730,1638,1644,1652,1658
*NSET,NSET=C4TRUCK
2010,2016,1924,1930,1838,1844,1752,1758
*NSET,NSET=C5TRUCK
2510,2516,2324,2330,2238,2244,2152,2158
*CLOAD,OP=NEW
C1TRUCK,3,-60000
C2TRUCK,3,-70000
C3TRUCK,3,-50000
C4TRUCK,3,-50000
C5TRUCK,3,-20000
****************REACTIONS***********
*NSET,NSET=REACT
56006,LEFT7,63206,RIGHT7
*NODEPRINT,NSET=REACT,TOTALS=YES
RF3
*ENDSTEP
*STEP
*STATIC
**********************************OUTER TRUCK LOADING
******************
*ELSET,ELSET=OTRUCK,GENERATE
19,2291,32
20,2292,32
```

```
21,2293,32
22,2294,32
23,2295,32
24,2296,32
25,2297,32
26,2298,32
27,2299,32
28,2300,32
29,2301,32
30,2302,32
*DLOAD,OP=NEW
OTRUCK,P,-2857
*NSET,NSET=O1TRUCK
142,148,154,160
*NSET,NSET=O2TRUCK
942,948,854,960
*NSET,NSET=O3TRUCK
1642,1648,1554,1560
*NSET,NSET=O4TRUCK
1742,1748,1754,1760
*NSET,NSET=O5TRUCK
2242,2248,2154,2160
*CLOAD,OP=NEW
O1TRUCK,3,-60000
O2TRUCK,3,-70000
O3TRUCK,3,-50000
O4TRUCK,3,-50000
O5TRUCK,3,-20000
*****************REACTIONS***********
*NSET,NSET=REACT
56006,LEFT7,63206,RIGHT7
*NODEPRINT,NSET=REACT,TOTALS=YES
RF3
*ENDSTEP
*STEP
*STATIC
**********************************INNER TRUCK LOADING
*****************
*ELSET,ELSET=ITRUCK,GENERATE
3,2275,32
4,2276,32
5,2277,32
6,2278,32
7,2279,32
8,2280,32
9,2281,32
```

```
10,2282,32
11,2283,32
12,2284,32
13,2285,32
14,2286,32
*DLOAD,OP=NEW
ITRUCK,P,-2857
*NSET,NSET=I1TRUCK
108,114,120,126
*NSET,NSET=I2TRUCK
1008,1014,920,926
*NSET,NSET=I3TRUCK
1908,1914,1820,1826
*NSET,NSET=I4TRUCK
2008,2014,1920,1926
*NSET,NSET=I5TRUCK
2508,2514,2420,2426
*CLOAD,OP=NEW
I1TRUCK,3,-60000
I2TRUCK,3,-70000
I3TRUCK,3,-50000
I4TRUCK,3,-50000
I5TRUCK,3,-20000
*****************REACTIONS***********
*NSET,NSET=REACT
56006,LEFT7,63206,RIGHT7
*NODEPRINT,NSET=REACT,TOTALS=YES
RF3
*ENDSTEP
```

APPENDIX E

C++ Program for Defining the Geometry and CHBDC Wheel Load Locations Applyied on the Curved Composite Box Girder Bridges

```
#include <functional>
#include <stdio.h>
#include <math.h>
#include <iostream.h>
#include <process.h>

//local function for distance elements dd
int distance(float Arc,float axle)
        {
         float d=axle/Arc;
    int dd = (int) d;
         if (d>=(dd+0.5))
         {
                 d=d+1;
                 dd=(int) d;
         }
         return dd;
  }

//local function for distance element eu
int elementu(float divi,float side)
{
        float eu=side/divi;
        int eeu=(int) eu;
        if (eu>=(eeu+0.5))
        {
                eu=eu+1;
                eeu=(int) eu;
        }
        return eeu;
}

FILE *stream;
//main function
void main(void)
 {
        //declaring the function distance
  int distance(float Arc,float axle);
  //declaring th function elementu
  int elementu(float divi,float side);

// determine the lanes, boxes, Radius, and the length
  float length,boxes,Ratio,lanes,topflg,botflg,height,Radius;
  float deck=225;
  float width,cita,fi,z0,z1,z2;
  cout << "How many lanes ?\n";
```

```
cin >> lanes;
cout << "How many boxes ?\n";
cin >> boxes;
cout << "How much is the length ?\n";
cin >> length;
cout << "How much is the Ratio: Length/Radius ?\n";
cin >> Ratio;
cout << "How much is the top flange thickness ?\n";
cin >> topflg;
  cout << "How much is the bottom flange thickness ?\n";
cin >> botflg;
height=length*1000/25;
Radius = length/Ratio;
// z coordinates
z0=0;
z1=-1*(deck+topflg)/2000;
z2=-1*(deck/2+height-botflg/2)/1000;

//difining fi
cita=(length/Radius);
fi= ( 3.14159265359 - cita)/2;

// defining  the radiui of all required nodes
width=(3.75*lanes + 1.8);
int N=boxes*8;
int i1=2;
int i2=i1+8004;
int o1=i1+N*2;
int o2=o1-4+8000;
int ir1=i1+7200;
int or1=o1+7200;
int i22=i2+48000;
int ir2=i2+7200;
int ir22=i22+7200;
int o22=o2+48000;
int or2=o2+7200;
int or22=o22+7200;

float div = width/N;

float Ri1 = (Radius-width/2);
float Ro1 = (Radius+width/2);
float Ri2 = (Ri1+2*div);
float Ro2 = (Ro1-2*div);

float xi1 = Ri1*(-1)*cos(fi);
```

```
float yi1 = Ri1*sin(fi);
float zi1 = z0;

float xo1 = Ro1*(-1)*cos(fi);
float yo1 = Ro1*sin(fi);
float zo1 =z0;

float xir1 = -xi1;
float yir1 = yi1;
float zir1 =z0;

float xor1 = -xo1;
float yor1 = yo1;
float zor1 =z0;

float xi2 = Ri2*(-1)*cos(fi);
float yi2 = Ri2*sin(fi);
float zi2 = z1;

float xi22 = xi2;
float yi22 = yi2;
float zi22 = z2;

float xir2 = -xi2;
float yir2 = yi2;
float zir2 = z1;

float xir22 = -xi22;
float yir22 = yi22;
float zir22 = z2;


float xo2 = Ro2*(-1)*cos(fi);
float yo2 = Ro2*sin(fi);
float zo2 = z1;

float xo22 = xo2;
float yo22 = yo2;
float zo22 = z2;

float xor2 = -xo2;
float yor2 = yo2;
float zor2 = z1;

float xor22 = -xo2;
float yor22 = yo2;
```

```
float zor22 = z2;

// Titles for the "coordin.inp" output file
  char nodes[]="    Nodes Coordinates";
  char begin[]="1,0,0,0";
  char N8001[]="8001,0,0";
  char N56001[]="56001,0,0";

  //titles for the "loads.inp" output file
  char loadsc[]="    Concentric Truck Loading ";
  char loadso[]="    Outer Truck Loading ";
  char loadsi[]="    Inner Truck Loading ";
  char condis[]="    Concentric Distributed Truck Loading";
  char outdis[]="    Outer Distributed Truck Loading";
  char inndis[]="    Inner Distributed Truck Loading";

  char ko1[]="*ELSET,ELSET=CTRUCK,GENERATE";
  char ko2[]="*DLOAD,OP=NEW";
  char ko3[]="CTRUCK,P";
  char ko4[]="*ELSET,ELSET=OTRUCK,GENERATE";
  char ko5[]="OTRUCK,P";
  char ko6[]="*ELSET,ELSET=ITRUCK,GENERATE";
  char ko7[]="ITRUCK,P";

  char con1[]="*NSET,NSET=C1TRUCK";
  char con2[]="*NSET,NSET=C2TRUCK";
  char con3[]="*NSET,NSET=C3TRUCK";
  char con4[]="*NSET,NSET=C4TRUCK";
  char con5[]="*NSET,NSET=C5TRUCK";
  char out1[]="*NSET,NSET=O1TRUCK";
  char out2[]="*NSET,NSET=O2TRUCK";
  char out3[]="*NSET,NSET=O3TRUCK";
  char out4[]="*NSET,NSET=O4TRUCK";
  char out5[]="*NSET,NSET=O5TRUCK";
  char inn1[]="*NSET,NSET=I1TRUCK";
  char inn2[]="*NSET,NSET=I2TRUCK";
  char inn3[]="*NSET,NSET=I3TRUCK";
  char inn4[]="*NSET,NSET=I4TRUCK";
  char inn5[]="*NSET,NSET=I5TRUCK";

//Opening the file
stream = fopen( "coordin.inp", "w" );
fprintf( stream, "\n%s\n\n", nodes );
fprintf( stream, "\n%s\n", begin );
fprintf( stream, "%s,%f\n", N8001,zi2 );
fprintf( stream, "%s,%f\n", N56001,zi22 );
```

```
fprintf( stream, "%d,%f,%f,%f\n", i1,xi1,yi1,zi1 );
fprintf( stream, "%d,%f,%f,%f\n", o1,xo1,yo1,zo1 );
fprintf( stream, "%d,%f,%f,%f\n", ir1,xir1,yir1,zir1 );
fprintf( stream, "%d,%f,%f,%f\n", or1,xor1,yor1,zor1 );
fprintf( stream, "%d,%f,%f,%f\n", i2,xi2,yi2,zi2 );
fprintf( stream, "%d,%f,%f,%f\n", i22,xi22,yi22,zi22 );
fprintf( stream, "%d,%f,%f,%f\n", ir2,xir2,yir2,zir2 );
fprintf( stream, "%d,%f,%f,%f\n", ir22,xir22,yir22,zir22 );
fprintf( stream, "%d,%f,%f,%f\n", o2,xo2,yo2,zo2 );
fprintf( stream, "%d,%f,%f,%f\n", o22,xo22,yo22,zo22 );
fprintf( stream, "%d,%f,%f,%f\n", or2,xor2,yor2,zor2 );
fprintf( stream, "%d,%f,%f,%f\n\n", or22,xor22,yor22,zor22 );

fclose( stream );
system( "type coordin.inp" );

//cross section spacings of Truck loads
double s1=1.875;
double so1=1.5;
double so2=1.5;
double s2=1.95;
double w=1.8;

float alfa = cita/72;



  float NS1=s1/div;
  int NNS1= (int) NS1;
  if (NS1>=(NNS1+0.5))
  {
  NS1=NS1+1;
  NNS1=(int) NS1;
  }

  float NSO1=so1/div;
  int NNSO1= (int) NSO1;
  if (NSO1>=(NNSO1+0.5))
  {
  NSO1=NSO1+1;
  NNSO1=(int) NSO1;
  }

  float NW=w/div;
  int NNW= (int) NW;
  if (NW>=(NNW+0.5))
```

```
{
NW=NW+1;
NNW=(int) NW;
}


//Truck Load for 4 lanes
if (lanes == 4)
{
 float NS2=s2/div;
 int NNS2= (int) NS2;
 if (NS2>=(NNS2+0.5))
 {
 NS2=NS2+1;
 NNS2=(int) NS2;
 }

 float NSO2=so2/div;
 int NNSO2= (int) NSO2;
 if (NSO2>=(NNSO2+0.5))
 {
 NSO2=NSO2+1;
 NNSO2=(int) NSO2;
 }

 int NNS3=N-(2*NNS1+4*NNW+2*NNS2);


 float Arc1=alfa*(Ri1+div*(NNS1+NNW/2));
 float Arc2=alfa*(Ri1+div*(NNS1+1.5*NNW+NNS2));
 float Arc3=alfa*(Ri1+div*(NNS1+NNS2+NNS3+2.5*NNW));
 float Arc4=alfa*(Ri1+div*(NNS1+2*NNS2+NNS3+3.5*NNW));

 float Arco1=alfa*(Ro1-div*(NNSO1+NNW/2));
 float Arco2=alfa*(Ro1-div*(NNSO1+1.5*NNW+NNSO2));

 float Arci1=alfa*(Ri1+div*(NNSO1+NNW/2));//so1=si1 and so2=si2
 float Arci2=alfa*(Ri1+div*(NNSO1+1.5*NNW+NNSO2));
//open file 4Lloads.inp
  stream = fopen( "4Lloads.inp", "w" );
if (length>40)
{
        int eucon=elementu(div,0.9);
        int eb1=eucon+1;
        int el1=eb1+N*71;
        int eb2=N-eucon;
```

```
	int el2=eb2+N*71;
	int eo2=eb2;
	int delta=elementu(div,0.6);
	int eo1=eo2-(2*NNW+NNSO2+2*delta);
	int ei1=eb1;
	int ei2=ei1+2*NNW+NNSO2+2*delta;

	signed int intensityc = -9000*lanes/div/(N-2*eucon);
	signed int intensityo = -9000*2/(div*(eo2-eo1+1));
	signed int intensityi = -9000*2/(div*(ei2-ei1+1));

 /*//open file 4ldistrb
 stream = fopen( "4ldistrb.inp", "w" );*/

 //write to the file
 //concentric elements
 fprintf( stream, "\n%s\n\n", condis );
 fprintf( stream, "%s\n", ko1 );

 for (int y=eb1;y<=eb2;y++)
 {
	int el=y+N*71;
 fprintf( stream, "%d,%d,%d\n",y,el,N );
 }
 fprintf( stream, "%s\n", ko2 );
 fprintf( stream, "%s,%d\n", ko3,intensityc );

 //outer elements
 fprintf( stream, "\n%s\n\n", outdis );
 fprintf( stream, "%s\n", ko4 );
 for (int y1=eo1;y1<=eo2;y1++)
 {
	int eol=y1+N*71;
 fprintf( stream, "%d,%d,%d\n",y1,eol,N );
 }
 fprintf( stream, "%s\n", ko2 );
 fprintf( stream, "%s,%d\n", ko5,intensityo );

//Inner elements
 fprintf( stream, "\n%s\n\n", inndis );
 fprintf( stream, "%s\n", ko6 );
 for (int y2=ei1;y2<=ei2;y2++)
 {
	int eil=y2+N*71;
 fprintf( stream, "%d,%d,%d\n",y2,eil,N );
 }
```

```
fprintf( stream, "%s\n", ko2 );
fprintf( stream, "%s,%d\n", ko7,intensityi );

//close the file
/*fclose( stream );
system( "type 4ldistrb.inp" );*/

}


//distances to second wheel
//concentric:
int dd1= distance(Arc1,6.6);

int dd2= distance(Arc2,6.6);

int dd3= distance(Arc3,6.6);

int dd4= distance(Arc4,6.6);
//outer:
int ddo1= distance(Arco1,6.6);

int ddo2= distance(Arco2,6.6);

//inner
int ddi1= distance(Arci1,6.6);

int ddi2= distance(Arci2,6.6);

//distances to third wheel
//concentric:
int ee1= distance(Arc1,13.2);

int ee2= distance(Arc2,13.2);

int ee3= distance(Arc3,13.2);

int ee4= distance(Arc4,13.2);

//outer
int eeo1= distance(Arco1,13.2);

int eeo2= distance(Arco2,13.2);

//inner
int eei1= distance(Arci1,13.2);
```

```
  int eei2= distance(Arci2,13.2);

//distances to fourth wheel
  //concentric
  int ff1= distance(Arc1,14.4);

  int ff2= distance(Arc2,14.4);

  int ff3= distance(Arc3,14.4);

  int ff4= distance(Arc4,14.4);

  //outer
  int ffo1= distance(Arco1,14.4);

  int ffo2= distance(Arco2,14.4);

  //inner
  int ffi1= distance(Arci1,14.4);

  int ffi2= distance(Arci2,14.4);

  //distances to fifth wheel
  //concentric
  int gg1= distance(Arc1,18);

  int gg2= distance(Arc2,18);

  int gg3= distance(Arc3,18);

  int gg4= distance(Arc4,18);

  //outer
  int ggo1= distance(Arco1,18);

  int ggo2= distance(Arco2,18);

  //inner
  int ggi1= distance(Arci1,18);

  int ggi2= distance(Arci2,18);

//concentric nodes:
  //I loads
  int I1 = 102 + 2*NNS1;
```

```
int I2 = I1 + 2*NNW;
int I3 = I2 + 2*NNS2;
int I4 = I3 + 2*NNW;
int I5 = I4 + 2*NNS3;
int I6 = I5 + 2*NNW;
int I7 = I6 + 2*NNS2;
int I8 = I7 + 2*NNW;

//J loads
int J1 = I1 + 100*dd1;
int J2 = I2 + 100*dd1;
int J3 = I3 + 100*dd2;
int J4 = I4 + 100*dd2;
int J5 = I5 + 100*dd3;
int J6 = I6 + 100*dd3;
int J7 = I7 + 100*dd4;
int J8 = I8 + 100*dd4;

//K loads
int K1 = I1 + 100*ee1;
int K2 = I2 + 100*ee1;
int K3 = I3 + 100*ee2;
int K4 = I4 + 100*ee2;
int K5 = I5 + 100*ee3;
int K6 = I6 + 100*ee3;
int K7 = I7 + 100*ee4;
int K8 = I8 + 100*ee4;

//L loads
int L1 = I1 + 100*ff1;
int L2 = I2 + 100*ff1;
int L3 = I3 + 100*ff2;
int L4 = I4 + 100*ff2;
int L5 = I5 + 100*ff3;
int L6 = I6 + 100*ff3;
int L7 = I7 + 100*ff4;
int L8 = I8 + 100*ff4;

//M loads
int M1 = I1 + 100*gg1;
int M2 = I2 + 100*gg1;
int M3 = I3 + 100*gg2;
int M4 = I4 + 100*gg2;
int M5 = I5 + 100*gg3;
int M6 = I6 + 100*gg3;
int M7 = I7 + 100*gg4;
```

```
int M8 = I8 + 100*gg4;

//outer nodes
//Io loads
int Io1 = 102+N*2-2*(NNSO1+2*NNW+NNSO2);
int Io2 = 102+N*2-2*(NNSO1+NNW+NNSO2);
int Io3 = 102+N*2-2*(NNSO1+NNW);
int Io4 = 102+N*2-2*NNSO1;


//Jo loads
int Jo1 = Io1 + 100*ddo2;
int Jo2 = Io2 + 100*ddo2;
int Jo3 = Io3 + 100*ddo1;
int Jo4 = Io4 + 100*ddo2;


//Ko loads
int Ko1 = Io1 + 100*eeo2;
int Ko2 = Io2 + 100*eeo2;
int Ko3 = Io3 + 100*eeo1;
int Ko4 = Io4 + 100*eeo1;

//Lo loads
int Lo1 = Io1 + 100*ffo2;
int Lo2 = Io2 + 100*ffo2;
int Lo3 = Io3 + 100*ffo1;
int Lo4 = Io4 + 100*ffo1;

//Mo loads
int Mo1 = Io1 + 100*ggo2;
int Mo2 = Io2 + 100*ggo2;
int Mo3 = Io3 + 100*ggo1;
int Mo4 = Io4 + 100*ggo1;

//inner nodes
//Ii loads
int Ii1 = 102 + 2*NNSO1;
int Ii2 = Ii1 + 2*NNW;
int Ii3 = Ii2 + 2*NNSO2;
int Ii4 = Ii3 + 2*NNW;

//Ji loads
int Ji1 = Ii1 + 100*ddi1;
int Ji2 = Ii2 + 100*ddi1;
int Ji3 = Ii3 + 100*ddi2;
```

```
int Ji4 = Ii4 + 100*ddi2;

//Ki loads
int Ki1 = Ii1 + 100*eei1;
int Ki2 = Ii2 + 100*eei1;
int Ki3 = Ii3 + 100*eei2;
int Ki4 = Ii4 + 100*eei2;

//Li loads
int Li1 = Ii1 + 100*ffi1;
int Li2 = Ii2 + 100*ffi1;
int Li3 = Ii3 + 100*ffi2;
int Li4 = Ii4 + 100*ffi2;

//Mi loads
int Mi1 = Ii1 + 100*ggi1;
int Mi2 = Ii2 + 100*ggi1;
int Mi3 = Ii3 + 100*ggi2;
int Mi4 = Ii4 + 100*ggi2;

//open file 4lanes
/*stream = fopen( "4Lpoint.inp", "w" );
*/
//write to the file
//concentric nodes
fprintf( stream, "\n%s\n\n", loadsc );
fprintf( stream, "%s\n", con1 );
fprintf( stream, "%d,%d,%d,%d,%d,%d,%d,%d\n",I1,I2,I3,I4,I5,I6,I7,I8 );
fprintf( stream, "%s\n", con2 );
fprintf( stream, "%d,%d,%d,%d,%d,%d,%d,%d\n",J1,J2,J3,J4,J5,J6,J7,J8 );
fprintf( stream, "%s\n", con3 );
fprintf( stream, "%d,%d,%d,%d,%d,%d,%d,%d\n",K1,K2,K3,K4,K5,K6,K7,K8 );
fprintf( stream, "%s\n", con4 );
fprintf( stream, "%d,%d,%d,%d,%d,%d,%d,%d\n",L1,L2,L3,L4,L5,L6,L7,L8 );
fprintf( stream, "%s\n", con5 );
fprintf( stream, "%d,%d,%d,%d,%d,%d,%d,%d\n",M1,M2,M3,M4,M5,M6,M7,M8 );
//outer nodes
fprintf( stream, "%s\n\n", loadso );
fprintf( stream, "%s\n", out1 );
fprintf( stream, "%d,%d,%d,%d\n",Io1,Io2,Io3,Io4 );
fprintf( stream, "%s\n", out2 );
fprintf( stream, "%d,%d,%d,%d\n",Jo1,Jo2,Jo3,Jo4 );
fprintf( stream, "%s\n", out3 );
fprintf( stream, "%d,%d,%d,%d\n",Ko1,Ko2,Ko3,Ko4 );
fprintf( stream, "%s\n", out4 );
fprintf( stream, "%d,%d,%d,%d\n",Lo1,Lo2,Lo3,Lo4 );
```

```
  fprintf( stream, "%s\n", out5 );
  fprintf( stream, "%d,%d,%d,%d\n",Mo1,Mo2,Mo3,Mo4 );
  //inner nodes
  fprintf( stream, "\n%s\n\n", loadsi );
  fprintf( stream, "%s\n", inn1 );
  fprintf( stream, "%d,%d,%d,%d\n",Ii1,Ii2,Ii3,Ii4 );
  fprintf( stream, "%s\n", inn2 );
  fprintf( stream, "%d,%d,%d,%d\n",Ji1,Ji2,Ji3,Ji4 );
  fprintf( stream, "%s\n", inn3 );
  fprintf( stream, "%d,%d,%d,%d\n",Ki1,Ki2,Ki3,Ki4 );
  fprintf( stream, "%s\n", inn4 );
  fprintf( stream, "%d,%d,%d,%d\n",Li1,Li2,Li3,Li4 );
  fprintf( stream, "%s\n", inn5 );
  fprintf( stream, "%d,%d,%d,%d\n",Mi1,Mi2,Mi3,Mi4 );

  //close the file
  fclose( stream );
system( "type 4Lloads.inp" );


}

   //Concentric Truck Load for 3 lanes
  if (lanes == 3)
{
  int NNS2 = (N-(2*NNS1+3*NNW))/2;

  float NSO2=so2/div;
  int NNSO2= (int) NSO2;
  if (NSO2>=(NNSO2+0.5))
  {
  NSO2=NSO2+1;
  NNSO2=(int) NSO2;
  }

  float Arc1=alfa*(Ri1+div*(NNS1+NNW/2));
  float Arc2=alfa*(Ri1+div*(NNS1+1.5*NNW+NNS2));
  float Arc3=alfa*(Ri1+div*(NNS1+2*NNS2+2.5*NNW));

  float Arco1=alfa*(Ro1-div*(NNSO1+NNW/2));
  float Arco2=alfa*(Ro1-div*(NNSO1+1.5*NNW+NNSO2));

  float Arci1=alfa*(Ri1+div*(NNSO1+NNW/2));//so1=si1 and so2=si2
  float Arci2=alfa*(Ri1+div*(NNSO1+1.5*NNW+NNSO2));

//to be checked since it's a copy from 4lanes:
```

```
 stream = fopen( "3Lloads.inp", "w" );
 if (length>40)
{
int eucon=elementu(div,0.9);
        int eb1=eucon+1;
        int el1=eb1+N*71;
        int eb2=N-eucon;
        int el2=eb2+N*71;
        int eo2=eb2;
        int delta=elementu(div,0.6);
        int eo1=eo2-(2*NNW+NNSO2+2*delta);
        int ei1=eb1;
        int ei2=ei1+2*NNW+NNSO2+2*delta;

        int intensityc = -9000*lanes/div/(N-2*eucon);
        int intensityo = -9000*2/(div*(eo2-eo1+1));
        int intensityi = -9000*2/(div*(ei2-ei1+1));

  //open file 3ldistrb
  /*stream = fopen( "3ldistrb.inp", "w" );*/

 //write to the file
 //concentric elements
 fprintf( stream, "\n%s\n\n", condis );
 fprintf( stream, "%s\n", ko1 );

 for (int y=eb1;y<=eb2;y++)
 {
         int el=y+N*71;
 fprintf( stream, "%d,%d,%d\n",y,el,N );
 }
 fprintf( stream, "%s\n", ko2 );
 fprintf( stream, "%s,%d\n", ko3,intensityc );

 //outer elements
 fprintf( stream, "\n%s\n\n", outdis );
 fprintf( stream, "%s\n", ko4 );
 for (int y1=eo1;y1<=eo2;y1++)
 {
         int eol=y1+N*71;
 fprintf( stream, "%d,%d,%d\n",y1,eol,N );
 }
 fprintf( stream, "%s\n", ko2 );
 fprintf( stream, "%s,%d\n", ko5,intensityo );
```

```
//Inner elements
  fprintf( stream, "\n%s\n\n", inndis );
  fprintf( stream, "%s\n", ko6 );
  for (int y2=ei1;y2<=ei2;y2++)
  {
          int eil=y2+N*71;
  fprintf( stream, "%d,%d,%d\n",y2,eil,N );
  }
  fprintf( stream, "%s\n", ko2 );
  fprintf( stream, "%s,%d\n", ko7,intensityi );

  //close the file
  /*fclose( stream );
  system( "type 3ldistrb.inp" );*/

}
  //distances to second wheel
  //concentric
  int dd1= distance(Arc1,6.6);

  int dd2= distance(Arc2,6.6);

  int dd3= distance(Arc3,6.6);

  //outer:
  int ddo1= distance(Arco1,6.6);

  int ddo2= distance(Arco2,6.6);

  //inner
  int ddi1= distance(Arci1,6.6);

  int ddi2= distance(Arci2,6.6);


  //distances to third wheel
  int ee1= distance(Arc1,13.2);

  int ee2= distance(Arc2,13.2);

  int ee3= distance(Arc3,13.2);

  //outer
  int eeo1= distance(Arco1,13.2);

  int eeo2= distance(Arco2,13.2);
```

```
//inner
int eei1= distance(Arci1,13.2);

int eei2= distance(Arci2,13.2);

//distances to fourth wheel
int ff1= distance(Arc1,14.4);

int ff2= distance(Arc2,14.4);

int ff3= distance(Arc3,14.4);

//outer
int ffo1= distance(Arco1,14.4);

int ffo2= distance(Arco2,14.4);

//inner
int ffi1= distance(Arci1,14.4);

int ffi2= distance(Arci2,14.4);


//distances to fifth wheel
int gg1= distance(Arc1,18);

int gg2= distance(Arc2,18);

int gg3= distance(Arc3,18);

//outer
int ggo1= distance(Arco1,18);

int ggo2= distance(Arco2,18);

//inner
int ggi1= distance(Arci1,18);

int ggi2= distance(Arci2,18);

//concentric nodes
//I loads
int I1 = 102 + 2*NNS1;
int I2 = I1 + 2*NNW;
int I3 = I2 + 2*NNS2;
```

```
int I4 = I3 + 2*NNW;
int I5 = I4 + 2*NNS2;
int I6 = I5 + 2*NNW;

//J loads
int J1 = I1 + 100*dd1;
int J2 = I2 + 100*dd1;
int J3 = I3 + 100*dd2;
int J4 = I4 + 100*dd2;
int J5 = I5 + 100*dd3;
int J6 = I6 + 100*dd3;

//K loads
int K1 = I1 + 100*ee1;
int K2 = I2 + 100*ee1;
int K3 = I3 + 100*ee2;
int K4 = I4 + 100*ee2;
int K5 = I5 + 100*ee3;
int K6 = I6 + 100*ee3;

//L loads
int L1 = I1 + 100*ff1;
int L2 = I2 + 100*ff1;
int L3 = I3 + 100*ff2;
int L4 = I4 + 100*ff2;
int L5 = I5 + 100*ff3;
int L6 = I6 + 100*ff3;

//M loads
int M1 = I1 + 100*gg1;
int M2 = I2 + 100*gg1;
int M3 = I3 + 100*gg2;
int M4 = I4 + 100*gg2;
int M5 = I5 + 100*gg3;
int M6 = I6 + 100*gg3;

//outer nodes
//Io loads
int Io1 = 102+N*2-2*(NNSO1+2*NNW+NNSO2);
int Io2 = 102+N*2-2*(NNSO1+NNW+NNSO2);
int Io3 = 102+N*2-2*(NNSO1+NNW);
int Io4 = 102+N*2-2*NNSO1;


//Jo loads
int Jo1 = Io1 + 100*ddo2;
```

```
int Jo2 = Io2 + 100*ddo2;
int Jo3 = Io3 + 100*ddo1;
int Jo4 = Io4 + 100*ddo2;


//Ko loads
int Ko1 = Io1 + 100*eeo2;
int Ko2 = Io2 + 100*eeo2;
int Ko3 = Io3 + 100*eeo1;
int Ko4 = Io4 + 100*eeo1;

//Lo loads
int Lo1 = Io1 + 100*ffo2;
int Lo2 = Io2 + 100*ffo2;
int Lo3 = Io3 + 100*ffo1;
int Lo4 = Io4 + 100*ffo1;

//Mo loads
int Mo1 = Io1 + 100*ggo2;
int Mo2 = Io2 + 100*ggo2;
int Mo3 = Io3 + 100*ggo1;
int Mo4 = Io4 + 100*ggo1;

//inner nodes
//Ii loads
int Ii1 = 102 + 2*NNSO1;
int Ii2 = Ii1 + 2*NNW;
int Ii3 = Ii2 + 2*NNSO2;
int Ii4 = Ii3 + 2*NNW;

//Ji loads
int Ji1 = Ii1 + 100*ddi1;
int Ji2 = Ii2 + 100*ddi1;
int Ji3 = Ii3 + 100*ddi2;
int Ji4 = Ii4 + 100*ddi2;

//Ki loads
int Ki1 = Ii1 + 100*eei1;
int Ki2 = Ii2 + 100*eei1;
int Ki3 = Ii3 + 100*eei2;
int Ki4 = Ii4 + 100*eei2;

//Li loads
int Li1 = Ii1 + 100*ffi1;
int Li2 = Ii2 + 100*ffi1;
int Li3 = Ii3 + 100*ffi2;
```

```
int Li4 = Ii4 + 100*ffi2;

//Mi loads
int Mi1 = Ii1 + 100*ggi1;
int Mi2 = Ii2 + 100*ggi1;
int Mi3 = Ii3 + 100*ggi2;
int Mi4 = Ii4 + 100*ggi2;

//open file 3lanes
/*stream = fopen( "3Lpoint.inp", "w" );*/

//write to the file
//concentric nodes
fprintf( stream, "\n%s\n\n", loadsc );
fprintf( stream, "%s\n", con1 );
fprintf( stream, "%d,%d,%d,%d,%d,%d\n",I1,I2,I3,I4,I5,I6 );
fprintf( stream, "%s\n", con2 );
fprintf( stream, "%d,%d,%d,%d,%d,%d\n",J1,J2,J3,J4,J5,J6 );
fprintf( stream, "%s\n", con3 );
fprintf( stream, "%d,%d,%d,%d,%d,%d\n",K1,K2,K3,K4,K5,K6 );
fprintf( stream, "%s\n", con4 );
fprintf( stream, "%d,%d,%d,%d,%d,%d\n",L1,L2,L3,L4,L5,L6 );
fprintf( stream, "%s\n", con5 );
fprintf( stream, "%d,%d,%d,%d,%d,%d\n",M1,M2,M3,M4,M5,M6 );
//outer nodes
fprintf( stream, "\n%s\n\n", loadso );
fprintf( stream, "%s\n", out1 );
fprintf( stream, "%d,%d,%d,%d\n",Io1,Io2,Io3,Io4 );
fprintf( stream, "%s\n", out2 );
fprintf( stream, "%d,%d,%d,%d\n",Jo1,Jo2,Jo3,Jo4 );
fprintf( stream, "%s\n", out3 );
fprintf( stream, "%d,%d,%d,%d\n",Ko1,Ko2,Ko3,Ko4 );
fprintf( stream, "%s\n", out4 );
fprintf( stream, "%d,%d,%d,%d\n",Lo1,Lo2,Lo3,Lo4 );
fprintf( stream, "%s\n", out5 );
fprintf( stream, "%d,%d,%d,%d\n",Mo1,Mo2,Mo3,Mo4 );
//inner nodes
fprintf( stream, "\n%s\n\n", loadsi );
fprintf( stream, "%s\n", inn1 );
fprintf( stream, "%d,%d,%d,%d\n",Ii1,Ii2,Ii3,Ii4 );
fprintf( stream, "%s\n", inn2 );
fprintf( stream, "%d,%d,%d,%d\n",Ji1,Ji2,Ji3,Ji4 );
fprintf( stream, "%s\n", inn3 );
fprintf( stream, "%d,%d,%d,%d\n",Ki1,Ki2,Ki3,Ki4 );
fprintf( stream, "%s\n", inn4 );
fprintf( stream, "%d,%d,%d,%d\n",Li1,Li2,Li3,Li4 );
```

```
 fprintf( stream, "%s\n", inn5 );
 fprintf( stream, "%d,%d,%d,%d\n",Mi1,Mi2,Mi3,Mi4 );

 //close the file
 fclose( stream );
system( "type 3Lloads.inp" );



}

 //Truck Load for 2 lanes
  if (lanes == 2)
{
 int NNS2 = (N-2*(NNS1+NNW));

 float Arc1=alfa*(Ri1+div*(NNS1+NNW/2));
 float Arc2=alfa*(Ri1+div*(NNS1+1.5*NNW+NNS2));

 float Arco1=alfa*(Ro1-div*(NNSO1+NNW/2));

 float Arci1=alfa*(Ri1+div*(NNSO1+NNW/2));//so1=si1 and so2=si2

 stream = fopen( "2Lloads.inp", "w" );
 if (length>40)
{
        int eucon=elementu(div,0.9);
        int eb1=eucon+1;
        int el1=eb1+N*71;
        int eb2=N-eucon;
        int el2=eb2+N*71;
        int eo2=eb2;
        int delta=elementu(div,0.6);

   int eo1=eo2-(NNW+2*delta);
        int ei1=eb1;
        int ei2=ei1+NNW+2*delta;

        int intensityc = -9000*lanes/div/(N-2*eucon);
        int intensityo = -9000/(div*(eo2-eo1+1));
        int intensityi = -9000/(div*(ei2-ei1+1));

  //open file 2ldistrb
/*stream = fopen( "2ldistrb.inp", "w" );*/

 //write to the file
```

```
//concentric elements
fprintf( stream, "\n%s\n\n", condis );
fprintf( stream, "%s\n", ko1 );

for (int y=eb1;y<=eb2;y++)
{
        int el=y+N*71;
fprintf( stream, "%d,%d,%d\n",y,el,N );
}
fprintf( stream, "%s\n", ko2 );
fprintf( stream, "%s,%d\n", ko3,intensityc );

//outer elements
fprintf( stream, "\n%s\n\n", outdis );
fprintf( stream, "%s\n", ko4 );
for (int y1=eo1;y1<=eo2;y1++)
{
        int eol=y1+N*71;
fprintf( stream, "%d,%d,%d\n",y1,eol,N );
}
fprintf( stream, "%s\n", ko2 );
fprintf( stream, "%s,%d\n", ko5,intensityo );

//Inner elements
fprintf( stream, "\n%s\n\n", inndis );
fprintf( stream, "%s\n", ko6 );
for (int y2=ei1;y2<=ei2;y2++)
{
        int eil=y2+N*71;
fprintf( stream, "%d,%d,%d\n",y2,eil,N );
}
fprintf( stream, "%s\n", ko2 );
fprintf( stream, "%s,%d\n", ko7,intensityi );

//close the file
//fclose( stream );
//system( "type 2ldistrb.inp" );

}


//distances to second wheel
//concentric:
int dd1= distance(Arc1,6.6);

int dd2= distance(Arc2,6.6);
```

```
//outer:
int ddo1= distance(Arco1,6.6);

//inner
int ddi1= distance(Arci1,6.6);

//distances to third wheel
//concentric
int ee1= distance(Arc1,13.2);

int ee2= distance(Arc2,13.2);

//outer
int eeo1= distance(Arco1,13.2);

//inner
int eei1= distance(Arci1,13.2);

//distances to fourth wheel
//concentric
int ff1= distance(Arc1,14.4);

int ff2= distance(Arc2,14.4);

//outer
int ffo1= distance(Arco1,14.4);

//inner
int ffi1= distance(Arci1,14.4);


//distances to fifth wheel
int gg1= distance(Arc1,18);

int gg2= distance(Arc2,18);

//outer
int ggo1= distance(Arco1,18);

//inner
int ggi1= distance(Arci1,18);

//concentric nodes:
//I loads
int I1 = 102 + 2*NNS1;
```

```
int I2 = I1 + 2*NNW;
int I3 = I2 + 2*NNS2;
int I4 = I3 + 2*NNW;

//J loads
int J1 = I1 + 100*dd1;
int J2 = I2 + 100*dd1;
int J3 = I3 + 100*dd2;
int J4 = I4 + 100*dd2;

//K loads
int K1 = I1 + 100*ee1;
int K2 = I2 + 100*ee1;
int K3 = I3 + 100*ee2;
int K4 = I4 + 100*ee2;

//L loads
int L1 = I1 + 100*ff1;
int L2 = I2 + 100*ff1;
int L3 = I3 + 100*ff2;
int L4 = I4 + 100*ff2;

//M loads
int M1 = I1 + 100*gg1;
int M2 = I2 + 100*gg1;
int M3 = I3 + 100*gg2;
int M4 = I4 + 100*gg2;

//outer nodes
//Io loads
int Io1 = 102+N*2-2*(NNSO1+2*NNW);
int Io2 = 102+N*2-2*(NNSO1);

//Jo loads
int Jo1 = Io1 + 100*ddo1;
int Jo2 = Io2 + 100*ddo1;

//Ko loads
int Ko1 = Io1 + 100*eeo1;
int Ko2 = Io2 + 100*eeo1;

//Lo loads
int Lo1 = Io1 + 100*ffo1;
int Lo2 = Io2 + 100*ffo1;

//Mo loads
```

```
int Mo1 = Io1 + 100*ggo1;
int Mo2 = Io2 + 100*ggo1;

//inner nodes
//Ii loads
int Ii1 = 102 + 2*NNSO1;
int Ii2 = Ii1 + 2*NNW;

 //Ji loads
int Ji1 = Ii1 + 100*ddi1;
int Ji2 = Ii2 + 100*ddi1;

 //Ki loads
int Ki1 = Ii1 + 100*eei1;
int Ki2 = Ii2 + 100*eei1;

//Li loads
int Li1 = Ii1 + 100*ffi1;
int Li2 = Ii2 + 100*ffi1;

 //Mi loads
int Mi1 = Ii1 + 100*ggi1;
int Mi2 = Ii2 + 100*ggi1;



//open file 2lanes
//stream = fopen( "2Lpoint.inp", "w" );

//write to the file
//concentric nodes
fprintf( stream, "\n%s\n\n", loadsc );
fprintf( stream, "%s\n", con1 );
fprintf( stream, "%d,%d,%d,%d\n",I1,I2,I3,I4 );
fprintf( stream, "%s\n", con2 );
fprintf( stream, "%d,%d,%d,%d\n",J1,J2,J3,J4 );
fprintf( stream, "%s\n", con3 );
fprintf( stream, "%d,%d,%d,%d\n",K1,K2,K3,K4 );
fprintf( stream, "%s\n", con4 );
fprintf( stream, "%d,%d,%d,%d\n",L1,L2,L3,L4 );
fprintf( stream, "%s\n", con5 );
fprintf( stream, "%d,%d,%d,%d\n",M1,M2,M3,M4 );
//outer nodes
fprintf( stream, "\n%s\n\n", loadso );
fprintf( stream, "%s\n", out1 );
fprintf( stream, "%d,%d\n",Io1,Io2 );
```

```
 fprintf( stream, "%s\n", out2 );
 fprintf( stream, "%d,%d\n",Jo1,Jo2 );
 fprintf( stream, "%s\n", out3 );
 fprintf( stream, "%d,%d\n",Ko1,Ko2 );
 fprintf( stream, "%s\n", out4 );
 fprintf( stream, "%d,%d\n",Lo1,Lo2 );
 fprintf( stream, "%s\n", out5 );
 fprintf( stream, "%d,%d\n",Mo1,Mo2 );
 //inner nodes
 fprintf( stream, "\n%s\n\n", loadsi );
 fprintf( stream, "%s\n", inn1 );
 fprintf( stream, "%d,%d\n",Ii1,Ii2 );
 fprintf( stream, "%s\n", inn2 );
 fprintf( stream, "%d,%d\n",Ji1,Ji2 );
 fprintf( stream, "%s\n", inn3 );
 fprintf( stream, "%d,%d\n",Ki1,Ki2 );
 fprintf( stream, "%s\n", inn4 );
 fprintf( stream, "%d,%d\n",Li1,Li2 );
 fprintf( stream, "%s\n", inn5 );
 fprintf( stream, "%d,%d\n",Mi1,Mi2 );

 //close the file
 fclose( stream );
system( "type 2Lloads.inp" );

}

//Holding the Monitor
cout<<"Have you finished ?";
char reply;
cin >> reply;

}
```