Addis Ababa Institute of Technology
School of Graduate Studies
School of Civil and Environmental Engineering

APPROXIMATE AND GRILLAGE ANALOGY METHODS OF ANALYSIS OF RC T- AND BOX GIRDER BRIDGES - COMPARATIVE STUDY,

A thesis submitted to the school of Graduate Studies in Partial fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

By

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Advisor: **Dr. Asnake Adamu**

April, 2016

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Declaration

I, the undersigned, declared that this thesis is my work and all sources of materials used for the thesis have been duly acknowledged.

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I am indebted to my advisor, Dr. Asnake Adamu, for his direction and support throughout my graduate studies at the Addis Ababa University Institute of Technology. His interest in my work provided me with the constant motivation needed to achieve my goal.

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g = Distribution Factor.

ERA = Ethiopian Roads Authority.

AACRA = Addis Ababa City Roads Authority.

AASHTO = American Association of State Highway and Transportation Officials.

App. = Approximate.

Fig. = Figure.

Grill. = Grillage.

Diap. = Diaphragm.

1D = One Dimensional.

3D = Three Dimensional.

D.O.F = Degree of Freedom

RCTG = Reinforced Concrete T-Girder

RCBG = Reinforced Concrete Box Girder

Abstract

Bridges are one part of the Road Infrastructures which needs care during design stages, among which include analysis. The most common Bridge superstructures forms widely used are RC T- and Box Girder types. To analyze such forms the most widely used method of analysis is Approximate Method based on Distribution Factor concept. This method is preferred due to its simplicity for use. This method has limitation for not considering stiffness of components sufficiently and effect of provision of diaphragm on load distribution; these parameters have great impact on load distribution between Girders. The result of this method is also considered conservative as compared to more refined method of analysis. In this study, the result obtained by this method and refined method of analysis (Grillage Analogy Method) are investigated.

Using these methods, RC T- and Box Girder superstructures are analyzed, considering different Traffic lanes and span length. This task involves examining the maximum Bending Moment and Shear Force using the two numerical models. Furthermore, the effect of Diaphragm on load distribution is also investigated.

This study provided useful information about the variation of Bending Moment, Shear Force with respect to change in Traffic Lanes, Span Length and arrangement of Diaphragm. It is concluded that the results obtained from Grillage analogy method are smaller than approximate method, except for shear force of Interior Girder of T-Girder Bridge, which gives slightly higher result where, the percentage differences varies from case to case. For all other cases considered, approximate method gives conservative values. In addition, since approximate method does not consider effect of diaphragm, provision of more number of diaphragms has effect on load distribution is observed for T-Girder than Box Girder in Grillage Analogy method.

Key words: T-Girder; Box Girder; Approximate Method (Distribution Factor Method); Grillage Analogy Method; Flexural Moment of Inertia; Torsional Moment of Inertia; Bending Moment; Shear Force; Vehicular Live Load; Traffic Lanes; Span Length

1 INTRODUCTION

1.1 Background

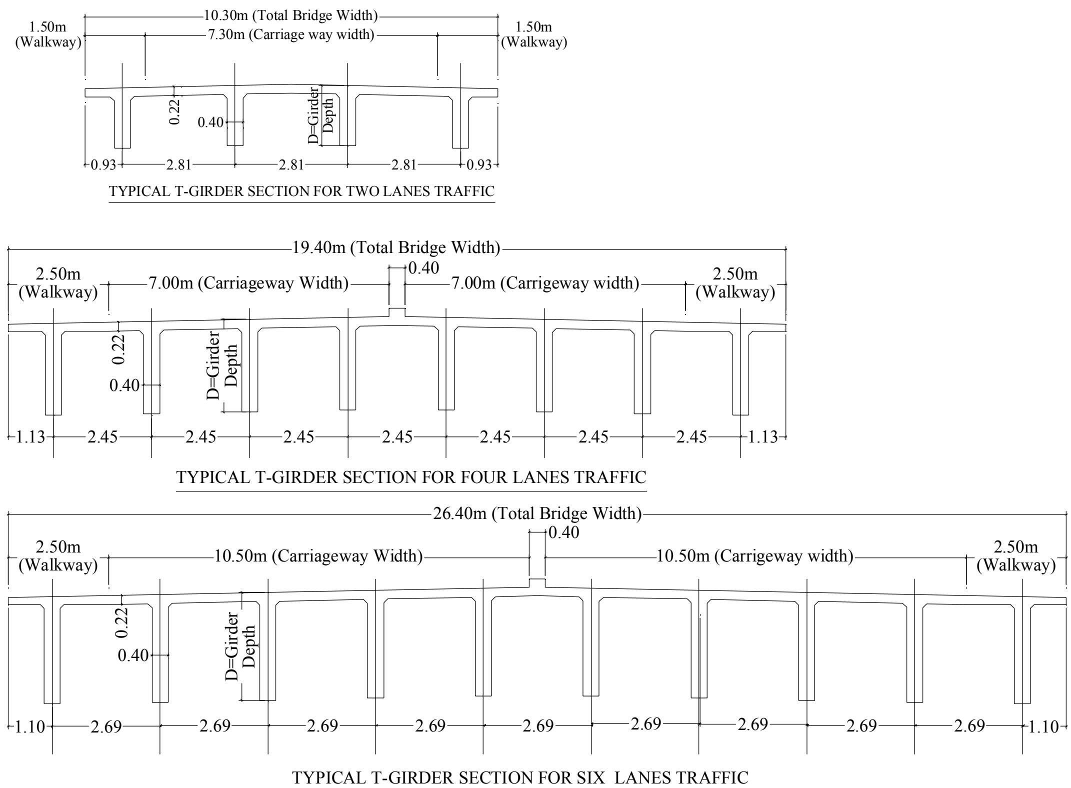
Bridge is one part of the road infrastructure which needs care during design stage and one of the most challenging works during construction. Bridge construction in Ethiopia is rapidly growing for the last fifteen years and the numbers and sizes of the bridges have continuously increased. The common bridge forms widely used are RC T-Girder and Box Girder Bridge, and, the selection between the two depends on the span length of the bridge. To analyze such types, it is necessary to break the form in to more manageable sub forms that comprised of different components. Sub forms include Beams (Girders), Deck Slab, Barrier system, Cross Frames and Diaphragms. In general, the distribution of the loads throughout the components requires equilibrium, compatibility, and constitutive relationships be maintained. To analyze such forms, many methods are available where; one of this is approximate method of analysis. It is developed by AASHTO and ERA and AACRA Design Manuals are also adopting this method. Approximate method of analysis which makes use of distribution factor concept were developed originally by Zokaie et al. (1991) and further investigated by the team and developed by AASHTO as distribution factor concept. This concept is easy and simple to use that makes it popular in Ethiopia, as the name also implies approximate, this method has limitation for not considering stiffness of components and effect of diaphragm explicitly. Hence, in the light of such effect a clear understanding of this method for the RC T and Box Girder Bridge is desired.

1.1.1 T-Girder Bridge Superstructure

The T-Girder bridge superstructure consists of transversely reinforced slab decks which span across to the longitudinal support girders. T-Girder Bridge is generally more economical for span of 12 to 24m. The girder stem thickness usually varies from 35 to 55cm and is controlled by the required horizontal spacing of the positive moment reinforcement. Optimum spacing of longitudinal girder in transverse direction is typically between 1.8m to 3.0m for a minimum cost of formwork and structural materials. However, where vertical supports for the formwork are difficult and expensive, girder spacing can be increased, [4].

T-Girder Bridge is usually used for a single span bridge, or non-continuous girders for multi span bridge. ERA bridge design manual and AASHTO bridge design specification usually recommends the number of girder to be provided should be minimum, to minimize the material (cost). The overhang should preferably not exceed 30 to 35% of girder spacing. Girder depth of the bridge may vary between 7-10% of the span length depending on the number of girder used.

Figure 1.1-1 Typical T-Girder Section for Two, Four and Six lanes Traffic,

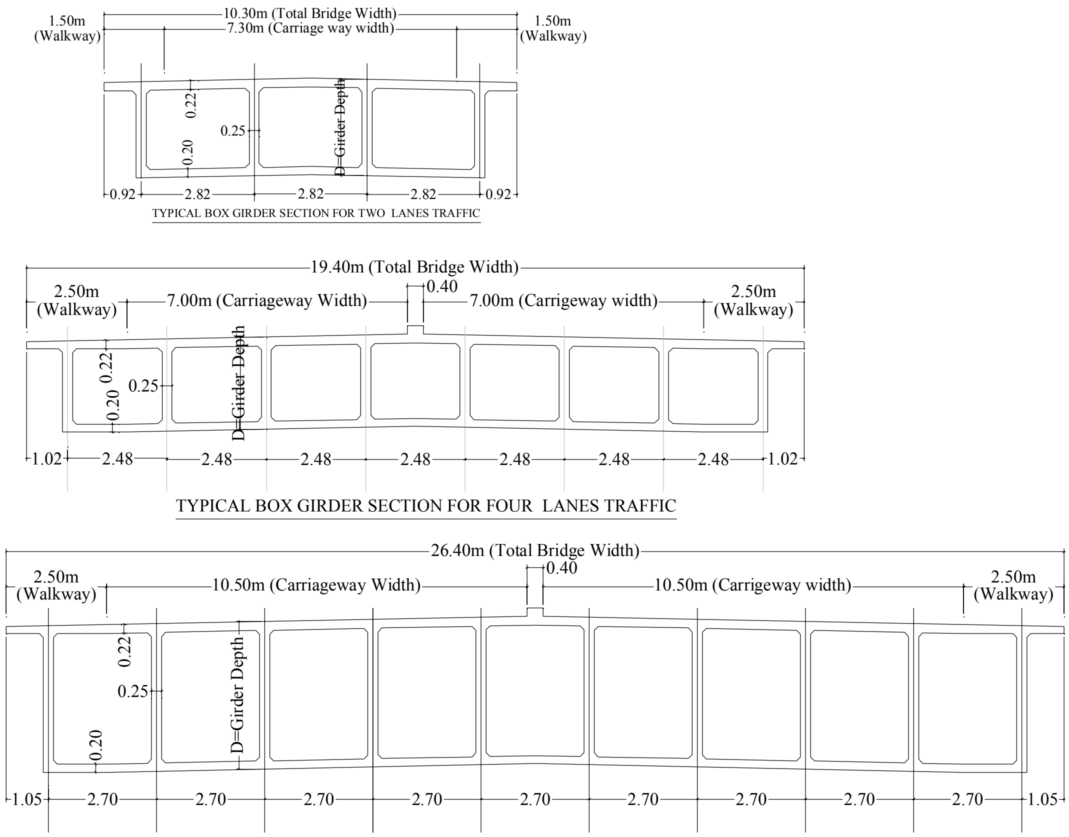


1.1.2 Box Girder Bridge Superstructure

The Box Girder bridge superstructure contains top deck, vertical web, and bottom slab are often used for span of 20 to 40m. The vertical web thickness usually varies from 20 to 30cm the high torsional strength of the box girder makes it particularly suitable for sharp curve alignment, skewed piers and abutments, super elevation, and transitions such as interchange ramp structures, [4].

Box Girder Bridge is difficult for formwork erection and demolishing and are used rarely except the site needs larger span and the typical dimension of Box girder superstructure are shown in the following figure.

Figure 1.1-2 Typical Box Girder Section for Two, Four and Six lanes Traffic,



1.2 Objectives and Scope of the study

The current study is about analysis comparison of T-Girder and Box Girder bridge superstructures by approximate method and Grillage analogy method. The objective and scope for the study are:

- Literature review of the analysis method, research work on Reinforced concrete T and Box girder superstructure according to AASHTO Bridge design specification and ERA bridge design manual.
- Develop grillage model for Analysis of T and Box girder bridges using STAD. Pro 2007 structural analysis software program.
- Develop approximate method for T and Box girder using spread sheet (Excel) on Microsoft office application.
- Study and compare the result of the two analysis method of T and Box Girder Bridge.

The study is limited to analysis comparison using the two method of RC T and Box girder superstructures, which have Two lanes, Four lanes and Six lanes Bridge width detail dimension of bridge width is presented in section 3 as well as, in the above two typical section figures, and Bridge span (length) of 20m and 24m for T-Girder Bridge, and 30m and 40m for Box Girder are considered. In addition, by increasing the span up to 30m of RC T Girder with different diaphragm spacing is also studied for comparison reason. However, skewness and curve are not considered in this study.

1.3 Outline of the Thesis

This thesis organized in to five sections, Section 1 is an introduction to the topic followed by the objective and scope of the study. Literature review on the analysis methods on RC T and Box Girder Bridge is presented in Section 2. Numerical Modeling for the two analysis methods are described including selection bridge dimension and illustrative example using the two numerical modeling are presented in Section 3. In Section 4, the comparison between Approximate and Grillage analogy Methods of RC T Girder and Box Girder Bridges are undertaken. Conclusion and Recommendation are presented in Section 5.

2 LITERATURE REVIEW

2.1 General Approach of Analysis

There are several methods available for the analysis of T-Girder and Box Girder bridges. In each analysis method, the three-dimensional bridge superstructure is usually simplified by means of assumptions in the geometry, materials and the relationship between its components. To analyze these, it is essential to break the bridge superstructure in to smaller, more manageable parts that are comprised of beams, deck slab, barrier system, cross frames and diaphragms. The forces and deformation with in these parts are essential to determine the size of the structures. In general, the transfer of loads on the superstructure components requires equilibrium, compatibility, and constitutive relationship be satisfied. Many analysis method are found now days which full fill the above requirements such as Approximate method of analysis and Grillage analogy method. Generally approximate method is the most commonly used analysis method in consulting firms found in Ethiopia. In this method the spatial dimensionality of the system is reduced by using a concept of distribution factor. This factor is established by analyzing the system with a refined method to establish the actions in the girders. Next, the same load is applied to a single girder and 1D beam analysis is performed. This method is recommended by AASHTO Bridge Design specification and ERA bridge design manual. The other method used in modeling the bridge superstructures is grillage analogy method. In this method the superstructure is converted in to a network of skeletal members rigidly connected beams or nodes. The deformation at the two ends of the beam element is related to bending and torsional moment through their bending and torsional stiffness, [3&6]. A brief review of the two analytical methods i.e. approximate method of analysis and Grillage analogy method are presented in the following section.

2.2 Approximate method of analysis

Approximate Method (Distribution Factor Method) sometimes known as Beam-Line Method, where, the spatial dimensionality is a primary modeling assumption, and then the system is modeled as 1D system. This is a simple model and is attractive for analysis. The primary issue is how the load is distributed to the girder, which is traditionally done by using an empirically determined distribution factor to transform the 3D system to a 1D system. Herein, this procedure is called the beam-line (girder-line) method because only one girder is considered as opposed to modeling the entire bridge as a single beam. This factor is established by analyzing the system with a refined method to establish the actions in the girders. Bending moment is used for illustration; the maximum moment at a critical location is determined with an analytical or numerical method and is denoted as $M_{refined}$. Next, the same load is applied to a single girder and a 1D beam analysis is performed. The resulting maximum moment is denoted as M_{beam}. The distribution factor is defined as:

$$Distribution\ Factor\ (g) = \frac{M_{Refined}}{M_{Beam}}$$

The background of AASHTO Bridge Design Specification distribution factor methods are based on the above concept and employed for many years.

$$g = S/D$$

Where S is the girder spacing (m), and D is a constant depending on bridge type, the number of lane loaded, and g may be thought of as the number of wheel lines carried per girder:

For example, for a concrete slab on a steel girder D = 5.5 was used for case where two or more vehicles are present .Obviously, this is a simplistic formula and easy to apply, but as expected, it does not always provide good estimates of the girder load in the full system and this problem is minimized in recent AASHTO distribution factor method by incorporating more number of parameters.

The recent distribution factor has the following limitation and used for bridges with fairly regular geometry and is limited to system with, [3].

- Constant cross section.
- Number of girder is four or more.
- Girders are parallel and have approximately the same stiffness.
- Roadway part of the cantilever overhang does not exceed 910mm.
- Plan curvature is small as required in AASHTO article A4.6.1.2.
- Cross section is consistent with the sections as shown in Table 2.2-1.

Table 2.2-1[1] Deck Superstructures Type,

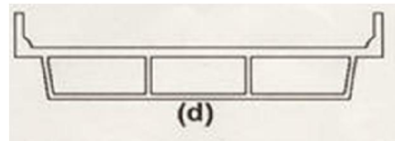
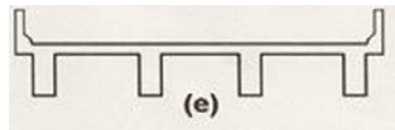
Supporting Components	Type of Deck	Typical Cross-Section
Cast-in-Place Concrete Multicell Box	Monolithic concrete	
Cast-in-Place Concrete Tee Beam	Monolithic concrete	

Table 2.2-2[2] "L" for use in Live Load Distribution Factor Equations,

Force Effect	**L (mm)**
Positive Moment	The length of the span for which moment is being calculated
Shear	The length of the span for which shear is being calculated

The above table describes how the term L (length) is determined for use in live load distribution factor. In rare occasion when the continuous span arrangement is such that an interior span does not have any positive uniform load moment (i.e. no uniform load point of contraflexure), the region of negative moment near the interior supports would be increased to the centerline of the span, and the L used in determining the live load distribution factors would be the average of the two adjacent spans.

[1] Table 2.2-1 is from AASHTO Bridge Design Specification, Table A4.6.2.2.1-1
[2] Table 2.2-2 is from AASHTO Bridge Design Specification, Table C4.6.2.2.1-1

Table 2.2-3[3] Distribution of Live Load per Lane for Moment in Interior Girder,

Type of Beams	**Applicable Cross-section from Table 2.2-1**	**Distribution Factors**	**Range of Applicability**
Concrete T-Beams	e	One Design Lane Loaded: $0.06 + \left(\frac{S}{4300}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{Lt_s^3}\right)^{0.1}$ Two or More Design Lanes Loaded: $0.075 + \left(\frac{S}{2900}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{Lt_s^3}\right)^{0.1}$	$1100 \leq S \leq 4900$ $110 \leq t_s \leq 300$ $6000 \leq L \leq 73000$ $N_b \geq 4$ $4x10^9 \leq K_g \leq 3x10^{12}$
		Use lesser of the values obtained from the equation above with $N_b = 3$ or the lever rule	$N_b = 3$
Multi cell Concrete Box Beam	d	One Design Lane Loaded: $\left(1.75 + \frac{S}{1100}\right)\left(\frac{300}{L}\right)^{0.35}\left(\frac{1}{N_c}\right)^{0.45}$ Two or More Design Lanes Loaded: $\left(\frac{13}{N_c}\right)^{0.3}\left(\frac{S}{430}\right)\left(\frac{1}{L}\right)^{0.25}$	$2100 \leq S \leq 4000$ $18\ 000 \leq L \leq 73000$ $N_c \geq 3$ If $N_c>8$ use $N_c=8$

S= Girder spacing (mm).

L= Span length (mm).

K_g= Longitudinal stiffness parameter (mm^4).

$K_g = n*(I_g+e_g^2*A)$, where

,n= modular ration (E_{girder}/E_{deck}).

I_g= moment of inertia of the girder (mm^4).

,e_g= girder eccentricity, which is the distance from the girder centroid to the middle centroid of the slab (mm).

[3] Table 2.2-3 is from AASHTO Bridge Design Specification, Table 4.6.2.2.2b-1

A= girder area (mm^2).

,d_e= distance from the center of the exterior girder and the inside edge of the curb or barrier (mm).

N_b= number of girder.

N_c= number of cell in the box girder.

Table 2.2-4[4] Distribution of Live Loads per Lane for Moment in Exterior Girders,

Type of Superstructure	**Applicable Cross-section from Table 2.2-1**	**One Design Lane Loaded**	**Two or More Design Lanes Loaded**	**Range of Applicability**
Concrete T-Beams.	e	Lever Rule	$g = e * g_{interior}$ $e = 0.77 + \frac{d_e}{2800}$	$-300 \leq d_e \leq 1700$
			Use lesser of the values obtained from the equation above with $N_b = 3$ or the lever rule	$N_b = 3$
Cast-in-Place Concrete Multi cell Box	d	$g = \frac{w_e}{4300}$	$g = \frac{w_e}{4300}$	$W_e \leq S$
		Or the provision for a whole-width design specified in Article 4.6.2.2.1		

[4] Table 2.2-4 is from AASHTO Bridge Design Specification, Table 4.6.2.2.2d-1

Table 2.2-5[5] Distribution of Live Load per Lane for Shear in Interior Girders,

Type of Beams	**Applicable Cross-section from Table 2.2-1**	**Distribution Factors**	**Range of Applicability**
Concrete T-Beams	e	One Design Lane Loaded: $$0.36+\frac{S}{7600}$$ Two or More Design Lanes Loaded: $$0.2+\frac{S}{3600}-\left(\frac{S}{10700}\right)^2$$	$1100 \le S \le 4900$ $110 \le t_s \le 300$ $6000 \le L \le 73000$ $N_b \ge 4$
		Use lever rule for both case	$N_b = 3$
Cast-in-Place Concrete Multi cell Box Beam	d	One Design Lane Loaded: $$\left(\frac{S}{2900}\right)^{0.6}\left(\frac{d}{L}\right)^{0.1}$$ Two or More Design Lanes Loaded: $$\left(\frac{S}{2200}\right)^{0.9}\left(\frac{d}{L}\right)^{0.1}$$	$1800 \le S \le 4000$ $6000 \le L \le 73000$ $890 \le d \le 2800$ $N_c \ge 3$

Table 2.2-6[6] Distribution of Live Load per Lane for Shear in Exterior Girders,

Type of Beams	**Applicable Cross-section from Table 2.2-1**	**Distribution Factors**	**Range of Applicability**
Concrete T-Beams	e	One Design Lane Loaded: Use lever rule Two or More Design Lanes Loaded: $$g = e * g_{interior}$$ $$e = 0.6+\frac{d_e}{3000}$$	$-300 \le d_e \le 1700$

[5] Table 2.2-5 is from AASHTO Bridge Design Specification, Table 4.6.2.2.3a-1
[6] Table 2.2-6 is from AASHTO Bridge Design Specification, Table 4.6.2.2.3b-1

Type of Beams	**Applicable Cross-section from Table 2.2-1**	**Distribution Factors**	**Range of Applicability**
		Use lever rule for both case	$N_b = 3$
Cast-in-Place Concrete Multi cell Box Beam	d	One Design Lane Loaded: Use lever rule Two or More Design Lanes Loaded: $g = e * g_{interior}$ $e = 0.64 + \frac{d_e}{3800}$	$-600 \le d_e \le 1500$

2.3 Grillage analogy method of analysis

2.3.1 Introduction

One of the best mathematical models for the deck is thin plate that may be modeled with the biharmonic equation (Timoshenko and Woinowsky Kreiger, 1959; Ugural, 1981):

$$\nabla^4 w = \frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{p(x)}{D} \quad (2.1)$$

Where w = vertical translation

x = transverse coordinate

y = longitudinal coordinate

p = vertical load

D = plate rigidity, equal to

$$D = \frac{Et^3}{12(1 - \vartheta^2)}$$

Where v = Poisson ratio

t = plate thickness

E = modulus of elasticity

Equation 2.1 is for an isotropic (same properties in all directions) slab. The development of Eq. 2.1 is based on several key assumptions i.e.

- The material behaves linearly elastically.
- The strain profile is linear.
- The plate is isotropic.
- The vertical stresses due to the applied load are neglected.
- The deformations are small relative to the dimension of the plate.

Closed form solution for the above equation is limited to case that is based on simplified boundary condition and loads. Thus, approximate techniques or numerical models are used for the solution the most common methods is Grillage analogy method.

Consider the first term only of Eq. 2.1, then becomes

$$\frac{\partial^4 w}{\partial x^4} = \frac{p(x)}{D} \tag{2.2}$$

This is the same as the mathematical model for a beam. Now neglect only the middle term of Eq. 2.1

$$\frac{\partial^4 w}{\partial x^4} + \frac{\partial^4 w}{\partial y^4} = \frac{p(x)}{D} \tag{2.3}$$

This is the mathematical model for a plate system that has no torsional stiffness or associated torsional actions. In practical sense such systems do not exist. However, this type of system would be similar to modeling a plate with a series of crossing beams where one element sits on top of the other as shown in Figure 2.3-1(a) and (b). Consider the grillage joint shown in Figure 2.3-1(c). Here, the joint is continuous for rotation in all direction, i.e. the displacements of the joint is defined with the three displacements (degree of freedom) shown in Figure 2.3-1(d), which includes vertical translation and two rotations. This type of joint, in combination with elements that have both flexural and torsional stiffness, is more like the continuum. This type of numerical model is called a grillage, [3].

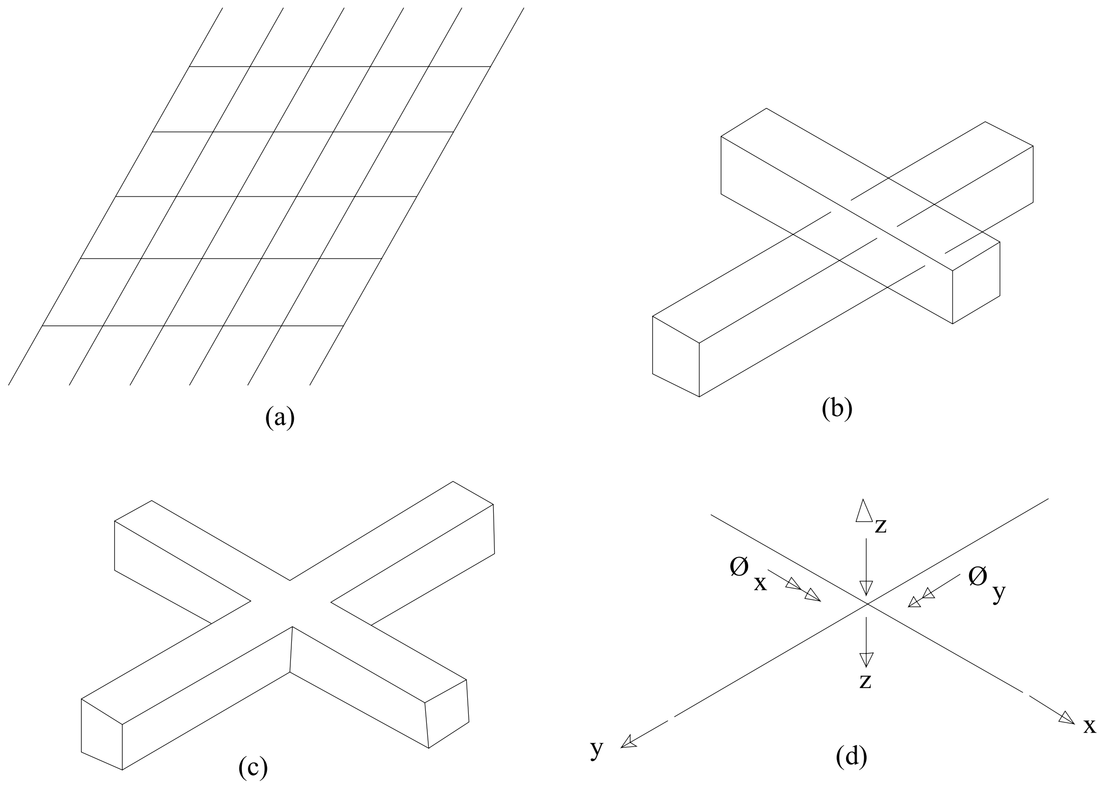


Figure 2.3-1 Grillage Model

(a) Grillage model, (b) crossing with translational continuity, (c) crossing with translational and rotational continuity, and (d) degree of freedom in grillage modeling.

2.3.2 Stiffness Method Applied to Grillage Analysis

2.3.2.1 Introduction

The bridge deck structure may be considered as an assembly of structural members connected together at discrete nodes forming a grid, the deformations and forces at nodes are inter-related by corresponding stiffness. In order to satisfy the equilibrium and compatibility conditions at each node, a large number of simultaneous equations will result and the manual solution of these may be difficult, however, using matrix method of structural analysis as a major approach, it becomes possible to obtain the solution, [2].

2.3.2.2 Matrix method of structural analysis

For an elastic structure, the action P (forces and moments) and displacement D (translations and rotations) are directly related as

$$\{P\} = [K]\ \{D\} \tag{2.4}$$

Where [K] is the stiffness matrix of the structure and is defined as the action required to produce a unit displacement. This is known as stiffness method (displacement method) in this method the redundant structure is converted in to fully restrained structure by locking of every joint and support. The solution of the problem then consists in finding the values of the displacement which must be applied to all joints and supports to restore equilibrium conditions at the joints. The unknowns are, therefore, kinematic unknowns.

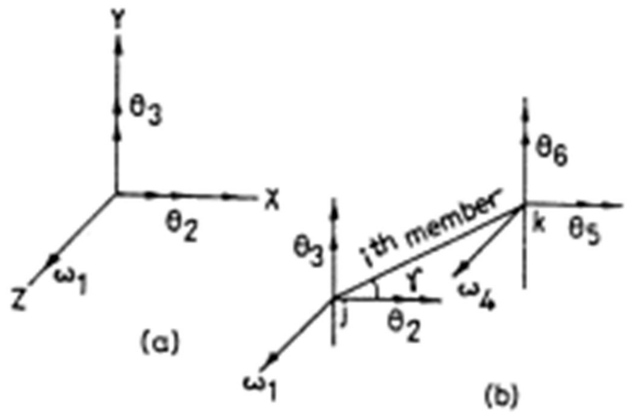
The stiffness method will be used in the analysis of bridge deck by grillage analogy based on certain assumptions.

- Hooke’s law applies-leading to the principle of superposition.
- Small deformation theory holds true.
- Shear deformation can be ignored.

2.3.2.3 Degrees Of Freedom

The Degree of Freedom (D.O.F) for structure is the independent deformations which define the deformed shape of the structure completely. In general, any structure has six degrees of freedom at a node. Depending on the significance of a deformation, in a particular type of structure form, some of the above degree of freedom can be ignored. Thus, the degrees of freedom in the case of grid are reduced to three at each node. These are translation perpendicular to the plane of grid and rotations about two orthogonal axes lying in the plane of the grid as shown in Figure. 2.3-2, [2].

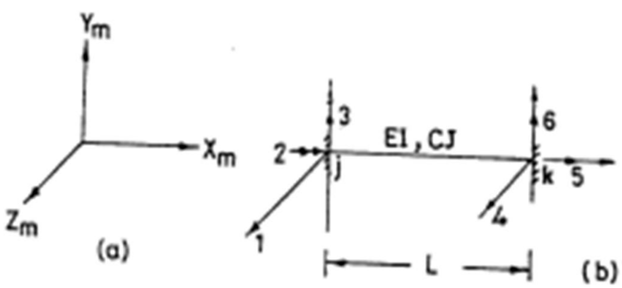
Figure 2.3-2 Global Axes and Degree of Freedom



2.3.2.4 Member Stiffness Matrix

Consider a grid member in Figure. 2.3-3 that are fully restrained at ends j and k. member stiffness consist of reaction exerted at the member ends by the restraints when unit deformations (one translation and two rotations) are imposed at each end of the member in turn.

Figure 2.3-3 Grid Elements with End Displacements



The stiffness matrix [K] for a grid member is of six by six matrixes and each column in the matrix represents the actions caused by the corresponding unit displacement.

$$[K_m] = \begin{bmatrix} \frac{12EI}{L^3} & 0 & -\frac{6EI}{L^2} & -\frac{12EI}{L^3} & 0 & -\frac{6EI}{L^2} \\ 0 & \frac{GJ}{L} & 0 & 0 & -\frac{GJ}{L} & 0 \\ -\frac{6EI}{L^2} & 0 & \frac{4EI}{L} & \frac{6EI}{L^2} & 0 & \frac{2EI}{L} \\ -\frac{12EI}{L^3} & 0 & \frac{6EI}{L^2} & \frac{12EI}{L^3} & 0 & \frac{6EI}{L^2} \\ 0 & -\frac{GJ}{L} & 0 & 0 & \frac{GJ}{L} & 0 \\ -\frac{6EI}{L^2} & 0 & \frac{2EI}{L} & \frac{6EI}{L^2} & 0 & \frac{4EI}{L} \end{bmatrix} \quad (2.5)$$

The stiffness matrix in (Eq. 2.5) for a grid is in terms of local degree of freedom, which is different for different members meeting at a joint. Since the equilibrium at a joint is to be satisfied, taking in to account the end actions of all members meeting at that joint together with the external forces if any, a common reference is essential. This is provided by global degree of freedoms is needed. This relationship is obtained in terms of a matrix known as transformation matrix, [2].

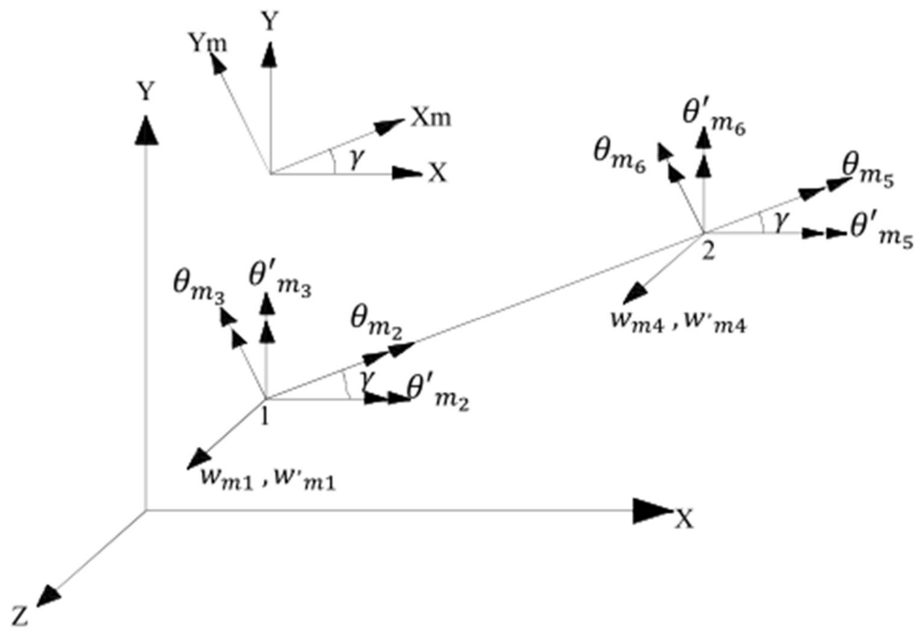


Figure 2.3-4 Transformation of Stiffness Matrix

Consider a grid member 1-2 in Fig. 2.3-4 with axes X_m and Y_m. The relation between the deformations at node 1 in the original direction and in the direction of global axes X and Y is shown. These deformations are related (Eq. 2.6) with the help of a 3x3 rotation matrix [ƛ] in terms of direction cosines. Now, local member deformations can be related to global member deformations as given in Eq. 2.7.

$$[\lambda] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & \sin\gamma \\ 0 & -\sin\gamma & \cos\gamma \end{bmatrix} \quad (2.6)$$

$$[T] = \begin{Bmatrix} w_{m1} \\ \theta_{m2} \\ \theta_{m3} \\ w_{m4} \\ \theta_{m5} \\ \theta_{m6} \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 & & & \\ 0 & \cos\gamma & \sin\gamma & & & \\ 0 & -\sin\gamma & \cos\gamma & & & \\ & & & 1 & 0 & 0 \\ & & & 0 & \cos\gamma & \sin\gamma \\ & & & 0 & -\sin\gamma & \cos\gamma \end{bmatrix} \begin{Bmatrix} w'_{m1} \\ \theta'_{m2} \\ \theta'_{m3} \\ w'_{m4} \\ \theta'_{m5} \\ \theta'_{m6} \end{Bmatrix}$$

Or $\{d_m\} = [T]\{d'_m\}$ (2.7)

Where $\{d_m\}$ and $\{d'_m\}$ are local and global member deformation vectors respectively and [T] is a 6x6 transformation matrix derived from the rotation matrix [ƛ] such that

$$[T] = \begin{bmatrix} \lambda & 0 \\ 0 & \lambda \end{bmatrix} \quad (2.8)$$

Similarly,

$$\{P_m\} = [T]\{P'_m\} \quad (2.9)$$

$$\{P'_m\} = [T]^T\{P_m\} \quad (2.10)$$

$$\{P_m\} = [K_m]\{d_m\} \quad (2.11)$$

$$\{P'_m\} = [K'_m]\{d'_m\} \quad (2.12)$$

Substituting for {Pm} in equation 2.10 from equation 2.11 gives,

$$\{P'_m\} = [T]^T[K_m][T]\{d'_m\} \quad (2.13)$$

Thus from equation 2.13 above,

$$\{K'_m\} = [T]^T[K_m][T] \quad (2.13)$$

2.3.2.5 Assembly of structure stiffness matrix

The member stiffness gives the relation between actions and deformations of a single member and satisfies member constitutive laws. But to satisfy equilibrium condition at any joint, we have to consider assemblage of the entire member meeting at that joint. The structure stiffness matrix element satisfying the joint equilibrium can be obtained by an assembly of member stiffness matrix elements.

$$[\boldsymbol{K_j}] = \sum_{i=1}^{n} \boldsymbol{K'}_{nj}^{(i)} \qquad (2.14)$$

Where $[K_j]$ is the assembled structure stiffness matrix corresponding to j^{th} degree of freedom and $[K'^{(i)}_{nj}]$ is the corresponding term of i^{th} member stiffness matrix.

The stability of the structure is now considered by introducing the boundary conditions.

$$\left[\begin{array}{c|c} K_{PP} & K_{PR} \\ \hline K_{PR}^{T} & K_{RR} \end{array}\right] \left\{\begin{array}{c} D_P \\ \hline D_R \end{array}\right\} = \left\{\begin{array}{c} P \\ \hline R \end{array}\right\} \qquad (2.15)$$

Where $[K_{PP}]$, $[K_{PR}]$, $[K^{T}_{PR}]$ and $[K_{RR}]$ are portioned sub matrices and $\{D_P\}$ and $\{D_R\}$ are free and restrained displacement vectors respectively. {P} is the external load vector and {R} is the reaction vector.

From Eq.2.15 we can write.

$$[K_{PP}]\{D_P\} + [K_{PR}]\{D_R\} = \{P\} \qquad (2.16)$$

$$[K_{PR}]^T\{D_P\} + [K_{RR}]\{D_R\} = \{R\} \qquad (2.17)$$

The solution of the above equation will determine the deformation vector $\{D_P\}$ and substitute in to equation (2.17) to get the reaction. A large number of simultaneous equations will result depending up on the size of the grid chosen and they are to be solved in an efficient manner utilizing the minimum computer time, [2].

2.3.3 Transformation of Bridge Deck in to Equivalent Grillage

2.3.3.1 Introduction

When a bridge deck is analyzed by the method of Grillage analogy, there are essential five steps to be followed for obtaining design responses:

- Idealization of physical deck into equivalent grillage.
- Evaluation of equivalent elastic inertias of members of grillage.
- Application and transfer of loads to various nodes of grillage.
- Determination of force responses and design envelopes and
- Interpretation of results

2.3.4 Idealization of Physical Deck into Equivalent Grillage

The method of grillage analysis involves the idealization of the bridge deck as a plane grillage of discrete inter-connected beams. This is the first important steps to be taken by the designer and needs utmost care and understanding of the structural behavior of the bridge decks

2.3.4.1 Guidelines for grillage Lay-out

Because of many types of deck shape and support condition, it is difficult to adopt hard and fast rules for choosing a grillage lay-out of the actual structure. Some basic guidelines regarding the location, direction, number and spacing of the longitudinal and transverse grid lines forming the idealized grillage mesh are described.

2.3.4.2 Location and Direction of Grid Lines

Grid lines are to be used along line of strength. In the longitudinal direction, these should be along the center line of girders, edge beams etc. Where isolated bearings are adopted, the grid lines are also to be chosen along the lines joining the center of bearings. In transverse direction, the grid lines are to be adopted, one at each end connecting the center of bearings and along the center lines of transverse beams.

2.3.4.3 Number and Spacing of Grid Lines

Whenever possible, an odd number of longitudinal and transverse grid lines are to be adopted. The minimum number of longitudinal grid lines may be three and the minimum number of transverse grid lines per span may be five. The ratio of spacing of transverse grid lines to those of longitudinal grid lines may be chosen between 1.0 and 2.0 this ratio should also reflect the span-width ratio of the bridge. Thus, for a short span and wide bridge it should be close to 1.0 and for long span and narrow bridge this ratio may close to 2.0. It may be noted that with an increase in number of grid lines, the accuracy of analysis increase, [2].

2.3.4.4 Grillage Idealization of T-Girder Bridge

The logical choice of longitudinal grid lines for T-Girder is to make them coincident with the center lines of physical girder and these longitudinal members are given the properties of the girders plus associated portions of the slab, which they represent. Additional grid lines between physical girders may also be set in order to improve the accuracy of the result. Edge grid lines may be provided at the edges of the deck or at suitable distance from the edge.

When intermediate cross-girders exist in the actual deck, the transverse grid lines represent the properties of cross girders and associated deck slabs. The grid lines are set-in along the center lines of cross-girders. When there is a diaphragm over the support in the actual deck, the grid lines coinciding with these diaphragms should also be placed, [2].

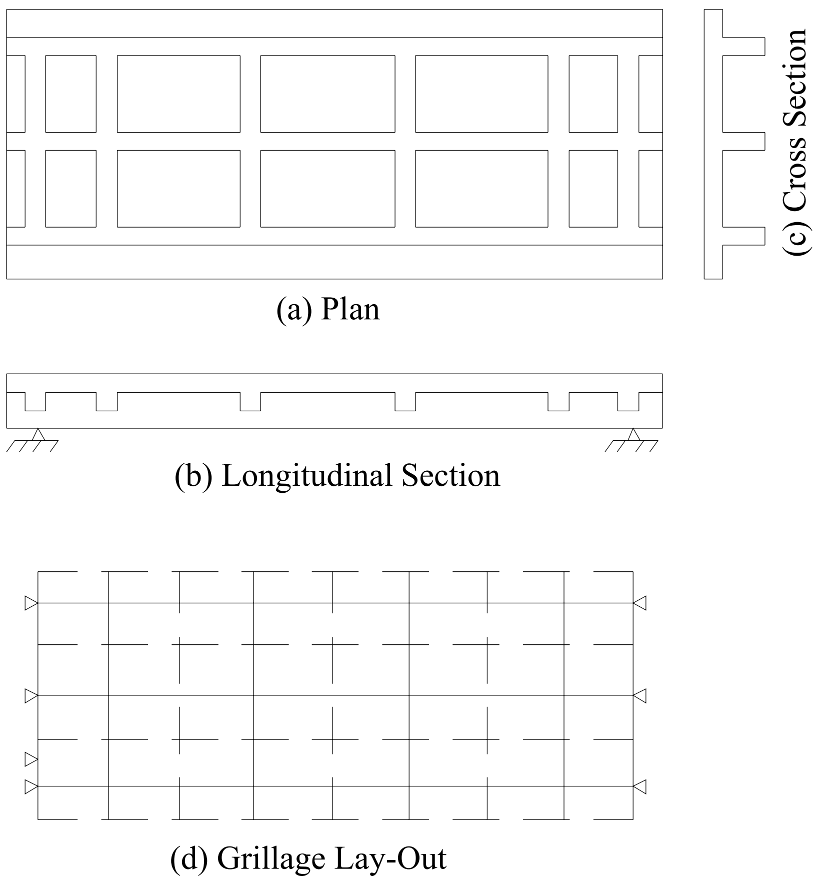


Figure 2.3-5 T-Girder Bridge and Grillage Lay-out

When no intermediate diaphragms are provided, the transverse medium i.e. deck slab is conceptually broken into a number of transverse strips and each strip is replaced by a grid line. The spacing of transverse grid lines is somewhat arbitrary but about 1/8 of effective span is generally convenient. As a guideline, it is recommended that the ratio of spacing of transverse and longitudinal grid lines be kept between 1 and 2 and the total number of lines be odd. This spacing ratio may also reflect the span-width ration of the deck. Therefore, for square and wider decks, the ratio can be kept as 1 and for long and narrow decks it can approach to 2. The transverse grid lines are also placed at abutments joining the center of bearings. A minimum of seven transverse grid lines are recommended, including end grid lines. It is advisable to align the transverse grid lines normal to the longitudinal lines wherever cross-girders do not exist. It should also be noted that the transverse grid lines are extended up to the extreme longitudinal grid lines.

In skew bridge with small skew angle less than 15 degree, the transverse grid lines are kept parallel to the support line as shown in Fig. 2.3-6(a) as in the case of right bridge. In skew bridges with higher skew angle, the transverse grid lines are kept perpendicular to the girder as shown in Fig. 2.3-6(b)

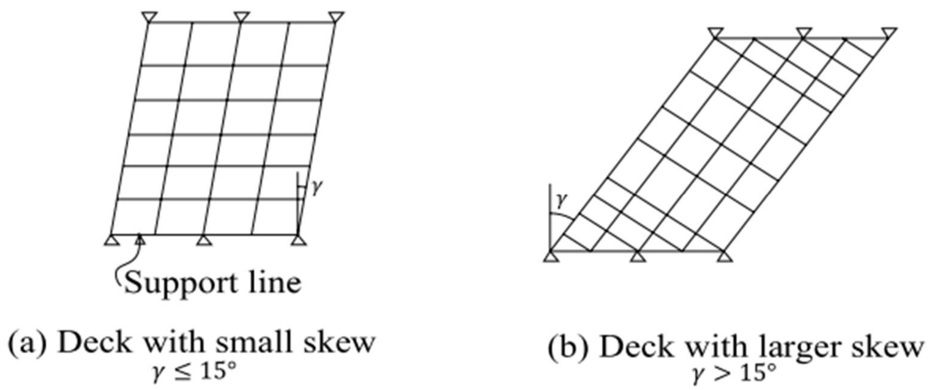
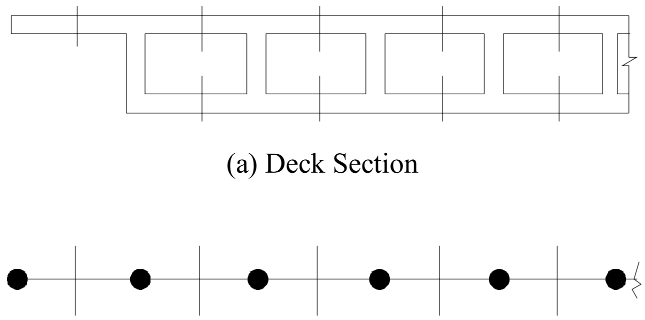


Figure 2.3-6 Grillage Arrangement in Skew Bridge,

2.3.4.5 Grillage Idealization of Box-Girder Bridge

Idealization of box-girder Bridge is similar to T-girder Bridge but there is a behavioral difference between them. The analysis of box-girder Bridge is associated with special problems of shear deformations (shear lag) due to usually wide flanges of the deck and distortions of the cells, if sufficient numbers of intermediate transverse diaphragms are not provided. The method is to be adopted where the effects of shear deformations and cell-distortions are negligible and could be ignored. The method is most appropriate for multi-cell rectangular box-girder decks.



(a) Deck Section

(b) Longitudinal Grid Lines

Figure 2.3-7 Grid Lines for Multi-Cell Box-Girder Deck,

Longitudinal grid lines are usually placed coincident with webs of the actual structure (Fig. 2.3-7). Additional longitudinal grid lines are located along the edge of cantilevers with nominal stiffness for the convenience of analysis.

The transverse medium consisting of top and bottom slabs only (with no diaphragms), is represented by equally spaced transverse grid lines along the span. The spacing and number of grid lines are similar to as adopted for T-Girder Bridge. If the deck is having diaphragms, the transverse grid lines are placed along each diaphragm including at supports. Additional grid lines representing the top and bottom slabs are placed in between the diaphragms, if needed, to meet the minimum requirements of transverse grid lines. A closer spacing of transverse grid lines will result in more continues structural behavior and will provide greater details of responses, [2].

2.3.5 Evaluation of Equivalent Elastic Properties

After the actual bridge structure is simulated in to equivalent grillage, consisting of longitudinal and transverse grid lines meeting at discrete nodes, the second important step in grillage analogy method is to assign appropriate elastic properties i.e. flexural and torsional stiffness to each member of the idealized grillage. This needs the computation of equivalent flexural moment of inertia I and torsional inertia J for the member of the grillage mesh. This is accomplished by considering isolated sections of the deck as if they are individual beams and the inertias are calculated for each section and allotted to the corresponding grillage beams representing that section.

2.3.5.1 Flexural Moment of Inertia, I

The computation of flexural moment of inertia I of different geometrical shapes is straight forward. However, in beams having T and Box sections where slab is cast monolithically with the web of the beam, effective flange width of the associated slab is to be considered.

2.3.5.2 Torsional Inertia, J

The torsional inertia J, often known as the Saint-Venant torsion constant, is generally not a simple geometrical property of the cross-section as the case with flexural moment of inertia I and needs careful consideration.

Saint-Venant derived an approximate expression for computing the torsional inertia J, of open sections which is applicable to all cross-sectional shape without having reentrant corners. The expression is,

$$J = \frac{A^4}{40 I_P} \tag{2.18}$$

Where A is the area of cross-section and I_p is the polar moment of inertia. For a rectangular of sides b and d, above expression reduce to,

$$J = \frac{3b^3 d^3}{10(b^2 + d^2)} \tag{2.19}$$

In the case of a thin rectangle where b > 5d, the J value is more accurately given by

$$J = \frac{bd^3}{3} \tag{2.20}$$

a. Flexural and torsional inertia of grillage member of T-Girder

T-Girder deck consists of a number of beams spanning longitudinally between abutments with a thin slab spanning transversely across the top. The thin slabs can be thought of as flanges of T-beams. When such T-beams bend, the flanges are subjected to flexural stresses. An element of the flange away from the rib or stem of the beam has less stress than the one directly over the rib due to shear deformation of the flange. Shear deformation relieves some amount of compressive stress in more distant elements. This phenomenon is known as shear lag. The variation of compressive stress across the width of flange is accounted for by considering the effective width of flange.

For the purpose of calculation of flexural and torsional inertias, the effective width of slab, to function as the compression flange of Interior-Girder or Exterior-Girder is taken as detailed below.

I. In case Interior Girders, the effective flange width may be taken as the least of:
   - One-quarter of the effective span length;
   - 12 times the average depth of the slab, plus the greater of web thickness or one-half the width of the top flange of the girder; or
   - The average spacing of adjacent beams.

II. In case Exterior Girders, the effective flange width may be taken as one-half the effective width of the adjacent interior beam, plus the least of:
   - One-eighth of the effective span length;
   - 6 times the average depth of the slab, plus the greater of one-half the web thickness or one-quarter of the width of top flange of the basic girder, or
   - The width of the overhang, [1&6].

Once the effective width of slab acting with the beam is decided, the deck is conceptually divided in to number of beams as the case may be.

b. Flexural and Torsional Inertia of Grillage Member of Box-Girder.

In the box-girder deck having longitudinal section as shown Figure below, the top and bottom slab flex in unison about their common center of gravity. The moment of inertia of transverse grillage per unit width, i_t, is calculated about the common centroid.

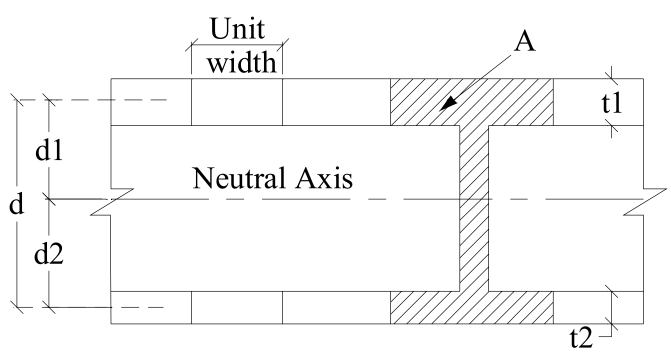


Figure 2.3-8 Longitudinal Section of Box-Girder Deck,

$$i_t = t_1 d_1^2 + t_2 d_2^2 \tag{2.21}$$

Since $t_1 d_1 = t_2 d_2$ and $(d_1 + d_2) = d$, we get

$$i_t = \frac{d^2 t_1 t_2}{t_1 + t_2} \tag{2.22}$$

If the transverse grillage members also include a diaphragm, as at 'A', (Fig. 2.3-8) the inertia should be calculated including the diaphragm.

2.3.6 Application of Loads, Analysis, Force Responses

2.3.6.1 Introduction

In this part discusses identification of panels in which the wheel loads of a vehicular loading system fall and transfer of loads to nodes of grillage in the form of equivalent nodal loads. The analysis of grillage is then carried out and response envelopes and the interpretation of results are discussed.

2.3.6.2 Evaluation and Application of Loads

The main live loading on Highway Bridge is of the vehicles moving on it, Ethiopian Road Authority (ERA) Bridge Design Manual recommends using HL-93 loading which is Equivalent to AASHTO loading.

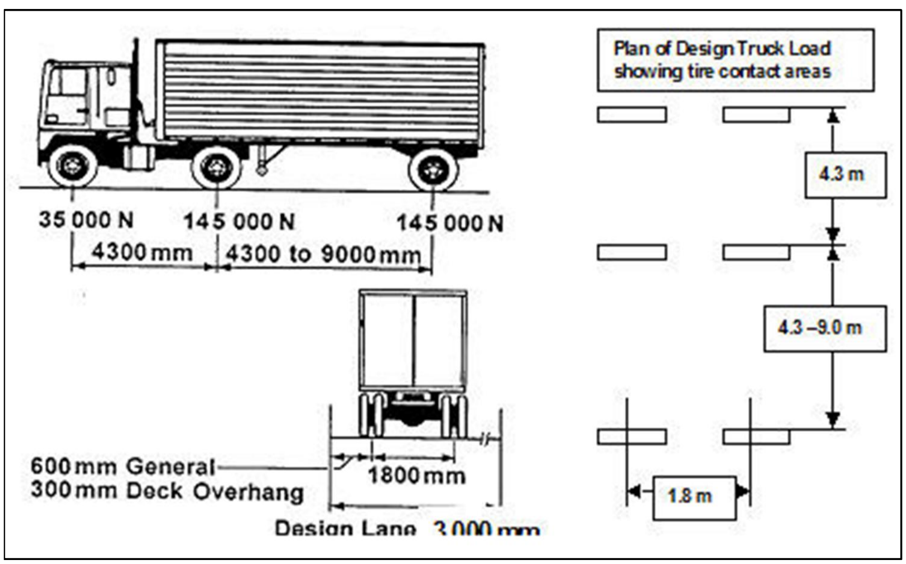


Figure 2.3-9 Characteristic of the Design Truck

The wheel load of this hypothetical vehicular loading will be either in the panels formed by the longitudinal and transverse grid lines, or on the nodes. The wheel loads falling in the panels are to be transferred to the surrounding nodes of the panels, the easiest approach in this case is to add another grillage line under the load called sub grillage as shown in Fig. 2.3-10. An alternative to this is to refine the mesh to a point simple beam nodal load assignments are viable because the fixed-end torsion and bending moment are relatively small.

In order to obtain the maximum response resultant for the design, different positions of each type of loading system are to be tried on the bridge deck, [2].

2.3.6.3 Identification of Panels in the Grillage

When longitudinal and transverse members of the grillage cross each other, they form panels and the grillage is therefore divided in to number of such panels. All the wheels of the vehicular loading system may not come directly on the nodes of the grid but usually majority of the wheels fall inside the panels. These wheel loads acting on the panels are to be transferred to the nodes forming the panel, before the grid is analyzed by the grillage analogy.

2.3.6.4 Transfer of Vehicular Load to the Nodes

The grillage analysis requires that loads be transferred to the corresponding nodes in the form of equivalent loads. These equivalent nodal loads consist of vertical shear and moments can be computed by assuming that the panel between the adjacent grillage elements is fixed at its edges, these are, for those loads which are applied within the panel.

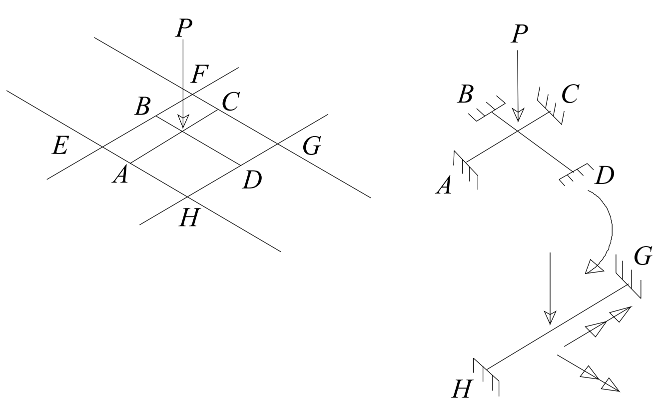


Figure 2.3-10 Load Positioned between Elements,

The transfer of concentrated wheel load lying in the panel of the grillage is carried out in two steps. First the load is distributed along the direction parallel to transverse grid lines and then these forces are transferred to the adjacent nodes of the longitudinal grid lines.

2.3.6.5 Force Responses

After the loads are transferred to the nodes of the grillage in the form of equivalent forces, the grillage may be analyzed to determine nodal deformation and member forces. The analysis result yields nodal deformations i.e. deflection, slope and rotation at each end of the member. The shear force for the member, the bending moments at the two ends of the member, the torsional moment in a member and reactions at the supported nodes are the usual output. However, these outputs can be modified and more details are possible. For the design of any bridge structure we need the envelope diagrams of various responses on it. The envelope diagram is the response diagrams drawn along the longitudinal grid lines with the largest values of responses picked up under vehicular load, [2].

2.3.7 Interpretation of Results

The output or the result obtained from the analysis of grillage consists of vertical deflection and X and Y rotations of each node, shear force and torsional moment of each beam element, bending moments at the two ends of each beam element and reaction at each support.

Since the deck has been initially idealized as a grillage and the analysis has been performed on the idealized grid, the results may sometimes need modifications and proper interpretations before they are finally used in design some of the important interpretation of the output and its modification due to local effects are discussed below.

The analysis will give positive or negative values for various force response with respect to each beam element and due care should be taken to adhere to the sign convention adopted in the computer program.

When a grillage member continues across a node, the value of moment at one end and other end of adjacent member in continuation will be usually different. This is due to torsional moments in the members framing in other direction to deal with such stepping or saw tooth in the moment value along a grid line at nodes, these two moments are averaged this also similar case for torque, [2].

2.4 Multiple Presence Factor

Truck will be present in adjacent lane on roadways with multiple design lanes, but it is unlikely that three adjacent lanes will be loaded simultaneously with the heavy loads. Therefore, adjustments in the design loads are necessary. To account for this effect, ERA Bridge Design manual provide an adjustment factor for the multiple presence.

Table 2.4-1 Multiple Presence Factor,

Number of Design Lanes	Multiple Presence Factor
1	1.2
2	1
3	0.85
More than 3	0.65

Multiple Presence factor are implicitly included in approximate method of analysis, [1&3]. Therefore no need applying for this analysis method. However, in Grillage analogy method the software output are multiplied by these factors throughout this thesis.

3 NUMERICAL MODELING

3.1 General

The two analysis method for analyzing RC T-Girder and Box Girder bridge superstructures as mentioned earlier in section 2. However, from the two analysis method, Grillage analogy method is considered to be powerful and flexible method. Although the 2D grillage analogy method is most involved and time consuming, it is still general and comprehensive in determining the structural response. The other method which is known as approximate method is recommended by AASHTO Bridge Design Specification and ERA bridge design manual, is the most commonly used method due to its simplicity but it has limited in scope and applicability. Due to recent development in computer technology, many frame analysis software can perform using grillage analogy method.

In the current research, both T and Box Girder Bridge are modeled using the two analysis method. In this section, a general description of the two analysis method next followed by selection of bridge dimension as per ERA Bridge Design Manual requirement that was utilized throughout this study for numerical modeling and finally illustrative example using approximate and grillage analogy method are presented.

3.2 Selection of Bridge Dimension

3.2.1 Width of Bridge

The width of the bridge should correspond with the roadway or carriageway width as determined according to the ERA *Geometric Design Manual.* The width is to be measured between the inside of the railings or the curbs.

Total width of bridge is defined as the distance between the inside of the outer railings including walkways, median and similar.

Table 3.2-1 Bridge Width used in this study

Application	Carriageway	Median	Walkway	Total Width (m)
Two-lanes	7.30	-	2*1.5	10.30
Four-Lanes	14.00	0.4	2*2.5	19.40
Six-Lanes	21.00	0.4	2*2.5	26.40

3.2.2 Minimum Dimensions

The minimum dimensions shall be used in bridge design and construction, [1&6].

Table 3.2-2 Minimum Dimensions

Type of Structures	Dimension
Concrete deck depth, excluding any provision for grinding and sacrificial surface	≥ 175 mm
Concrete deck for pedestrians bridge	≥ 150 mm

3.2.3 Design Depth of Superstructure

Design depth of superstructure is the thickness of the superstructure excluding the pavement thickness. Normally it will be measured in middle of the span. The design depth is a very important parameter for the construction work.

Recommended dimensions for cast-in-place Box and T-beams are:

The thickness of top flanges serving as deck slab not less than either:

- Same as for bridge decks listed in Table 3.2-2.
- Not less than 5% of the clear span between fillets, haunches, or webs, unless transverse ribs at spacing equal to the clear span are used.

And for the bottom flange thickness not less than either:

- 140 mm,
- 1/16 of the distance between fillets or webs of non prestressed girders and beams, or
- 1/30th of the clear span between fillets, haunches or webs for prestressed girders, unless transverse ribs at spacing equal to the clear span are used, [1&6].

The thickness of Webs (Girder) shall be determined by requirements for shear, torsion, concrete cover and placement of concrete. For adequate field placement and consolidation of concrete, usually a minimum web thickness of 200 mm is needed for webs without prestressing ducts. For girders over about 2.4 m in depth, the above dimensions should be increased to compensate for the increased difficulty of concrete placement, [1&6].

Table 3.2-3[7] Traditional Minimum Depths for Constant Depth Superstructures,

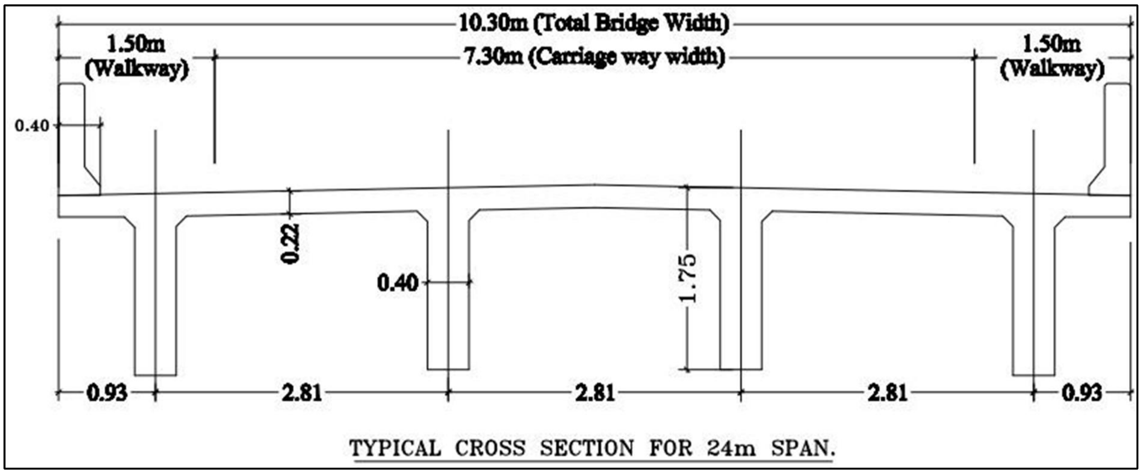
Superstructure		Minimum Depth (Including Deck) When variable depth members are used, values may be adjusted to account for changes in relative stiffness of positive and negative moment sections.	
Material	Type	Simple Spans	Continuous Spans
Reinforced Concrete	Slab with main reinforcement parallel to traffic	$\frac{1.2(S+3000)}{30}$	$\frac{S+3000}{30} \geq 165mm$
	T-Beams	0.070L	0.065L
	Box Beams	0.060L	0.055L

[7] Table 3.2-7 is from AASHTO Bridge Design Specification, Table A2.5.2.6.3-1

3.3 Approximate method of analysis

In this section illustrative analysis is presented considering 10.3m bridge width and 24m bridge span (length) as shown on the typical section below, using Approximate Method.

Figure 3.3-1 Typical Cross Section for 24m Bridge Span,



Determine the AASHTO distribution factor for bridge shown in the above typical section. The system dimension and properties are as follows:

Girder spacing, S= 2.81m

Span length, L= 24.6m

Top slab thickness, t_s= 0.22m

Top slab modulus of elasticity, E_s= 25GPa

Girder modulus of elasticity, E_g= 25GPa

Modular ratio, n= E_s/E_g= 1

Girder area, A_g= (1.75m-0.22m)*0.40m= 0.612m^2

Girder moment of inertia, I_g= (1/12)*0.40m*(1.75m-0.22m)^3 = 0.119385m^4

Girder eccentricity, e_g= 1.75m-(0.22m/2)-((1.75m-0.22m)/2) = 0.875m

Stiffness parameter, $K_g = n*(I_g + e_g^2*A_g)$ = 0.5879484m^4

d_e = 0.94m-0.4m = 0.535m

The AASHTO distribution factors for moment are determined using Table 2.2-3 up to Table 2.2-4.

- The distribution factor for moment in the interior girder for one lane loaded is.

$$g = 0.06 + \left(\frac{S}{4300}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{Lt_s^3}\right)^{0.1}$$

$$g = 0.06 + \left(\frac{2810}{4300}\right)^{0.4}\left(\frac{2.81}{24.6}\right)^{0.3}\left(\frac{0.5879}{24.6 * 0.22^3}\right)^{0.1} = 0.537\ lane/girder$$

The distribution factor for wheel load (i.e. two lines of wheels) is two times the above factor

g = 0.537*2 = 1.074 lane/ girder

- The distribution factor for moment in the interior girder for multiple lanes loaded is.

$$g = 0.075 + \left(\frac{S}{2900}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{Lt_s^3}\right)^{0.1}$$

$$g = 0.075 + \left(\frac{2810}{2900}\right)^{0.6}\left(\frac{2.81}{24.6}\right)^{0.2}\left(\frac{0.5879}{24.6 * 0.22^3}\right)^{0.1} = 0.764\ lane/girder$$

The distribution factor for wheel load (i.e. two lines of wheels) is two times the above factor

g = 0.764*2 = 1.529 lane/ girder

- The distribution factor for moment in the exterior girder for multiple lanes loaded is.

This requires an adjustment factor:

$$e = 0.77 + \frac{d_e}{2800} \geq 1$$

$$e = 0.77 + \frac{535}{2800} = 0.96 \geq 1, use\ e = 1.0$$

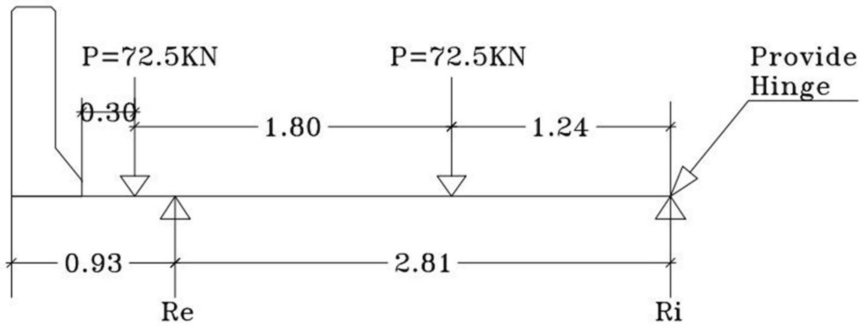
The adjustment factor for moment is multiplied by the factor for the interior girder and the result is.

$$g = e * g_{interior} = 1.0 * 1.529$$

g = 1.529 lane/ girder

- The distribution factor for moment in the exterior girder for one lane loaded is.

As per Table 2.2-6 distribution factor for moment in the exterior girder for one lane loaded is computed using lever rule method. This is done by assuming the Slab (Deck) is simply supported by each girder except over the exterior girder where the cantilever is continuous.



The reaction at R_E taking moment at R_I

$2.81*R_E = P*3.04 + P*1.24$

$R_E = 1.523*P$

g =1.523 lane/ girder

- The distribution factor for shear using Table 2.2-5 for the interior girder with one lane loaded is.

$$g = 0.36 + \frac{S}{7600}$$

$$g = 0.36 + \frac{2810}{7600} = 0.730$$

The distribution factor for wheel load (i.e. two lines of wheels) is two times the above factor.

g = 2*0.730 = 1.459 lane/ girder

- The distribution factor for shear for the interior girder with multiple lanes loaded is.

$$g = 0.2 + \frac{S}{3600} - \left(\frac{S}{10700}\right)^2$$

$$g = 0.2 + \frac{2810}{3600} - \left(\frac{2810}{10700}\right)^2 = 0.912$$

The distribution factor for wheel load (i.e. two lines of wheels) is two times the above factor.

g = 2*0.912 = 1.823 lane/ girder

- The distribution factor for shear using Table 2.2-6 for the exterior girder with one lane loaded is. The table recommend to use lever rule for one lane loaded case

Therefore, the distribution factor is the same as for moment case above.

g = 1.523 lane/ girder

- The distribution factor for shear for the exterior girder with multiple lanes loaded is.

This requires an adjustment factor.

$$e = 0.6 + \frac{d_e}{3000}$$

$$e = 0.6 + \frac{535}{3000} = 0.778$$

$$g = e * g_{interior}$$

g = 0.778*0.912 = 0.710

The distribution factor for wheel load (i.e. two lines of wheels) is two times the above factor.

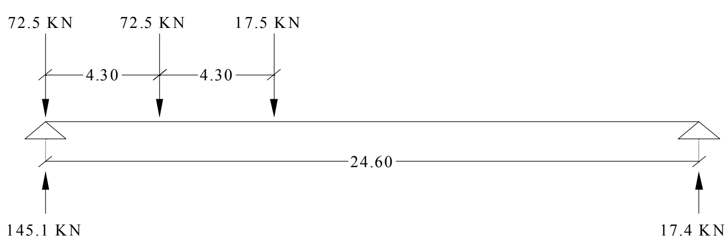
g = 2*0.710 = 1.419 lane/ girder

The T-Girder Bridge illustrated in the above typical section drawing with a simply supported span of 24.6m is used. Model the entire bridge as a single beam to determine the support reactions, shears, and bending moments using the design truck load.

A free body diagram is shown below with the design truck positioned near the critical location for shear and bending moment.

NB. The absolute maximum value is a little greater than this but for comparison purpose the vehicular live load is placed at the middle of the span for easiness throughout this thesis.

* Load position for Maximum Shear (Reaction).



* Load position for Maximum Bending Moment.

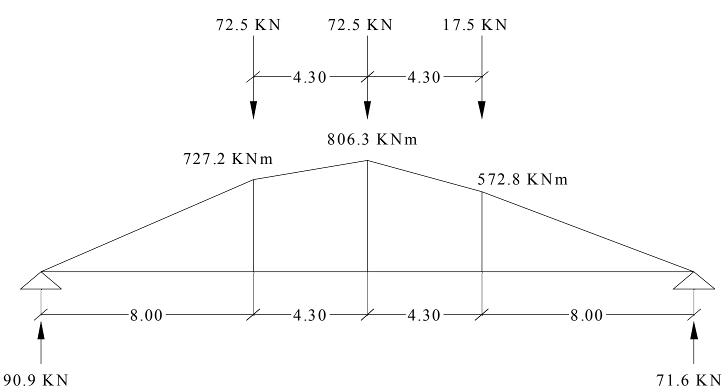


Figure 3.3-2 Load Arrangement for Maximum Shear and Moment,

Table 3.3-1 Approximate (Distribution Factor) Method Results.

Girder Location	Number of Lanes Loaded	Simple Beam Moment (KNm)	Moment Distribution Factor (g)	Girder Moment (KNm)	Simple Beam Reaction (KN)	Shear Distribution Factor (g)	Girder Shear (KN)
Exterior	1	806.3	1.523*1.2	1473.6	143.7	1.523*1.2	262.6
Exterior	2	806.3	1.529*1	1232.8	143.7	1.419*1	203.9
Interior	1	806.3	1.074	866.0	143.7	1.459	209.7
Interior	2	806.3	1.529	1232.8	143.7	1.823	262.0

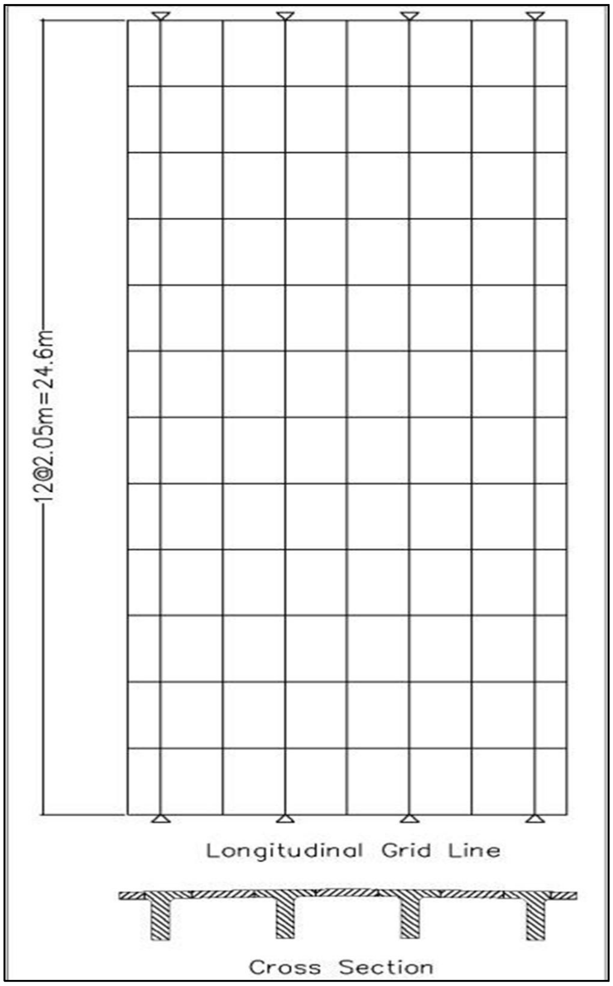
3.4 Grillage analogy method using STAD. Pro program

The grillage modeling and analysis performed in this study were done using a general purpose structural analysis and design program, STAD. Pro is a commercial structural analysis and design program developed by Bentley Solutions Center. The program is available for personal computer. The analyses in this thesis were performed using STAD. Pro Version 2007.

In this section illustrative analysis is presented considering 10.3m bridge width and 24m bridge span (length) similar to the typical section shown in section 3.3, using Grillage Analogy Method.

- The first step in grillage analysis is, converting the bridge deck structure in to a network of rigidly connected beam at discrete node. The following figure shows the details of bridge deck having T-Girder with nine longitudinal grid lines, out of this four are along the center of the girders are chosen. Thirteen transverse grid lines are chosen at variable spacing as shown below.

Figure 3.4-1 Grillage Mesh and Types of its Member,



- After the actual bridge structure is simulated in to equivalent grillage, consisting of longitudinal and transverse grid lines meeting at discrete nodes, the second important step is to assign appropriate elastic properties i.e. flexural and torsional stiffness to each member of the grillage so idealized.

Figure 3.4-2 Type of member in transverse direction.

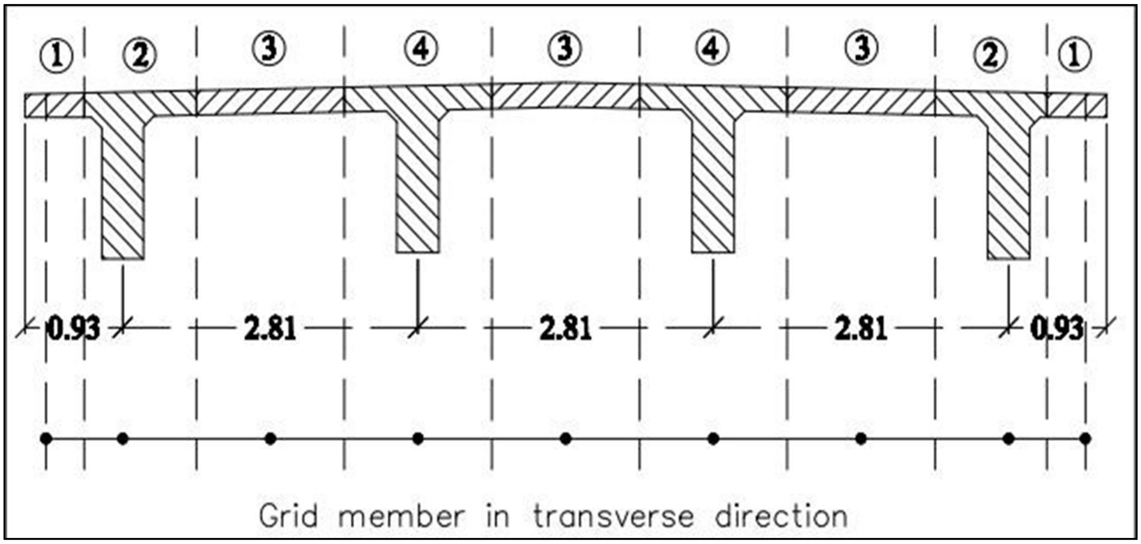


Figure 3.4-3 Type of member in longitudinal direction,

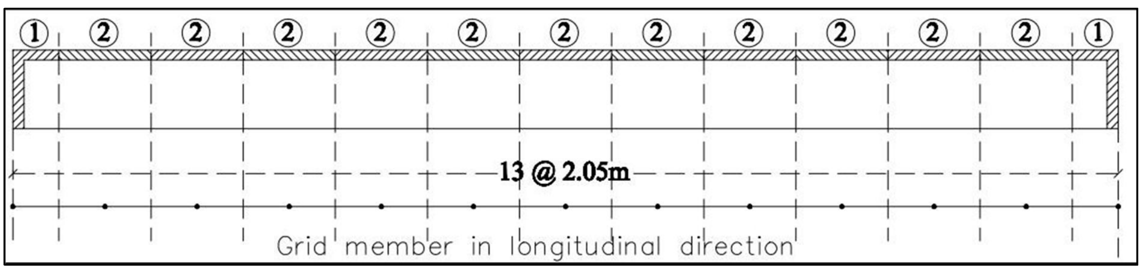
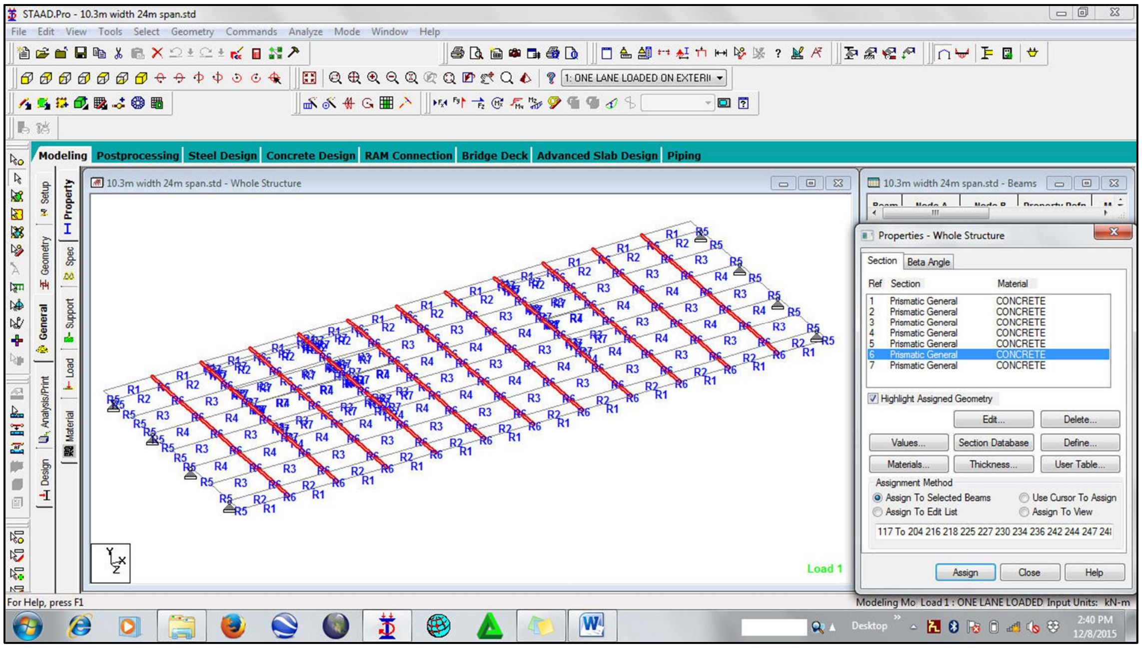


Table 3.4-1 Flexural and Torsional Moment of Inertia of the section,

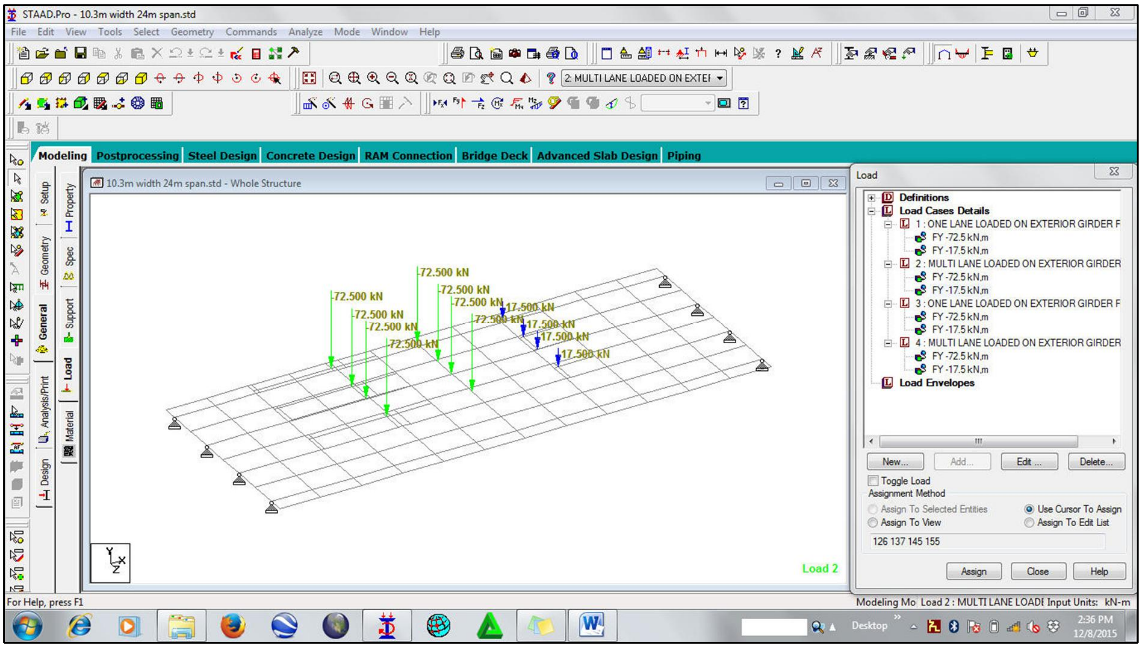
Computation of section property in longitudinal direction		
Member type	Flexural moment of Inertia (m^4)	Torsional moment of Inertial (m^4)
1	0.00050356	0.00100712
2	0.2504977	0.5009955
3	0.0012467	0.00249341
4	0.2778714	0.5557428
Computation of section property in transverse direction		
1	0.1841409	0.3682818
2	0.00181903	0.00363807
Interior Diaphragm	0.2348948	0.4697896

Figure 3.4-4 Section Property assignment in STAD. Pro software,



- The third step is application of loads; grillage analysis requires that the applied loads be transformed in to equivalent loads at nodes. If the load is applied directly to element as member loads, then the algorithm inherent in the software should correct determine the joint load force and moment. If the load is applied within a grillage panel, the easiest approach in this case is to add another grillage line under the load called sub grillage. An alternative to this is to refine the mesh to a point where the simple beam nodal load assignments are viable because the fixed-end torsion and bending moment are relatively small.

Figure 3.4-5 Load assignment in STAD. Pro software.



- The last step is interpretation of the result, the output obtained from the analysis of grillage consists of vertical deflection and X and Z rotation of each node, shear force and torsional moment of each beam element, bending moment at the two ends of each beam element and reaction at support.

Figure 3.4-6 Result of STAD. Pro software in Graphical Interface,

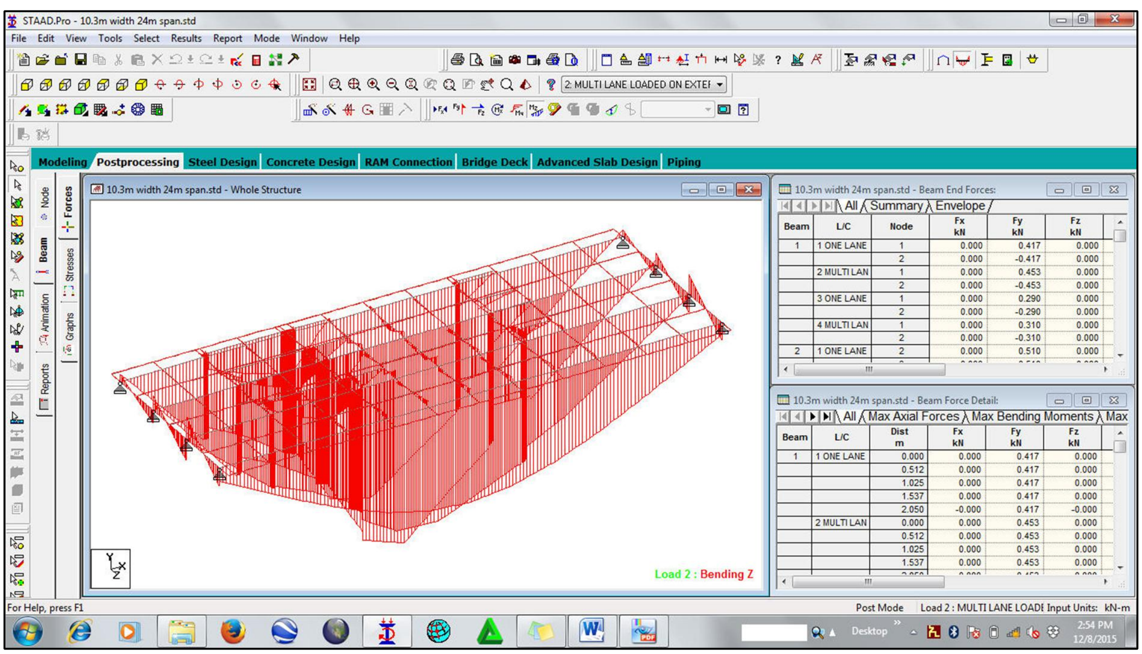


Figure 3.4-7 Grillage Analogy Method Results with provision of two diaphragms,

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	1	674.1	244.2
Exterior	2	921.8	208.4
Interior	1	614.1	215.8
Interior	2	948.0	287.1

4 DISCUSSION ON NUMERICAL RESULTS

4.1 Introduction

The analysis process of both T and Box Girder Bridge using approximate and Grillage analogy method involve output of bending moment, shear and torsion in the girders at different live load pattern, therefore, to provide the more insight in to the result difference by the two analysis method comparison were made on T and Box Girder bridge model with different span length and bridge width, where for T-Girder model a span of 20m and 24m and bridge width of two lane, four lane and six lane. In addition, 30m span T-Girder analyzed for comparison purpose. For the Box Girder bridge model a span of 30m and 40m and bridge width of two lanes, four lanes and six lanes were used. This chapter summarizes and compares the results of approximate and Grillage analogy method for the five different span length of the bridge superstructure model. It consists of the following comparison:

- Comparison of the result of T-Girder bridge model using the two analysis method
- Comparison of the result of Box Girder bridge model using the two analysis method
- Study the effect of diaphragm on load distribution.

4.2 Results from approximate method of analysis

In this part, the result for maximum Girder Moment and maximum Girder Shear computed by approximate method of analysis considering different bridge width (lane width) such as 10.3m, 19.4m and 26.4m, and with a different span (bridge length) of 20m, 24m and 30m for T-Girder Bridges, and 30m and 40m for Box Girder Bridges are presented.

4.2.1 Results of T-Girder Superstructures

Table 4.2.1-1 10.3m Bridge Width and 20m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1111.0	257.0
Exterior	Multiple	932.6	199.5
Interior	Single	665.6	205.2
Interior	Multiple	932.6	256.3

Table 4.2.1-2 10.3m Bridge Width and 24m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1409.6	263.7
Exterior	Multiple	1179.0	204.7
Interior	Single	828.3	210.6
Interior	Multiple	1179.0	263.0

Table 4.2.1-3 19.4m Bridge Width and 20m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1179.4	272.7
Exterior	Multiple	869.7	196.0
Interior	Single	611.4	191.9
Interior	Multiple	845.2	232.9

Table 4.2.1-4 19.4m Bridge Width and 24m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1495.8	279.8
Exterior	Multiple	1099.4	201.1
Interior	Single	761.0	196.9
Interior	Multiple	1068.5	238.9

Table 4.2.1-5 26.4m Bridge Width and 20m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1188.1	274.7
Exterior	Multiple	920.2	206.7
Interior	Single	647.8	200.8
Interior	Multiple	903.7	248.6

Table 4.2.1-6 26.4m Bridge Width and 24m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1506.9	281.9
Exterior	Multiple	1163.3	212.1
Interior	Single	806.2	206.0
Interior	Multiple	1142.5	255.1

Table 4.2.1-7 10.3m Bridge Width and 30m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1850.2	269.5
Exterior	Multiple	1567.3	209.1
Interior	Single	1079.5	216.3
Interior	Multiple	1567.3	270.4

Table 4.2.1-8 19.4m Bridge Width and 30m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1867.9	272.1
Exterior	Multiple	1429.1	199.4
Interior	Single	997.1	203.1
Interior	Multiple	1429.1	247.1

Table 4.2.1-9 26.4m Bridge Width and 30m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1941.5	282.8
Exterior	Multiple	1522.2	214.2
Interior	Single	1050.8	211.7
Interior	Multiple	1518.9	262.3

4.2.2 Results of Box Girder Superstructures

Table 4.2.2-1 10.3m Bridge Width and 30m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1321.1	269.5
Exterior	Multiple	1100.9	217.1
Interior	Single	1059.3	219.8
Interior	Multiple	1564.1	279.5

Table 4.2.2-2 10.3m Bridge Width and 40m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1851.5	276.3
Exterior	Multiple	1542.9	222.6
Interior	Single	1344.6	225.3
Interior	Multiple	2042.4	286.5

Table 42.2-3 19.4m Bridge Width and 30m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1281.4	272.1
Exterior	Multiple	1067.9	200.0
Interior	Single	671.6	203.5
Interior	Multiple	1066.8	249.0

Table 4.2.2-4 19.4m Bridge Width and 40m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1795.9	278.9
Exterior	Multiple	1496.5	205.0
Interior	Single	852.5	208.6
Interior	Multiple	1393.0	255.2

Table 4.2.2-5 26.4m Bridge Width and 30m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1360.8	282.8
Exterior	Multiple	1134.0	218.0
Interior	Single	664.0	214.1
Interior	Multiple	1115.8	268.8

Table 4.2.2-6 26.4m Bridge Width and 40m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
Exterior	Single	1907.1	289.9
Exterior	Multiple	1589.3	223.9
Interior	Single	843.0	220.0
Interior	Multiple	1457.0	276.1

4.3 Results from grillage analogy method of analysis

In this part, the result for maximum Girder Moment and maximum Girder Shear computed by grillage analogy method of analysis using STAD. Pro 2007 structural analysis software are presented considering different bridge width (lane width) such as 10.3m, 19.4m and 26.4m, and with a different bridge span (bridge length) of 20m, 24m and 30m for T-Girder Bridges, and 30m and 40m for Box Girder Bridges, parallel three diaphragm cases are consider to see the effect of diaphragm on load distribution.

4.3.1 Results of T-Girder Superstructures

Table 4.3.1-1 10.3m Bridge Width and 20m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	512.3	238.6	439.7	239.1	453.1	237.7

Exterior	Two	713.2	207.9	687.6	214.8	693.3	222.4
Interior	One	480.4	196.0	416.1	187.4	432.5	173.5
Interior	Two	746.3	267.8	681.1	255.3	701.2	237.8

Table 4.3.1-2 10.3m Bridge Width and 24m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	674.1	244.2	586.1	244.3	598.9	242.9
Exterior	Two	921.8	208.4	897.1	214.7	900.1	223.2
Interior	One	614.1	215.8	524.2	208.0	541.9	191.2
Interior	Two	948.0	287.1	852.9	275.3	873.6	254.9

Table 4.3.1-3 19.4m Bridge Width and 20m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	494.9	254.9	412.4	253.7	413.1	250.4
Exterior	Two	641.1	228.1	601.7	232.4	591.3	237.7
Exterior	Three	668.2	188.8	661.7	197.0	648.2	205.3
Exterior	Four	567.3	140.1	576.9	146.7	570.0	152.2
Interior	One	389.4	190.1	355.1	179.8	344.9	156.4
Interior	Two	641.4	243.7	546.6	226.5	538.5	199.1
Interior	Three	696.6	213.5	636.4	199.4	620.8	180.8
Interior	Four	602.3	163.1	578.9	155.9	564.1	144.7

Table 4.3.1-4 19.4m Bridge Width and 24m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	593.5	267	468.2	263.3	467.5	256.3
Exterior	Two	780.4	228.7	697.1	234.1	687.6	241.6
Exterior	Three	813.1	190	784.4	199.6	765.6	210.5
Exterior	Four	695.5	143.1	695.5	150.6	682.5	158.2
Interior	One	489.4	193.6	401.3	184.0	400.4	166.0
Interior	Two	753.2	244.1	616.4	230.1	614.8	209.7
Interior	Three	827.2	209.8	719.4	200.2	725.2	189.4
Interior	Four	721.5	161.3	676.0	156.7	669.5	151.4

Table 4.3.1-5 26.4m Bridge Width and 20m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	545.6	266.4	427.1	262.9	432.5	256.3
Exterior	Two	697.8	226.7	636.2	233.4	617.3	242.3
Exterior	Three	712.1	189.2	698.1	200.1	672.7	211.7
Exterior	Four	597.8	142.9	607.1	151.4	588.1	160.0
Exterior	Five	628.7	145.2	647.9	149.7	633.9	153.3
Exterior	Six	647.1	141.3	669.5	146.1	663	151.8
Interior	One	394.9	204.1	373.3	192.4	359.3	171.4
Interior	Two	672.1	263.5	541.1	246.3	552.7	221.8
Interior	Three	731.6	226.0	642.5	214.0	640.5	200.2
Interior	Four	631.2	173.6	590.6	167.6	583.2	159.7

Interior	Five	676.0	174.0	656.5	170.2	646.9	163.6
Interior	Six	695.5	174.2	695.5	171.7	689.0	165.9

Table 4.3.1-6 26.4m Bridge Width and 24m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	629.3	270.2	489.0	267.6	487.4	261.2
Exterior	Two	817.9	235.8	730.7	241.8	712.9	249.6
Exterior	Three	848.8	197.3	819.0	207.6	790.6	219.4
Exterior	Four	721.5	148.8	728.0	157.7	702.0	166.8
Exterior	Five	773.5	147.6	793.0	155.4	767.0	163.2
Exterior	Six	799.5	146.8	825.3	152.6	812.5	158.8
Interior	One	511.9	204.8	419.8	195.7	414.1	176.9
Interior	Two	793.4	265.3	640.8	250.6	636.9	227.4
Interior	Three	875.5	229.1	747.5	217.7	750.0	204.2
Interior	Four	760.5	176.2	702.0	169.9	695.5	162.5
Interior	Five	825.5	176.7	786.5	172.5	780.0	166.6
Interior	Six	864.5	177.1	845.0	174.3	838.5	169.3

Table 4.3.1-7 10.3m Bridge Width and 30m Bridge span,

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	851.8	256.3	691.4	254.2	691.9	251.2
Exterior	Two	1150.0	219.2	1070	220.9	1070.0	226.8
Interior	One	826.7	228.6	727.7	217.0	726.6	203.6

Interior	Two	1290.0	290.7	1150.0	277.7	1180.0	264.0

Table 4.3.1-8 19.4m Bridge Width and 30m Bridge span,

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	698.2	258.5	560.2	256.7	528.7	252.6
Exterior	Two	915.2	222.5	826.9	225.7	778.1	232.1
Exterior	Three	960.5	184.9	909.5	190.7	875.5	198.9
Exterior	Four	832.0	138.9	786.5	143.3	786.5	148.8
Interior	One	639.4	198.0	609.7	192.1	501.4	179.0
Interior	Two	980.4	250.5	930.3	241.9	789.1	227.1
Interior	Three	1079.5	216.7	1079.5	210.8	926.5	203.1
Interior	Four	949.0	166.7	981.5	163.9	864.5	160.2

Table 4.3.1-6 26.4m Bridge Width and 30m Bridge span,

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	754.0	268.8	557.8	267.0	549.6	262.7
Exterior	Two	980.4	232.3	821.0	236.2	806.2	242.7
Exterior	Three	1020.0	193.6	926.5	200.4	901.0	209.7
Exterior	Four	877.5	145.9	832.0	151.5	806.0	158.4
Exterior	Five	936.0	144.5	910.0	149.4	890.5	155.0
Exterior	Six	981.5	143.6	968.5	147.2	955.5	151.5
Interior	One	676.0	212.3	526.2	204.5	513.7	187.8
Interior	Two	1040.0	270.1	818.3	258.2	803.5	238.3

Interior	Three	1139.0	232.9	960.5	223.8	943.5	212.2
Interior	Four	1001.0	178.7	890.5	173.7	877.5	167.7
Interior	Five	1079.0	179.1	1007.5	175.8	988.0	171.3
Interior	Six	1137.5	176.1	1092.0	174.7	1072.5	173.2

4.3.2 Results of Box Girder Superstructures

Table 4.3.2-1 10.3m Bridge Width and 30m Bridge span,

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	590.9	239.5	597.0	239.3	594.8	239.2
Exterior	Two	897.2	232.8	901.1	232.6	899.1	232.4
Interior	One	819.1	183.5	821.5	183.5	820.4	183.5
Interior	Two	1320.0	242.9	1330.0	242.9	1320.0	242.9

Table 4.3.2-2 10.3m Bridge Width and 40m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	788.9	246.2	789.5	246.2	789.2	246.2
Exterior	Two	1230.0	241.8	1230.0	241.8	1230.0	241.8
Interior	One	1107.6	185.6	1107.5	185.6	1107.5	185.6
Interior	Two	1800.0	243.5	1800.0	243.5	1800.0	243.5

Table 4.3.2-3 19.4m Bridge Width and 30m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	388.2	228.5	406.6	228.4	401.9	228.5
Exterior	Two	581.8	229.5	587.9	229.2	581.8	229.2
Exterior	Three	663.7	206.1	667.2	205.9	661.3	205.6
Exterior	Four	611.7	156.3	613.3	156.1	609.2	155.7
Interior	One	499.3	158.8	502.8	158.8	497.6	158.9
Interior	Two	772.3	204.0	776.6	203.9	770.0	204.1
Interior	Three	909.5	190.1	909.5	190.0	901.0	190.2
Interior	Four	851.5	153.3	851.5	153.2	851.5	153.4

Table 4.3.2-4 19.4m Bridge Width and 40m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	496.0	230.4	496.2	230.4	495.8	230.3
Exterior	Two	743.2	233.5	743.6	233.4	743.1	233.3
Exterior	Three	867.0	211.9	867.0	211.8	867.0	211.8
Exterior	Four	819.0	162.1	819.0	162.1	819.0	162.1
Interior	One	631.6	162.5	631.4	162.5	631.0	162.5
Interior	Two	993.2	207.6	992.9	207.6	992.3	207.6
Interior	Three	1190.0	193.1	1190.0	193.1	1181.5	193.1
Interior	Four	1137.5	155.5	1137.5	155.4	1137.5	155.4

Table 4.3.2-5 26.4m Bridge Width and 30m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	400.3	235.3	409.4	235.1	400.7	235.0
Exterior	Two	580.1	237.3	588.5	237.0	576.3	236.7
Exterior	Three	657.1	215.6	663.1	215.3	650.2	215.0
Exterior	Four	601.6	167.0	605.1	166.7	594.4	166.3
Exterior	Five	682.5	164.6	682.5	164.3	669.5	163.9
Exterior	Six	741.0	159.7	741.0	159.5	734.5	159.0
Interior	One	489.7	165.8	489.1	165.8	488.5	165.8
Interior	Two	752.3	214.5	751.6	214.5	750.7	214.5
Interior	Three	875.5	199.2	875.5	199.2	875.5	199.2
Interior	Four	812.5	160.4	812.5	160.4	812.5	160.4
Interior	Five	936.0	165.2	936.0	165.2	936.0	165.2
Interior	Six	1027.0	62.5	1027.0	62.5	1027.0	62.5

Table 4.3.2-6 26.4m Bridge Width and 40m Bridge span.

Girder Location	Number of Lanes Loaded	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)	Maximum Girder Moment (KNm)	Maximum Girder Shear (KN)
		Two Diaphragm case		Three Diaphragm case		Five Diaphragm case	
Exterior	One	481.0	236.9	480.8	236.9	480.4	236.6
Exterior	Two	713.5	240.9	713.7	240.8	712.9	240.7
Exterior	Three	824.2	221.2	824.7	221.2	823.7	221.1
Exterior	Four	767.0	172.9	767.0	173.0	767.0	173.0
Exterior	Five	884.0	171.7	884.0	171.7	884.0	171.7

Exterior	Six	981.5	167.3	981.5	167.3	981.5	167.4
Interior	One	598.0	168.8	597.6	168.8	596.9	168.8
Interior	Two	932.7	216.9	932.2	216.9	931.2	216.9
Interior	Three	1105.0	201.5	1105.0	201.5	1105.0	201.5
Interior	Four	1046.5	162.2	1046.5	162.2	1046.5	162.2
Interior	Five	1222.0	167.1	1222.0	167.1	1222.0	167.1
Interior	Six	1371.5	170.0	1371.5	170.0	1371.5	170.0

4.4 Comparison Figures

The analysis result of both T-Girder and Box Girder bridge superstructures are investigated by comparing the result obtained by approximate method and grillage analogy method of analysis. The comparison of T-Girder superstructures are presented in the following Figure 4.4-1 to Figure 4.4-9. Figure 4.4-10 to Figure 4.4-15 shows the comparison of Box Girder superstructures respectively.

Figure 4.4-1 Comparison for 10.3m Bridge Width and 20m Bridge Span of RCTG,

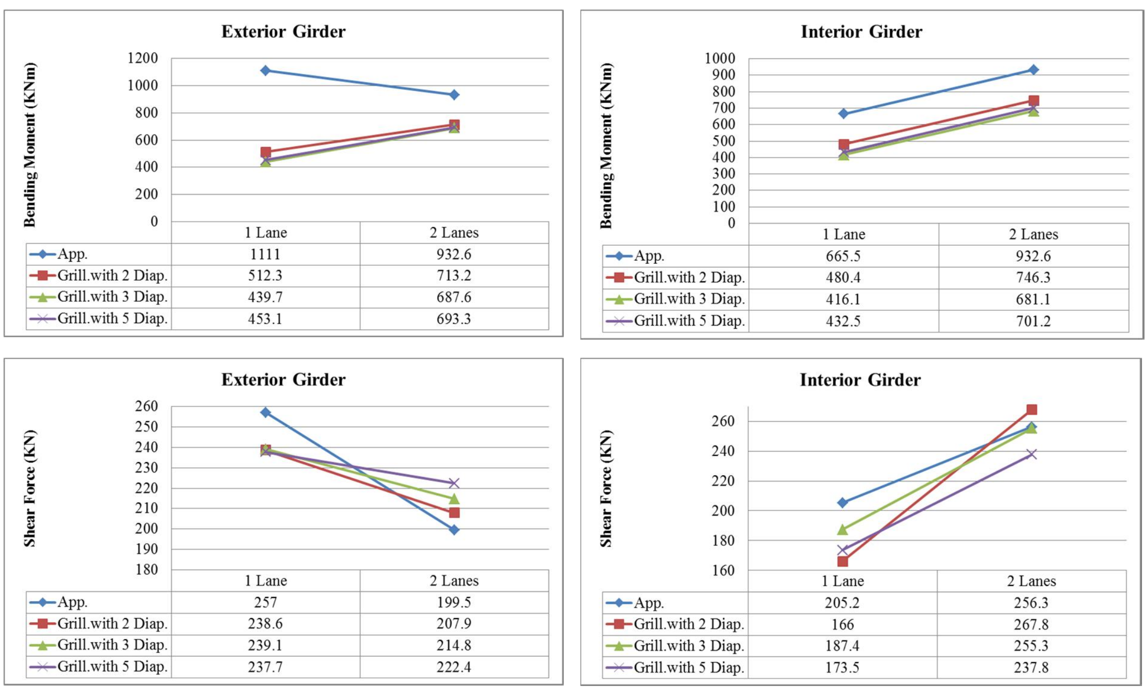
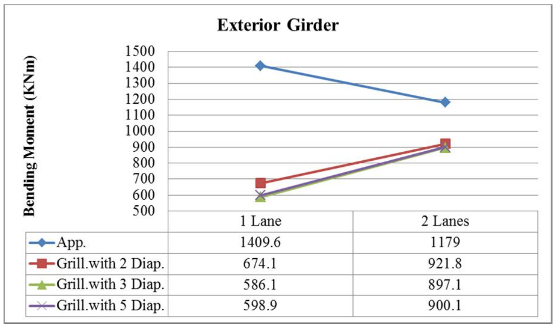
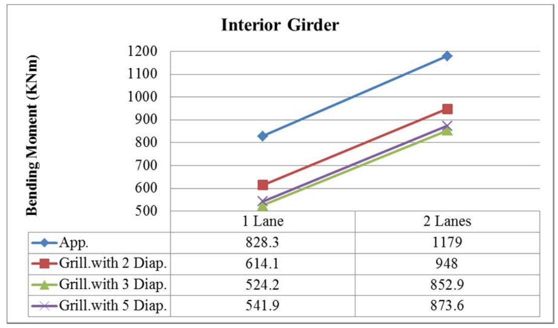


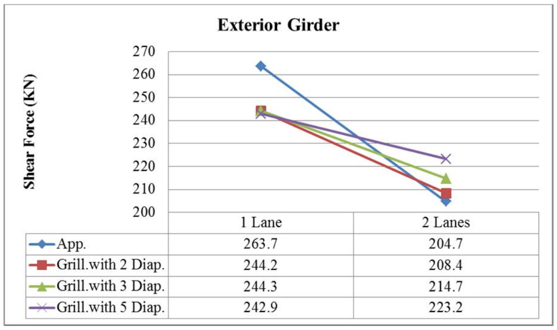
Figure 4.4-2 Comparison for 10.3m Bridge Width and 24m Bridge span of RCTG,



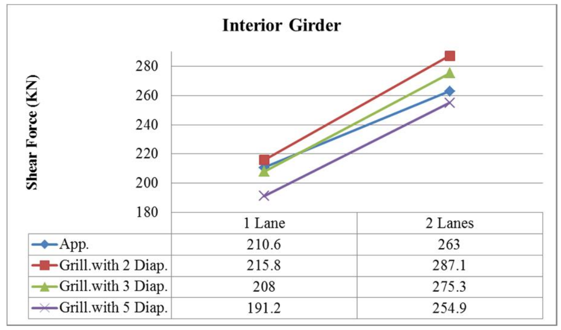
	1 Lane	2 Lanes
App.	1409.6	1179
Grill.with 2 Diap.	674.1	921.8
Grill.with 3 Diap.	586.1	897.1
Grill.with 5 Diap.	598.9	900.1



	1 Lane	2 Lanes
App.	828.3	1179
Grill.with 2 Diap.	614.1	948
Grill.with 3 Diap.	524.2	852.9
Grill.with 5 Diap.	541.9	873.6

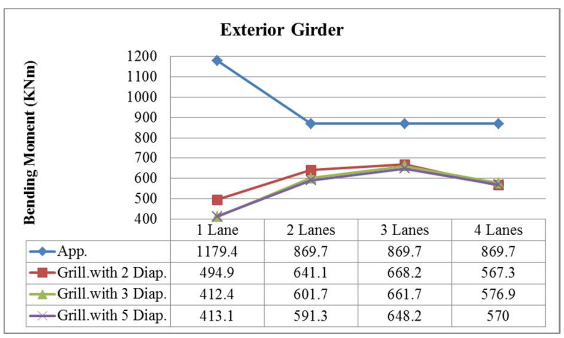


	1 Lane	2 Lanes
App.	263.7	204.7
Grill.with 2 Diap.	244.2	208.4
Grill.with 3 Diap.	244.3	214.7
Grill.with 5 Diap.	242.9	223.2

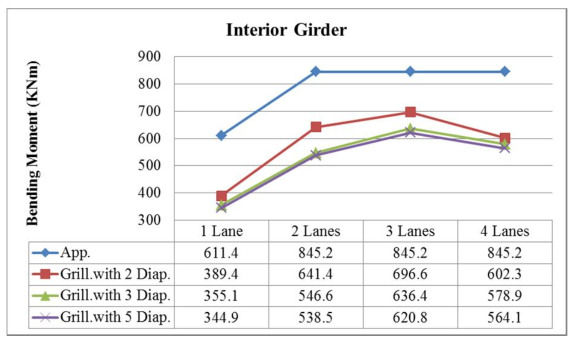


	1 Lane	2 Lanes
App.	210.6	263
Grill.with 2 Diap.	215.8	287.1
Grill.with 3 Diap.	208	275.3
Grill.with 5 Diap.	191.2	254.9

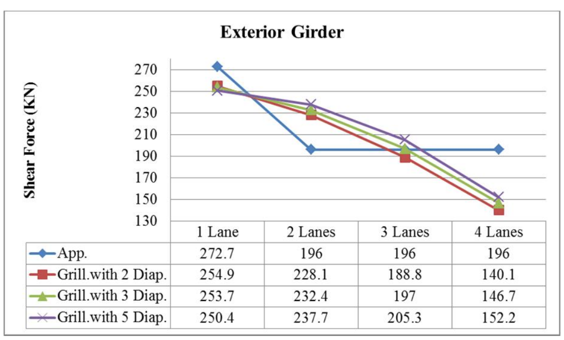
Figure 4.4-3 Comparison for 19.4m Bridge Width and 20m Bridge Span of RCTG,



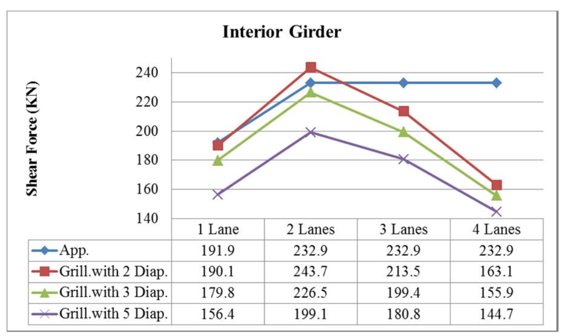
	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	1179.4	869.7	869.7	869.7
Grill.with 2 Diap.	494.9	641.1	668.2	567.3
Grill.with 3 Diap.	412.4	601.7	661.7	576.9
Grill.with 5 Diap.	413.1	591.3	648.2	570



	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	611.4	845.2	845.2	845.2
Grill.with 2 Diap.	389.4	641.4	696.6	602.3
Grill.with 3 Diap.	355.1	546.6	636.4	578.9
Grill.with 5 Diap.	344.9	538.5	620.8	564.1

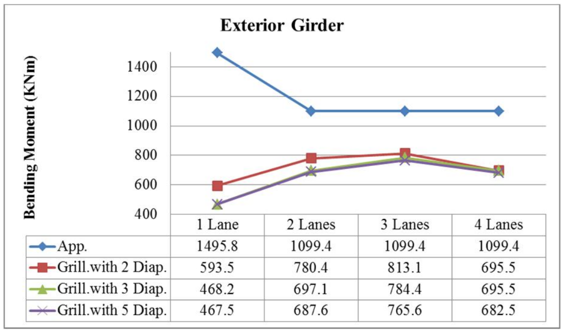


	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	272.7	196	196	196
Grill.with 2 Diap.	254.9	228.1	188.8	140.1
Grill.with 3 Diap.	253.7	232.4	197	146.7
Grill.with 5 Diap.	250.4	237.7	205.3	152.2

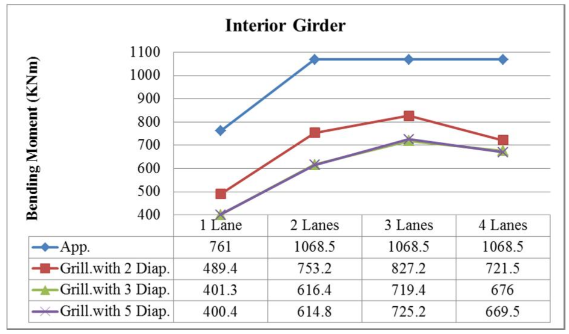


	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	191.9	232.9	232.9	232.9
Grill.with 2 Diap.	190.1	243.7	213.5	163.1
Grill.with 3 Diap.	179.8	226.5	199.4	155.9
Grill.with 5 Diap.	156.4	199.1	180.8	144.7

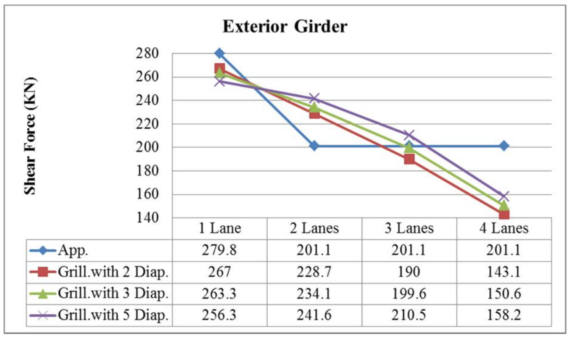
Figure 4.4-4 Comparison for 19.4m Bridge Width and 24m Bridge Span of RCTG,



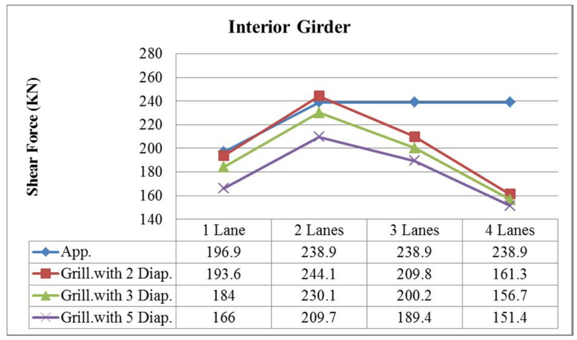
	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	1495.8	1099.4	1099.4	1099.4
Grill.with 2 Diap.	593.5	780.4	813.1	695.5
Grill.with 3 Diap.	468.2	697.1	784.4	695.5
Grill.with 5 Diap.	467.5	687.6	765.6	682.5



	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	761	1068.5	1068.5	1068.5
Grill.with 2 Diap.	489.4	753.2	827.2	721.5
Grill.with 3 Diap.	401.3	616.4	719.4	676
Grill.with 5 Diap.	400.4	614.8	725.2	669.5

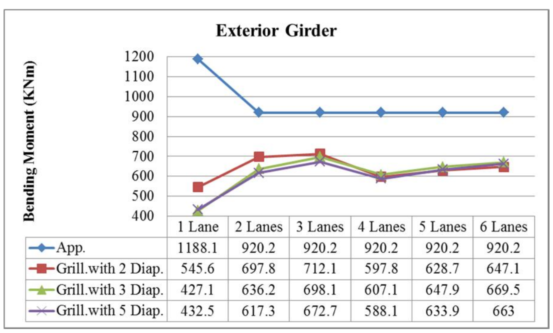


	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	279.8	201.1	201.1	201.1
Grill.with 2 Diap.	267	228.7	190	143.1
Grill.with 3 Diap.	263.3	234.1	199.6	150.6
Grill.with 5 Diap.	256.3	241.6	210.5	158.2

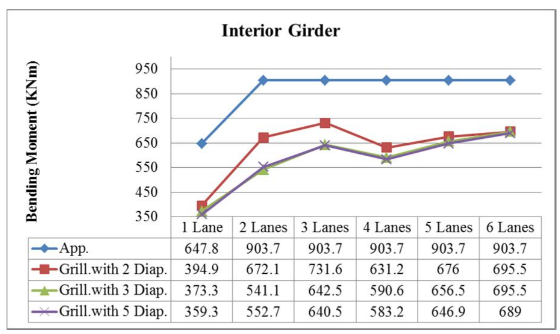


	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	196.9	238.9	238.9	238.9
Grill.with 2 Diap.	193.6	244.1	209.8	161.3
Grill.with 3 Diap.	184	230.1	200.2	156.7
Grill.with 5 Diap.	166	209.7	189.4	151.4

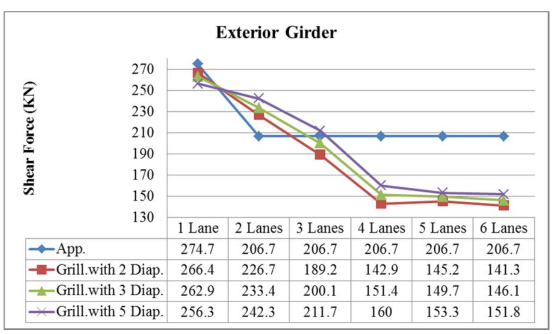
Figure 4.4-5 Comparison for 26.4m Bridge Width and 20m Bridge Span of RCTG,



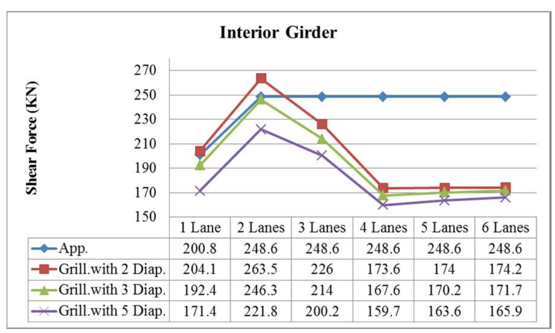
	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	1188.1	920.2	920.2	920.2	920.2	920.2
Grill.with 2 Diap.	545.6	697.8	712.1	597.8	628.7	647.1
Grill.with 3 Diap.	427.1	636.2	698.1	607.1	647.9	669.5
Grill.with 5 Diap.	432.5	617.3	672.7	588.1	633.9	663



	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	647.8	903.7	903.7	903.7	903.7	903.7
Grill.with 2 Diap.	394.9	672.1	731.6	631.2	676	695.5
Grill.with 3 Diap.	373.3	541.1	642.5	590.6	656.5	695.5
Grill.with 5 Diap.	359.3	552.7	640.5	583.2	646.9	689

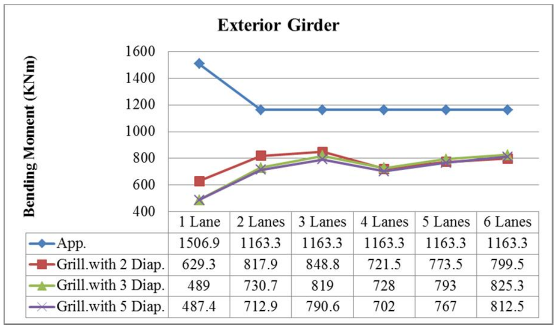


	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	274.7	206.7	206.7	206.7	206.7	206.7
Grill.with 2 Diap.	266.4	226.7	189.2	142.9	145.2	141.3
Grill.with 3 Diap.	262.9	233.4	200.1	151.4	149.7	146.1
Grill.with 5 Diap.	256.3	242.3	211.7	160	153.3	151.8

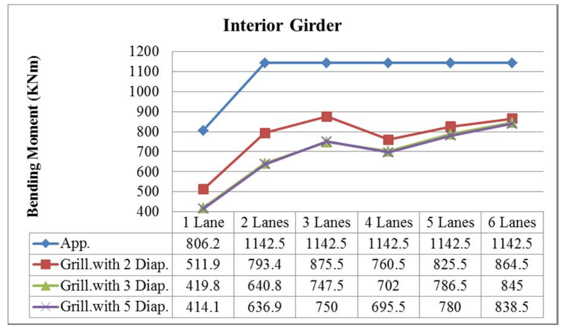


	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	200.8	248.6	248.6	248.6	248.6	248.6
Grill.with 2 Diap.	204.1	263.5	226	173.6	174	174.2
Grill.with 3 Diap.	192.4	246.3	214	167.6	170.2	171.7
Grill.with 5 Diap.	171.4	221.8	200.2	159.7	163.6	165.9

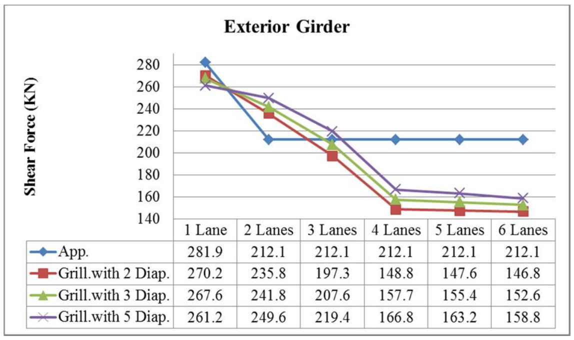
Figure 4.4-6 Comparison for 26.4m Bridge Width and 24m Bridge Span of RCTG,



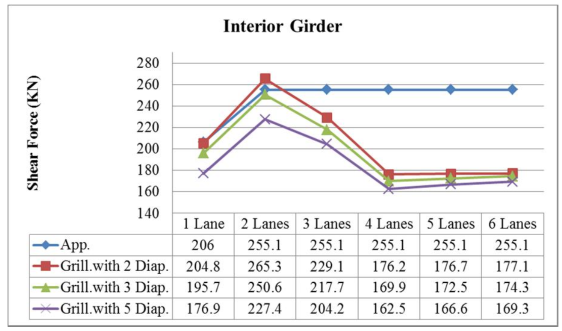
	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	1506.9	1163.3	1163.3	1163.3	1163.3	1163.3
Grill.with 2 Diap.	629.3	817.9	848.8	721.5	773.5	799.5
Grill.with 3 Diap.	489	730.7	819	728	793	825.3
Grill.with 5 Diap.	487.4	712.9	790.6	702	767	812.5



	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	806.2	1142.5	1142.5	1142.5	1142.5	1142.5
Grill.with 2 Diap.	511.9	793.4	875.5	760.5	825.5	864.5
Grill.with 3 Diap.	419.8	640.8	747.5	702	786.5	845
Grill.with 5 Diap.	414.1	636.9	750	695.5	780	838.5

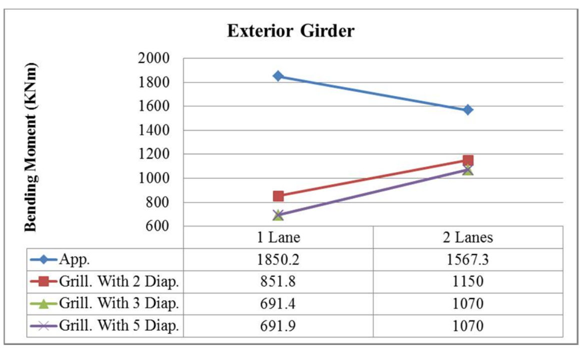


	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	281.9	212.1	212.1	212.1	212.1	212.1
Grill.with 2 Diap.	270.2	235.8	197.3	148.8	147.6	146.8
Grill.with 3 Diap.	267.6	241.8	207.6	157.7	155.4	152.6
Grill.with 5 Diap.	261.2	249.6	219.4	166.8	163.2	158.8

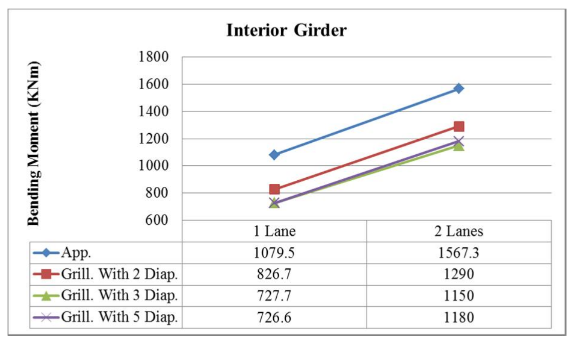


	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	206	255.1	255.1	255.1	255.1	255.1
Grill.with 2 Diap.	204.8	265.3	229.1	176.2	176.7	177.1
Grill.with 3 Diap.	195.7	250.6	217.7	169.9	172.5	174.3
Grill.with 5 Diap.	176.9	227.4	204.2	162.5	166.6	169.3

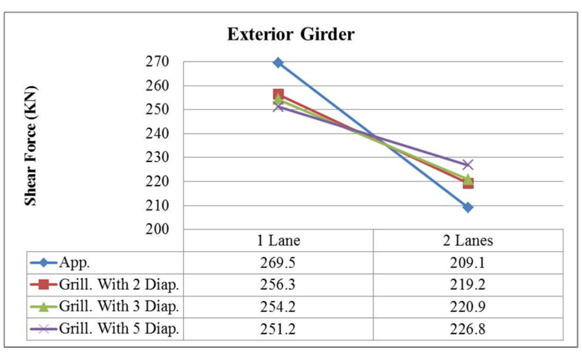
Figure 4.4-7 Comparison for 10.3m Bridge Width and 30m Bridge Span of RCTG,



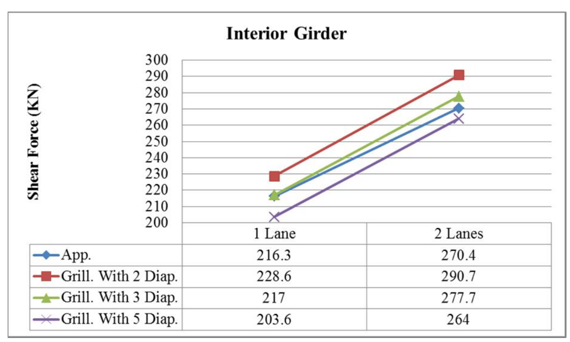
	1 Lane	2 Lanes
App.	1850.2	1567.3
Grill. With 2 Diap.	851.8	1150
Grill. With 3 Diap.	691.4	1070
Grill. With 5 Diap.	691.9	1070



	1 Lane	2 Lanes
App.	1079.5	1567.3
Grill. With 2 Diap.	826.7	1290
Grill. With 3 Diap.	727.7	1150
Grill. With 5 Diap.	726.6	1180

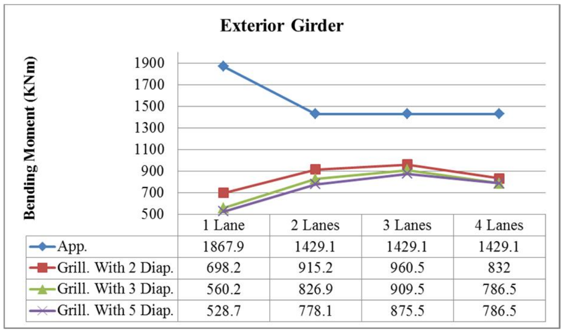


	1 Lane	2 Lanes
App.	269.5	209.1
Grill. With 2 Diap.	256.3	219.2
Grill. With 3 Diap.	254.2	220.9
Grill. With 5 Diap.	251.2	226.8

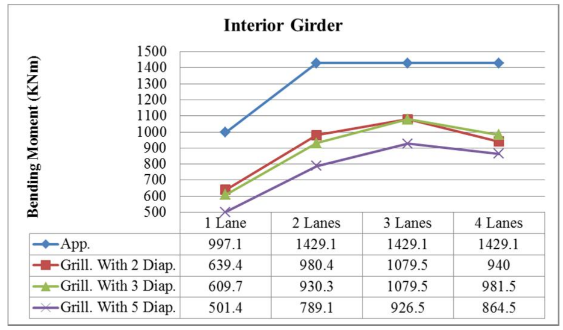


	1 Lane	2 Lanes
App.	216.3	270.4
Grill. With 2 Diap.	228.6	290.7
Grill. With 3 Diap.	217	277.7
Grill. With 5 Diap.	203.6	264

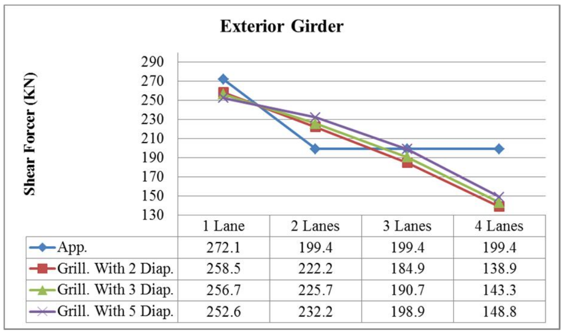
Figure 4.4-8 Comparison for 19.4m Bridge Width and 30m Bridge Span of RCTG



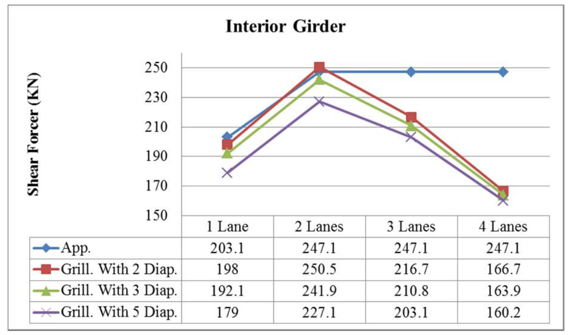
	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	1867.9	1429.1	1429.1	1429.1
Grill. With 2 Diap.	698.2	915.2	960.5	832
Grill. With 3 Diap.	560.2	826.9	909.5	786.5
Grill. With 5 Diap.	528.7	778.1	875.5	786.5



	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	997.1	1429.1	1429.1	1429.1
Grill. With 2 Diap.	639.4	980.4	1079.5	940
Grill. With 3 Diap.	609.7	930.3	1079.5	981.5
Grill. With 5 Diap.	501.4	789.1	926.5	864.5

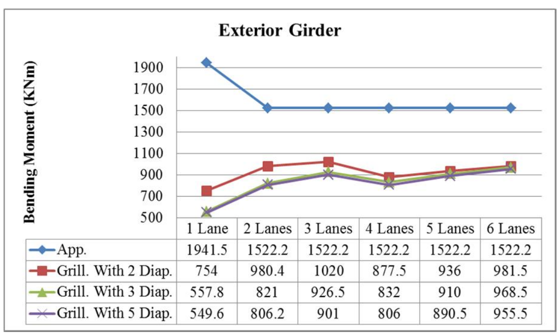


	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	272.1	199.4	199.4	199.4
Grill. With 2 Diap.	258.5	222.2	184.9	138.9
Grill. With 3 Diap.	256.7	225.7	190.7	143.3
Grill. With 5 Diap.	252.6	232.2	198.9	148.8

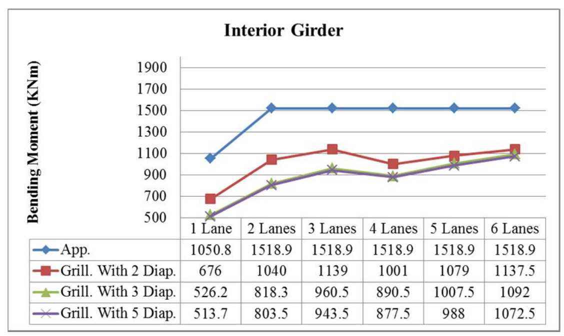


	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	203.1	247.1	247.1	247.1
Grill. With 2 Diap.	198	250.5	216.7	166.7
Grill. With 3 Diap.	192.1	241.9	210.8	163.9
Grill. With 5 Diap.	179	227.1	203.1	160.2

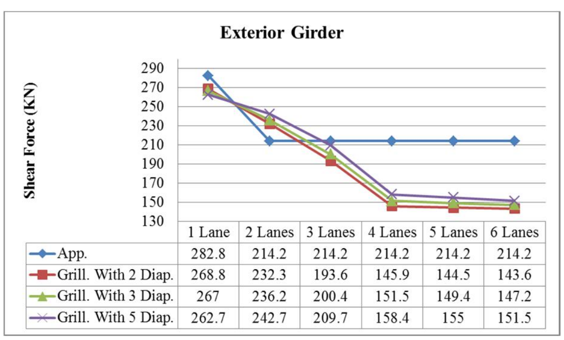
Figure 4.4-9 Comparison for 26.4m Bridge Width and 30m Bridge Span of RCTG,



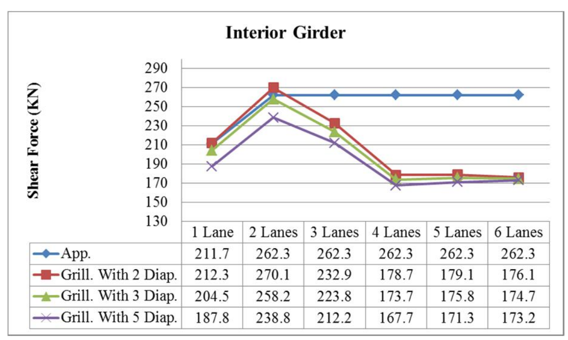
	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	1941.5	1522.2	1522.2	1522.2	1522.2	1522.2
Grill. With 2 Diap.	754	980.4	1020	877.5	936	981.5
Grill. With 3 Diap.	557.8	821	926.5	832	910	968.5
Grill. With 5 Diap.	549.6	806.2	901	806	890.5	955.5



	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	1050.8	1518.9	1518.9	1518.9	1518.9	1518.9
Grill. With 2 Diap.	676	1040	1139	1001	1079	1137.5
Grill. With 3 Diap.	526.2	818.3	960.5	890.5	1007.5	1092
Grill. With 5 Diap.	513.7	803.5	943.5	877.5	988	1072.5

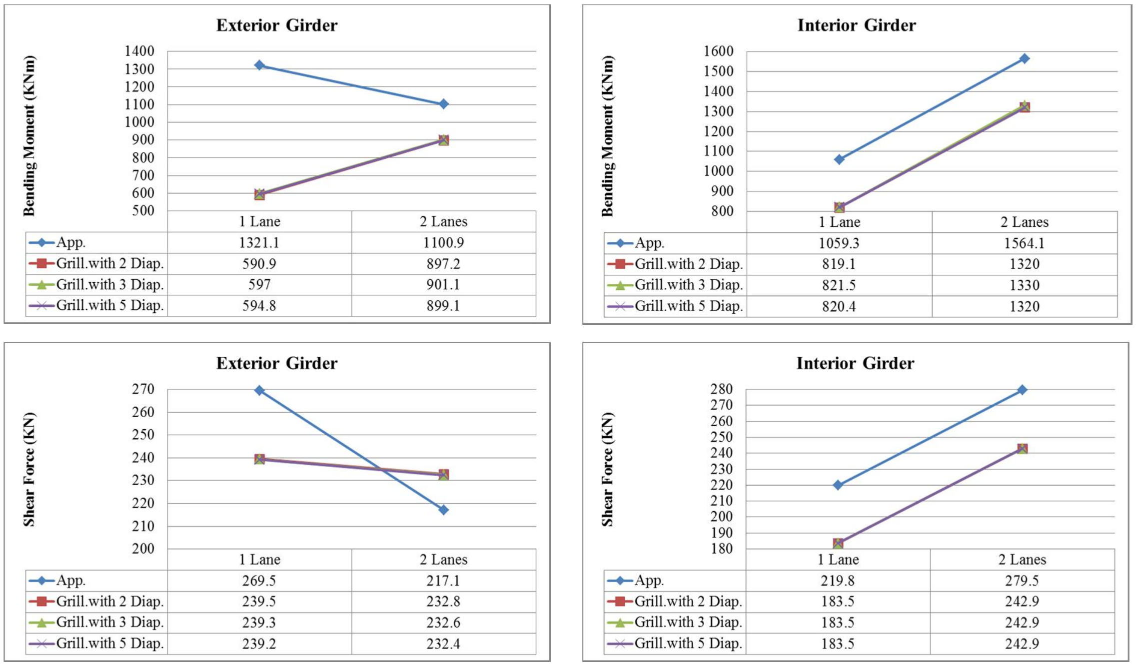


	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	282.8	214.2	214.2	214.2	214.2	214.2
Grill. With 2 Diap.	268.8	232.3	193.6	145.9	144.5	143.6
Grill. With 3 Diap.	267	236.2	200.4	151.5	149.4	147.2
Grill. With 5 Diap.	262.7	242.7	209.7	158.4	155	151.5



	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	211.7	262.3	262.3	262.3	262.3	262.3
Grill. With 2 Diap.	212.3	270.1	232.9	178.7	179.1	176.1
Grill. With 3 Diap.	204.5	258.2	223.8	173.7	175.8	174.7
Grill. With 5 Diap.	187.8	238.8	212.2	167.7	171.3	173.2

Figure 4.4-10 Comparison for 10.3m Bridge Width and 30m Bridge Span of RCBG,



Exterior Girder – Bending Moment (KNm)

	1 Lane	2 Lanes
App.	1321.1	1100.9
Grill.with 2 Diap.	590.9	897.2
Grill.with 3 Diap.	597	901.1
Grill.with 5 Diap.	594.8	899.1

Interior Girder – Bending Moment (KNm)

	1 Lane	2 Lanes
App.	1059.3	1564.1
Grill.with 2 Diap.	819.1	1320
Grill.with 3 Diap.	821.5	1330
Grill.with 5 Diap.	820.4	1320

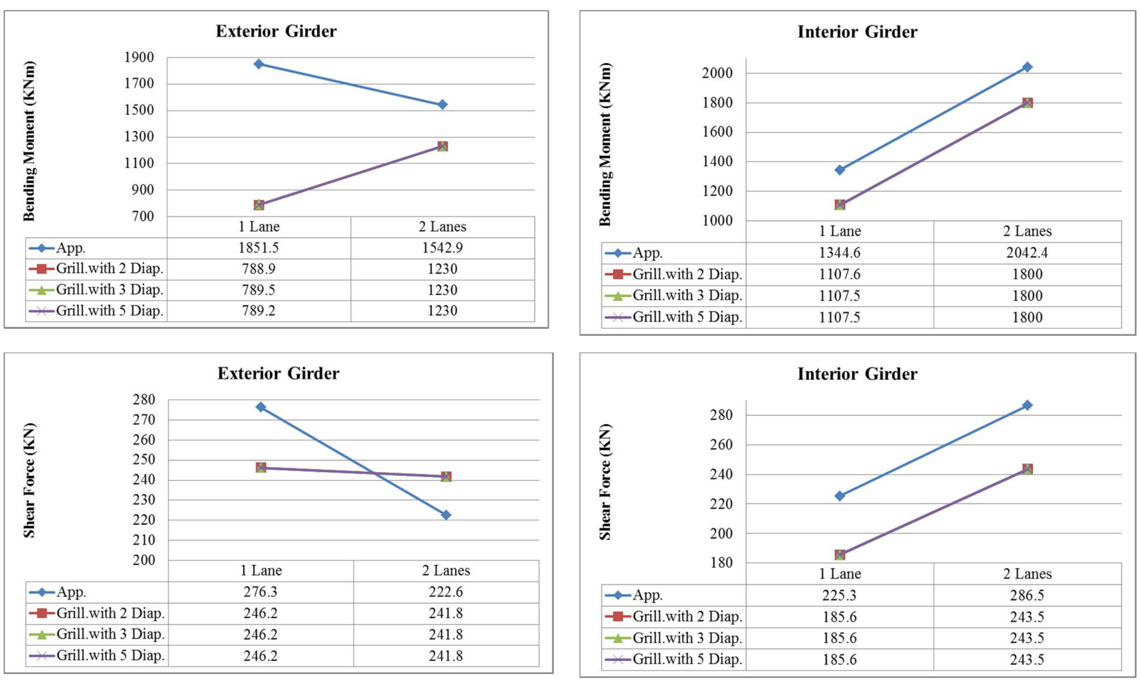
Exterior Girder – Shear Force (KN)

	1 Lane	2 Lanes
App.	269.5	217.1
Grill.with 2 Diap.	239.5	232.8
Grill.with 3 Diap.	239.3	232.6
Grill.with 5 Diap.	239.2	232.4

Interior Girder – Shear Force (KN)

	1 Lane	2 Lanes
App.	219.8	279.5
Grill.with 2 Diap.	183.5	242.9
Grill.with 3 Diap.	183.5	242.9
Grill.with 5 Diap.	183.5	242.9

Figure 4.4-11 Comparison for 10.3m Bridge Width and 40m Bridge Span of RCBG,



Exterior Girder – Bending Moment (KNm)

	1 Lane	2 Lanes
App.	1851.5	1542.9
Grill.with 2 Diap.	788.9	1230
Grill.with 3 Diap.	789.5	1230
Grill.with 5 Diap.	789.2	1230

Interior Girder – Bending Moment (KNm)

	1 Lane	2 Lanes
App.	1344.6	2042.4
Grill.with 2 Diap.	1107.6	1800
Grill.with 3 Diap.	1107.5	1800
Grill.with 5 Diap.	1107.5	1800

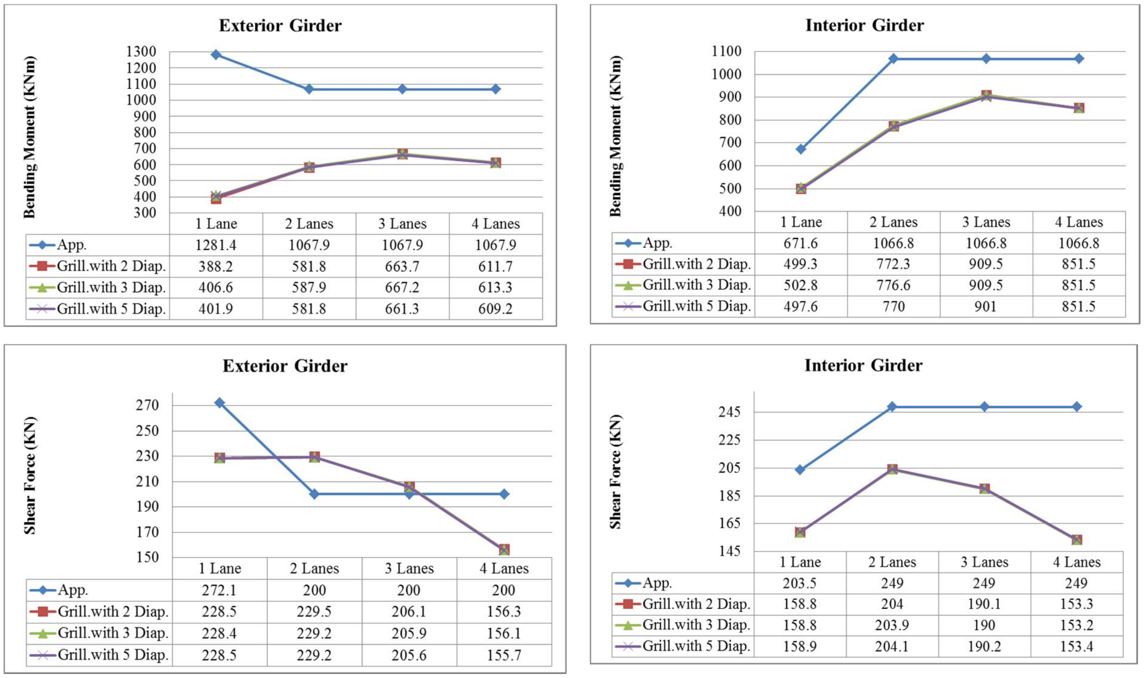
Exterior Girder – Shear Force (KN)

	1 Lane	2 Lanes
App.	276.3	222.6
Grill.with 2 Diap.	246.2	241.8
Grill.with 3 Diap.	246.2	241.8
Grill.with 5 Diap.	246.2	241.8

Interior Girder – Shear Force (KN)

	1 Lane	2 Lanes
App.	225.3	286.5
Grill.with 2 Diap.	185.6	243.5
Grill.with 3 Diap.	185.6	243.5
Grill.with 5 Diap.	185.6	243.5

Figure 4.4-12 Comparison for 19.4m Bridge Width and 30m Bridge Span of RCBG,



Exterior Girder – Bending Moment (KNm)

	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	1281.4	1067.9	1067.9	1067.9
Grill.with 2 Diap.	388.2	581.8	663.7	611.7
Grill.with 3 Diap.	406.6	587.9	667.2	613.3
Grill.with 5 Diap.	401.9	581.8	661.3	609.2

Interior Girder – Bending Moment (KNm)

	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	671.6	1066.8	1066.8	1066.8
Grill.with 2 Diap.	499.3	772.3	909.5	851.5
Grill.with 3 Diap.	502.8	776.6	909.5	851.5
Grill.with 5 Diap.	497.6	770	901	851.5

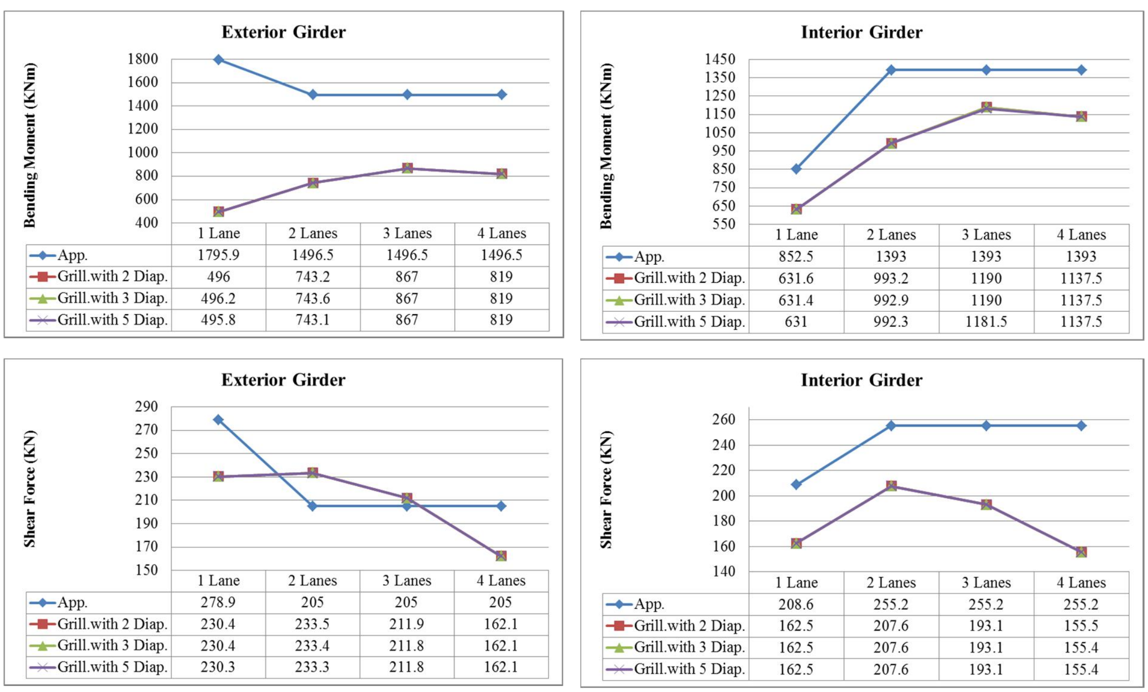
Exterior Girder – Shear Force (KN)

	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	272.1	200	200	200
Grill.with 2 Diap.	228.5	229.5	206.1	156.3
Grill.with 3 Diap.	228.4	229.2	205.9	156.1
Grill.with 5 Diap.	228.5	229.2	205.6	155.7

Interior Girder – Shear Force (KN)

	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	203.5	249	249	249
Grill.with 2 Diap.	158.8	204	190.1	153.3
Grill.with 3 Diap.	158.8	203.9	190	153.2
Grill.with 5 Diap.	158.9	204.1	190.2	153.4

Figure 4.4-13 Comparison for 19.4m Bridge Width and 40m Bridge Span of RCBG,



Exterior Girder – Bending Moment (KNm)

	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	1795.9	1496.5	1496.5	1496.5
Grill.with 2 Diap.	496	743.2	867	819
Grill.with 3 Diap.	496.2	743.6	867	819
Grill.with 5 Diap.	495.8	743.1	867	819

Interior Girder – Bending Moment (KNm)

	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	852.5	1393	1393	1393
Grill.with 2 Diap.	631.6	993.2	1190	1137.5
Grill.with 3 Diap.	631.4	992.9	1190	1137.5
Grill.with 5 Diap.	631	992.3	1181.5	1137.5

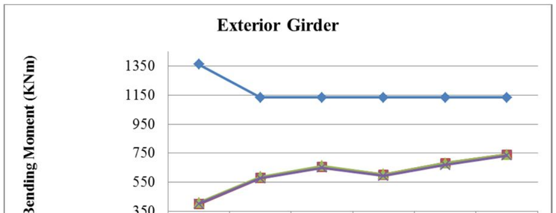
Exterior Girder – Shear Force (KN)

	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	278.9	205	205	205
Grill.with 2 Diap.	230.4	233.5	211.9	162.1
Grill.with 3 Diap.	230.4	233.4	211.8	162.1
Grill.with 5 Diap.	230.3	233.3	211.8	162.1

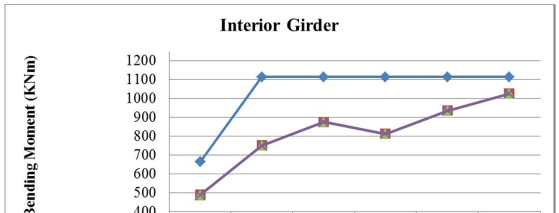
Interior Girder – Shear Force (KN)

	1 Lane	2 Lanes	3 Lanes	4 Lanes
App.	208.6	255.2	255.2	255.2
Grill.with 2 Diap.	162.5	207.6	193.1	155.5
Grill.with 3 Diap.	162.5	207.6	193.1	155.4
Grill.with 5 Diap.	162.5	207.6	193.1	155.4

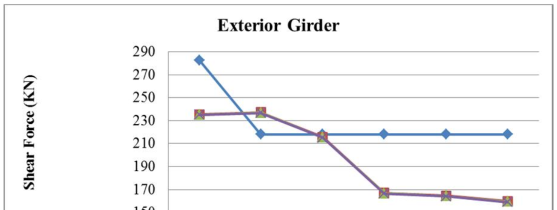
Figure 4.4-14 Comparison for 26.4m Bridge Width and 30m Bridge Span of RCBG,



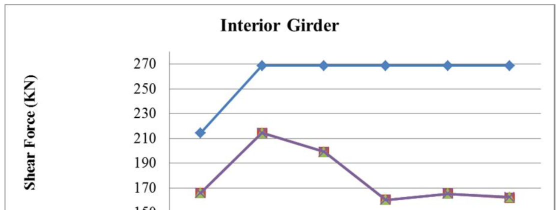
	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	1360.8	1134	1134	1134	1134	1134
Grill.with 2 Diap.	400.3	580.1	657.1	601.6	682.5	741
Grill.with 3 Diap.	409.4	588.5	663.1	605.1	682.5	741
Grill.with 5 Diap.	400.7	576.3	650.2	594.4	669.5	734.5



	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	664	1115.8	1115.8	1115.8	1115.8	1115.8
Grill.with 2 Diap.	489.7	752.3	875.5	812.5	936	1027
Grill.with 3 Diap.	489.1	751.6	875.5	812.5	936	1027
Grill.with 5 Diap.	488.5	750.7	875.5	812.5	936	1027

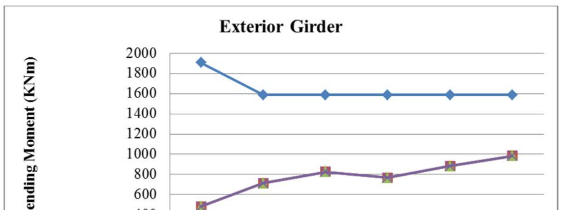


	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	282.8	218	218	218	218	218
Grill.with 2 Diap.	235.3	237.3	215.6	167	164.6	159.7
Grill.with 3 Diap.	235.1	237	215.3	166.7	164.3	159.5
Grill.with 5 Diap.	235	236.7	215	166.3	163.9	159



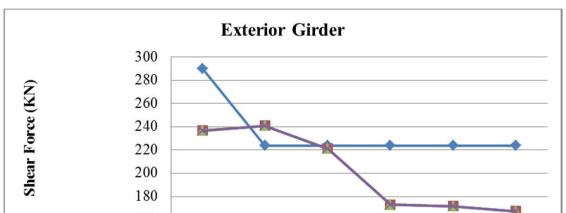
	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	214.1	268.8	268.8	268.8	268.8	268.8
Grill.with 2 Diap.	165.8	214.5	199.2	160.4	165.2	162
Grill.with 3 Diap.	165.8	214.5	199.2	160.4	165.2	162.5
Grill.with 5 Diap.	165.8	214.5	199.2	160.4	165.2	162.5

Figure 4.4-15 Comparison for 26.4m Bridge Width and 40m Bridge Span of RCBG,

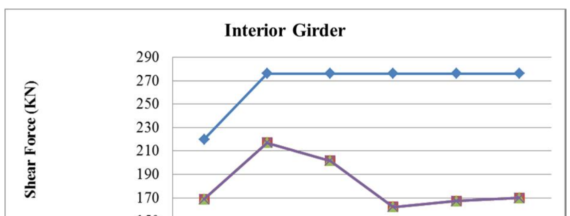


	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	1907.1	1589.3	1589.3	1589.3	1589.3	1589.3
Grill.with 2 Diap.	481	713.5	824.2	767	884	981.5
Grill.with 3 Diap.	480.8	713.7	824.7	767	884	981.5
Grill.with 5 Diap.	480.4	712.9	823.7	767	884	981.5

	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	843	1457	1457	1457	1457	1457
Grill.with 2 Diap.	598	932.7	1105	1046.5	1222	1371.5
Grill.with 3 Diap.	597.6	932.2	1105	1046.5	1222	1371.5
Grill.with 5 Diap.	596.9	931.2	1105	1046.5	1222	1371.5



	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	289.9	223.9	223.9	223.9	223.9	223.9
Grill.with 2 Diap.	236.9	240.9	221.2	172.9	171.7	167.3
Grill.with 3 Diap.	236.9	240.8	221.2	173	171.7	167.3
Grill.with 5 Diap.	236.6	240.7	221.1	173	171.7	167.4



	1 Lane	2 Lanes	3 Lanes	4 Lanes	5 Lanes	6 Lanes
App.	220	276.1	276.1	276.1	276.1	276.1
Grill.with 2 Diap.	168.8	216.9	201.5	162.2	167.1	170
Grill.with 3 Diap.	168.8	216.9	201.5	162.2	167.1	170
Grill.with 5 Diap.	168.8	216.9	201.5	162.2	167.1	170

4.5 Discussion of the results

Results at the two analysis method are used to compare the maximum bending moment and maximum shear force for both superstructures types. Since this study is to analyze, study the result difference and effect of diaphragm on load distribution, the following comparison of the two methods are made:

4.5.1 Comparison of T-Girder Bridge of the two method

Details of the comparison tables are presented in the previous section. To compare the results, taking the maximum value for both exterior and interior girder from different number of lane loaded case and summarized in the table below.

Table 4.5-1 Summary of Maximum Values for T-Girder,

Superstructure Type	Moment (KNm)	Shear (KN)	Approximate Method	Grillage analogy Method	% difference.
10.3m width and 20m span.	Exterior		1111.0	713.2	36%
	Interior		932.6	746.3	20%
		Exterior	257.0	239.1	7%
		Interior	256.3	267.8	-5%
10.3m width and 24m span.	Exterior		1409.6	921.8	35%
	Interior		1179.0	948.0	20%
		Exterior	263.7	244.3	7%
		Interior	263.0	287.1	-9%
19.4m width and 20m span.	Exterior		1179.4	668.2	43%
	Interior		845.2	696.6	18%
		Exterior	272.7	254.9	7%
		Interior	232.9	243.7	-5%
19.4m width and 24m span.	Exterior		1495.8	813.1	46%
	Interior		1068.5	827.2	23%
		Exterior	279.8	267.0	5%
		Interior	238.9	244.1	-2%
26.4m width and 20m span.	Exterior		1188.1	712.1	40%
	Interior		903.7	731.6	20%

Superstructure Type	Moment (KNm)	Shear (KN)	Approximate Method	Grillage analogy Method	% difference.
		Exterior	274.7	266.4	3%
		Interior	248.6	263.5	-6%
26.4m width and 24m span.	Exterior		1506.9	848.8	44%
	Interior		1142.5	875.5	23%
		Exterior	281.9	270.2	4%
		Interior	255.1	265.3	-4%
10.3m width and 30m span.	Exterior		1850.2	1150.0	38%
	Interior		1567.3	1290.0	18%
		Exterior	269.5	256.3	5%
		Interior	270.4	290.7	-7.5%
19.4m width and 30m span.	Exterior		1867.9	960.5	49%
	Interior		1429.1	1079.5	24%
		Exterior	272.1	258.5	5%
		Interior	247.1	250.5	-1.4%
26.4m width and 30m span.	Exterior		1941.5	1020.0	47%
	Interior		1518.9	1139.0	25%
		Exterior	282.8	268.8	5%
		Interior	262.3	270.1	-3%

It can be noted from the above table that Approximate Method of analysis gives higher value for moment. Such that in exterior girder average of 42% and interior girder average of 21% gives more value than Grillage Analogy Method of analysis. Whereas for shear gives slightly higher value for exterior girder (average 5%) and gives slightly lower value for interior girder (average 5%) than Grillage Analogy Method of analysis.

4.5.2 Comparison of Box Girder Bridge of the two method

Details of the comparison tables are presented in the previous section. To compare the results, taking the maximum value for both exterior and interior girder from different number of lane loaded case and summarized in the table below.

Table 4.5-2 Summary of Maximum Values for Box Girder,

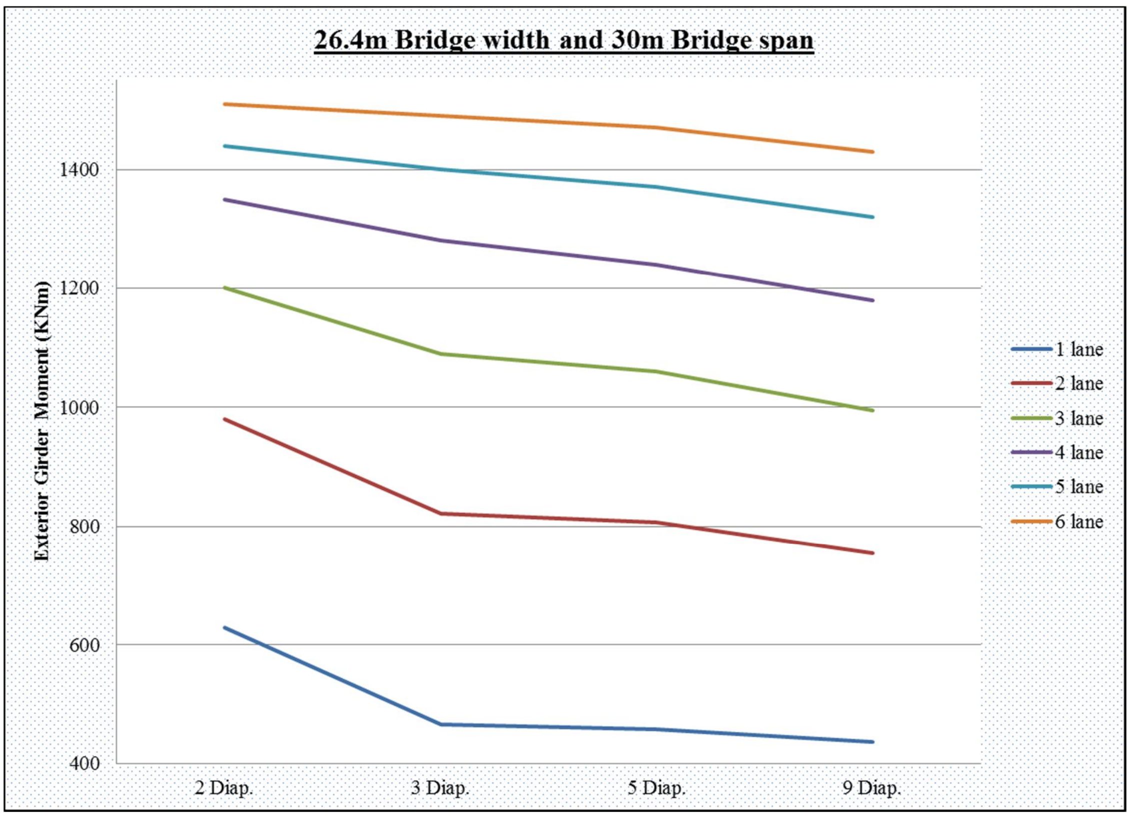
Superstructure Type	Moment (KNm)	Shear (KN)	Approximate Method	Grillage analogy Method	% difference.
10.3m width and 30m span.	Exterior		1321.1	901.1	31.8%
	Interior		1564.1	1330	15%
		Exterior	269.5	239.5	11.1%
		Interior	279.5	242.9	13.1%
10.3m width and 40m span.	Exterior		1851.5	1230.0	33.6%
	Interior		2042.4	1800.0	12.0%
		Exterior	276.3	246.2	10.9%
		Interior	286.5	243.5	15.0%
19.4m width and 30m span.	Exterior		1281.4	667.7	47.9%
	Interior		1066.8	909.5	14.7%
		Exterior	272.1	229.5	15.7%
		Interior	249.0	204.1	18.0%
19.4m width and 40m span.	Exterior		1795.9	867.0	51.7%
	Interior		1393.0	1190.0	14.6%
		Exterior	278.8	233.5	16.2%
		Interior	255.2	207.6	18.7%
26.4m width and 30m span.	Exterior		1360.8	741.0	45.5%
	Interior		1115.8	1027.0	8.0%
		Exterior	282.8	235.3	16.8%
		Interior	268.8	214.5	20.2%
26.4m width and 40m span.	Exterior		1907.1	981.5	48.5%
	Interior		1457.0	1371.5	5.9%
		Exterior	289.9	240.9	16.9%
		Interior	276.1	216.9	21.4%

It can be noted from the above table that Approximate Method of analysis gives higher value for moment. Such that for exterior girder gives average of 43.2% and for interior girder gives average of 11.7% more value than Grillage Analogy Method of analysis. In addition for shear gives average of 14.6% for exterior girder and 17.7% for interior girder than Grillage Analogy Method of analysis.

4.5.3 Diaphragm effect

From the details of analysis result using Grillage analogy method presented above the effect of diaphragm on load distribution is observed for T-Girder. However, in Box Girder the effect is small because of closeness of flexural and torsional stiffness of diaphragm and nearby grillage member. Typical load distribution figure is shown below for 26.4m Bridge Width and 30m Bridge Span.

Figure 4.5-1 Typical Load Distribution on Exterior Girder,



From the above chart, The Moment received by one girder is different with respect to number of loaded lane as the number of diaphragm (bracing) provided is more. The percentage difference of the above load distribution figure is shown in table below as compared to two diaphragm case considered.

Table 4.5-3 Typical Diaphragm effect on Load Distribution as Compare to Two Diaphragm Case for Exterior Girder of 26.4m Bridge Width and 30m Bridge Span,

No. of Loaded Lanes	3 Diap. Case	5 Diap. Case	9 Diap. Case
1	26%	27%	30%
2	16%	17%	23%
3	9%	11%	17%
4	5%	8%	12%
5	3%	5%	8%
6	1%	3%	5%

From the above table provision of more number of diaphragms has a considerable effect on load distribution. However, the effect is different with the number of loaded lane as shown in the above table.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the result obtained from Approximate and Grillage Analogy analysis methods, the following conclusions and recommendation are made:

- It is observed from the result that Approximate Method of analysis gives higher results for Moment irrespective of the Bridge width and Bridge span for T-Girder and Box Girder superstructures.
- Comparison of the results obtained from Approximate Method of analysis for Shear gives slightly less value for Interior girder than Grillage Analogy Method irrespective of Bridge width and Bridge span for T-Girder Superstructure whereas for Box Girder superstructure gives higher values for all cases considered.
- In Grillage Analogy Method, effect of diaphragm on load distribution is more noticeable for T-Girder superstructure as shown in section 4.3, 4.4 and Typical Figure 4.5-1, Table 4.5-3 whereas, in Box Girder superstructure the effect is small or nil as shown in the detail comparison table presented above in section 4.3 and 4.4.

5.2 Recommendation

- It is recommended that, intermittently check the analysis using Grillage Analogy method, this analysis method can be done in any commercially available software like frame analysis, and easy to use even though time taking.
- From all the case, only shear in Interior Girder is underestimated from 2 to 9% range in T-Girder superstructure by Approximate Method. However, gives conservative values with a marginal value of 3% for 5 Diap. Case. Therefore the author recommends to get conservative values with Approximate Method at least five number of diaphragm must be provided per span.
- The author recommends provision of adequate number of diaphragm (bracing) for T-Girder superstructure, this improve the ability of the cross section to transfer loaded from one girder to an adjacent one.
- Finally the author suggests that such a study shall further be conducted considering skewness and curve of the cross section.

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