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Behavior and Analysis of Horizontally Curved Composite Steel Girder Bridge System

Gourav Gajrani[1], Dr. L. M. Gupta[2]
[1,2]*(Department of App. Mechanics, VNIT, Nagpur, India)*

ABSTRACT: *Horizontally curved composite steel girder bridge systems are gaining popularity in modern bridge infrastructural system. The curved bridge facilitates smoother flow of traffic where land constraints are prevailing and change in the direction of movement is required. However, some shortcomings of horizontally curved bridge system are that they are more difficult to predict their behavior and to construct in comparison to the straight bridges. The current study focuses on determination of effects of number of parameters on the maximum total bending moment of the horizontally curved composite girder bridge system subjected to IRC loading. The modeling of the bridges used in this study is done by generalized grillage beam systems consisting of horizontally curved beam elements for steel girders, beam grid elements for modeling deck slab and cross frames which consist of truss elements. The finite-element analysis software package "MIDAS Civil" is used to examine the key parameters that can influence the response of horizontally curved composite steel girder bridge system. In the present study it has been observed that cross frame spacing, radius, support skewness and lateral bracing configuration most significantly affects the behavior of bridge. Comparison of the results obtained by the grillage analysis is made with V-load analysis method.*
Keywords – *Grillage analysis, horizontally curved, IRC loading, V-load.*

I. INTRODUCTION

During recent years horizontally curved steel I-girder composite bridge systems are frequently found in complex highway interchanges to accommodate higher volumes of traffic within geographical constrains. Due to their relatively strong torsional stiffness when adequately provided with diaphragms and cross frames and simplicity in fabrication and erection, curved steel I-girder bridges have been a preferred choice in practice and an interesting subject of research during the past few decades. Due to the always presence of offset in the line of action of applied load and the reactions offered by the supports the horizontally curved bridge assembly is subjected to the non-uniform torsion and consequently lateral bending moment as shown in the Fig. 1. Due to the presence of curvature resulting in the inherent presence of non uniform torsion turns out the behavior of bridge assembly more complicated. The bridge assembly considered in the present study consists of a concrete deck slab supported over five-steel girders. End diaphragms, Cross bracing at suitable intervals along with bottom lateral bracing are provided to enhance the structural integrity.

In the present study an attempt has been made to identify the key parameters affects the flexural behavior of the horizontally curved steel girder composite bridge assembly. Parameters including radius of curvature, Central angle, lateral bracing configuration, spacing of the cross-bracings, and the support skewness are varied to identify the impact of the variation on the flexural characteristics of the bridge assembly. In the past few decades horizontally curved bridges have gained more popularity over the kinked structures, numerous studies have been conducted in the area of straight bridges whereas curved bridges still needs in-depth studies to predict the actual behavior of the curved bridges. The very first attempt made in the field of curved bridges was by Barré de Saint Venant in 1843 as referred by Zureik (1998, 1999). A survey of most published works pertaining to horizontally curved bridges was first presented by McManus et al. (1969), The American Society of Civil Engineers and the American Association of State Highway and Transportation Officials (ASCE-AASHTO) Committee on Flexural Members (1977) compiled the results of most of the research efforts prior to 1976 and presented a single source set of recommendations pertaining to the design of curved I-girder bridges. James et al. (1996) presented parametric effect of cross frame spacing [1]. Ching et al. (2008) presented comparison of various modeling strategies for horizontally curved bridges. Provisions for designing highway bridges to resist dead, live, and other loadings are given by the American Association of State Highways and Transportation Officials (AASHTO) [2]. Whereas specifications issued by IRC for design of highway bridges are silent on the behavior, analysis and strength of the horizontally curved bridges.

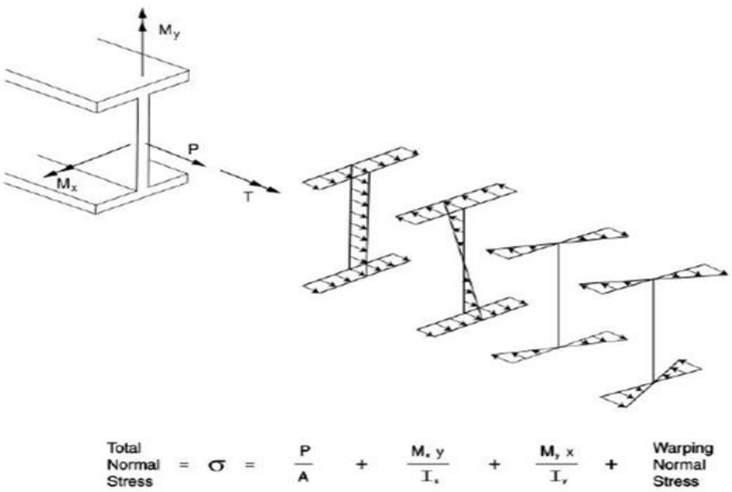


Fig.1. Normal Stress distribution in Curved I-girder

II. BRIDGE CONFIGURATION

The Bridge considered in this study is a 5 girder single span bridge. The deck slab bridge comprises of 220 mm thick, 12.5m wide RCC deck slab. Cross frame and lateral bracing are provided at suitable intervals. Central angle of the bridge is varied from 5° to 45°. The central girder is having a constant span of 24m, whereas the span of the outer and inner girder is varied depending upon the central angle of the bridge assembly. The centre to centre distance between individual girders is kept as 2.5 m. The bridge assembly is shown in fig. 2; Cross-bracings are represented by CB in the centre line plan, details of the member size are listed in table 1. Grade of the steel girders is FE440A and M25 grade concrete is used.

Table 1. Details of Bridge assembly members

Deck Slab	Thickness = 220 mm
I-Girder	Web = 1500mm * 14mm
	Top Flange = 500mm * 28 mm
	Bottom Flange = 700mm * 36 mm
End Diaphragm	Top Flange = 200mm * 12mm
	Bottom Flange = 200mm * 12mm
	Web= 900mm*18mm
Cross Frame	Top Bracing= 2ISMC 100
	Bottom Bracing=2ISMC100
	Diagonal Bracing=2ISMC125
Lateral Bracing	ISA 65*65*8

As shown in Fig. 2(a) nomenclature of the bridge girders is done as G5 to G1 from outwards to inwards respectively. Nomenclature of the cross-frame is done as CB-2 to CB-4 depending on the number of cross-frame from the left hand and the end diaphragm as nomenclature as CB-1 and CB-2 respectively. Bridge assembly is subjected to vehicular loading as per IRC 6:2010.

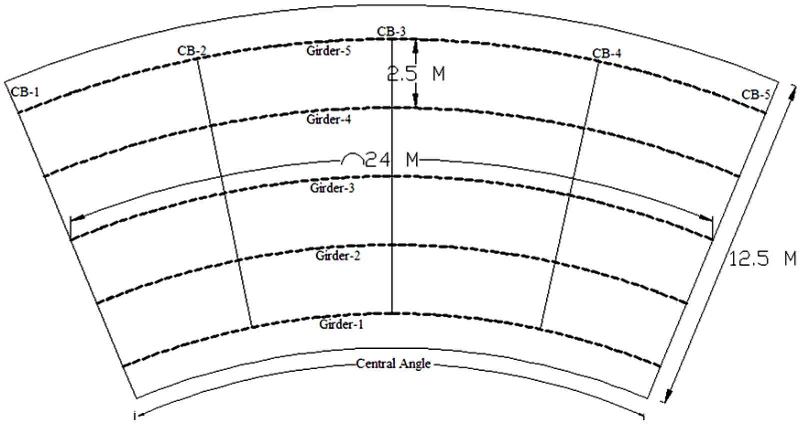


Fig. 2(a). Centre-line plan of bridge assembly

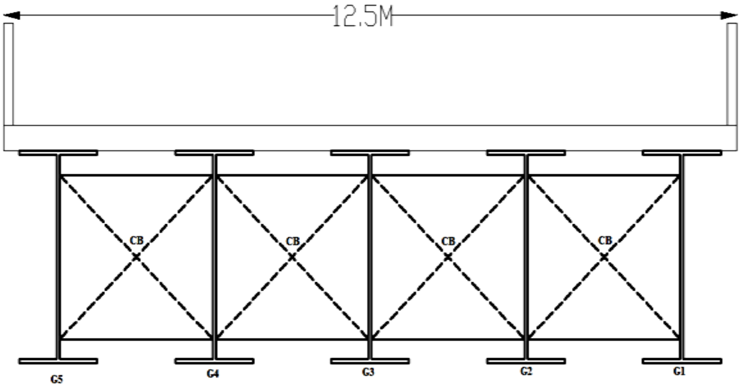


Fig. 2(b). Cross-Section of bridge assembly

III. ANALYSIS OF BRIDGE ASSEMBLY

Due to always presence of inherent torsion due to curvature in the horizontally curved bridges involves cumbersome analysis. Although with advent of computers it has become easier to analyze such structures. Two of the primary differences between curved girders and straight girders are the presence of torsion and the interaction between adjacent girders. When deciding the type of analysis to perform, the degree of curvature is one of the primary variables to consider. When curvature does affect the primary moments, there are several types of methods currently used to design curved I-shape steel girder bridges such as the V-LOAD, grillage and 3D finite element methods. Depending on the severity of the bridge geometric conditions and the specific needs regarding the geometry control, a simple analysis solution may be sufficient or a more refined analysis may be necessary. In the present study V-load analysis and grillage analysis have been taken under consideration to predict the behavior of horizontally curved bridge assembly.

3.1 V-load Analysis

An approximate method of analysis for horizontally curved bridges using equivalent straight girders if the torque produced by the curvature is represented by the self equilibrating loads on the girders was developed by the United States steel Corporation, Known as the V-load method, These additional loads are called V-loads because they are a set of Vertical shears on the equivalent straight girders. The V-loads are developed from equilibrium requirements and are primarily a function of the radius of curvature, width of the bridge unit, and spacing of diaphragms between the girders [3]. Initially, the V-load method was first derived for two girder assembly and concepts were later on extended for multi-girder bridges.

3.2 Grillage Analysis

With the advent of computer age, a more refined analysis using grillage was developed and subsequently incorporated into commercial computer programs. Using a general analysis program or a commercial computer program, a grillage analysis can be developed for a horizontally curved steel bridge. Various girder horizontal alignments and support arrangements can be directly modeled. In both general analysis and commercial computer programs, the model can be either a plane grid or a space frame. The cross frames are usually modeled by using an equivalent beam. Supports are modeled using pins or rollers. Most programs internally calculate member self-weights, however additional weight due to beam details (e.g., connections, shear connectors) must be added as either a percentage increase of the self-weight or as an additional uniform line load applied to each girder [4]. Other non composite and composite dead loads can be applied to the structure as uniform line loads to specific girders.

IV. GRILLAGE MODELING OF BRIDGE ASSEMBLY

Finite element software package "Midas Civil" used for the study offers facility of composite section, i.e. the longitudinal stiffness of the bridge deck is modeled with the main girder itself whereas the transverse stiffness of the bridge deck has been modeled using transverse weightless dummy elements. The cross-bracings are modeled by hybrid elements, i.e. the top and bottom members are modeled using beam elements whereas the cross elements are modeled by truss elements. Grillage modeling of the bridge assembly is shown in fig. 3. In modeling the bridge supports in this study, the end nodes of the girders are modeled as simply supported. Supports are provided with spring stiffness values. The vertical stiffness is provided as 915469 KN/m, whereas the longitudinal and transverse stiffness is provided as 1562.5 KN/m.

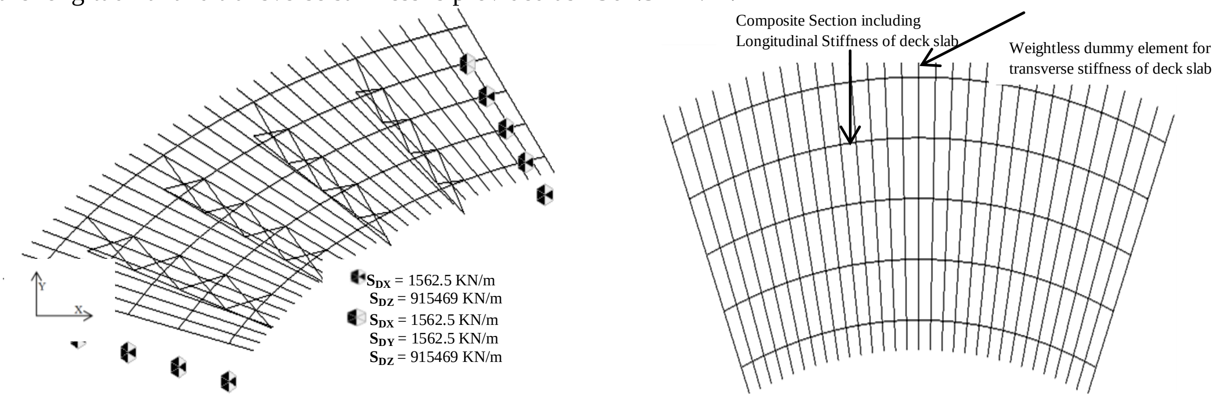


Fig.3. Grillage Modeling of Bridge Assembly

V. COMPARISON OF RESULTS BY V-LOAD METHOD & GRILLAGE ANALYSIS

Shifting of load from the inner girder to the outer girder is an important characteristic of horizontally curved bridge assembly. V-load method assumes that the internal torsional load on the bridge resulting solely from the curvature is resisted by self equilibrating sets of shears between adjacent girders. The method assumes a linear distribution of girder shears across the bridge section; thus, the girders at a given cross-section should have approximately the same vertical stiffness [5].

A comparative Analysis has been done among the bending moments values obtained from V-load Analysis & Grillage. Included Central Angle of the Bridge assembly has been varied from 5°to 20°. Spacing of cross-frames has been kept as Span/5. Results obtained from the Comparative Analysis for the bridge assembly subjected SIDL loading are shown in table-2.

Table 2. Comparison of Maximum Bending Moment Values (KN-m) by V-load & Grillage Analysis

Included Angle	Girder-5	Girder-4	Girder-3	Girder-2	Girder-1
5 degree	0.58%	0.65%	-0.01%	-0.71%	-0.54%
10 degree	-5.96%	-2.89%	-0.35%	4.76%	9.63%
15 degee	-11.59%	-6.35%	-0.96%	6.77%	10.58%
20 degree	-16.14%	-9.54%	-1.80%	10.65%	12.58%

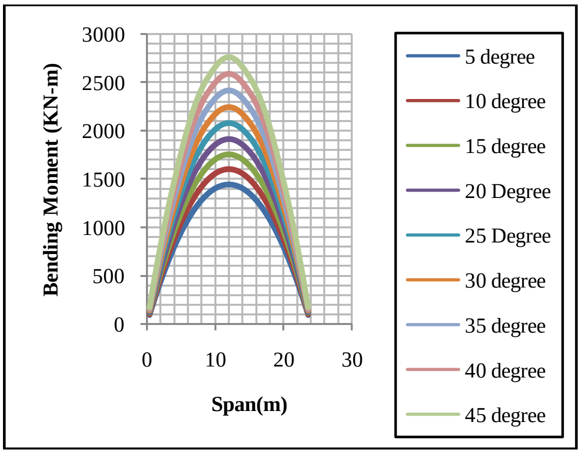
$$\%D = \left(\frac{Vload - FEM}{FEM}\right)\times 100 \tag{1}$$

As the radius of curvature decreases the load carried by the outer girder increases, while the load carried by the inner girder decreases. However the V-load analysis overestimates the shifting of the load from inner to outer girder. The slab contributes a significant torsional stiffness to the unit which is not accounted in for in the V-load analysis. V-load method is also not applicable to the bridge assembly having lateral bracing.

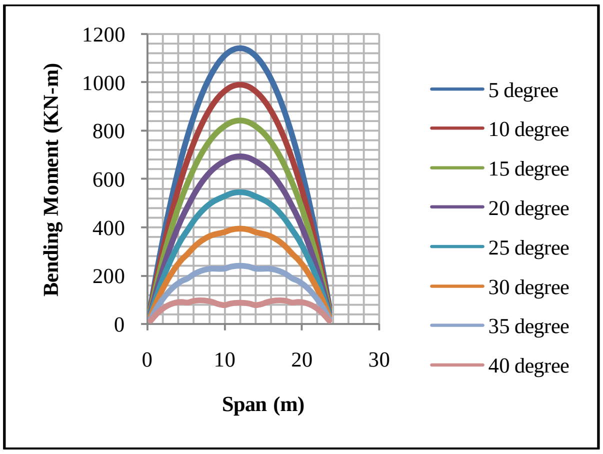
As per AASHTO LFRD V-load analysis can be used up to 10° central included angles, for higher included angles V-load analysis can be only used for the preliminary size selection, final selection of the member size to be done only after analysis by grillage analysis or detailed finite element analysis.

VI. PARAMETRIC STUDY

In the present study an attempt has been made to identify the key parameters affects the flexural behavior of the horizontally curved steel girder composite bridge assembly Curvature introduces the additional moment in bridge assembly, included angle of the bridge assembly has been varied from 5° to 45°. The effect of curvature on the total bending moment has been studied. The effect of curvature on the total bending moment of the horizontally curved bridge assembly is shown in graph 1(a-b). From Graph 1(a) and 1(b), it can be observed that with the increase in the included angle the bending moment values goes on increasing in the outer girders, whereas the bending moment values goes on decreasing with the increase in the included angle of the bridge girder assembly. As per AASHRO LFRD while designing the horizontally curved bridges the effect of curvature over the bridge can be neglected up to 10 degree central angle, for bridge having central angle more than 10 degree effect of curvature necessarily to be counted while analysis and design.

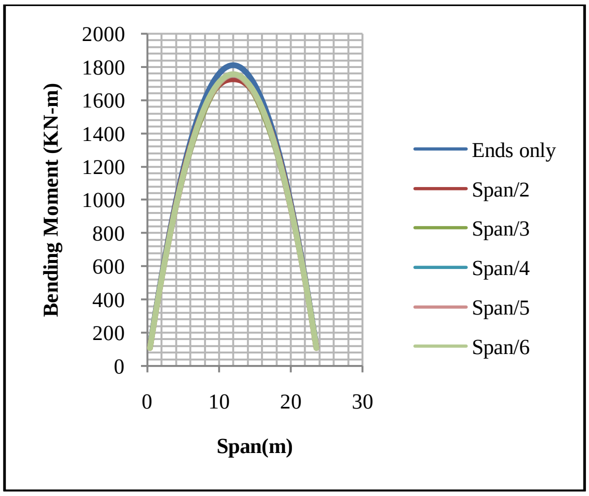


Graph 1(a) Bending Moment Variation due to included angle in Girder-5

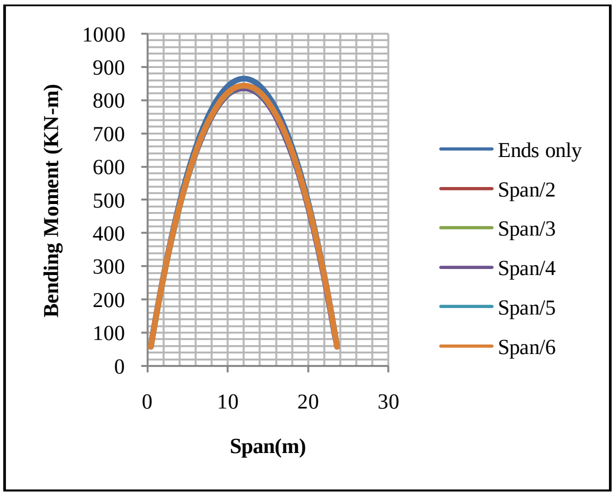


Graph 1(b) Bending Moment Variation due to included angle in Girder-1

The design of curved composite concrete deck-steel I-girder bridges requires the utilization of bracing systems between girders to stabilize the girders and redistribute the loads. Spacing of the cross-frame has been varied form span/1 to span/6 and its effect on the total bending moment is shown in graph 2(a-b).



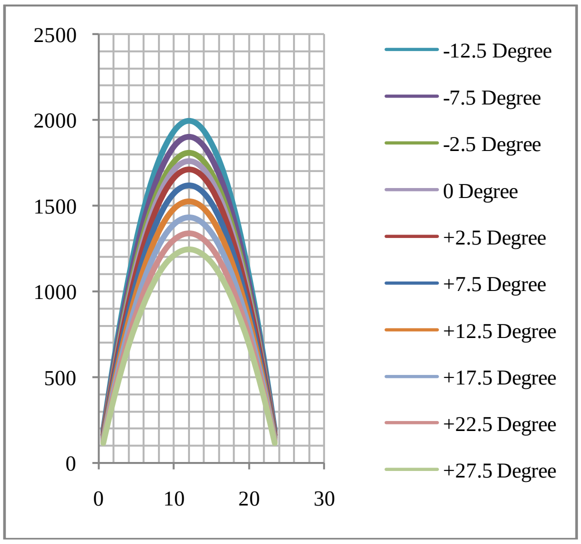
Graph 2(a) Bending Moment Variation due to variation in cross-frame spacing in Girder-5



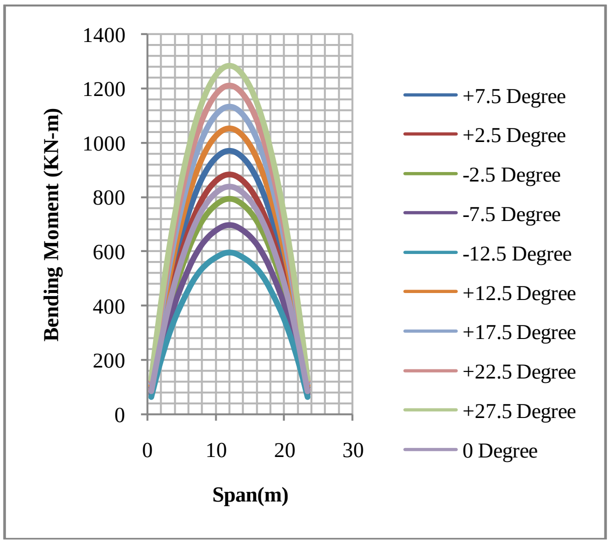
Graph 2(b) Bending Moment Variation due to variation in cross-frame spacing in Girder-1

From graph 2(a) and 2(b) it can be observed that there is no predominant effect of cross-frame spacing on the total bending moment in the girders of the bridge assembly, whereas spacing of the cross-frame effects the lateral torsional buckling moment in the horizontally curved girder bridge assembly predominantly.

When the support line is not normal to the direction of traffic flow, such type of bridge are called as skewed bridge. An attempt is made to observe the effect of support line skewness on bending moment, shear, and longitudinal, lateral torsion values of the girder. Support line is rotated up to 27.5° in clockwise and up to 12.5° in anticlockwise direction with respect to the no skew support line condition i.e. radial support condition. The effect of the support orientation in the bending moment is shown in graph 3(a-b).



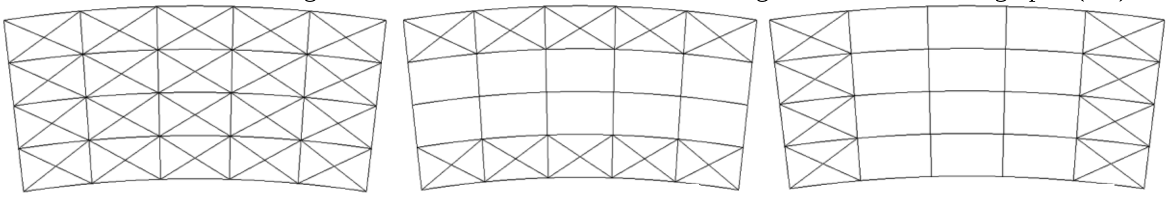
Graph 3(a) Bending Moment Variation due to support skewness in Girder-5



Graph 3(b) Bending Moment Variation due to support skewness in Girder-1

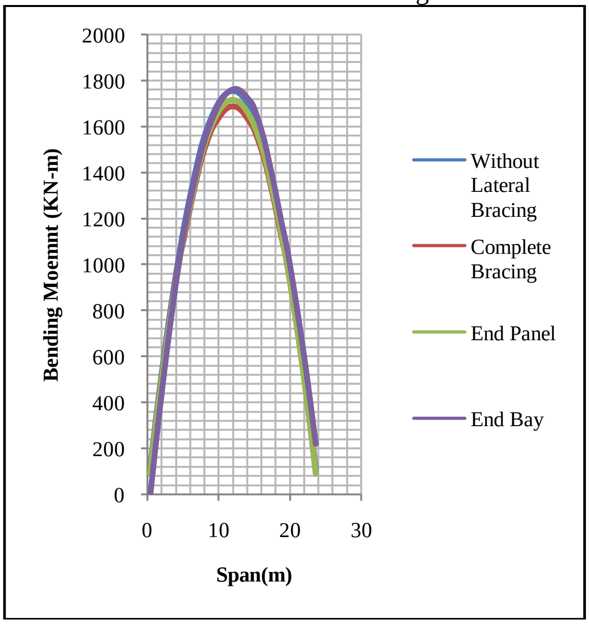
From Graph 3(a) and 3(b), it can be observed that the support skewness plays predominating effect on the bending moment values. For outer girders on rotating the support in clockwise direction, bending moment values goes on decreasing, whereas for inner girders on rotating the support in clockwise direction, bending moment values goes on increasing, as it has been observed that for a horizontally curved girder bridge assembly, outer girders share more bending moment as compared to the inner girders, hence bending moment on the outer girders can be minimized on the outer girders by providing proper orientation of support, or a horizontally curved girder bridge assembly can be designed in such a manner that the bending moments shared by all girders can be approximately equal by properly selecting the orientation of the bridge assembly.

Lateral bracing are provided in the bridge assembly to prevent the lateral movement of the structural system, depending upon the span of bridge and function the lateral bracing can be either temporary or permanent. Different lateral configuration as shown in Fig. 4(a-c) is provided and effect over the bending moment is observed. Bending moment values for different lateral configuration are shown in graph 4(a-b).

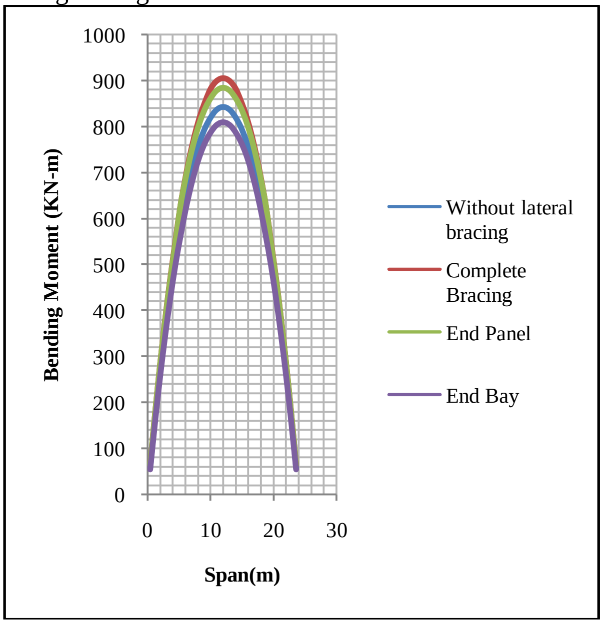


a. Complete Bracing   b. End Bays   c. End Panels

Figure 4 Lateral Bracing Configuration



Graph 4(a) Bending Moment Variation due to different lateral bracing configuration in Girder-5



Graph 4(b) Bending Moment Variation due to different lateral bracing configuration in Girder-1

From graph 4(a) & 4(b), it can be seen that there is no much difference among the bending moment values in the girder due to different bracing configurations. Lateral bracing can be provided for the lateral stability of the bridge. Among the different bracing configurations shown above, bracings provided in end bays serves the purposes and is recommended one.

VII. CONCLUSION

An attempt is made to study the behavior of horizontally curved girder bridge assembly and to identify the key parameters affecting the total bending moment in the girders of the horizontally curved girder bridge assembly. It is observed in a particular curved bridge assembly bending moments shared by the outer girders are more than the bending moment shared by the inner girders. Bridge assembly is analyzed by V-load analysis and computer aided grillage analysis. V-load analysis involves less input for the analysis of the bridge assembly as compared to the cumbersome grillage or FEM modeling of bridge assembly. Despite the lesser effort for analyzing the bridge assembly by V-load analysis, it can only be used up to 10° included angle, for higher degree of included angles more refined methods to be used. Bending moments for the outer girders by V-load are conservative, whereas bending moments by V-load method for inner girders are on higher side as compared to grillage analysis, with the increases the included angle of the bridge assembly difference between the values goes on increasing, V-load analysis can be used for preliminary sizing of the members, final selection of sections must be done on basis of detailed analysis like grillage analysis or 3D FEM analysis. To identify the key parameters affecting the bending moment distribution among the girders parameters including included angle, Lateral bracing configuration, cross-frame spacing, and support skewness were altered. It has been observed that the included angle and support skewness are the key parameters affecting the bending moment, with increase in the included angle the bending moment in the outer girder goes on increasing, whereas bending moment in the inner girders decreases on increasing the included angle. Support orientation predominantly affects the distribution of bending moment, on rotating the support in clockwise direction with respect to global y-direction bending moment in the outer girders goes on decreasing, whereas bending moment in the inner girders increases with the increases in the angle of support line in clockwise direction with respect to the global y-direction, while selecting the orientation of the support a good combination can be made such that the bending moment shared by all the girders of the horizontally curved bridge assembly can be approximately same. The present study is limited up to flexural behavior of the bridge assembly. The above parameters can be studied for their impact on shear and torsional behavior of the bridge assembly.

REFERENCES

[1]. Zureick and R. Naqib, Horizontally Curved Steel I-Girders State-Of-The-Art Analysis Methods, *Journal Bridge Engineering, 4(1),* 1999, 38-47.
[2]. AASHTO (2012). *Aashto Lfrd bridge design specifications. (6th edition*), (Washington D.C.: American Association of State and Highway Transportation Officials, 2012)
[3]. Richardson, Gordon and Associates. *Structural Report Analysis and Design of Horizontally Curved Steel Bridge Girders*. (Pittsburgh, PA,: United States Steel, 1963).
[4]. Domenic Coletti, and Jay Puckett, *Steel Bridge Design Handbook: Structural Analysis* (Springfield, VA: National Technical Information Service, 2012).
[5]. Ann L. Fiechtl, Gregory L. Fenves , and karl H. Frank. *Approximate analysis of horizontally curved girder bridges.* (Pittsburgh, PA,: United States Steel, 1987).
[6]. IRC 6 (Section II). *Standard Specifications and code of practice for road bridges, (fifth revision*), (New Delhi, India: IRC, 2010).
[7]. James S. Davidson, Mark A. Keller, and Chai H. Yoo, Cross-Frame Spacing and Parametric Effects in Horizontally Curved I-Girder Bridges, *Journal of Structural Engineering, 122(9),* 1995, 1089-1096.
[8]. Ching-Jen Chang, Donald W. White, An assessment of modeling strategies for composite curved steel I-girder bridges, *Engineering Structures, 30,* 2008, 2991-3002.