Evalution the Load Distribution Factors for Horizontally Curved Composite Concrete-Steel Girder Bridges

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Received on: 18/12/2012 & Accepted on: 5/12/2013

ABSTRACT

In this research paper, a 3-D finite element model was used for the analysis of curved concrete slab on steel girder bridges. A parametric study was carried out to calculate the load distribution factors for horizontally curved steel I-girder bridges based on (AASHTO LRFD) live loads .The bridges are analyzed by three dimensional finite elements using SAP 2000 software (Structural Analysis Program) with shell elements. The parameters considered in this study were: span-to-radius of curvature ratio, span length and the analysis of bridge will be performed for the case of full live load and partial live loads. The full data are given together with AASHTO LRFD calculations up to L/R equal to (0.6).

Keywords: Curved Steel I-Girder Bridge, Load Distribution Factors, AASHTO LRFD

معاملات توزيع الاحمال للجسور المركبة – المنحنية افقيا

الخلاصة

في هذه الدراسة تم استخدام نموذج العناصر المحددة ثلاثي الابعاد لتحليل الجسور المركبة والمنحنية بالمستوي الافقي. تم اجراء دراسة لبيان تأثير بعض العوامل على معامل التوزيع الافقي للاحمال للجسور المركبة والمنحنية بالمستوي الافقي وبالاعتماد على طبيعة ونوع الاحمال المذكور في المواصفة (AASHTO LRFD).تم تحليل الجسور باستخدام طريقة العناصر المحددة ثلاثية الايعاد, والعناصر القشرية باستخدام برنامج SAP 2000 (برنامج التحليل الأنشائي). تضمنت هذه العوامل نسبة الفضاء الى نصف قطر الانحناء الافقي، طول الفضاء، وكذلك نسبة الاحمال الحية المسلطة سواء كانت كلية او جزئية . جميع البيانات والحسابات المعطاة مقارنة مع (AASHTO LRFD) كانت لنسبة الانحناء الى الجسر (L/R) تصل الى (0.6).

https://doi.org/10.30684/etj.32.4A.5
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INTRODUCTION

Generally, bridges can be constructed either entirely from reinforced concrete, pre-stressed concrete, steel or from composite concrete deck-steel girders. In the past, alignment of the curved bridges is provided by straight girders on chords that meet the required curvature. Curved steel girders are used where the curvature and complex geometries are required, and these types of girders have permitted greater span and fewer piers [1].

The curved I-shaped plate girders used in bridges with curved alignment are subjected to forces that cause significant distortion of the cross section during construction and application of live loads. Furthermore, the simple addition of curvature reduces the vertical bending stiffness, increases deflection nonlinearities, and changes stability characteristics of behavior. Although, the design equations in the AASHTO [2], the subject needs more researches to study the parameters effecting this behavior.

The main advantages of curved steel I-girders are:

1. Simplicity of fabrication and construction,
2. Less land is needed during erection,
3. Shallower sections can be designed,
4. Impose lighter weight on bridge foundation when compared with that of precast /pre-stressed beams or segmental pre-stressed concrete box girder deck.
5. Excellent serviceability performance.

The construction of composite bridges offers remarkable static and economic advantages. The load-bearing steel structure and the overlying concrete cast, suitably tied to each other by means of connectors, guarantee the static unity of the two different materials while enabling them to express their individual characteristics. The most evident advantages are the reduced weight of the steel structures, the lower total height of the floors, greater flexural rigidity and higher fire resistance. The headed stud connector, welded to the beam, is the commonly adopted solution for the shear connection in composite bridges [3].

The main purpose of this research is to investigate the behavior of horizontally curved composite concrete-steel bridges. The parameters included in research are bridge span, span to curvature ratio, girder spacing and type of live loads. Effect of these parameters on load distribution factor is the main goal of this research.

COMPOSITE BRIDGE CONFIGURATIONS

Figure (1) shows the details of the typical composite deck steel I-girder bridge cross-section used in this study. X-type cross-bracings with top and bottom chords are utilized in this study. These bracings are spaced at equal intervals between the support lines and are made of single steel angles dimensioned L (75X75x6) mm and of 900 mm^2 cross- sectional area. The equal intervals spacing between these cross-bracings are based on equation (C6.7.4.2-1) from LRFD [4]. Typical plan of straight and curved girders with the distribution of the transverse bracings are shown in Figure (2). The study is based on the following assumptions:

1. The reinforced concrete slab deck has composite action behave as full interaction with steel member.
2. The bridges are considered along with simply supported boundary conditions.

3.The material is linearly elastic & homogeneous.
4.The effect of road super-elevation, and curbs are neglected;
5.Curved bridges have constant radius of curvature between support lines.

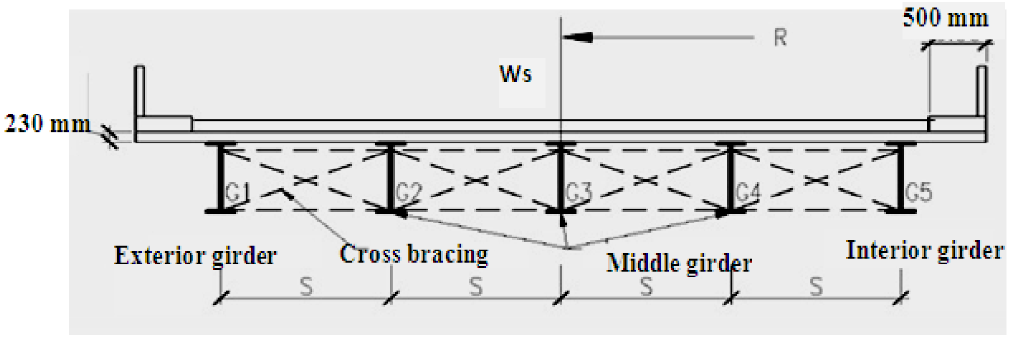
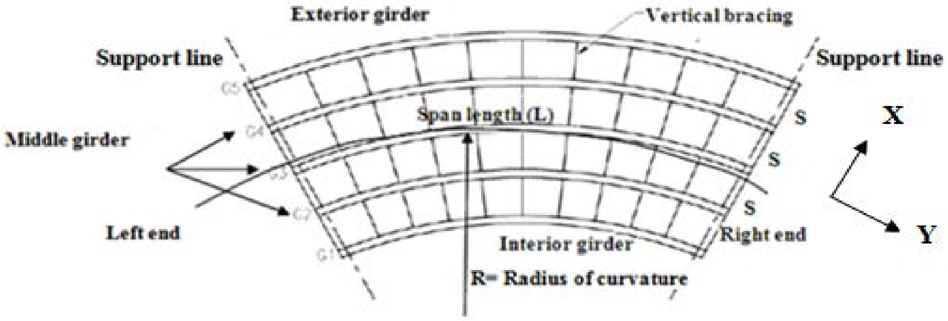
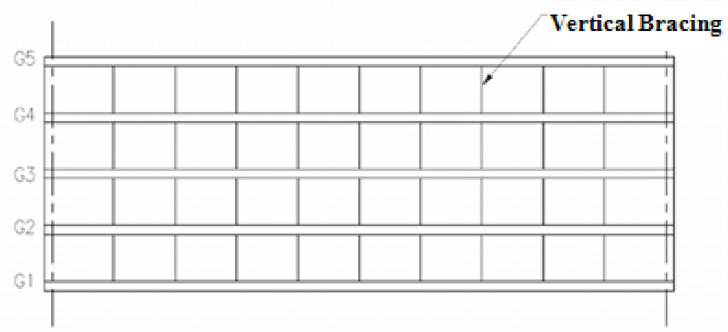


Figure (1) Cross-Section of a Composite Concrete Steel I-Girder Bridge.



a)I-Girder with Radial Cross-Bracing (Curved)



b) I-Girder with Transverse Cross Bracings

Figure (2) Plan of the Steel Girder Arrangement.

Table (1) Bridge Configurations Considered in the Parametric Study.

Span of bridge (meter) L	No. of girders (N)	Girder Spacing(S) (meter)	No. of lanes (n)	Span to Curvature ratio (L/R)	Bridge Width (meter)	Deck Width (meter) Ws
15	3	2.5	2	0,0.2,0.3	7.5	6.5
	3	3	2	0,0.2,0.3	9	8
	4	2	2	0,0.2,0.3	8	7
	4	2.5	2	0,0.2,0.3	10	9
	4	3	3	0,0.2,0.3	12	11
	5	2	2	0,0.2,0.3	10	9
30	3	2.5	2	0,0.2,0.3,0.4	7.5	6.5
	3	3	2	0,0.2,0.3,0.4	9	8
	4	2	2	0,0.2,0.3,0.4	8	7
	4	2.5	2	0,0.2,0.3,0.4	10	9
	4	3	3	0,0.2,0.3,0.4	12	11
	5	2	2	0,0.2,0.3,0.4	10	9
35	3	2.5	2	0,0.2,0.3,0.4,0.6	7.5	6.5
	3	3	2	0,0.2,0.3,0.4,0.6	9	8
	4	2	2	0,0.2,0.3,0.4,0.6	8	7
	4	2.5	2	0,0.2,0.3,0.4,0.6	10	9
	4	3	3	0,0.2,0.3,0.4,0.6	12	11
	5	2	2	0,0.2,0.3,0.4,0.6	10	9

Other bridge configurations are listed below:

- The deck slab thickness (t_s) is taken as 230 mm,
- The deck slab width (Ws) is taken equal to the total bridge width minus 1.0m to consider the parapet thickness of 0.5 m on each side of the bridge,
- Two headed shear stud connectors with 22 mm in diameter are designed, so that the behavior is full interaction (slip very small).
- The depth of the girder webs is taken (0.04 L) of the centre line span[4].
- The girder web thickness is considered equal to 15 mm.
- The bottom and top steel flanges width and thickness are maintained 300 mm, and 18 mm, respectively for L=15m,30 m and the bottom and top steel flanges width and thickness are maintained 300 mm and 40 mm respectively for L=35 m.

  Where, L is span length of bridge.

BRIDGE LOADING

According to AASHTO LRFD -2004[4], the highway live loadings on the roadways of bridges or incidental structures shall consist of standard trucks and lane loads that are equivalent to truck trains. Two types of loading are provided, truck and lane loading (HL93) which is equivalent to TRUCK loading in AASHTO. While in AASHTO, only truck loading or lane loading is considered in AASHTO LRFD truck plus lane loading should be applied together. Also, the geometry according to LRFD is smaller than if compared to AASHTO specification. These renounces affect on the results of MDF and DDF and also on the empirical equations.

Each lane load will consist of uniform load per linear meter of traffic lane combined with a single concentrated load concentrated loads in placed on the span to produce maximum flexural. The concentrated and uniform loads will be considered as uniformly distributed over a 3000 mm width on a line normal to the center line of the lane. The truck loadings consist of a two-axel truck

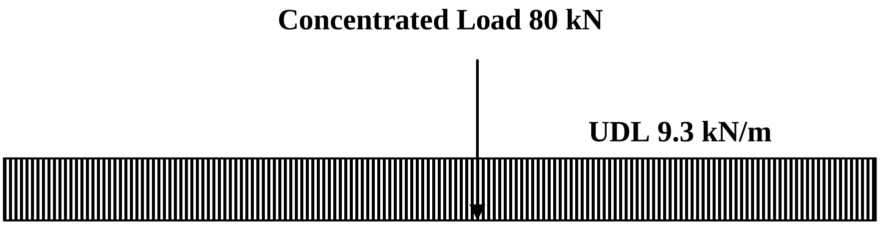
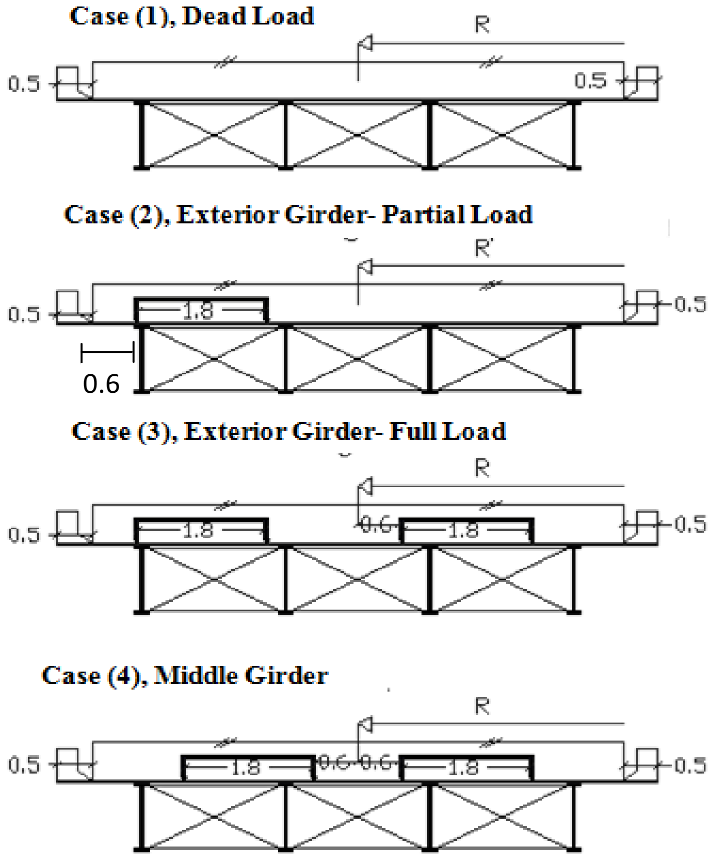


Figure (3) Lane Loading along the Bridge.

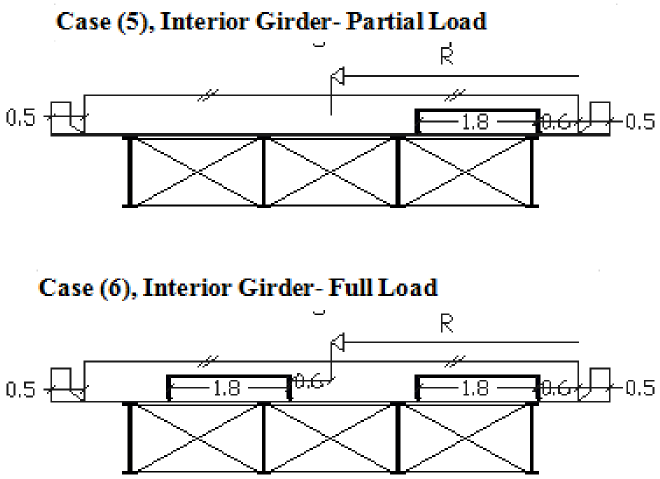

Case (1), Dead Load

Case (2), Exterior Girder- Partial Load

Case (3), Exterior Girder- Full Load

Case (4), Middle Girder

Figure (4) Live Loading Cases for Two-lane Bridge[4].


Case (5), Interior Girder- Partial Load

Case (6), Interior Girder- Full Load

Figure (4) Continued

BOUNDARY CONDITIONS

The bridge supports modeling in this study, lower nodes of the web ends are restrained against translation in such way to simulate temperature-free bridge superstructure. The interior support at the right end as shown in Figure (2) of the bridge is restrained against movements in all directions. The middle supports and the exterior support at the same right end of the bridge are restrained against the vertical movement and against the movement in y-direction (towards the bridge longitudinal direction). On the other end of the bridge (left end), all the supports are restrained only against vertical movement, except for the interior support which in addition to the vertical restraining, it is restrained in x-direction (towards the bridge transverse direction [5].

CALCULATION OF THE MOMENT DISTRIBUTION FACTORS

To determine the moment distribution factor (MDF) for curved girder, the maximum flexural stresses, $(\sigma_{str})_{LL}$, $(\sigma_{str})_{DL}$ are calculated for a straight simply supported beam subjected to AASHTO LRFD loading,. The span of the straight simply supported girder is taken as the curved length of the bridge centerline. From the finite-element analysis, the maximum longitudinal moment stresses along the bottom flange for dead load, fully loaded cases and partially loaded lanes are calculated. Consequently, the moment distribution factors (MDF) are calculated as follows; [5]

For Exterior girders:

$$(MDF)_{DLe}=(\sigma_{FEe})_{DL}/(\sigma_{Str})_{DL} \quad \ldots(1)$$

$$(MDF)_{FL.e}=(\sigma_{FE.e})_{FL}*N/((\sigma_{Stt})_{LL}*n) \quad \ldots(2)$$

$(MDF)_{PLe} = (\sigma_{FE.e})_{PL} * N * ML' / ((\sigma_{Str})_{LL} * n * ML)$ … (3)

For Middle girders:

$(MDF)_{DL.m} = (\sigma_{FE.m})_{DL} / (\sigma_{Str})_{DL}$ …(4)

$(MDF)_{FL.m} = (\sigma_{FL.m})_{FL} * N / ((\sigma_{Strt})_{LL} * n)$ … (5)

For Interior girders:

$(MDF)_{DL.i} = (\sigma_{FE.i})_{DL} / (\sigma_{Strt})_{DL}$ …(6)

$(MDF)_{FL.i} = (\sigma_{FE.i})_{FL} * N / ((\sigma_{Strt})_{LL} * n)$ …(7)

$(MDF)_{PL.i} = (\sigma_{FE.i})_{PL} * N * ML' / ((\sigma_{Strt})_{LL} * n * ML)$ …(8)

Where, $(MDF)_{FL}$ and $(MDF)_{PL}$ are the moment distribution factors for fully loaded lanes, and partially loaded lanes, respectively. The symbols e, m, and i refer to the exterior, middle, and interior girders, respectively. $(\sigma_{FE.\,e})_{FL}$ and $(\sigma_{FE.\,e})_{PL}$ are the maximum longitudinal stresses which are the greater at bottom flange points 1 and 3, as shown in Figure (5), found from the finite-element analysis for the exterior girder due to , fully loaded lanes, and partially loaded lanes respectively. In the same criteria, $(\sigma_{FE.m})_{FL}$, $(\sigma_{FE.i})_{FL}$ and $(\sigma_{FE.i})_{PL}$ are the maximum stresses which are the greater of points 1 and 3 but for the middle and interior girders under the same above types of loading. While ML, ML′, n and N are defined as:

n: number of design lanes, as listed in Table (1)

ML: multi-lane factor based on the number of the design lanes, as shown in Table (2)

ML′: multi-lane factor based on the number of the loaded lanes, as shown in Table (3)

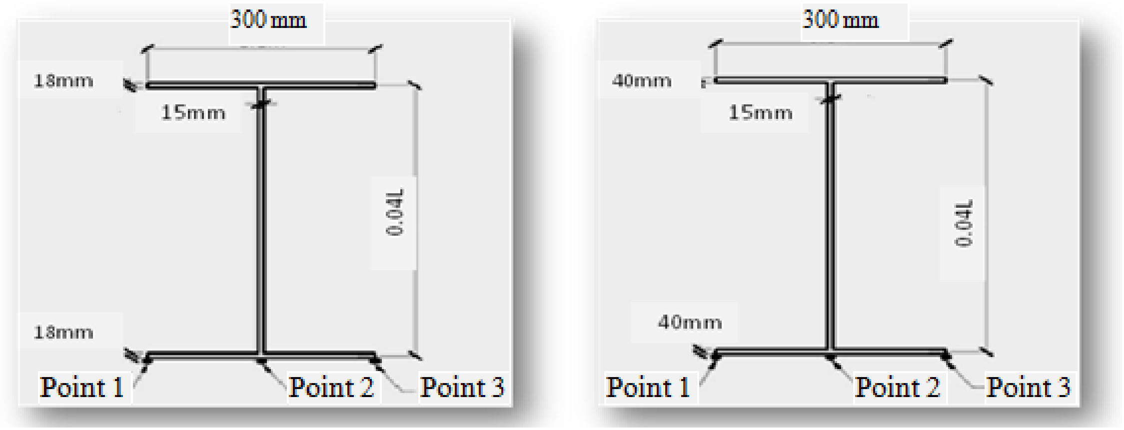
N: number of girders.

Table (2) Number of Design Lanes.

Ws	ML
Over 6.0 m to 10.0 m included	2
Over 10.0 m to 13.5 m included	3
Over 13.5 m to 17.0 m included	4

Table (3) Modification Factors for Multilane Loading.

Number of Loaded Design Lanes	**Modification Factor (ML′)**
1 or 2	1
3	0.85
4 or more	0.75



a) For L= 15 & 30m **b) For L=35m**

Figure (5) Cross-Section Dimension of the Steel Girders.

CALCULATION OF THE DEFLECTION DISTRIBUTION FACTORS

To determine the deflection distribution factor (DDF) for curved girder, the mid-span deflection, $(\delta_{Str})_{DL}$ and $(\delta_{Strt})_{LL}$ are calculated for a straight simply supported girder subjected to AASHTO LRFD loading, respectively. Similar to the above MDF cases, the span of the straight simply supported girder is taken as the curved length of the bridge centre-line. The deflection values of the idealized girder due to live loading are calculated using finite element method. From the finite-element analysis, the mid-span deflection values at the middle of the bottom flange due to fully loaded lanes, and partially loaded lanes are obtained. Consequently, the deflection distribution factors (DDF) are calculated from the following relationships [5]:

For exterior girders:

$$(DDF)_{DL.e} = (\delta_{FE.e})_{DL} / (\delta_{Strt})_{DL} \quad \text{... (9)}$$

$$(DDF)_{FL.e} = (\delta_{FE.e})_{FL} * N / ((\delta_{Strt})_{LL} * n) \quad \text{... (10)}$$

$$(DDF)_{PL.e} = (\delta_{FE.e})_{PL} * N * M\,L' / ((\delta_{Strt})_{LL} * n * M\,L) \quad \text{... (11)}$$

For middle girders:

$$(DDF)_{DL.m} = (\delta_{FE.m})_{DL} / (\delta_{Strt})_{DL} \quad \text{... (12)}$$

$$(DDF)_{FL.m} = (\delta_{FE.m})_{FL} * N / ((\delta_{Strt})_{LL} * n) \quad \text{... (13)}$$

For interior girders:

$$(DDF)_{DL.i} = (\delta_{FE.i})_{DL} / (\delta_{Strt})_{DL} \quad \text{...(14)}$$

$$(DDF)_{FL.i} = (\delta_{FE.i})_{FL} * N / ((\delta_{Strt})_{LL} * n) \qquad \ldots(15)$$

$$(DDF)_{PL.i} = (\delta_{FE.i})_{PL} * N * M\,L' / ((\delta_{Strt})_{LL} * n * M\,L) \qquad \ldots(16)$$

Where, $(DDF)_{DL}$ $(DDF)_{FL}$, and $(DDF)_{PL}$, are the deflection distribution factors for dead load, fully loaded lanes, and partially loaded lanes, respectively. The symbols e, m, and i refer to the exterior, middle, and interior girders, respectively. $(\delta_{FE.e})_{DL}$, $(\delta_{FE.e})_{FL}$, and $(\delta_{FE.e})_{PL}$ are the deflections at point 2, refer to Figure(5), found from finite-element analysis for the exterior girder due to dead load, fully loaded lanes, and partially loaded lanes, respectively. In the same manner, $(\delta_{FE.m})_{FL}$, , $(DDF)_{DL,}$ $(DDF)_{FL.i}$, and $(\delta_{FE.i})_{PL}$ are the finite element deflections for the middle and interior girders under the same above types of loading while, ML, ML′, n, and N are defined as before.

FINITE ELEMENT MODELING

In the present study, the elastic analysis of composite bridge was performed by the three dimensional finite elements using structural analysis package program (SAP 2000) under loading cases mentioned in previous sections. In this program, the web and flange plate and slab are divided to a number of finite shell elements. The element is a linear quadratic element consisting of four degree of freedom (3 translations & 3 rotations), Whereas, frame elements, pinned at both ends, are used to model the cross-bracings with the top and bottom chords. Figure (6) shows view from the SAP2000 finite-element models for 3- girder curved bridge. In this program calculates the stresses and deflections for exterior, middle and interior straight girders, and then calculates the moment distribution factor and deflection distribution factor when the external loads (live loads) as truck and lane loading. Deflections and stresses for each girder are calculated also for dead load including wearing load.

Results of stresses and deflections of girders for each load case are obtained using the program (SAP 2000). A computer program is built in this study using Visual Basic to determining the moment distribution factors (DDF), as mention in previous sections.

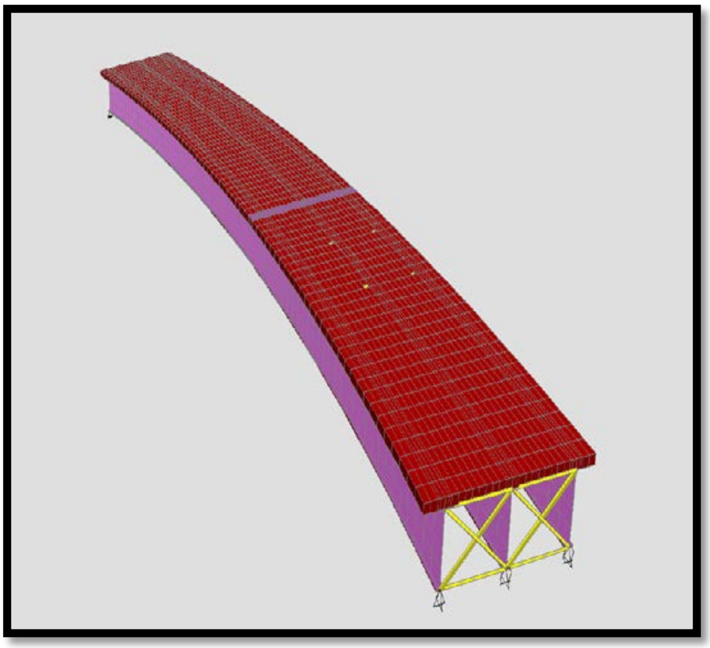


Figure (6) View from the SAP2000 Finite-Element Models for 3- Girder Curved Bridge.

RESULTS &DISCUSSION

The data presented in Tables (4) and (5) for live load (as truck and lane loading) are considered and taken from AASHTO LRFD for abnormal case for analysis and design. Geometry of each elements of composite bridge is calculated and preliminarily designs. Materials properties are assumed but matching the requirements of AASHTO LRFD.

Table (4) Types of Loading.

Type of Loading	Values
Dead load	Self weight for members+ wt.of asphalt with 100mm thick.
Live load	HL 93
Lane load	UDL =9.3 N/mm with concentrated load=80000 N

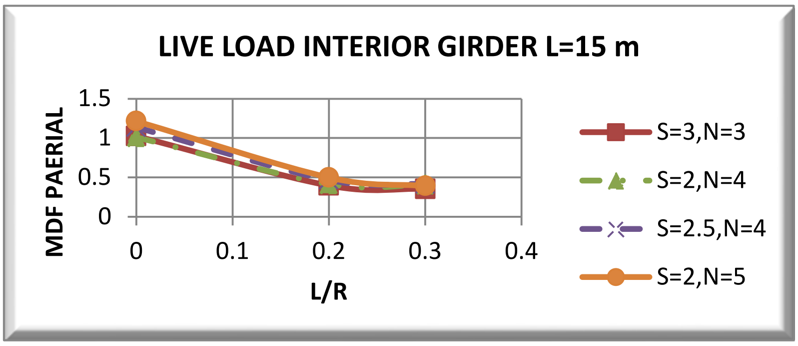
Table (5) Material properties.

Properties	Values
Concrete	
Modulus of elasticity (E_C)	23500 MPa
Poisson ratio (ν)	0.15
Cylinder compressive strength (f_c')	25 MPa
Steel	
Modulus of elasticity (E_s)	200000 MPa
Poisson ratio (ν)	0.3

MOMENT DISTRIBUTION FACTOR

Effect of Curvature

The result of the current parametric study reveals that curvature of the bridge is one of the most significant parameters affecting the distribution of moments between the longitudinal girders. For each model, the full data are given together with AASHTO LRFD calculations up to L/R equal to (0.3), after this ratio the results are non consistent (torsion and bending) if compared with AASHTO limitations thus it is better to using another method of analysis and design for such cases it recommended that L/R not greater than (0.4). Figure (7) shows below the variation in the moment distribution factor for the interior girder of two and three-lanes bridge with three, four and five girders, with the increase in the span-to radius of curvature ratio (L/R) due to fully-loaded lanes and partially-loaded lanes with live loading, respectively.. It can be observed that the moment distribution factor for the exterior girder increases in the ranges of (0.2-0.3) with the increase in span-to-radius of curvature ratio and decrease for straight girder in the range (0-0.2), because of the applied loads are normal to the girders, and the eccentricity vanish thus no torsion .It can also be noticed that the rate of increase of the moment distribution factor generally increases with the increase in span length. In case of middle and interior, girders similar performance has been observed.



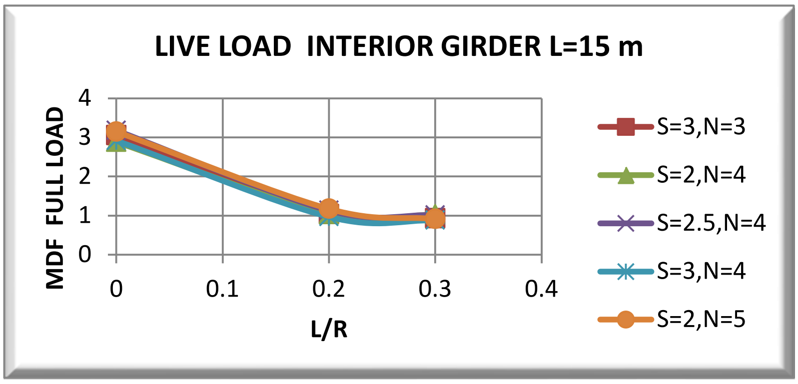


Figure (7) Effect of Curvature on the Moment Distribution Factor for the Interior and Exterior Girder due to Live Load.

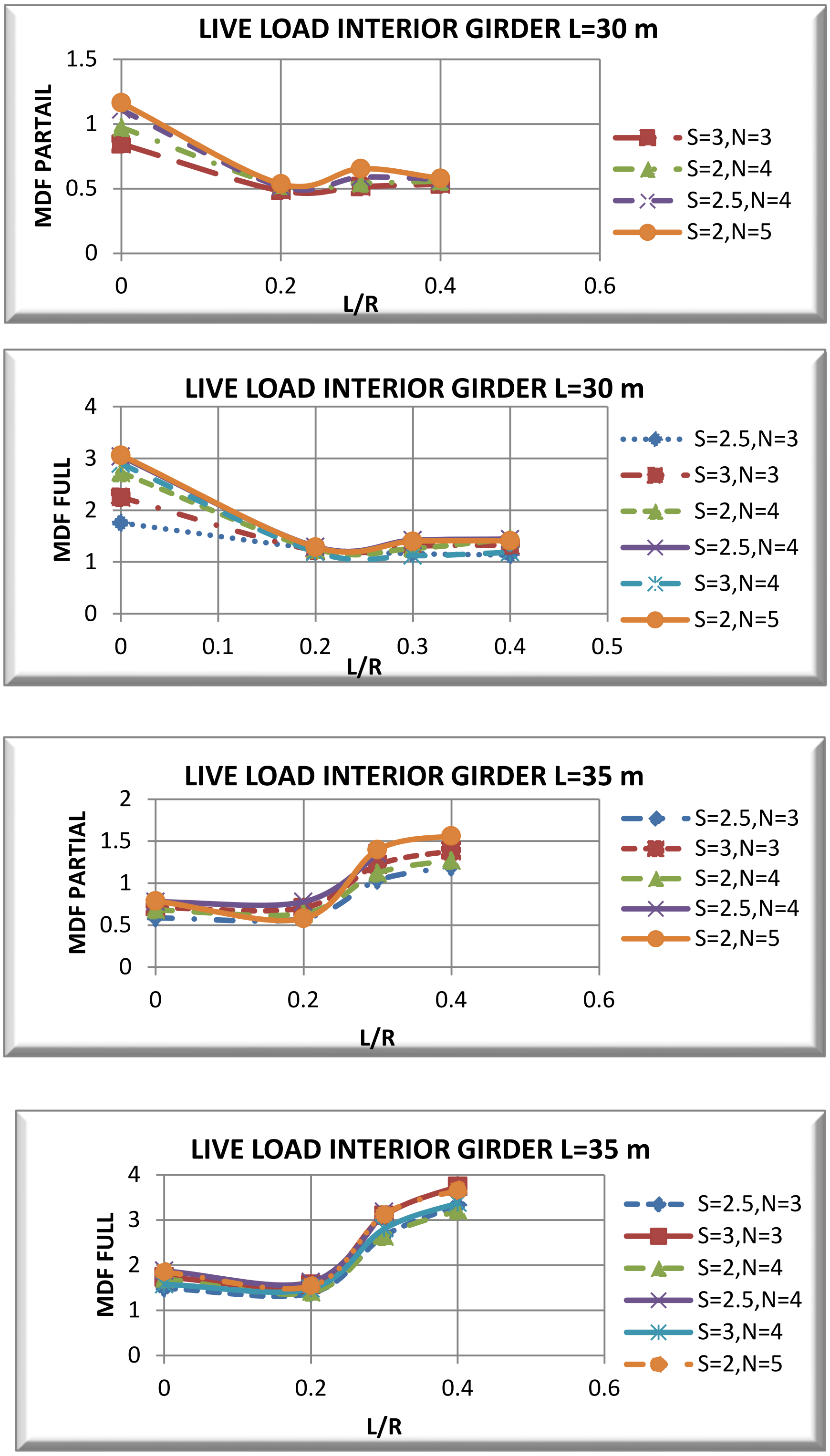
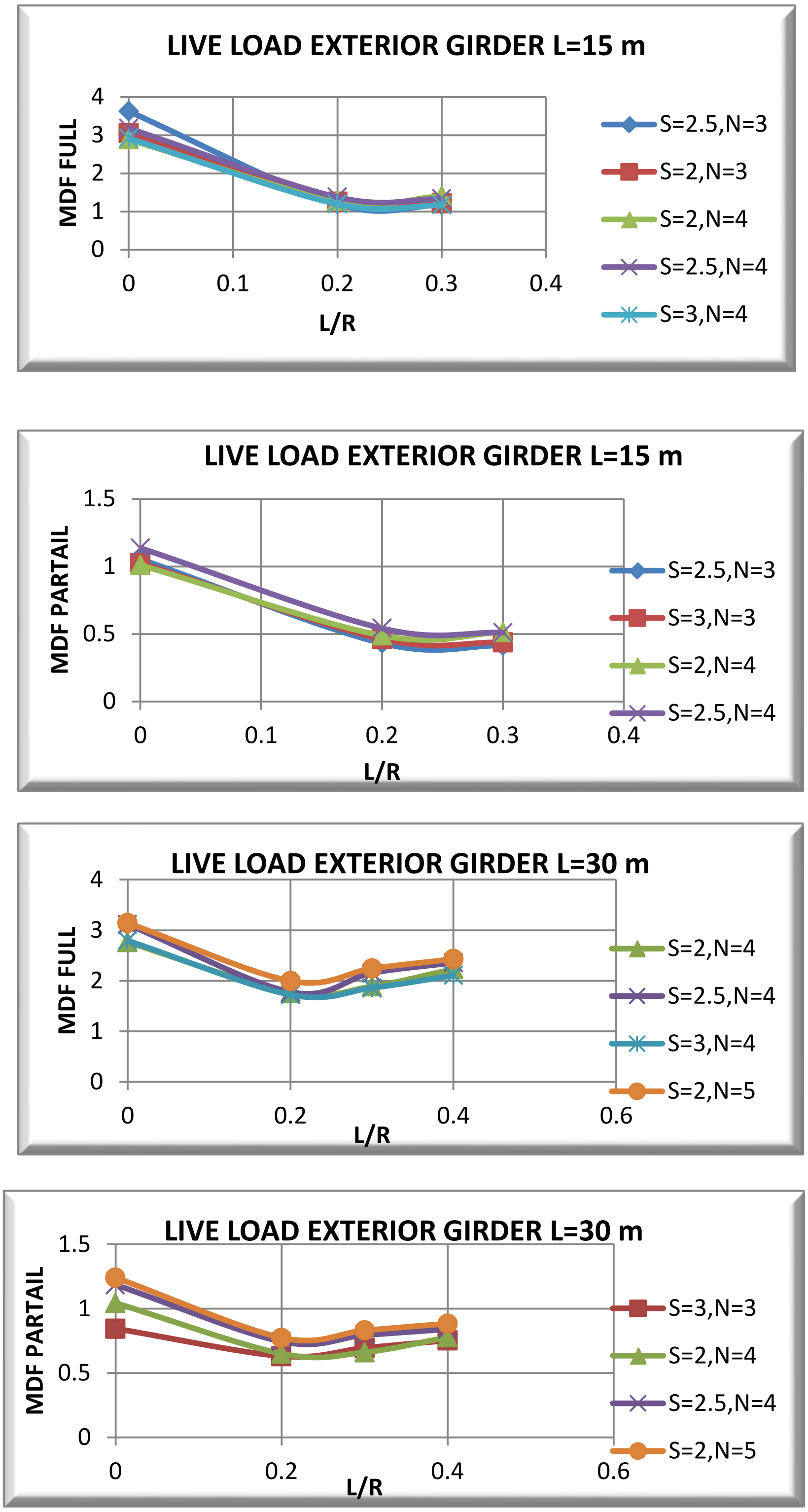


Figure (7) Continued.



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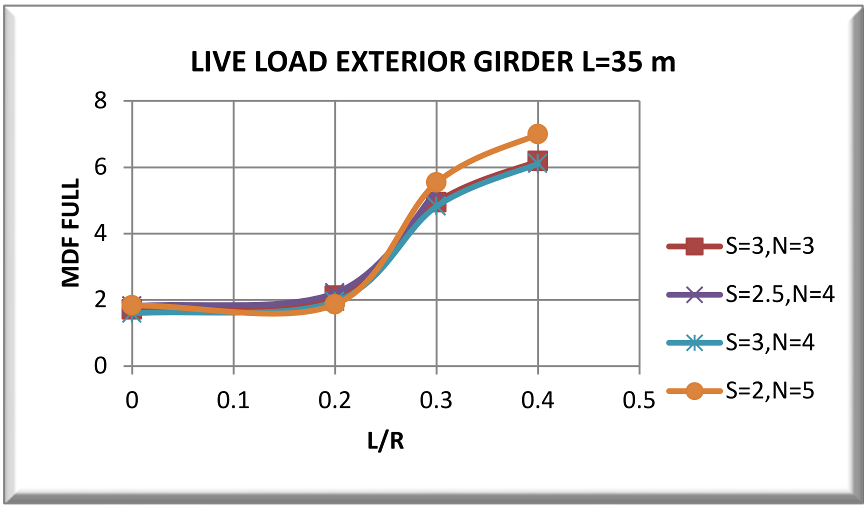

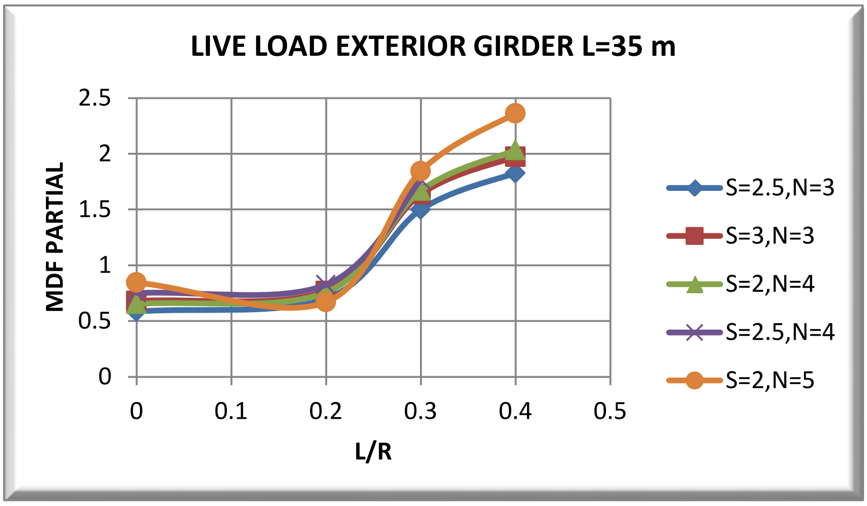

Figure (7) Continued.

EFFECT OF SPAN LENGTH

Figure (8) depicts the selected results for the effect of bridge span length on the moment distribution factors for the exterior and interior girders of two-lane, four girders due to fully-loaded lanes and partially-loaded lanes with live loading, respectively. It can be observed that the effect of the span length on the moment distribution factor generally increases, because of the loaded length increase when the length increases, so that the moment distribution factor increases. Also when the length of span increases, the geometry of steel girder increases and so on the depth increases then after the moment of inertia increases this reason the stress decrease so the MDF increase.

Similar behavior is observed in case of the middle girder of straight bridges. However, for curved bridges, the moment distribution factor of the girders is noticed to increase with the increase in the span length.

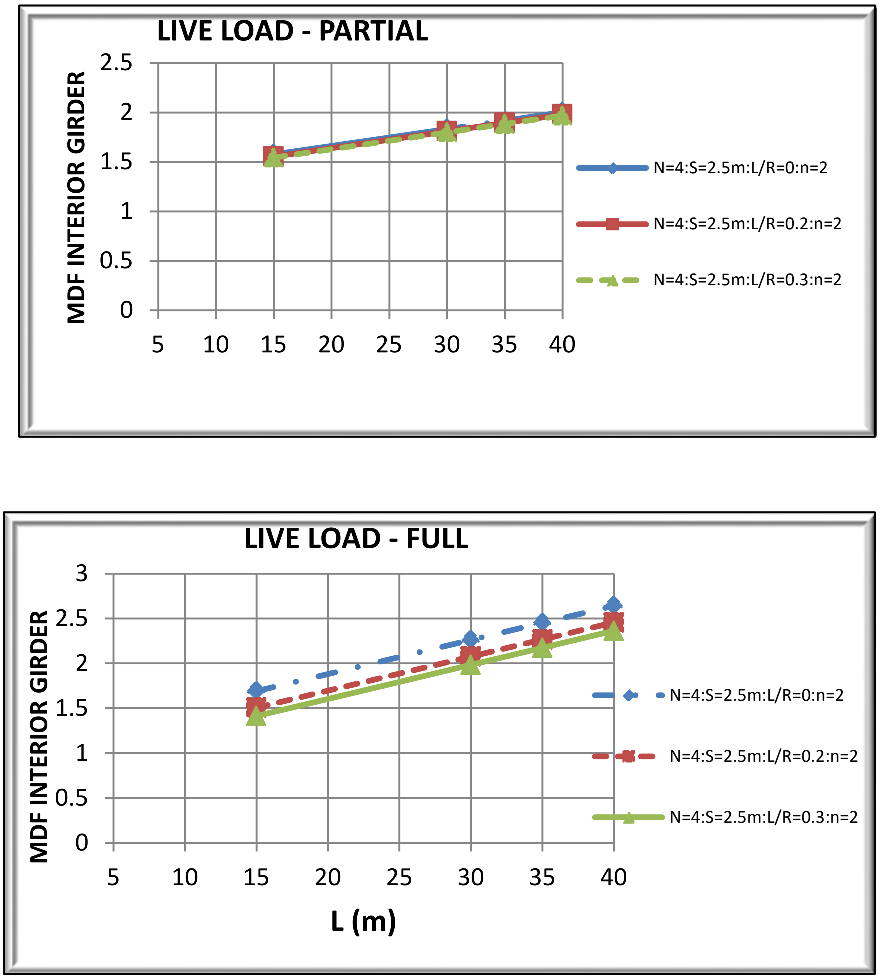

Figure (8) Effect of Span Length on the Moment Distribution Factor for the Interior Girder due to Live Load.

DEFLECTION DISTRIBUTION FACTOR

Effect of Curvature

The results of the current parametric study reveal that the curvature of the bridge is one of the most significant parameters affecting the distribution of deflection between the longitudinal girders. Figure(9) below examine the effect of curvature on the deflection distribution factors for t middle girders of two and three-lane curved bridges with 2 m, 2.5 m and3 m spacing girders for the live load cases, it can be seen that the deflection distribution factor for the middle girder increase in the ranges of (0.2-0.3) with the increase in span-to-radius of curvature ratio and decrease for straight girder in the range (0-0.2), because in case of straight girder, the control is the span of the bridge and there is no arching to resist the deflection so that the deflection increases. It can also be noticed that the rate of increase of the deflection distribution factor generally increases with the increase in span length. In case of interior and exterior, it showed similar performance.

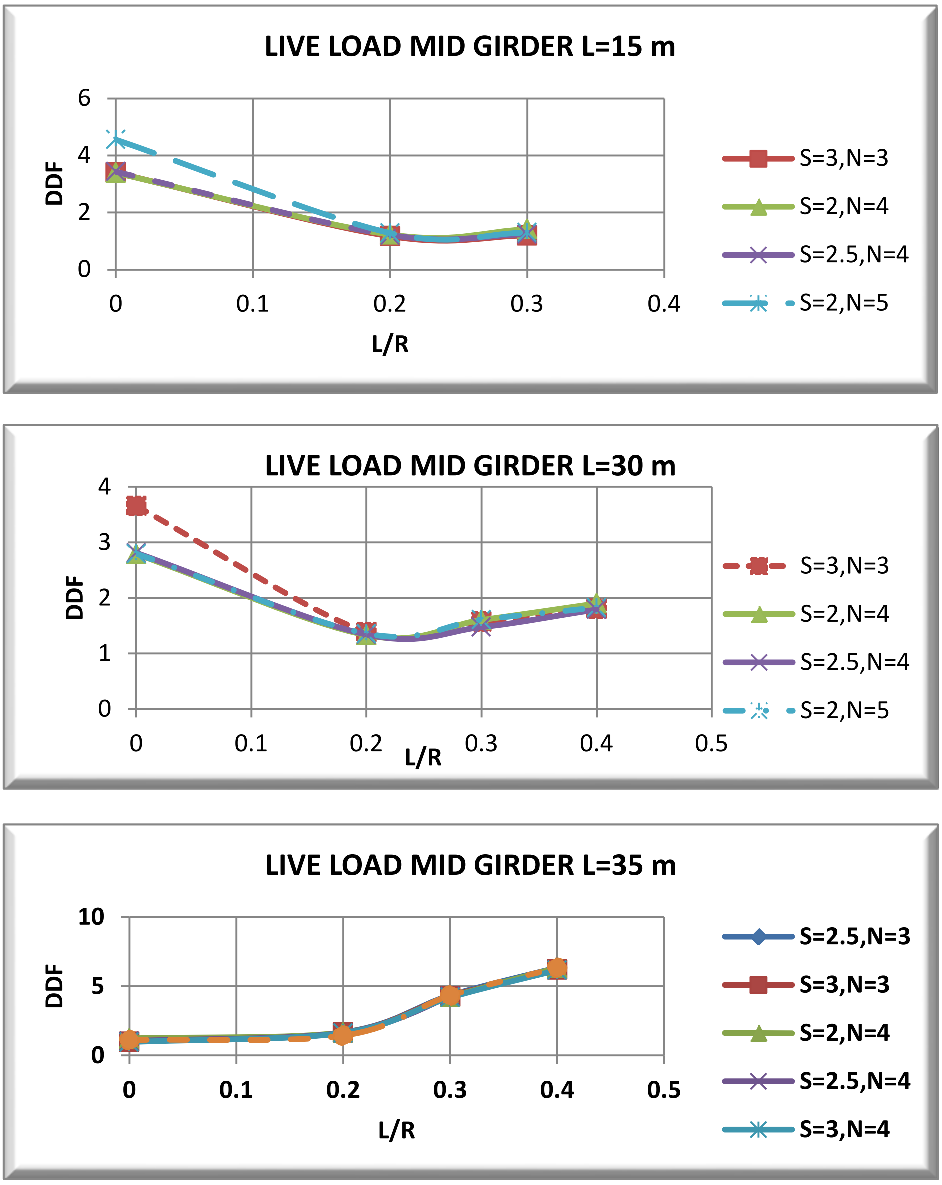

Figure (9) Effect of Curvature on the Deflection Distribution Factor for the Middle Girder due to Live Load.

EFFECT OF SPAN LENGTH

Figure (10) show selected results for the deflection distribution factors for the interior girder of a two-lane, four-girder Bridge with 2.5 m spacing for different span lengths and degrees of curvature. It can be observed that the effect of the span length on the deflection distribution factor generally increases because of the loaded length increase when the length increases so that the deflection distribution factor increases. Also, when the length of span increase the geometry of steel girder increase and so on the depth increases then after the moment of inertia increases , for this reason the stress decrease so the DDF increase.

Similar behavior is noted in case of the middle girder of straight bridges. However, for curved bridges, the deflection distribution factor of the girders is observed to increase with the increase in the span length. Some results from the analysis if compared to the limitations according to AASHTO LRFD and AISC manual showed greater than limits because of the geometry of girders. In case of spans 35 m models are changed in geometry (thickness of bottom flange) to match the requirements of deflection and stresses (also warping) according to codes.

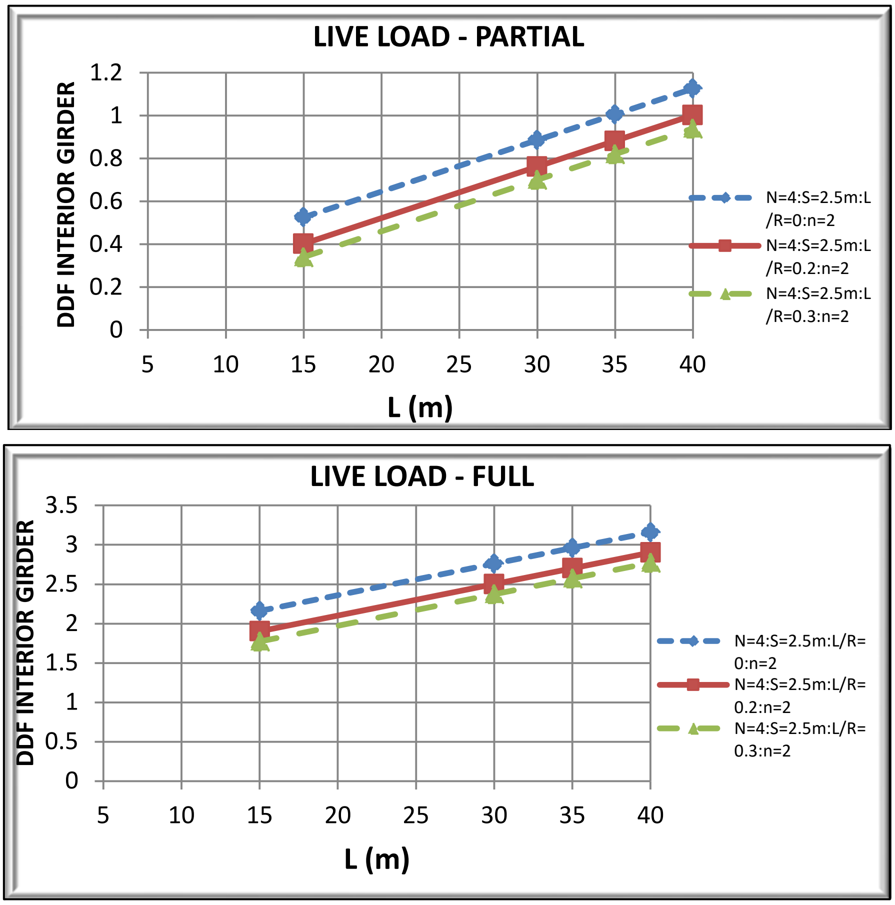

Figure (10) Effect of Span Length on the Deflection Distribution Factor for the Interior Girder due to Live Load.

CONCLUSIONS

1. The moment distribution factor and deflection distribution factor for the exterior, interior and middle girder increase in the ranges of (0.2-0.3) with the increase in span-to-radius of curvature ratio and decrease for straight girder in the range of (0-0.2). When the straight girder is considered as reference, the range in decrease between (0-80%) and the range of increase between (0-214%) for MDF. While the range in decrease between (0-77%) and the range of increase between (0-500%) for DDF.
2. The moment distribution factor and deflection distribution factor generally increase with the increase of span length. The range of increase with the increase of span length between (33%-170%) for MDF. The range of increase is between (28%-145%) for DDF.

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