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Assessment of Al-Sabtea Bridge under the Effects of Static Loadings

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Abstract

The behavior and strength of composite for composite bridges relay on the connectors that used to connect the steel beams or girders with reinforced concrete deck slab. Different type of shear connectors that available in the market such as headed stud or steel channels are commonly welded to the top face of the steel section to prevent slip at the interface between the two different materials. In present paper, existing composite bridge built in Iraq is modelled using finite elements approach by ANSYS. The bridge is simulate by adopt real dimensions and geometry to check out the performance of connectors and strengths of composite girder under worst static loading conditions proposed by general Iraqi Standard Specification for Road and Bridges such as track, knife and military loadings. The analysis results indicate that the three types applied loading show that all stresses within the acceptable limits and did not reach high values compared capacities of these materials according to the AASHTO ASD code. The maximum stress at bottom face of steel girder is 114.7 MPa and the maximum deflection is 59 mm these values within limits of code.

Keywords: ANSYS; Finite Element; Composite Steel-Concrete Girder; Shear Connector.

1. Introduction

Composite bridges consists of I girder as steel or precast connected with concrete deck slab by means of shear connectors.Composite bridges of steel and concrete are a common and economical form of construction used in a wide variety around the world. Many researches were focused into the performance of composite bridge under the effects of static loadings. Newmark et al. [1], Yam and Chapman [2] and Jasim [3]. Lam and El-Lobody [4] suggested and developed a model consists of set of differential equations. Gelfi and Giuriani [5] reviewed a relationship that was approximated between the increment of deflection and the maximum connection slip and suggested a simple approximated relationship that described the increased in deflection due to presence of slip. Al-Thebhawi [6] presented a nonlinear finite element for the analysis of composite steel-concrete beams. Jabir [7] carried out analysed a nonlinear three-dimensional finite element to predict the load-deflection performance of a composite girder under static and transient loads by ANSYS. Bachachi [8] studied the load deflection performance of composite beams under static loads as a nonlinear three dimensional finite element model by ANSYS. Ahmed [9] investigated studied nonlinear external pre-stressing performance simply supported composite beams. Bukka et al, [10] studied the nonlinear performance of composite beams under the effects of static and dynamic loadings. The analysis results evaluated by experimental tests data by other researchers and showed close. D. R. Panchal [11] reviewed the recent ideas that discussed before by researchers that focused on the analysis and design of composite girder and then suggested a new technique of analysis and design of composite structures. Pedro et al, [12] studied the efficient methodologies to optimized of composite steel I girder bridge by finite elements approach. The analysis results treated by statistical analysis to optimized the composite

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sections. Ali Al-Adhami and Laith Khalid Al-Hadithy [13] studied the effects of pure shear on the stud shear connectors that presence at the top face of the composite steel girders, finite elements approach by ABAQUS software was adopted to simulated the models. The analysis results indicated that the grade of concrete embedment significantly decreases the prototype ultimate shear force, relative slip and shear toughness. EL-Shihy et al, [14] studied the effects of partial interaction of shear connectors on the performance and strength of composite beams by finite elements approach. The analysis results indicated that the partial interaction theory gave increased in deflections and stresses as compared with the full interaction performance. The purpose of present study to evaluate the performance of Al SABTIA bridges using finite element approach by ANSYS software under static loads based on the Iraq specification of road and bridge.

2. Finite Element Model

Finite elements approach is select to analyze the composite bridge models by ANSYS version 15.07. The types of elements adopts in present study to simulate the composite bridge are SOLID65 element for concrete beam , LINK180 for steel reinforcements, SHELL181 for steel girder, SOLID185 for steel plates, COMBIN39 for shear connectors, CONTA-174 and TARGE 170 as interface elements and BEAM188 for bracings. Each selected element types represent and simulated the actual behavior of each material. Figure 1 show the front view of the composite girder with actual dimensions as built in site.

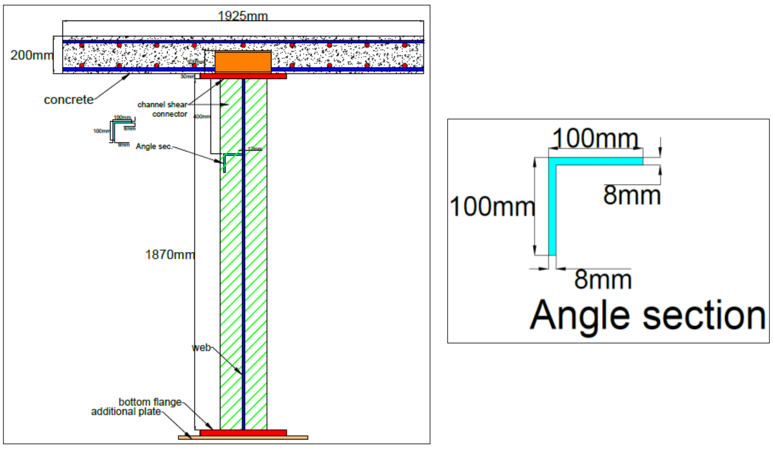


Figure 1. composite beam consist of steel section and concrete slab

The model that build in ANSYS as finite elements shown in Figure 2 the boundary condition of composite girder is simply supported and simulate by apply displacement at the location of nodes that represent the support of the composite girder at the bottom face equal to zero. The number of elements that adopt are (51588) and the method of iterative solution is Newton-Raphson method [9].

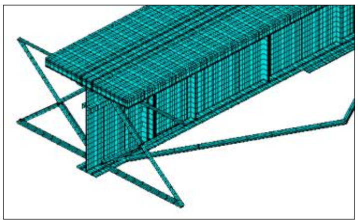
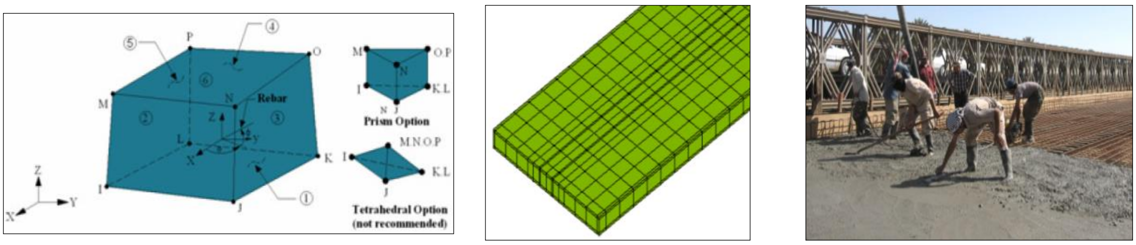


Figure 2. Composite bridge model

2.1. Concrete Element

SOLID65 is select to simulate the concrete, this element is capable of plastic deformation, cracking in three orthogonal directions, and crushing, as shown in Figure 3 [15].

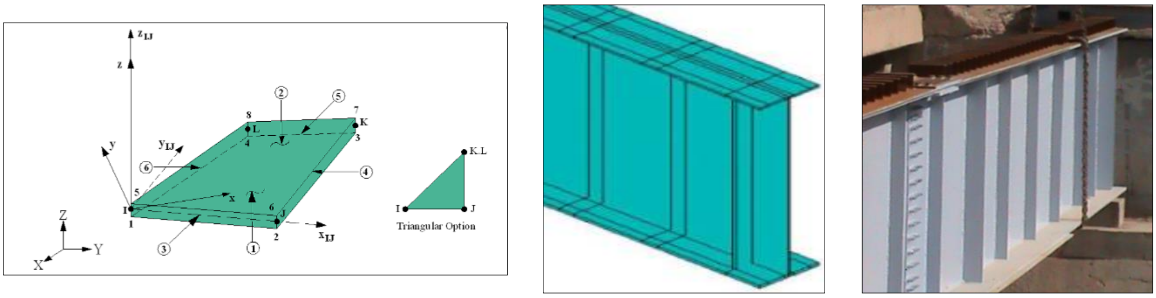


(a) **(b)** **(c)**

Figure 3. (a) SHELL181 geometry [15], (c) Steel girder in actual case

2.2. Steel Girder Element

The steel girder representation in the finite elements is shell element that desirable together with three translations in x, y and z in each node to accomplish the condition of compatibility with translation in x, y and z in neighbouring element .For this aim, shell elements with three-dimensional (4-node), which is characterized as (SHELL181) is used. The geometry, the coordinate system and node locations for these elements are shown in Figure 4 [15].



(a) **(b)** **(c)**

Figure 4. (a, b) SHELL181 geometry [15], (c) Steel girder in actual case

2.3. Steel Plate's Element

At the loading position, steel plates are added to avoid concentration to simulate the steel plate SOLID185. The element is distinct by 8 nodes owning degrees of freedom is three at every node translations in the nodal x, y, and z directions as shown in Figure 5 [15].

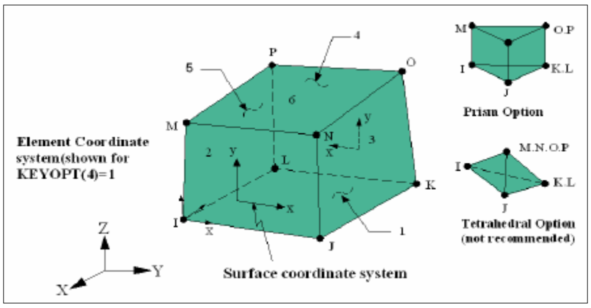


Figure 5. SOLID185 geometry [15]

2.4. Shear Connectors Element

Elements of nonlinear springs COMBIN39 is used to model the channel shear connectors. COMBIN39 elements represents the load opposite slip connector's behavior [16]. The geometry, node location, and the system of coordinate for these elements are shown in Figure 6 in which the points represent the coordinate of load slip from experimental push-out test under static load [11].

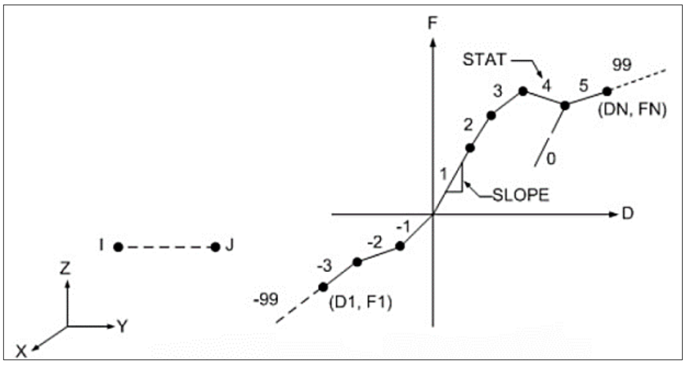


Figure 6. COMBIN39 geometry [15]

2.5. Reinforcement Element

The 3-D spar LINK180 element is a uniaxial tension-compression with three degrees of freedom at every node as shown in Figure 7 [15]. Figure 8 represent the comparison between the actual and finite element simulations of shear connectors and main reinforcements.

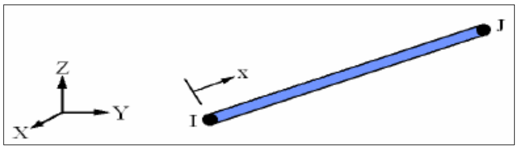
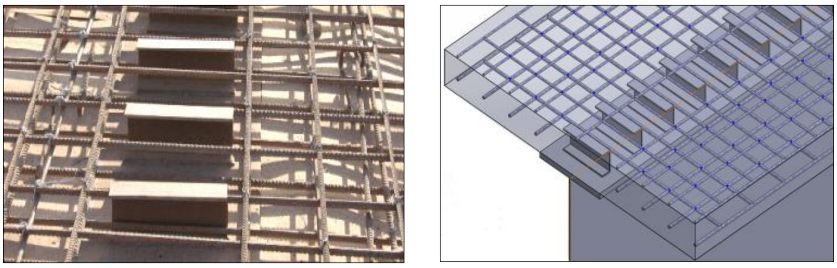


Figure 7. LINK180 geometry [15]



a) **b)**

Figure 8. a) Reinforcement in actual case, b) ANSYS model

2.6. Interface Surface Element

Surfaces to surfaces contact is assumed to describe the relationship between top steel girder and the bottom of deck slab so that the elements that selects are (CONTA-174 and TARGE 170) and shown in Figure 9 [15]. The contact-pair comprises of the contact among two boundaries, one of the boundaries take the form contact, slid and deformable surface taken as contact surfaces (CONTA-174) and the other take the form rigid surfaces taken as a target surface (TARGE-170) [15].

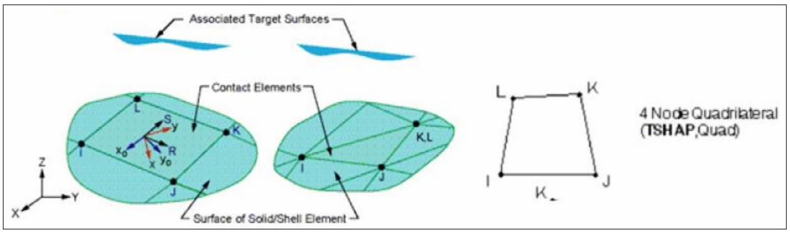


Figure 9. Geometry of (CONTA-174 and TARGE 170) [15]

2.8. Bracing Element

The element BEAM188 is select to model the bracings between girders as shown in Figure 10. These comprise translations in the x, y, and z directions and rotations about the x, y, and z directions [15].

a) **b)**

Figure 10. a) BEAM188 geometry, b) bracing in actual case

3. Modeling of Materials

All materials that simulated in finite elements approach by ANSYS were insert as real design values as mechanical properties, modulus of elasticity and Poisson's ratio.

3.1. Concrete Modeling

The concrete is assumed as homogeneous and isotropic and the stress-strain curve similar that shown in Figure 11 [17] by adopt the following relationships that let the concrete behavior as nonlinear material.

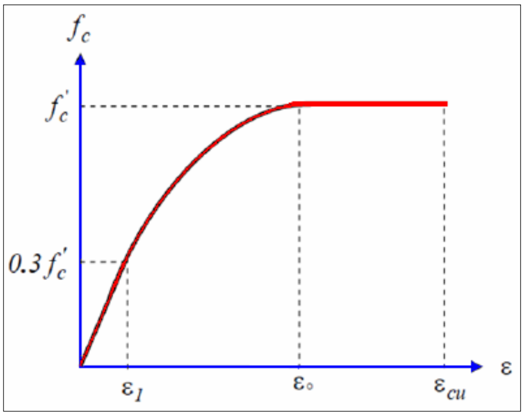


Figure 11. Stress-strain curve for concrete [17]

$$E_c = 4700\sqrt{f_c'} \quad (1)$$

Where

fc'= Compressive strength of concrete, MPa

E_c=Modulus of elasticity, MPa

$$f_c = \varepsilon E_c \qquad 0 < \varepsilon < \varepsilon_c \quad (2)$$

$$f_c = \frac{\varepsilon E_c}{1+(\frac{\varepsilon}{\varepsilon_c})^2} \qquad \varepsilon_1 < \varepsilon < \varepsilon_c \quad (3)$$

$$f_c = f_c' \qquad \varepsilon_0 < \varepsilon < \varepsilon_{cu} \quad (4)$$

$$\varepsilon_1 = \frac{0.3 f_c'}{E_c} \quad (5)$$

$$\varepsilon_0 = \frac{2 f_c'}{\varepsilon_c} \quad (6)$$

Where:

ε_1= *Strain corresponding, 0.3 fc'*

ε_o= Strain at peck point

ε_{cu}= ultimate strain

3.2. Steel Girder

The behavior of strain-stress curve for steel girder assumed that elastic –full plastic with inclination angle as show in Figure 12, the modulus of strain hardening E_t is supposed to be $0.03E_s$ [18]. This model also adopt for main reinforcements that embedded in concrete deck slab but different in mechanical properties than steel girder [19].

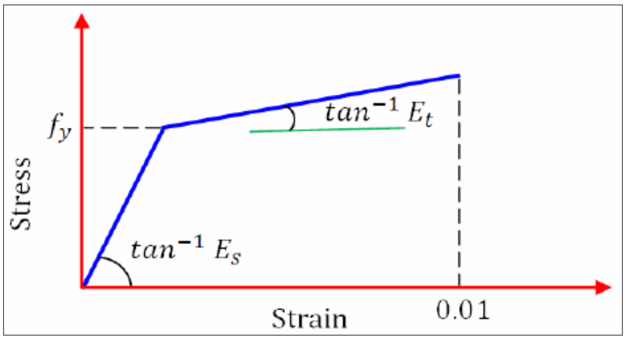


Figure 12. Bilinear stress-strain relationship of steel [18]

3.3. Surface Contact and Shear Friction

The friction model basic Coulomb is adopt and apply at the interface between steel girder and concrete deck slab, the shearing stress using the two contacting surfaces up to a definite magnitude through their interface before they begin sliding comparative to each other. Once the shearing stress is surpassed, the two surfaces will slide relative to each other .coefficient of friction with μ=0.7 has been used [20]. The properties of all materials are lists in Table 1.

Table 1. Material properties

Material Type	Parameter	Definition	Value
Concrete	fc'	Ultimate compressive strength (MPa)	28
	E_c	Young's modulus of elasticity (MPa)	25000
	v_s	Poisson's ratio	0.15
Steel girder	f_y	Yield strength (MPa)-Web	319
		Yield strength (MPa)-Flange	385
	E_S	Modulus of elasticity (MPa)	200000
	v_s	Poisson's ratio	0.2
Reinforcement	E_S	Modulus of elasticity (MPa)	200000
	f_y	Yield strength (MPa)	420
	v_s	Poisson's ratio	0.3
Steel Plate	f_y	Yield strength (MPa)	319
	E_S	Modulus of elasticity (MPa)	200000
	v_s	Poisson's ratio	0.3
Shear Connector	f_y	Yield strength (MPa)	319
	E_S	Modulus of elasticity (MPa)	200000
	v_s	Poisson's ratio	0.3
Contact surface	μ	Coefficient of friction	0.7

4. Case Study-Al SABTIA Bridge

The bridge Al SABTIA is construction On the Diyala River in Iraq as shown in Figure 13. The present study consist of multi-girder Al SABTIA bridge development various similarly measured longitudinal girder are composed at uniform separating through the bridge width. The deck slab traverses transversely among the longitudinal and cantilevers transversely outer the girder. At supports the girders are propped together and at some transitional positions. Composite activity between the reinforced concrete deck slab and the longitudinal girder was accomplished by methods for shear connectors welded on the top flanges of the steel girders. The present study we select the interior composite steel-concrete girder of the bridge Al SABTIA the length of the part that has been rehabilitated 36 and 21 m width are analyzed, the dimensions of the composite steel concrete girder are illustrated in Figure 13.

Figure 13. Al SABTIA Bridge

5. Loads Application

The applied load on the composite bridge based on the Iraq code specifications [21]. Followings are the load types that adapt in present study.

5.1. Non-Composite Dead Load

The steel girder weight was considered as a body forces for the erected non-composite structure in the analysis with steel density of 78.5 kN/m^3. The entire concrete deck was treated as the applied uniform load on girders with concrete density of 25 kN/m^3.

5.2. Superimposed Dead Load

The flexural stresses due to superimposed dead load related with long-term composite section which is calculated by transforming the concrete deck to the equivalent area .Only wearing surface layer was adopted as a superimposed dead load with asphalt density of 22 kN/m^3 and 80 mm layer thickness.

5.3. Live Load

The live load application based on Iraqi standard specification .Since the carriageway width equal to 7.5 m, therefore there are three traffic lane with lane width of 2.5 m and the live load application are:

A) Lane Load: Loaded Length =35.75 m

Uniform Distributed Load (UDL) = 23 N/mm per lane

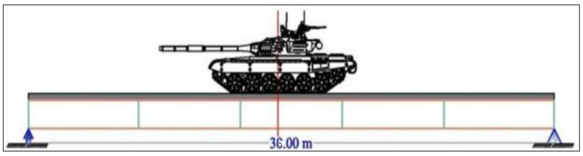
Knife Edge Load (KEL) = 40.18 N/mm per lane

Figure 14C and 15 show the application of the lane load with using represented of channel shear connector as combined element 39 for model MS3 and using as a solid element for model MS3L.

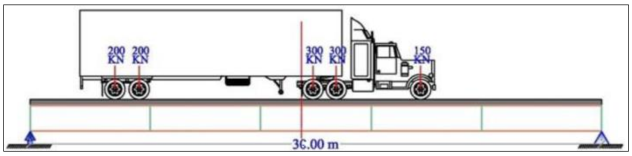
B) Military Loading: According to Iraqi Standard Specification [4], when the carriageway width of the bridge fewer than 8.3 m, one-Lane military loading joint with full foot-path loading, the foot-path loading in the design case is not considered.

a. Tracked Vehicles Class 100: acts at mid-span as shown in the Figure 14 a and 16 with using represented of channel shear connector as combined element 39 for model MS2 and using as a solid element for model MS2T.

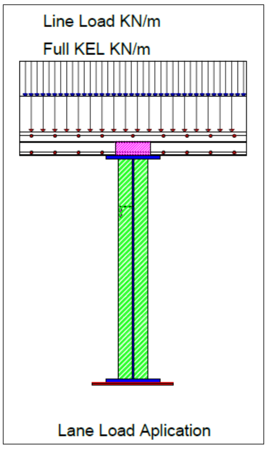
b. Wheeled Vehicles Class 100: This wheeled loads perform longitudinally at position to yield the bridge maximum response as shown in the Figure 14 b and 17 with using represented of channel shear connector as combined element 39 for model MS1 and using as a solid element for model MS1W.



a) Tracked Vehicles



b) Wheel Vehicles



c) UDL and KEL

Figure 14. Load case, a) Tracked Vehicles, b) Wheel Vehicles, c) UDL and KEL

6. Analysis Results

In present study the theory of full interaction composite action is applied for analysis and the followings are the analysis results:

6.1 Deflection at Bottom Steel Girder

The deflection of the steel girder as shown in figures it can be noted that the finite element analysis investigations are concur well with the computation comes about all through the whole scope of behavior. Figure 15 to 18 represents the deflection-distance at the bottom of the steel girder for all applied loading MS1, MS2 and MS3. The deflection increase as the applied loading increase and the cumulative deflection at the bottom center become more assume that the equivalent stiffness of composite girder is constant so that the higher deflection in case of MS2 because of this type of load represent the worst case of loading as shown in Table 2. The values of deflection at bottom steel girder for load case MS2 larger than as compared with load case MS1 9% and larger than as compared with load case MS3 13.6%. Figure 20 Compare the deflection at the bottom of the steel girder for all applied loading MS1W, MS2T, MS3L and MS1, MS2, MS3, with using represented of channel shear connector as solid element and combined element 39 respectively, noted the deflection difference in the results is small 2.5% to 3.7%.

6.2 Slip at Interface

Figure 15 to 19 represent the full performance of slip - distance at the interface of steel girder for all applied loading MS1, MS2 and MS3. When the applied load increase the slip increase and become maximum at the end of girder due to the cumulative slip starting from center line of composite bridge toward the end of girder. due to the symmetry the slip sign convention become inversely start from center line of composite girder so that the higher slip in case of MS3 because of this type of load represent this worst case of loading. The values of slip at interface between top steel girder and bottom of concrete for load case MS3 larger than as compared with load case MS2 15% and larger than as compared with load case MS1 21.4 %. Show Figure 21 the slip along composite bridge at the bottom of the steel girder for all applied loading MS1W, MS2T, MS3L and MS1, MS2, MS3 with using represented of channel shear connector as solid element and combined element 39 respectively, noted the value of slip difference is small 2.5% to 3.7%.

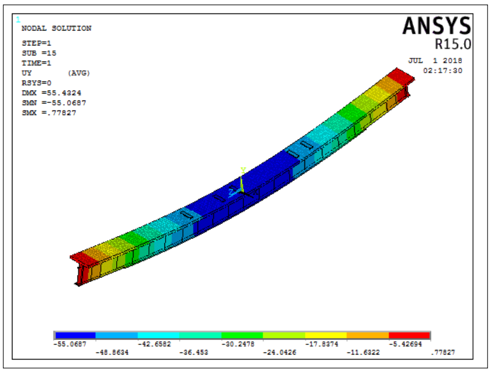


Figure 15. Deflection curve for MS1

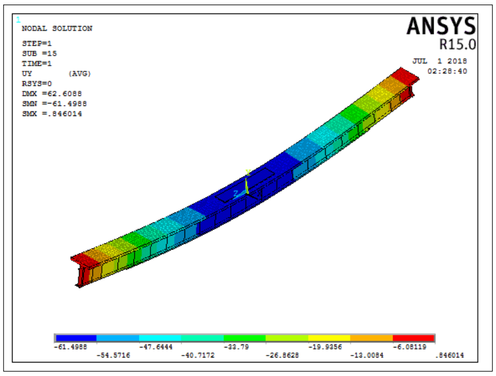


Figure 16. Deflection curve for MS2

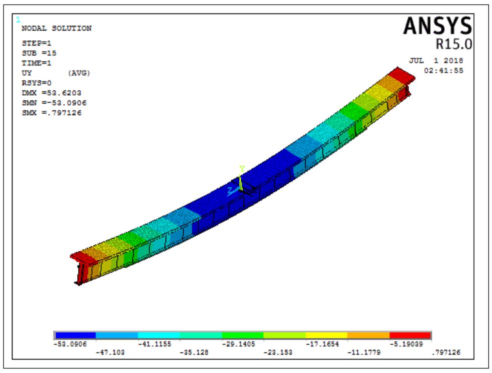


Figure 17. Deflection curve for MS3

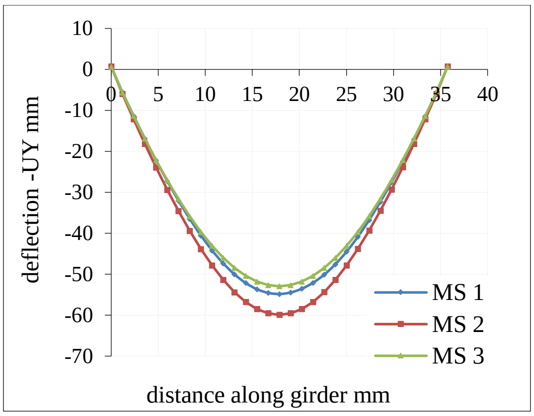


Figure 18. Deflection at bottom steel along distance of girder

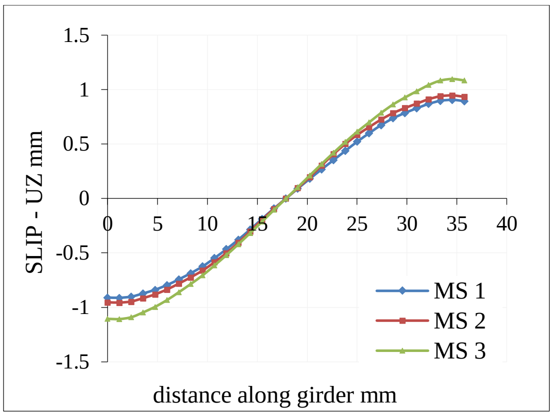


Figure 19. Slip at interface between concrete and steel along distance of girder

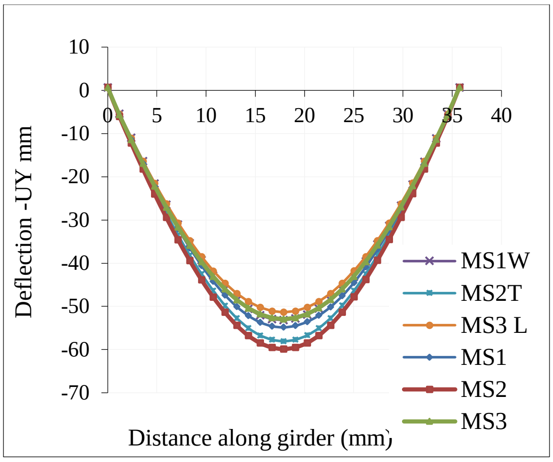


Figure 20. Compare deflection at bottom steel girder

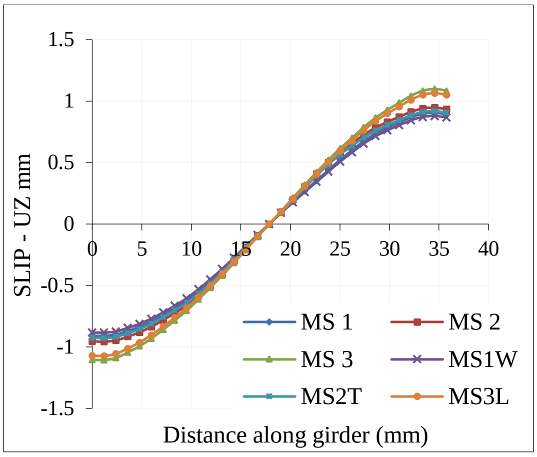


Figure 21. Compare slip at bottom at interface between concrete and steel

6.3. Stress for Composite Steel Girder

The applied load - stress of the composite bridge shown in Figure 22 to 25 that represent the variation of bending stress along the girder in the line of the bottom face of steel girder for all applied loading MS1, MS2, MS3. The bending stress value relay on location at magnitude of applied loading so that the higher in case of MS2 because of this type of load represent this worst case of loading as shown in Table 2. The maximum bending stress at the center line of the girder occurs at that point. The positive value of bending stress is positive because the bottom face of steel girder lie at the tension face. The value of bending stress at bottom steel girder for load case MS2 larger than as compared with load case MS1 14.24% and larger than as compared with load case MS3 20.23 % .

Figure 26 Represent the full performance of bending stress at the interface between top steel girder and the bottom reinforced concrete slab for all applied loading MS1, MS2, MS3.The sign convention is negative because the location of interface lie above neutral axis so that become negative. The maximum bending stress is higher in case of MS2 occurs at the middle point of composite girder because same reasons mentioned.

Figure 27 Represent the bending stress at the top face of concrete slab along the composite girder for all applied loading MS1, MS2, MS3. The values of bending stress smaller than as compared with the bottom steel girder because the arm level distance is less than the distance from neutral axis to the bottom of composite girder. The maximum value of bending stress occurs in case of MS2 due to the magnitude of applied load.

Show Figure 29 the bending stress along composite girder at the bottom of the steel girder for all applied loading MS1W, MS2T, MS3L and MS1, MS2, MS3 with using represented of channel shear connector as solid element and combined element 39 respectively, noted the stress difference in the results is small 2.5% to 3.7%**.**

6.4. Shear Stress at Interface

Figure 28 the shear stress along the composite girder that developed due to applied load MS1, MS2, MS3.The maximum shear stress accrue at the support because of the maximum shear force occurs at that point, noted that the maximum shear stress in case of load case MS3 due to higher value of applied loading. The shear stress become zero at the middle point of composite girder because the shear at that point is zero due to symmetry. The values of shear stress at interface between top steel girder and bottom of concrete for load case MS3 larger than as compared with load case MS1, 10.53% and larger than as compared with load case MS2, 2 %.

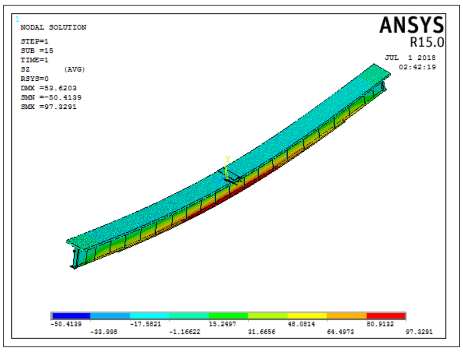


Figure 22. Load-stress curve for MS3

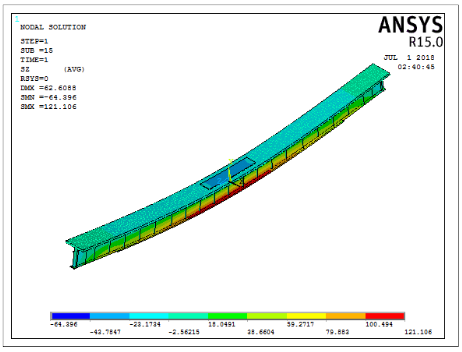


Figure 23. Load-stress curve for MS2

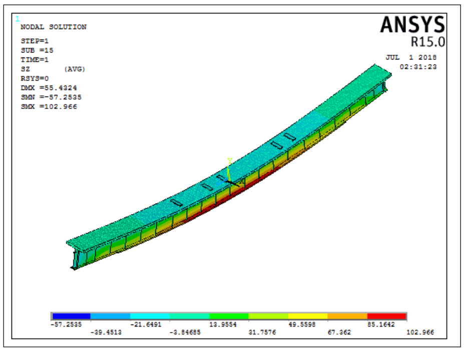


Figure 24. Load-stress curve for MS1

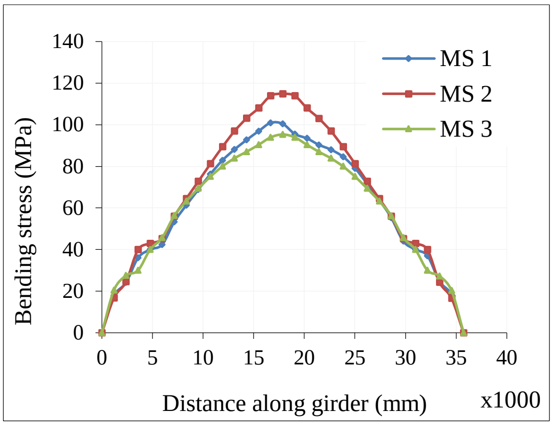


Figure 25. Bending stresses at bottom Steel along distance of girder

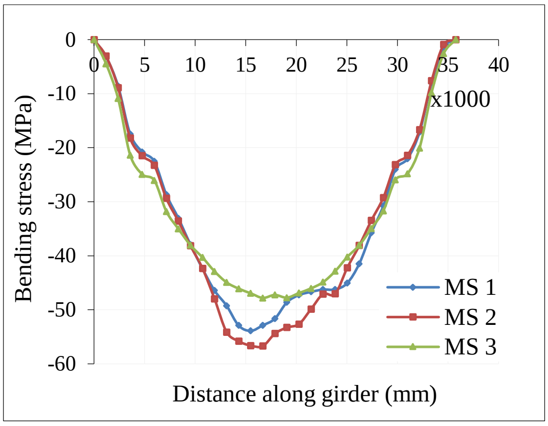


Figure 26. Bending stress at interface between concrete and steel girder

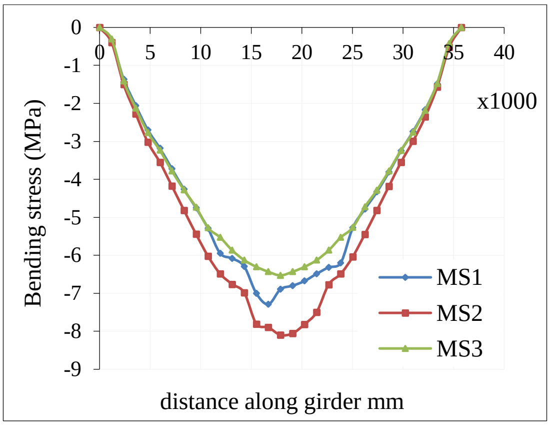


Figure 27. bending stresses at top steel along distance of girder

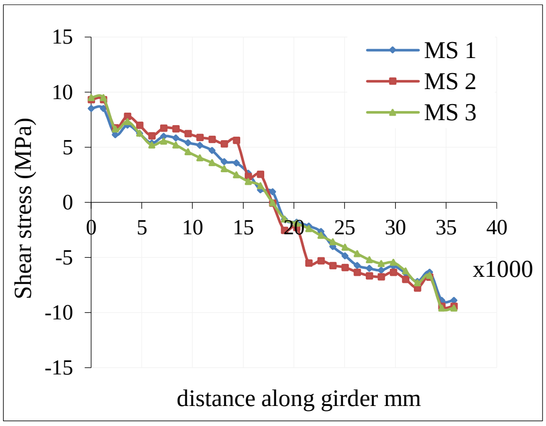


Figure 28. shear stress at interface between concrete and steel girder

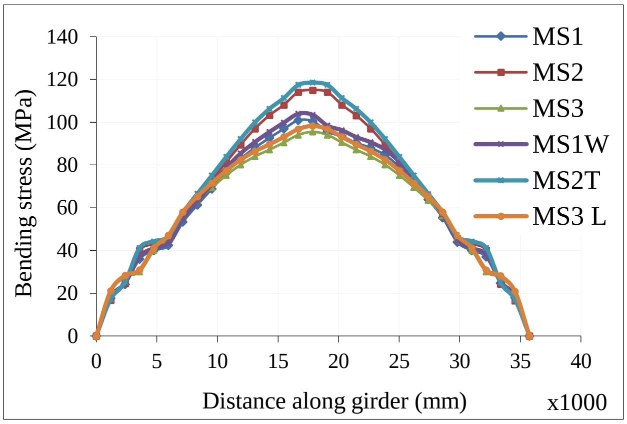


Figure 29. Compare bending stress at bottom of steel girder

Table 2. Max. Deflection and stress for various type of load case

Load type	UY (mm)	Stress-SZ (Mpa)
Wheel Vehicles Class(100)(W100)	55	100.4
Tracked Vehicles Class(100)(T100)	59	114.7
(UDL) and (KEL)	53	95.4

7. Conclusions

The numerical analysis results as finite elements approach by ANSYS software that adopt to simulate the existing bridge as actual dimensions and mechanical properties to check out the full performance following points are the conclusions drawn from this work:

- The representation of channel shear connectors through elements of combined element 39 provided a simple and powerful modelling of the connectors in comparison with using elements of the 3D solid type, which leads to a refilled mesh and, consequently, large computational efforts. We also found that the difference in the results is small 2.5% to 3.7%, especially since the number of shear connectors is large and use combined element 39 reduces the time and number of element.
- It is concluded that under the worst loading of single truck condition, the stresses in the steel beam, shear connectors and concrete slab do not reach high values compared to the ultimate capacities of these materials. The maximum stress does not exceed 31.47% of the steel yield stress for load case (MS1) and 35.78% of the steel yield stress for load case (MS2) and 29.91% of the steel yield stress for load case (MS2) and the maximum deflection along the bridge span was 59 mm for a span of 35.75 m and 55 mm for load case (MS1) and 53 mm for load case (MS3).
- The deflection increase when the applied loading increase and the cumulative deflection at the bottom center become more. By assume that the equivalent stiffness of composite girder is constant so that the higher deflection in case of (MS2) because of this type of load represents this worst case of loading.
- As the applied loading increase the slip increase and become maximum at end of composite girder at support. The slip increase when the shear force increase and that relay on the applied external loads.
- Bending stress at the bottom face of steel girder, interface and top face of concrete deck slab increase as the applied external load increase and become maximum. The maximum value of bending stress occurs in case of (MS2) due to the magnitude of applied load.
- The values of bending stress at top face of concrete smaller than as compared with the bottom steel girder because the arm level distance is less than the distance from neutral axis to the bottom of composite girder.
- The maximum shear stress accrues at the support because the maximum shear force occurs at that point. The maximum shear stress in case of load case (MS3) due to higher value of applied loading.
- The results of deflection and stresses within permissible limits based on AASHTO ASD.
- The bridge which is the subject of this study is safe from the point of the composite action, where are use large number of shear connector and thus approaching its behavior toward full interaction.

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