The Nucleus 56, No. 1 (2019) 1-5

www.thenucleuspak.org.pk

The Nucleus
ISSN 0029-5698 (Print)
ISSN 2306-6539 (Online)

Effect of Gap between Prefabricated Concrete Deck Elements on Stiffness of Composite Bridges

A. Abbas[1], A. Ajwad[2*], M.A. Khan[1], A. Aqdas[1], U. Ilyas[2], M.U. Rashid[2], Abdullah[2] and M.A. Adnan[2]

[1]*The University of Lahore, Raiwand Road Campus, Lahore, Pakistan*

[2]*University of Management and Technology, Johar Town, Lahore, Pakistan*

ARTICLE INFO

Article history:
Received: *10 July, 2017*
Accepted: *24 April, 2019*
Published: *29 April, 2019*

Keywords:
Prefabricated deck elements,
Linear finite element analysis,
Composite bridges,
Dry joints

ABSTRACT

Composite bridges are a new dimension of today's bridges, which involves two materials of different properties that are combined to give a unique property together. In this research, such a bridge made of Concrete and steel was chosen where the supporting medium was a steel beam with a concrete deck on top of it. One of the more advanced steps in this bridge was to prefabricate the concrete deck. The influence of the gap between the prefabricated concrete deck elements and its effect on the bridge stiffness was studied under serviceability loading. It was found that increasing the gap did affect the stiffness of composite bridge. The deflection increased linearly with the increase in gap of concrete deck elements. Also when compared with the hand calculation, the results from ABAQUS showed presence of shear lag.

1. Introduction

Composite bridges are structures with composite materials. Essentially a composite bridge consists of a steel girder and concrete slabs, which are either pre-casted or casted on site. The use of composite bridges mainly depends on the site conditions, local costs of the material, engineers and contractors experience. One advantage is that the steel girder can take the weight of the pre-cast or the wet concrete. It also acts as a form work for the concrete, which means that there is little need of scaffoldings and other supports. Composite bridges can be constructed with less effort and also in less time, which saves a lot of money for the tax-payers and the government. So it can be said that a composite bridge is economical compared to other bridge types. Construction of composite bridges involves placing of concrete deck elements on top of steel girders which then is considered to be a composite [1]. Fig. 1 demonstrates how the placing of concrete elements on top of steel girders is done. A gap clearance ranging between 0 to 10 mm is investigated for a medium sized bridge spanning 24 m.

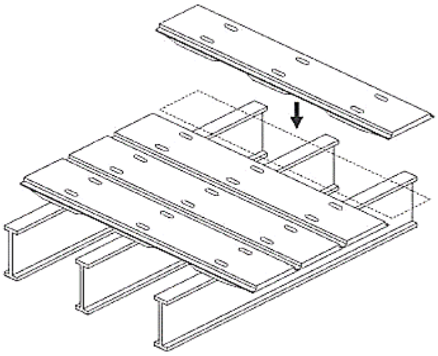

Fig. 1: Layout of composite bridges.

Considerable amount of research has been done in the field of composite bridges and their behavior under loading. Kartopoltsev et al. [2] did assessment of dynamic properties and stiffness of composite bridges with pavement defects and found that the dynamic stiffness of the vehicle–span system is a combination of the vehicle stiffness (stiffness of suspensions) and the stiffness of the reinforced concrete girder at a stage of inertial loading taking the decay effect into account. Zhou [3] studied stiffness and strength of fiber reinforced polymer composite bridge deck systems and observed that, the span with one transverse rod (west span) is stiffer and stronger than the span with 5 transverse rods (east span). Siwowski et al. [4] studied structural behavior of an all-composite road bridge by using fiber reinforced polymers, these results revealed that an all-composite bridge can meet the relevant strength and deflection design criteria; however, the stiffness remained questionable due to addition of Fiber Reinforced Polymers (FRP). Yanas-Armas et al. [5] looked into system transverse in-plane shear stiffness of pultruded Glass Fiber Reinforced Polymers (GFRP) bridge decks and their results revealed that the system in-plane shear modulus of the trapezoidal beams represented approximately 2–3% of that of the triangular beams. Tuwair et al. [6] modeled and analyzed GFRP Bridge deck panels filled with polyurethane foam, they found out that the finite-element results in terms of strength, stiffness, and deflection were found to be in good agreement with those from the experimental results. Nijgh et al. [7] studied Elastic behavior of a tapered steel-concrete composite beam optimized for reuse and their Experimental and numerical results indicated that the number of shear connectors are necessary to fulfil deflection; and end-slip limits can be reduced by concentrating near the supports of a simply-supported beam. Results obtained using finite element models closely matched the experimental results in

---

[*]*Corresponding author: ali.ajwad@umt.edu.pk*

terms of deflection, stresses and curvature. Similar study was done by Noel et al. [8] they did experimental investigation of connection details for precast deck panels on concrete girders in composite deck construction. These results revealed that the highest shear capacity is observed at low displacement levels as well as the highest pull-out capacity. However, the three configurations showed higher capacities than expected according to the Canadian highway bridge design code. Marcusson [9] studied design and construction of composite bridges and concluded that it is important to carefully consider the different material characteristics of steel and concrete to achieve an optimum design both in respect of erection sequence and material quantities. The concrete slab has a high resistance to compression forces whereas steel is prone to buckling, but has a high tension capacity. Mohan and Tholkapiyan [10] studied behavior and impact of concrete deck slab, shear connector and steel beam in composite bridge and concluded that while the complete quadratic combination method is reasonable for single action effects (one excitation direction only), it is difficult to apply to multiple action effects arising from different excitation directions that interact with each other.

The main aim of this research was to check a composite bridge using ABAQUS (Static and dynamic stress analysis simulations) [11], which is a Finite element computer software, and essentially studying the effects of gaps, which will occur due to the prefabricated concrete deck elements taking into consideration various loading conditions including self-weight and traffic loading. The response was studied in the serviceability limit state and shear lag due to the gaps was carefully investigated for dry open gaps only. ABAQUS is a software suite for finite element analysis and computer-aided engineering.

2. Methodology

Finite element method was used to solve complex structural mechanics problems where numerical or analytical solutions are difficult to solve and impractical as well [12]. There are almost an infinite number of variables which determined the performance of a physical body or a structure. FEM (Finite Element Modelling) was developed in the 1950's for the aviation industry [13]. It has since been adopted into many fields of scientific research such as stress analysis, heat transfer, fluid mechanics, etc.

The basic concept of FEM is division of the structure into pieces called elements which is bounded by nodes. The network of nodes and elements is known as a mesh. The structure is discretized and then solved for independent variables located at nodes. If we have more number of elements we can get more accurate results.

Usually, when solving these kind of complex problems software which are designed exclusively for finite element analysis are used. In this case ABAQUS version 6.9 was used for the results presented in this research [11].

2.1 *Linear-Elastic FE-Model*

The bridge was loaded according to the rules given by the Swedish Road Administration [14]. The purpose of this analysis was to determine the influence of the transverse dry joints between the prefabricated concrete deck elements on the bridge behavior (deflection and stiffness). For self-weight, only traffic loading was considered when examining the behavior of the composite bridge. Figs. 2 and 3 show plan view of bridge before and after application of load.

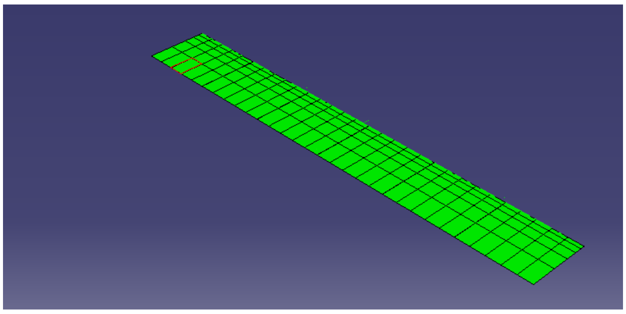

Fig. 2: Plan view of bridge in ABAQUS before loading.

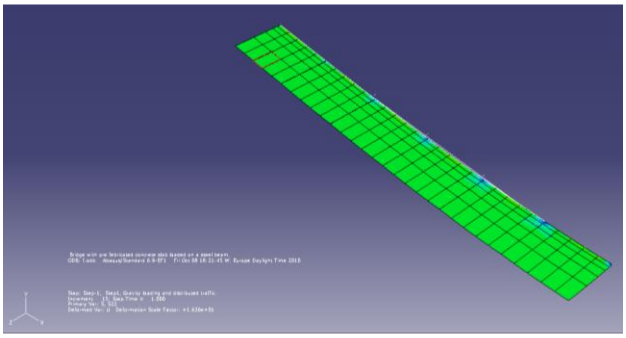

Fig. 3: Plan view of bridge in ABAQUS after loading.

In case of ABAQUS, a gap increment of 0.2mm was used for deflection. As the bridge was a medium sized 24m span one, it was calculated that the gap of 5mm will be the maximum as after this gap, the concrete deck elements would become dead load and the whole traffic loading will be carried by steel girders only. Fig. 4 is a transverse view of bridge showing the gaps due to prefabricated elements whereas Fig. 5 shows the application of axle loads on top of bridge deck.

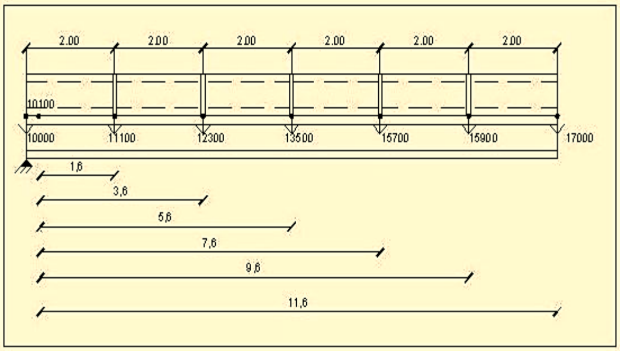

Fig. 4: Transverse view of the bridge showing the presence of gaps due to pre-fabricated elements.

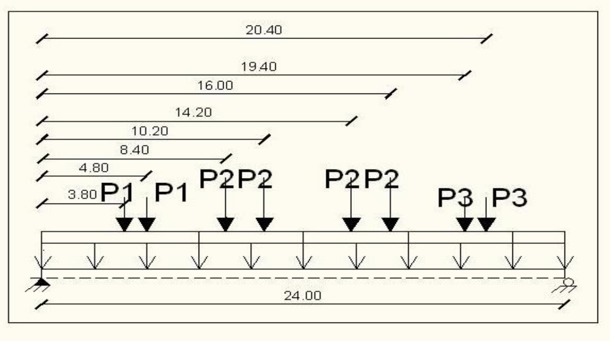

Fig. 5: Position of the axle load due to heavy vehicles.

Reinforcement weight was considered as a part of the concrete with a density value of 24 kN/m^3. The reason for this was that the concrete plate contains a lot of transverse reinforcement and a large number of shear stud connectors whose own weight is not included explicitly.

Table 1 show the cross-section dimensions of the bridge girder whereas Fig. 6 shows its schematic drawing. Fig. 7 shows cross-section of steel section and beam with concrete deck element.

Table 1: Cross section dimensions of bridge girder.

Composite cross section properties	
b_{con}, mm	3200
t_{con}, mm	230
$h_{c,c}$, mm	1000
b_c, mm	600
t_c, mm	20
h_w, mm	945
t_w, mm	20
b_t, mm	850
t_t, mm	35

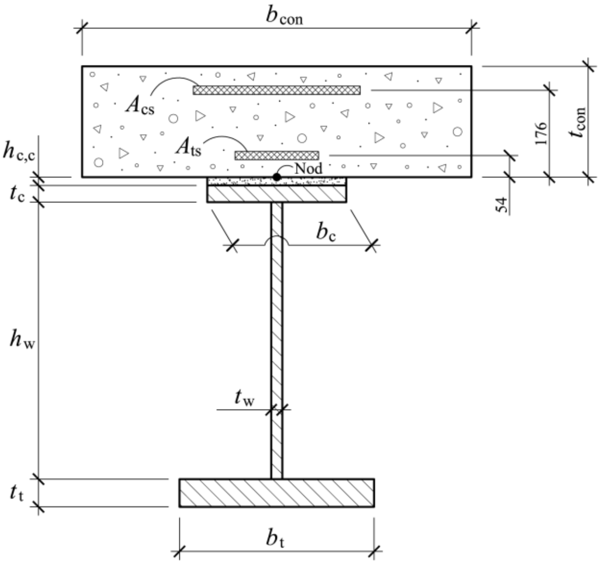

Fig. 6: Schematic drawing of a cross section belonging to one of the two parallel beams. The specified dimensions are given in mm.

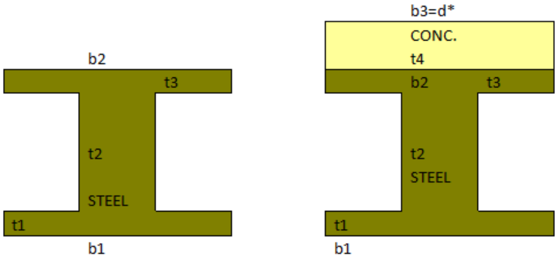

Fig. 7: Cross-Section of Beam and beam with concrete deck element.

In order to calculate deflection in composite bridge under ideal conditions, equations (1) and (2) were used [15].

Maximum Deflection due to Self-weight of steel beam only

$$\Delta_{\text{max (beam only)}} = \frac{Pb\left(l^2-b^2\right)^{3/2}}{9\sqrt{3}l^2EI} \tag{1}$$

Where

P = Ultimate load
b = distance from right end
l = Total span
E = Modulus of elasticity
I = Moment of inertia

Deflection due to concrete slab and steel beam (composite)

$$\Delta_{\text{max (composite)}} = \frac{5\omega L^4}{384EI} \tag{2}$$

Where

ω = Maximum load
L = Total span
E = Modulus of elasticity
I = Moment of inertia

Due to the complexity of the equation, Microsoft excel was used to do the manual calculations.

3. Results and Discussion

Table 2 shows the calculations of deflection calculated manually and by ABAQUS. The first two columns of data in Table 2 were obtained from ABAQUS which show the total deflection values of composite bridge at various gap sizes between placed slabs. For comparison, Column 3 and 4 of Table 2 show deflection of steel beam without concrete slab (gap of 5 mm) and composite section (gap of 0 mm) which were calculated manually. It can be noticed that all the values obtained from software lie in-between the minimum and maximum values of deflection obtained through manual calculation.

The model had been analyzed by using a linear material behavior and the model was working properly. The analysis had been performed by applying a specific traffic load equivalent to 447.81 kN at the mid-span of each concrete deck element. Deflection results were compared in Table 2 for large number of initial gap clearance d. Comparison were also made with the upper and lower limits established through hand calculations.

Table 2: Calculations of deflection calculated manually and by ABAQUS.

G (Gap) (mm)	d (Deflection) (mm)	Deflection without slab (mm)	Deflection with slab composite section (mm)
5	146.8	178	60.5
3.4	146	178	60.5
3.2	145.3	178	60.5
3	138.3	178	60.5
2.8	135.5	178	60.5
2.6	132.4	178	60.5
2.4	129.2	178	60.5
2.2	125.9	178	60.5
2	121.4	178	60.5
1.8	117	178	60.5
1.6	112.8	178	60.5
1.4	108.1	178	60.5
1.2	103.3	178	60.5
1	98	178	60.5
0.8	92.6	178	60.5
0.6	87	178	60.5
0.4	81.6	178	60.5
0.2	77.4	178	60.5
0	73.1	178	60.5

It is clear from Table 2 that gap clearance between concrete slab elements effects the vertical deformation of the bridge. The material behavior was taken as linear, so the variation was almost straight line. The results obtained by ABAQUS were compared by hand calculations. This comparison verifies the ABAQUS results. The hand calculations are done by considering the structure as composite which gave the deformation of 60.5 mm at mid span of the bridge. The deflection by considering composite structure was less than the deformation at the same point by considering 0 mm gap clearance between the concrete deck elements. A second hand calculation was done by taking steel beam without concrete deck element; this gave a deflection, greater than the deflection possible by maximum gap clearance between concrete slabs. At a gap value of 5 mm, total deflection obtained through manual calculation was 178 mm. At such large span value, the deck slabs will be so far from each other that they will not behave as a composite system with steel beam anymore. Hence, the total load will be borne by steel beam only and deflection of 178 mm will be considered as deflection in steel beam only without concrete deck slab. The gap increment was skipped after 3.4 mm to 5mm because the maximum deflection that the bridge could bear had already reached.

As no major change was expected in the outcomes of the readings, a gap value of 5 was taken to confirm the outcomes of research. For both gap values of 3.4 and 5, there was no change in deflection which shows that the outcomes of research were satisfactory.

The difference of the result from ABAQUS with gap clearance zero and the result by considering composite structure in hand calculation was due to two reasons:

1. Shear lag in Concrete deck elements: on account of shear strain, the longitudinal tensile or compressive bending stress in wide beam flanges diminishes with the distance from the webs; this stress diminution is called shear lag.
2. Longitudinal slipping between the concrete element and Steel beam.

4. Conclusions

Following conclusions can be drawn from this research.

- Decreasing of gap width will increase composite action in the bridge.
- To decrease the gap up to 0 mm is almost impossible in practice. Although, the least gap that can be obtained during casting procedure by using match casting is less than one mm for which we can get fairly good composite reaction.
- This gap can be obtained by match casting, in which one casted slab element is used as a formwork for the other slab element and this procedure is repeated.

If we compare the cast in situ and prefabricated slab elements, it is very easy to understand the importance of prefabricated slab bridge construction. If we consider cast in situ, it needs 1 to 2 weeks after casting for hardening the concrete to get its strength and to reduce the moisture content such that bitumen or asphalt products can be fixed to the deck surface. The extra time is not needed when using prefabricated deck elements.

By using this model, the research can be extended by considering non-linear material behavior and result can then be more accurate. This model can be used for parametric studies by changing the dimensions of the steel beam and concrete deck element.

References

[1] U. Kuhlman and B. Braun, “COMBRI Design Manual – Part II: State-of-the-Art and Conceptual Design of Steel and Composite Bridges”, RFCS project RFS2-CT-2007-00031, Universitat Stuttgart, 2008.

[2] V. Kartopoltsev, A. Kartopoltsev and B. Kolmakov, “Assessment of dynamic properties and stiffness of composite bridges with pavement defects”, AIP Conference Proceedings 1800, 040016; https://doi.org/10.1063/1.4973057, 2017.

[3] A. Zhou, “Stiffness and strength of fiber reinforced polymer composite bridge deck systems”, PhD Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA, 2002.

[4] T. Siwowski, D. Kaleta and M. Rajchel, “Structural behaviour of an all-composite road bridge”, Comp. Structures, vol. 192, pp. 555-567, 2018.

[5] S. Yanas-Armas, J.D. Castro and T. Keller, “System transverse in-plane shear stiffness of pultruded GFRP bridge decks”, Engg. Structures, vol. 107, pp. 34-46, 2016.

[6] H. Tuwair, J. Volz, M.A. Elgawaday and K. Chandrashekhara, “Modeling and analysis of GFRP bridge deck panels filled with polyurethane foam”, J. Brdg. Engg., vol. 21, pp. 126-135, 2016.

[7] M.P. Nijgh, I.A Girbacea and M. Viljkovic, “Elastic behaviour of a tapered steel-concrete composite beam optimized for reuse”, Engg. Structures, vol. 183, pp. 366-374, 2019.

[8] M. Noel, N. Wahab and K. Soudki, "Experimental investigation of connection details for precast deck panels on concrete girders in composite deck construction", Engg. Structures, vol. 106, pp. 15-24, 2016.

[9] J.B. Marcusson," Design and construction of composite bridges", Bridge Structures, vol. 1, pp. 12-17, 2017.

[10] A. Mohan and M. Tholkapian, "Behavior and impact of concrete deck slab, shear connector and steel beam in composite bridge", Int. J. Pure & App. Math., vol. 115, pp. 247-255, 2017.

[11] A. Hibbet, J. Karlsson and G. Sorenson, "ABAQUS/CAE User's Manual", Principia Ingenieros Consultores, Madrid, p. 1306, 2000.

[12] D. Simulia, "Abaqus/CAE User's Manual", Release 6.6.1, Dassault Systems, Warwick, United States, p. 1173, 2013.

[13] J.T. Oden, "Finite elements: An introduction, in Handbook of Numerical Analysis II, Finite element methods (Part I)", North-Holland, Amsterdam, pp. 3-12, 1991.

[14] J. Brandborn and R. Johannsen, "General Technical description for classifying of overpasses", The National Academies of Sciences, Engineering, and Medicine, p. 110, 1998.

[15] H. Sundquist "Beam and Frame Structures", Ordfront and Galago Publishing, Stockholm, Sweden, p. 342, 2008.