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Under Slung Steel Truss Bridge with Composite RCC Deck Bridge

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Abstract: **The most common cause of structural failure in steel bridges is buckling of a compression member. Buckling failure is a sudden failure and offers no warning before collapse. Recently, in the year 2012, a 190m span steel truss bridge over river Alaknanda, in Uttrakhand, India, suddenly collapsed during casting of the deck slab due to buckling of one of its top cord compression members. Its failure during construction stage raised doubts on current design practices where, the factor of safety provided by the codes do not guarantee performance of the bridge in overload conditions. In the case of composite under slung bridges, premature buckling of top cord compression member is prevented by the RCC deck connected with the steel truss with the help of shear studs. Further, this allows the steel truss members to take stress up to their ultimate strength. A 30 m span bridge is analysed with composite action of RCC deck for service and overload conditions. The maximum flexural strain due to live load alone in the RCC deck slab is found to be 0.00026. Shrinkage strain for M30 concrete deck slab is taken as 0.0003. Hence, even during service condition, composite action between the steel girder and RCC deck slab may not take place. For the analysed deck type bridge, total load on the bridge in terms of uniformly distributed load in service conditions for (DL+LL) case is 153.7kN/m, and in overload condition for 1.5x(DL+LL) case it is 230.55kN/m. At plastic stage the bridge can carry an equivalent udl of 635.98kN/m. Thus, for the plastic collapse, apart from warning due to excessive deflection, there is a factor of safety of 4.1 in comparison to service load. For prestressed concrete bridges, load combination at ultimate strength for severe condition, as per Cl. 12 of IRC: 18-2000, is prescribed as 1.5G+2SG+2.5Q. Whereas, in case of steel truss bridges, as per IRC: 24-2010 and IRC: 6-2010, load combinations and permissible stresses are given in Table 1, Cl. 202.3 for service condition only. IRC codes haven't provided any specific provision for ultimate strength of steel truss bridges. Therefore, a parallel clause for ultimate strength of steel truss bridges also may be added, for which composite under slung bridges may be found to be suitable.**

***Index Terms*— Buckling, Composite bridge, Under slung truss, Shrinkage strain.**

I. INTRODUCTION

Steel-concrete composites are common in building construction. In composite plate girder bridges, the composite construction comprises RCC deck slab connected with steel plate girders. Literature on composite steel truss bridges is not readily available. Many new ideas on composite truss construction has emerged [1], [2], though proper design guidelines and standards are not available. In the year 2012, an open web steel girder non composite deck type bridge connecting two cities of Uttrakhand state namely, Srinagar on the left bank and Chauras on the right bank of river Alaknanda, collapsed during casting of the deck slab claiming lives of six people [3]. The failure was due to buckling of one of its top chord compression members. Failure of bridge could have been more disastrous had it failed after completion in overload condition. Another Garudchatti bridge [4], built on the same design was successfully completed. Due to excessive vibrations, it was strengthened before commissioning. Buckling of a compression member in open web steel girder bridges is the most common mode of structural failure [5]. Composite deck type steel truss bridges are one of the most efficient and aesthetically attractive design solution in bridge engineering [6]. One common and efficient solution in an under slung truss. When the deck slab is connected with the top cord of the truss using shear studs, deck slab acts in composite action with the compression chord (Fig. 1). But, the concept only holds at positive bending moment sections

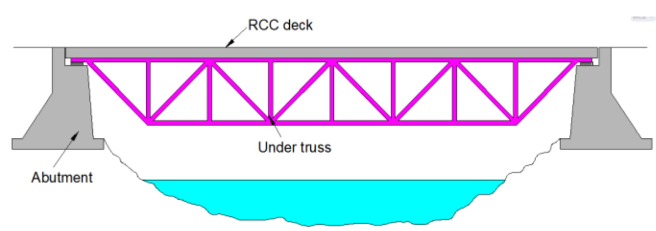

Fig. 1 Under slung open web steel Girder Bridge

In deck type composite truss bridge, RCC deck slab provides lateral support to the top chord compression members of the truss. Thereby, prevents their buckling and premature failure, and permits these to stress up to their ultimate strength. In the Czech Republic twelve simply supported composite truss

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bridges with spans between 21m to 63 m were completed during last decade [7].

II. PREVENTION OF BUCKLING

The top chord and web compression members of a simply supported steel truss bridge may buckle much before the tension members reach their ultimate strength (Fig. 2). Composite action of the RCC deck slab with the top chord compression members prevents their buckling. Shear transfer in composite steel truss bridges between the steel truss and concrete deck slab is mobilised using shear studs. Due to shrinkage strain in the deck slab of a deck type composite truss bridge, composite action between the steel truss and the deck slab starts only when the shrinkage strain in the deck slab is overcome by the flexural stresses due to live load. Therefore, the steel truss may be designed for service condition with fatigue for full dead load and live load, and advantage of the composite section may be derived during overload of the bridge and in its plastic collapse condition.

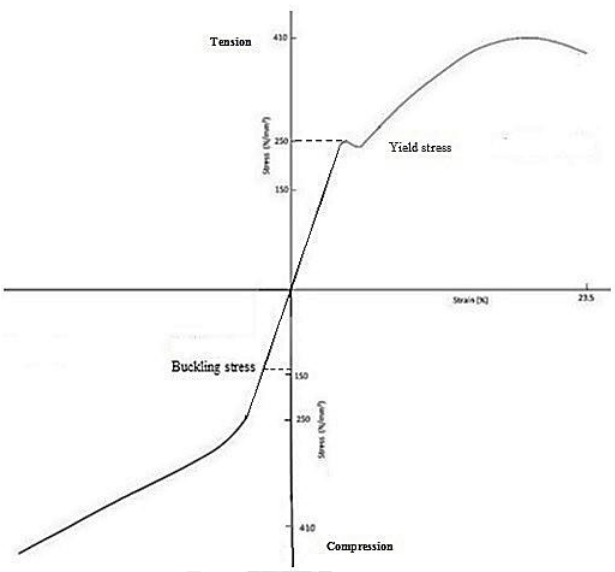

Fig. 2 Stress-Strain curves for E 250 structural steel

III. ANALYSIS FOR SHRINKAGE IN DECK SLAB CONCRETE

In the deck type composite bridge construction, steel truss is first launched and then deck slab and SIDL are casted. After hardening of the deck slab and SIDL, the bridge is open to traffic. Shrinkage strain in M30 grade deck slab concrete may be taken as 0.0003 [8]. Therefore, it is assumed that composite action between RCC deck and steel truss will not take place until strain in the deck slab concrete exceeds 0.0003.

Geometric details of a 30m span bridge are given below.
Height of Truss (C/C distance between top chord and bottom chord members) =7m
C/C distance between two trusses = 7.9 m
Width of roadway = 7.4 m
Panel length = 3.75m
Number of 3.75m top panels =8
Number of 3.75m bottom panels = 4
Elevation of the analysed bridge model is given in Fig. 3.

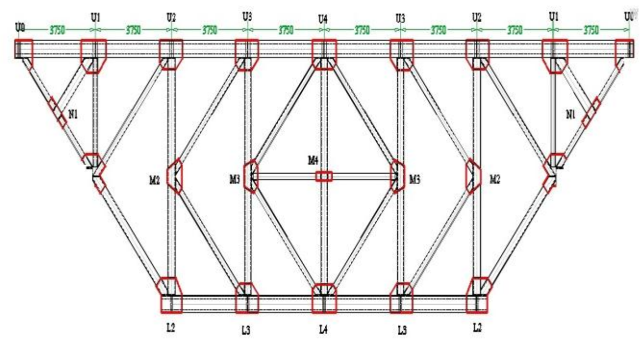

Fig. 3 Elevation of 30m span bridge

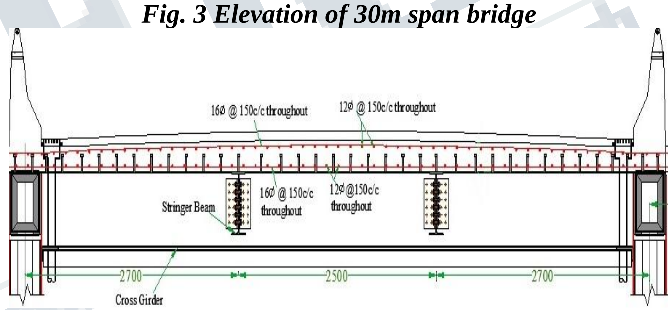

Fig. 4 Shear stud arrangement

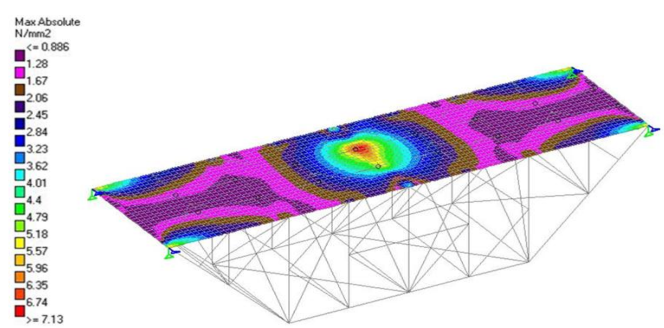

Fig. 5 Deck slab stress under LL alone

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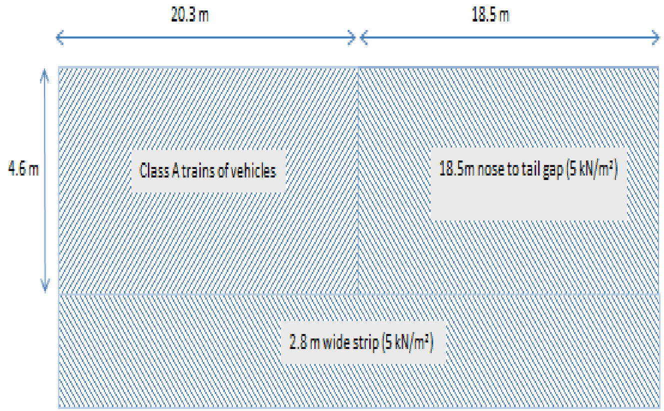


Fig. 6 Loading arrangement for fully loaded deck slab

The deck slab is modeled using plate elements, which are connected over the two trusses at every 0.5m interval with the help of rigid studs in four rows (Fig. 4). STAAD.Pro V8i [9] software has been used for modeling and analysis. As per STAAD analysis result, maximum stress in the deck slab concrete at mid span for live load with impact alone is found to be 7.13 N/mm2 (Fig. 5). Strain corresponding to 7.13 N/mm2 stress is 0.00026, which is less than 0.0003 deck slab shrinkage strain. Therefore, composite action in structure is not possible even under full service load condition.
Although, composite action between deck slab and truss is not possible in the service condition, top chord compression members of the truss are laterally supported by the shear connectors and their lateral buckling is prevented. Thereby, higher compressive stress than the buckling stress, up to the ultimate compressive strength, may take place in these members, provided web members are designed to remain safe [10].

IV. TYPICAL DESIGN OF A 30.0M SPAN COMPOSITE TRUSS BRIDGE

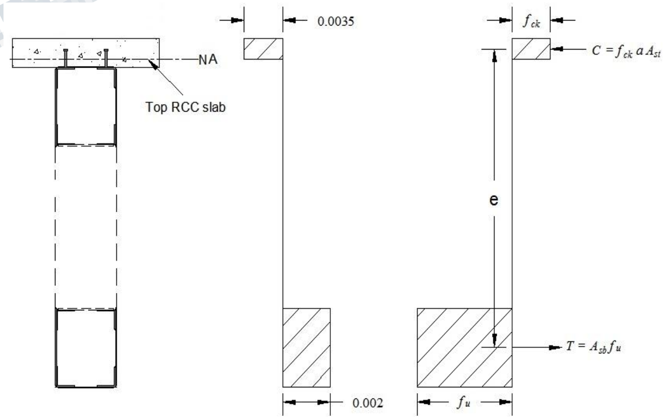
Design of a 30.0m span deck type truss bridge is carried out for serviceability condition as per IRC: 24-2010 [11].
Interactive steel design facility in STAAD Pro.v8i is used, which directly gives interaction ratios under combined axial force and biaxial bending moments. Optimum design of the truss members is carried out using interaction ratio. In the design for overload condition at 1.5x(DL+LL) load, interaction ratio is limited to 1.0 in all tension members and laterally restrained top chord compression members. For laterally unsupported web compression members it is limited to 0.66.

A. Live load during adverse/overload condition

Standard minimum gap between two trains of vehicles is taken, and in the remaining area a load of 5kN/m2 as prescribed in table 2, IRC: 6-2010.
Example for a fully loaded deck slab (Fig. 6) is given below.
Carriageway width = 7.4m
Width of class A train of vehicle= 2.3m
Length of Class A train of Vehicle=20.3m
Minimum gap between two trains of vehicles=18.5m
Thus, without considering impact ratio of maximum possible live load during adverse overload condition and service condition live load is equal to 2.03. Ever increasing vehicle load and corrosion of the bridge with time will require even higher load factor at the limit state of strength. Therefore, as applicable in the case of prestressed concrete bridges (Cl-12: IRC :18-2000), composite steel truss bridges may also be checked at failure at an ultimate load of (1.25G+2SG+2.5Q) for moderate exposure condition.

B. Plastic collapse condition

There is no direct literature available for capacity calculation of the composite steel truss bridges in plastic stage [7]. Therefore, design of the bridge at collapse in plastic condition is carried out as per provisions given for composite truss and OWSJ for buildings in CISC 2003 [12] and ASCE Task Committee on Design Criteria for Composite Structures in Steel and Concrete [13]. The design provisions have been modified in accordance with IRC: 24-2010 [11]. For the capacity calculation it has been assumed that the web compression members are sufficiently strong and will not fail before failure of other members.



a. Cross section at x-x   b. Strain diagram   c. Stress diagram
Fig. 7. Force equilibrium at plastic collapse

Details of the composite bridge model for plastic condition are given in Fig. 3. The section for plastic design is

considered adjacent to the center of the bridge (Fig. 3). Hence, only bottom chord and composite top chord carry axial forces. Force equilibrium diagram at the mid span section of the bridge is given in Fig. 7. As given by Cran [14] and Bouchair, J. et al [15], area of the top chord truss members below the neutral axis is neglected in calculating the moment of resistance.
a = depth of neutral axis from top of the deck slab
Ast = cross-sectional area of steel top chord,
Asb = cross-sectional area of steel bottom chord,
e = lever arm
bf = effective width of slab, and
fu = specified ultimate strength of steel.
Equating compression and tension forces;
or
1000 x 30 x a x8.3/2=11540 x 410
Therefore, a = 38.0 mm.
Eccentricity, e = 7480 + (200-38.0)/2 = 7561mm.
The plastic moment of resistance (Mp) of the composite section is computed as,
Mp= As x fu x e = 2 x 11540x 410 x 1000 x 7561
=7.15 x x1010 Nmm= 71548.23kNm
Corresponding equivalent udl on the bridge at plastic collapse 'wp' is given by;
(wpx l2)/8=71548.23
or wp = 635.98 kN/m.

C. Comparisons of plastic collapse load with service load and the overload

Total applied load in service condition, (DL+LL) = 4612.7kN
Equivalent udl = 4612.7 /30.0 = 153.7 kN/m
Factor of safety at plastic collapse w.r.to service load = 635.98/153.7 = 4.1
Factor of safety at plastic collapse w.r.to the overload condition, = 635.98/ (1.5 x 153.7) = 2.7
Thus, in the composite steel truss bridge, there is a factor of safety against plastic collapse of 4.1 in comparison to service condition, and 2.7 in comparison to the overload condition.

V. CONCLUSIONS

Sudden failure of Chauras Bridge, due to buckling of one of its top chord members during casting of the deck slab, has triggered the idea for suitable revision of the design load at the limit state of strength, and construction of composite steel girder bridges. From the presented analytical study on composite steel truss bridges, the following conclusions are drawn.

1. Shrinkage strain in M30 grade deck slab concrete is of the order of 0.0003. Maximum flexural strain due to live load in service condition, in the analyzed 30.0m deck type truss bridge is found to be 0.00026. Therefore, it may be concluded that, there is no composite action of the deck slab even in service condition.

2. Before shrinkage strain in the deck slab concrete is overcome by loading on the bridge, the deck slab provides effective lateral support to the top chord compression members, preventing their buckling, and permitting these to take stress beyond yield stress up to their ultimate compressive strength. Thus, in the overload condition the bridge can excessively deflect but cannot suddenly collapse, provided the web compression members are strong enough.

3. IRC 6:2010 provides for minimum gap between two trains of vehicles, and in the remaining area a load of 5kN/m2 is prescribed. Accordingly, maximum possible live load (without impact) to normal live load (with impact) ratio works out to 2.4. Ever increasing vehicle load and corrosion of the bridge with time will require even higher load factor.

4. For the analyzed 30.0m span deck type composite steel truss bridge, where it is assumed that premature web failure is prevented, load in terms of udl in service condition for (DL+LL) case is 153.7 kN/m, and at the plastic stage it is 635.98 kN/m. Therefore, for the plastic stage there is a factor of safety of 4.1 in comparison to service condition.

5. As applicable in the case of prestressed concrete bridges (Cl-12: IRC: 18-2000), composite steel truss bridges may also be checked at failure at an ultimate load of (1.25G+2SG+2.5Q) for moderate exposure condition.

Composite under slung steel truss bridge helps in preventing premature buckling of the top chord compression members, and economically enhances the collapse load in plastic condition to approximately 4.1 times the load in service condition.

REFERENCES

[1] A. Reis, J.O. Pedro, Composite truss bridges: New trends, design and research, Steel Construction 4, No. 3, 2011.

[2] A. Reis, J.O. Pedro, Composite truss bridges: New trends, Design and Research, Eurosteel Conference Aug-31st –Sep 2nd , Budapest Hungry, 2011.

[3] H. S. Birajdar, P. R. Maiti, P. K. Singh. "Failure of Chauras bridge." Engineering Failure Analysis, Elsevier, Vol. 45, 2014, pp. 339-346.

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 11,November 2017

[4] H. S. Birajdar, P. R. Maiti, P. K. Singh. "Strengthening of Garudchatti bridge after failure of Charus Bridge" Engineering Failure Analysis, Elsevier, Vol. 62, pp. 339-346, 2015.

[5] B. M. Imam, M. K. Chryssanthopoulos, “A review of metallic bridge failure statistics,” Proc. 5th International conference on bridge maintenance, safety and management, Philadelphia, USA, IABMAS, pp. 635-636, 2010.

[6] A. J. Reis, “Bridge decks: composite systems for improved aesthetics and environmental impact.” Proc. 3rd Int. Meeting on Composite Bridges, Madrid, pp. 645, 2001.

[7] J. Machacek, M. Charvat. "Design of Shear Connection between Steel Truss and Concrete Slab", 11th International Conference on Modern Building Materials, Structures and Techniques, MBMST 2013, Procedia Engineering, Elsevier, 57, pp. 722-729, 2013.

[8] IS: 1343-1980, Code of Practice for Prestressed Concrete, India, 1999.

[9] User Manual, STAAD.Pro V8i, Bently software, 2017.

[10] M. H. Azmi, 'Composite Open-Web Trusses with metal Cellular Floor', Master of Engineering thesis, McMaster University, Hamilton, Ontario, 1972.

[11] IRC: 24-2010, Standard specifications and code of practice for road bridges, Section V, Steel road bridges, India, 2010.

[12] Canadian Institute of Steel Construction (CISC), Handbook of Steel Construction, CAN/CSA S16.1 94, Section 16, “Open-Web Steel Joists”, 7th Edition, Willowdale, Ontario, 2003.

[13] ASCE Task Committee on Design Criteria for Composite Structures in Steel and Concrete, “Proposed Specification and Commentary for Composite Joists and Composite Trusses, ASCE, Journal of Structural Engineering, 122 (4), 1996.

[14] J.A. Cran. 'Design and Testing Composite Open Web Steel Joists', Technical Bulletin 11, Stelco, January, p. 28, 1972.

[15] A. Bouchair, , J. Bujnak , P. Duratna,. Connection in Steel-Concrete Composite Truss, Procedia Engineering, Steel Structures and Bridges (40), pp. 96–101, 2012.

