CHAPTER 5

SHEAR CONNECTION IN COMPOSITE TRUSS BRIDGES

5.1 GENERAL

Shear connectors in simply supported composite truss bridges on the top chord members provide the means to achieve composite action between the deck slab and the truss, thus increasing both stiffness and strength of the bridge. The acting together of the girder and slab as a unit is ensured by the use of mechanical device known as shear connectors. The shear flow between steel truss and the reinforced concrete deck slab is a natural consequence of the requirement for composite action. The presence of a shear connection prevents the slip between the two components and achieves a much stiffer and stronger bridge.

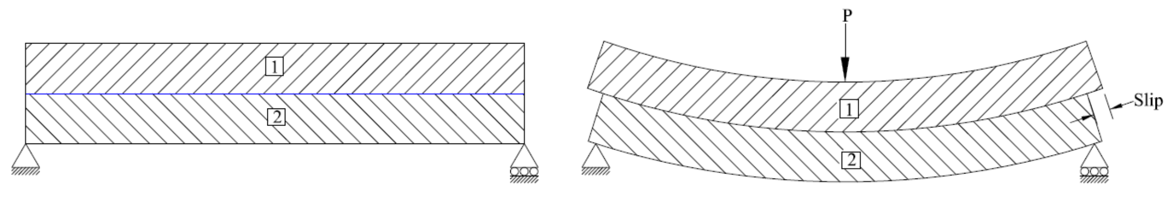
There are no specific provisions for design of shear connectors for composite steel truss bridges in any code. The design of composite trusses with deck-slabs is generally based on the requirements for joists and composite beams. Due to shrinkage strain and cracking in the RCC deck slab, main role of the composite RCC deck slab is to prevent lateral buckling of the top chord members in addition to transfer of longitudinal shear between the steel truss top chord members and the RCC deck. Composite action between the steel truss and the RCC deck from strength consideration comes into play only after shrinkage strain in the RCC deck slab is overcome. The main difference between composite plate girder bridges and composite steel truss bridges from shear stud design consideration is that composite truss bridges are very stiff.

In the present research work an innovative semi deck type truss bridge is designed on the basis of design guidelines proposed in Chapter-4. Till today no semi deck type truss bridge is constructed in the world.

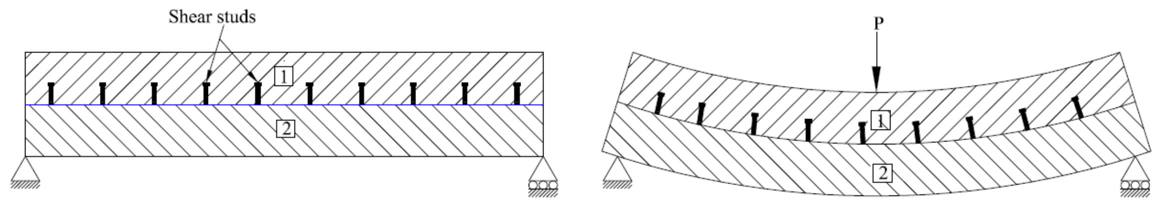
In this chapter design of shear studs for a 42.0m span semi deck type truss bridge using Indian code, American code, Canadian code and Eurocode is carried out. The design of shear studs using different codes is compared. Also, FEM analysis of the bridge is carried out to get the total longitudinal shear in shear studs. Finally, based on the design comparison of shear studs using different codes and FEM analysis, few recommendations are given for the design of shear studs for composite truss bridges.

5.2 BEHAVIOUR OF SHEAR CONNECTORS

Considering a simply supported non-composite beam (Figure 5.1.a) comprising two different beams 1 and 2, when loaded with external load 'P' (Figure 5.1.b), due to shear at the interface of the beams, these will behave individually and slippage will occur at the interface. When beams ‘1’ and ‘2’ are made composite with the help of shear studs (Figure 5.1.c), the shear at their interface is transferred through shear studs and these act together under external loading (Figure 5.1.d).



(a) Non-composite beam before bending (b) Non-composite beam after bending

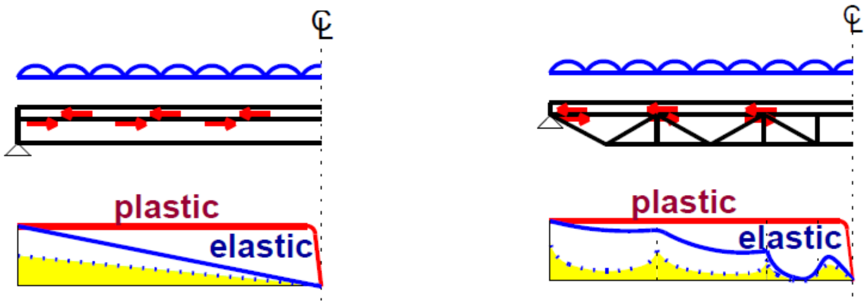


(c) Composite beam before bending (d) Composite beam after bending

Figure 5.1 Non-composite and composite beams

5.2.1 Longitudinal shear flow in solid and open web girder bridges.

Figure 5.2 shows shear flow through shear connectors in case of solid and open web girder bridges for elastic and plastic conditions (J. Machaceka, *et. al*, 2013). In case of solid web bridges (Figure 5.2.a) under udl shear transfer between the web and the deck takes place at a constant rate during the elastic condition, and in the plastic condition shear transfer becomes constant through all the shear connectors.

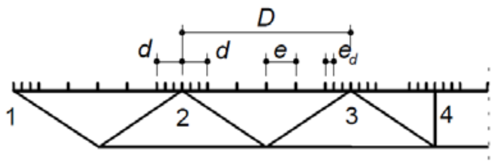


a. Solid web girder b. Open web girder

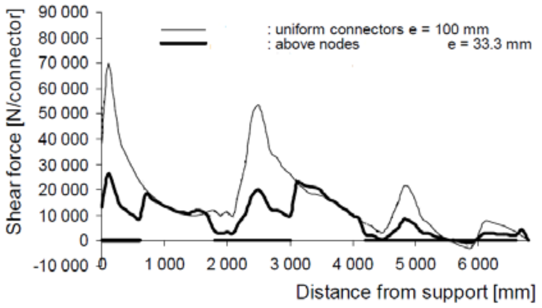
Figure 5.2 Shear flow in shear connectors (J. Machaceka, *et. al*, 2013)

In the case of open web girder bridges (Figure 5.2.b) shear flow in elastic condition between the web and the deck is concentrated near the truss joints, for which densification of studs is required. However, in the plastic condition shear flow through the shear studs becomes uniform in this case also.

Densification of shear connectors over truss nodes required for shear transfer in elastic condition is shown in Figure 5.3. Figure 5.3.a shows arrangement of shear studs in the case of composite truss where concentration of studs is shown in distance ‘d’ from the nodes and ‘e’ is the spacing of studs in the remaining length. Figure 5.3.b shows the variation in shear force per connector for uniform spacing of shear connectors and for connectors above nodes.



a. Arrangement of shear studs



b. Variation in shear force per connector

Figure 5.3 Densification of shear connectors (J. Machaceka, *et. al*, 2011)

In composite steel truss bridges casting of the deck slab is cast after launching of the steel truss. In the composite system shrinkage strain occurs in the deck slab during hardening process. Average shrinkage strain in M40 grade concrete of the deck slab is of the order of 0.0003 (IS: 1343-1980). Until this shrinkage strain is overcome by the flexural stress under the live load condition, the studs can mainly offer lateral support to the top chord members of the truss, and full advantage of composite deck will not be available. Therefore, spacing of the shear studs in the case of steel truss bridges will be mainly guided by the lateral restraint consideration and not by purely shear transfer consideration. Therefore, it is recommended to provide uniform spacing of the shear studs which is also required from the plastic stage consideration.

5.3 CODE PROVISIONS FOR SHEAR CONNECTORS

Various provisions in codes for shear connectors in composite building trusses and composite solid web bridges are discussed here. The design of shear studs is carried out by different existing code provisions for a 42.0m span semi deck type composite truss bridge. The results obtained by different codes are compared and on the basis of this comparative study few recommendations are proposed for design of shear studs in logical manner.

5.3.1 Indian code provisions.

Indian code IRC:22-2008 provides details of shear connectors mainly in composite solid web girder bridges. Mathematical formula given in this code for calculating longitudinal shear is not applicable to composite steel truss bridges. Therefore, longitudinal shear for composite truss bridges has to be defined by any other suitable method.

In Indian code the fatigue strength of stud connectors, is given by the following expression

$$Q_r = \alpha \times A \times 10^{-3}$$

Where,

Qr =Allowable range of horizontal shear per stud connector (kN)

A = Area of stud (mm^2)

α = 55 MPa for $2x10^6$ cycles

Except the provision for longitudinal shear given above, other provisions for calculating spacing of shear studs may be applied in case of composite truss bridges also.

5.3.2 Canadian code provisions

In Canadian code, provisions given composite truss and Open Web Steel Joist (OWSJ) for buildings are given in CISC 2003 (CAN/CSA S16.1, 1997).

As per this code, OWSJs are designed for loads acting in the plane of the joist applied to the top chord, which is assumed to be prevented from lateral buckling by the deck. For the purpose of determining axial forces in all members, members are assumed to be pin-connected and the loads are replaced by statically equivalent loads applied at the panel points.

The total horizontal shear for full shear connection, V_h, at the junction of the steel truss or joist and the concrete slab or steel deck to be resisted by shear connectors distributed between the point of maximum bending moment and each adjacent point of zero moment shall be taken as the maximum force in the bottom chord tension member. It is assumed in this code that entire tension is taken by the bottom chord and equal compression is taken by the composite deck slab above the neutral axis.

The number of shear connectors to be located on each side of the point of maximum bending moment (positive or negative, as applicable), distributed between that point and the adjacent point of zero moment, shall be not less than:

$$n = \frac{V_h}{q_{rs}}$$

Where, q_{rs} is the factored shear resistance for headed end welded studs in solid slabs and is given by

$$q_{rs} = 0.50\phi_{sc} A_{sc} \sqrt{f_c^{'} E_c} \le \phi_{sc} A_{sc} F_u$$

Here, F_u = 415 MPa for commonly available studs
A_{sc} = cross-sectional area of a steel shear connector
ϕ_{sc} = The resistance factor to be used with the shear resistances = 0.80
E_c = the modulus of elasticity of concrete = $4500\sqrt{f_c^{'}}$

5.3.3 American code provisions

Provisions in American codes for composite steel truss for bridges are not provided and for buildings these are given in American National Standard for Standard Specification for Composite Steel Joists C-J series, SJI-CJ-2010.

Shear capacity of a single shear stud for studs in 1.5 in. (38 mm), 2 in. (51 mm), or 3 in. (76 mm) deep decks with $d_{stud}/t_{top\ chord} \le 2.7$, is given by,

$$Q_n = Min\left[0.5A_{stud}\sqrt{f_c^{'}E_c} or \left(\frac{R_p R_g A_{stud} F_{ustud}}{1000}\right)\right] kN$$

Shear capacity of a single shear stud for studs in 1.5 in. (38 mm), 2 in. (51 mm), or 3 in. (76 mm) deep decks with $2.7 < d_{stud}/t_{top\ chord} \le 3$, is given by,

$$Q_n = Min\left[0.5A_{stud}\sqrt{f_c^{'}E_c}\, or \left(\frac{R_p R_g A_{stud} F_{ustud}}{1000}\right) - 6.67\left(\frac{d_{stud}}{t_{topchord}} - 2.7\right)\right] kN$$

Where,

A_{stud} = cross–sectional area of shear stud, in^2 (mm^2)

d_{stud} = diameter of shear stud, in. (mm)

E_c = modulus of elasticity of the concrete, ksi (MPa)

f'_c = specified minimum 28 day concrete compressive strength, ksi (MPa)

$F_{u\ stud}$ = minimum tensile strength of stud, 65 ksi (450 MPa)

Q_n = shear capacity of a single shear stud, kips (kN)

R_p = shear stud coefficient

R_g = 1.00 for one stud per rib or staggered position studs

= 0.85 for two studs per rib side-by-side

= 0.70 for three studs per rib side-by-side

$t_{top\ chord}$ = thickness of top chord horizontal leg or flange, in. (mm)

5.3.4 Eurocode provisions

Design of composite bridges as per European codes is dealt in ENV 1994-2: 2001, 'Design of Composite Steel and Concrete Structures, Part - 2, Composite Bridges' (Eurocode-4).

As per Eurocode 4, in a solid slab, the capacities of shear connectors to resist longitudinal shear should be taken as smaller of values obtained by following equations.

$$Q_m = 0.29d^2\sqrt{f_c E_{cm}} \qquad \text{or} \qquad Q_m = 0.8 f_u (\pi d^2 / 4)$$

Where, f_c is the concrete compressive strength;

E_{cm} is the mean elastic modulus of the concrete;

d is the diameter of the stud shank; and

f_u is the tensile strength of the stud shank.

The value of E_{cm} is given by:

$$E_{cm} = 22\left(\frac{f_{cy}}{10}\right)^{0.3} = 32500 MPa$$

Where, f_{cy} is the cylinder strength of the concrete.

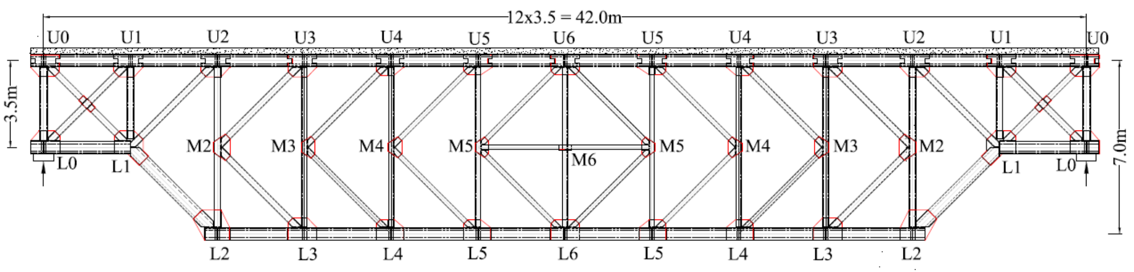
5.4 DESIGN OF SHEAR STUDS USING STANDARD CODES

In this section design of shear studs is carried out for a 42.0m span semi deck type composite truss bridge. Geometric details of the 42.0m span semi deck type composite truss bridge shown in Figure 5.4 are given below.

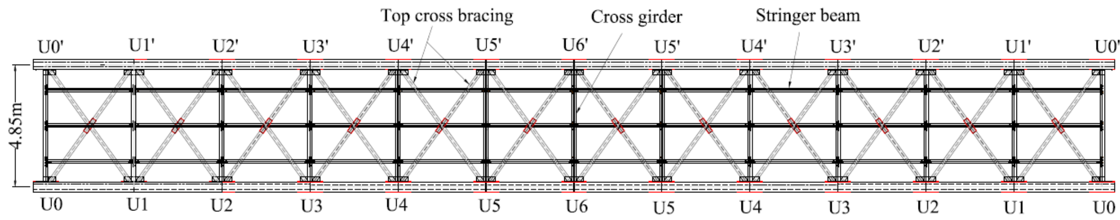
i. Height of Truss (C/C distance between top chord and bottom chord members) = 7.0m.
ii. C/C distance between two trusses = 4.85m
iii. Width of roadway = 4.25m
iv. Panel length = 3.5m
v. Number of 3.5m top panels = 12
vi. Number of 3.5m bottom panels = 12
vii. C/C distance between cross girders = 3.5m

Properties of structural steel used for design are given below.

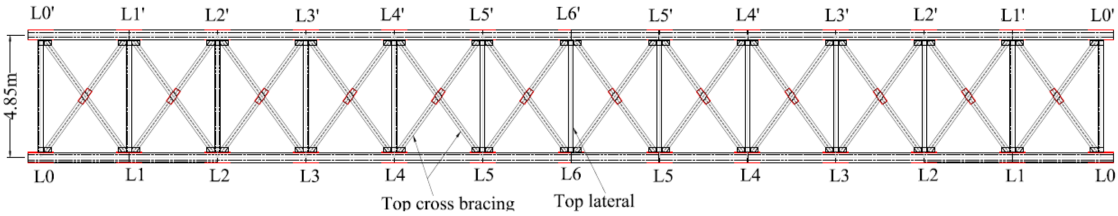
Grade of steel	= E250
Yield strength (f_y)	= 250 N/mm^2
Ultimate stress (f_u)	= 410 N/mm^2
Young's modulus of elasticity, E_s	= 2.0 x 10^5 MPa
Poisson's ratio	= 0.3
Shear modulus	= 76.9 x 10^3 MPa
Coefficient of thermal expansion	= 1.2 x 10^{-5} /°C



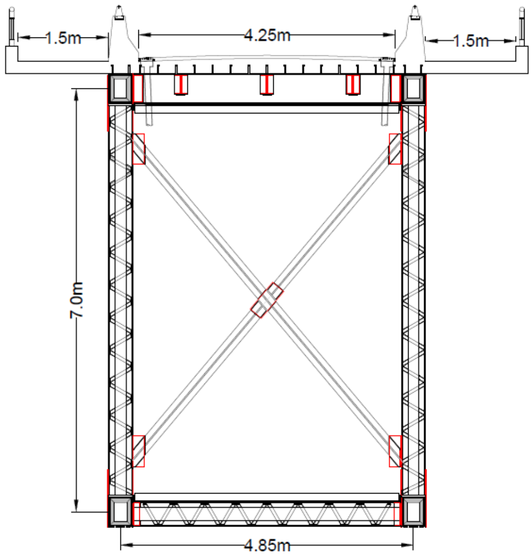
a. Side elevation



b. Top plan



c. Bottom plan



d. Front elevation

Figure 5.4 Details of 42.0m span bridge

Analysis and design of the bridge is carried out for single lane Class A loading as per recommended design guidelines for composite truss bridges in Chapter - 4. General arrangement and cross section details of the bridge given in Annexure-II. Top and bottom chord members are built up box sections of size 400mmx500mm consisting four angle sections and two plates. Diagonal and vertical members are built up box sections consisting two channel sections and two plates. Members of truss are connected together with the help of gusset plates using welds. Spacing of shear studs using different codes is carried out as given below.

5.4.1 Spacing of shear studs as per IRC: 24 - 2010

Diameter of stud, D = 22 mm

Height of stud, H = 150 mm

H/D for each stud = 6.8 > 4 ok

c/s area of each stud = 380 mm^2

Number of rows of studs = 2

Fatigue parameter for 2×10^6 cycles, α = 55 N/mm^2

Shear strength for each stud (= $\alpha A.10^{-3}$), Qr = 20.91 kN say 20.0 kN

Total longitudinal shear between the point of maximum bending moment and each adjacent point of zero moment shall be taken as the maximum force in the bottom chord tension member is used.

Max. axial force in bottom chord member for (DL+LL) case = 2501.4 kN

Number of shear studs per row = $\frac{2501.3}{20.0 \times 2}$ = 63

Total number of shear studs for the bridge = 8x63 = 504

Spacing of shear studs = $\frac{21000}{63}$ = 333.3mm

= 300 mm (Say)

Note: Spacing of the studs as calculated as above of 300.0mm is for full dead load and live load condition. However, in cast in situ deck slabs shear transfer is required only for the live load. Further, due to shrinkage strain and micro cracking of the deck slab, shear transfer from the steel truss to the deck slab through the shear studs will take place only after micro cracks of the deck slab are closed under the flexural stresses due to the live load. Therefore, design of shear studs by Indian code is quite over safe.

5.4.2 Spacing of shear studs as per CAN/CSA-S16-01

Diameter of stud, D = 22 mm

Height of stud, H = 150 mm

c/s area of each stud = 380 mm^2

Number of rows of studs = 2

Shear strength for each stud, q_{rs} = $0.50\phi_{sc}A_{sc}\sqrt{f_c^{'}E_c}$

= 162.2 kN

but, $\phi_{sc}A_{sc}F_u = 124.7kN < 162.2kN$

Therefore, q_{rs} = 124.7 kN

Total longitudinal shear between the point of maximum bending moment and each adjacent point of zero moment shall be taken as the maximum force in the bottom chord tension member is used.

Max. axial force in bottom chord member for DL case = 1973.2 kN

Max. axial force in bottom chord member for LL case = 528.2 kN

Factored maximum axial force in bottom chord member = 1.25×1973.2+1.5×528.2

= 3258.8 kN

Number of shear studs per row = $\frac{3258.8}{124.7\times2}$ = 14

Total number of shear studs for the bridge = 8x14 = 112

Spacing of shear studs = $\frac{21000}{14}$ = 1500 mm

As per cl. 1.7.2.4 of CAN/CSA-S16-01, The maximum spacing of studs shall not exceed 1000 mm. Therefore, studs shall be provided @ 1000mm c/c.

5.4.3 Spacing of shear studs as per SJI-CJ-2010

Diameter of stud, D = 22 mm

Height of stud, H = 150 mm

c/s area of each stud = 380 mm^2

Number of rows of studs = 2

Shear strength for each stud, Q_n $= Min\left[0.5A_{stud}\sqrt{f_c^{'}E_c}\ or\left(\frac{R_pR_gA_{stud}F_{ustud}}{1000}\right)\right]kN$

$0.5A_{stud}\sqrt{f_c^{'}E_c}$ = 193.8kN

$\left(\frac{R_pR_gA_{stud}F_{ustud}}{1000}\right)$ = 66.2 kN

Therefore, Shear strength for each stud, Q_n = 62.2 kN

Total longitudinal shear between the point of maximum bending moment and each adjacent point of zero moment shall be taken as the maximum force in the bottom chord tension member is used.

Max. axial force in bottom chord member for DL case = 1973.2 kN

Max. axial force in bottom chord member for LL case = 528.2 kN

As per cl. 103.2 of SJI-CJ-2010, factored load is maximum of following,

Factored load = Max[1.4DL or 1.2DL+1.6LL]

Factored maximum axial force in bottom chord member = 1.2×1973.2+1.6×528.2

= 3212.9 kN

Number of shear studs per row $= \frac{3212.9}{62.2\times2}$ = 26

Total number of shear studs for the bridge = 8x26 = 208

Spacing of shear studs $= \frac{21000}{26}$ = 807.8 mm

As per section 106 of SJI-CJ-2010, to resist uplift, the steel deck shall be anchored to all supporting members at a spacing not to exceed 18 inches (460 mm) and such anchorage shall be provided by stud connectors, a combination of stud connectors and arc spot (puddle) welds, or other devices. Therefore, provide 22mm dia studs @ 460mm c/c.

5.4.4 Spacing of shear studs as per Eurocode

Height of stud, H = 150 mm

c/s area of each stud = 380 mm^2

Number of rows of studs = 2

Shear strength for each stud, Q_n =

$$Min\left[Q_m = 0.29d^2\sqrt{f_c E_{cm}} or 0.8 f_u(\pi d^2/4)\right]$$

$0.29d^2\sqrt{f_c E_{cm}}$ = 146.5kN

$0.8 f_u(\pi d^2/4)$ = 124.7kN

Therefore, Shear strength for each stud, Q_n = 124.7 kN

Total longitudinal shear between the point of maximum bending moment and each adjacent point of zero moment shall be taken as the maximum force in the bottom chord tension member is used.

Max. axial force in bottom chord member for DL case = 1973.2 kN

Max. axial force in bottom chord member for LL case = 528.2 kN

Factored maximum axial force in bottom chord member = 1.35×1973.2+1.5×528.2

= 3456.1 kN

Number of shear studs per row = $\frac{3456.1}{124.7\times 2}$ = 14

Total number of shear studs for the bridge = 8x14=112

Spacing of shear studs = $\frac{21000}{14}$ = 1500 mm

As per Eurocode, the centre-to-centre spacing of the shear connectors in the direction of compression should be not greater than $22t_f\sqrt{235/f_y}$ where, t_f is the thickness of the flange and f_y is the nominal yield strength of the flange in N/mm^2.

Therefore, $22t_f\sqrt{235/f_y}$ = 256.0mm

Therefore, provide 22mm dia studs @ 256.0mm c/c.

Comparison of shear stud design results using different codes is given in Table 5.1.

Table 5.1. Design results for shear studs

Code	Capacity of shear stud (kN)	Load combination	Total longitudinal shear per truss in half span (kN)	Calculated spacing (mm)	Maximum allowable spacing (mm)	Provided spacing (mm)
American (SJI-CJ-2010)	66.0	1.2×DL+1.6×LL	3072.6	875.0	460.0	460.0
Canadian (CAN/CSA-S16-01)	130.7	1.25×DL+1.5×LL	3079.6	1750.0	1000.0	1000.0
Euro code (ENV 1994-2: 2001)	110.8	1.35×DL+1.5×LL	3238.8	1400.0	256.0	256.0
Indian (IRC:22-1986)	20.0	DL+LL	2323.1	362.0	600.0	300.0
STAAD study	-	DL+LL	2318.5	-	-	-

IRC: 22-1986 code provides for design of shear studs in composite plate girders, in which design of shear studs is carried out in service condition using fatigue factor. Calculated spacing of the 22.0mm diameter studs for the complete bridge is 362.0mm as per IRC: 22-1986, which is based only on shear capacity of the studs in fatigue condition. Required deck slab thickness, and concentration of stress around the studs in the deck slab concrete are not suitably addressed in Indian code.

Design of shear studs by Canadian code is based on limit state of strength design and suitable load factors are used for DL and LL. Spacing of the studs by this code is calculated as 1750 mm but the maximum spacing is limited to 1000 mm. The provided spacing of the studs accounts for deck slab thickness and bearing pressure by the studs on the surrounding concrete in the expression $0.50\phi_{sc}A_{sc}\sqrt{f_c^{'}E_c}$ for shear capacity of stud. Maximum spacing of 1000.0mm provided in code does not take into account thickness of the deck slab and effective lateral restrained requirement for the top chord truss members.

As per American code, calculated spacing of the studs at the limit state of strength is 875.0mm, which is restricted to 460.0mm to resist uplift of the deck slab.

As per Eurocode 4, spacing of the studs in the limit state of strength is calculated as 1400.0mm based on shear capacity of stud but it is adopted as 256.0mm based on bearing on the surrounding concrete.

5.5 TOTAL LONGITUDINAL SHEAR IN SHEAR STUDS USING FINITE ELEMENT ANALYSIS

FEM analysis of the present semi deck type truss bridge of span 42.0m is carried out to get the total longitudinal shear in shear studs. FEM model in STAAD Pro. where the deck slab is modelled using plate elements is shown in Figure 5.5.

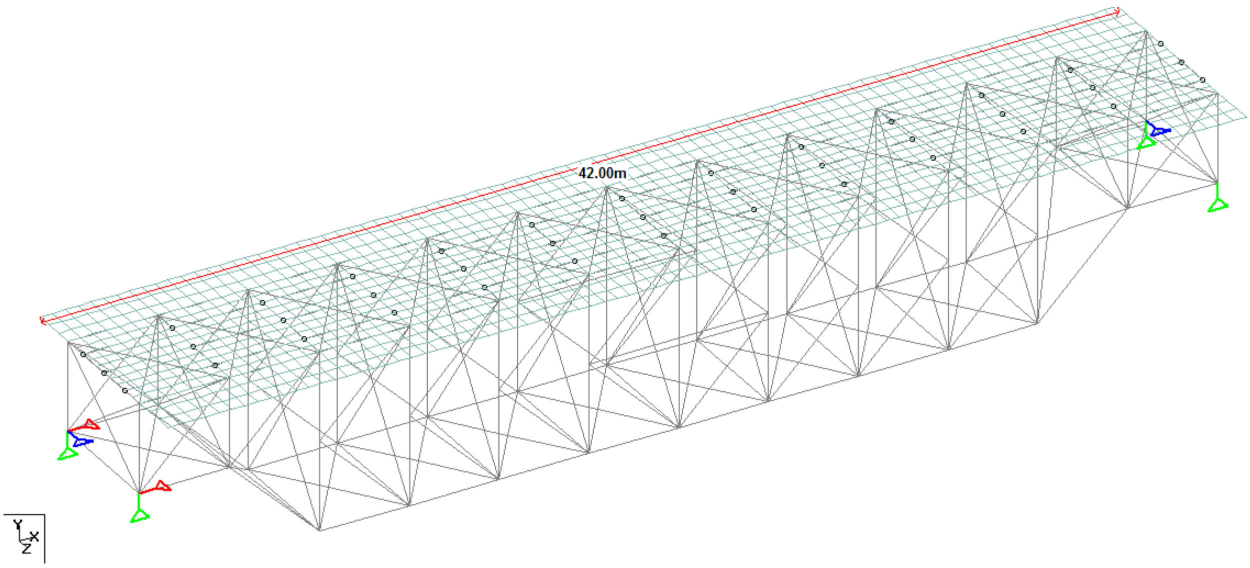


Figure 5.5 STAAD model with plate elements

Shear connectors are used on top chord members of the steel truss at a spacing of 0.5m c/c longitudinally. Shear force in the studs under the (DL+LL) case is given in Table 5.2.

Table 5.2 Longitudinal shear along the bridge span

Member	Distance form end	Longitudinal shear under (DL)	Longitudinal shear under (LL)	Longitudinal shear under (DL+LL)
U0U1	0	195.1	67.0	262.1
	0.5	87.7	30.1	117.8
	1	56.6	19.6	76.3
	1.5	39.6	14.2	53.8
	2	35.8	13.3	49.0
	2.5	44.8	17.1	61.9
	3	78.4	30.2	108.6
	3.5	275.3	104.0	379.2
U1U2	4	78.8	31.0	109.8
	4.5	37.8	15.4	53.3
	5	19.1	8.5	27.6
	5.5	9.3	5.2	14.5
	6	2.3	4.0	6.3
	6.5	4.4	4.4	8.8
	7	25.4	11.1	36.5
U2U3	7.5	0.2	6.0	6.2
	8	3.0	4.5	7.5
	8.5	4.6	3.9	8.5
	9	6.9	4.3	11.2
	9.5	13.3	6.5	19.8
	10	30.3	13.1	43.4
	10.5	123.2	49.0	172.2
U3U4	11	40.4	17.0	57.4
	11.5	22.7	10.0	32.7
	12	15.2	7.0	22.2
	12.5	13.1	6.2	19.3
	13	16.2	7.6	23.8
	13.5	28.6	13.1	41.7
	14	99.1	43.2	142.3
U4U5	14.5	33.6	15.5	49.2
	15	18.7	9.1	27.9
	15.5	11.9	6.3	18.1
	16	9.0	5.3	14.3
	16.5	9.5	6.0	15.6
	17	15.6	9.8	25.5
	17.5	56.0	32.0	88.0
U5U6	18	19.1	11.5	30.6
	18.5	9.8	6.5	16.2

	19	4.6	4.1	8.7
	19.5	1.3	4.0	5.3
	20	-1.0	5.4	4.4
	20.5	-2.6	10.0	7.4
	21	0.0	33.8	33.8
Total		**1592.6**	**725.9**	**2318.5**

From Table 5.2 it is seen that total shear transferred between the mid span and the truss end for (DL+LL) case is 2318.5 kN. The total shear of 2318.5 kN by FEM analysis tallies closely with the maximum tension in the bottom chord, which is 2323.1 kN as per the STAAD analysis result. As per the Canadian and American codes, total longitudinal shear to be resisted by shear connectors distributed between the point of maximum bending moment and point of zero moment shall be taken as the maximum force in the bottom chord tension member. Thus, the provisions of the two codes are verified by the STAAD analysis.

Thus, the simple longitudinal shear calculation procedure given in the Canadian or American code can be adopted safely for evaluation of the total longitudinal shear in the shear studs.

Once the total longitudinal shear in the studs is evaluated, IRC: 22-1986 or similar other code provisions can be used for calculating shear stud capacity and spacing of the studs.

5.6 SPACING OF SHEAR STUDS

Variation of longitudinal shear in shear studs along the bridge span as obtained from the STAAD analysis is shown in Figure 5.6. From the figure it is seen that longitudinal shear between the interface of steel top chord member and RCC deck in general decreases from bearing location to the mid span to zero. At every truss joint longitudinal shear increases sharply. Increase in longitudinal shear over truss joints suggests densification of shear studs, as also given by J. Machacek (J. Machaceka, *et. al.*, 2009, 2013).

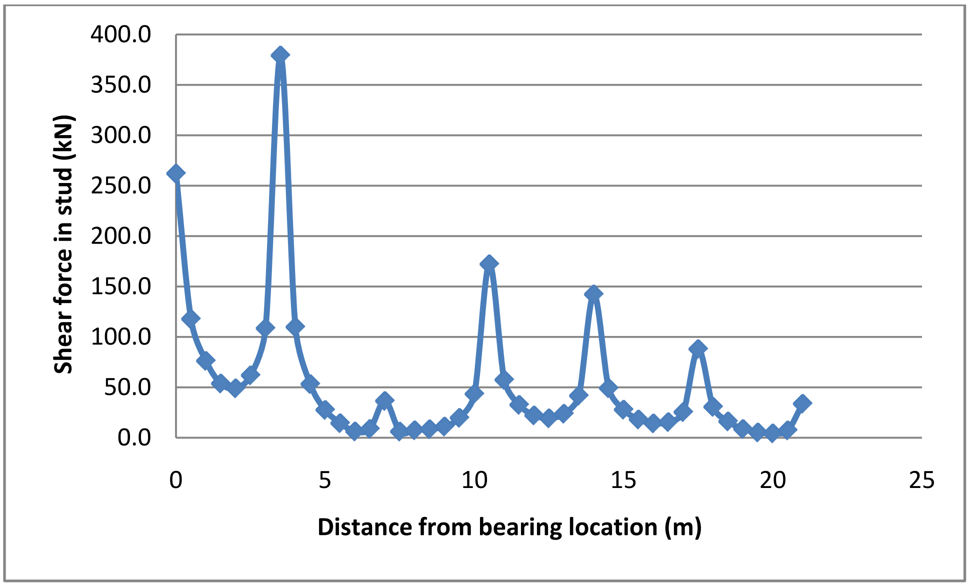


Figure 5.6 Variation of longitudinal shear along the bridge span

There is no stress in the deck slab under dead load as the deck slab concrete is green and total load has to be carried by the truss alone. For M40 grade concrete in the deck slab its shrinkage strain is of the order of 0.0003. Maximum stress in the deck slab for live load alone is 2.29 N/mm^2 (Figure 5.7).

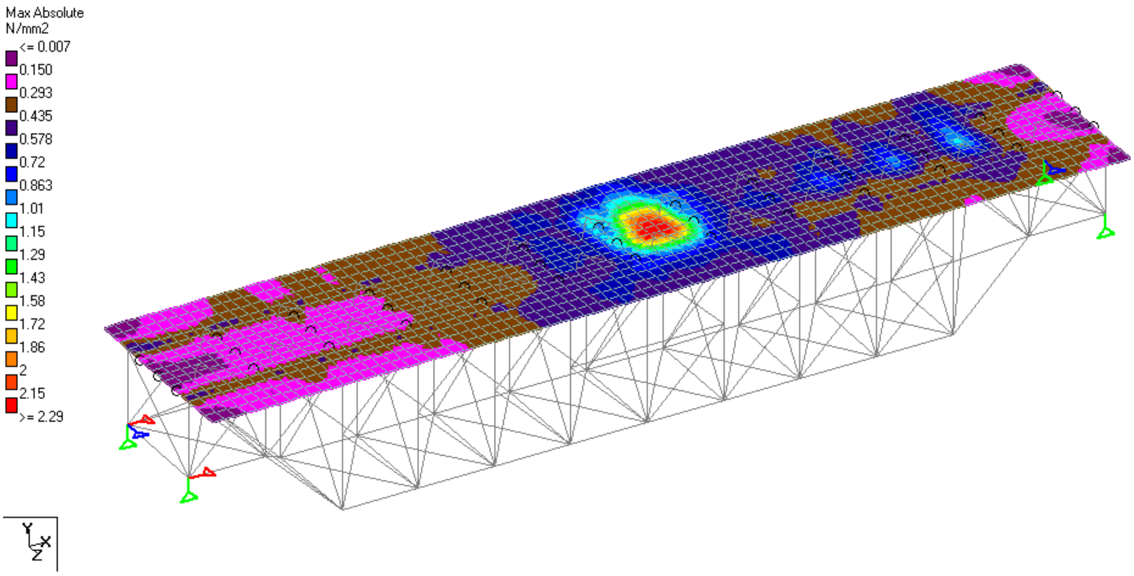


Figure 5.7 Deck slab stress

Strain corresponding to 2.29 N/mm^2 stress is 0.000072, which is far below the 0.0003 shrinkage strain. Therefore, composite action in composite truss bridges is not possible under service load condition also.

Shear studs in the composite bridges provide lateral support to the top chord compression members of the steel truss and effectively prevent their premature buckling. Thus, the top chord steel truss members can support bridge load up to their yield strength without premature failure due to buckling.

During the limit state of strength condition of composite bridges, there is plastic flow in the shear studs and surrounding concrete, and shear force distribution among the shear studs is equalized. Thus, from the plastic deformation of the shear studs, and effective lateral support to the deck slab considerations, uniform spacing of shear studs is required.

5.7 RECOMMENDATIONS FOR DESIGN OF SHEAR STUDS

In composite steel truss bridges longitudinal shear in the studs can appear only after deck slab concrete has hardened. During the process of hardening shrinkage strain of the order of 0.0003 takes place in the concrete resulting in its tensile stress and micro cracking. Even after application of live load in this condition, composite action between the deck slab concrete and the steel truss may not fully take place until the tensile stress developed in the concrete is overcome due to the flexural stress as a result of live load. FEM analysis shows that the composite action generally does not start even after full live load is applied. Therefore, shear transfer from the truss to the deck slab concrete does not take place and design carried out for elastic or plastic condition as per various codes is on the over safe side. Main function of the shear studs between the steel truss and RCC deck, is therefore to provide lateral support to the top chord steel truss members and restricting their buckling, and thereby allowing stress up to the ultimate stress in these members.

Longitudinal shear distribution in the shear studs becomes uniform in the plastic condition, and uniform spacing of the studs is also required from lateral restraint of the top chord members' consideration, and therefore, uniform spacing of the shear studs throughout the truss span is recommended.

Once the total longitudinal shear in the studs is determined standard code provisions can be used for calculating shear stud capacity and spacing of the studs. Design of the shear studs for service condition or the overload condition, as given by various codes is found satisfactory, provided spacing of the studs is limited from the lateral restraint requirement consideration. Therefore, uniform spacing of the shear studs without densification at the truss joints is recommended in the present study.

5.8 CONCLUDING REMARKS

On the basis of the presented analytical study on shear connectors in composite open web steel girder bridges, the following main conclusions are drawn.

1. Although composite truss technology is advantageous to apply in bridges, there are no special provisions made for design of shear studs in composite steel truss bridges in any design standards. Design of shear studs for a 42.0m span semi deck type composite steel truss bridge is carried out using different code provisions and comparative results are presented for which uniform spacing for four rows of 22.0mm dia. shear studs is recommended as 300.0mm which is also adequate for preventing lateral buckling of the top chord steel truss members.
2. The methodology given in Canadian code for calculation of longitudinal shear in composite OWSJs for buildings is applied for the design of shear studs in a 42.0m span composite steel truss bridge and longitudinal shear calculated as per the

Canadian code is compared with the STAAD result. The longitudinal shear without load factors calculated according to the codes is found to vary by 0.20% from the 3-D finite element analysis result. Therefore, it is concluded that total longitudinal shear in studs can be taken as maximum tensile force in the bottom chord else 3D analysis result may be used.

3. In composite steel truss bridges, during the process of hardening of the deck slab, shrinkage strain of the order of 0.0003 takes place, resulting in tensile stress and micro cracking. Even after application of live load, composite action between the deck slab concrete and the steel truss does not take place as strain due to live load is much lower than the concrete shrinkage strain.

4. In the case of open web girder bridges shear flow in elastic condition between the web and the deck slab is concentrated near the truss joints, for which densification of studs near the joints is indicated. However, longitudinal shear distribution in the shear studs becomes uniform in the plastic condition. Uniform spacing of the studs is also required from the truss top chord lateral restraint consideration. Therefore, uniform spacing of the shear studs throughout the truss span is recommended.

5. IRC: 22-2008 code provision can be used for calculating shear stud capacity with fatigue, and uniform spacing of the shear studs can be calculated using the maximum tensile force in the bottom chord member of the truss in service condition.