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Bolted Connections of Hot Rolled Beams in Composite Bridges

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Summary

Composite bridges with hot rolled beams, continuous on several spans, need beam splices. The position of the joint should be chosen according to the type of connections and to the moments diagrams by considering the characteristic load and the fatigue behaviour. An end plates connection by high strength bolts in composite bridges has no problem to satisfy ultimate limit states, however, the fatigue life is often limited. By comparison with several types of connections, an end plates connection should be a safe and cheap solution.

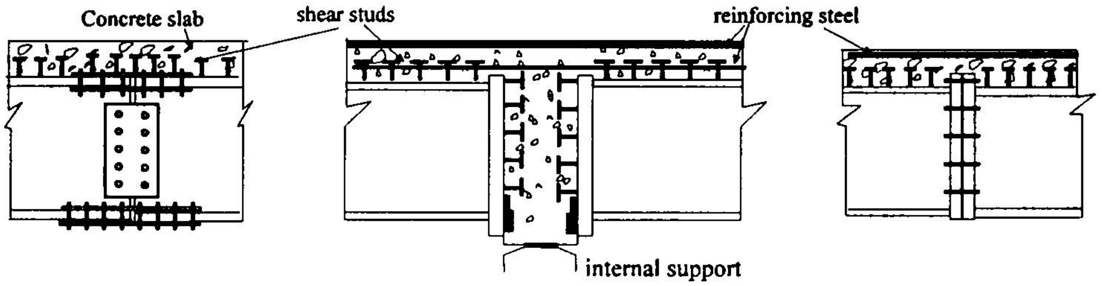
1. Introduction

It is well known that composite bridges with rolled beams may be a cheap solution in middle span bridges. High strength steels FeE460 and FeE600 permit to reach longer span [9,10]. To obtain maximum span lengths, two solutions should be envisaged. One solution considers the biggest rolled section with flange thickness not more than 40mm, HLM1100. In this case, if span length is only designed by considering ultimate limit states of the composite section steel-concrete, span length may reach 58.6 meters, for bridges with five beams in FeE460, and 61 meters, for bridges with four beams in FeE600[9,10]. For bridges with continuous beams, deflection and vibration problems arise. Bridges in steel grade FeE600 are not more interesting than steel FeE460 taking into account the limits due to deflection and vibration. Vibration and deflection conditions limit maximum span lengths, respectively to 53.5 meters and 48 meters for bridges in steel FeE460[9,10]. As this solution needs welded plates reinforcing the steel section on internal supports, fatigue life of bridges is always limited by the end of welded plates which presents much low fatigue strength. The second solution considers the rolled section HLA1100 in span and HLM1100 on the internal supports as reinforced section. In this case, a bridge with five beams in steel FeE460 may reach a span length of 51 meters, but deflection limits the span length to 42 meters. Vibrations do not limit the span length[9,10]. In the present investigation, we will consider the bridge with three beams in rolled sections HLA1100 and HLM1100. It is obvious that this solution needs a connection to splice rolled beams.

The purpose in this paper is to investigate an end plates connection by high strength preloaded bolts in composite bridges with rolled beams, satisfying ultimate limit states and fatigue behaviour. The connection position is chosen to evade the high bending moment near the internal supports and the fatigue damage. Finally, a comparison among several connections in current use is carried out.

2. Choice of the connection position

Three types of connections may be considered for beam splice. Traditional connection with cover plates and high strength friction-grip bolts(Fig.1a) may be designed anywhere along span, if it satisfies ultimate limit state. However, the connection location may be limited by the requirement of structure, economical consideration and fatigue behaviour. An end plates connection with shear studs, that has been proposed recently in composite bridges (Fig.1b), is naturally located on the internal supports[8]. For an end plates connection by bolts (Fig.1c), the location is limited in general by the characteristic load effects and fatigue behaviour. It should be chosen in function of the bending moments corresponding to the characteristic load and the fatigue loads.



(a)Bolted cover plates connection (b)End plates connection with shear studs (c)End plates connection by bolts

Figure 1: Types of the connections in composite bridges

As an example, we treat here of a bridge with three beams, in steel grade FeE460 and two continuous spans of 32.5 meters(Fig.2). To reach this span length, the rolled section HLM1100 (FeE460) and 1.5% of reinforcing steel (S500) in concrete slab (C35/45) is foreseen on internal support. In the area of the negative bending moment, the concrete slab is considered as cracked, and do not support any tensile force. It was clear that rolled section HLM1100 should be used along the whole span to reach this span length if an end plates connection with shear studs(Fig.1b) was carried out. For other types of connections(Figs.1a and 1c), a lighter section may be acceptable in span, here, rolled section HLA1100(Fig.2). The lengths of these rolled sections may be determined by plastic moment resistance of cross section, including HLA1100 + 1.5% reinforcing steel, on the bending moment diagram given in figure 3a. Consequently, length of rolled section HLM1100 should be limited between section A and support 2(Fig. 3a). Between section C and support 2, the lower flange of the beam is always in compression under characteristic loads. The connection at section C is submitted to the lowest bending moment and the lowest shear force in the ultimate limit design, while the connection at section A corresponds to a shorter length of the reinforced section HLM1100. Considering fatigue behaviour, figure 3b shows the bending moments respectively, under fatigue loads FLM1 of Eurocode ENV1991-3 and under combination of the fatigue loads and dead loads. Between section D and support 2, the lower flange of the beam is not submitted to tension and a lower fatigue safety factor may be taken into account. Finally, the connection position should be located between section A, 1.7 m away from support 2 and section C, 5.2 m away from support 2. But, bending moment is higher near section A, while bending moment range ΔM_f is higher near section C. Minimum bending moment range ΔM_f appears at section B, located 2.5 m away from the support 2. From section A to section B, the design moment falls down from 10000kN.m to 7720kN.m, and total reinforced length increases only 2×0.8m. The connection is finally chosen at section B.

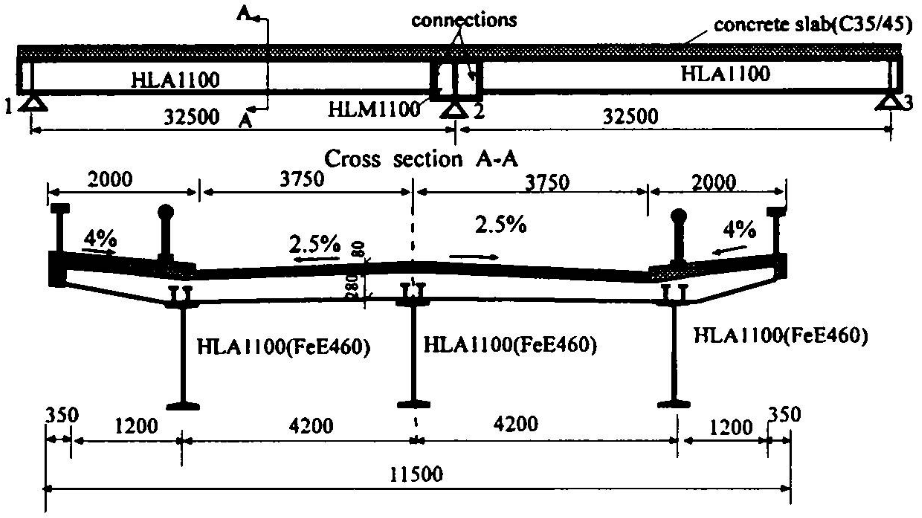


Figure 2: Composite bridge with three rolled beams

(a) Envelop of bending moment under fundamental combinaison of characteristic loads following the Eurocode-ENV1991

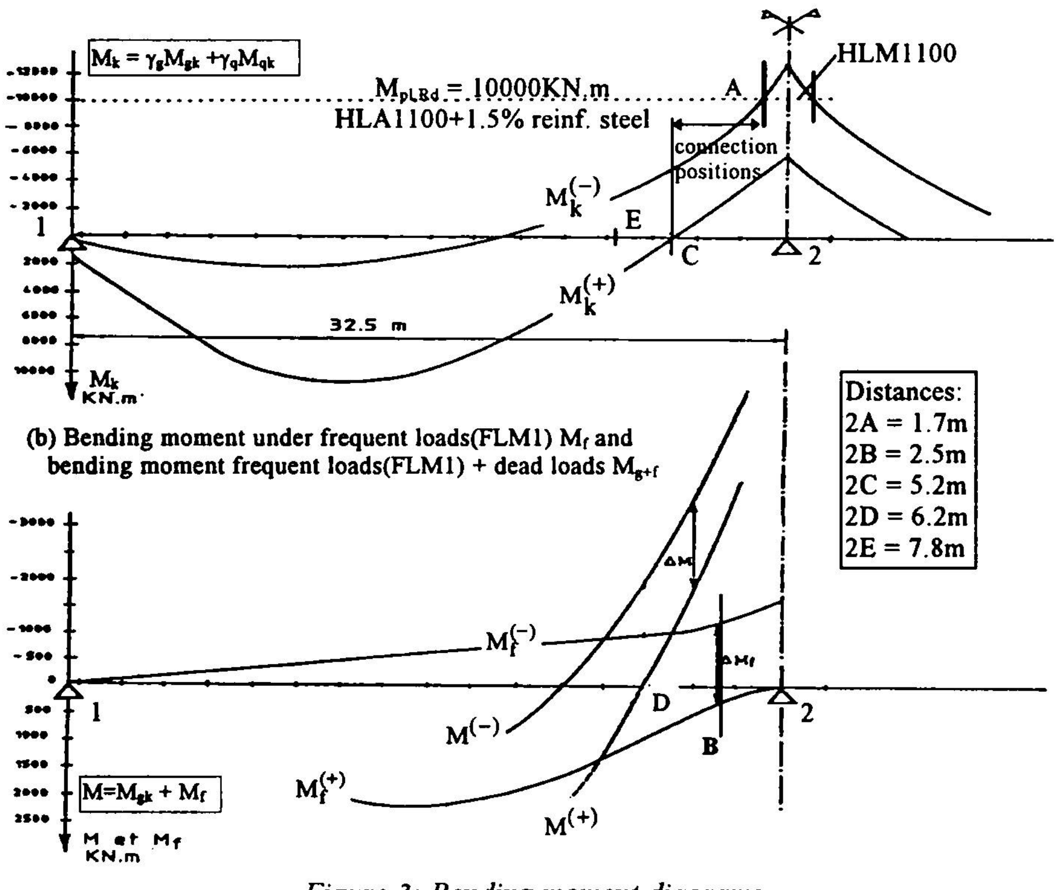


Figure 3: Bending moment diagrams

3. End-plates connection by bolts

Full penetration welds are performed between end plates and rolled beams. End plate thickness is equal to 35mm following the design method proposed by Packer and Morris[7], that is a thickness between the flanges thickness of HLA1100 (31mm) and of HLM1100 (40mm). High strength bolts M27-10.9 are used.

Design moment resistance at the connection results from three forces (Fig.4) : design tension resistance of reinforcing steel in concrete $F_{Rd,steel} = A_{s,t}f_{yd}$; design tension resistance resulted from tensile region of the connection $F_{Rd,con}$ and design resistance on compressive flange of the rolled beam $F_{Rd,comp}$. These resistance values are given in the table 1.

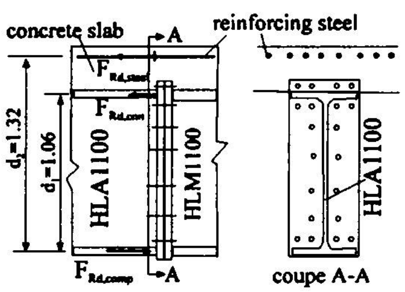


Fig.4: Ultimate resistance

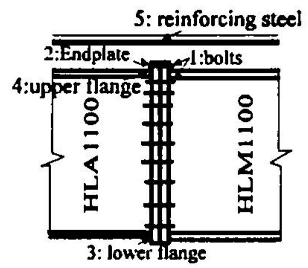


Fig. 5: Fatigue evaluations

Design tension resistance of tensile region of the connection $F_{Rd,con}$ could be determined only by considering the eight bolts close to the tensile flange, neglecting the effect of the web and another tensile bolts. That behaviour corresponds to a bolted T-stub connection for which the calculation may be performed following the method proposed in Eurocode ENV1993-1 by three possible modes of the failure. The deformation of the connection shows that the reinforcing steel reaches ultimate resistance $F_{Rd,steel}$, before the resistances $F_{Rd,comp}$ and $F_{Rd,con}$. The ultimate limit state results from the ultimate resistance of the reinforcing steel and the ultimate resistance of the flange in compression. The force in connection is below the ultimate value : $F_{Rd,com} - F_{rd,steel} < F_{Rd,con}$. As M_{Rd} is higher than the design moment M_{sd} (table 1) ultimate limit state is satisfied. Total number of bolts results from the design shear force Q_{Sd} : 20 high strength bolts of M27(10.9) are necessary(table 2).

Fatigue evaluation of the connection concerns mainly following elements in the side of section HLA1100(Fig.5) : flanges near the welds, end-plate near the weld on the upper flange, bolts in tension and reinforcing steel. The methods to determine maximum stress ranges in end plate and in bolts subject to tension and bending have been developed in elastic behaviour[10]. Fatigue life is evaluated by the method presented in the reference[1]. Fatigue strength of high strength bolts proposed in Eurocode ENV1993-1 is much lower than the value obtained by experimental results [2,5,10]. Here, we consider the fatigue strength of bolts, given in Eurocode and in the reference[10] which is similar to the one proposed in the ECSC report[2]. Fatigue evaluation results are given in the table 3. Fatigue safety factor γ_{MF}

Table 1: Ultimate moment resistance

$F_{Rd,con}$ (kN)	$F_{Rd,steel}$ (kN)	$F_{Rd,comp}$ (kN)	$F_{Rd,comp} - F_{Rd,steel}$ (kN)
2597	5888	7063	1175
$M_{Rd} = F_{Rd,steel}\, d_2 + (F_{Rd,comp} - F_{Rd,steel})d_1 = 9016$kN.m $> M_{Sd} = 7720$kN.m			

Table 2: Number of high strength bolts

	M27-10.9
M_{Sd} = 7720kN.m	8
Q_{Sd} = 1945kN	19
Total number of bolts	20

is chosen according to the values given in Eurocode. The values 1.0 and 1.35(or1.25) correspond respectively to the elements in compression and in tension. Fatigue life in connection is governed by the lower flange near the weld (45 million cycles), this fatigue life satisfies the traffic category 2 (33 millions cycles), proposed in the Eurocode ENV1991-3.

Table 3 : Fatigue evaluation results:

	1. Bolts		2. End-plate	3. Lower flange	4. Upper flange	5. Reinforcing steel
Fatigue strength $\Delta\sigma_c$ for 2.10^6 (N/mm^2)	96 proposed value	36 value in Eurocode	71 value in Eurocode	68 value in Eurocode	68 value in Eurocode	180 value in Eurocode
Fatigue safety factor γ_{MF}	1.35	1.35	1.35	1.0	1.35	1.35
Stress range (F.L.M.1) (N/mm^2)	17.8	17.8	60.6	79.2	39.2	61.2
Stress range (F.L.M.3) (N/mm^2)	-	-	24.9	32.1	15.9	-
Fatigue life N ($\times 10^6$)	∞>133	∞>133	**46>33**	**45>33**	>133	∞>133
Traffic category	1	1	2	2	1	1

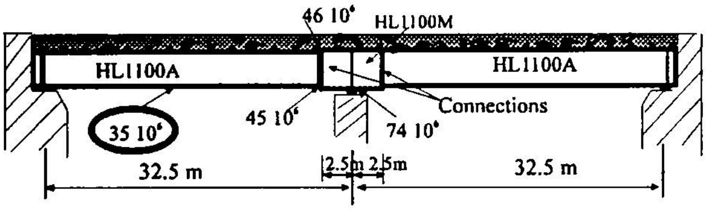


Fig 6: Results of the fatigue verification of bridge

Nevertheless, fatigue life of the whole bridge is summarised in the figure 6, in which 35×10^6 (γ_{MF}=1.25 for the element in tension) represents the fatigue life of rolled section in span and 74×10^6 (γ_{MF} =1.0 for the element in compression) represents the fatigue life of lower flange near welded stiffener on the internal support. It is clear that the end plates connection at the chosen position can offer a fatigue life (45×10^6) longer than the one governed by lower flange of the section HLA1100 in span (35×10^6). We may conclude that the connection proposed here do not limit fatigue life. In addition, to improve the fatigue life, a heavier rolled beam in stead of HLA1100 and a thicker end plate should be used.

4. Comparison with other types of connections

When an end plates connection with shear studs(Fig.1b) is envisaged, the same rolled beams HLM1100 is needed along whole span. Both, bending moment and shear force at the support, are very high and they require 48 headed shear studs (d=20mm,h=70mm) welded on the end plates for one connection and more reinforcing steel in concrete in order to transfer high bending moment on the internal support. As advantage, whole bridge needs one connection. Fatigue life in whole bridge is limited by the lower flange near the weld of the end plate to 40×10^6 cycles. This value satisfies also traffic category 2 of the Eurocode.

When a connection with cover plates and bolts is envisaged, we consider two positions, one corresponds to section B chosen for the end plates connection, and the other corresponds to the section E, located 7.8 meters away from support 2, where the number of bolts is minimum[10]. One connection with cover plates and bolts needs 108 bolts of M27-10.9 at section B, more than five times the number for an end plates connection. Fatigue life is longer than 133×10^6 (γ_{MF} = 1.0), that corresponds to the category 1 of Eurocode. The section E needs 44 bolts of M27-10.9. Fatigue life is reduced to 10×10^6(γ_{MF} = 1.25), fall down to the category 3 of the Eurocode. Total used length of rolled beam HLM1100 reaches 2x7.8 meters, in stead of 2x2.5 meters for the section B. In addition, eight cover plates at least are needed for this type of connection, but this type of connection has no weld. A comparison among the three types of connections is given in the table 4.

Table 4 : Comparison of the three types of connections

		Number of bolts or headed studs	Number of the plates	Length of HLM1100	Weld	Fatigue life(10^6)	Category
connection by shear studs		24×2	2	65.0 m	yes	40	2
covered plate connection	position 1	108×2	8×2	5.0 m	non	>133	1
	position 2	44×2	8×2	15.6 m	non	10	3
End plates connection		20×2	2×2	5.0 m	yes	45	2

5. Conclusions

Analysis of the stress distribution of an end plates connection by high strength bolts in composite bridges with rolled beams shows that the most part of the tensile force is reported with reinforcing steel in concrete and the compressive force is transferred by the direct contact between the end plates. It is favourable to locate the connection close to the internal supports in order to obtain a short length of reinforced section. The choice of the point of an end plate connection may be deduced from the moments diagrams considering ultimate limit states and fatigue.

The present investigation shows that an end plates connection by bolts could satisfy both, ultimate limit states and fatigue behaviour. Fatigue life of an end plates connection is not shorter than the weakest one governed by details outside the connection. The end plates connection by bolts allows an important reduction of the weight of beams in comparison with the connection by shear studs and a important reduction of the number of bolts and plates in comparison with the bolted cover plates connection. The comparison among three solutions shows that an end plates connection constitutes a cheap solution.

References

1. A. Bruls, "Résistance des Ponts Soumis au Trafic Routier - Modélisation des Charges, Réevaluation des Ouvrages" Thèse de doctorat, Université de Liège, Belgium, 1995.
2. A. Bruls and E. Piraprez " Fatigue Strength of Steel Bridge" Measurement and Interpretation of Dymamic Loads on Bridges, E.C.S.C. Final report, 1995.
3. A. Bruls "Loading Effects in Modern Codes : Eurocodes" 3rd Internationalymposium on steel bridges, Rotterdam, the Netherlands, 30 Octobre -1 November,1996
4. P.J. Dowling , P.R. Knowles and G.W. Owens "Structural Steel Design" The Steel Construction Institute,1988.
5. A. Kuperus "The Fatigue Strength of Tensile Loaded Tightened HSFG Bolts" Delft University of Technology, Report 6-74-4, October 1974
6. W.H. Munse and K.S. Petersen " Rivets and High-Strength bolts - Strength in Tension" Transaction, ASCE. Vol. 126, part II, 1961.
7. J.A. Packer and L.J. Morris "A Limit State Design Method for the Tension Region of Bolted Beam-column Connections" The Structural Engineer Vol. 55, N°. 8, Aug. 1978.
8. J.B. Schleich "Acier HLE pour Ponts Mixtes à Portées Moyennes de 20 à 50 m" Report de ARBED Recherches N° 108/91.
9. J.P. Wang and A. Bruls "Composite Bridges with Hot Rolled Beams in High Strength Steel FeE460 and FeE600 upto 60 meters" RPS report N°118/92, ARBED Recherches.
10. J.P. Wang "Etude des Assemblage par Boulons Précontraints Soumis à Traction en vue de leur Application dans les Ponts Mixtes" Thèse de doctorat, Université de Liège, Belgium, 1996.