

## 186 m footbridge in Kalmar, Sweden

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### Summary

Hansabron is a 186 m long footbridge in Kalmar, Sweden. The bridge crosses the E22 motorway and was opened for traffic in May 2013. A clearance of only 4.7 m above the motorway complicates the design due to a vehicular impact load of 500 kN. Unusually much steel was needed to pre-stress the deck to handle the load. Special screws were used to reinforce the timber in areas where crossbeams run through the 600 mm thick deck. Large deck elements were prefabricated and lifted into position on site to minimize installation time. The bridge was subjected to extensive control by the Swedish Road Authorities. Some rules from the Norwegian Public Road Authorities' bridge handbook were allowed to better the design.

**Keywords:** timber deck, accidental loads, reinforcement screws, prefabrication, assembly

## 1. Introduction

### 1.1 Hansabron, Kalmar

Hansabron is a 186 m long and 4.5 m wide footbridge in Kalmar, Sweden. The bridge crosses the E22 motorway and connects the city's pedestrian and bicycle network with the Hansa City shopping area. It has separate lanes for pedestrians and bicyclists. The bridge also connects the new football arena with the city. Hansabron was opened for traffic on May 17<sup>th</sup> 2013.

In 2011 the municipality of Kalmar (Kalmar kommun) developed a bridge design proposal and held a competition to build the bridge. The Swedish construction company NCC won this competition.

The proposal showed a bridge with only 4.7 m clearance above the motorway and crossbeams that ran through the timber deck. This complicates the design of the bridge considerably, as will be

discussed in this paper.

The structure is divided into 10 spans with a main span of 50.4 m over the motorway between axis 9 and 10. There is an expansion joint in axis 7 which serves to separate the bridge's two different structural systems. All timber components are pressure treated with copper. Exposed members are protected with steel claddings.

- Between axes 1-7 there is a continuous stress-laminated T-beam timber deck. The largest span is 15.8 m. This part of the bridge was designed by Finnmap Consulting.
- Between axes 7-11 there is a continuous stress-laminated glulam deck which is supported by a cable-stayed steel structure. The glulam deck height varies from 600 to 642 mm. This part of the bridge was designed by Sweco. This paper is about this part.



*Fig. 1 Hansabron looking east*



*Fig. 2 Hansabron looking north*

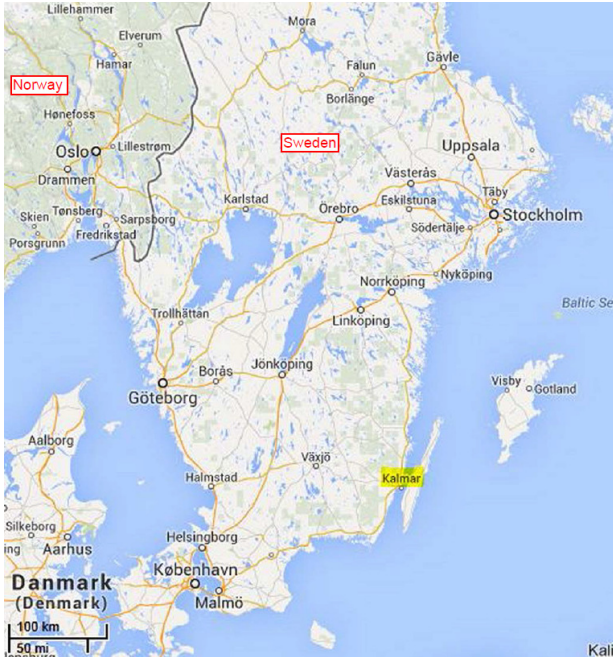


Fig. 3 Map where Kalmar is highlighted

## 1.2 Location

Hansabron is located in the southeast of Sweden, approximately 400 km south of Stockholm and 330 km east of Copenhagen. To locate the bridge follow motorway E22 outside of Kalmar and you cannot miss it!

## 1.3 Swecos assignment

NCC hired Sweco and Finnmap Consulting to do the bridge design. Finnmap was responsible for all foundations and concrete structures, as well as the stress-laminated T-bridge timber deck between axes 1-7. Sweco was responsible for the steel structures (Sweco Stockholm) and timber structures (Sweco Norway) between axes 7-11, as well as design management.

## 2. Accidental actions and pre-stressing of timber deck

### 2.1 Accidental actions

Kalmar kommun and Kalmar kommun's architect made the condition that the bridge deck should be placed as low as possible over the motorway. Consequently the bridge deck was designed with the lowest permissible clearance above the road, which was 4.7 m at the time. During the design period Swedish authorities published new regulations with increased clearance, but this was not to be used for this bridge. The design was done according to TK Bro 2009 [4]

Swedish bridges must be designed for accidental actions according to Eurocode 1991-1-7 [1]. The vehicular impact load is 500 kN. The E22 motorway presently has 2 lanes in each direction, but can be widened to 3 lanes in each direction. The impact load can hit the bridge deck within the shoulders of the future 2x3 lane configuration.

Horizontal forces on the bridge between axes 7-11 are transferred to the substructure through the pylons in axis 9 and 10, and the abutment in axis 11. The highest shear force was calculated to 414 kN. This force was decisive for the design of the pre-stressing of the deck.

### 2.2 Pre-stressing the timber deck

Chapter 6.1.2 in Eurocode 5-2 [3] specifies a method for design of stress-laminated deck plates. In addition, rules from the Norwegian Bridge Handbook no 185 [5] are used. We have utilized the following formula for assessment of longitudinal shear:

$$F_{v,Ed} = V / (0,9 \times \text{deck width})$$

When calculating the compressive stress due to pre-stressing the coefficient of friction between the lamellas plays an important role. The Eurocode has the following design values for  $\mu_d$ :



Tabell 6.1 – Dimensioneringsvärden på friktionskoefficienten  $\mu_d$

Lamellernas yttråhet (endast barrträ)	Vinkelrätt fiberriktningen		Parallellt fiberriktningen	
	Fuktkvot	Fuktkvot	Fuktkvot	Fuktkvot
	$\leq 12\%$	$\geq 16\%$	$\leq 12\%$	$\geq 16\%$
Sågat virke mot sågat virke	0,30	0,45	0,23	0,35
Hyvlat virke mot hyvlat virke	0,20	0,40	0,17	0,30
Sågat virke mot hyvlat virke	0,30	0,45	0,23	0,35
Trä mot betong	0,40	0,40	0,40	0,40

Fig. 4 Coefficient of friction from the Swedish Eurocode 1995-2

The Norwegian Bridge Handbook no 185 [5] states that the friction factor for glulam in bridge decks can be taken as  $\mu_d=0.30$  perpendicular to grain and  $\mu_d=0.25$  parallel to grain. The Swedish Road Authorities accepted that these friction coefficients could be used for the design of the bridge deck, since they are recommended by the Norwegian Public Road Authorities. The Norwegian Bridge Handbook also recommends a maximum 50% bar force loss for pre-stressed glulam decks with a sealing layer. This also was accepted for this bridge.

Using these values the calculated minimum initial pre-stressing force per bar was 409 kN. We chose to use 419 kN. This equals an initial compressive stress due to pre-stressing of  $1.4 \text{ N/mm}^2$ .

Dywidag WR 26.5 bars spaced 500 mm were used to achieve this unusually high compression stress in the deck. If we would have had to use the Eurocode only, the whole side of the timber deck would have been covered with steel anchor plates.

Page 11 of European technical approval ETA-05/0123  
 Validity from 14.11.2011 to 18.09.2015, replaces  
 ETA-05/0123 with validity from 19.09.2010 to 18.09.2015



Designation	Nominal bar diameter	Nominal cross-sectional area	Maximum prestressing force <sup>1)</sup>	Maximum overstressing force <sup>1), 2)</sup>
—	$d_s$	$S_n$	$0.8 \cdot F_{pk}$	$0.95 \cdot F_{p0.1k}$
—	mm	mm <sup>2</sup>	kN	kN
<b>Threadbar</b>				
18 WR	17.5	241	204	219
26 WR	26.5	552	464	499

Fig. 5 Capacity of Dywidag 26 WR pre-stressing bar

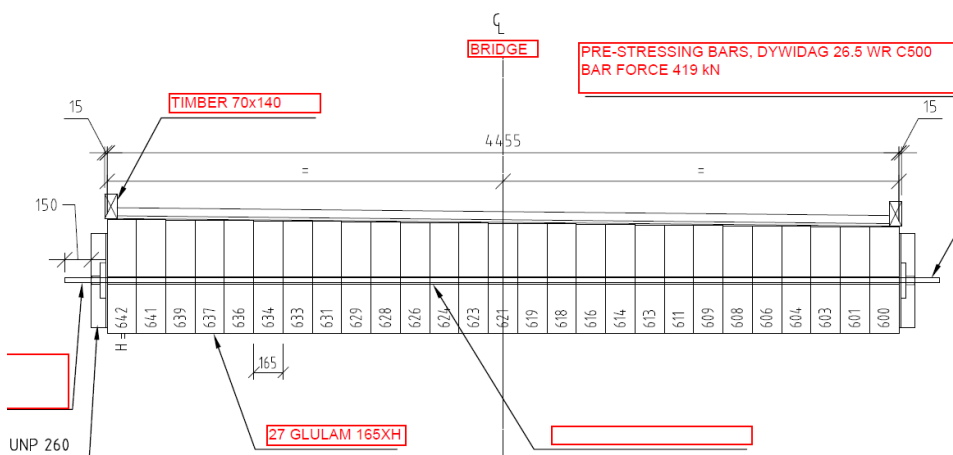


Fig. 6 Typical cross-section of bridge deck

The allowable compression stress perpendicular to grain at installation is  $3.43 \text{ N/mm}^2$ . Channel sections UNP 260 with a height of 530 mm were used to distribute the bar forces correctly to the deck. See fig. 8

### 3. Crossbeams through the deck

One of the main challenges for this bridge was to design the deck according to Kalmar kommun's bridge proposal. The deck was not allowed to rest on underlying crossbeams; hence the beams were forced to run through the deck.

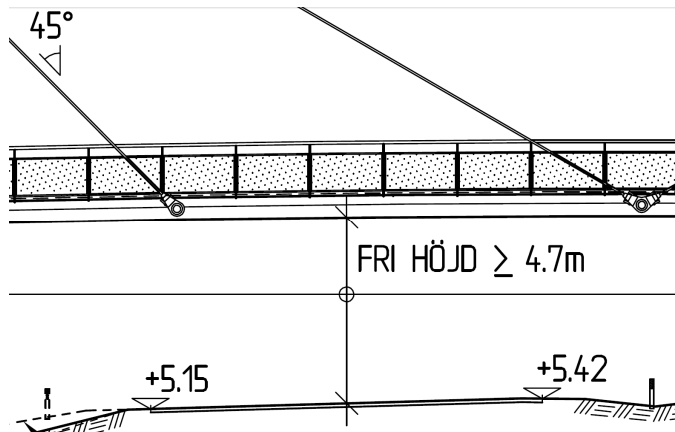


Fig. 7 Cut-out from the proposal drawing showing crossbeams through the deck and clearance of 4.7 m.

Initially we tried to place the crossbeam in a recess in the lower part of the deck, but this was discarded due to dramatically reduced longitudinal stiffness. There was a need for rigid crossbeams in relation to the available cross-sectional height. We selected to use a beam welded from 40 mm steel plates. We positioned the beam eccentrically in the vertical direction in order to have sufficient support for the glulam beams.

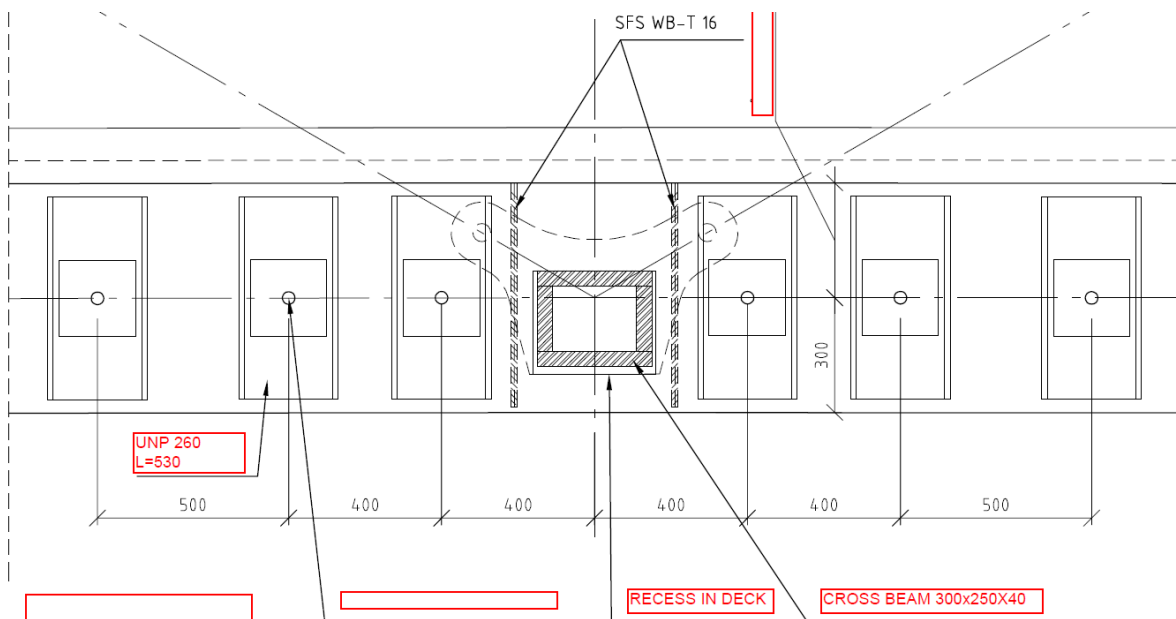


Fig. 8 Detail of the deck in the area around a crossbeam

The bridge between axes 7-11 is modeled using FEM-Design 3D Structure [7]. Using this program we could assess the stiffness of the crossbeam in relation to the deck stiffness in the transverse direction. Since the beam is relatively soft compared to the deck, the forces are concentrated around the deck edges, as shown in Fig. 9.

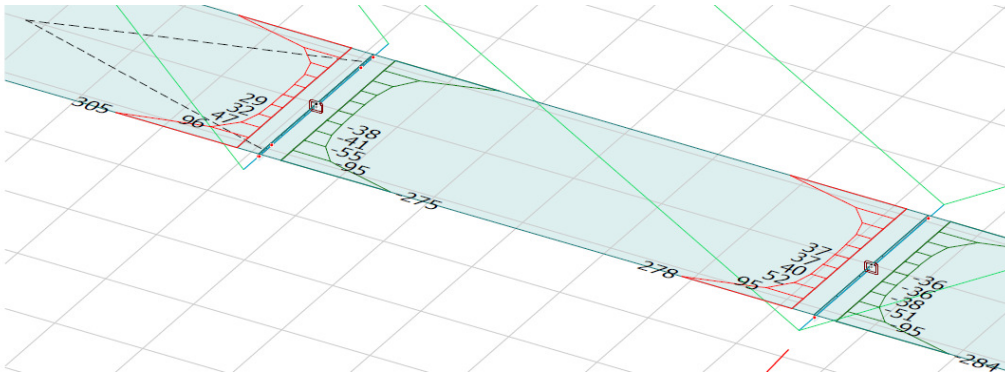


Fig. 9 FEM-Design plot of vertical shear force in the deck

It is well known that beams with a notch at the support have reduced capacity, ref Eurocode 5 chapter 6.5.2 [2]. However, the kind of support we have in this case is not handled by the Eurocode. We had to seek other sources to verify the solution, and chose to use SFS Intec WB threaded rod [6] for this purpose. These screws are approved according to the German standard DIN 1052.

**Proposal of design** according to DIN 1052: 2004-08

The reinforcements must be calculated for the following tensile force  $F_{t,90,d}$

$$F_{t,90,d} = 1.3 \cdot V_D \cdot [3 \cdot (1 - \alpha)^2 - 2 \cdot (1 - \alpha)^3]$$

mit  $\alpha = \frac{h_e}{h}$

$V_D$  design value of transverse force

$$\frac{F_{t,90,d}}{n \cdot R_{ax,d}} \leq 1$$

$n$  number of fasteners (only one fastener is permitted in the longitudinal direction of the beam)

$R_{ax,d}$  design value of the load-bearing capacity of a fastener

Values  $R_{ax,d}$  can be found in the table below

$l_{ef} = \min [l_{ad,1}; l_{ad,2}]$

The distance from the fastener to the bottom edge of the beam must be as small as possible, so that no further lateral tensile proof is necessary.

**Arrangement**

**Minimum spacing**

	WB-T-16	WB-T-20
$a_2$	48 mm	60 mm
$a_{1,c}$	40 mm	50 mm
$a_{2,c}$	40 mm	50 mm

Please note that in the case of notching only one rod may be allowed in the longitudinal direction of the beam.

Fig. 10 SFS guidelines for using WB-T timber screws as reinforcement

**System WB gemäss Z-9.1-777**

		Rohdichte $\rho_k$ [kg/m <sup>3</sup> ]	350	380	410	430	450
WB-T-16xL [mm]	l <sub>ef</sub> [mm]	100	13,7	16,2	18,8	20,7	22,7
		200	27,4	32,3	37,7	41,4	45,4
		300	41,2	48,5	56,5	62,1	68,0
		400	54,9	64,7	75,3	82,8	90,7
		500	68,6	80,9	94,1	103,5	113,4
		600	82,3	97,0	113,0	124,3	136,1
		700	96,0	113,2	131,8	145,0	158,8
		800	109,8	129,4	150,6	165,7	181,4
		Zugbruch Befestiger R <sub>2,k</sub> [kN]	91,5				

Fig. 11 Characteristic capacity of SFS WB-T screws

By inserting 16 mm SFS WB-T screws on both sides of the opening in every 165 mm glulam lamination, as shown in Fig. 8, we achieved a vertical shear capacity of 207 kN/m.



Fig. 12 Picture of crossbeam and bar anchor plates



#### 4. Assembly procedure

The bridge crosses the heavily trafficked E22 motorway. A lot of effort was put into doing the assembly as quick and hassle free as possible. NCC, Sweco and the Finnish glulam manufacturer Versowood chose to emphasize on a high degree of prefabrication. Versowood preferred to split the 94 m long bridge deck into three large prefabricated elements. The longest element was 36 m.

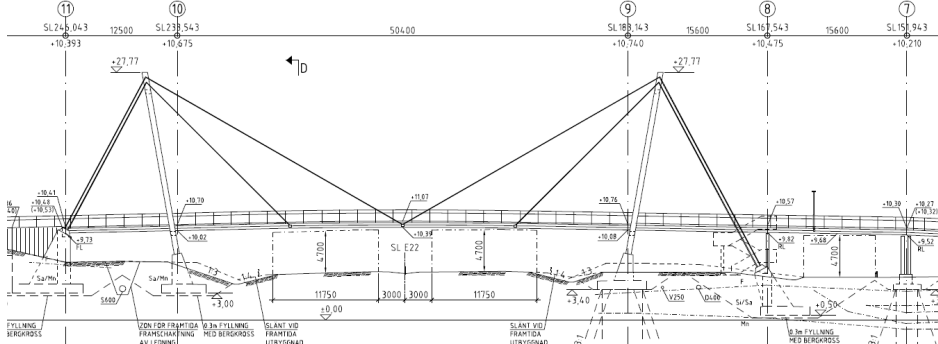


Fig. 13 Elevation of bridge between axes 7-11

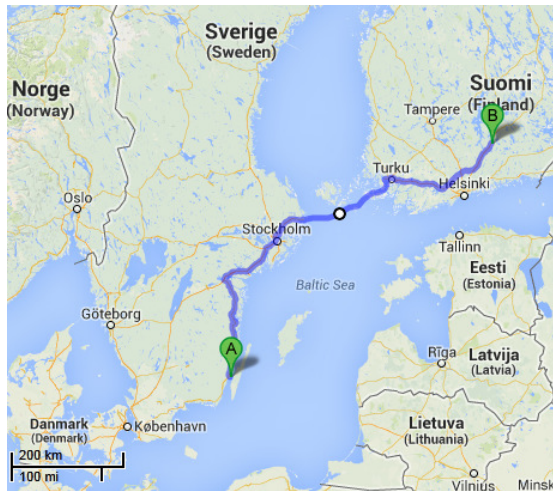


Fig. 14 (left) Transportation of bridge deck elements. The elements were manufactured at Versowood's factory in Vierumäki, Finland and transported about 750 kilometers by truck.



Fig. 15 (right) The crossbeams were pulled through the deck on site before the large elements were lifted into position by two large mobile cranes.

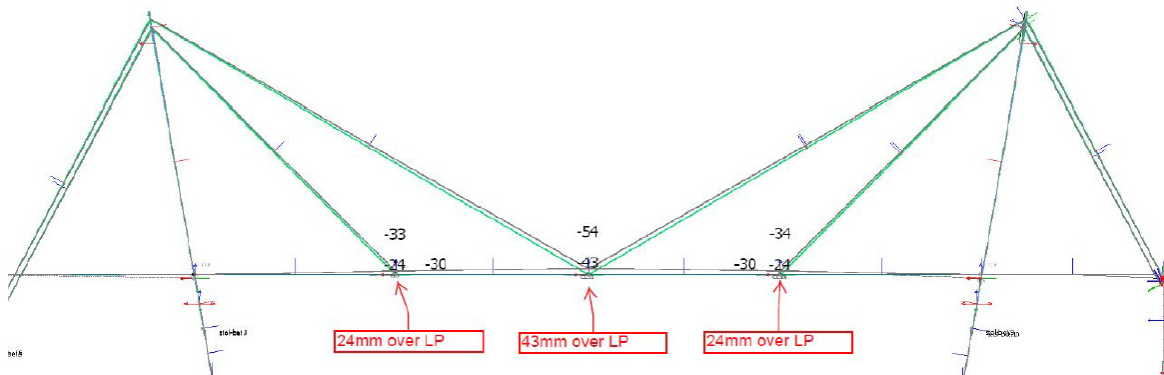


Fig. 16 The prefabricated elements are joined in a 3,0 m long connection zone. Not more than one butt joint occurs in any four adjacent laminations





*Fig. 17 A detailed procedure was developed for the installation of pylons, deck and stays.*



*Fig. 18 The stays had to be adjusted upwards prior to adding the asphalt wearing course, to compensate for the vertical deflections*



*Fig. 19 After installation the bridge deck's sides were covered with thin steel plates*

## 5. Conclusions

Swedish bridges must follow Eurocode when designing stress-laminated timber decks. In this project Swedish Road Authorities allowed us to use alternative values for friction values and bar loss. These are values that are well documented in Norway and Sweden. Future timber bridges in Sweden should be given the opportunity to use these values in order to increase the cost competitiveness of timber bridges.

Unusually much steel was needed to pre-stress the deck for Hansabron. This was a result of the impact load from vehicles. In general considerable amounts of timber and steel can be saved if one ensures that the bridge deck has sufficient clearance above an underlying road. Calculations we have done show that by lifting the bridge to avoid the impact load, and positioning the crossbeams under the deck, the deck thickness of Hansabron could have been reduced from 600 mm to 450 mm.

Letting the crossbeams run through the deck complicates design and installation significantly as well as increases the costs. This is hardly a smart move to make timber bridges cost competitive with other bridges. On the positive side crossbeams through the deck give the bridge a somewhat smoother look, and improve the aesthetics. Kalmar kommun have gotten a nice looking bridge that can be used for many generations to come. Congratulations!

## 6. Acknowledgements

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