Eurocode verification of a runway beam subject to wheel loads – Part 2

In Part 1 of this article, Dorota Koschmidder-Hatch of the SCI described the checks covering the design of a runway beam in accordance with BS EN 1993-6. In this Part, a worked example is presented. Readers should refer to Part 1 for nomenclature and detail on the design verifications.

Beam and loading details (Figure 1)

The beam is a 406 × 178 × 60 in S355, which spans 6 m.

The maximum lifted load is 3 T, or 30 kN

The hoist is assumed to weigh 750 kg, or 7.5 kN

The wheels are assumed to be at 300 mm centres, and to be located very close to the edge of the flange (μ = 0.1)

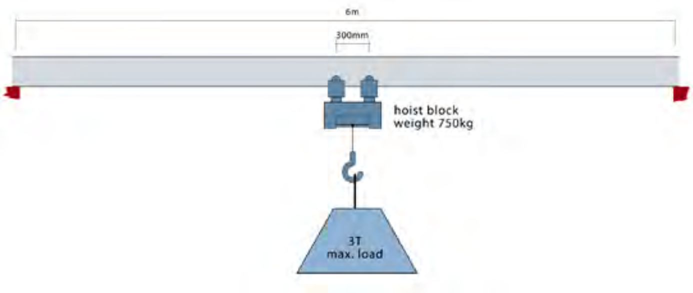


Figure 1: Details of monorail beam

ULS checks

LTB resistance

The design bending moment, $M_{y,Ed}$, depends on the design value of the point load. BS EN 1991-3 prescribes several design combinations conditions to be considered, with amplification factors depending on the type of hoist, hoist speed, static and dynamic test loads etc (see Table 2.2 and Table 2.4 of the Standard).

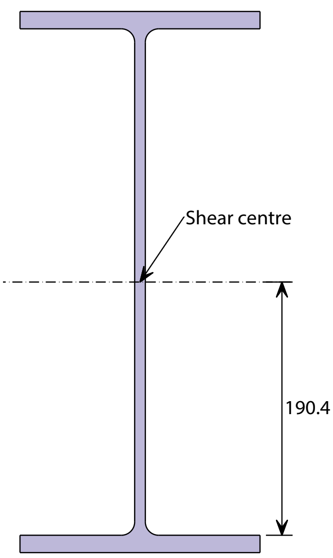


Figure 2: Application of the wheel loads

Following this guidance, the design point load is calculated as 61.8 kN

As an approximate check, note that 1.35 × (30 + 7.5) = 50.6 kN, so with some amplification to allow for dynamic effects, the design point load is of the correct order. Note that the use of 1.35 for the lifted load is prescribed in Table A.1 of BS EN 1991-3 and confirmed by clause NA.2.6 the UK National Annex.

The design bending moment is therefore 97.2 kNm, including self weight of the beam.

With a central point load, the C_1 factor is 1.35

From the Blue Book, $M_{b,Rd}$ = 215 kNm

In fact, clause 6.3.2.2(3) of BS EN 1993-6 allows the benefit of stabilising loads to be taken into account, as explained in Part 1. With loads applied on top of the bottom flange, z = -190.4 mm, as shown in Figure 2 (negative as the loads are applied below the shear centre). If advantage is taken of this effect, $M_{b,Rd}$ increases to 280 kNm.

Even without the benefit of stabilising loads, the LTB resistance is satisfactory.

From the Blue Book, the shear resistance is 709 kN. The applied shear is 30.9 kN, which has no impact on the cross sectional moment resistance, $M_{c,y,Rd.}$ Since the LTB resistance is satisfactory, the cross sectional moment resistance must be satisfactory. For completeness, $M_{c,y,Rd}$ = 426 kNm, which is significantly greater than 97.2 kNm.

Flange resistance

The geometry of the applied wheel loads must be established. Dimension *m* is from the wheel load to the root radius. Dimension *n* is from the wheel load to the edge of the flange, and relates to the ratio μ, as given in clause 5.8(4). The dimensions are shown in Figure 3.

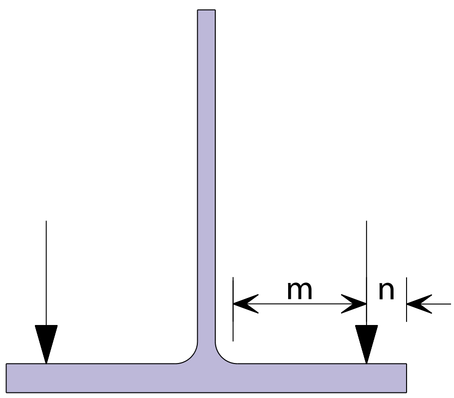


Figure 3: Nomenclature for flange resistance checks

$n = \mu\,(b - t_w)/2 = 0.1\,(177.9 - 7.9)/2 = 8.5$ mm (expression 5.7, rearranged)

$m = 0.5\,(177.9 - 7.9) - 0.8 \times 10.2 - 8.5 = 68.3$ mm (expression 6.3)

Assuming that the wheels are remote from the end of the beam (case (b) of Table 6.2), the length of yield line is established by first calculating the length $4\sqrt{2}\,(m + n)$ and comparing this to the wheel centres.

$4\sqrt{2}\,(m + n) = 4\sqrt{2}\,(68.3 + 8.5) = 434.7$ mm

Because this is larger than the wheel centres, x_w, which were assumed to be 300 mm, the effective length of yield line is given by:

$l_{eff} = 2\sqrt{2}\,(m + n) + 0.5\,x_w = 2\sqrt{2}\,(68.3 + 8.5) + (0.5 \times 300) = 367.3$ mm

The resistance of the flange is reduced by the stress at the midline of the flange, as given by clause 6.7(1).

Stress at the midline of the flange is given by:

$$\sigma_{f,Ed} = 97.2 \times 10^6 \times \frac{(406.4 - 12.8) \times 0.5}{21600 \times 10^4} = 88.6 \text{ N/mm}^2$$

Design resistance of the bottom flange to a wheel load:

$$F_{t,Rd} = \frac{l_{eff}\, t_f^2 f_y / \gamma_{M0}}{4m}\left[1 - \left(\frac{\sigma_{f,Ed}}{f_y/\gamma_{M0}}\right)^2\right]$$

$$= \frac{367 \times 12.8^2 \times 355/1}{4 \times 68.3}\left[1 - \left(\frac{88.6}{355/1}\right)^2\right] \times 10^{-3} = 73.3 \text{ kN}$$

The applied load is 61.8 / 4 = 15.4 kN, which is satisfactory.

SLS checks

Deflection

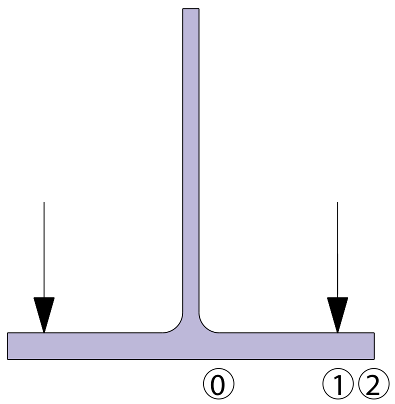
The SLS load = 30 + 7.5 = 37.5 kN. This load has not been amplified to allow for dynamic effects. With this load at midspan, the calculated deflection is 3.7 mm. According to case (a) of Table 7.2, the limiting deflection is span/600 or 10.0 mm.

Combined stress checks

With $\mu = 0.1$, and using the formulae in Table 5.2 (rather than the coefficients in Table 5.3), the calculated local stresses are as follows:

Position	Stress (N/mm²)	
	longitudinal	transverse
0	11.0	-108.6
1	131.8	31.4
2	124.1	0.0

The locations are shown in Figure 4.



⓪ at the root radius

① under the load

② at the flange tip

Figure 4: Locations for SLS stress checks

The longitudinal stress at the extreme fibre, under the SLS load of 37.5 kN is given by

$$\sigma_{f,ser,Ed} = \frac{37.5 \times 10^3 \times 6000}{4}\;\frac{406.4 \times 0.5}{21600 \times 10^4} = 52.9 \text{ N/mm}^2$$

From the shear resistance of 709 kN taken from the Blue Book, the shear area, A_v can be calculated, since $V_{pl,Rd} = \dfrac{A_v\left(f_y/\sqrt{3}\right)}{\gamma_{M0}}$

Therefore, $A_v = 3459$ mm²

The shear stress at SLS is therefore = 5.4 N/mm²

Conservatively assuming that the maximum longitudinal stress, plastic shear stress and local stresses are coincident, the expressions in clause 7.5 can be verified. The sign convention of the local transverse stress is reversed if required to produce the most onerous combined stress result, reflecting that the more onerous position may be on the underside or top side of the bottom flange.

At each location, 0, 1 and 2, (see figure 5.6 of BS EN 1993-6) the local longitudinal stress is added to the overall longitudinal stress.

Although each position must be verified, for conciseness only the most onerous, position 1 in this case, is shown below.

Location 1

$\sigma_{x,Ed,ser} = 52.9 + 131.8 = 184.7$ N/mm²

$\sigma_{y,Ed,ser} = 31.4$ N/mm²

$\tau_{xy,Ed,ser} = 5.4$ N/mm²

$\sqrt{(184.7)^2 + 3\,(5.4)^2} = 185.0$ N/mm² (expression 7.2c)

$\sqrt{(184.7)^2 + (31.4)^2 - (184.7)\,(-31.4) + 3\,(5.4)^2} = 202.4$ N/mm² (expression 7.2d)

The maximum permissible stress is given in clause 7.5 as $f_y/\gamma_{M,ser}$ is given by the UK NA to BS EN 1993-6, in clause NA.2.12 as 1.1, (a variation from the recommended value of 1.0) so the maximum permissible stress is

$355/1.1 = 322.7$ N/mm²

Thus the local stress checks are satisfactory.

Vibration of the bottom flange

Distance between lateral restraints $L = 6$ m

For simplicity, the inertia of the bottom flange will be taken as half of I_z.

Thus the bottom flange inertia = 0.5 × 1200 × 10⁴ = 600 ×10⁴ mm⁴

The radius of gyration of the flange, $i_z = \sqrt{\dfrac{600 \times 10^4}{177.9 \times 12.8}} = 51.3$ mm

Slenderness, $L/i_z = 6000/51.3 = 117 < 250$, so vibration is satisfactory.