

Eurocode verification of a runway beam subject to wheel loads – Part 1

Dorota Koschmidder-Hatch of the SCI describes the design of runway beams carrying an underslung hoist or crane to BS EN 1993-6 – in particular the verification of the bottom flange at ULS and SLS. Part 1 describes the requirements of the Standard. Part 2 will include a worked example.

Before the Eurocodes were introduced, BS 2853 covered design and testing of overhead runway beams. Following revision in 2011, BS 2853 now only provides guidance on testing overhead runway beams. BS EN 1993-6:2007 (EC3-6) covers the design of steel crane supporting structures, which includes overhead runway beams, while guidance on determining actions induced by cranes is given in BS EN 1991-3.

This article focuses on crane runway beams supporting either a monorail hoist block travelling on the bottom flange (see Figure 1) or an underslung crane, which is also supported on the bottom flange of the beam. The guidance in this article covers beams with parallel flanges, though EC3-6 also includes information for beams with tapered flanges.

The bottom flange is subject to a complex state of stress, experiencing direct stresses from the global bending, but also local stresses around the wheel positions, which vary with the proximity of the hoist to the end of the beam. Figure 2 shows a typical situation, with a four wheeled hoist. The local resistance of the flange is based on nominal yield lines, shown in the plan.

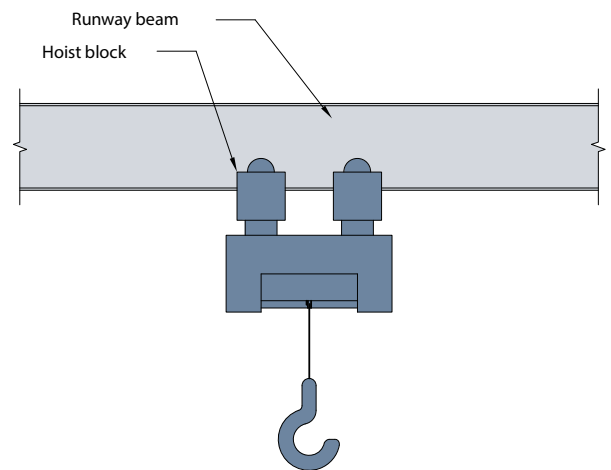


Figure 1: Crane runway beam supporting a monorail hoist block

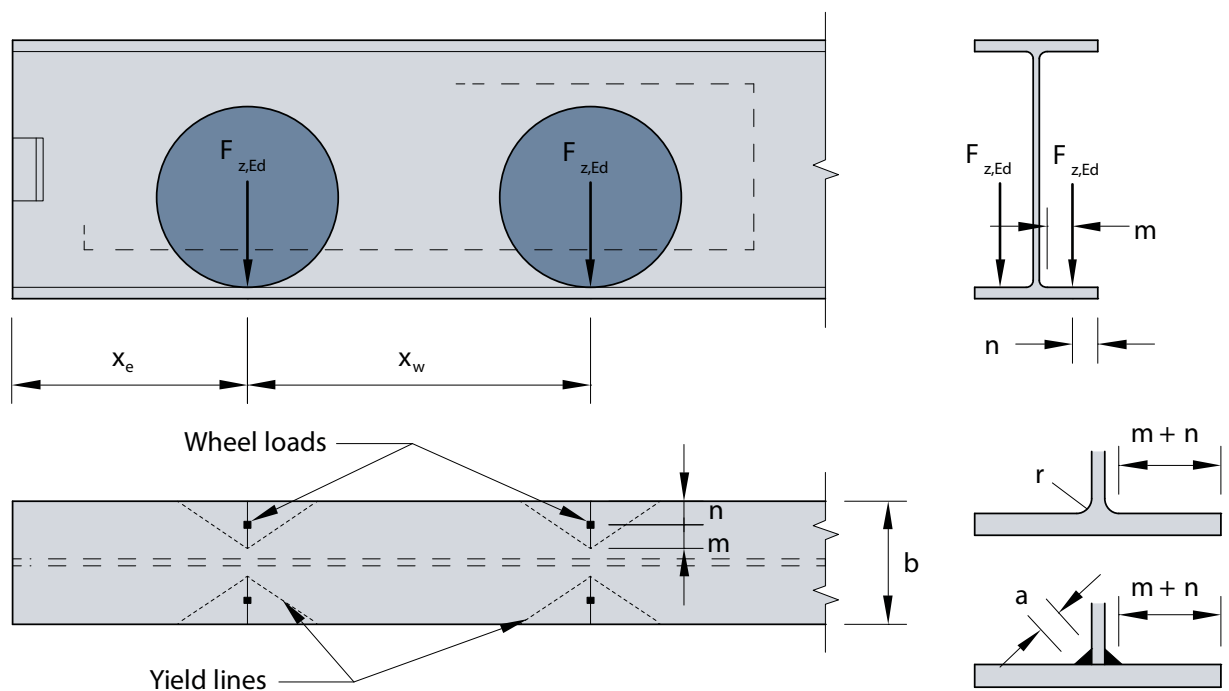


Figure 2: Four-wheel hoist

1. ULTIMATE LIMIT STATE

At the ultimate limit state (ULS), runway beams must be verified for bending due to vertical loads in combination with the effect of lateral loads. Because the lateral loads are applied eccentrically to the shear centre of the beam, they cause minor axis bending, but also apply a torque to the section. EC3-6 clause 6.3.2.3(1) recommends that the combination of lateral torsional buckling, minor axis bending and torque be verified using an interaction expression given in Annex A. The UK National Annex to EC3-6 endorses this approach.

In a runway beam with an underslung hoist or crane, the vertical loads are applied below the shear centre, at the bottom flange. This is a stabilising load, as the vertical loads act in opposition to the movement of the compression flange. Clause 6.3.2.2(3) allows this benefit to be taken, but requires that the loads should be assumed to be applied no lower than the top surface of the bottom flange. This limit is because a swinging load could reduce the beneficial effect of the stabilising load.

To calculate M_{cr} for a stabilising load, the free software *LTBeam*¹ could be used, or the formula given in NCCI document SN003². It is conservative to ignore the beneficial stabilising effect.

In addition to the usual ULS checks, clause 2.7(2) requires that the bottom flange of the beam be verified. The bottom flange experiences a combination of direct stresses from overall bending, combined with local stresses from the wheels. Clause 2.7(2) directs designers to clause 6.7 to verify the bottom flange.

1.1 Verification of bottom flange at ULS

Clause 6.7 provides expression 6.2 to verify the bottom flange, as shown below.

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

The resistance is based on the length of a yield line, l_{eff} , which is given in Table 6.2 of EC3-6 for various locations of a wheel. Wheels close to a free end have a lower effective length; wheels adjacent to a 'welded closer plate' (a full depth end plate) have a higher effective length and consequently a greater resistance.

Designers should note that the resistance is based on the plastic modulus, $\frac{l_{eff} t_f^2}{4}$, which means that a check of the flange at SLS is also necessary. The influence of the direct stress is seen in the reduction factor $\left[1 - \left(\frac{\sigma_{f,Ed}}{f_y / \gamma_{M0}} \right)^2 \right]$, where $\sigma_{f,Ed}$ is the tensile stress at the midline of the flange. The reduction may be considerable, but because runway beams are subject to relatively onerous deflection limits (which may dominate the design), the bending stress may be lower than usually found in ordinary beams.

2. SERVICEABILITY LIMIT STATE

EC3-6 has a series of deflection limits, for the runway beams and the supporting structure, vertically and horizontally to minimise vibrations and to avoid an excessive slope for the hoist when travelling along the runway beam.

In addition, clause 2.7 requires that the stresses in the bottom flange be checked at SLS. Because the ULS check of the flange uses the plastic modulus, a check at SLS is particularly important.

The SLS checks of the bottom flange are covered in clause 7.5, which combines direct stresses, shear stresses and local stresses.

2.1 Local stresses due to wheel loads

Local stresses are to be determined from clause 5.8, which provides a simple approach to calculate local longitudinal and transverse stresses at three locations in the flange, as shown in Figure 3

Stresses are to be determined at:
Position 0, at the junction between the flange and the root radius
Position 1, under the wheels, and
Position 2, at the tip of the flange.

The local longitudinal and transverse stresses are given by:

$$\sigma_{ox,Ed} = c_x F_{z,Ed} / t_1^2 \text{ (for local longitudinal bending stress)}$$

$$\sigma_{oy,Ed} = c_y F_{z,Ed} / t_1^2 \text{ (for local transverse bending stress)}$$

In the formulae, coefficients c_x and c_y are taken from tables, depending on the lateral spacing of the wheels with respect to the flange width. The formulae are valid as long as the wheels are more than $1.5b$ from the end of the beam (b is the flange width). Expressions are given to calculate c_x and c_y , (which appear to be the result of curve fitting) for both parallel and tapered flanges. In the common case, when the wheels are located close to the tips of the flanges (the lateral spacing of the wheels is 90% of the beam width) the expressions are replaced with single values for c_x and c_y – but these values are simply the product of the rather more complicated expressions. The results are valid if the wheels are spaced no less than $1.5b$ longitudinally; if closer the calculated stresses must be superposed.

The situation is more complicated close to the end of a beam (within $1.5b$), where there is no continuity of the flange. An expression is offered, or the alternative of reinforcing the flange as shown in Figure 4.

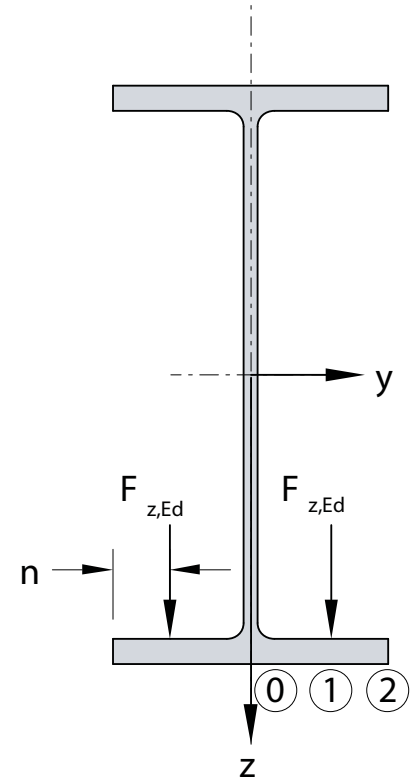


Figure 3: Flange locations for SLS stress verification

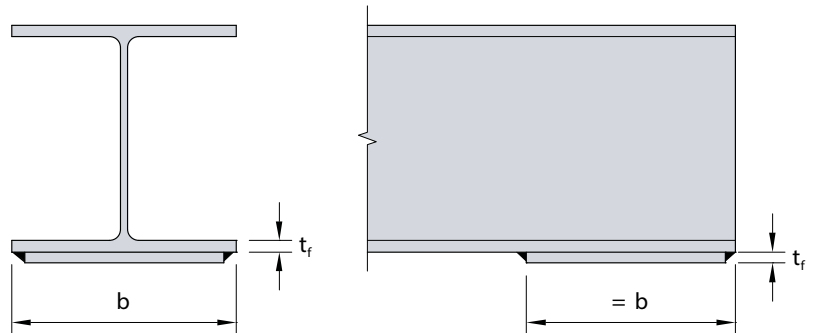


Figure 4: Reinforced beam end

2.2 Combined stresses

Clause 7.5 provides five expressions to verify combined stresses at SLS. The local stresses must be included in the verifications. In the following expressions (taken from EC3-6), the stresses $\sigma_{x,Ed,ser}$ and $\sigma_{y,Ed,ser}$ are the sum of the global stress and local stress.

$$\sigma_{Ed,ser} \leq f_y / \gamma_{M,ser}$$

$$\tau_{Ed,ser} \leq \frac{f_y}{\sqrt{3} \gamma_{M,ser}}$$

$$\sqrt{(\sigma_{x,Ed,ser})^2 + 3(\tau_{y,Ed,ser})^2} \leq f_y / \gamma_{M,ser}$$

$$\sqrt{(\sigma_{x,Ed,ser})^2 + (\sigma_{y,Ed,ser})^2 - (\sigma_{x,Ed,ser})(\sigma_{y,Ed,ser}) + 3(\tau_{y,Ed,ser})^2} \leq f_y / \gamma_{M,ser}$$

where $\sigma_{x,Ed,ser} = \sigma_{global,x,Ed,ser} + \sigma_{ox,Ed,ser}$
and $\sigma_{y,Ed,ser} = \sigma_{global,y,Ed,ser} + \sigma_{oy,Ed,ser}$

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- ◀ 25 $\gamma_{M,ser}$ is to be taken as 1.1, according to the UK National Annex. EC3-6 does not indicate where precisely stresses should be checked at positions 0, 1 and 2. At the extreme fibres on the underside of the flange, the global bending stress $\sigma_{x,Ed,ser}$ is at a maximum, as is the local transverse bending stress $\sigma_{oy,Ed,ser}$, but the shear stress is zero. At other locations, the shear stress will be combined with a reduced global bending stress. It is conservative simply to combine maximum stresses, especially as the shear stress based on clause 6.2.6 of BS EN 1993-1-1 is likely to be small.

2.3 Vibration of the bottom flange

A further serviceability requirement concerning runway beams is the need to avoid noticeable lateral vibration of the bottom flange. Clause 7.6 of EC3 6 recommends that the slenderness ratio of the bottom flange L/i_z should be limited to 250, where i_z is the radius of gyration of the bottom flange and L is the distance between lateral restraints.

1. LTBeam software, available from www.cticm.com
2. SN003 Elastic critical moment for lateral torsional buckling, available from www.steel-ncci.co.uk