Document Reference LEEA-075 – V3 – March 2022

Guide to the Verification of Runway Beams

Lifting Equipment Engineers Association

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CONTENTS **Page**

1.0 Introduction

Runways are widely used in industry to provide a track upon which a lifting appliance is fitted to allow loads to be raised, lowered, and travelled along the path of the runway.

Runways are often manufactured from standard rolled profile steel sections or from special track section systems and may be supported from building structures (figure 1), dedicated free standing structures (figure 2) or a combination of both. They may also be built into machines or the bodywork of service vehicles. Typical examples are shown in figure 1.

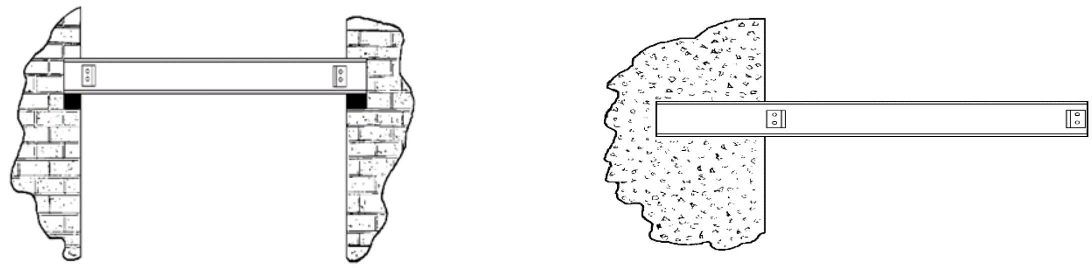


Figure 1 runway beams supported from a building structure.

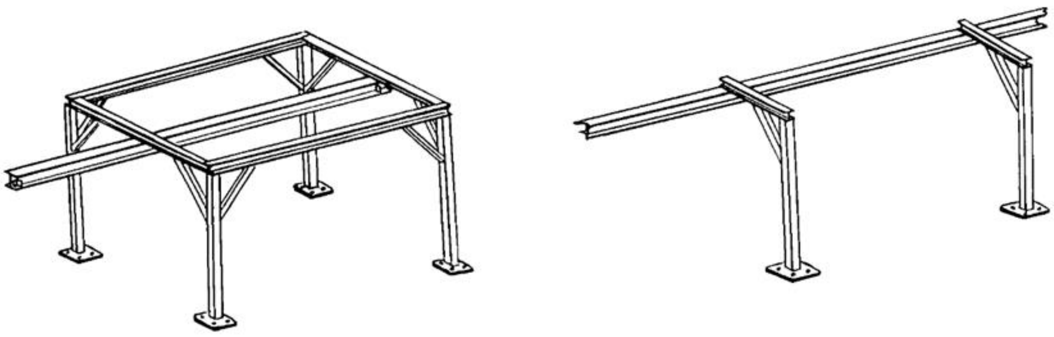


Figure 2 runway beams supported from a dedicated free-standing support structure.

A further variation of the runway is the lift shaft beam. Although such beams are usually intended for use with fixed point lifting arrangement, their design and testing requirements are to the same criteria as runway beams.

Runway beams were previously designed and verified using a single standard, BS 2853:1957. This standard was a simple, clear, and concise guide to the design and verification of runways. However, following the introduction of the Eurocodes a large proportion of this standard had to be withdrawn leaving only a guide to the thorough examination following installation.

There are a total of 10 Eurocodes each of which are split into numerous sub parts covering a huge range of structures and structural elements. This has resulted in a mass of information for the runway designer to sift through, which is proving problematic for SMEs that do not have the resources available to enable them to adopt the changes. This guide has therefore been produced as a means of directing the runway designer and tester to those parts of the Eurocodes relevant to them. For simplicity, only the imposed loads induced by the hoist unit have been considered

2.0 Standards and Legislation

The primary standards and legislation to be considered when designing, manufacturing, and verifying runways are listed as follows:

- Eurocode 0 – The basis of structural design.
- Eurocode 1 – Actions on structures
- Eurocode 3 – Design of steel structures

- BS 2853:2011 Specification for the testing of steel overhead runway beams for hoist blocks.

Runway beams are defined as supporting structures and are therefore not within the scope of The Supply of Machinery (Safety) Regulations 2008. If they offer support in some manner, for example wind bracing, to a building, then they would be considered within the scope of the Construction Products Regulations requiring CE marking, refer to LEEA 058 for guidance on CPR.

Once in service and fitted with a lifting appliance, runways fall under the Provision of Use of Work Equipment Regulations (PUWER) and the Lifting Operations and Lifting Equipment Regulations (LOLER).

3.0 Design, Manufacture and Verification of Runway Beams.

It is important that runway beams fully comply with the Eurocodes in terms of design verification, and BS 2853:2011 in terms of thorough examination. That includes runway beams manufactured by the user.

In most cases a runway is considered as a supporting structure only and therefore the Supply of Machinery (Safety) Regulations 2008 does not apply. However, due to the fact that these regulations are relevant in other cases, then it is recommended that the principles of the Machinery Directive are adopted.

3.1 Technical File.

The technical file is very important and must contain all the information relevant to the manufacture of the runway beam. Should a runway beam fail in service, then it is this technical file that will be scrutinised. If it cannot be proven that other factors, such as misuse, were the cause of the failure, then the manufacturer will rely upon the technical file to show that everything reasonably practicable was done to ensure the safety of the equipment.

The technical file does not have to be a physical entity, but it must be possible to assemble it from various sources should the need arise. Typical information that should form a technical file for runway system is as follows:

- A list of the Essential Health and Safety Requirements (EHSRs) which apply to the runway beam.
- A description of the methods used to eliminate hazards or reduce risks.
- A list of standards to which the equipment has been made.
- Information from user.
- Design information: Calculations, detailed drawings, fabrication / welding procedures.
- Material traceability: Details of all materials and assemblies should be retained in the technical file. This will be a mill certificate for steelwork.
- Test reports: These could be the reports of a load test, or a non-destructive test done on the structure.
- Instructions for use.

The technical file is the evidence which supports the documentation for the runway. The manufacturer’s certificate should be added to the technical file and a copy should accompany the runway and its components

3.2 Eurocode Verification.

Eurocode verification of runways is done through calculation, although in some cases the design may be verified by testing. The calculations should be carried out by a person competent for the task, have sufficient theoretical knowledge and experience of structures to ensure that the design is safe and fit for purpose. It is also recommended that there is a procedure in place to ensure that these calculations are suitably checked.

The calculations and load cases that must be used are defined in the Eurocodes and the following sections identify those parts that are relevant to Runways

Note: the runway designer need not concern themselves with the building or foundations to which the runway or free-standing structure is fitted. The runway designer's responsibility is to provide the building owner with the calculated maximum forces that are transferred to the building or foundations from the runway structure. The owner is ultimately responsible for ensuring that they have the building or foundations checked by a suitable design authority. The runway designer does have a duty of care to advise that this is done, and this should be documented

3.2.1 Actions on Structures.

Eurocode 1 or EN 1991 covers the variety of load conditions to be considered when designing structures. For Runway design there are two parts that must be considered, which are 'EN 1991-1-1:2002 Actions on Structures, General Actions' and 'EN 1991-3 Actions on Structures, Actions induced by Cranes and Machinery'

3.2.1.1 EN 1991-1-1 General actions

This part of the code covers densities, self-weights, and imposed loads for buildings. The runway designer need only consider sections 3 and 5.

Section 3 requires the relevant permanent and imposed loads to be determined for each design situation that has been selected considering the circumstances under which the structure is required to fulfil its function.

Permanent loads are generally defined as those loads that are relatively constant over time, for example the weight of the structure itself. Imposed loads on the other hand are temporary, of short duration, such as a moving load. Imposed loads are covered later on in this guidance.

Section 5 states that for permanent loads the total self-weight of structural and non-structural members should be considered in combinations of actions as a single action. Non-structural elements would include cables, electrical control boxes and conduits for example.

The self-weight of the structure may be represented by a single characteristic value (GK) and be calculated on the basis of the nominal dimensions and mean unit masses. Nominal densities of materials can be found in annex A of EN 1991-1-1, though most steel suppliers will define the unit mass per meter of steel section that they supply.

3.2.1.2 EN 1991-3:2006 Actions Induced by Cranes and Machinery.

For simplicity of this guidance only indoor runway systems have been considered, thus negating the requirements for wind and snow loadings. Other factors such as provisions for seismic design and resistance to fire have also been omitted. Therefore, only the imposed loads induced by the hoist block need to be considered.

Section 2 of this part of Eurocode 1 specifies the actions induced by trolleys on runways. The actions induced by hoists are classified as variable and accidental actions.

For normal service conditions variable crane actions result from a variation in time and location. They include gravity loads including hoist block loads, and inertial forces caused by acceleration or deceleration.

The variable actions are separated into:

- The variable vertical actions caused by the self-weight of the hoist and the hoist load.

- The variable horizontal actions caused by acceleration or deceleration.

These variable actions are composed of a static and dynamic component, for example:

Variable action = static load x dynamic factor.

There are a variety of dynamic factors, and these can be found in table 2.1 of EN 1991-3.

The actions to be considered should be those exerted on the runway beam by the wheels of the hoist and possibly by the guide rollers and are generally as follows.

Vertical loads; should be taken as composed of the self-weight of the hoist block, the hoist load, and the dynamic factor.

Horizontal forces; in the absence of a more accurate value the longitudinal forces should be taken as 5% of the maximum vertical wheel load, neglecting the dynamic factor.

The vertical loads to be considered are therefore:

Load case 1 = Fφ,k1=(Qc×φ1)+(Qh×φ2) = Excitation of the runway due to lifting the hoist load off the ground.

Load case 2 = Fφ,k2=(Qc×φ4)+(Qh×φ4) = Load induced when the hoist is travelling on runway.

Load case 3 = Fφ,k3=(Qc×φ1)+(Q_T×φ_6) = Dynamic Test Load.

Load case 4 = Fφ,k4=(Qc×φ1)+(Q_T×φ_6) = Static Test Load.

Load case 8 = Fsls,k8= γg (Qh+Qc) = Serviceability Limit States.

Load case 9 = Fφ,fat,k9)=(φfat x λ1×Qmax,i)= Fatigue Load.

The dynamic factors specified above should be supplied by the manufacturer; however, if you are designing a structure for use with a non-specific hoist, then you can estimate these dynamic factors with reference to table 2.4 of EN 1991-3:2006.

The corresponding horizontal load would therefore be:

Load case 5 = $\mathrm{F}_{L,k5} = (F_{sls} \times\ 0.05) + (K \times \varphi_5)$ = Longitudinal horizontal force induced by drives

Load case 6 = $\mathrm{F}_{T,k6} = 0.10F_{z,6}$Transverse horizontal force related to acceleration or deceleration of the trolley

Load case 7 = $\mathrm{F}_{L,k7} = \varphi_7 v_1\sqrt{m_c S_B}$ = Longitudinal horizontal force induced from collisions between the buffers and the crane, a worked example can be found in Annex A and a connection design example in Annex B

3.2.2 Verification.

The runway structure must be verified in accordance with Eurocode 3. This standard is split into 23 sub-parts and of those the following are relevant:

- BS EN 1993-1-1 General Rules and Rules for Buildings
- BS EN 1993-1-8 Design of joints.
- BS EN 1993-1-9 Fatigue
- BS EN 1993-6 Crane supporting structures

Other relevant standards are:

- BS EN 13001-1 Cranes. General design. General principles and requirements
- BS EN 13001-2 Crane safety. General design. Load actions
- BS EN 1991-3 Actions on structures. Actions induced by cranes and machinery.

You can find the relevant calculations as well as an example for the verification of a runway beam with a fitted hoist block, see Annex A.

4.0 Manufacture.

Runway beams shall be manufactured in accordance with suitable quality procedures with appropriate internal checks at critical stages of the production process. The following sections offer some guidance to the common process used to manufacture runway structures.

4.1 Runway Welding Quality Requirements.

Specification of quality requirements for welding processes is important because the quality of these processes cannot be readily verified. Therefore, they are considered to be a special process as noted in ISO 9001:2015, (8.5.1 – Control of production and service provision).

Also, stated in ISO 3834-1 Quality requirements for fusion welding of metallic materials – part 1, 'Quality cannot be inspected into a product, it has to be built in. Even the most extensive and sophisticated non-destructive testing does not improve the quality of the product. For products to be free from serious problems in production and in service, it is necessary to provide controls, from the design phase, through material selection, into manufacture and subsequent inspection. For example, poor design may create serious and costly difficulties in the workshop, on site, or in service. Incorrect material selection may result in problems, such as cracking in welded joints. To ensure sound and effective manufacturing, management needs to understand and appreciate the sources of potential trouble and to implement appropriate procedures for their control.'

For a given application, the main way of ensuring adequate weld quality is to specify the procedure and the skill level of the welding operator.

4.1.1 Welding Procedure Approval.

The key document is the Welding Procedure Specification (WPS) which details the welding variables to be used to ensure a welded joint will achieve the specified levels of weld quality and mechanical properties.

The WPS is supported by a number of documents (e.g. a record of how the weld was made, NDE, mechanical test results) which together comprise a welding procedure approval record termed the WPAR (BS EN ISO 15614).

Typically, the route followed to produce a WPS is BS EN ISO 15614 (steels).

The manufacturer initially drafts a preliminary welding procedure (pWPS) which is used by one of the manufacturer's competent welders to prove that it is capable of producing a welded joint to the specified levels of weld quality and mechanical properties. The welding procedure approval record (WPAR) is a record of this weld. If the WPAR is approved by the examiner, it is used to finalise one or more WPS which is the basis for the work instructions given to the welder.

It is noteworthy that the welder carrying out a satisfactory welding procedure approval test is approved for the appropriate range of approval given in the relevant standard (BS EN ISO 9606, formally EN 287).

4.1.2 Welder Approval.

The welder approval test is carried out to demonstrate that the welder has the necessary skill to produce a satisfactory weld under the conditions used in production as detailed in the approved WPS or Work Instruction.

As a general rule, the test piece approves the welder not only for the conditions used in the test but also for all joints which are considered easier to weld.

As the welder's approval test is carried out on a test piece which is representative of the joint to be welded, it is independent of the type of construction. The precise conditions, called 'essential variables', must be specified in the approval test, e.g. material type, welding process, joint type dimensions and weld position. The extent of approval is not necessarily restricted to the conditions used for the test but covers a group of similar materials or range of situations which are considered easier to weld.

In BS EN 287 and BS EN ISO 9606, the certificate of approval testing is issued under the sole responsibility of the examiner / examining body. The welder approval certificate remains valid subject to the requirements of the application standard.

In BS EN 287 and BS EN ISO 9606, it can be extended at six monthly intervals by the employer for up to two years provided the welder has been successfully welding similar joints. After two years, prolongation of the welder's qualification will need approval of the examiner who will require proof that his or her performance has been of the required standard during the period of validity. As the examiner will normally examine the company's records on the welder's work and tests as proof that he has maintained his skill, it is essential that work records are maintained by the company

4.1.3 How This Works in Production.

The first process will be the design of the runway components which will include specification of the material to be used and the type, fillet and/or butt weld, and size of the welds required to give the required strength in service.

The next step is to identify a suitable existing weld procedure, weld procedure qualification record, which will ensure the welded joint will achieve the specified levels of weld quality and mechanical properties. Among the things that will need to be considered when looking at the qualification range of existing weld procedures include, type of joint, parent material groups and sub- groups, yield stress, parent material thickness and weld size.

If there is no existing weld procedure that will produce the required weld(s) then the process of qualifying a weld procedure (BS EN ISO 15614-1) will need to be carried out

Once it has been established that a satisfactory weld procedure is in place a weld procedure specification (WPS) is drawn as an instruction to the welder on how the weld is to be carried out. The WPS will include information including the joint design, pre-heat temperature, current, voltage, travel speed, filler wire designation, etc.

The welder carrying out the welds will hold a current welder qualification test certificate (WQTC) with a range of approval that qualifies them for the weld.

Depending on the requirements and complexity of the project it may be required that a weld map is drawn up and issued so that each weld is given a unique reference and the details of who welded it and when it was welded are entered onto this. A 3.1 certificate for the welding consumable used will also be added to the records.

After fabrication and welding of the beam has been completed it will then be subject to inspection.

This is very much down to project requirements. For repeat welding of common components which have already been subject to past design verification, i.e. manufacture and design verification, proof load testing followed by NDT of the welds, it is probable that the welds will be given a visual inspection for obvious defects by the manufacturer before the item continues on to the next process (blasting and painting).

Where project requirements dictate, especially where proof load testing is to be carried out, the welded component will be subject to a suitable NDT method. For fillet welds this would typically be MPI. These inspections will be carried out by independent and suitably qualified operatives holding PCN qualification and the permissible quality imperfection levels will be defined in accordance with BS EN ISO 5817, which specifies different types of imperfections and the limits put on these for different quality levels (D, C & B).

If proof load testing is to be carried out, then it is common practice to carry out an MPI and visual inspection of welds prior to testing and after testing to ensure that the forces involved in overloading the fabrication have not caused cracking.

Once NDT has been successfully carried out a report will be issued by the NDT technician to confirm that all the welds were satisfactorily inspected as per the requirements.

4.2 Fixings and Joints.

Runway structures are usually manufactured as a kit which is then assembled on site. For simplicity this is usually done by means of bolted connections.

For lifting purposes, it is recommended that as a minimum grade 8.8 bolts are used. In the case of runways where there is likely to be a lot of vibration, due to use or environment, standard nuts can work loose. Therefore, the bolt assembly should include components to minimise this risk, i.e. spring washer, locking nuts, etc.

All holes shall be machined within the tolerances specified by the designer.

The running surface at the joint should be properly aligned and levelled to prevent damage to the trolley and allow smooth operation.

4.3 Materials.

The mechanical properties at ambient temperature for flat and long products of steel grades and qualities with values for the impact strength should satisfy the requirements in table 7 of EN 10025-2. The minimum recommend grade for runways is grade S235 for hollow sections and S275 for rolled steel beams and plates

5.0 Installation.

The following sections outline the responsibilities, in accordance with BS 2853:2011, of the tester and certifier of the runway beam. The runway designer is responsible for supplying the installer and certifier with full details of the loads to be handled and the service required of the runway. This information will form the basis of a test. These loads must include any additional items, such as apparatus or services which may have to be supported by the runway. The designer should also provide detailed drawings for the installation and its location.

The design and layout of the beam must be such that before the application of a load the slope is not more than 1 in 250 from the horizontal or from the intended slope.

5.1 End stops.

The competent person must ensure that suitable end stops are fitted to prevent collision with supports and / or to prevent the trolley from running off the ends of the track. End stops must be of adequate strength and must not operate on the flanges of the trolley wheels.

5.2 Testing and Inspection.

The process for testing and inspecting a runway beam to BS 2853:2011 is described as follows.

Note: the following procedure applies to the testing of the runway only and not the lifting appliance. Further tests may be required for lifting appliances and guidance on specific types of lifting appliance can be sought in the LEEA Code of Practice for the Safe Use of Lifting Equipment (COPSULE).

5.2.1 Preliminary inspection.

Before the application of any load a preliminary inspection should be carried out. The inspection should include all joints, connections and supports paying particular attention to the security of nuts on bolts.

The inspection must include the condition of walls surrounding and adjacent to the end fasting of runways fixed therein. Where a runway beam is carried on timber supports (which in many cases might be roof trusses), it is the responsibility of the owner to satisfy the tester that the members are suitable for the load to be carried

In the case where concrete beams are used for the suspension of runways, the beams should be coated with whitewash or similar, to reveal any cracks that develop under the proof load.

5.2.2 Measuring equipment.

The load, which includes the test frame, slings, etc, must be measured by a load cell calibrated to BS EN ISO 7500-1, such that the sum of the inaccuracies of the load and the load cell do not exceed +/- 2%.

The device for measuring deflections must be capable of measuring the vertical defection of the beam at any point within +/-5% of the maximum permitted deflection of the beam.

5.2.3 Proof load.

The test load to be applied is the weight of the appropriate heaviest lifting appliance, as specified by the designer, to be supported by the runway plus 125% of the safe working load of this appliance.

Where the runway supports more than one transporting or lifting appliance, the test must be such that it includes the permissible proximity of any other appliance or appliances supported by the runway.

5.2.4 Application of the test loads.

A test load equivalent to maximum weight of the lifting appliance specified for the runway and the maximum safe working load should be applied and traversed along the length of the runway. The load must be halted at critical positions along the runway, such as the centre span and end of cantilever for example and kept at rest while stable deflection readings are recorded. Deflection measurements should also be taken at corresponding support points so that net values can be determined.

The maximum measured deflection of a runway beam under safe working load, relative to its supports, must not exceed 1/500th of the span.

For a cantilever beam, the maximum measured deflection under safe working load, relative to its supports, must not exceed 1/250th of the span.

Next the proof load as defined in section 5.2.3 is applied in the same manner as that for the test at safe working load. The stable net deflection must then be recorded, but only at the position where the maximum reading was obtained during application of the test at safe working load.

5.2.5 Inspection and thorough examination.

During the application of either of the above test loads the runway must be kept under visual observation as to ensure the ready detection of any obvious defects.

Following the application of the proof load the runway shall be thoroughly examined in order to ascertain that it has withstood the proof load without damage or permanent set. This thorough examination should be supplemented, where relevant, by other tests including NDT of critical welds and checking the tightness of pre-loaded bolts, in order to arrive at a reliable conclusion as to the safety of the runway

6.0 Marking.

In accordance with BS 2853:2011, runways should be marked with the following minimum particulars:

- Safe working load
- Identification Number
- Any limiting conditions marked on the runway must be clearly visible (i.e. reduced capacity towards the end of a cantilever).
- Maximum hoisting speed for a powered hoist unit(s) or else the words Manual Hoist.

Note: the safe working load on the runway is applicable to the runway only and does not apply to the trolley or lifting appliance. The maximum load that can be lifted therefore is the lowest value on the *equipment in the lifting assembly*

7.0 Documentation following installation and test.

Before any runway beam is taken into use for the first time after erection, re-erection or having undergone any substantial alteration or repair, a certificate that the runway beam has been tested and subsequently thoroughly examined must be issued to the owner of the equipment. The contents of this certificate are as follows:

- The date on which the proof load was applied, and the thorough examination made.
- Date of the report.
- Report number.
- Name and address of the owner of the equipment.
- Address of the premises at which the examination was made.
- Description and identification of the equipment which must include its distinguishing number or mark and grades of steel, its size and length.
- The position and magnitude of the deflections obtained during the traversing of the test at SWL and the proof load.
- The maximum safe working load.
- That the runway beam conforms in all respects to BS 2853:2011
- Date of manufacture.
- Reason for the examination, i.e. after first installation and before being used for the first time.
- Particulars of any defect found during the examination and affecting the maximum safe working load and the particulars of the steps taken to remedy such defect.
- A statement stating that the equipment is safe to operate or not
- A statement indicating clearly that it applies to the runway beam only and not to any trolley or lifting appliance that may be fitted.
- Date of next thorough examination.
- Name, signature, and qualifications of the person making the report.
- Name and signature of person authenticating the report
- Name and address of the employer of persons making and authenticating this report.

8.0 Documentation following periodic examination.

Once in service a runway beam should be thoroughly examined at the same interval as the lifting appliance fitted to it. If environmental conditions may cause deterioration at intervals between these periods, then interim inspections should be set up. It is recommended that such inspections are set up at the same time as scheduled maintenance, although the frequency must be defined by risk assessment.

If examining the runway beam only then the examiner will need to refer to the documentation supplied following installation and test as some of the information required for the examination report will be contained on it. The examination report for the runway should contain the following minimum information:

- Date of examination.
- Date of the report following the installation and test.
- Date of report.

- Report Number.
- Name and address of employer for whom the thorough examination was made.
- Address of the premises at which the examination was made.
- Description and identification of the equipment which must include its distinguishing number or mark and grades of steel, its size and length.
- Safe working loads.
- Date of manufacture.
- Date of last thorough examination
- Reason for the examination, i.e.12 monthly or after exceptional circumstances.
- Identification of any part found to have a defect which is or could become a danger to persons and a description of the defect. If none state none.
- Is the defect an existing or imminent danger to persons. (if so send a copy of the report to HSE).
- If the defect is not yet a danger to persons, could it become a danger? If so state date when it is likely to become a danger.
- Particulars of any tests done to support the examination.
- A statement stating that the equipment is safe to operate or not
- A statement indicating clearly that it applies to the runway beam only and not to any trolley or lifting appliance that may be fitted.
- Date of next thorough examination.
- Name, signature, and qualifications of the person making the report.
- Name and signature of person authenticating the report
- Name and address of the employer of persons making and authenticating this report.

Annex A

Worked Example for the Verification of a Runway Beam with a Hoist Unit

A.1.0 Introduction

The following example seeks to provide guidance to the designer of runway beams, in particular an appropriate method for the verification of steel beams with a fitted underslung hoist unit. This worked example considers only the most essential load cases, it is recommended this document is read alongside the relevant Eurocodes and that all relevant forces are considered.

A mind-map with the relevant clauses applicable to this example can be found in Annex C, the clauses in blue have been covered by this worked example.

A.2.0 Design Configuration

A simply supported beam spans 6 meters. The beam has been installed with an underslung hoist unit, the hoist unit weighs 250kg and its safe working load is 5 tonnes when the hoist unit is at mid-span the load acts through the centre wheels of the hoist unit meaning that the there is a load applied at either side of the bottom flange with an eccentricity of 80mm from the centre of gravity.

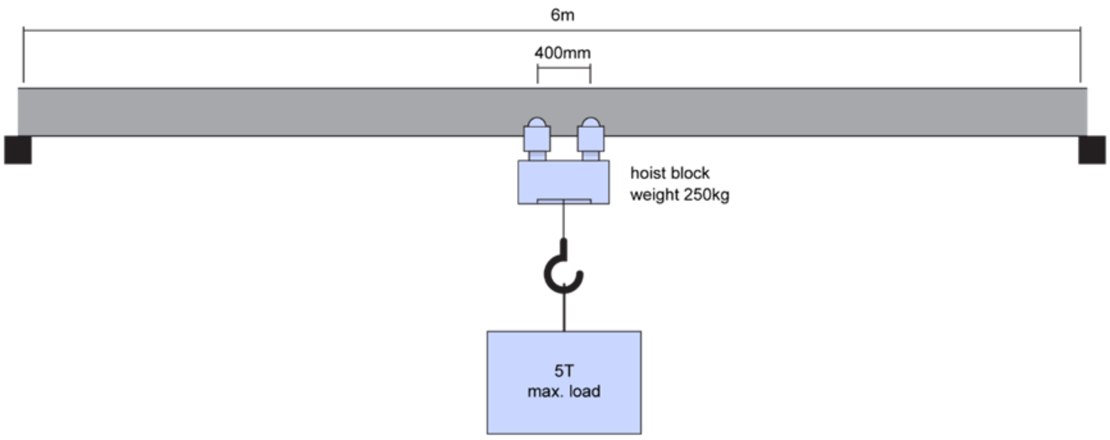


Figure A.1: Runway beam supporting a hoist unit

A.3.0 Section Properties

$\text{Universal Beam UKB} = 406 \times 178$		$Mass\ per\ metre = 60.1\,{}^{kg}/_{m}$
$b = 177.9mm$	$I_w = 0.466dm^6 = 4.66 \times 10^{-7}m^6$	$Buckling\ parameter\ U = 0.88$
$h = 406.4mm$	$I_T = 33.3cm^4 = 3.33 \times 10^{-7}m^4$	$Torsional\ index\ X = 33.7$
$t_w = 7.9mm$	$A = 76.5cm^2 = 7650mm^2$	$E = 210000\,{}^{N}/_{mm^2}$
$t_f = 12.8mm$	$W_{pl,y} = 1200cm^3 = 1200 \times 10^{-6}m^3$	$G = 80769.2\,{}^{N}/_{mm^2}$
$r = 10.2mm$	$W_{pl,z} = 209cm^3 = 209 \times 10^{-6}m^3$	$f_y = 355\,{}^{N}/_{mm^2}$
$e = 0.80mm$	$\mu = 0.1$	$a = 1.91m$
$I_y = 21600cm^4$	$z_g = -190.44mm$	
$I_z = 1200cm^4$		

A.4.0 Classification of Cross-section

[§5.5 of BS EN 1993-1-1]

§5.5.2(6) A cross-section must be classified according to the highest (least favourable) class of its compression parts.

Limits	Class 1 Plastic	Class 2 Compact	Class 3 Semi-compact
Flange Outstand	$c/t_f \leq 9\varepsilon$	$c/t_f \leq 10\varepsilon$	$c/t_f \leq 9\varepsilon$
Web in bending	$c/t_w \leq 72\varepsilon$	$c/t_w \leq 83\varepsilon$	$c/t_w \leq 124\varepsilon$
Web in compression	$c/t_w \leq 33\varepsilon$	$c/t_w \leq 38\varepsilon$	$c/t_w \leq 42\varepsilon$

Table A.1: Relation between dimensional properties and class type

Where:

$$c_{\mathrm{flange}} = (\mathrm{b} - \mathrm{t_w} - 2\mathrm{r})/2 \quad c_{\mathrm{flange}} = (177.9 - 7.9 - 2(10.2))/2 = 74.8\mathrm{mm}$$

$$c_{\mathrm{web}} = \mathrm{h} - 2\mathrm{t_f} - 2\mathrm{r} \quad c_{\mathrm{web}} = 406.4 - 2(12.8) - 2(10.2) = 360.4\mathrm{mm}$$

$$c_{\mathrm{flange}}/\mathrm{t_f} = 5.84$$

$$c_{\mathrm{web}}/\mathrm{t_w} = 45.6$$

Limits	Class 1 Plastic
Flange outstand	$5.84 \leq 9(0.81)$ ✓ *this is satisfactory.*
Web subject to bending and compression	$\alpha > 0.5: \alpha = 0.6: \ c_{web}/t_w \leq \dfrac{396(0.81)}{13(0.6) - 1} = 47.17$ $\alpha \leq 0.5: \alpha = 0.5: \ c_{web}/t_w \leq \dfrac{36(0.81)}{0.5} = 58.32$ $45.6 < 47.17$✓ *this is satisfactory.* $45.6 < 58.32$✓ *this is satisfactory.*

Table A.2: Section classification of each beam component

The classification type of this section is Class 1 plastic, this means that this cross-section can form a plastic hinge with the rotation capacity required from plastic analysis without reduction of the resistance.

Other classes are defined in §5.5.2(1) of EN 1993-1-1.

A.5.0 Load Case 1 – Excitation of the runway due to lifting the hoist load off the ground

[§6.4.3.2 of EN 1990]

The general format for the combination of actions in accordance with EN 1990 (6.9b) gives us the following expression:

$$\mathrm{E_d} = \sum \gamma_{\mathrm{G,j}} \mathrm{G_{k,j}} + \gamma_{\mathrm{P}} \mathrm{P} + \gamma_{\mathrm{Q,1}} \mathrm{Q_{k,1}} + \sum \gamma_{\mathrm{q,i}} \Psi_{0,\mathrm{i}} \mathrm{Q_{k,i}}$$

$$\mathrm{F_k} = \sum \mathrm{Q_{k,\varphi}}$$

$$E_d = F_k + f_k$$

Where:

Mass of the beam per metre: $g_{k,j} = 60.1\,{}^{kg}/_{m}$
The maximum load to be lifted is 5 tonnes therefore: $Q_h = 50kN$
The hoist block is assumed to have a mass of 250kg: $Q_c = 2.5kN$

The relevant dynamic components should be obtained from table 2.4 of EN 1991-3;

$$\varphi_2 = \varphi_{2,min} + \beta_{2,min} \times v_h$$

For HC2, then:

$$\varphi_2 = 1.1 + 0.34 \times 0.3 = 1.2$$

[§2.5.1.1(1) of EN 1991-3]

The variable actions Q_k are composed of a static and dynamic component, therefore for normal service conditions, vertical loads should be composed of the self-weight of the hoist block, the hoist load, and the dynamic factor:

$$Q_{h,\varphi 1} = \varphi_1 Q_h = 1.1 \times 50 = 55kN$$

$$Q_{c,\varphi 2} = \varphi_2 Q_c = 1.2 \times 2.5 = 3kN$$

$$F_k = 1.35Q_{k,\varphi 1} + 1.35Q_{k,\varphi 2}$$

$$F_1 = 74.25 + 4.05 = 78.3kN$$

Permanent loads need to be considered; therefore we must consider the self-weight of the beam:

$$Mass\ per\ metre\ G_{k,j} = \frac{60.1 \times 9.81}{1000} = 0.59\,{}^{kN}/_{m}$$

$$f_1 = \gamma_{G,j} G_{k,j} = 1.35 \times 0.59 = 0.80\,{}^{kN}/_{m}$$

$$f_1 = 0.80\,{}^{kN}/_{m}$$

For the concentrated load acting at mid-span with an eccentricity of 0.08 meters.

$$T_d = 0.08F_k$$

$$T_1 = 0.08 \times 78.3 = 6.26\text{kNm}$$

A.5.1 Design value of bending moment and shear force – Case 1

These can be solved by drawing the appropriate shear force and bending moment diagrams, the area under the graphs will provide you with the expressions required to obtain the bending moment and shear force. The first term of the equations accounts for the forces induced by the hoist load, whereas the second term considers the self-weight of the beam.

These equations are relevant to the shape of the shear force and bending moment diagram, a typical diagram for a simply supported beam with a point load is included for your information.

At mid-span: $M_{y,Ed} = \frac{F_k L}{4} + \left(\frac{f_k L^2}{8}\right)$

$$M_{y,Ed} = \frac{78.3 \times 6}{4} kNm + \left(\frac{0.80 \times 6^2}{8} kNm\right) = 117.45 + 3.6 = 121.05kNm$$

At the supports: $V_{Ed} = \frac{F_k}{2} + \frac{f_k L}{2}$

$$V_{Ed} = \frac{78.3}{2}kN + \frac{0.80 \times 6}{2}kN = 41.55kN$$

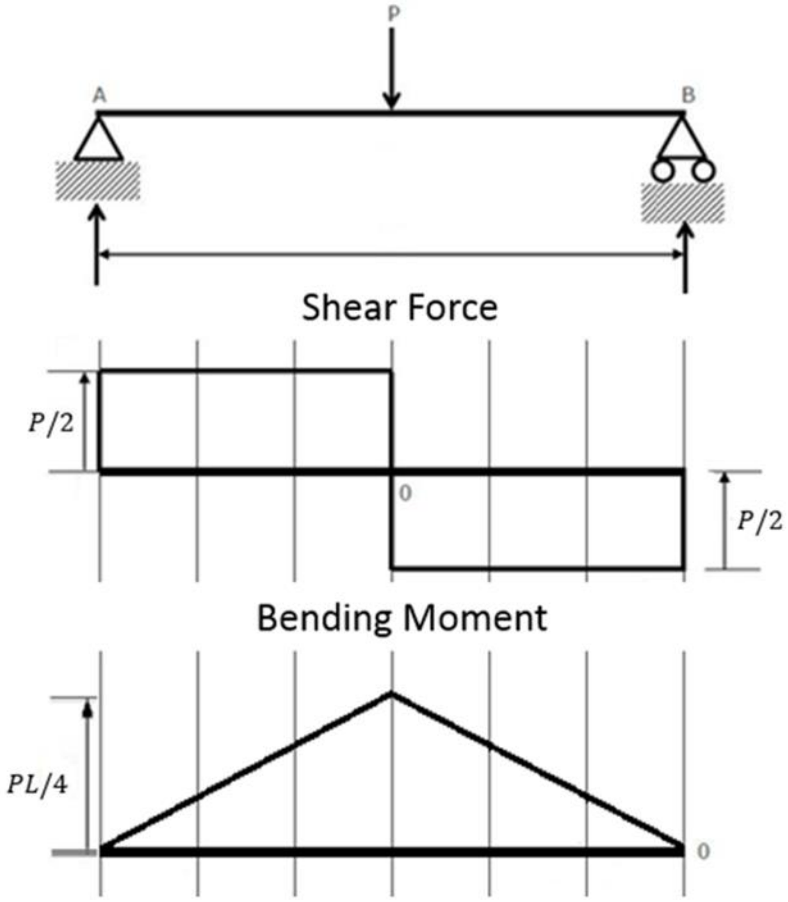


Figure A.1: Shear force and bending moment diagram associated with a simply supported beam experiencing a point load at the centre.

A.5.2 Verification of the bottom flange at the ultimate limit states – Case 1

[§6.7 of BS EN 1993-6]
This clause gives an expression to verify the design resistance $F_{f,Rd}$ of the bottom flange when exposed to a wheel load $F_{z,Ed}$.

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

To calculate the distance $\boldsymbol{n}$, we can rearrange the equation given in §5.8(4) of 1993-6:

$$\mu = \frac{2n}{b - t_w}$$

$$n = \frac{\mu(b - t_w)}{2} = \frac{0.1(177.9 - 7.9)}{2} = 8.5mm$$

$$m = 0.5(b - t_w) - 0.8r - n$$

$$m = 0.5(177.9 - 7.9) - 0.8(10.2) - 8.5$$

$$m = 85 - 8.16 - 8.5 = 68.34mm$$

The distance between the wheel centres x_w is $400mm$, therefore the effective length l_{eff} is given by:

$$l_{eff} = 4\sqrt{2}(m + n)$$

$$l_{eff} = 4\sqrt{2}(68.34 + 8.5) = 434.7mm$$

The stress at the midline of the flange due to overall internal moment in the beam is given by $\sigma_{f,Ed}$, where:

$$\sigma_{f,Ed} = \frac{M\bar{y}}{I} = \frac{121.050 \times 10^6 \times (406.4 - 12.8) \times 0.5}{21600 \times 10^4} = 110.29 \, {}^{N}/_{mm^2}$$

$$F_{f,Rd} = \frac{434.7 \times 12.8^2\left({}^{355}/_{1}\right)}{4(68.34)}\left[1 - \left(\frac{110.29}{{}^{355}/_{1}}\right)^2\right]$$

$$F_{f,Rd} = 92491.74 \times [0.90348] = 83564.44N$$

$$F_{f,Rd} = 83.56kN$$

The following check must be satisfied:

$$F_z < F_{f,Rd}$$

The design point load applied at the ultimate limit states is:

$$F_1 = 78.3kN$$

For a four-wheeled hoist, the design wheel load F_z, becomes:

$$F_{1,z} = \frac{78.3}{4} = 19.6kN \checkmark \; this\ is\ satisfactory.$$

A.5.3 Conservative assessment of torsional effects – Case 1

[§6.2.7(7) of BS EN 1993-1-1]

As a simplification, in the case of members with open cross-sections, such as I or H, it may be assumed that the effects of St. Venant torsion can be neglected.

The requirements given in Clause §5.6.2.4(a) of BS EN 1993-6 state that the torsional moments are to be resisted by couples acting horizontally at the top and bottom flange.

Where the force is given by:

$$F_{w,d} = \frac{T_d}{h - t_f}$$

$$F_{w,1} = \frac{T_1}{h - t_f} = \frac{6.26}{0.406 - 0.0128} = 15.93kN$$

At mid-span, the mid-moment in the flange is:

$$M_{w,Ed,1} = \frac{F_{w,d1}L}{4} = \frac{15.93 \times 6}{4} = 23.88kN$$

A.5.4 Verification of the design bending moment & bending moment resistance – Uniaxial Bending – Case 1

The bending resistance about the major axis $M_{y,Rd}$ for class 1 sections can be obtained from §6.2.5(2) of BS EN 1993-1-1:

$$M_{y,Rd} = \frac{W_{pl,y} f_y}{\gamma_{M0}}$$

$$M_{y,Rd} = \frac{1200 \times 10^{-6}(355 \times 10^6)}{1} = 426kNm$$

The design value of the bending moment MyEd at each cross section must satisfy §6.2.5(1) of BS EN 1993-1-1:

$$\frac{M_{y,Ed}}{M_{y,Rd}} \leq 1.0$$

$$M_{y,Ed,1} = 121.05kNm \quad ; M_{y,Rd} = 426kNm;$$

$$\frac{M_{y,Ed}}{M_{y,Rd}} = 0.28 \checkmark this\ is\ satisfactory.$$

The bending resistance about the minor axis $M_{Z,Rd}$ is:

$$M_{z,Rd} = \frac{W_{pl,z}f_y}{\gamma_{M0}}$$

$$M_{z,Rd} = \frac{209 \times 10^{-6}(355 \times 10^6)}{1} = 74.2kNm$$

The minor axis bending induced by rotation $M_{z,Ed,1}$ is:

$$M_{z,Ed,1} = \emptyset M_{y,Ed}$$

The minor axis bending induced by rotation M_(z,Ed,1) is:

$$a = \sqrt{\frac{EI_w}{GI_T}} = \sqrt{\frac{21 \times 10^{10}(4.66 \times 10^{-7})}{80.7692 \times 10^9(3.33 \times 10^{-7})}} = 1.91$$

$$\frac{L}{a} = \frac{6}{1.91} = 3.14$$

Using graph, A for ϕ Case 3, $\alpha = 0.5$ of SCI P385 [9]

$$\frac{\phi GI_T}{Ta} = 0.3$$

$$\phi = \frac{0.3(6.26)1.91}{80.7692 \times 10^6(3.33 \times 10^{-7})} = 0.1333rads = 7.6°$$

$$M_{z,Ed,1} = 0.1333(121.05) = 16.1kNm$$

$$\frac{M_{z,Ed}}{M_{z,Rd}} = 0.23 \checkmark\ this\ is\ satisfactory.$$

For more information on how to account for the effects of torsion more accurately, the designer is advised to refer to Appendix C & D of 'Steel Beams in Torsion (SCI P385)' [9].

A.5.5 Biaxial bending Effects – Case 1

[§6.2.9.1(6) of BS EN 1993-1-1]

For biaxial-bending of symmetrical I section, the following criterion may be used:

$$\left[\frac{M_{y,Ed}}{M_{y,Rd}}\right]^{\propto} + \left[\frac{M_{z,Ed}}{M_{z,Rd}}\right]^{\beta} \leq 1$$

Where: $\propto = \mathbf{2}$ and $\beta = 5n$ but $\beta \leq 1$

$$\left[\frac{121.05}{426}\right]^{\propto} + \left[\frac{16.1}{74.2}\right]^{\beta} \leq 1$$

$$0.2842 + 0.2170 = 0.5\checkmark\ this\ is\ satisfactory.$$

A.5.6 Elastic critical moment M_{cr}

To calculate M_{cr} for a stabilising load, the free software 'LTBeam' [14] may be used or the formula given in NCCI document [SN003a-EN-EU] [6]. It is conservative to ignore the beneficial stabilising effect.

$$M_{cr} = C_1 \frac{\pi^2 EI_z}{(kL)^2}\left\{\sqrt{\left(\frac{k}{k_w}\right)^2 \frac{I_w}{I_z} + \frac{(kL^2)GI_t}{\pi^2 EI_z} + \left(C_2 z_g\right)^2} - C_2 z_g\right\}$$

$C_1 = 1.348$; $C_2 = 0.630$;

[§6.3.2.2(3) of BS EN 1993-6]

This clause also allows for this stabilizing effect to be taken, however due to the possible effects of swinging hoist loads, in the absence of a more precise analysis the vertical reaction should not be taken as being effectively applied below the level of the top surface of the bottom flange.

Wheel loads are applied below the shear centre, therefore:

$$z_g = -0.19044m$$

$$M_{cr} = 1.348(690872.308)\left\{\sqrt{0.03883 + 0.0389 + 0.01439} + 0.1199\right\}$$

$$M_{cr} = 391703.3Nm$$

The underlying assumption adopted in the use of this expression is that the beam is being supported by fork supports at each end.

A fork support is defined to have the following boundary conditions:

- Translation in x, y and z (Fixed)
- Rotation about x-axis (Fixed)
- Rotation about y-axis (Fixed)
- Rotation about z-axis (Fixed)
- Warping (Free)

When fork supports are used, k and k_w are taken to equal 1.

A.5.6.1 Non-dimensional slenderness

[§6.3.2.2 of 1993-1-1]

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}} \qquad \bar{\lambda}_{LT} = \sqrt{\frac{0.0012 \times 355 \times 10^6}{391703.3}} = 1.04$$

A.5.6.2 Lateral torsional buckling curves for rolled sections

[§6.3.2.3 & NA2.17 of 1993-1-1]

$$\phi_{LT} = 0.5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - \bar{\lambda}_{LT,0}\right) + \beta\bar{\lambda}_{LT}^2\right]$$

$$\frac{h}{b} = 2.28$$

Therefore, buckling curve c must be used, where the imperfection factor is $\propto_{\mathrm{LT}} = 0.49$

$$\phi_{\mathrm{LT}} = 0.5\left[1 + 0.49\left(\bar{\lambda}_{\mathrm{LT}} - 0.4\right) + 0.75\overline{\lambda_{\mathrm{LT}}^{2}}\right]$$

$$\phi_{\mathrm{LT}} = 0.5[1 + 0.49(1.04 - 0.4) + 0.75 \times 1.04^{2}] = 1.06$$

$$\mathcal{X}_{\mathrm{LT}} = \frac{1}{\phi_{\mathrm{LT}} + \sqrt{\phi_{\mathrm{LT}}^{2} - \beta\overline{\lambda_{\mathrm{LT}}^{2}}}}$$

$$\mathcal{X}_{\mathrm{LT}} = \frac{1}{1.06 + \sqrt{1.06^{2} - 0.75(1.04)^{2}}} = \frac{1}{1.06 + \sqrt{0.2809}} = 0.63$$

A.5.6.3 Correction Factor Kc

[§6.3.2.2 of 1993-1-1] kc is a correction factor according to Table 6.6

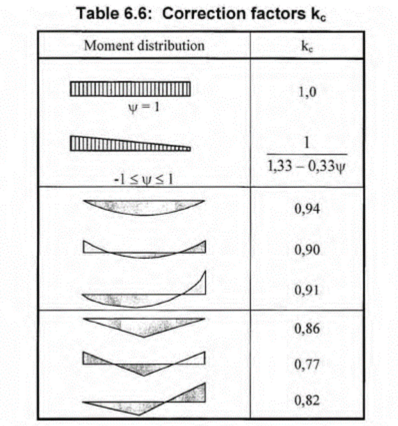


Table 6.6: Correction factors k_c

Moment distribution	k_c
$\psi = 1$	1,0
$-1 \le \psi \le 1$	$\frac{1}{1,33 - 0,33\psi}$
	0,94
	0,90
	0,91
	0,86
	0,77
	0,82

A.5.6.4 Buckling Resistance $\mathbf{M_{b,Rd}}$

[§6.3.2.3(1) of 1993-1-1] Allows for the design buckling resistance of a class 1 cross-sections to be taken as:

$$\mathrm{M_{b,Rd}} = \mathcal{X}_{\mathrm{LT}} \times M_{y,Rd}$$

$$M_{b,Rd} = 0.63 \times 426 = 267.9kNm$$

A.5.6.5 Conservative assessment method for lateral-torsional buckling – Case 1

[A.2 of EN 1993-6] This method may be used to check the lateral-torsional buckling resistance of a simply supported runway beam of uniform cross section, with vertical and lateral horizontal actions applied eccentrically to its shear centre. The actions should be expressed as vertical and horizontal forces applied through the shear centre with the addition of a warping torsional moment T_w.

$$\frac{M_{y,Ed}}{\mathcal{X}_{LT}M_{y.Rk}/\gamma_{M1}} + \frac{C_{mz}M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} + \frac{k_w k_{zw} k_{\alpha} M_{w,Ed}}{M_{w,Rk}/\gamma_{M1}} \le 1$$

$$M_{w,Rd} = M_{pl,f,Rd} = \frac{M_{pl,z,Rd}}{2} = 37.1$$

$$k_w = 0.7 - \frac{0.2M_{w,Ed}}{M_{w,Rk}/\gamma_{M1}} = 0.7 - 0.1283 = 0.57$$

$$k_{zw} = 1 - \frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} = 1 - 0.21698 = 0.78$$

$$k_{cr} = \frac{1}{1 - M_{y,Ed}/M_{y,cr}} = \frac{1}{1 - 121.05/391.7} = \frac{1}{0.69} = 1.45$$

$$\frac{121.05}{267.9} + \frac{0.9 \times 16.1}{74.2} + \frac{0.57 \times 0.78 \times 1.45 \times 23.8}{37.1} \leq 1$$

$$0.45 + 0.2 + 0.41 = 1.06\ this\ is\ unsatisfactory$$

A.5.6.6 Verification for lateral-torsional buckling accounting for torsion effects – Case 1

The warping moment used in 5.6 is conservative, to obtain a more accurate value that accounts for the effects of torsion, the following equation may be used:

$$M_w = \frac{EI_w\phi''(h - t_f)}{2}$$

Using graph B, for ϕ'' Case 3, $\alpha = 0.5$, of SCI P385

$$\frac{\phi'' GI_T a}{T} = 0.46$$

$$\phi'' = \frac{0.46T}{GI_T a} = \frac{0.46 \times 6.26}{1.91 \times 80.7692 \times 10^6 \times 3.33 \times 10^{-7}} = 0.056\ {rads}/{m^2}$$

For more information on how to account for the effects of torsion more accurately, the designer is advised to reference Appendix C & D of 'Steel Beams in Torsion (SCI P385)' [9].

For bi-symmetric I sections, the warping moment may be expressed as:

$$M_w = \frac{EI_f\phi''(h - t_f)}{2}$$

$$M_w = \frac{21 \times 10^{10}(6 \times 10^{-6})0.06 \times 10^{-3}(393.6)}{2} = 13.9kNm$$

$$k_w = 0.7 - \frac{0.2M_w}{M_w/\gamma_{M1}} = 0.7 - \frac{0.2 \times 13.9}{37.1} = 0.63$$

$$\frac{M_{y,Ed}}{\chi_{LT}M_{y.Rk}/\gamma_{M1}} + \frac{C_{mz}M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} + \frac{k_w k_{zw} k_\alpha M_{w,Ed}}{M_{w,Rd}/\gamma_{M1}} \leq 1$$

$$\frac{121.05}{267.9} + \frac{0.95 \times 16.1}{74.2} + \frac{0.63 \times 0.78 \times 1.45 \times 13.9}{37.1} \leq 1$$

$$0.45 + 0.2 + 0.27 = 0.92 \checkmark\ this\ is\ satisfactory.$$

A.6.0 Load Case 2

A.6.1 – Load induced when the hoist is travelling on the runway

The dynamic factor φ_4 is induced when the hoist block is travelling on rail tracks or runways, it has a value of 1 when the tolerances for rail tracks or rolled structural sections specified in EN 1993-6 are observed.
When the load is travelling over a gap or a step the dynamic factor φ_4 should be calculated in accordance with §4.2.2.4 of EN 13001-2.

This case assumes the hoist unit is travelling on an even surface and the beam tolerances are met, therefore:

$$Q_{2,\varphi 4} = \varphi_4 Q_h = 1 \times 50 = 50kN$$

$$Q_{2,\varphi 4} = \varphi_4 Q_c = 1 \times 2.5 = 2.5kN$$

The vertical load F_2 is then determined as follows:

$$F_2 = 1.35Q_{2,\varphi 4} + 1.35Q_{2,\varphi 4}$$

$$F_2 = 67.5 + 3.375 = 70.9kN$$

In the case of fixed runway beams for monorail underslung trolleys the longitudinal horizontal forces $H_{L,k}$ should be taken as 5% of the maximum vertical wheel load.

$$H_k = 0.05 \times \frac{F_2}{4}$$

$$H_2 = 0.05 \times 17.725 = 0.88625kN$$

$$H_{L,2,\varphi 5} = \varphi_5 \times H_2 = 1.5 \times 886.25 = 1329.4N$$

Now we must consider the effects of tension or compression arising from the longitudinal horizontal actions H_k. Where the following condition must be satisfied:

$$\frac{N_{Ed}}{N_{c,Rd}} \leq 1$$

$$\frac{H_{2,\varphi 5}}{N_{c,Rd}} = \frac{1329.4}{2715750} = 0.0004895 \checkmark this\ is\ satisfactory$$

A.7 Test Loads

A.7.1 Load case 3 – Dynamic test loads

[§2.10.4 of EN 1991-3]

$$\mathrm{F}_{3,\varphi 6} = (\mathrm{Q_c} \times \varphi_1) + (\mathrm{Q_T} \times \varphi_6)$$

$$Q_{T,dynamic} = 1.1 \times 50 = 55$$

$$\varphi_{6,dynamic} = 0.5(1 + \varphi_2) = 1.1$$

$$F_{3,\varphi 6} = (2.5 \times 1.1) + (1.1 \times 55)$$

$$F_{3,\varphi 6} = 60.543kN$$

A.7.2 Load case 4 – Static test loads

[§2.10.4 of EN 1991-3]

$$F_{4,\varphi 6} = \left(Q_c \times \varphi_1\right) + \left(Q_T \times \varphi_6\right)$$
$$Q_{T,static} = 1.25 \times 50 = 62.5$$
$$\varphi_{6,static} = 1$$
$$F_{4,\varphi 6} = \left(2.5 \times 1.1\right) + \left(62.5 \times 1\right)$$
$$F_{4,\varphi 6} = 64.010kN$$

A.8.0 Load Case 5 - Longitudinal horizontal force K induced by the drives when the hoist is loaded

[§2.7.2 of EN 1991-3]

In the case of fixed runway beams for monorail underslung trolleys the longitudinal horizontal forces $H_{L,k}$ should be taken as 5% of the maximum vertical wheel load, neglecting the dynamic factor

$$H_{L,k} = 0.05 \times F_k$$

$$H_{L,5} = 0.05 \times 52.5 = 2.63kN$$

In this load case the vertical loads should be composed of the self-weight of the hoist block, the load, and the partial factor. This load case considers the induced horizontal loads K arising from the hoist drive, if the drive force K, cannot be obtained from the crane supplier then:

$$K = K_1 + K_2 = \mu \sum Q^*_{r,max}$$
$$K = \mu \times m_w \times Q_{r,max}$$
$$K = 0.2 \times 1 \times \frac{78.3}{4} = 3.915kN$$

For this example, we will assume that the drive forces change smoothly, φ_5:

$$H_k = \varphi_5 K = 1.5 \times 3915 = 5872.5N$$

$$H_5 = 5872.5N$$

Now we must consider the effects of tension or compression arising from the longitudinal horizontal actions H_k. The following conditions must be satisfied:

$$\frac{N_{Ed}}{N_{c,Rd}} \leq 1$$

$$\frac{H_5}{N_{c,Rd}} = \frac{5872.5}{2715750} = 0.002 \checkmark \; this\ is\ satisfactory$$

A.9.0 Load case 6 – Transverse horizontal force related to the acceleration or deceleration of the trolley

[§2.11 of EN 1991-3]

Clause §2.7.5 of 1991-3 allows for the horizontal transverse force to be accounted for through the use of clause §2.11, therefore;

Provided that the payload is free to swing, the horizontal transverse force $H_{T,6,\varphi 7}$ can then be calculated by:

$$F_6 = \left(Q_c \times 1\right) + \left(Q_h \times 1\right)$$

$$F_6 = 52.5kN$$
$$F_{z,6} = \frac{52.5 \times 10^3}{4} = 13125N$$

$$H_{T,6} = H_{B,2} = 0.10F_{z,6} = 1312.5N$$

The lateral loads are applied eccentrically to the shear centre of the beam creating minor axis bending and a torsional moment. As a result, we must consider the effects of biaxial bending and torsion arising from the vertical actions and the lateral horizontal loads

A.10 Load case 7 – Longitudinal horizontal force arising from collisions in between the

hoist and the buffers

[§2.11.1 of EN 1993-1]

Where buffers are used, the forces on the crane supporting structure arising from collision with the buffers shall be calculated from the kinetic energy of all relevant parts of the crane.

$$H_{L,7,\varphi 7} = H_{B,1} = \varphi_7 v_1 \sqrt{m_c S_B}$$

Hooke's law states that the spring constant will be the slope of the force-displacement graph, since we are using linear elastic analysis, $S_B = 1, \xi_b = 0.5$.

$$H_{B,1} = \varphi_7 v_1 \sqrt{m_c S_B}$$

$$H_{B,1} = 1.25 \times 0.3 \times \sqrt{5250}$$

$$H_{L,7,\varphi 7} = H_{B,1} = 27.2N$$

A.11.0 Load case 8 – Serviceability Limit States

The stresses and displacements should be determined by linear elastic analysis. In addition to the ultimate limit state criteria, the criteria outlined in §7.1 of BS EN 1993-6 should also be satisfied. These are as follows:

1. Deformations and displacements §7.3
2. Plate Slenderness to avoid excessive breathing that might result in fatigue at, or adjacent to, the web-to-flange connections §7.4
3. Stresses, to ensure reversible behaviour §7.5
    A. The action effects on runways due to temperature variations shall be considered where necessary. In general, non-uniform distributed temperature need not be considered. §2.8(1) of BS EN 1991-3.
    B. §5.4.1(2) For crane supporting structures where fatigue resistance is required, elastic global analysis is recommended. If plastic global analysis is used for the ultimate limit state verification, a serviceability limit state stress check should also be carried out in accordance with §7.5.

Where:
SLS Partial factor – $\gamma_g = 1$;
Serviceability Limit Load $F_{8,sls} = \gamma_g(Q_h + Q_c) = F_{8,sls} = 52.5kN$

A.11.1 Local bending stresses in the bottom flange due to wheel loads – Case 8

[§5.8 of BS EN 1993-6]

The following method should be used to determine the local bending stresses in the bottom flange due to wheel loads. Provided that the distance x_w between adjacent wheel loads is not less than 1.5b and the application of the wheel loads occurs at a distance larger than b from the end of the beam.
The force will be uniformly distributed amongst its four wheels therefore:

$$F_{z,Ed,sls} = \frac{F_{sls}}{4} = \frac{52.5}{4} = 13.13kN$$

Then the bending stresses should be obtained from these equations:

$$\sigma_{ox.Ed} = {c_x F_{z,Ed}}/{t_1^2}$$

$$\sigma_{oy.Ed} = {c_y F_{z,Ed}}/{t_1^2}$$

As a simplification, we can utilize the coefficients below according to clause §5.8(5) but only if we apply the wheel loads near the outside edges of the flange.

The relevant coefficients that conform with this condition i.e. $\mu = 0.10$ appear in table below.

Stress Coefficient	Parallel flange beams
C_{x0}	0.2
C_{x1}	2.3
C_{x2}	2.2
C_{y0}	-1.9
C_{y1}	0.6
C_{y2}	0.0

Table A.3: Coefficients for calculating local stresses at locations 0, 1 and 2

$$\sigma_{x0.Ed} = {0.2 \times 13.13 \times 10^3}/{12.8^2} = 16.03MPa$$

$$\sigma_{x1.Ed} = {2.3 \times 13.13 \times 10^3}/{12.8^2} = 184.32MPa$$

$$\sigma_{x2.Ed} = {2.2 \times 13.13 \times 10^3}/{12.8^2} = 176.31MPa$$

$$\sigma_{y0.Ed} = {-1.9 \times 13.13 \times 10^3}/{12.8^2} = -152.26MPa$$

$$\sigma_{y1.Ed} = {0.6 \times 13.13 \times 10^3}/{12.8^2} = 48.08MPa$$

Position	Longitudinal Local Stress $\sigma_{0x.Ed}$ (MPa)	Transverse Local Stress $\sigma_{0y.Ed}$ (MPa)
0	16.03	-152.26
1	184.32	48.08
2	176.31	0

Table A.4: Longitudinal and transverse local stresses at locations 0, 1 and 2

A.11.2 Global stresses – Case 8

The longitudinal global stress $\sigma_{x,Ed,ser}$ is given by:

$$\sigma_{global,ser,Ed} = \frac{F_{sls} \times L \times \bar{y}}{4I_y} = \frac{52.5 \times 10^3 \times 6 \times 406.4 \times 0.5 \times 1000}{4 \times 21600 \times 10^4} = 74.08MPa$$

A.11.3 Shear stresses – Case 8

These shear stresses can be obtained using several clauses, some are more accurate than others. We will check the reversibility behaviour of the stress obtained through A.11.3.3 and clause §6.2.6(3).
At the supports

$$V_{Ed,sls} = \frac{Q_h + Q_c}{2} + \frac{G_{k,j}L}{2}$$

$$V_{Ed,sls} = \frac{52.5}{2} + \frac{0.59 \times 6}{2} = 26250 + 1.77 = 28.02kN$$

A.11.3.1 Conservative shear stress – Case 8

[§6.2.6(5) of EN 1993-1-1]

If the limits specified in clause 6.2.6(5) are met, which in this case they are, then the following equation may be used:

$$\tau_{Ed} = \frac{V_{Ed,sls}}{A_w} = \frac{28.02 \times 10^3}{3008.32} = 9.31MPa$$

A11.3.2 Shear stress – Case 8

[§6.2.6(4) of EN 1993-1-1]

The simplification allowed for in §6.2.6(5) is conservative, elastic design also allows for the shear stress to be obtained from clause §6.2.6(4), where τ_{Ed} is given by:

$$\tau_{Ed} = \frac{V_{Ed}S}{It}$$

Where:
S is the first moment of area about the centroidal axis of that portion of the cross-section between the point at which the shear is required and the boundary of the cross-section.
The portion of the cross-section desired is the section of the beam acting in compression, this constitutes the top flange and one fifth of the web as outlined in §6.3.2.3, an alternative assessment method can be found in Annex A of EN 1993-6

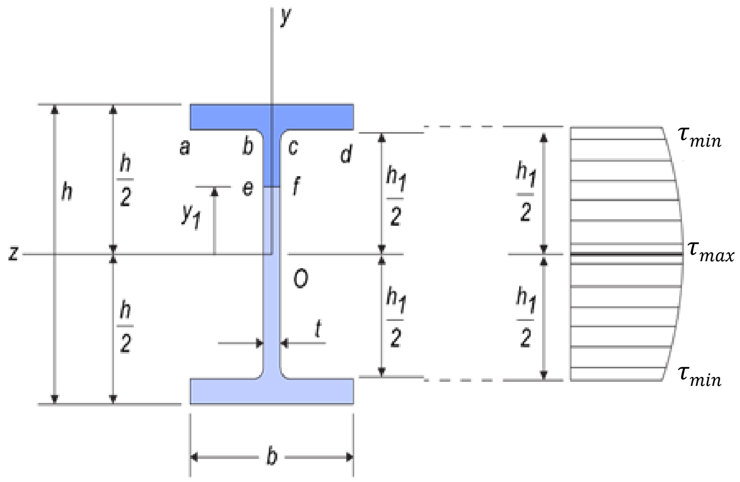


Figure A.2: Nomenclature for calculating shear stress using the formula given in §6.2.6(4)

Following this nomenclature, we can derive and solve S to obtain τ_{Ed} for clause §6.2.6(4).

$$A_{flange} = b(t_f) = 177.9(12.8) = 2277.12$$

$$h_1 = h - 2t_f = 406.4 - 2(12.8) = 380.8$$

$$y_1 = \frac{h_1}{2} - \frac{h_1}{5} = 114.24$$

$$A_{\frac{1}{5}web} = t\left(\frac{h_1}{2} - y_1\right) = 7.9\left(\frac{380.8}{2} - 114.24\right) = 598.5$$

$$S = A_{flange}\left(\frac{h_1}{2} + \frac{h/_2 - h_1/_2}{2}\right) + A_{\frac{1}{5}web}\left(y_1 + \frac{h_1/_2 - y_1}{2}\right)$$

$$S = 2277.12\left(\frac{380.8}{2} + \frac{406.4/_2 - 380.8/_2}{2}\right) + 598.5\left(114.24 + \frac{380.8/_2 - 114.24}{2}\right)$$

$$S = 2277.12(196.8) + 598.5(152.32)$$

$$S = 448137.216 + 91163.52 = 539300.74$$

$$\tau_{Ed} = \frac{28.02 \times 10^3(539300.74)}{21600 \times 10^4 \times 7.9} = 8.85MPa$$

A.11.3.3 Shear stress – Case 8

[§6.2.6(3) of EN 1993-1-1]

$$V_{Ed} = \frac{G_1 + G_2}{2} + \frac{G_{k,j}L}{2} = \frac{52.5 \times 10^3}{2} + \frac{0.59 \times 10^3 \times 6}{2} = 26250 + 1770 = 28020N$$

Clause §6.2.6(3) allows for the shear area to be taken as $A_v = A - 2bt_f + (t_w + 2r)t_f$

$$A_v = 7650 - (2 \times 177.9 \times 12.8) + \big(7.9 + 2 \times 10.2\big)12.8$$

$$A_v = 7650 - 4554.24 + 362.24 = 3458mm^2$$

$$\tau_{xy,Ed,ser} = \frac{V_{Ed}}{A_v} = \frac{28020}{3458} = 8.1MPa$$

§6.2.7(9) Allows for I beam sections to ignore the effects of St. Venant torsion, we will use this simplification to calculate the design shear plastic resistance in accordance with §6.2.6(2).

A.11.4 Nominal stresses for monorail hoist blocks – Case 8

[§7.5(3) of BS EN 1993-6]

The nominal stresses for runway beams with a monorail hoist block or an underslung crane should include local stresses in addition to the global stresses, therefore:
Location 1

$$\sigma_{x,Ed,ser} = \sigma_{x1.Ed} + \sigma_{global,x,ser,Ed}$$

$$\sigma_{x,Ed,ser} = 184.32 + 74.08 = 258.40MPa$$

$$\sigma_{y,Ed,ser} = 48.08MPa$$

$$\tau_{xy,Ed,ser} = 8.1MPa$$

A.11.5 Reversible behaviour stress check – Case 8

The following criteria from §7.5 must be satisfied:
The maximum allowable direct stress is:

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

§NA2.12 allows for γM,ser to be taken as 1.1

$$\sigma_{Ed,ser} \leq {}^{355}/_{1.1}$$

$$\sigma_{Ed,ser} \leq 322.72 \checkmark \; this\ is\ satisfactory$$

The maximum allowable shear stress is:

$$\tau_{Ed,ser} \leq {}^{f_y}\!/_{\sqrt{3}\gamma_{M,ser}}$$

$$\tau_{Ed,ser} \leq {}^{355}\!/_{1.1\sqrt{3}}$$

$$\tau_{Ed,ser} \leq 186.33\checkmark \; this\ is\ satisfactory$$

Checks in accordance with expressions 7.2c and 7.2d from BS EN 1993-6.

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

$$\sqrt{258.4^2 + 3(8.1)^2} \leq {}^{355}\!/_{1.1}$$

$$258.8 \leq 322.72\checkmark \; this\ is\ satisfactory$$

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

$$\sqrt{(258.4)^2 + (48.8)^2 + (258.4)(48.08) + 3(8.1)^2} \leq {}^{f_y}\!/_{\gamma_{M,ser}}$$

$$\sqrt{66770.56 + 2381.44 + 12443.104 + 172.82} = 286$$

$$286 \leq 322.72\checkmark \; this\ is\ satisfactory$$

A.11.6 Deflection of the Beam – Case 8

[§7.3 of BS EN 1993-6]

The vertical deformation δ_z should be taken as the total deformation due to vertical loads, less the possible pre-camber, as for max δ_{max} in figure A.1.1 of EN 1990

$$\delta_z = \frac{PL^3}{48EI}$$

$$\delta_z = \frac{52.5 \times 10^3 \times 6000^3}{48 \times (210000) \times 21600 \times 10^4} = 5.2mm$$

A.11.6.1 Deflection Limits – Case 8

[§Table 7.1 & 7.2]

Note: The limits given in table 7.1 are recommended for horizontal deflections under characteristic combination of actions, whereas those limits given in table 7.2 are recommended for vertical deflections under characteristic combination of actions without any dynamic amplification factors, therefore:

$$\delta_{z,limit} \leq {}^{L}\!/_{500}$$

$$\delta_{z,limit} \leq {}^{6000}\!/_{500} = 12mm$$

Therefore:

$$5.2 < 12 \checkmark \; this\ is\ satisfactory$$

A.11.7 Vibration of the bottom flange – Case 8

[§7.6 of EN 1993-6]

Lateral vibration of the bottom flange of a simply supported crane runway beam should be avoided.

As a result, we must perform a vibration check for the bottom flange.

This check is satisfied if:

$$L/_{i_z} < 250$$

Since the flanges carry most of the second moment of area, as a simplification we can assume that the moment of inertia of the flange is half of its respective moment of inertia, therefore:

$$i_{zz} = \sqrt{\frac{I_z}{2 \times A_{flange}}} = \sqrt{\frac{1200 \times 10^4}{2 \times 2277.12}} = 51.3mm$$

$$i_{zy} = \sqrt{\frac{I_y}{2 \times A_{flange}}} = \sqrt{\frac{21600 \times 10^4}{2 \times 2277.12}} = 217.9mm$$

$$L/_{i_{zz}} = {}^{6000}/_{51.3} = 117 \checkmark \; this\ is\ satisfactory$$

$$L/_{i_{yy}} = {}^{6000}/_{217.9} = 27.5 \checkmark \; this\ is\ satisfactory$$

A.12.0 Load Case 9 – Fatigue Assessment

Guidance on the fatigue verification of a runway beam can be found in chapter 13.0 of LEEA Guide to the Verification of Crane Systems using the Allowable Stress Method.

A.13.0 Limitation of Web Breathing

[§7.4 of EN 1993-6]

The slenderness of web plates should be limited to avoid excessive breathing that might result in fatigue at, or adjacent to, the web-to-flange connections.

Excessive web breathing may be neglected in web panels without longitudinal stiffeners when the ratio is:

$$b/_{t_w} < 120$$

$${}^{406.4}/_{7.9} = 51$$

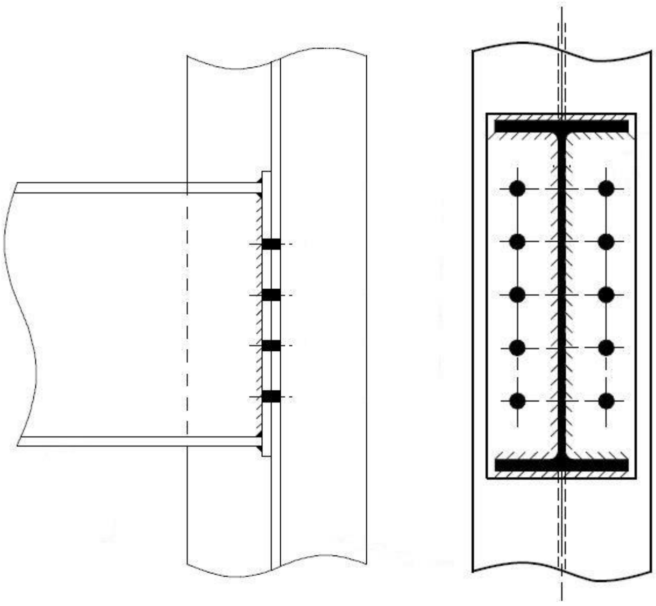
$$51 < 120 \checkmark \; this\ is\ satisfactory$$

A.14.0 Conclusion

The calculations associated with the verification of a runway beam with an underslung hoist unit in accordance with the Eurocodes were illustrated in the worked example.

The worked example shows that the runway beam satisfies the criteria outlined in the Eurocodes

Annex B
Worked Example for the Verification of Beam to Column Connections



The following section seeks to provide pertinent information, design recommendations and a worked example highlighting the design checks necessary for the verification of nominally pinned joints.

B.1.0 Verification of nominally pinned joints

Nominally pinned joints should be used for these simple connections.

Verifying the strength of a nominally pinned joint involves three stages:

- Ensuring that the joint is detailed such that it develops only nominal moments which do not adversely affect the members or the joint itself.
- The joint should be detailed so that it behaves in a ductile manner.
- Identifying the load path through the joint i.e. from the beam to the supporting member.
- Checking the resistance of each component.

B.2.0 Full depth end beam to column connections

Full depth end plates welded all around the supported beam will provide an increased resistance to tying and (where vertical resistance is governed by web shear) an enhanced vertical resistance compared to partial depth end plates. If the recommended detailing rules are followed, then a full depth end plate has sufficient flexibility to be classified as a nominally pinned joint.

This worked example covers the necessary design checks for a one-sided beam to column connection, the full depth end plate is welded at the end of the beam, which is then bolted onto the column.

B.3.0 Design recommendations

B.3.1 End plates

A 150 x 10mm flat plate with bolts at 90mm cross centres will generally be adequate for beams up to 457mm deep. For deeper beams, a 200 x 12mm flat is recommended with a 140mm bolt gauge. End plates of this thickness with reasonable edge and end distances, will be adequate in most situations.

Increasing the end plate thickness above this value may lead to an increased moment resistance which does not satisfy BS EN 1993-1-8 requirements for pinned connections.

The minimum length of the end plate should be 60% of the height of the beams cross section, i.e. $0.6h_{Beam}$.

For joints subject to fatigue, minimum and maximum spacing as well as end and edge distances are given in EN 1993-1-9.

B.3.2 Welds

The weld must be performed by a competent welder, they must hold the relevant welder qualification test certificate with a range of approval that qualifies them for the weld in question, the welder must also follow a suitable weld procedure specification that must be supported by a procedure qualification record.

This will ensure the quality of the weld meets the specified levels of weld quality and mechanical strength.

All welds should be subject to inspections however where project requirements dictate, especially where proof load testing is to be carried out, the welded component will be subject to a suitable NDT method. For fillet welds this would typically be MPI. These inspections will be carried out by independent and suitably qualified operatives holding PCN qualification and the permissible quality imperfection levels will be defined in accordance with BS EN ISO 5817, which specifies different types of imperfections and the limits put on these for different quality levels (D, C & B).

If proof load testing is to be carried out, then it is common practice to carry out an MPI and visual inspection of welds prior to testing and also after testing to ensure that the forces involved in overloading the fabrication have not caused cracking.

Once NDT has been successfully carried out a report will be issued by the NDT technician to confirm that all the welds were satisfactorily inspected as per the requirements.

For these connections, full strength welds are adequate, but it is important to note that the minimum requirement for the weld is that the end plate should yield before the weld fractures. The welds used for these connections are typically simple fillet welds carried out by a metal arc process in accordance with BS EN 1011-1.

In crane supporting structures, intermittent fillet welds should not be used where they would result in the formation of rust pockets. They can be used where the connection is protected from the weather, e.g. inside box sections.

Intermittent fillet welds should not be used for the web-to-flange connections of runway beams where the welds are subject to local stresses due to wheel loads.

For high fatigue crane classes, transverse web stiffeners or other attachments should not be welded to the top flanges of runway beams. Cranes are high fatigue if they are classified as $\boldsymbol{S_7}$ to $\boldsymbol{S_9}$ in accordance with Annex B of EN 1991-3.

The following weld properties are recommended:

Typical fillet welds length s,

$s = 6\ to\ 8mm$

Normal design	S275	S355
	$a = 0.40t_w$	$a = 0.48t_w$

Table B.1 Weld throat thickness a for different steel grades

In almost all cases, the tying force will be no more than the shear force and the weld size for normal design may be adopted. If the tying force were larger than the shear force, the weld should be in accordance with the standard'. [10]

Note: All welded constructional details subjected to cyclical loading should be verified through fatigue analysis, more information can be found on §8 of EN 1993-1-8.

B.3.3 Bolts, Holes & Washers

Bolts

For bolts used in lifting applications, the minimum recommended grade is 8.8 therefore M20 8.8 fully threaded 60mm long bolts are recommended, although some heavily loaded connections may need larger diameter bolts.

Where joint slip is unacceptable or when deformation is cause for concern, the use of 8.8 preloaded bolts is recommended. Only bolt assemblies of classes 8.8 and 10.9 conforming to the requirements given in 1.2.4 Reference Standards: Group 4 for High Strength Structural Bolting for preloading with controlled tightening in accordance with the requirements in 1.2.7 Reference Standards: Group 7 may be used as preloaded bolts

Washers

For 8.8 bolts a washer shall be used under the bolt head or the nut, whichever is to be rotated.

Dimensions and steel grades of plate washers shall be specified, and they shall not be thinner than 4mm.

Holes

Punching holes is permitted provided that the nominal thickness of the component is not greater than the diameter of the hole, or for a non-circular hole, its minimum dimension.

Holes of 22mm or 26mm can be safely punched through grade S275 material up to 12mm thick.

Hole diameter, d_0

$d_0 = d + 2mm$ for $d < 24mm$
$d_0 = d + 3mm$ **for** $d > 24mm$

B.3.4 Surge Connectors

[§8.3 of EN 1993-6]

Surge connectors attaching the top flange of a runway beam to the supporting structure should be capable of accommodating:

- The movements generated by the end rotation of the runway beam due to vertical loading,
- The movements generated by the end rotation of the top flange of the runway beam due to lateral crane forces,
- The vertical movements associated with the vertical compression of the runway beam and its support, plus wear and settlement of the bearings of the runway beam.

The detailing of the surge connectors and their connections should consider the possible need for lateral and vertical adjustment of the runway beams in order to maintain the alignment of the crane runway, whilst also respecting the tolerance on location of the rail relative to the centreline of the web of the runway beam.

At supports where no surge connectors are used, the runway beam and the fasteners should be designed to transmit all vertical and horizontal force from the crane wheels to the support

B.4.0 Design Information

Beam UKB 406 x 178 x 60 S355	Column UKC 305 x 305 x 137 S275	Bolts M20 grade 8.8
$t_f = 12.8mm$; $t_w = 7.9mm$; $h_{Beam} = 406.4mm$; $f_y = 355\ {}^{N}/_{mm^2}$	$t_w = 13.8mm$; $t_f = 21.7mm$; $f_y = 275\ {}^{N}/_{mm^2}$	Bolt diameter, $d = 20mm$ Gauge, $p_3 = 90mm$; $n_1 = 4$ rows; $n = 8$ bolts; Table 3.1 of EN 1993-1-8: $f_{yb} = 640\ {}^{N}/_{mm^2}$; $f_{ub} = 800\ {}^{N}/_{mm^2}$
End Plate 150 x 10 S275	Holes $d_0 = 22mm$	Welds $s = 6mm$
$f_y = 275\ {}^{N}/_{mm^2}$; $f_u = 410\ {}^{N}/_{mm^2}$	Hole diameter, d_0 $d_0 = d + 2mm$ for $d < 24\boldsymbol{mm}$ $d_0 = d + 3mm$ for $d > 24mm$	Typical fillet weld length $\boldsymbol{s}$ $s = 6\ to\ 8mm$

Table B.2: Design Information

B.5.0 Design Checks

B.5.1 Design Recommendations – Check 1

End plate: 150 x 10mm thick

Web bolts: 20mm diameter at 90mm cross centres

Spacing, end and edge distances in accordance with figure 3.1 of EN 1993-1-8:

$$e_1 \geq 1.5d;\ e_1 \geq 30;\ e_1 = 30mm$$
$$e_2 \geq 1.5d;\ e_2 \geq 30;\ e_2 = 30mm$$
$$p_1 \geq 2.5d;\ p_1 \geq 50;\ p_1 = 70mm$$
$$p_2 \geq 2.5d;\ p_2 \geq 50;\ p_2 = 90mm$$

The recommendations for the connection details were followed. ✓

B.5.2 Weld Properties – Check 2

Requirement:

$a \geq 0.48 t_{w,beam}$ for S355

$$a \geq 0.48 \times 7.9 \geq 3.792mm$$
$$a = 0.7s = 0.7 \times 6$$
$$a = 4.2mm\ ✓$$

B.5.3 Web of the Runway Beam in Shear – Check 3

Shear resistance of beam web at the end plate.

Requirement:

[§6.2.6 of EN 1993-1-1]

$$V_{Ed} \leq V_{c,Rd}$$

$A_v = A - 2bt_f + (t_w + 2r)t_f$;
$A_v = 3458mm^2$;

$$V_{c,Rd} = A_V \frac{f_{y,beam}}{\sqrt{3}\gamma_{M0}}$$

$$V_{c,Rd} = 3458 \frac{355}{\sqrt{3}} \times 10^{-3} = 708.74kN$$

$$41.55 < 708.74 \checkmark \ this\ is\ satisfactory$$

B.5.4 Bolt Group – Check 4

Requirement:

$$V_{Ed} \leq F_{Rd}$$

Shear resistance of a single bolt:

[Table 3.4 of EN 1993-1-8]

$$F_{v,Rd} = \frac{\alpha_v f_{u,bolt} A}{\gamma_{M2}}$$

$$F_{v,Rd} = \frac{0.6 \times 800 \times 245}{1.25} \times 10^{-3} = 94.08kN$$

A can be taken as the tensile area of the bolt A_s.

Bearing resistance of a single bolt:

[Table 3.4 of EN 1993-1-8]

$$F_{b,Rd} = min(F_{b,Rd,plate}; F_{b,Rd,2})$$

Bearing on the supporting member:

$$\frac{k_{1,2}\alpha_{b,2}f_{u,2}dt_2}{\gamma_{M2}}$$

Bearing on the end plate:

$$F_{b,Rd,plate} = \frac{k_{1,p}\alpha_{b,p}f_{u,p}dt_p}{\gamma_{M2}}$$

For inner bolts, $k_{1,p}$:

$$k_{1,p} = min\left(\frac{1.4p_2}{d_0} - 1.7; 2.5\right)$$

For edge bolts, $\boldsymbol{k_{1,p}}$:

$$k_{1,p} = min\left(\frac{2.8e_2}{d_0} - 1.7; \frac{1.4p_2}{d_0} - 1.7; 2.5\right)$$

$$k_{1,p} = min\left(\frac{2.8 \times 30}{22} - 1.7; \frac{1.4 \times 90}{22} - 1.7; 2.5\right)$$

$$k_{1,p} = min(2.12; 4.03; 2.5)$$

$$k_{1,p} = 2.12$$

$$\alpha_{b,p} = min\left(\frac{p_1}{3d_0} - \frac{1}{4}; \frac{f_{u,bolt}}{f_{u,plate}}; 1.0\right)$$

$$\alpha_{b,p} = min\left(\frac{70}{3 \times 22} - \frac{1}{4}; \frac{800}{410}; 1.0\right)$$

$$\alpha_{b,p} = min(0.81; 1.7; 1.0)$$

$$\alpha_{b,p} = 0.81$$

$$F_{b,Rd,plate} = \frac{2.12 \times 0.81 \times 410 \times 20 \times 10}{1.25} \times 10^{-3} = 112.65kN$$

Bearing on the supporting column:

The thickness of the web of the supporting column is thicker than the end plate thickness, the bolt spacing as well as the end and edge distances are the same as those in the end plate, both the column and the end plate have the same yield strength. Therefore, the bearing resistance of the supporting column will be greater than that obtained for the end plate, calculating for the end plate, we find that:

$$0.8F_{v,Rd} < F_{b,Rd}$$

$$0.8F_{v,Rd} = 0.8 \times 94.08 = 75.26kN$$

$$F_{b,Rd,p} = 112.65$$

$$75.26 < 112.65 \checkmark this\ is\ satisfactory$$

Therefore:

$$V_{Ed} < F_{Rd}$$

$$F_{Rd} = 0.8nF_{v,Rd} \text{ [12]}$$

$$F_{Rd} = 0.8 \times 8 \times 94.08 = 602kN$$

$$41.55 < 602 \checkmark this\ is\ satisfactory$$

B.5.5 Local shear resistance of supporting column web – Check 5

Requirement:

$$\frac{V_{Ed}}{2} \leq V_{Rd,min}$$

Local shear resistance of supporting member, $V_{Rd,min}$:

[§6.2.6(2) of EN 1993-1-1]

$$V_{Rd,min} = min\left(\frac{A_v f_{y,2}}{\sqrt{3}\gamma_{M0}}; \frac{A_{v,net} f_{u,2}}{\sqrt{3}\gamma_{M2}}\right)$$

Where:

t_2 is the thickness of the supporting member, i.e. $t_{w,column}$;

$t_{w,column} = 13.8mm$ hence $f_y = 265\ {}^{N}/_{mm^2}$

$e_t = min(e_{1,t}; 5d)$;

Since the connection is not near the top of the column,

$$e_t = 5 \times 20 = 100mm$$

$$e_b = min\left({}^{p_3}/_2 ; 5d\right);$$

$$e_b = \left({}^{90}/_2 ; 100\right)$$

$$e_b = 45mm$$

A_v is the shear area of the supporting member;

$A_v = (e_t + (n_1 - 1)p_1 + e_b)t_2$;

$$A_v = (e_t + (n_1 - 1)p_1 + e_b)t_{w,column}$$

$$A_v = (100 + (4 - 1)70 + 45)13.8 = 4889mm^2$$

$$\frac{A_v f_{y,2}}{\sqrt{3}\gamma_{M0}} = \frac{4889 \times 265}{\sqrt{3}} \times 10^{-3} = 749kN$$

$A_{v,net}$ is the net shear area of the supporting member;

$A_{v,net} = A_v - n_1 d_0 t_2$;

$$A_{v,net} = 4899 - (4)22(13.8) = 3685mm^2$$

Shear resistance of the net section is:

$$\frac{A_{v,net} f_{u,2}}{\sqrt{3}\gamma_{M2}} = \frac{3685 \times 410}{1.25\sqrt{3}} \times 10^{-3} = 698kN$$

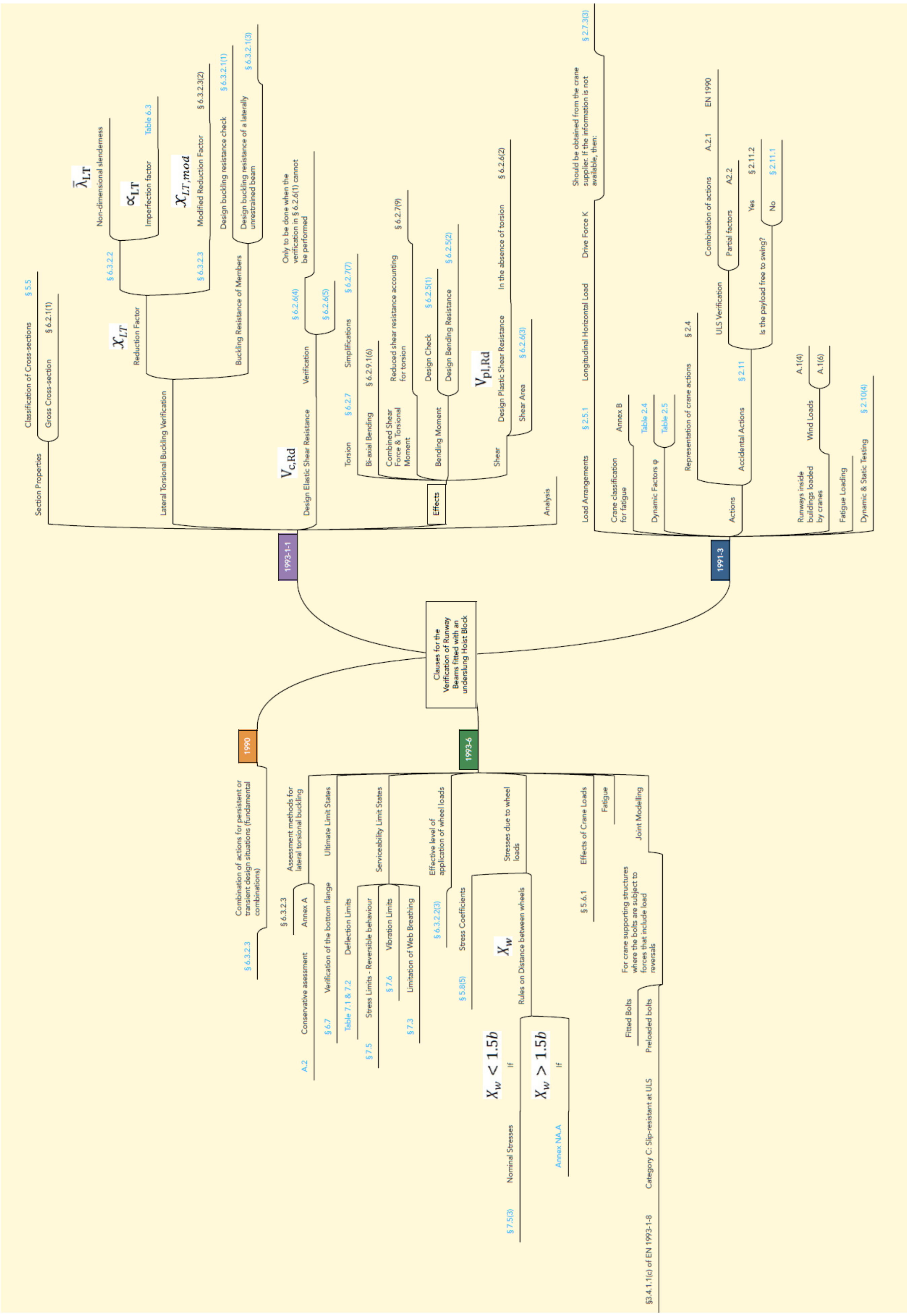
$$V_{Rd,min} = min(749; 698)$$

$$\frac{41.55}{2} \leq 698 \checkmark \ this\ is\ satisfactory$$

B.6 Conclusion

The calculations associated with the verification of a full depth end plate beam to column connection in accordance with the Eurocodes were illustrated in the worked example.

For more information on the design of nominally pinned joints, the designer is advised to refer to 'Simple joints to Eurocode 3 (SCI P358)', [10] this document covers the design approach to an array of simple connections in accordance with the Eurocodes.



Clauses for the Verification of Runway Beams fitted with an underslung Hoist Block
1993-1-1
Section Properties
Classification of Cross-sections
§ 5.5
Gross Cross-section
§ 6.2.1(1)
Lateral Torsional Buckling Verification
χ_{LT}
Reduction Factor
§ 6.3.2.2
$\bar{\lambda}_{LT}$
Non-dimensional slenderness
α_{LT}
Imperfection factor
Table 6.3
§ 6.3.2.3
$\chi_{LT,mod}$
Modified Reduction Factor
§ 6.3.2.3(2)
Buckling Resistance of Members
Design buckling resistance check
§ 6.3.2.1(1)
Design buckling resistance of a laterally unrestrained beam
§ 6.3.2.1(3)
$V_{c,Rd}$
Design Elastic Shear Resistance
Verification
§ 6.2.6(4)
Only to be done when the verification in § 6.2.6(1) cannot be performed
§ 6.2.6(5)
Effects
Torsion
§ 6.2.7
Simplifications
§ 6.2.7(7)
Bi-axial Bending
§ 6.2.9.1(6)
Combined Shear Force & Torsional Moment
Reduced shear resistance accounting for torsion
§ 6.2.7(9)
Bending Moment
Design Check
§ 6.2.5(1)
Design Bending Resistance
§ 6.2.5(2)
Shear
$V_{pl,Rd}$
Design Plastic Shear Resistance
In the absence of torsion
§ 6.2.6(2)
Shear Area
§ 6.2.6(3)
Analysis
1991-3
Load Arrangements
§ 2.5.1
Longitudinal Horizontal Load
Drive Force K
Should be obtained from the crane supplier. If the information is not available, then:
§ 2.7.3(3)
Crane classification for fatigue
Annex B
Dynamic Factors φ
Table 2.4
Table 2.5
Actions
Representation of crane actions
§ 2.4
Accidental Actions
§ 2.11
ULS Verification
Combination of actions
A.2.1
EN 1990
Partial factors
A2.2
Is the payload free to swing?
Yes
§ 2.11.2
No
§ 2.11.1
Runways inside buildings loaded by cranes
Wind Loads
A.1(4)
A.1(6)
Fatigue Loading
Dynamic & Static Testing
§ 2.10(4)
1990
Combination of actions for persistent or transient design situations (fundamental combinations)
§ 6.3.2.3
1993-6
Assessment methods for lateral torsional buckling
§ 6.3.2.3
Annex A
Conservative asessment
A.2
Ultimate Limit States
Verification of the bottom flange
§ 6.7
Serviceability Limit States
Deflection Limits
Table 7.1 & 7.2
Stress Limits - Reversible behaviour
§ 7.5
Vibration Limits
§ 7.6
Limitation of Web Breathing
§ 7.3
Effective level of application of wheel loads
§ 6.3.2.2(3)
Stresses due to wheel loads
Stress Coefficients
§ 5.8(5)
X_w
Rules on Distance between wheels
$X_w < 1.5b$
If
Nominal Stresses
§ 7.5(3)
$X_w > 1.5b$
If
Annex NA.A
Effects of Crane Loads
§ 5.6.1
Fatigue
Joint Modelling
For crane supporting structures where the bolts are subject to forces that include load reversals
Fitted Bolts
Preloaded bolts
Category C: Slip-resistant at ULS
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