Connections made with preloaded bolts

No. 2.06

Scope

This guidance note covers the design and detailing of connections made with preloaded bolts in slip-resistant connections. For comments on size, position and drilling of holes, see GN 5.08; for comments on installation, see GN 7.05; for comments on protective treatment, see GN 8.01.

Comments are given in relation to shear connections, where the connection transfers force from one component to another in shear across the interface. Girder splices, with single or double cover plates, and lapped connections, such as at the end of ladder deck cross girders, are shear connections.

General

For design to the Eurocodes, the relevant bolt standard is EN 14399. This Standard is in 10 Parts and covers hexagon head bolts of type HR and HV, HRC bolts (commonly seen in the UK in the form of TCB bolts) and Direct Tension Indicators (traditionally known as load indicating washers). HV bolts are not used in the UK.

A useful reference on the design of bolted connections is Owens & Cheal (Ref 2).

Benefits of using preloaded bolts

The advantages of preloaded bolts over other types of bolts are:

- rigidity of joints (no slip in service)
- no loosening of bolts due to vibrations
- better fatigue performance
- tolerance for fabrication/erection (because of the use of clearance holes)
- familiarity within industry.

The actual disadvantages are minimal, but the perceived disadvantages quoted by some designers are:

- difficulty of ensuring that all bolts are adequately preloaded
- In double cover connections, small differences in ply thickness in plates of nominally the same thickness can result in the preload from bolts near the centre of joint being applied to the wrong side of the joint, see Figure 1.

These 'disadvantages' are generally overcome by ensuring a good standard of fabrication, attention to plate thickness tolerances and by following erection procedures that recognize the potential problem.

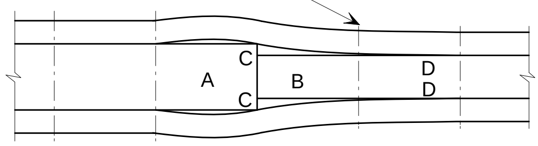

Figure 1 *Lack of fit in a double cover plate splice*

How a preloaded connection works

The bolts are tightened such that a high tension (usually beyond yield) is developed in the bolts. The plates of the connection are thus clamped together so that shear transfer between the plates is achieved through friction.

Design according to the Eurocodes

EN 1993-1-8 defines two types of slip resistant bolted shear connection:

- Category B: Slip resistant at SLS. The connection can slip into bearing shear at ULS.
- Category C: Slip resistant at ULS.

Rules for determining slip resistance and bearing shear resistance for individual bolts are given in EN 1993-1-8 and are not discussed further here, although attention is drawn to the warning in AD 383 about the use of alkali-zinc silicate on faying surfaces.

Choice between categories B and C

Most preloaded bolted connections are designed as category B, which generally requires fewer bolts. However, category C connections, with no slip at ULS are chosen in certain circumstances:

- If oversized or slotted holes are specified or are expected to be needed for greater accommodation of tolerances during erection
- Where rigidity of the joint is required at ULS (e.g. sometimes at U-frame corners when its stiffness needs to be increased.

Connection design

Designers almost always use linear elastic analysis to determine forces on the individual bolts (i.e. force on each bolt is proportional to its distance from the centre of rotation for the group), although this is only explicitly stated for forces at ULS in Category C connections and in bearing/shear connections where shear resistance governs.

Double shear should be used where possible, because:

- the contribution of each bolt is doubled
- cover material can be evenly disposed either side of the member being spliced, thus avoiding eccentricities at the connection.

For any bolted joint, the following need to be considered in design:

- maximum force on a bolt (shear, and/or external tension)
- stresses in the part joined (the parent plate)
- stresses in cover plates.

Compression member splices and compression flange splices are verified for:

- The design forces applied to the member but with axial force increased to allow for second order effects when the splice is not near a lateral restraint (note that this is not applicable for composite flanges).
- The design resistances of the cover plates are evaluated as compression elements and thus γ_{M0} applies and there is no deduction in area of section for bolt holes, unless the holes are oversized or slotted.

Tension member splices and tension flange splices are verified for:

- The design forces applied to the member
- The design resistances of the cover plates evaluated as the lesser of the plastic resistance on the gross area (not deducting for holes) and the ultimate resistance of the net section (after deducting for holes). The factor γ_{M0} applies in the former case and the γ_{M2} factor applies in the latter case.

Web splices are verified for:

- The design values of the shear, axial and bending effects on the web (i.e. no shedding of moment from web to flanges is allowed) and taking account of moments caused by the eccentricity of the connection
- When the predominant stress is compressive, the design resistances of the parent plate and cover plates are evaluated as compression member
- When the predominant stress is tensile, the design resistances plates are evaluated as tension member (therefore holes are to be deducted).

Detailing the connection

Careful detailing can result in material savings, easier erection and a more durable structure. Minimum and maximum spacing, edge and end distances are given in Table 3.3 of EN 1993-1-8 and the following additional comments should be noted.

- Add 5 mm to 10 mm to the minimum pitch to give greater clearance for tightening.
- Add 5 mm to the minimum edge and end distances if possible (see also GN 5.08).
- The minimum edge and end distances are to ensure adequate load transfer without slip and adequate bearing/shear in a slipped joint at ULS.
- The maximum pitch and edge distances are to prevent buckling of plates and to avoid opening of gaps at plate edges where crevice corrosion might initiate. (See also GN 1.07 for splices in weather resistant steel.)
- Consider access for bolt tightening, noting possible problems at web/flange corners, so that all bolts can be placed, properly assembled and tightened fully and safely using standard tools. ((Ref 4 gives minimum distances of 60 mm for M24, 70 mm for M30 bolts, see Figure 2; add 45 mm or 50 mm (for M24 and M30 respectively) for a washer, nut and protruding thread).

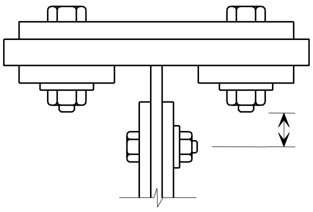

Figure 2 *Access at web/flange corners*

- Bolts are usually tightened by rotating the nut, but the bolt head can be turned, if an extra washer is used under the head.
- Standardize bolt sizes (it is preferable to use M24 throughout the structure rather than M24 for main connections and limited number of M20 bolts for bracings).
- Do not use adjacent bolt sizes (one serial size up or down) on one structure (or even on one site).
- Avoid end plate connections if possible (less tolerance, increased prying forces).
- Slotted holes should in general be avoided, but they do have their uses, for example where a larger tolerance is required for erection.
- Countersunk preloaded bolts should in general be avoided, but they can be of use, for example, for attaching bearing plates and in the Network Rail standard box girder bridge (where the connections between deck plates are bolted using countersunk preloaded bolts to give a flush surface suitable for waterproofing).
- Tightening from above (i.e. bolt heads down) gives easier access and gives better appearance on the soffit.
- Overstresses in parent and cover plates can be avoided by reducing the number of bolts in the cross-section by use of staggered pitch at highly stressed areas, (see Figure 3).
- When plates of different nominal thickness are connected, packs should be specified

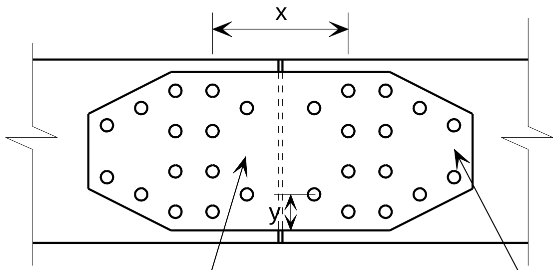

Figure 3 *Layout of bolts in a flange splice*

Note:
X< 14t or 200
Y < 40 + 4t
where t = cover plate thickness

- In proportioning cover plates, the designer should consider how they are to be handled and assembled - heavy covers can be split into more than one component, provided the usual rules on edge distances, etc. and any design implications regarding eccentricity are observed.
- Thick cover plates can exceptionally be replaced by two plates of half the thickness to make them more easily handled and easier to draw together during bolt tightening. This should be discussed with the fabricator and bridge installer.

Pack thickness

Where plate thicknesses at a joint change by 2 or 3 mm, as they commonly do in girder webs, a 1 mm pack is required on each face to avoid offsetting the webs and consequently increasing the risk of having problems installing bolts in the flanges. However, a lower limit on pack thickness of 2 mm has been introduced in BS EN 1090-2, covering both preloaded and non-preloaded joints. It could be argued that 1 mm thick packs would be acceptable in preloaded joints because the plies are pulled up tight and corrosion of the pack is prevented.

Pack material

Clause 8.1 of BS EN 1090-2 states that “Packing plates shall have compatible … mechanical strength with the adjacent plate components of the connection”. In this case, “compatible” should not be interpreted as “similar” because it is not always possible to obtain small quantities of thin material for packs in preloaded joints in grades that are the same as the members being joined. For packs less than 7 mm thick, carbon steel can only be bought in grades such as DC01 to BS EN 10130, which has no guaranteed mechanical properties, and weathering steel shims are only available in “Corten A”, which has a lower yield strength and UTS than S355W to BS EN 10025-5 and no toughness guarantee. In practice, the compressive stress due to the preload and the shear stress from the slip resistance are much lower than the lowest value of yield stress for such materials, and there is no risk of brittle fracture, so these alternative materials are acceptable for use as packing in preloaded joints.

References

1. Owens & Cheal, Structural steelwork connections, Butterworths, 1989.
2. EN 14399 High-trength structural bolting assemblies for preloading (in 10 Parts)
3. Hayward A & Weare F, Steel Detailers’ Manual, Second Edition (revised by Oakhill) Blackwell Science, 2002.
4. CIRIA Technical Note 98.
5. Advisory Desk Note AD 383: Use of alkali-zinc silicate paint in slip-resistant bolted connections, SCI, 2014 (available on www.steelbiz.org)