Installation of preloaded bolts

No. 7.05

Scope

This guidance note relates to the use of preloaded System HR bolts to EN 14399-3 (Ref 1) and System HRC bolts to EN 14399-10 (Ref 2) in bridge steelwork. The principal uses are in making main girder connections (web-to-web and flange-to-flange) but they are also used in connecting bracing members, to main girders and to each other. This Note refers to use in such details. Special applications should be considered in their own context.

Comments on accommodating tolerances in hole sizes and positions is given in GN 5.08.

Source References

EN 1993-1-8 clause 2.1 (Ref 3) states that the design methods for joints assume that the standard of construction is as specified in EN 1090-2 (Ref 4). Particular clauses in EN 1090-2 that relate to preloaded bolted connections include:

5.6.4 - specifies that structural bolting assemblies for preloading shall conform to the appropriate part of EN 14399;
5.6.6 – permits the use of the ASTM standard for weather resisting assemblies;
6.6 - covers the requirements for holing;
8.1 - covers thickness of packing plates;
8.2.2 - defines the minimum length of protrusion and the number of clear threads required under the nut;
8.2.4 - covers the type and number of washers required depending on the joint configuration and the bolt grade;
8.4 - covers the preparation of contact surfaces;
8.5 - describes the various tightening methods.

General

Connections made with preloaded bolts are designed on the basis of a minimum preloading force in each bolt, no matter how many bolts in the connection, nor their distribution.

Hence the key to effective jointing is to ensure that minimum preload is achieved.

The actual preload in any bolt is governed by three things:

- the tensile strength of the material; the “property class” in accordance with EN 14399
- the thread diameter of the bolt; as specified by EN 14399
- the extent to which the bolt is strained (extended) during the installation and tightening process; which is required to be in accordance with EN 1090-2.

By means of careful manufacture and installation the designed minimum preload is easily achieved in a simple unrestrained lap joint between two plates. Problems begin to arise in joints which are restrained, when the contact surfaces are not flat and/or not properly aligned.

Unfortunately, the manufacture of individual elements to the tolerances specified in the various clauses of EN 1090-2 does not guarantee that the connection will fit sufficiently well to permit the connection to perform as intended. Unfavourable combinations of the maximum and minimum tolerances in any particular assembly and/or in any adjacent assemblies, can result in misfits which will affect the performance of the connection. CIRIA Report 87 (Ref 5) deals with the common instances of these and gives guidance on the likely effects. A commentary on that document is given at the end of this Note.

GN 2.06 suggests connection details that are least sensitive to these unfavourable combinations of permissible tolerances. It also gives guidance with regard to the misfits of those joints/details that are not so tolerant. The guidance in the present Note assumes that the joint details and fit are reasonably good.

Assembly

The following points are important:

- Contact surfaces should be flat and free of any buckles, dents or burrs around the holes
- Contact surface should be clean and free of any oil, grease, paint or other material that could act as a lubricant. Moisture on a face, in the form of clean water, rain or dew should not be a problem unless it washes in dirt or is present for so long that

serious rusting occurs. Light rusting is not detrimental to the performance of the joint.

- Bolts should be able to be inserted without damaging them or the holes. This does not mean that all holes should be perfectly aligned, as bolts can be worked into quite big joints one at a time by moving the joints faces slightly relative to one another (see GN 5.08).
- The connection should be drawn together by using a pattern of bolts, not a single one tightened to a very high load. 'Service' bolts may be used, but it is perfectly acceptable to use the permanent bolts so long as they are not damaged or stretched. *(Service bolts are temporary bolts used to hold elements together and in the correct orientation to each other during assembly. In normal circumstances they are non-preloaded bolts in clearance holes, of the same diameter as the permanent preloaded bolts. They have to be replaced by the new permanent bolts in the final joint assembly. As they are seldom tightened to more than 'spanner tight', they can be reused time and time again.)*
- Preloaded bolts should only be used for pulling joints together so long as they can be inserted without any damage to the threads, and so long as only hand spanners or small (low-torque) impact wrenches are used to draw the plies together. This practice is not recommended when the torque method or the combined method of tightening is to be employed because the slackening, removal and reuse will change the thread friction from that for which the equipment was calibrated.
- After insertion and initial tightening, the nut should be fully engaged on the bolt threads. This is to avoid possible damage to the threads during final tightening. The ideal situation is to have one or two threads protruding through the nut after final tightening, although EN 1090-2 clause 8.2.2 only requires a protrusion of one thread.
- If it is suspected that a preloaded connection has relaxed for some reason and the torque method of tightening has been used (after correct assembly), such bolts may be retightened to the correct torque. If relaxation is suspected and the part-turn method has been used, the bolts should be replaced and tightened one by one.
- Preloaded bolts which have been fully or partly tightened should not be re-used in the Permanent Works, because they have already been stretched. They can be useful as service bolts, but care must be exercised to ensure that they are not accidentally retained in the completed assembly. Note that some thread distortion may have occurred, preventing free rotation of the nuts, in which case they should be discarded, even as service bolts.
- Protective treatment - some additional guidance on the treatment of connections made with preloaded bolts is given at the end of this Note.

Methods of tightening in EN 1090-2

EN 1090-2 describes four methods of tightening system HR preloaded bolts:

- Torque method

  (N.B. the torque method is not allowed in SHW 1800 (Ref 6), Clause 1808.5.1(6), unless specifically requested by the designer in Appendix 18/1– but the following is provided for information.)

  The torque method is a three-stage operation (snug-fit, initial torque, final torque) using a calibrated torque wrench. The main shortcoming of this method is that the variation in bolt preload, for the same batch of bolts and nuts, can be as much as ±30% and even more if the bolts are coated. This variation is caused mainly by the variability of the thread condition, surface conditions under the nut, lubrication, and other factors that cause energy dissipation without inducing tension in the bolts. The result is an erratic torque-tension relationship and an unreliable preload.

  EN 1090-2 attempts to minimize variability by requiring the use of 'K2 class' bolts for the torque method. K2 class bolts require greater performance measurement during manufacture (see EN 14399-3), with additional information about the torque v tension relationship required on the product certificate. For these 'higher class' bolts, the requirements for wrench calibration are then only that the equipment be checked "for accuracy at least weekly, and in the case of pneumatic wrenches, every time the hose is changed". From experience, it is considered by UK steelwork contractors that much more frequent calibration is required.

Additionally, there is a supply problem in the UK in that the main supplier of bolts for preloading (Cooper and Turner) will only supply K0 class bolts - this class does **not** have a designated bolt force / rotation relationship and, according to EN 1090-2, is not suitable for any of the described methods, other than the direct tension indicator method.

- Combined method

  This is a method that is new to the UK. It is a combination of the torque and part-turn methods, so it has all of the disadvantages associated with torque control. It requires three tightening operations (snug-tight, preliminary tightening and final tightening).

- HRC method

  The HRC bolt has a spline at the end of the threaded end of the bolt that shears off at a predetermined torque. It is not necessary to calibrate the wrench in this case because the strength of the break-neck determines the maximum torque. However the actual preload induced depends on the torque/preload relationship and this is still related to the thread friction. The variability of the friction is controlled by supplying the bolts in drums to protect them from weather and contamination, but the lubrication can be affected by rain once the bolts are in place and ready to be tightened. They are now available in weathering steel in the quantities required for most bridge projects – but designers are recommended to check availability with suppliers.

- Direct tension indicator method.

  Direct tension indicators (Ref 6) are washers that have compressible nibs that deform to indicate when the minimum preload has been achieved. However, crevices are created that would become corrosion traps: when used on painted bridges, the gaps in the washers have to be sealed by hand before painting; for weathering steel bridges, although they are available their use is prohibited by the Specification for Highway Works (SHW 1805.6.5) and EN 1090, 5.6.5.

- Part-turn method of tightening

  Many fabricators of UK steel bridges still prefer to use a long -established alternative method of tightening referred to as the part-turn method. Similar to the combined method, this requires two tightening operations (snug-tight by the application of a defined bedding torque, followed by a part turn). Although the part-turn method is not specifically defined in EN 1090-2, SHW 1800 defines it as a variation of the combined method and allows its use as a tightening method for Grade 8.8 preloaded bolts of K0 class. SHW 1800 Clauses 1808.5.1 (4) and (5) refer.

  The main advantage of part-turn tightening is that it is a strain control method and is therefore almost totally independent of the friction and torque characteristics of the nut and bolt assembly. The part-turn method induces a specific strain (related to the part turn and thread pitch) that is well in excess of the elastic limit and which takes the bolt into a region where the load-elongation curve is relatively flat, so the variations in (the relatively modest) bolt load applied during bedding result in only minor variations in the preload of the installed bolt.

  This consistency provides the following benefits to the steelwork contractor and the client:

  - Predictability: Preload always exceeds the minimum specified;
  - Reliability: Simple to control and supervise on site;
  - Economy: No calibration on site and less risk of re-work, so lower costs;
  - Versatility: Suitable for both non-alloy steel and weathering steel bridges.

Initial fit-up

All tightening methods need the components to be brought together to a snug-tight condition before commencement of preloading. However, there are occasions when the initial tightening does not achieve this, for example when thick splice plates and rippled flanges coincide, or where geometric fit-up is imperfect. Installers and inspectors should therefore be vigilant that all the plies are in contact before the main preloading process starts. Plate rippling is usually greatest at the ends, due to the mechanics of the rolling process. In this case it can be difficult to bed splice plates in excess of 25 mm thick when using bolts up to and including 24 mm diameter. To overcome the problem, laminated splice covers should be used (two or three thinner plates, which together provide the required thickness).

Inspection
A significant part of the cost of using preloaded bolts is related to the inspection. This is the key to the effective use of preloaded bolts so should be carried out strictly in accordance with the requirements of EN 1090-2.

Preloaded bolting should be considered as a connection method that requires formal procedures just as much as welding does.

While it is not specified in EN 1090-2, it is suggested that:

- only personnel qualified by experience and training are used;
- only tested and calibrated equipment is used;
- written procedures are used to control the work;
- inspection is performed and records are kept to a formal procedure.

Bolt supply
The source of bolts should be an accredited supplier, as low-cost versions that do not comply with EN 14399 are marketed. Beware of ‘certificates of conformity’, because they are not reliable from these cheap sources.

Protective treatment and protection of contact surfaces
For preloaded connections is it imperative that the friction surface preparation (and consequent coefficient of friction) assumed by the connection designer is achieved in the fabricated steelwork friction contact (faying) surfaces when the bolts are tightened on site. This usually requires the contact surface area to be protected until the connections are assembled

Whilst designers are free to consider a range of different friction surfaces in EN 1090:2 Table 18, the final choice needs a consideration of various aesthetic and construction aspects.

Table 18 'Class A' surfaces of 'grit-blasted steel with loose rust removed' will have the implication that the surfaces will need masking off until the connections are closed – to avoid the build-up of loose rust after initial blasting. The usual protective method is with adhesive masking tape, of which there are a number of varieties on the market. Experience has shown that those tapes which give the best level of protection tend to leave adhesive deposits on the friction surface when peeled off, especially if they have been left in sunlight for extended periods, or have been over-coated with paints with high solvent levels. Such deposits can be cleaned from the friction surface with solvents and scrapers or wire brushes or the like, but such activities can reduce the slip factor. The tapes which do not leave deposits on the friction surface tend to be only effective for a limited period in the open, usually two to three months.

There is also evidence to suggest that uncoated grit blasted steel surfaces can undergo subsequent heavy rusting over the long term life of a structure, which might lead to a theoretical reduction in slip factor or unsightly staining. As a consequence they need to be considered with care when there is heavy emphasis on aesthetics over the long term or where the structure is located in a particularly corrosive environment. Good splice detailing, which minimises paths for moisture ingress into the faying surface area over time, will also assist in mitigating any potential problems.

If uncoated contact surfaces are not preferred, then the usual two alternatives are to coat the surfaces with either aluminium metal spray or alkali-zinc silicate paint. Both these methods avoid the need to seal and mask-off the joint at an early stage. In the case of aluminium metal spray, a slight browning of an unsealed aluminium coated surface exposed to moisture is to be expected and is not a matter for concern. The aluminium will also need to be applied locally in the faying surface areas, as aluminium metal spray is no longer specified as the base layer for the Type II protective system for bridge structural steelwork in the current SHW Series 1900 (Ref 8).

Alkali zinc-silicate paint is simpler to apply than aluminium metal spray but experience has shown that the coefficient of friction achieved is very sensitive to the thickness of paint provided and curing regime adopted. If subsequent research or previous slip test results cannot prove otherwise, slip tests on sample splices representative of the actual zinc silicate paint, bolts, and tightening method are strongly recommended in conjunction with careful policing of the painting application and curing to ensure that the paint provided in the friction surface is representative of that used for the slip test..

References

1. EN 14399-3, High strength structural bolting assemblies for preloading - Part 3: System HR - Hexagon bolt and nut assemblies.
2. EN 14399-10, High-strength structural bolting assemblies for preloading - Part 10: System HRC - Bolt and nut assemblies with calibrated preload.
3. EN 1993-1-8, Design of Steel Structures – Part 1-8: Design of Joints.
4. EN 1090-2, Execution of steel and aluminium structures – Part 2: Technical Requirements for Steel Structures.
5. Report 87, Lack of Fit in Steel Structures, CIRIA, 1981.
6. Specification for Highway Works, Series 1800, Structural steelwork, 2014.
7. EN 14399-9, High-strength structural bolting assemblies for preloading. System HR or HV - Direct tension indicators for bolt and nut assemblies.
8. Specification for Highway Works, Series 1900, Protection of steelwork against corrosion, 2014

Guidance Note

No. 7.05

CIRIA report 87, although an old publication, is still recommended reading for designers, contract managers and site staff. The following bullets highlight some of the key conclusions in the report. Reference to HSFC bolts have been changed to refer to preloaded bolts, which is the terminology now used.

Comments on CIRIA Report 87 - LACK OF FIT IN STEEL STRUCTURES

- The report reinforces a long-held view that preloaded bolts give an excellent rigid and fatigue/crevice-free joint, but all attempts to obtain precise bolt tensions are a total waste of time!
- Ultimate strength of preloaded joints is not affected by lack of fit, or the amount of bolt pretension, for joints in shear (see 2.5.2 & 2.8.2) or tension (2.8).
- The annulus which is effectively clamped extends over an area equivalent to twice the nominal bolt diameter. (2.5.1)
- For end plate connections, bowing is not detrimental to tensile capacity, provided it is convex on outer face (i.e. gaps between end plates at outer edges, not at centre). However, top and bottoms of end plates to be in contact (2.6) especially in region of compression flange (2.8.1). Contact elsewhere unimportant. Lack of fit around bolts of up to 1 mm may not affect performance. (Appendix 2).
- In fatigue situations (i.e. where reversal of load occurs) good fit-up around the bolts is important (2.9). (Applies particularly to bridge girders spliced near the point of contraflexure.)
- Shimmed end plate joints are satisfactory (2.10).
- For oversize and slotted holes a reduction in capacity is evident (2.11) but it is implied that inner ply oversize/slots are not detrimental.
- For bolts in shear, reaming of misaligned holes “could be harmful” (3.2.2)
- Varied misalignment in a group reduces slip under load causing more gradual (and presumably beneficial) deformation (3.3).
- Hole misalignment does not affect bolt tensile capacity. (3.7).
- Distorted bolt ends, up to 3°, are acceptable. (3.8.1).
- Full nut engagement may not be necessary for bolts in shear (3.8.2) - this would apply to ULS capacity after slip; full engagement is required for preloaded bolts, to ensure friction capacity.
- Corrosion in crevices is highest with a gap of 0.75 mm. (7.3.1).

