Guidance Note 5.08

Hole sizes and positions for preloaded bolts

Scope

This Guidance Note gives advice on design code requirements for the sizes and positions of holes for preloaded bolts used in bridge steelwork. Advice is also given on current practice in fabrication and erection. Holes for bolts other than preloaded bolts are not covered by this Note.

General requirements

The design resistances for preloaded bolts given by BS EN 1993-1-8 apply where the execution of holes is in accordance with BS EN 1090-2.

- Diameter
  The hole diameters for normal round holes, oversized holes and slotted holes, are defined in BS EN 1090-2 [1], Clause 6.6.1. For holes other than normal round holes, BS EN 1993-1-8 Table 3.6 [2], gives reduction factors for the slip resistance.
- Elongation
  Drifts (close-fitting tapered pins of hardened steel) are necessary to bring holes in the various plies into alignment, so that bolts may be freely inserted. GN 7.05 comments that on a large bolt group, the plates forming the joint may need various relative movements to work the bolts into the holes. This is normally done with drifts. Limits on elongation produced by drifting are given in BS EN 1090-2, clause 6.9.
- Back marks
  Minimum edge and end distances for bolt holes (back marks from the edge of the element) are given in BS EN 1993-1-8 but Clause 3.5 (2) indicates that for structures subjected to fatigue the larger values in BS EN 1993-1-9 [3] should be used. This rule should be applied to all bridges subject to repeated fluctuations of stress. The symbol d used in Table 8.1 in BS EN 1993-1-9 in the formulae for edge and end distance and spacing is not defined. It should be taken as the hole diameter for edge and end distance, and as the bolt diameter for bolt spacing, in line with existing UK practice.
- Tolerances
  Functional manufacturing tolerances for the position, spacing, twist and shape of fastener holes are shown in BS EN 1090-2, Table B.8. The tolerance on hole diameter for preloaded bolts is given in BS EN 1090-2, clause 6.6.2.

Designers should remember that all dimensions can only be achieved within practical tolerances. It is good practice to dimension the hole positions at least 5 mm further from an edge than the minimum value but generally the bearing resistance of the fastener may be determined on the basis of the chosen nominal dimension, with no reduction for tolerance. It may be noted that BS EN 1090-2 specifies a zero negative tolerance on hole position from the end of a member but no tolerance is specified on distance to the side of a member.

Methods of marking and drilling hole groups

Many techniques are used by fabricators to achieve alignment of holes, some of those most commonly used are described below:

- Individual manual marking and drilling of holes
  Errors are probable within each hole group and between groups. Satisfactory for small isolated hole groups only.
- Match marking
  Achieved by pre-drilling approximately half the holes in the components, then assembling the components in their calculated relative geometry and marking the holes through. The components are then dismantled and drilled. The system is especially effective for complex geometry, but requires accurate drilling to the marks on dismantling. The location and orientation of components so drilled should be recorded as parts nominally identical may not be subsequently interchangeable.

It is also possible to drill the holes in the girder using the permanent splice plate as a bush, when the permanent splice plates have been NC drilled. This avoids dismantling the joint for drilling.

- Bush templates
  Used to drill repetitive patterns of holes in splice plates, large hole groups, typically web and flange connections, on fully assembled and welded girders or panels. Drilling is carried out through the template, typically using a radial arm drill. Hardened bushes are inserted in the holes of the template to avoid wear from the drill bit. The accuracy of holes within a group is good. Inter-group dimensions are subject to general setting out tolerances.
- CNC plate drills
  Computer Numeric Controlled (CNC) drilling beds that can provide any pattern of holes on plates prior to assembly. The relationship between holes in a group is good. The initial inter-group dimensions are good, but these are subsequently modified by the difference between the anticipated and actual weld shrinkage, as components so drilled are joined into fabrications. It should be appreciated that methods for calculating weld shrinkage provide only broad approximations.
- CNC girder drills
  Fully computer controlled machines that can provide accurate hole groupings in fully assembled and welded plate girders or panels, either at the ends of components or at intermediate positions. Such machines remove the uncertainty of allowances for weld shrinkage and give good relationships between holes in a group and good relationships between groups of holes measured along the member. However the machines' datum devices rely on uniform girder cross sections. Assembly tolerances can therefore produce small lateral shifts of hole groups.
- CNC saw drill lines
  These can provide accurate hole patterns and inter group dimensions on rolled sections or narrow plates.

Each fabricator will have a preference which is likely to be governed by available machinery, space and how they control and manage misalignment of joints.

Holes for bridges may be formed by drilling, laser, plasma or other thermal cutting with the provISO in BS EN 1090-2, Clause 6.6.3 that the finished hole complies with the local hardness and surface quality requirements in Clause 6.4. In practice however, it is difficult to satisfactorily form a round hole or the curved sections of a slotted hole by thermal cutting so this method is rarely used.

Rectification of misaligned holes

On final assembly or trial erection there is a probability that some holes may be found to misalign by an amount that cannot be accommodated by normal drifting operations (i.e. the degree of misalignment is such that the forces in drifting distort the metal around the holes, or there is misalignment to the extent that drifts cannot be entered).

If the amount of misalignment is significant then a modified splice plate or bracing may have to be produced. Alternatively a hole can be plug welded and re-drilled. Whichever approach is adopted, it should only be carried out with the full knowledge and written agreement of the designer.

It is more likely, however, that the amount of misalignment is relatively small and in this situation the solution for many years has been to ream out that hole by the minimum amount to get the bolt into the modified hole without force.

Reaming is an effective and economic solution to remedy localized and minor misalignments. As long as the reamer diameter is equal to or less than the original hole size, it creates a degree of slotting in each hole in each ply forming the joint. The amount of metal removed from each ply may not be equal, as the tool tends to create greater elongation in the thinner plies than in the thicker plies, should they be misaligned.

Tests have shown that over-sizing and slotting of holes can significantly influence the level of bolt preload when bolts are tightened by the strain control method, i.e. the part turn method. Because the head of the bolt is seated on a reduced area, due to the enlargement of the hole, there tends to be localised yielding and distortion which causes a partial relaxation of the preload in the bolt.

It has also been shown by test that the bolt clamping forces are reacted within the plies of the joint over relatively small areas local to each bolt. Removal of metal by hole enlargement causes the inter-ply load to be reacted over a smaller area, and therefore increases the inter-ply pressure. Excessive inter-ply contact pressure can cause local flattening of surface irregularities and thereby a reduction in slip resistance of the joint.

Slip resistance normally governs the joint design, at either SLS or ULS depending on the design category, so both of the above issues are important if holes are enlarged beyond the normal specified clearances. The shear and bearing resistances can also be affected.

- Slip resistance
  Research has shown that the potential for preload relaxation can be overcome quite easily by the addition of an additional hard round washer under the bolt head. For M24 bolts this approach is satisfactory in bolt holes enlarged to bolt diameter +6 mm (i.e. 4 mm oversized). For bolt diameters greater than 24 mm in oversized holes, thicker washers are necessary.

  On the other hand, preload relaxation because of reduced bearing area under the bolt head is not an issue if a method of direct tensioning is used to tighten the bolts. Load indicating washers would provide such a method, but with enlarged holes such washers (which are usually used under the head of the bolt) would need the support of an additional plain washer.

  The matter of reduced slip resistance due to excessive inter-ply contact pressure can only be controlled by limiting the amount of hole enlargement. It has been shown that for 24 mm diameter bolts this effect is not significant for over-sizing less than bolt diameter +6 mm.
- Shear and bearing resistances
  Shear or bearing resistance will become important when slip has occurred up to the point where sufficient bolts come into bearing within the holes in the various piles.

  In the event that some holes within that group are enlarged, the strength of the joint is a function of how many bolts can simultaneously come into bearing, each side of the joint being considered independently. This is affected by: the number of holes enlarged; the direction of enlargement in each hole; the amount of that enlargement; and the bearing capacities of the various plies within the joint.

  Clearly, odd holes enlarged transversely present less of a problem when slippage occurs than holes enlarged longitudinally, provided that sufficient member cross section remains. But it is not possible to give general advice on the proportion of holes within a joint that may be enlarged or by how much. Any joint which may require some hole enlargement to fit bolts should be assessed individually, taking into account the above factors.

BS EN 1993-1-8 gives rules for the reduction in slip resistance of joints with oversized holes, short slotted holes, and long slotted holes, but these rules were drafted for member joints where all the holes conform to one of the above categories, rather than the situation where a small proportion of the holes in the joint are enlarged.

Fabricators and erectors should not be permitted to ream any hole at will. However there will be times when it is to the advantage of all parties to overcome a particular problem by reaming some holes. To cover this situation it is suggested that specifiers require that reaming of bolt holes may only be carried out subject to notification and written approval from the designer in each case.

Holes for bolts in weather resistant steel

Traditionally, weathering grade preloaded bolts, for use in weathering grade structures, were not readily available in metric sizes. It was therefore recommended that the design be carried out assuming the use of metric M24 or M30 bolts but that the joint be detailed such that the slightly larger imperial 1” or 1¼” bolts could be substituted without compromising the hole spacing and edge distance limitations. However, more recently, M24 and M30 weathering grade HRC tension control bolts are now commonly used in the UK so this is now less of an issue.

References

[1] BS EN 1090-2:2018+A1:2024- Execution of steel structures and aluminium structures – Part 2: Technical requirements for steel structures.

[2] BS EN 1993-1-8: 2005 - Design of steel structures - Design of Joints.

[3] EN 1993-1-9: 2005 – Design of steel structures – Fatigue.