AD 274

Post-slip capacity of connections using preloaded bolts to BS 5950-1: 2000

The SCI continues to receive questions about preloaded bolts (HSFG bolts), particularly concerning the "capacity after slipping" addressed in clause 6.4.4 of BS 5950-1: 2000. This AD attempts to explain where "capacity after slipping" may be important and how it should be checked.

Clause 6.4.1 of BS 5950-1: 2000 provides the designer with the following three design options for preloaded bolted connections:

a) a normal "bearing type" connection;
b) non-slip in service;
c) non-slip under factored loads.

It is option (b) that is used most commonly. This option has caused some confusion because preloaded bolted joints designed to option (b) need to be checked twice for the ULS loading; firstly, for slip resistance in clauses 6.4.2 and 6.4.5 and, secondly, for capacity after slipping against clauses 6.4.4, 6.3.2 and 6.3.4.4 as required.

OPTION (A) A NORMAL "BEARING TYPE" CONNECTION

Option (a) is, in fact, to design the connection as a normal bearing joint with the bolts as non-preloaded bolts, in accordance with section 6.3 of BS 5950-1 thereby allowing slip of the connected plies to occur (the bolts do not need to be preloaded for option (a)). This option is seldom exercised in the UK because the cost of preloaded bolts is prohibitive in comparison with non-preloaded (ordinary) bolts.

OPTION (C) NON-SLIP UNDER FACTORED LOADS

In option (c), the friction caused by the preload in the bolt resists the shears between the components of the joints right up to the ultimate loads. The bolts do not act in shear and bearing.

For option (c), the slip resistance of a bolt is calculated as follows:

1) Where there is no externally applied tension acting out of the plane of the faying surfaces, use the second equation in clause 6.4.2

$$P_{sL} = 0.9\,\mu\,K_s\,P_o$$

2) Where there is externally applied tension acting out of the plane of the faying surface, use the second equation in clause 6.4.5

$$\frac{F_s}{P_{sL}} + \frac{F_{tot}}{0.9P_o} \leq 1 \quad \text{(Where } P_{sL} = 0.9\,\mu\,K_s\,P_o\text{)}$$

The applied tension F_{tot} must include any prying forces generated and be calculated according to the more exact method described in clause 6.3.4.3.

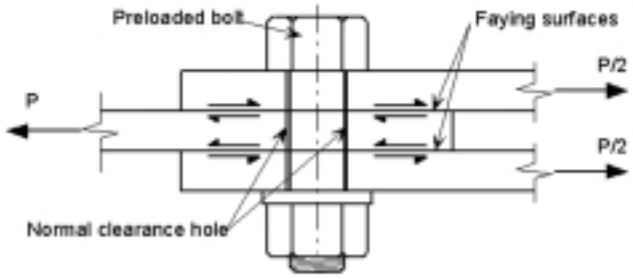
OPTION (B) NON-SLIP IN SERVICE

GENERAL

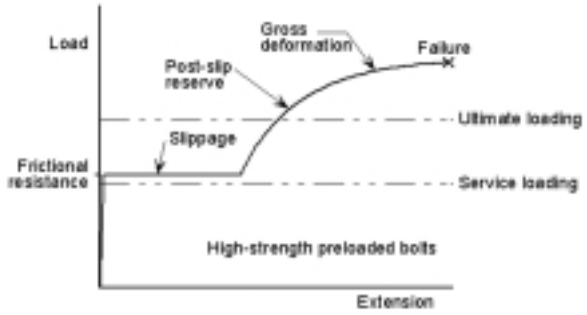
If the number of bolts required to resist the ULS loading on a joint is determined from option (b), fewer bolts will be required than for option (c) and slip will occur before the ULS loading is realised.

Figure 1 shows an idealised load extension curve for a preloaded bolted connection designed to option (b) subjected to applied loading. The important feature to note is that failure of the joint does not occur when the capacity of the frictional resistance is reached. At this stage the bolts slip into shear and bearing and the joint will continue to sustain increased applied loading while undergoing gross deformation until failure is reached, most likely by rupture of the plies. At slip, the load transfer mechanism changes from frictional resistance to shear and bearing of the bolts.

Until slip takes place the applied shear loading is carried by friction between the plies (on the faying surfaces) and the bolts have only direct tension stresses from the effect of the preload; they are not subject to shear stresses. After slip, the bolts are then subjected to applied shear and bearing stresses. As the applied load increases the bolts deform under combined bending and shear and the preload is lost. The bolts then behave in the same manner as non-preloaded bolts.



Load P is applied perpendicular to longitudinal axis of the bolt - bolt in shear



Idealised load – extension curve for connection designed to option (b)

SLIP RESISTANCE

As noted in clause 6.4.1, the resistance to slip in service for a preloaded bolt is a serviceability criterion but for ease of use BS 5950-1 presents the design check in a modified form, suitable for checking under the Ultimate Limit State loads.

Prior to slip, BS 5950-1: 2000 does not require a 'long joint' check on preloaded bolted connections. However, BS 5400-3: 2000 does require a 'long joint' check prior to slip. For option (b), the slip resistance of a bolt is calculated as follows:

1) Where there is no externally applied tension acting out of the plane of the faying surfaces, use the first equation in clause 6.4.2.

$$P_{sL} = 1.1\,\mu\,K_s\,P_o$$

2) Where there is externally applied tension acting out of the plane of the faying surfaces, use the first equation in clause 6.4.5.

$$\frac{F_s}{P_{sL}} + \frac{F_{tot}}{1.1P_o} \leq 1 \quad \text{but} \quad F_{tot} \leq A_t p_t \quad \text{(where } P_{sL} = 1.1\,\mu\,K_s\,P_o\text{)}$$

The applied tension F_{tot} must include any prying forces generated and be calculated according to the more exact method described in clause 6.3.4.3.

CAPACITY AFTER SLIPPING

The joint slips into shear and bearing when the applied loading is between the Servicability Limit State (SLS) loading and the ULS loading. Therefore, in order to ensure the ability of the joint to sustain the full ULS loading, the capacity after slipping must be checked, with the bolts in shear and bearing, in accordance with clause 6.4.4. Clause 6.4.4 refers the designer to clause 6.3.2. In these checks, the bearing strengths given by clause 6.4.4 for the ply material are higher (50% increase) than for the same ply material in normal non-preloaded bolts joints. This is because the deformation after slipping for preloaded bolted connections is not as critical a consideration as for connections with ordinary bolts since the slip does not occur until after the SLS loading has been realised. In ordinary (non-preloaded) connections, the bearing stress in the plies for the ULS checks is limited (Tables 32) to avoid unacceptable deformation at SLS.

When calculating the capacity after slipping, the joint should be checked for all the additional provisions of clause 6.3.2, including packing, large grip and long joint.

Where there is externally applied tension acting out of the plane of the faying surfaces, a combined shear and tension check on the bolts must be carried out according to the second part – the more exact method – of clause 6.3.4.4 as follows:

$$\frac{F_s}{P_s} + \frac{F_{tot}}{P_t} \leq 1.4$$

The applied tension F_{tot} must include any prying forces generated and be calculated according to the more exact method described in clause 6.3.4.3.

PLY CAPACITY CHECKS

At ULS the plies in **all** preloaded bolted connections should be checked for net section failure in tension in accordance with clause 4.6.1 or compression as appropriate. In addition, the shear capacity of the plies, if required, should be based on the net section in accordance with clause 6.2.3

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