Simple connections to Eurocode 3

The Eurocode Green Book on Simple Connections is well underway and some important aspects related to this connection type have been identified and are being addressed. Edurne Nunez Moreno of SCI explains some of these issues: the bearing resistance of a bolt group and the tying resistance of end plates.

Although the resistance equations in Eurocode 3 look different to those in BS 5950, both Standards address the same structural mechanics. With some modest differences, the new Standard produces very similar resistances to BS 5950 for simple connections and their components, just like they do in most aspects of steel design.

The design of connections between steel members is dealt with in BS EN 1993-1-8 and its National Annex. This Standard covers various aspects of connections, including connections made with bolts, welded connections, joint classification, connections between H or I sections and connections between hollow sections.

Bolts and Welds

Table 3.4 of BS EN 1993-1-8 gives expressions to calculate the resistance of a bolt in tension, shear and bearing. The resistance of welds can be calculated from expressions in section 4. Table 1 of this article compares the resistances of bolts and welds typically used in simple connections according to BS 5950 and BS EN 1993. It is observed that BS EN 1993 does not introduce significant changes to the basic capacities of these components.

M20, 8.8 bolt	BS 5950-1:2000	BS EN 1993-1-8:2005
Tension	137kN	141kN
Shear	91.9kN	94.1kN
Bearing (10mm thick plate, S275)	91.9kN	88.1kN (end bolts, e_1=40mm) 117kN (inner bolts, p=70mm)
Welds in S275 steel	220N/mm^2	233N/mm^2
Welds in S355 steel	250N/mm^2	261N/mm^2

Table 1. Bolt and weld resistances according to BS 5950 and BS EN 1993-1-8

Note that the tensile resistance according to BS EN 1993 is equivalent to the BS 5950 capacity according to the "more exact method" of Clause 6.3.4.3. There is no equivalent to the "simple method" in BS 5950, which means that connection designers must allow for prying if bolts are subject to tension.

Designers will also note that the bearing resistance has changed in BS EN 1993. Experienced designers to BS 5950 will have been aware of the rule that in S275 material, bearing will not govern if the material is at least half the diameter of the bolt. So, according to BS 5950, the bearing resistance in 10mm S275 material, is equal to the shear resistance. With judicious choice of bolt setting out, it is possible to calculate a much higher bearing resistance according to the BS EN 1993 rules. In Table 1 above, by adjusting the setting out, the maximum bearing resistance would be 145kN. Of course, the bolt shear resistance would then govern, but this increased resistance may be an advantage when bolts are in double shear, perhaps through the thin web of a supporting beam.

An important change for UK designers with respect to bolts is given in clause 3.7(1) of BS EN 1993-1-8, where rules for the overall resistance of a group of fasteners are given. According to this clause if the bearing resistance of any individual bolt is lower than the shear resistance of the bolt, then the total resistance of the group of fasteners is calculated as the lowest bearing resistance multiplied by the total number of bolts. The following example illustrates the application of this clause.

Example 1:

M20, 8.8 bolts, 10mm thick plate, S275

e_1 = 40mm

p = 70mm

e_2 = 30mm

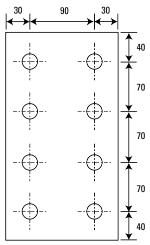
Shear resistance of bolts: $F_{v,Rd}$ = 94.1kN

Bearing resistance of inner bolts: $F_{b,Rd,in}$ = 117kN

Bearing resistance of end bolts: $F_{b,Rd,end}$ = 88.1kN

Resistance of bolt group:

$$F_{group} = 8 \times 88.1 = 705\text{kN}$$



Typical bolt setting out for end plate connections in the UK

Example 2:

M20, 8.8 bolts, 8mm thick plate, S275

e_1 = 50mm

p = 70mm

e_2 = 30mm

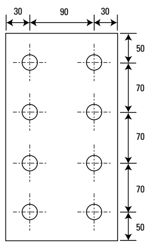
Shear resistance of bolts: $F_{v,Rd}$ = 94.1kN

Bearing resistance of inner bolts: $F_{b,Rd,in}$ = 93.6kN

Bearing resistance of end bolts: $F_{b,Rd,end}$ = 87.8kN

Resistance of bolt group:

$$F_{group} = 2 \times 88.8 + 6 \times 93.6 = 737\text{kN}$$



Bolt setting out for increased connection resistance

Tying resistance

Due to the more onerous rules in the Building Regulations, many simple connections must be designed to carry (as a separate check) a high tying force, often equal to the applied shear force. Fin plate and double angle cleat connections can carry a high tying force compared to their shear resistance and therefore they do not pose a problem in satisfying the Building Regulations. The response from consulting engineers is shown in Figure 1.

Partial depth flexible end plate connections, on the other hand, generally have a smaller resistance to tying. In order to increase the tying capacity of partial depth flexible end plates it is tempting simply to increase the thickness of the end plate.

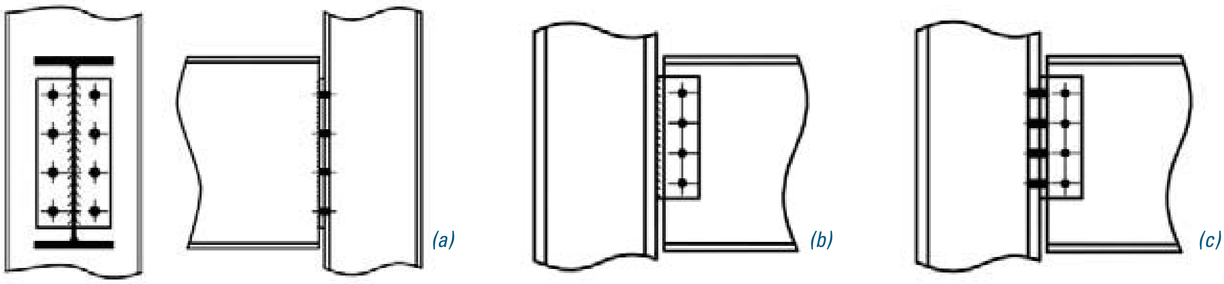


Figure 1. Commonly used simple connections in the UK
(a) Partial depth flexible end plate
(b) Fin plate
(c) Double angle cleats

Unfortunately, this may compromise the connection classification if the BS EN 1993 rules are not checked – a so-called pinned connection may be stiffer than anticipated.

Responding to the requirement to increase the tying resistance of end plate connections, the SCI is working on the development of a new detail and a new tying model to improve the tying resistance, whilst retaining the nominally pinned classification of end plate connections.

The SCI is studying the possibility of employing the T-Stub model from BS EN 1993 commonly used to calculate the resistance in the tensile zone of a moment resisting connection, but basing the calculated resistance on the factored ultimate strength, rather than the factored yield strength. Noting the differences in behaviour at yield and at ultimate, it is hoped that appropriate testing will be undertaken at some stage to fully validate the approach. Tying is of course an accidental load case, and the Standard notes that irreversible deformation is expected.

In addition to thicker end plates, there are a number of modifications which would increase the tying resistance of the 'standard' partial depth end plates. One option is to weld the end plate to the top and bottom flanges of the beam. Reducing the gauge (horizontal cross centres) and nestling the bolts close to the flanges are also effective measures to increase the tying resistance.

However all the above measures might also increase the moment resistance or reduce the rotation capacity of a connection, meaning that the connection might not be classified as pinned.

Connection classification

In order for a structure to behave as expected, the connections must behave as assumed in the beam and column design. Connections can be classified as nominally pinned, semi-rigid and rigid based on the connection stiffness, or based on the connection strength. Connections may also be classified on the basis of experience, or experimental evidence. There are clearly decades of experience that demonstrate the satisfactory performance of the 'standard' partial depth end plates, fin plates and double angle cleats. Unfortunately, the new details are a departure from the existing 'standard' details, and classification cannot easily be based on experience.

The calculation of the connection stiffness is a long and arduous task which involves calculating effective lengths depending on yield patterns (see section 6.3 of BS EN 1993-1-8). Stiffnesses of individual components are calculated, and assembled into a large model with springs in series and in parallel.

Connections can also be classified based on their strength. In order to be classified as pinned, a joint must satisfy the following two requirements:

1. The moment resistance of the connection must be less than 25% of the moment resistance of the supported beam.
2. The connection must be capable of providing enough rotation to accommodate the deflection of the supported beam in a ductile manner.

For flexible end plate connections the rotation requirement can easily be checked by applying equation 6.32 of BS EN 1993-1-8:

$$t \leq 0.36d \sqrt{\frac{f_{ub}}{f_y}}$$

Where:

- t is the plate thickness
- d is the diameter of the bolts
- f_{ub} is the ultimate tensile strength of the bolts
- f_y is the yield strength of the plate

From this equation it is concluded that for S275 end plates using M20, 8.8 bolts, plate thicknesses of up to 12mm will provide sufficient rotation capacity. This thickness reduces to 10mm when using S355 end plates, offsetting the potential improvement in tying resistance from the higher plate strength. In practice, most steelwork contractors wished to retain only the S275 plates, so the new details will follow this recommendation.

The moment resistance requirement must be checked in an individual basis for each connection and no simple rules are available for its assessment.

Work to date

Initial calculations suggest that welding the end plate the top and bottom flange, and increasing the plate thickness to 12mm shows very promising results. Retaining the existing 'standard' bolt positions means that the moment resistance is less than 25% of the beam moment resistance, demonstrating that the new details are pinned in accordance with the rules in the Standard. In many cases the tying resistance is close to the shear resistance (noting that both the applied shear force and applied tying force may be considerably smaller than the resistance). It is also noted that according to the Eurocode, the tying force should be treated as an accidental action, with reduced combination factors compared to the normal load cases.

Publication schedule

The new publication is sponsored by Corus, BCSA and SCI, and is due to be published later in 2009.