The use of S355 fin plates

Increasing interest in the use of S355 for fin plates prompted questions about the stiffness of such connections – are they still nominally pinned? David Brown of the SCI presents the results of the project comparing the behaviour of fin plate connections with both S275 and S355 fin plates.

Existing guidance

Rules for the design and detailing of fin plates were originally presented in the BS 5950 version of the Green Book[1]. At the time, fin plates were all from S275 material. Standardised connection details were presented, with design rules for each of the components. In support of the introduction of this type of connection to the UK, a series of physical tests were completed by Moore and Owens[2].

With any nominally pinned connection, ductility is required. One critical detailing rule to achieve ductile behaviour was therefore that either the supported beam web, or the fin plate, could be no thicker than $d/2$ in S275 material or $0.42d$ in S355 material. This rule was arranged that for Class 8.8 bolts, the bolt shear resistance (perceived as a relatively brittle failure mode) was no less than the bearing resistance – which was perceived as a ductile behaviour.

Thus for an M20 Class 8.8 bolt, according to BS 5950, the shear resistance is 92 kN

The bearing capacity for a bolt (assuming the end distance was not critical) is given by:

$P_{bs} = k_{bs} d t_p p_{bs}$

where:

k_{bs} = 1.0 for bolts in standard clearance holes

d is the bolt diameter

t_p is the thickness of the plate

p_{bs} = 460 N/mm^2 in S275 and 550 N/mm^2 in S355 (from Table 32 of BS 5950)

Thus for a 20 mm bolt in 10 mm thick S275 material, the bearing capacity is given by:

$P_{bs} = 1.0 \times 20 \times 10 \times 460 \times 10^{-3} = 92$ kN

If the material was S355, to ensure the shear resistance of the bolt is not critical, then

$$t_p < \frac{92 \times 10^3}{1.0 \times 20 \times 550} = 8.36 \text{ mm or } 0.42d$$

The advent of the Eurocodes

When the Eurocodes were introduced in 2005, two important changes had an impact on the rules for the design of fin plate connections. Firstly, the Eurocode demanded that the connections be formally classified – in the case of a fin plate to demonstrate that the connection was nominally pinned and secondly, the bearing resistance according to the Eurocode increased substantially.

Bearing resistance to BS EN 1993-1-8

According to BS EN 1993-1-8, the bearing resistance is given by:

$$F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}}$$

If end and edge distance do not limit, then $k_1 = 2.5$ and $\alpha_b = 1.0$. In 10 mm thick S275 material, with $f_u = 410$ N/mm^2 the bearing resistance for an M20 bolt becomes 164 kN, much higher than the BS 5950 value of 92 kN, and much higher than the bolt shear resistance, which according to the Eurocode is 94 kN for a Class 8.8 M20 bolt. Thus the previous rule to ensure ductility, that the bearing resistance should be less than the shear resistance, was impossible to meet in practice.

Connection classification to BS EN 1993-1-8

The Eurocode provided rules for the numerical calculation of connection stiffness, and a stiffness limit for nominally pinned connections. The rules are unfortunately only appropriate for end plate connections. Clause 5.2.2.1(2) also allows a joint to be classified on the basis of experimental evidence or evidence of previous satisfactory performance.

The Green Book to the Eurocode

In 2014, SCI and BCSA published the Eurocode Green Book[3]. The view taken was that there was both test evidence and significant previous experience to demonstrate that the standardised connections performed satisfactorily in practice, but that was conditional on the previous proven rules being followed. The Eurocode Green Book was at pains to point out that only the standardised connections were known to be satisfactory, and that varying the details might invalidate the proven behaviour. An important part of the limited scope was that the previous rules regarding fin plate or beam web thickness must be observed.

Changes to modern practice and the need for research

In recent years, the use of S355 has become more widespread, such that S355 is now the normal grade for rolled sections in the UK. In parallel, the use of S355 plate is becoming more common, and some steelwork contractors wished to use S355 fin plates. The limiting thickness of 8 mm was considered by many to be simply too thin – and so the need to assess the performance of fin plate connections with S355 plate was identified. The objective of the research was simply to compare moment-rotation and stiffness performance of fin plate connections. If connections with S355 fin plates were markedly stiffer than those with S275 plates, the classification as nominally pinned would be threatened.

Research programme

Firstly, an extensive desk study was undertaken to identify tests of fin plate connections. Physical test results are essential if the Finite Element (FE) model is to be calibrated – in other words to demonstrate that the FE model is a good model of the real behaviour. The test results must be comprehensive, as the measured properties of the components are needed, not just the nominal values. In addition, the results must be sufficiently detailed to allow a comparison of the moment-rotation behaviour. After reviewing the available test results, the original research by Moore and Owens[2] was the most comprehensive containing the necessary data.

For the connection chosen to calibrate the FE model, the comparison between the FE and the test results is shown in Figure 1.

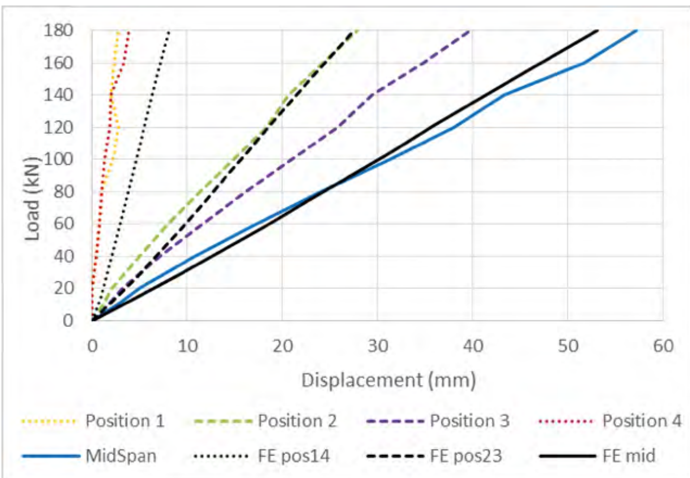

Figure 1: Comparison of FE and test results

In each case, the straight (black) lines in Figure 1 are the FE results, and illustrate deflection at points along the supported beam. The irregular lines show the measured deflections.

From Figure 1, it can be seen that the FE model was a good predictor of the test results. The stress patterns at the fin plate connection are shown in Figure 2. As anticipated, the higher stresses are at the extreme bolt locations in the fin plate. It should be noted that the stresses indicated are three-dimensional Von Mises stresses, so are not immediately comparable to (for example) a calculated bearing stress at a bolt location. The deformed shape of the fin plate (with an exaggerated horizontal scale) is also shown in Figure 2, and demonstrates behaviour as expected.

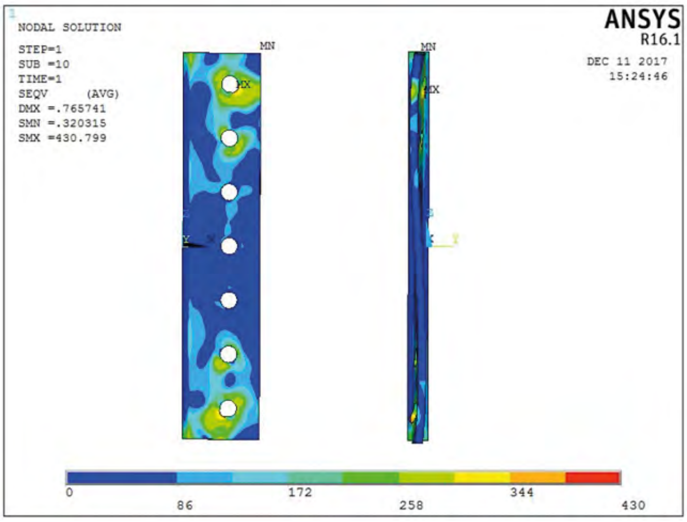

Figure 2: Stress diagram and deformed fin plate

Once the FE model was considered to provide a good model of the connection behaviour, a parametric study was undertaken, considering 28 different fin plate connections. Beams and connections were selected:

- with thin beam webs, so that the influence of the fin plate should not be significant,
- with thicker beam webs, so that the behaviour of the fin plate would be important,
- with one and two vertical columns of bolts,
- with a range of bolt rows.

In every case, the geometry of the standardised details shown in the Green Book was respected. Each case was analysed with a S275 fin plate and with a S355 fin plate.

Typical analysis results

Figure 3 shows the moment-rotation behaviour for the smallest connection considered – a 254 × 102 × 22 UB with just two bolts. Figure 3 also shows the limit for a nominally pinned classification, according to BS EN 1993-1-8. The connection is nominally pinned, and the moment-rotation plots are identical for S275 and S355 fin plates. This behaviour is expected, as the beam web is only 5.7 mm, so would be expected to be the critical component rather than the fin plate.

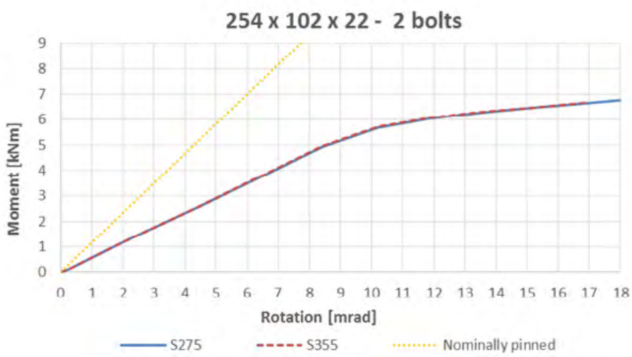

Figure 3: Moment-rotation curves for 254 × 102 UB, 2 bolts

Figure 4 shows the moment-rotation relationship for a 406 × 178 × 54 UB, with two vertical columns each of four bolts. Some small difference between the S275 and S355 fin plates is shown, at higher rotations. The initial stiffness is identical, and the connection would be classed as nominally pinned.

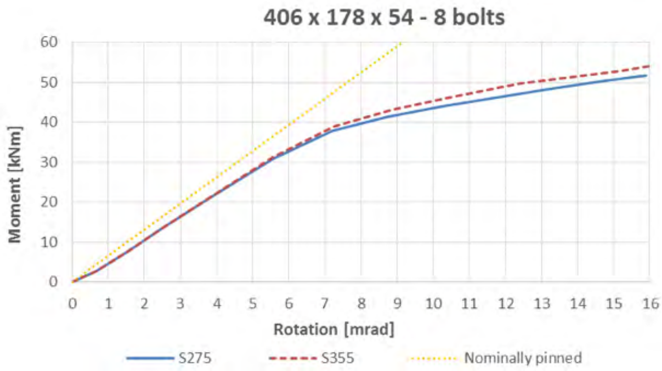

Figure 4: Moment-rotation curves for 406 × 178 UB, 8 bolts

The largest connection modelled was an 838 × 292 × 176 UB, with two vertical columns of 8 bolts. The web of this beam is 14 mm, so it would be expected that the behaviour would be dominated by the fin plate. The moment-rotation curves are shown in Figure 5. The connection is nominally pinned, with some increased stiffness at higher rotations with the S355 fin plate. It is suggested that the initial stiffness of the connection is dominated by deformation in bearing and that initially, this deformation is similar for both material grades.

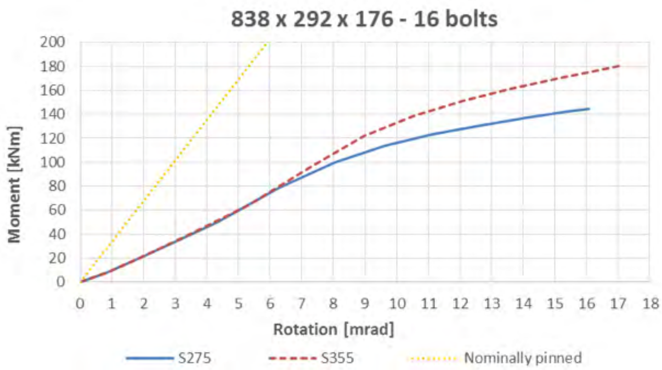

Figure 5: Moment-rotation curves for 838 × 292 UB, 16 bolts

Conclusions

The study has shown that as long as the standardised connection geometry presented in the Green Book[3] is respected, 10 mm fin plates in S355 are classed as nominally pinned connections and may be used as an alternative to S275 plates.

If the connection stiffness largely depends on the fin plate (i.e. the web of the beam is relatively thick), the connection stiffness for a given fin plate detail is similar and independent of the beam size. In contrast, the stiffness limit for a nominally pinned classification depends on the beam stiffness, which increases with the larger beams, making the nominally pinned classification more readily achieved for the larger sections.

One final observation is that the challenges of FE work should not be underestimated. This apparently straightforward study of a simple connection type involved contact surfaces, three-dimensional stresses, constraint by the bolts and plastic strains – reinforcing the need for calibration against physical tests.

Acknowledgements

This study was commissioned and funded by the BCSA and Steel for Life. The study was completed by Antonia Pilpilidou, formerly SCI.

References

1 Joints in steel construction. Simple connections (in accordance with BS 5950-1), (P212) "Green Book to BS 5950", SCI, 2009
2 Moore, D. B. and Owens, G. W., "Verification of design methods for fin plate connections", The Structural Engineer, Vol. 70, No.3/4 1992
3 Joints in steel construction. Simple joints to Eurocode 3, (P358) "Green Book", SCI, 2014