

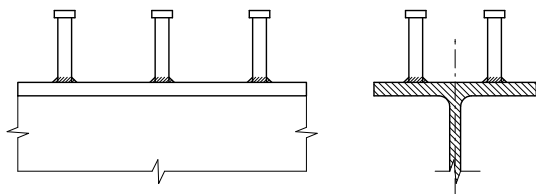
#### Scope

This Guidance Note gives advice on the shear connection between the steel girder and concrete slab of a typical steel composite bridge. Various means of providing the shear connection are mentioned, but this note focuses on the use of shear studs, which are predominantly used. EN 1994-2 only gives specific design rules for shear studs, but other connectors may be designed in accordance with the other Eurocode rules. The National Annex to BS EN 1994-2 gives some design rules for block and hoop connectors.

This brief note is intended to outline the design issues to consider, guide the reader to the appropriate code clauses, and discuss some fabrication aspects.

#### General

Shear connectors are required on the top flange of steel composite bridge girders to provide the necessary shear transfer between the steel girder and composite slab that is required for composite action. The most widely used form of shear connector is the headed stud, or shear stud. Refer to Figure 1.



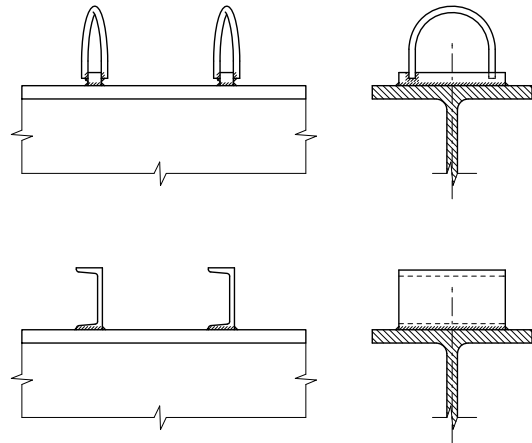
**Figure 1** Typical shear stud connectors

The advantages of shear studs over other forms of connectors are that the welding process is quick and simple, they provide little obstruction to the slab reinforcement, permit more satisfactory compaction of the concrete around the connectors, and provide equal shear strength in all directions.

Other forms of shear connector, which are sometimes used include block and hoop, and channel connectors, as illustrated in Figure 2. These types of connector are typically used where large shear transfers are required, as an alternative to closely spaced shear studs.

Shear connectors must be designed to provide static strength, and for fatigue loading. The shear flow varies along the length of a girder, being highest near the supports, and it is customary to vary the number and spacing

of connectors to provide just sufficient shear resistance for economy. Hence, shear flows should be calculated at supports, at midspan, and at least one position in between, i.e. quarter points, in order to plot a shear flow profile along a girder. There may also be a need to calculate shear flow at a significant change in beam section.



**Figure 2** Block and hoop, and channel shear connectors

#### Static design

The shear connection needs to be verified at ULS and at SLS. The requirement at SLS is given in Clause 6.8.1(3) of EN 1994-2 as a limit to the maximum force under the characteristic combination of actions. The SLS limit will usually only be critical for long span bridges with a high dead load component.

For Class 1 or 2 sections, because the bending resistance at ULS is calculated in terms of a plastic stress distribution, shear flow in zones where the slab is in compression must also be calculated using a plastic stress distribution. In zones where the slab is in tension, the shear flow may be calculated on the basis of elastic section properties and assuming the concrete to be uncracked. The unconservative neglect of plasticity is offset by the conservatism of ignoring cracking.

The design resistance of shear connectors is given by Clause 6.6.3.1 of EN 1994-2-2. For elastically designed zones, the spacing of the connectors may provide a 'stepped' resistance, subject to the provision of sufficient total resistance over each length. The maximum calculated shear flow within the length of any such group must not be more than

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10% in excess of its design resistance per unit length. For plastically designed zones, this provision does not apply as the connectors must be proportioned to resist the average force in the inelastic zone.

### Fatigue design

Verification of the connectors for fatigue is carried out for an equivalent constant range of shear stress given by Clause 6.8.6.2 of EN 1994-2, based on the stress range due to the fatigue load model 3 (FLM3) and damage equivalence factors. The fatigue strength curve is that for detail category 90. Adequacy is assessed to Clause 6.8.7.2; for connectors on tension flanges interaction with the tensile stress in the flange needs to be considered but does not normally govern, since worst shear and worst tension rarely coexist. Fatigue may govern the spacing of connectors in midspan regions of longitudinal members but does not often govern near supports.

### Transverse reinforcement

Transverse reinforcement is required in the slab to provide shear resistance. This is needed both to prevent splitting of the concrete adjacent to the stud and to allow load to spread out across the width of the slab. Refer to EN 1994-2, Clauses 6.6.5 and 6.6.6. An interaction between steel requirements for bending in the slab and longitudinal shear has to be considered. Particular care is needed for ladder deck construction where the transverse reinforcement required for bending is usually smaller, and may not be sufficient on its own to transfer high shear flows. Additionally, cross girders in ladder decks may have their transverse reinforcement in tension from the global behaviour of the main beams. In such cases, the effect of this tension must be fully added to that from longitudinal shear – see Hendy and Johnson (Ref 4) or P356 (Ref 5).

### Practical aspects

Standard sizes for shear studs, which are readily available from suppliers and typically used in steel composite bridge decks, are indicated in Table 1. Stud heights outside this range are available, and stud manufacturers should be contacted to check availability. Although studs over 19 mm diameter are available, they are not preferred by fabricators, as a higher level of defective welds can

be expected, due to the higher currents and magnetic field effects.

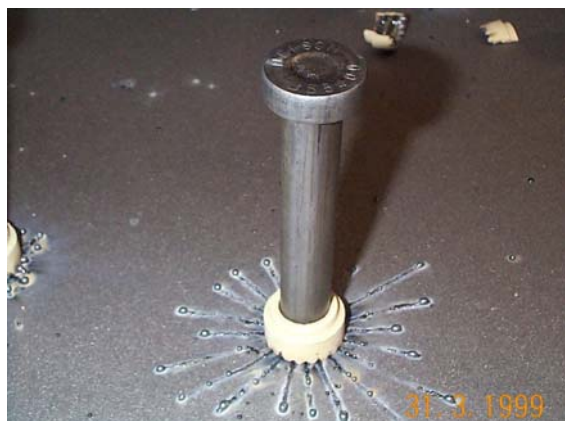
**Table 1** Standard sizes of Shear Studs

Stud height (mm)	Stud diameter (mm)			
	16	19	22	25
125	Available but rarely used in bridges	Occasionally used in bridges	Commonly used in bridges	Commonly used in bridges
150	Available but rarely used in bridges	Commonly used in bridges	Commonly used in bridges	Commonly used in bridges
175	Available but rarely used in bridges	Commonly used in bridges	Commonly used in bridges	Commonly used in bridges
200	Available but rarely used in bridges	Commonly used in bridges	Commonly used in bridges	Commonly used in bridges
250	Available but rarely used in bridges	Commonly used in bridges	Commonly used in bridges	Commonly used in bridges
	Commonly used in bridges			
	Occasionally used in bridges			
	Available but rarely used in bridges			

EN 1090-2 refers to EN ISO 13918 for the requirements for stud shear connectors. In that Standard, two grades of carbon steel stud are given, SD1 and SD2. Grade SD1 has the higher strength (minimum yield strength of 350 N/mm<sup>2</sup>, and a minimum tensile strength of 450 N/mm<sup>2</sup> but these values are less than those for studs previously supplied to BS 5400-5. It is suggested that SD1 studs be specified but with minimum yield strength of 385 N/mm<sup>2</sup>, and minimum tensile strength of 495 N/mm<sup>2</sup>, which is the strength that has been available in the UK for very many years.

Shear studs are generally attached to the top flanges of girders using a stud welding gun. The stud is held in the welding gun and an arc is struck between the stud and the flange plate. The arc melts a portion of both the stud and the plate in a set time. The gun then automatically plunges the stud into the molten pool of metal and holds it there until the weld solidifies. The molten metal is held in place by a ceramic ferrule, which also serves to shield the arc. Figure 3 illustrates a stud with the ceramic ferrule still in place.

Testing shows that the weld collar so formed is very important in transmitting shear. The resistances for shear studs in EN 1994-2 therefore only apply to studs attached in this way. Studs attached by friction welding, for example, cannot be designed using the EN 1994-2 rules for static or fatigue strength.



**Figure 3** Typical shear stud after welding

Shear studs should be welded in accordance with the manufacturer's instructions, including preheating where necessary. The studs, and plate to which they are welded, must be dry and clean otherwise the quality of the weld will be adversely affected, and welding should not be carried out when the temperature is below 0°C.

The equipment required for stud welding is specialist but readily portable, so although the majority of studs are welded in the shop, they could be welded on site if required, although it is unlikely to be economic for small numbers of studs: fillet welding is more practical for small numbers and such welds are structurally satisfactory. Where studs are manually welded on site, there should be a defined weld procedure; it is likely that preheat will be needed because the weld is small in extent.

#### Spacing of shear connectors

The minimum distance between the edge of a shear connector and the edge of a flange plate is specified as 25 mm in EN 1994-2, Clause 6.6.5.6(2). However, other issues need to be considered as follows.

Many steel composite decks are constructed using permanent formwork, usually either precast concrete 'Omnia' planks or GRP panels. Allowance needs to be made for the bearing or seating lengths required, which are typically 50 mm, and also tolerances on the girder spacing. The extent of the painting envelope is also important, as shear connectors should ideally not be painted but a minimum bond length for the paint of 25 mm beyond the end of the precast element should

be provided. This leads to a recommended minimum edge distance of 100 mm where permanent formwork is used, comprising a 25 mm return of the paint into the in-situ concrete/steelwork contact area, a 25 mm tolerance on girder seating and formwork length and a 50 mm seating length. In other cases, a minimum of 50 mm will generally be sufficient.

The minimum spacing between the centre-lines of shear studs is governed by access requirements for the stud welding gun. A minimum spacing of between 60 mm and 70 mm is possible, depending on the size of the studs, but a minimum of 100 mm is preferred by fabricators.

The maximum longitudinal spacing is defined in EN 1994-2, Clause 6.6.5.5(3), and is the lower of the following:

- 800 mm
- 4 x concrete slab thickness
- A lower value if needed to restrain local buckling of the flange such that it achieves a classification of Class 1 or 2

There are also further limits in EN 1994-2 Table 9.1 on the spacing of studs on composite plates, such as in composite box girders, where it is necessary for the studs and concrete to restrain the flange.

In determining the actual spacing of shear studs along the length of the steel girder it is usual to adopt a spacing equal to the transverse deck reinforcement spacing, or multiples thereof. This facilitates the easy fixing of the deck reinforcement.

Note that in steel box girders with composite flanges, there will be a concentration of shear transference local to the box webs. Shear studs will need to be arranged to suit this, resulting in a higher density of connectors above the webs - see EN 1994-2 Clause 9.4.

#### Size of shear connectors

Clearly, the design for shear transfer will have a bearing on the size of the shear stud. However, EN 1994-2 defines other criteria to consider:

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Clause 6.6.5.7 requires that the diameter of the shear stud should not exceed one and a half times the plate thickness, if the plate is subjected to tensile stress and fatigue loading, and two and a half times the plate thickness in other cases.

Clause 6.6.5.1 requires that the underside of the head of the stud should project at least 30 mm above the bottom transverse reinforcement. This will usually govern the height of the stud. Additional height should be considered on shear connectors, particularly on decks where there is severe crossfall. This provides additional tolerance in construction, and assists in achieving the required projection of the head above the transverse reinforcement. There is an additional requirement in Clause 6.6.5.7 that the height should not be less than three times the stud diameter but this seldom governs.

The welding current needed to weld the studs increases rapidly as the stud diameter increases. For 25 mm studs, the heat input and rapid cooling of the weld metal mean that it can be very difficult to find a weld procedure that will keep hardness in the HAZ within specification. Equipment to weld 25 mm studs is not suitable for site work.

### Testing

On visual inspection, the weld to a stud connector should form a complete collar around the shank, be free from cracks and excessive splashes of weld material, and have a 'steel-blue' appearance.

The Highways Agency's Specification for Highway Works Series 1800 (Ref 6) includes inspection and testing requirements in the absence of comparable requirements in EN 1090-2.

There are two tests to check the fixing of shear studs: the ring test and the bend test.

The ring test simply involves striking the side of the head of the stud with a 2 kg hammer. A ringing tone after striking indicates good fusion, whereas a dull tone indicates a lack of fusion. All studs should be checked in this way by the welder or the welder's mate.

The bend test requires the head of a stud to be displaced laterally by approximately a quarter of its height using a 6 kg hammer. The weld should then be checked for signs of cracking or lack of fusion. Figure 4 illustrates a typical stud after a bend test. It is important to note that studs should not be bent back as this is likely to damage the weld. The testing rate should be specified by the designer and is usually 1 stud in 50. However, any studs which fail the ring test, or are suspect on visual inspection should also be checked in this way.



**Figure 4** *Shear stud after bend test*

### References and further reading

1. EN 1994-2:2005, Eurocode 4: Part 2, Steel and concrete composite bridges.
2. Plus the UK National Annex:
3. NA to BS EN 1994-2:2005, BSI, 2007
4. Hendy C R and Johnson, R P, Designers' Guide to EN 1994-2, Thomas Telford, 2006
5. Composite Highway Bridge Design (P356), SCI, 2010
6. Manual of Contract Documents for Highway Works, Volume 1 - Specification for Highway Works, Series 1800 Structural steelwork, Highways Agency, 2014