U-frames in bridges

Bridge designers will be familiar with compression flanges restrained by u-frames. David Brown of the SCI introduces the concept and illustrates the same principle commonly found in the design of portal frames.

Engineers are always concerned with the buckling of elements in compression and how restraint might be provided. In bridge construction and (for example) a twin truss span, it may be possible to brace between compression chords, as shown in Figure 1, to form an enclosed box.

Figure 1: Truss bridge with bracing between the compression chords

If bracing between the compression chords is to be avoided, some other means of restraining the compression chord (or compression flange, if the member is a beam) must be found. There are many examples of older footbridges where a horizontal cross member is extended laterally at deck level, and a diagonal brace provided to restrain the compression flange, as shown in Figure 2. People without an engineering background often think the metalwork was provided to support pipework (and it was often used for this), but the arrangement has a much more important function.

Figure 2: Bridges with external bracing to restrain the compression flange

With so-called "half-through" bridges, such as that shown in Figure 3, clearly no bracing is possible between the compression flanges. In this form of construction, the compression flanges are restrained by intermediate u-frames.

Figure 3: "Half-through" bridge

A typical cross section at a u-frame location is shown in Figure 4. A u-frame consists of a horizontal member (usually part of the deck steelwork) and vertical members. The connection between the horizontal member and the vertical member is continuous or semi-continuous forming a u-shaped stiff frame to provide restraint to the compression elements.

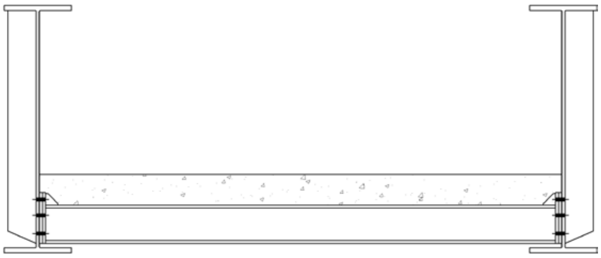

Figure 4: "Half-through" bridge typical cross section

Bridge design codes such as BS 5400-3 or BS EN 1993-2 allow designers to calculate an effective buckling length of the compression flange. The effective length primarily depends on the stiffness of the vertical members, the stiffness of the horizontal member and the stiffness of the connection between the members. Increased flexibility in the members or at the connections will lead to a longer buckling length. Detailed information on the design of half-through bridges, including the effect of u-frames, may be found on *steelconstruction.info*.

U-frames can also be seen in the footbridge pictured in Figure 5 (over page). In this form of construction, the compression flanges of the main girders are formed of square hollow sections, orientated as a diamond. Restraint to these compression flanges is provided by external u-frames fabricated from plate, which wrap around the bridge cross section at intervals along the span.

Application in buildings

Although u-frames are associated with bridge construction, the same principle is found in portal frames, when the inside flanges of the members are restrained by bracing back to the purlins or side rails, as shown in Figure 6.

Some authorities (notably in other parts of Europe) consider this restraint system results in axial loads in the secondary steelwork, and that the restraint is only effective if purlins (or rails) assumed to provide restraint intersect with a node on the bracing (typically in the end bay). In the UK, there is no such requirement and our understanding is that the torsional restraint is effective because of the u-frame action.

Figure 5: Footbridge with u-frames; cross section

Figure 6: typical bracing to rafter

A section along a building is shown in Figure 7, along the line of a purlin, with inner flange restraints to a number of rafters. The compression in the inside flange would ordinarily result in lateral torsional buckling, with the purlins providing restraint to the tension flange only. Figure 7 shows that the rafters are restrained with respect to the purlin, forming an inverted u-frame.

Design requirements in portal frames

Two obvious requirements are clear from Figure 7. Firstly the purlin (or rail) must be continuous to be effective. If there is a break in the member, there is no u-frame action. This situation arises when side rails are interrupted, for example by a roller shutter door. In this case, short side rails between door jambs should not be relied on to provide restraint.

Secondly, as discussed in the context of bridges, the members of the u-frame must have appropriate stiffness. A traditional rule of thumb was to provide a side rail or purlin of at least 25% of the depth of the member being restrained. Horne and Ajmani proposed a rule to determine the necessary stiffness in 1973[1]. It is sobering to reflect that this rule was based on tests using members with tapered flanges and hot-rolled side rails, not the members typically used some 45 years later.

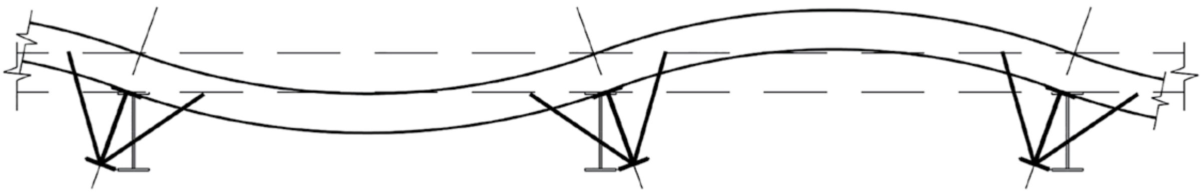

Figure 7: U-frame action in purlin restraint

The rule considered the necessary restraint at a plastic hinge and may be expressed as:

$$\frac{I_s}{I_f} \geq \frac{f_y}{190 \times 10^3} \frac{B(L_1+L_2)}{L_1 L_2}$$

where,

f_y is the design strength of the portal frame member

I_s is the second moment of area of the purlin or rail in its major axis

I_f is the second moment of area of the frame member

B is the span of the rail or purlin

L_1 and L_2 are the distances each side of the plastic hinge to the eaves or points of contraflexure, as shown in Figure 8.

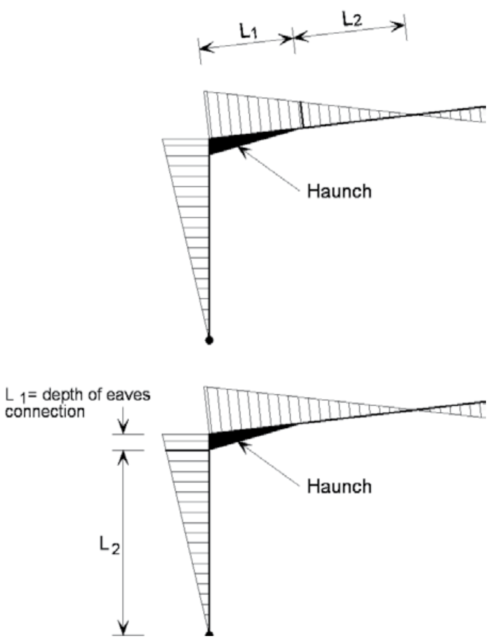

Figure 8: Lengths L_1 and L_2 used to check restraint member stiffness

As an illustration, for a rafter (Figure 8), and a span of 35 m, a reasonable assumption is that L_1 = 3.5 m and L_2 = 4 m

Assuming the member is a 457 × 191 × 67 UB, then I_f = 29400 cm^4. If the rafter is S355 and the span of the purlin is 7 m, the stiffness requirement for the purlin becomes:

$$I_s \geq \frac{29400 \times 10^4 \times 355 \times 7000 \times (3500 + 4000)}{190 \times 10^3 \times 3500 \times 4000 \times 10^4} = 206\text{cm}^4$$

This order of inertia is provided by a 170 mm deep purlin, so normal frame arrangements appear to be adequate.

Unorthodox situations

The selection of purlins and side rails is normally made based on the span and loading on the member without any recourse to the check illustrated above. For orthodox construction, the relationship between the selected member and the stiffness necessary to provide u-frame action appears to be satisfactory. An issue can arise if the portal frames are long span, but nevertheless spaced at typical centres. Since the purlin (or rail) selection is based on the span and spacing of the secondary members, the purlins and rails selected for a long span frame may be the same as would be chosen for an orthodox span, but clearly the demands on stiffness are much higher.

The general advice is that orthodox frames with usual member sizes function satisfactorily with the 'normal' sizes and spacing of secondary steelwork. Situations where more care is needed are long span frames, and where the secondary steelwork is not continuous.

References

1 Horne, M, R and Ajmani, J,L.
Failure of columns laterally supported on one flange: Discussion
The Structural Engineer, Vol 50, No. 7, July 1973