



STEEL INDUSTRY
GUIDANCE NOTES

Web openings in composite beams

A common method of incorporating services within the structural depth of composite beams is by cutting circular or rectangular openings in the webs of rolled or fabricated beams, or by manufacturing cellular beams with regular circular openings. Transfer of shear at large openings is the dominant effect and gives rise to Vierendeel bending moments that are resisted by local bending of the Tee sections around the openings. For composite beams, composite action of the top Tee with the slab increases the local bending resistance, which means that larger openings can be used in comparison to steel beams. Although most beams with web openings are designed by purpose-written software, it is important to give guidance on the size and spacing of openings for use in scheme design, which is the purpose of this note.

Background

There are two main types of beams with web openings that are directly related to the method of manufacture of the beams, as follows:

- Isolated rectangular or circular openings cut out of the web at positions where the interaction between the openings is minimised
- Regular circular openings (sometimes with elongated openings) in which the interaction between the openings is included in the analysis – these are known generically as ‘cellular beams’.

There are three methods of manufacture:

- Hot rolled I sections with individually cut openings, in which the steel section is symmetric in shape. This method is mainly used for beams with isolated openings.
- Fabricated sections, which are formed from three plates that are welded together to form an I section. The section can be asymmetric (for example, with a larger bottom flange) and the beams can be tapered in depth along their length.
- Hot rolled sections which are cut to a profile along the web and rewelded to form a deeper beam with a series of regular circular openings. These ‘cellular beams’ can be asymmetric in cross-section, when the Tees are cut from different I sections.

The use of one or more of these methods of construction depends on the number and size of the service ducts and pipes that are required to be integrated in the structural zone, taking account also of the requirements for future re-servicing and change of use of the space. Openings can be purpose-designed for specific applications or regular openings can be provided, which means that only some openings are used for service distribution.

Floor Layouts

The ability to design long spans (typically up to 18m) with facility for service integration is one of the main benefits of steel construction. The provision of large openings in the webs of composite beams has become the main way of accommodating service ducts and pipes, and various techniques may be used. Structurally, web openings cause a significant reduction in the shear resistance of beams, due to the loss of a major proportion of the web, but cause a smaller reduction in their bending resistance. The shear transfer across sections with large openings is therefore an important design requirement.

Cellular beams with regular openings are more often used for long span secondary beams, whose design is generally controlled by serviceability requirements, whereas fabricated beams with isolated

openings are often used for long span primary beams, whose design is more controlled by the higher shear forces acting on these beams. Secondary beams are generally designed to span the longer distance in the floor grid, as shown in Figure 1, and therefore the primary beam span depends on the number and spacing of secondary beams. The depth of these beams is generally dependent on the overall floor zone of typically 900 to 1200 mm less the raised floor, composite slab and ceiling depths.

Alternatively, where primary beams span the longer distance in a floor grid, as shown in Figure 2, large openings should be placed preferably in the lower shear regions of the beam. At long openings, the beam can be strengthened with welded horizontal stiffeners to improve the local bending resistance of the flange-web Tee sections. Also, fabricated beams can be manufactured with thicker webs or openings in cellular beams can be in-filled in order to resist higher shear forces.

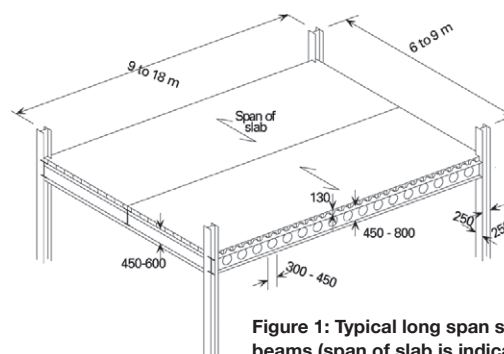


Figure 1: Typical long span secondary beams (span of slab is indicated)

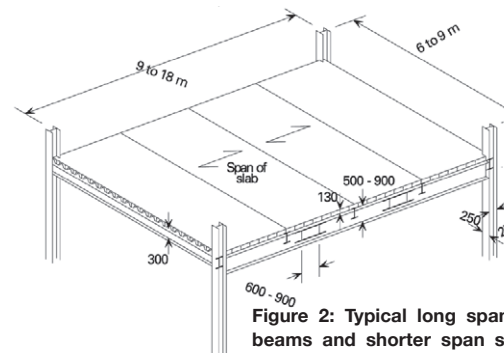


Figure 2: Typical long span primary beams and shorter span secondary beams (span of slab is indicated)

Design of beams with large openings

The various modes of failure that may occur at or around large openings, are illustrated in Figure 3. Some modes of failure occur due to local effects around single large openings, whereas others arise due to the failure of the web-post between closely spaced openings.

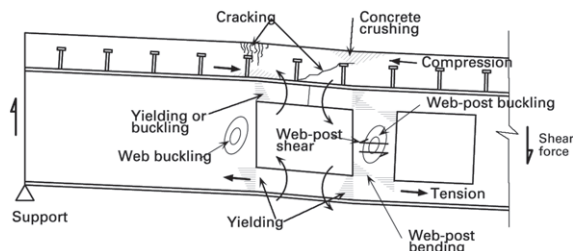


Figure 3 Modes of failure at large closely spaced openings

The principal modes of failure are:

Global bending (dependant on composite action at the opening position)

Vertical shear (dependant on the reduced steel section).

Local Vierendeel bending (dependant on the shear transfer by bending across the opening).

Web-post horizontal shear (which may govern for closely spaced openings).

Web-post bending (this occurs mainly between closely spaced rectangular openings).

Web-post buckling (this may occur for slender web-posts between closely spaced openings)

Shear buckling (may occur in slender webs adjacent to large openings).

Shear transfer across large openings occurs by Vierendeel bending in the flange-web 'Tee' sections at the four 'corners' of the opening. This effect will dominate for long openings and so it is necessary to limit the length: depth ratio of the openings. The resistance to Vierendeel bending may be improved by horizontal stiffener plates. Vertical stiffeners are not normally required. Composite action of the top Tee with the composite or solid slab also increases the Vierendeel bending resistance, which can more than double the bending resistance of the top Tee. Furthermore, the local flexibility due to shear and bending deformation may also be significant for large openings, and this is taken into account in serviceability calculations.

Web-post buckling and horizontal shear often controls the design of cellular beams with narrow web-posts and so for satisfactory design,

it is often necessary to choose an opening size with a suitable web-post width. Web-post failure is exacerbated when circular openings are made into elongated openings by removing the web-post between adjacent openings. Web-post failure is more likely between rectangular openings and so these openings should be spaced wider apart.

Guidance on the fire resistance of beams with web openings using intumescent coatings has been prepared, which takes account of the higher temperatures that can occur in narrow web-posts. At elevated temperatures, the web is more susceptible to local buckling, which means that the shear resistance of the web reduces at a faster rate than the bending resistance of the beam. Therefore, in some shear dominated design cases, it is necessary to increase the thickness of fire protection relative to an equivalent non-perforated beam.

General guidance on positioning of openings

The proposed geometric limits given in Table 1 should normally be observed at the scheme design stage when providing large openings in the webs of composite beams. Low shear regions are defined as those regions where the applied shear force is less than half of the maximum shear force acting on the beam. The guidance differentiates between cellular beams with circular openings and beams with isolated rectangular or elongated openings. Design outside these limits may be possible if justified by calculation or by using purpose – written design software available from the cellular beam manufacturers.

Detailing limits for the particular case of large rectangular openings in high shear regions near the supports are illustrated in Figure 4. The position of these openings is controlled by the stability of the web subject to forces at the end connections and from any point loads close to the supports, and also by the need to transfer forces from the shear connectors into the beam.

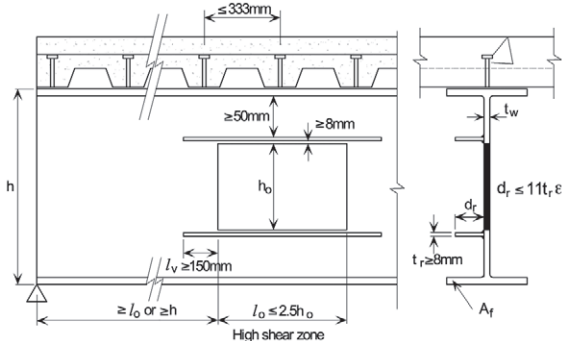


Figure 4: Proposed detailing limits for rectangular openings in high shear zones

Table 1 Proposed geometric limits for use in scheme design of composite beams with web openings

Parameter	Opening Type		Comment
	Circular	Rectangular	
Max. depth of opening:	$\leq 0.8h$	$\leq 0.7h$	This is a sensible limit which satisfies the limits below.
Min. depth of Tees:	$\geq t_s t + 30 \text{ mm}$	$\geq 0.1h$	Sensible limit, based on draft Annex N of ENV 1993-1-1: 1992.
Min. depth of Top Tee:	As above	$\geq 0.1 l_o$, if unstiffened	Limited by deformation and stability of top Tee.
Max ratio of depth of Tees: $h_o/h_t \leq$ $h_o/h_t \geq$	≤ 3 ≥ 0.5	≤ 2 ≥ 1	Asymmetry of opening position can cause web-post moments. It is preferable to provide an upward (positive) eccentricity of the opening in the web depth.
Max. unstiffened opening length, l_o	—	$\leq 1.5 h_o$ - high shear $\leq 2.5 h_o$ - low shear	This aspect ratio limits the deformation across the opening and possible tension failure in the shear connectors. Stricter limits are required for openings in high shear regions.
Max. stiffened opening length, l_o	—	$\leq 2.5 h_o$ - high shear $\leq 4 h_o$ - low shear	
Min. width of web-post: - General case- - High shear regions	$\geq 0.3 h_o$ $\geq 0.4 h_o$	$\geq 0.5 l_o$ $\geq h_o$	The design of the web-posts is subject to further checks. It is recommended that stricter limits are adopted for openings in high shear regions.
Min. width of endpost s_e :	$\geq 0.4 h_o$	$\geq l_o$ and $\geq h_o$	Dependent on horizontal shear stresses and web buckling at the first opening.
Corner radius:	—	$r_o \geq 2t_w$ but $r_o \geq 15 \text{ mm}$	Based on draft Annex N of ENV 1993-1-1: 1992/A2.
Min. distance to point load: - no stiffener - with stiffeners	$\geq 0.5 h$ $\geq 0.25 h_o$	$\geq h$ $\geq 0.5 h_o$	A separate check is required on web buckling at a point load position.

Further sources of Information

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5. Guidance on the Fire Protection of Beams with web Openings, SCI RT 1187, 2008
6. SCI Advisory Desk 319 Update on the Fire Protection of Beams with Web Openings
7. Cellbeam software is available from www.westok.co.uk
8. FBEAM software is available from www.fabsec.co.uk
9. BDES for Advance sections is available from www.corusconstruction.com