# AD 418: Web-post buckling in composite beams with rectangular and elongated web openings

The design of composite beams with large web openings is presented in SCI P355, which has been adopted in the development of software for the design of both hot rolled and fabricated steel sections with openings of various shapes and sizes. In P355, the method for addressing web buckling next to or between rectangular or elongated openings identifies two cases; closely spaced and widely spaced openings. For rectangular openings, the transition between the two cases is taken at an edge-to-edge spacing $s_o$, equal to the length of the opening $\ell_o$. For elongated openings, this transition occurs at an equivalent opening length, which may be taken as $\ell_o$ - $0.55h_o$.

For widely spaced openings, web buckling next to an opening is checked by considering the local transfer of the vertical shear force in the Tees acting on a strut of width equal to half the opening depth.

For closely spaced openings, the relevant compression force acting on the equivalent strut is taken as equal to the horizontal shear force in the web-post and the check for web-post buckling is based on an inclined strut whose slenderness depends on the spacing of the openings.

The issue in the design of beams with large web openings is the potentially high 'step' in the shear resistance at the transition between closely and widely spaced openings, which occurs due to the high slenderness of the inclined strut. To partly reduce this issue, some changes in the application of P355 are now appropriate, which relax the current rules for long openings. These relaxations align with the current work to provide normative clauses on the design of beams with large web openings in Eurocodes 3 and 4.

## Web-post buckling in P355

In P355, the buckling length of the web-post for closely spaced openings is given by:

$\ell_w = 0.7(h_o^2 + s_o^2)^{0.5}$ for rectangular openings (1)

$\ell_w = 0.5(h_o^2 + s_o^2)^{0.5}$ for circular or elongated openings (2)

where:

$h_o$ is the opening height

$s_o$ is the edge-to-edge distance between the openings.

For rectangular and elongated openings, the maximum opening length is $\ell_o \le 2.5\, h_o$ for unstiffened openings and the minimum edge-to-edge spacing, $s_o$ should exceed $0.5\, \ell_o$. In comparison, for circular openings, $s_o \ge 0.1h_o$ for steel beams and $\ge 0.3h_o$ for composite beams.

## Relaxation for adjacent rectangular openings

For adjacent rectangular openings, it is now accepted that to align with the work on large web openings in the new part of Eurocode 3, EN 1993-1-13, the maximum buckling length for web-post buckling between rectangular openings of the same height may be taken as:

$$\ell_w \le h_o \quad (3)$$

This leads to an upper bound nondimensional slenderness of the web-post given by:

$$\bar{\lambda}_{wp} \le \frac{3.5h_o}{t_w \lambda_1} \quad (4)$$

where:

$\lambda_1 = \pi(E/f_y)^{0.5}$

$\bar{\lambda}_{wp}$ is used to obtain $\chi_{wp}$, which is the reduction factor due to buckling of the web-post acting as a strut. For rolled sections, buckling curve 'a' in EN 1993-1-1 may be used and for fabricated sections, buckling curve 'c' should be used. The buckling resistance of the web-post is given by:

$$N_{wp,Rd} = \chi_{wp}\, t_{w,min}\, s_o\, f_y / \gamma_{M1} \quad (5)$$

where:

$t_{w,min}$ is the smaller web thickness above/below the opening

$f_y$ is the yield strength of the steel

This buckling resistance is compared to the horizontal shear force, $V_{wp,Ed}$, acting in the web-post. The upper bound shear resistance is given by $\chi_{wp} = 1/\sqrt{3} = 0.577$, which corresponds to pure shear resistance of the web-post rather than buckling.

For rectangular openings, a further check should be made on the in-plane moment acting at the top or bottom of the web-post due to the effects of horizontal shear, which may control for narrow web-posts. For a symmetric section, this moment is given by $0.5V_{wp,Ed}\, h_o$, which should not exceed the in-plane bending resistance of the web-post, which is taken as $t_{w,min}\, s_o^2\, f_y / (6\gamma_{M1})$.

## Relaxation for adjacent elongated openings or circular and elongated openings

The maximum buckling length for web-post buckling between circular or circular and elongated openings of the same height may be taken as:

$$\ell_w \le 0.7h_o$$

This leads to an upper bound nondimensional slenderness of the web-post given by:

$$\bar{\lambda}_{wp} \le \frac{2.4h_o}{t_w \lambda_1} \quad (6)$$

## Relaxation for adjacent circular and rectangular openings

For adjacent circular and rectangular openings, or openings of different lengths, it is proposed that the transition between closely spaced and widely spaced openings is taken as the average of the two opening lengths. For adjacent circular and rectangular openings, this corresponds to a transition at an edge-to-edge spacing of $s_o = 0.5(\ell_o + h_o)$. It is proposed that the minimum edge-to-edge spacing is $0.25(\ell_o + h_o)$ for the case of adjacent rectangular and circular openings. The upper bound nondimensional slenderness of the web-post is taken as the average of the two openings.

A further AD will address unequal opening height and positions in the beam depth.


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