AD 269
The use of intumescent coatings for the fire protection of beams with circular web openings.

Beams with web openings, including traditional castellated beams, cellular beams with circular openings, and beams with multiple openings of varying size and shape have traditionally been fire protected using the guidance given in *Fire protection for structural steel in buildings*, the "Yellow Book". This gives an empirical rule for calculating the passive fire protection thickness to be applied to castellated and cellular beams, in which the thickness required for the solid parent beam is increased by 20% in recognition of the fact that castellated beams have been found to heat up at a slightly faster rate than solid beams. The limited tests from which this conclusion was drawn were carried out on loaded castellated beams protected with a thick insulating, spray applied, fire protection material.

The Yellow Book states that the rule applies to passive materials and that no general guidance is available for active (intumescent) materials. However, because no other guidance was available, the rule has been widely applied to perforated or cellular beams protected using intumescent coatings. In the absence of other guidance, the rule was given without restriction in the SCI publication, *Structural fire design, Off-site applied thin film intumescent coatings*, and was adopted in the current version of BS5950-8. Although the BS5950-8 rule relates to castellated beams, it is widely interpreted as applying to cellular beams with circular openings.

In the last two years, rigorous fire resistance tests have been carried out at approved laboratories on beams with web openings protected using one type of intumescent coating. These tests showed that the 20% rule could not be safely applied, as the temperature of the web between openings is significantly higher than the temperature of the bottom flange of the section. As a direct result, in the revision to BS5950-8 expected later this year, the 20% rule will be limited to passive sprayed and board fire protection and no guidance will be given on any increase for beams protected using intumescent coatings.

More recently, indicative tests on symmetric and asymmetric cellular beams fabricated from hot rolled sections and protected by two types of intumescent coating have also shown that web posts between openings become hotter than the bottom flange of the section. This effect has been shown to occur regardless of the thickness of coating applied.

The SCI feels that in light of this recent knowledge, new guidance on the protection requirements for the use of intumescent coatings for cellular beams and beams with large discrete openings is required. The reason for the increases in temperature in the web between openings is under active investigation by both the steelwork contracting and the intumescent coating industries.

The following guidance is therefore interim and will be updated when more information is available. It is based on a number of conservative assumptions with regard to the temperature profile in the beam and the calculation of the fire protection thickness and has been calibrated against an analytical thermal model as well as the available test data. More detailed guidance is available in RT983, *Interim guidance on the use of intumescent coatings for the fire protection of beams with web openings*, available on Steelbiz at www.steelbiz.org. Paper copies may be purchased for £30 through the SCI Publications Department.

Provided the guidance is followed, beams should have adequate fire resistance, i.e., performance in a standard fire resistance test. However, in assessing the implications of this guidance, especially for existing construction, it should be recognised that the performance of composite buildings in real fires is significantly enhanced compared with the behaviour of individual beams in standard fire tests[1].

Interim Guidance

For optimum economy, liaison is required between the structural engineer responsible for the design and the fire protection supplier. This is particularly important when an intumescent coating is to be applied to beams with large web openings. It can be economically very important to take account of the level of loading on different parts of the beam. Cellular beams in which the utilisation factors are significantly below unity require less protection than more highly stressed beams.

The SCI recommends one of the following options for design of beams with circular web openings, protected using an intumescent coating. The option selected will depend on the amount of design information available and whether evidence of performance in fire tests is available.

Option 1

Table 1 applies to composite beams subject to the following: equal top and bottom tees, centrally positioned circular openings with diameters up to 80% of the beam depth, width of end posts, E, not less than 30% of the opening diameter, the ratio of opening spacing to opening diameter (S/d_o) not less than 1.4 and supporting uniformly distributed loading, typical of office buildings. The Table is based on the average performance of a number of intumescent coatings; it assumes that the voids formed by steel decking above the top flange are "filled" (Yellow Book, Section 2.3). For beams that do not comply, more comprehensive design information is available in RT983.

The following geometric information is required: beam depth, span, average web thickness, t, the distance between flanges (or fillets), d, spacing of openings, S, opening diameter, d_o , web post width, P, and the dimensions of the bottom tee (Figure 1).

Initially, the required thickness of intumescent coating should be obtained from the tabular data in the Yellow Book for a **3 sided exposed beam**. In using these tables from the Yellow Book, the section factor, H_p/A, should be based on the section factor of the **bottom tee of the cellular beam**. The thickness should then be multiplied by the appropriate factor from Table 1

Span/ Depth	S/d_o	Web Post Width (mm)	Maximum utilization = 1.0 d/t			Maximum utilization = 0.8 d/t		
			$\leq 50\varepsilon$	62ε	80ε	$\leq 50\varepsilon$	62ε	80ε
12 - 16	1.4	130	1.6	1.6	1.5	1.4	1.3	1.2
		200	1.5	1.5	1.5	1.3	1.3	1.3
		250	1.5	1.5	1.5	1.2	1.2	1.2
		≮300	1.4	1.4	1.4	1.1	1.1	1.1
	1.6	200	1.4	1.5	1.5	1.1	1.2	1.2
		250	1.3	1.4	1.4	1.1	1.2	1.1
		≮500	1.1	1.3	1.2	1.0	1.1	1.1
	1.8	250	1.3	1.4	1.4	1.0	1.1	1.1
		≮500	1.1	1.2	1.2	1.0	1.1	1.0
≮24	1.4	130	1.4	1.5	1.6	1.1	1.3	1.4
		200	1.3	1.4	1.5	1.1	1.2	1.3
		250	1.3	1.4	1.5	1.0	1.0	1.1
		≮300	1.2	1.3	1.4	1.0	1.0	1.1
	1.6	200	1.2	1.3	1.4	1.0	1.1	1.2
		250	1.2	1.3	1.4	1.0	1.0	1.1
		≮500	1.0	1.1	1.1	1.0	1.0	1.0
	1.8	250	1.2	1.3	1.3	1.0	1.0	1.1
		≮500	1.0	1.1	1.1	1.0	1.0	1.0

Note: Maximum utilization is for normal, cold, design
For S355 steel ε = 0.88, for S275 steel ε = 1.0
For discrete openings use S/d_o = 1.8 and web post width 500mm
Scope of application is defined in option 1 above

Table 1 Thickness modification factors for symmetric beams with web openings and this thickness should be applied to all exposed surfaces. The bottom tee is used because the underlying engineering model is based on the temperature of the bottom flange. Using the proportions of the section, the temperatures of the top flange and web are set relative to the bottom flange temperature.

The factors in Table 1 are for materials assessed at a limiting steel temperature of 620°C. Intumescent materials assessed at lower temperatures, require a smaller increase in protection thickness. For intumescent materials assessed at a temperature of 550°C, the values given in Table 1 may be reduced by 20%. Linear interpolation between the values in Table 1 is permitted.

For asymmetric sections, including sections with offset openings, the thickness of fire protection should be further increased. The increase varies with the degree of asymmetry, which is defined as the area of the bottom tee divided by the area of the top tee. The multiplication factors in Table 1 may be applied to asymmetric sections if the

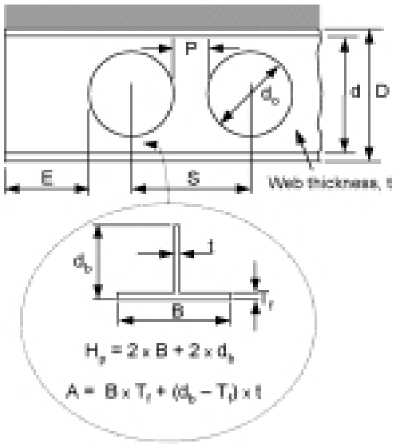

Figure 1 Significant dimensions

initial thickness of coating is first increased by 20% for an asymmetry ratio of up to 2:1 and by 30% for an asymmetry ratio between 2:1 and 3:1. Additional design information for asymmetric sections can be found in RT983.

Option 2

Design software that explicitly calculates the load carrying capacity for beams with web openings at the fire and ultimate limit states may be used. The development of such software should be based on the observed temperature distribution throughout the beam for different coating thicknesses and the observed performance of the beam in loaded fire resistance tests.

Option 3

The thickness may be assessed using a structural model based on the principles given in EC4-1-2. The model should take account of the increased temperatures of the web posts relative to the flanges. Information on temperatures may be obtained from fire tests.

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[1] *The behaviour of multi-storey steel framed buildings in fire. A European joint research programme,* British Steel plc, Swindon Technology Centre, 1999. Available from Corus.