SCI PUBLICATION P129

Building Design using Cold Formed Steel Sections: Fire Protection

ISBN 1 870004 97 3

British Library Cataloguing-in-Publication Data.
A catalogue record for this book is available from the British Library.

The Steel Construction Institute
Silwood Park, Ascot
Berkshire SL5 7QN
Telephone: 0344 23345
Fax: 0344 22944

CONTENTS

In real fires, the temperature-time regime is generally less severe in duration, but often peak temperatures are higher for short periods, due to the use of synthetic materials which have a high calorific value. The thermal response of protected sections is relatively insensitive to local peak temperatures and it is the total heat produced by the fire which is more critical. It should not be assumed that a 1 hour fire resistance means that the structure would survive for just one hour in a real fire. However, the fire resistance requirement is a reflection of the potential severity of a fire, the importance of the structure, and the control of fire spread. Sprinklers are effective in reducing the severity of a fire.

2.3 Fire limit state

In structural design terms, fire is considered to be an 'accidental' limit state and one for which the structure must not collapse, but is not readily repairable. Loads and their factors of safety used in design at the fire limit state reflect the low probability of occurrence and the gross deformations that are permitted in such circumstances (see Table 2 below).

Table 2 *Partial factors of safety used in structural design*[2]

Load Case	Factors of Safety	
	Normal	Fire
Dead loads	1.4	1.0
Permanent loads	1.6	1.0
Variable loads	1.6	0.8

On average, the loads to be considered at the fire limit state are about half of the loads under normal conditions for general building applications (i.e. buildings with a high proportion of variable loading).

Many members are over-designed under normal conditions and, therefore, the proportion of their load carrying capacity that is utilised at the fire limit state is significantly less than 0.5. This parameter is known as the 'load ratio' (see Section 5.2).

3. PERFORMANCE OF COLD FORMED STEEL AT ELEVATED TEMPERATURES

3.1 General features of steel

All types of steel lose strength at temperatures above 300°C and eventually melt at about 1500°C. Importantly, for design, the greatest rate of loss of strength is in the region of 400 to 600°C.

The performance of hot rolled steel in fire does not vary significantly with steel grade. In design to BS 5950: Part 8[(2)], it is assumed that strains of at least 1.5% can occur in beams, and strains of at least 0.5% can occur in columns at the deflections corresponding to failure in a fire test. These strain limits are used in assessing the member strength at the fire limit state.

3.2 Strength of cold formed steel

The loss of strength of cold formed steel at elevated temperatures exceeds that of hot rolled steel by between 10 and 20% based on data obtained from tests performed by British Steel (Welsh Laboratories)[(10)] which is presented in Figure 3. This data is based on a 95% confidence limit (or probability of exceedance) with respect to the nominal material properties. The confidence limit means that the actual strength of the sections in fire conditions will generally exceed the design values, and often by a significant margin.

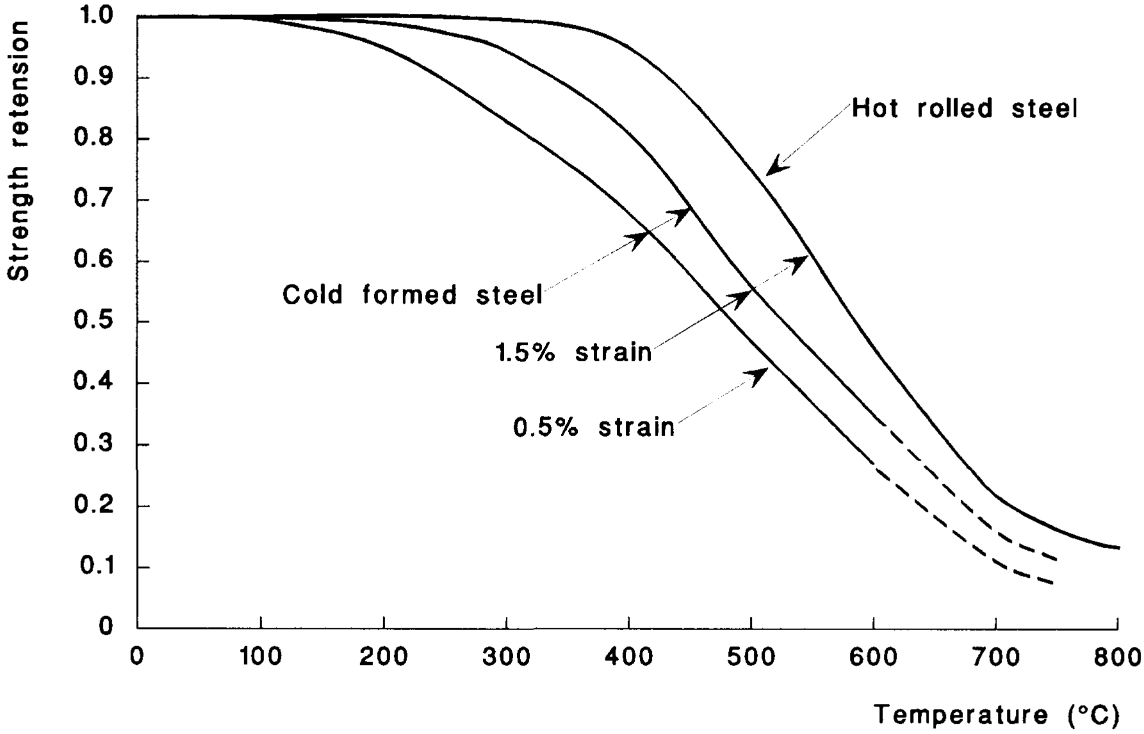


Figure 3 *Strength of steel at elevated temperatures relative to normal yield strength*

The difference between the performance of hot rolled and cold formed steel at elevated temperatures is a complex phenomenon and has not yet been fully explained. It is partly due to metallurgical composition and molecular surface effects. The influence of cold working in the rolling of the steel strip should be relatively small, as a result of the further annealing process in its manufacture. Therefore, further loss of strength in fire due to the loss of the cold working effect will be small.

Additionally, any influence of cold working in the forming of the steel section will be lost at temperatures above 500°C. The data is appropriate for steel to BS 2989[11] and for steel grades of Z22 to Z35 (220 to 350 N/mm^2 yield strength). There is little effect of the zinc coating on the performance of the steel.

The strength of cold formed steel that may be used in calculations at the fire limit state is presented in Table 3. These strength reduction factors (or more correctly strength 'retention' factors) are expressed as a ratio of the normal (room temperature) strength, and are based on the 95% confidence limit[10].

Table 3 *Strength reduction factors for cold formed steel at elevated temperatures (°C)*

Temperature (°C)	200	250	300	350	400	450	500	550	600
0.5% strain	0.95	0.89	0.83	0.76	0.68	0.58	0.47	0.37	0.27
1.5% strain	1.00	0.99	0.95	0.88	0.82	0.69	0.56	0.45	0.35

(Table 3 is reproduced with the kind permission of BSI.)

The significance of the strain limit in Table 3 is that the strength reduction factor at the higher strain may be used for beams or members failing in bending, and the strength reduction factor at the lower strain is used for members failing by buckling in compression. These data are used in establishing the limiting temperatures of cold formed sections used as structural members (see Section 5.2).

3.3 Other properties

The elastic modulus of steel reduces broadly at the same rate as the strength of steel at 0.5% strain. This effect leads to an increase in deflections due to loss of stiffness of the section.

The coefficient of thermal expansion for all steels may be taken as $14 \times 10^{-6}/°C$ at temperatures of 100 to 700°C. This is about 20% higher than the equivalent room temperature value. Elongation and thermal bowing in fire conditions may be significant.

Properties such as the specific heat and thermal conductivity of steel may be taken as defined in BS 5950: Part 8. These properties are not normally needed for design calculations.

4. PLANAR PROTECTION TO WALLS AND FLOORS

4.1 General aspects

Walls and floors in domestic and small commercial buildings often comprise stud walls or floor joists at relatively close spacing. Conventionally, gypsum plasterboard is used as the internal finish for the walls and ceiling and is supported either directly off the wall and floor members, or indirectly via battens (furrings) and other secondary members.

The gypsum plasterboard also provides an important role as fire protection to the structural members within the wall. 'Planar' protection, as shown in Figure 4, is usually treated as being subject to fire from one side only, as the walls are expected to contain the fire within a compartment. Cases where load-bearing walls are potentially subject to fire from both sides should be identified and treated differently (see Section 5.1).

Multiple layers of board may be required to achieve fire resistance periods greater than 30 minutes. Glass fibre and other additives are often used to provide enhanced properties of the core material by preventing break-up of the board and excessive movement at the joints. Typical products of this type are 'Fireline'* or 'Firecheck'* board. These boards are generally manufactured in 12.5 or 15 mm thickness with maximum spanning capabilities of 600 mm, or in some applications, 900 mm for the thicker board.

The joints between the individual panels may provide a route for the direct passage of heat through to the section and better performance is obtained by using secondary battens, or by staggering the joints in multi-layer systems. However, in making recommendations on planar protection in this document, it is assumed that battens are not used.

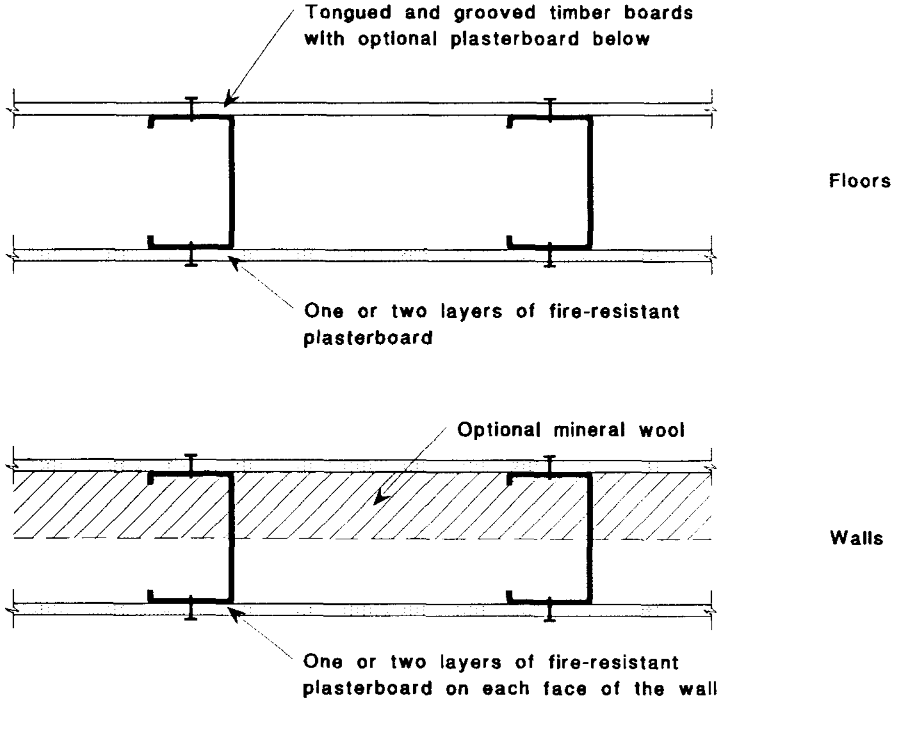


Figure 4 *Planar protection to floors and walls*

---

* These are tradenames of certain manufacturers, defining generic materials of this type.

Ceiling elements provide protection to floor members from the effects of fire from below. The flooring material is less critical, but tongued and grooved chipboard or other closely-fitting material are often necessary to satisfy the insulation requirements of the floors in fire. Additional mineral wool insulation, which may also be needed for acoustic requirements, can provide an important role in improving the fire resistance of the floor.

4.2 Test data

There are various sources of fire test data on generic board products and generally the information is equally applicable to timber or cold formed steel sections[3,4,7] used in planar applications. A summary of the test information and subsequent design guidance is presented in Table 4.

Gypsum plasterboard has a high moisture content of 20% which is water of crystallisation chemically combined with calcium silicate. The material is chemically inert below 1200°C and has good insulating properties. The high moisture content also affects the 'dwell' in thermal response due to evaporation of moisture within the material, as illustrated in Figure 2.

Eventually, the boards tend to become dislodged due to distortion of the construction and may break off the members they are protecting. For this reason, double layers of gypsum board are specified for achieving more than 30 minutes fire resistance. Alternatively, 'special' fire resisting boards have been developed which possess better strength and shrinkage resistance properties and are preferred in applications requiring 60 minutes or longer fire resistance.

Table 4 *Fire resistance of typical floors, walls and partitions comprising cold formed steel sections and planar board protection, and heated from one side only*

Form of construction	Number of layers of board	Protection thickness (mm)	Fire resistance (hours)		Notes
			Plasterboard	Fire resistant board†	
Floors with ceiling protection	1	12.5	–	½	–
	2	12.5	½	1	+ 60 mm glass wool mat**
	2	15	–	1½	..
Non-load-bearing walls (partitions) (number of layers per face)	1	12.5	½	½	–
	1	12.5	½	1	+ 25 mm glass wool mat*
	1	15	½	1	–
	2	12.5	1	1½	–
	2	12.5	1	2	boxed section depth > 60 mm
	2	15	1½	2	–
Load-bearing walls	1	12.5	–	½	–
	2	12.5	½	1	–
	2	15	–	1½	–

† 'Fireline' or 'Firecheck' board or similar

* Glass wool mat is required for insulation purposes for more than 30 minutes fire resistance

** For floors, the glass wool mat is <u>only</u> necessary for fire resistant suspended ceilings

The guidance given in Table 4 refers to non-load-bearing walls (i.e. partitions), load-bearing walls and floors protected by ceilings. It is assumed that the same thickness of board is applied to both sides of a wall. In some cases a glass wool mat is introduced to give better fire and acoustic insulating properties, although insulation can be provided by other means (e.g. the flooring material). For ceiling protection directly attached to the joists, additional insulation is not usually required. For suspended ceilings, the insulation material reduces the temperature of the cavity and risk of fire spread (see Section 6.1.3).

In load-bearing applications of walls and floors, it is usually the load-carrying capacity that is the controlling criterion (see Section 2.2), whereas for non-load-bearing walls, it is the insulation criterion which determines the fire resistance of the wall. The maximum loads that may be applied at the fire limit state are presented in Section 4.4.2.

The data in Table 4 is the 'lower-bound' of a number of manufacturers' data and may be used for general guidance. Individual manufacturers may provide better data in certain applications.

4.3 Heat flow through walls or floors

Walls or floors heated from one side only are designed to satisfy all the criteria presented in Section 2.2. The total thermal resistance of the wall or floor should be such that the heat entering the element does not:

- cause the steel sections within the wall or floor to lose strength excessively.
- lead to temperatures on the unexposed external surface higher than the specified maximum.

The temperature regime within the planar element may be predicted using heat flow equations of the form:

Heat flow through the exposed face - Heat loss from the unexposed face

= Heat absorbed by the wall (steel, board and air). (1)

This equation may be solved incrementally in time-steps in terms of the time-temperature curve in a standard fire resistance test. This approach is too complicated for hand analysis and can only be solved by computer. Therefore, certain approximations are appropriate.

For walls of relatively thin construction it may be assumed that the temperature in the steel section is the average of the temperatures on the external faces of the wall. After 60 minutes in a standard fire test, the fire temperature is 945°C. If, for a particular thickness of wall, the maximum temperature of the unexposed surface is 180°C, the temperature of the steel section within the wall is therefore approximately 550°C. Referring to Table 3, it is apparent that the steel section can resist between 37 and 45% of its design capacity at this temperature (depending on its use).

It is assumed that the joints between the planar elements do not permit passage of heat directly into the member. Consequently, the steel members at the joints in the boards will tend to be hotter than those elsewhere. However, significant load sharing occurs among the floor and wall members in fire, and so local hot points may not be as critical as in individual members.

This approximate analysis may be compared with an 'exact' analysis based on the heat flow equation (1). In this case, a wall is assumed to comprise one or two layers of 12.5 mm gypsum plasterboard on both faces with appropriate thermal properties input for this material. The results are presented in Figure 5, and show that the approximate analysis gives a close correlation to the true behaviour for the case with a single layer of board. For two layers, the thermal inertia of the plasterboard causes a slower heating rate of the section within the wall and also reduces the effect of premature break-off of the individual boards.

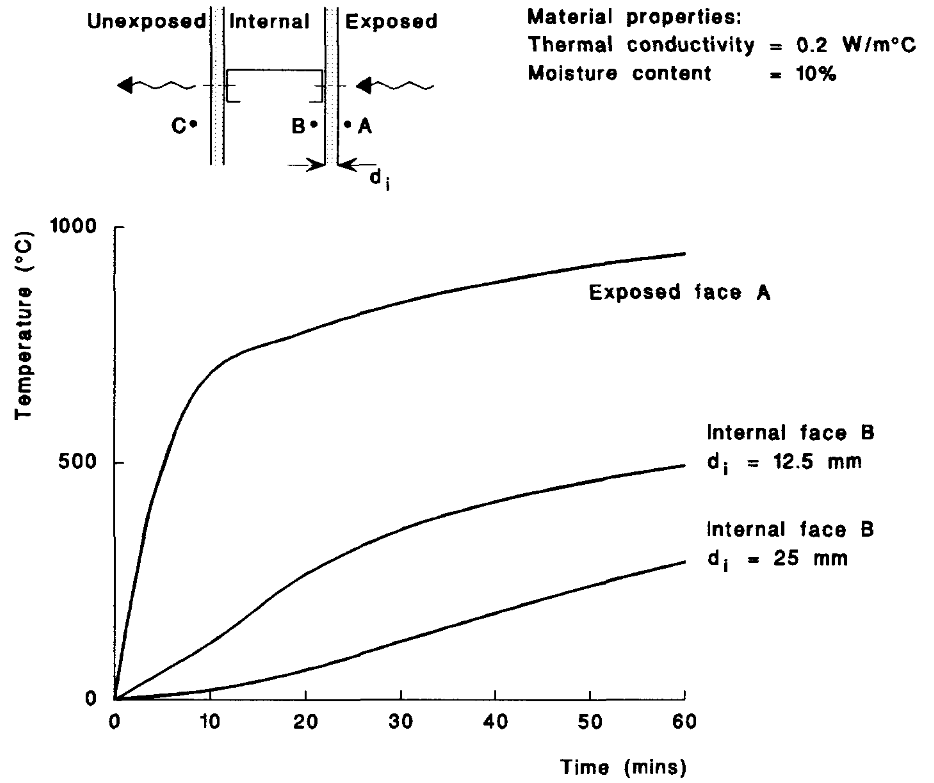


Figure 5 *Examples of temperature rise in a wall comprising one or two layers of plasterboard per face*

4.4 General guidance on planar protection

Where floors or walls act as compartment boundaries they may be treated as being heated from one side only. Load-bearing walls heated from both sides should be treated as in Section 5.

For one-side heating, three criteria have to be satisfied (see Section 2.2): insulation, integrity and load-carrying capacity. For non-load-bearing elements, load-carrying capacity is not critical (except if failure is due to self weight alone). It is normally the insulation criterion that determines the configuration of the wall in such cases, subject to other structural and acoustic criteria being satisfied.

4.4.1 Non-load-bearing walls

Partitions or other similar forms of construction do not resist vertical loads (hence are non-load-bearing) but resist lateral loads. Guidance on the minimum thickness of gypsum or 'special' fire resistant board to be used in non-load-bearing wall applications is given in Table 4. The maximum height of these walls is normally based on the following approximate relationships for adequate structural performance:

$\dfrac{\text{wall height}}{\text{wall thickness}}$	≤ 30	for steel studs with single layers of board on each face.
..	≤ 35	for steel studs with double layers of board.
..	≤ 40	for boxed steel studs with double layers of board.

The wall thickness is defined as its external dimension. The use of internal glass wool mats is beneficial for acoustic properties, although not essential for fire resistance. Therefore, it may be preferable to use multi-layer boards where fire resistance criteria dominate.

More slender walls may be permitted in certain applications, although the manufacturer should be consulted before proceeding.

4.4.2 Load-bearing walls

Load-bearing walls support vertical loads from floors or other supported elements. The fire resistance of load-bearing walls is generally lower than the same configuration subject to no additional load. Therefore, additional fire protection is required so that the steel sections retain more of their strength in fire.

The proportions of load-bearing walls are normally sized on their stability under normal conditions. Heavily loaded walls are generally relatively stocky so that they are more stable under compression. In using the guidance in Table 4 for load-bearing walls, it is proposed that:

$$\frac{\text{wall height}}{\text{wall thickness}} \leq 25 \text{ for load-bearing steel studs (in most cases).}$$

The wall thickness is again defined as its external dimension. The definition of the maximum load to be used in such cases is less clear as the fire test data is limited. Compression members may suffer additional adverse moment effects due to their lateral deflection at mid-height. Consequently, it is proposed that the loads that may be applied to the studs at the fire limit state should be taken as not greater than the following proportion of their design capacity under normal conditions:

Walls: $0.4 \times$ stud axial capacity based on the slenderness of the wall

Allowing for the partial factors given in Table 2, it follows that the studs should not be designed for more than 80% of their axial capacity under normal conditions. This limitation is not unduly onerous as load-bearing studs are rarely designed for heavy loads. Load sharing among the studs may be assumed to occur at failure due to the in-plane stiffness of the wall boards.

In all load-bearing applications, it is recommended that only special fire resistant boards or their derivatives should be used. These boards may be fixed directly to the steel sections, provided there are no gaps between the boards. It may be possible to justify a reduction of thickness of board, if steel battens or plasterboard backing strips are used to avoid a route for the direct passage of heat to the section.

4.4.3 Floors and ceilings

By definition, suspended floors are load-bearing. For adequate serviceability performance (i.e. control of deflections), the proportions of the floor joists would normally satisfy the following condition:

$$\frac{\text{floor span}}{\text{joist depth}} \leq 25$$

The members are assumed to be protected by the ceiling material from fires occuring within the room beneath. Guidance on the thickness of the ceiling board protection is presented in Table 4. It may be necessary to install additional steel secondary battens or furrings to provide local support to the boards where the joist spacing exceeds the recommended values for the boards (see Section 6.1.2). Suspended ceilings below the joists require a separate support framework (see Section 6.1.3).

It is proposed that the loads that may be applied to the joists at the fire limit state should not be greater than 50% of the loads corresponding to joist bending capacity under normal conditions. Allowing for the partial factors in Table 2, it follows that the floor joists may be designed effectively up to their bending capacity under normal conditions.

The span/depth proportions of the floor joists may be increased to 30, provided the loads on the joists are reduced to satisfy normal deflection limits. In this case the joists will be relatively over-designed for strength purposes and the loads at the fire limit state will be a smaller proportion of their design capacity.

In all cases requiring more than 30 minutes fire resistance, special fire resistant boards or their derivatives should be used. Where the ceiling boards are directly attached to the joists or by using steel furrings, no additional mat insulation is usually required for fire resistance purposes. This assumes that the floor boards possess reasonable insulating properties, which is the case for most modern materials fitted without gaps in the boards.

Recent fire tests on 4 m span suspended floors have shown that fire resistances significantly in excess of those given in Table 4 can be achieved for designs following the above requirements. Further information on these tests can be obtained from The Steel Construction Institute.

Cold formed sections supporting concrete floors may be expected to show proportionately better behaviour in fire due to the 'heat sink' effect of the concrete. Therefore, the above guidance is also conservative for those sections protected by ceilings. No further guidance is readily available on this subject. Any composite action between the slab and beams is also beneficial.

5. PROTECTION TO BEAMS AND COLUMNS

The fire protection of individual beams and columns using hot rolled steel sections is covered by existing guidance in BS 5950: Part 8[2] and in the ASFPCM/SCI/FTSG publication *Fire protection for structural steel in buildings*[1]. The extension of this guidance to the use of cold formed steel sections is covered in this section.

5.1 Section factor definitions

The rate of heating of a steel section is a function of its 'section factor'; which is defined by the following parameters:

$$\frac{H_p}{A} = \frac{\text{Heated perimeter of section}}{\text{Cross-sectional area of section}} \tag{2}$$

The units are usually expressed in metres^{-1} and typical section factors for hot rolled steel sections are in the range of 100 to 250 m^{-1}. However, for cold formed sections, typical values are in the range of 300 to 800 m^{-1}, which means that these thin sections will heat up more quickly than hot rolled sections.

Account may be taken of the insulating or 'heat sink' effect of the attachment of the member to a concrete slab or embedment in a masonry wall. The part of the section affected by these heat sink effects is neglected in calculating H_p. Timber floors do <u>not</u> offer a significant benefit and their effect is generally neglected.

There is also an important difference between 'profile' and 'box' protection. In profile protection (and unprotected sections), H_p is taken as the exposed perimeter of the section. In box or board-type protection, H_p is taken as the internal perimeter of the box. Formulae are presented in Figure 6. This difference between the two forms usually means that the section factors of box protection systems can be up to 30% lower than those of profile protection systems.

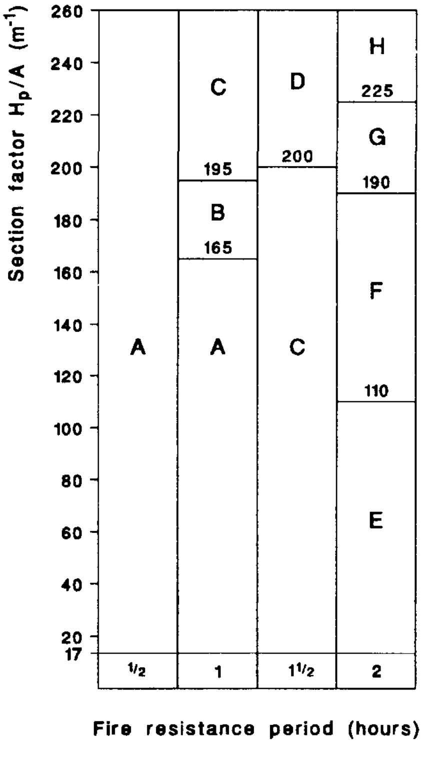
The thickness of spray materials can normally be varied continuously. Modern materials do not generally require the use of additional fine steel mesh around the section. The thickness of board materials can only be varied in increments as only finite board dimensions are produced.

Table 7 *Protection thickness of typical vermiculite cement spray for hot rolled steel section*

H_p/A up to	Dry thickness in mm to provide fire resistance of					
	½ hour	1 hour	1 ½ hours	2 hours	3 hours	4 hours
30	8	8	10	13	19	24
50	8	10	14	18	25	33
70	8	12	16	21	30	38
90	8	13	18	23	33	43
110	9	14	19	25	35	46
130	9	15	20	26	37	48
150	10	15	21	27	38	50
170	10	16	22	28	40	52
190	10	16	22	28	41	53
210	10	17	23	29	42	54
230	10	17	23	30	42	55
250	11	17	24	30	43	56
270	11	17	24	30	44	57
290	11	18	24	31	44	57
310	11	18	24	31	45	58

Note: Slightly different protection thicknesses may be required for different products.

Table 8 *Protection thickness of gypsum based fire resistant board for hot rolled steel section*



Legend
A – 12.5 mm
B – 15 mm
C – 12.5 mm + 12.5 mm
D – 15 mm + 12.5 mm
E – 15 mm + 15 mm
F – 12.5 mm + 12.5 mm + 12.5 mm
G – 15 mm + 12.5 mm + 12.5 mm
H – 15 mm + 15 mm + 12.5 mm
This data is appropriate for British Gypsum 'Fireline' board

Fire resistant boards would normally be available in thicknesses of 12.5, 15, 20 and 25 mm. Thicker protection can be achieved with multi-layers (maximum of 3).

The maximum value of section factor of the hot rolled steel sections that are fire tested is normally about 300 m^{-1}. It is not usually permitted to extrapolate from the test data and therefore the guidance on hot rolled sections is not directly applicable to cold formed steel sections (see following section). However, some general principles may be applied, leading to a conservative calculation of fire protection thickness for these thin sections.

5.4 BS 5950: Part 8 method

The design method for determining the required thickness of fire protection is based on a formula derived from considering the heat flow through the protection. The required thickness of fire protection (expressed in metres) is given by:

$$d_i = k_i \frac{I_f}{10^6} \frac{H_p}{A} F_w \qquad (6)$$

where k_i = effective thermal conductivity of fire protection material
I_f = insulation factor in terms of the fire resistance period and limiting temperature
F_w = modification factor for thick insulation materials and the effect of moisture content.

k_i is not directly tabulated in any guidance, but it is back-calculated from fire tests. Typical values are in the range of 0.1 to 0.2 W/m°C for common fire protection materials.

I_f has the value given in Table 16 of BS 5950: Part 8[(2)].

F_w tends to unity for thin protection materials but can have a value as low as 0.5 for thick materials and high section factors.

Equation (6) has been used to extend the existing tabular guidance for vermiculite board by using the following input data typical of this material.

k_i = 0.16 W/m°C
c ≃ 1% moisture content
ρ = 500 kg/m^3 density.

The results are presented in Figure 7 for three fire resistance periods (30, 60 and 90 minutes) and three limiting temperatures (450, 500 and 550°C). The results for a section factor of 250 m^{-1} agree broadly with the existing data for hot rolled sections corresponding to a limiting temperature of 550°C, as given in the ASFPCM/SCI/FTSG publication [(1)].

Similar values may be obtained using the following input data for mineral fibre spray:

k_i = 0.12 W/m°C
c ≃ 7%
ρ = 300 kg/m^3.

The calculated thicknesses for this material vary by only up to 2 mm from the results in Figure 7. The main observation of these analyses is that the required thickness of fire protection is relatively insensitive to the input parameters for such thin steel sections. This suggests that relatively simple guidance is possible for a range of commonly used protection materials, provided appropriate detailing rules are observed to ensure the material does not break off prematurely in fire.

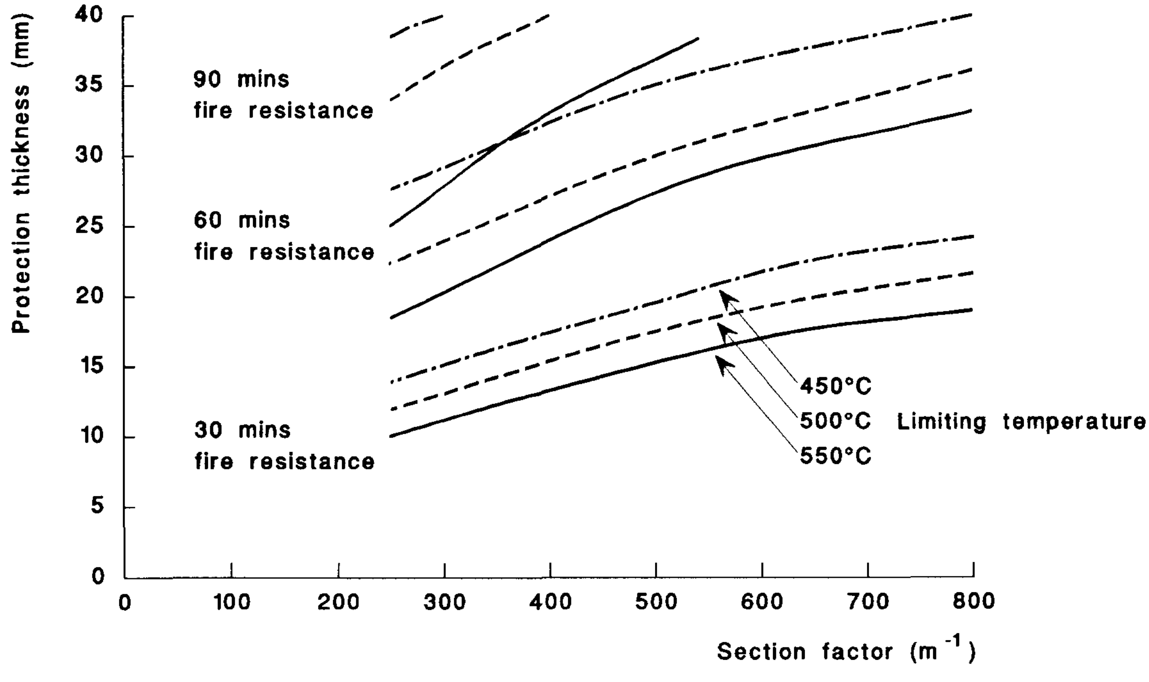


Figure 7 *Calculated protection thicknesses for a typical vermiculite cement spray for different section factors and limiting temperatures based on an extension of existing data*

5.5 General guidance on sprayed protection systems

The limiting temperatures of cold formed steel members in fire conditions are a function of the member type and the load ratio, as presented in Table 6. Three limiting temperatures may be conservatively adopted for three categories of members in general building applications, as follows:

Category	Application	Limiting temperature
A	Beams supporting concrete slabs	550°C
B	Beams supporting timber floors	500°C
B	Stocky columns (e.g. in walls)	500°C
C	Slender columns (e.g. unrestrained)	450°C

Using the data obtained in Figure 7, it is possible to present general design tables for the three application categories (A, B and C) for 'generic' sprayed fire protection materials. These design thicknesses of protection are presented in Table 9 for three periods of fire resistance. In practice, cold formed steel sections can readily achieve 60 minutes fire resistance with practical protection thicknesses (up to 35 mm).

Comparing the guidance in Tables 4 and 9, it is apparent that members heated on all sides heat up much more quickly and, hence, require thicker fire protection than members heated from one side.

In using this guidance, it should be noted that specific manufacturers may have their own test information and design tables. Therefore, Table 9 should be used only for general guidance and individual manufacturers should be contacted regarding the application of their products to cold formed sections.

Table 9 *Required thickness (mm) of a typical sprayed protection for different applications of cold formed steel sections used as structural members*

Section factor (m^{-1})	Fire resistance period (mins)								
	30			60			90		
	A	B	C	A	B	C	A	B	C
250 to 300	10	12	14	18	22	27	25	33	38
300 to 400	12	15	17	23	27	31	30	38	43
400 to 500	14	16	18	26	29	33	35	40	46
500 to 600	16	18	20	29	32	36	38	43	48
600 to 800	17	20	22	31	34	38	43	45	50
800 to 1000	18	22	24	33	36	40	48	50	53

Note: Fire protection categories A, B and C are defined in Section 5.5

5.6 General guidance on board protection systems

The same approach for board materials may be adopted as in Section 5.5 as their thermal properties are similar to those used in the examples considered. In this case, standard board thicknesses have to be used. Design thicknesses of generic board protection are presented in Table 10 for three periods of fire resistance. A maximum of two layers of board with basic thicknesses of 12, 15, 20 and 25 mm are used. Because of the lower section factors of members with 'box' protection, the tables are presented for a maximum section factor of 800 m^{-1}.

Again, Table 10 should only be used for general guidance as many board materials may not have been fire tested up to the thicknesses given (particularly above 40 mm). Individual manufacturers should be contacted regarding the application of their products to cold formed sections. In particular, manufacturers' fixing requirements should be followed.

Table 10 *Required thickness (mm) of a typical board protection (in units of 12, 15, 20 and 25) for different applications of cold formed steel sections used as structural members*

Section factor (m^{-1})	Fire resistance period (mins)								
	30			60			90		
	A	B	C	A	B	C	A	B	C
250 to 300	12	12	15	2 × 12	2 × 12	12 + 15	2 × 15	15 + 20	2 × 20
300 to 400	12	15	20	2 × 12	12 + 15	2 × 15	15 + 20	2 × 20	2 × 20
400 to 500	15	15	20	12 + 15	2 × 15	15 + 20	15 + 20	2 × 20	20 + 25
500 to 600	15	20	2 × 12	12 + 15	2 × 15	15+20	2 × 20	20 + 25	20 + 25
600 to 800	20	20	2 × 12	2 × 15	15 + 20	2 × 20	2 × 20	20 + 25	2 × 25

Note: Fire protection categories A, B and C are defined in Section 5.5

6. DETAILING OF PROTECTION

Various fixing and detailing rules have to be observed in order to ensure adequate performance of the protection in avoiding gaps and premature failure of the steel section. These rules are presented as follows:

6.1 Detailing of protection to floors and walls

Planar protection using plasterboard or its derivatives is detailed in a standard manner. Three cases may be considered; walls, floors and suspended ceilings. Shaft walls are treated rather differently (see Section 6.5).

6.1.1 Walls

Non-load-bearing walls (or partitions) are usually contained within a header-track which allows for some differential vertical movement between the wall and floor above. The boards are fixed to the sections which are generally spaced at a maximum of 600 mm. All butt joints between the boards are taped and filled. In multi-layer systems, the boards are 'staggered' to avoid joints occurring one above the other.

Fasteners for boards are typically 4 mm diameter counter-sunk self-drilling self-tapping screws of an appropriate length for the boards and steel thickness to be used. Typically, they are 10 to 12 mm longer than the total thickness of board used per face in order to drill and tap effectively into the steel.

Load-bearing walls are detailed in a similar manner except that the studs are usually installed prior to attachment of the floors and further walls above. Direct load transfer is achieved by the connections between the members in the floor and wall with consequently no provision for relative movement.

6.1.2 Floors and ceilings

For detailing purposes, floors may be treated in a similar manner to walls. Secondary supports (called steel furrings, battens or resilient bars) may be needed to provide local support to the ceiling boards, or for acoustic insulation purposes. These supports are essential if the spacing of the floor joists exceeds 600 mm (for 12.5 mm boards). They are attached to the underside of the joists at 450 mm spacing along the joists and, consequently, provide support to the ceiling boards at this spacing. Alternatively, a separate suspended ceiling arrangement may be used (see Section 6.1.3).

The boards are fixed to their supports at not more than 150 mm spacing along the edges of the boards and 230 mm internally, as shown in Figure 8. Double layers of boards are 'staggered' to avoid overlapping joints.

Gypsum planks may be installed above the joists for acoustic or fire insulation reasons. Floor boards may be attached directly to the joists or through the planks, with fixings at not more than 300 mm spacing. Typically, 19 mm thick softwood boards or 22 mm thick tongue and groove chipboard are used when the joists are spaced at 600 mm.

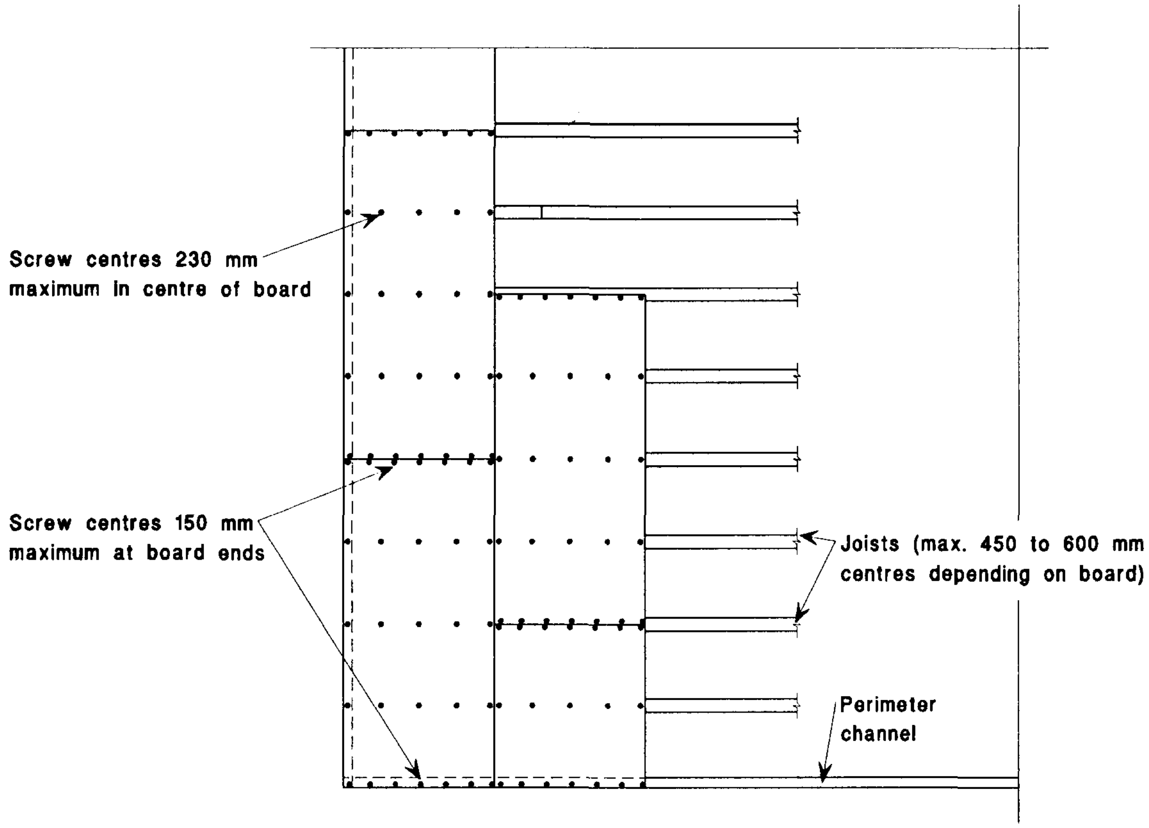


Figure 8 *Fixing of boards to ceiling joists*

6.1.3 Suspended ceilings

Suspended ceilings are installed as a separate layer below the floor joists creating a gap between the ceiling and floor for services, etc. Typical systems include hangers attached to the joists at no more than 1200 mm spacing. A separate two dimensional grid of members, spaced at not more than 450 mm and 600 mm in the two directions, is suspended from the hangers, as shown in Figure 9. This grid of members supports the ceiling layer which is fixed as discussed in Section 6.1.2.

Proprietary access panels can be introduced into the ceiling boards, but more sophisticated suspended ceiling systems should be used if a large proportion of the ceiling void is to be accessed periodically(12). Control joints in the ceiling system may be necessary to help relieve stresses induced by thermal movement, both of the ceiling itself and the surrounding structure, in fire conditions. Fire resistances of at least 30 minutes can generally be achieved by these proprietary ceiling systems and 60 minutes-rated systems are available.

It should be noted that the cavity above the suspended ceiling is potentially a fire propagation route. Therefore, regular cavity barriers are required, and the primary structural members should be fire protected in this zone. A 'fire resistant' suspended ceiling must satisfy the stability, integrity and insulation requirements for a stated period. A rock-wool or glass wool mat, laid across the back of the ceiling grid, provides the necessary insulation. In such cases, it is often possible to make a relaxation in the need for cavity barriers and fire resistance of the columns and primary beams in this zone.

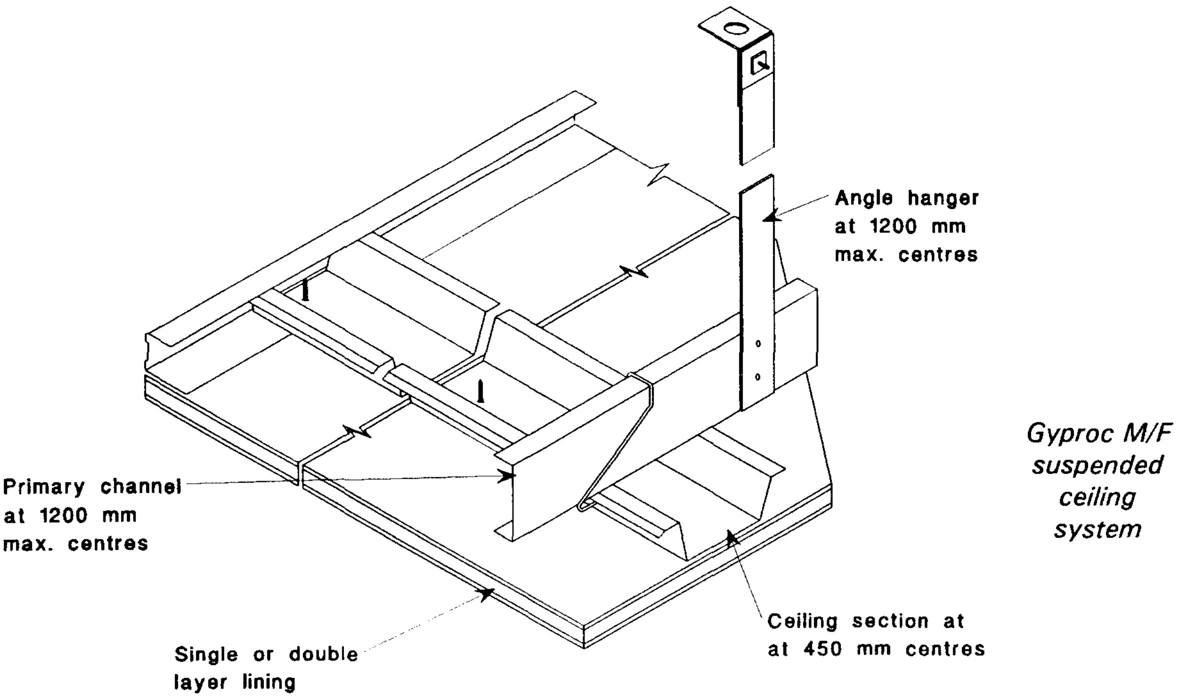


Figure 9 *Detail of typical suspended ceiling*

6.2 Detailing of box protection

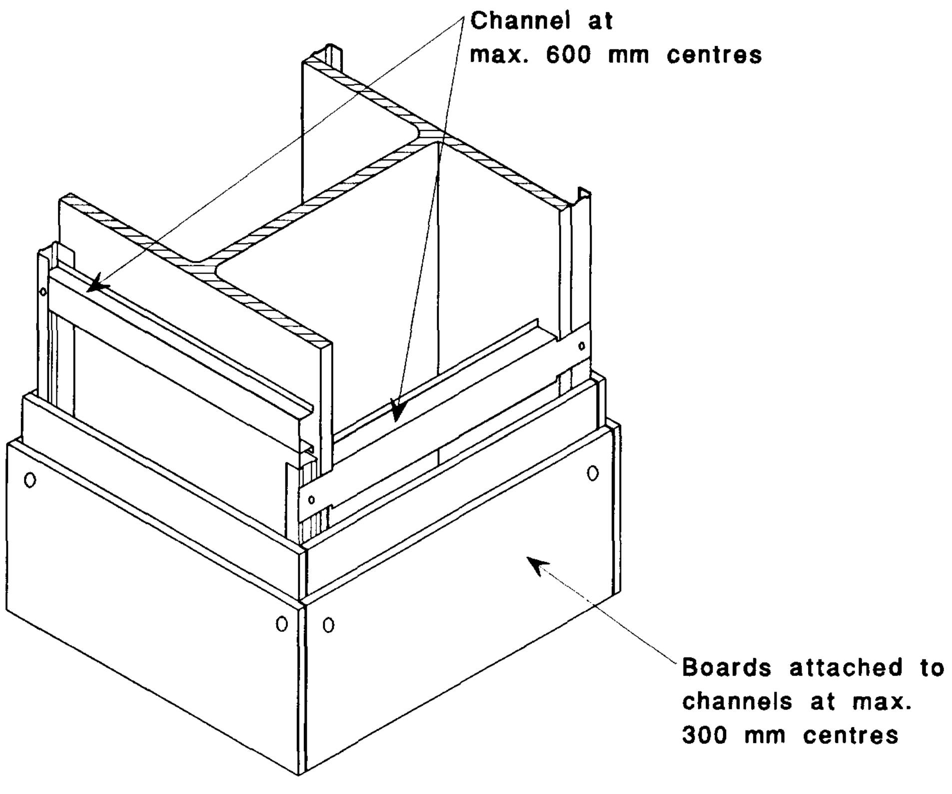
Box protection to individual cold formed sections used as beams and columns is of the same form as for hot rolled sections. Traditionally, a separate system of thin steel angles is fixed to the steel section to provide a local attachment point for the boards. However, the lips at the edges of the flanges of cold formed sections may provide this function and the boards may be directly fixed to the sections. An air gap is provided at the flanges by use of a secondary resilient bar or furring.

Detailing of the fire protection to a typical column is illustrated in Figure 10. Fixings are installed at not more than 300 mm spacing, or the width of the member (whichever is less).

An alternative board system has also been developed where the boards are attached to each other at their corners, as shown in Figure 11. This system is only appropriate for protection thicknesses of 15 mm or greater. No air gap at the flanges is provided in this case.

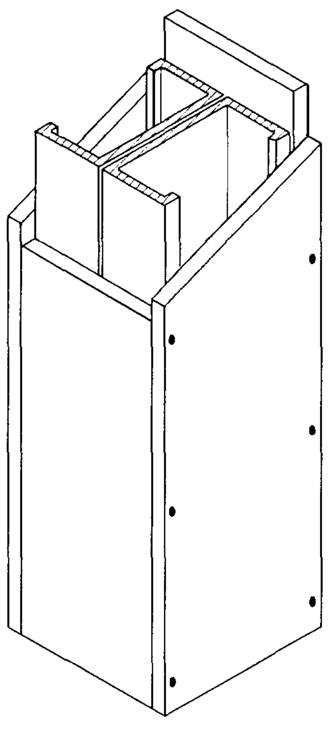
6.3 Detailing of spray protection

Spray systems are generally employed for beams in cases where a separate suspended ceiling is used. Sprays are not normally used for columns because of the usual requirement for a further facia board. Conventionally, sprays are applied by a 'gun' using materials mixed on site. Relatively rapid coverage rates can be achieved making them often cheaper than board systems. However, they are 'messy' and should be used with care, particularly adjacent to existing cladding or finishes.



Gyproc Fireline board, using MF5 and MF6A channels

Figure 10 *Detailing of a typical board protection to a hot rolled column*



Glasroc S system

Figure 11 *Detailing of board protection requiring no secondary attachments*

Spray protection generally follows the profile of the section. For deep cold formed sections, it may be more economic to attach a secondary steel gauze to the outside of the section to form an effective 'box' around it and to reduce the section factor of the member. This should only be considered when protection thicknesses exceed 40 mm, and is not necessary for thinner protection or small sections.

Locally, the thickness of spray protection may be up to 10% less than the nominal thickness, provided this variation is compensated for by thickening elsewhere on the section (the flanges being more important than the web of the section).

6.4 Detailing for movement in fire

Relative movement between elements of construction can lead to additional forces in otherwise weak members. Partitions or other non-load-bearing walls can be provided with movement joints at the top of the walls to allow for deflection of the floor above. These movement joints are introduced to allow for normal structural deflections but they also act to relieve forces on the wall in fire. A typical example is shown in Figure 12.

It is important that walls at compartment boundaries do not fail prematurely and in these circumstances it is necessary to take account of the potential movement that may occur in fire conditions, whilst maintaining the integrity of the wall.

The amount of movement allowed for depends on the span of the floor or beam above. Normally, a 15 mm gap is sufficient for floors in residential-scale buildings, but greater gaps may be necessary for compartment walls in commercial-type buildings.

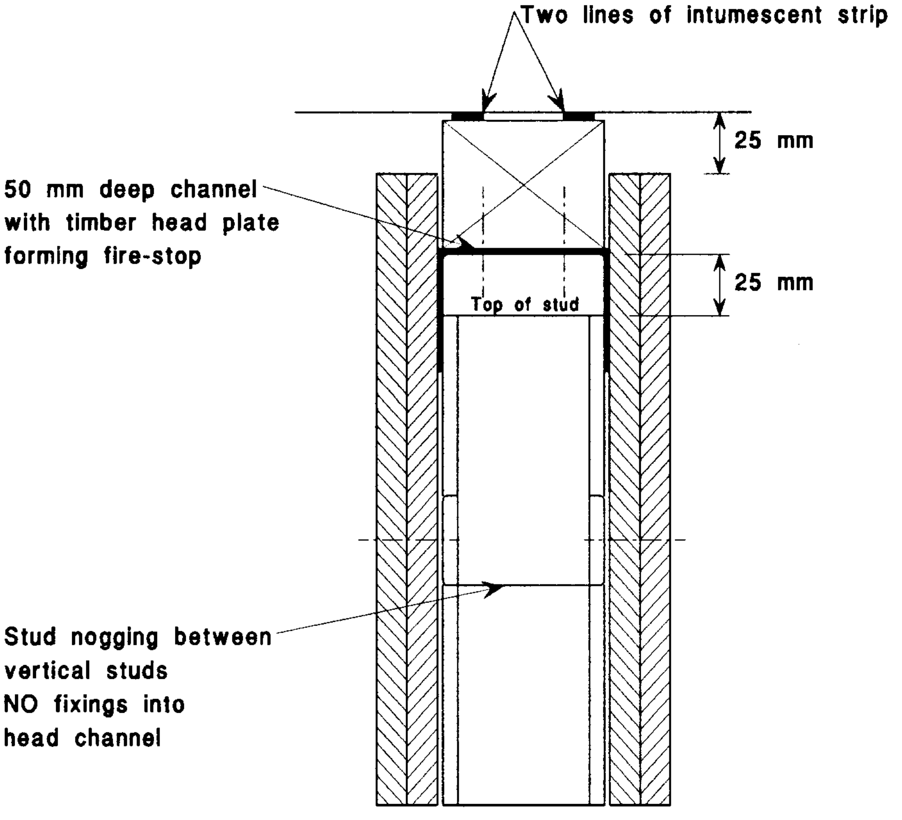
BS 5950: Part 8 recommends that movement joints should be capable of allowing for a beam deflection of span/100 in cases where the integrity of slender compartment walls in fire conditions is not to be affected by the additional forces that may be generated by deflection of the floor above. This limit is conservative in that it neglects the compression strength and compressibility of the wall. In practice, compartment walls in commercial buildings with beam spans up to 10 m should be designed to permit movement of up to 50 mm. Partition walls not at compartment boundaries need be designed to accommodate only normal structural movements, as they are not required to provide a fire resistant function.

The header detail in Figure 12 provides for lateral restraint at the top of the wall and prevents the passage of smoke or flames across it. Additional intumescent seals are required at compartment boundaries (refer to the board manufacturer for details).

6.5 Shaft walls

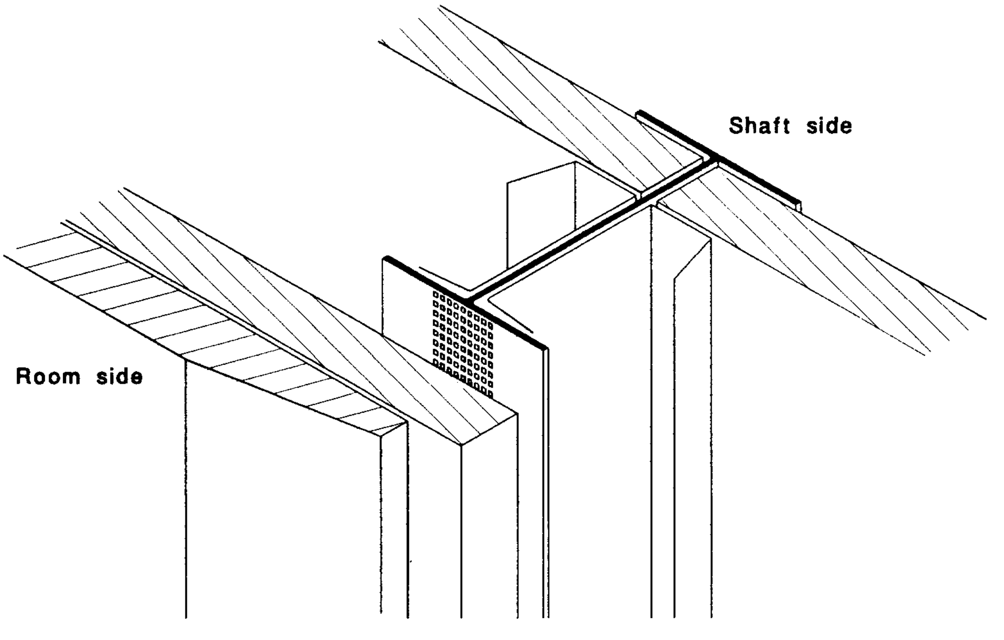
Walls to fire protected lift shafts, stairways or lobbies are treated rather differently to other internal walls. They are required to prevent fire passing into the protected area which is used as a means of escape, and the shafts are often pressurised to reduce the air movement in them. These walls are often formed continuously on the inside of the shaft and may provide attachment for the lift guides etc. Hence, spans and loads are often greater than in normal applications.

A typical example of the details of a shaft wall is shown in Figure 13. Often, two layers of board are used on the 'room' side and a single layer on the shaft side. A 90 mm deep stud with three layers of 15 mm fire resistant boards is required for a 2 hour fire resistant shaft wall of up to 6 m height. Manufacturers' guidance should be followed in the design of shaft walls and other 'special' forms of construction[3,4].



Gyproc head channel system

Figure 12 *Typical details of attachment at top of partition to permit 25 mm movement*



Gyproc Shaftwall system

Figure 13 *Typical section and detail used in a shaft wall*

7. CONCLUSIONS

The fire resistance of cold formed steel sections is dependent on the strength of steel at elevated temperatures and the rate of heating of the relatively thin section. The strength retention of cold formed steel is not as good as the equivalent grade of hot rolled steel. Strains of 1.5% and 0.5%, corresponding to failure, are adopted for beams and columns respectively in fire conditions, the difference being due to the effect of lateral buckling of columns.

The rate of heating of cold formed sections may be established from conventional principles. These members are often located within floors or walls and are heated from one side only. The compartment boundaries also have to provide the necessary barriers to prevent the passage of heat and smoke and it is often the insulation criteria that determine their design. Guidance is based on manufacturers' data. Typically, one layer of 12.5 mm fire resistant gypsum board is required beneath floor joists, or on each side of a load-bearing wall, for 30 minutes fire resistance, and two layers for 60 minutes fire resistance.

For individual beams and columns heated from all sides, the thicknesses of fire protection are based on the rate of heating to reach a certain limiting temperature. Three cases are established, corresponding to limiting temperatures of 550, 500 and 450°C for members that are fully stressed under normal conditions.

The guidance is based on an extension of the method given in BS 5950: Part 8 in which the thermal properties of the protection material are defined. Section factors of typical cold formed C sections (or double C) are presented, leading to a tabulation of thicknesses of fire protection in each case. This guidance is provided for generic spray and board materials.

Many manufacturers of purpose-designed steel buildings have their own fire resistance data(13) and specifications, which may be used as a less conservative alternative in these applications.

8. DESIGN SUMMARY

This section contains the important aspects of fire protecting cold formed steel sections used in floors and walls and as individual structural members.

1. Floors or walls protected by plasterboard (or its derivatives) and subject to fire from one side only.

   - Non-load-bearing walls are those which do not resist vertical loads, but may be required to act as compartment boundaries.
   - Load-bearing walls resist vertical loads and are required to be stable under fire conditions.
   - Refer to Table 4 for general requirements for compartment walls (repeated on following page).
   - Refer also to the requirements for acoustic insulation (see reference 6).
   - Special fire resistant boards are recommended in most load-bearing applications.

2. Individual beams or columns subject to fire around the section.

   - Limiting temperatures of cold formed steel sections are below those of their hot rolled equivalents. Three categories may be defined:

A	beams supporting concrete slabs	550°C
B	other beams, or columns in walls	500°C
C	individual columns	450°C

   - The approximate thicknesses of fire protection required for double C sections acting as individual beams or columns are given in Table 11.

Table 11 *Approximate thicknesses of fire protection (mm) for cold formed steel sections used as beams or columns (to be used for initial design)*

	Fire Resistance (mins)		
Steel thickness t (mm)	30	60	90
Beams			
2 mm	17	29	40
3 mm	15	25	35
4 mm	12	22	32
Columns			
2 mm	18	33	45
3 mm	17	29	40
4 mm	15	26	37

These thicknesses assume that the protection is applied in box form and the sections are placed back to back. The steel thickness is t, and the section depth is assumed to be in the range of 150 to 300 mm.

Manufacturers should be consulted about precise information on protection thickness and detailing requirements (see reference 1).

Table 4 *Fire resistance of typical floors, walls and partitions comprising cold formed steel sections and planar board protection, and heated from one side only*

Form of construction	Number of layers of board	Protection thickness (mm)	Fire resistance (hours)		Notes
			Plasterboard	Fire resistant board†	
Floors with ceiling protection	1	12.5	–	½	–
	2	12.5	½	1	+ 60 mm glass wool mat**
	2	15	–	1½	..
Non-load-bearing walls (partitions) (number of layers per face)	1	12.5	½	½	–
	1	12.5	½	1	+ 25 mm glass wool mat*
	1	15	½	1	–
	2	12.5	1	1½	–
	2	12.5	1	2	boxed section depth > 60 mm
	2	15	1½	2	–
Load-bearing walls	1	12.5	–	½	–
	2	12.5	½	1	–
	2	15	–	1½	–

† 'Fireline' or 'Firecheck' board or similar

* Glass wool mat is required for insulation purposes for more than 30 minutes fire resistance

** For floors, the glass wool mat is <u>only</u> necessary for fire resistant suspended ceilings

Refer to manufacturers' data for more detailed information, which, in some circumstances, may lead to higher fire resistances than given in the table above.

REFERENCES

1. ASSOCIATION OF FIRE PROTECTION CONTRACTORS AND MANUFACTURERS / THE STEEL CONSTRUCTION INSTITUTE / FIRE TEST STUDY GROUP
Fire protection for structural steel in buildings (second edition - revised)
ASFPCM/SCI/FTSG, 1992

2. BRITISH STANDARDS INSTITUTION
BS 5950: Structural use of steelwork in building
Part 8: 1990: Code of practice for fire resistant design
BSI, 1990

3. BRITISH GYPSUM LTD
The White Book, 1993

4. REDLAND LTD
Redland Drywall Systems. Systems Specification Guide, 1991

5. RHODES, J. and LAWSON, R.M.
Design of structures using cold formed steel sections
The Steel Construction Institute, 1992

6. CLOUGH, R.H. and OGDEN, R.G.
Building design using cold formed steel sections: acoustic insulation
The Steel Construction Institute, 1993

7. GYPSUM ASSOCIATION
Fire resistance; sound control design manual
Twelfth Edition, Washington D.C., 1988

8. BUILDING REGULATIONS, 1991
HMSO, 1991

9. BRITISH STANDARDS INSTITUTION
BS 476: Fire tests on building materials and structures
Part 20: 1987: Method for determination of the fire resistance of elements of construction (general principles)

Part 21: 1987: Methods for determination of the fire resistance of load-bearing elements of construction

Part 22: 1987: Methods for determination of the fire resistance of non-load-bearing elements of construction
BSI, 1987

10. SIDEY, M.P. and TEAGUE, D.P.
Elevated temperature data for structural grades of galvanised steel
British Steel (Welsh Laboratories) report, January 1988

11. BRITISH STANDARDS INSTITUTION
BS 2989: 1992: Specification for continuously hot-dip zinc coated and iron-zinc alloy coated steel flat products: tolerances on dimensions and shape
BSI, 1992

Refer also to:

(continued over)

BRITISH STANDARDS INSTITUTION
BS EN 10142: 1991: Specification for continuously hot-dip zinc coated low carbon steel sheet and strip for cold forming: technical delivery conditions
BSI, 1991

12. BRITISH STANDARDS INSTITUTION
BS 8290: Suspended ceilings
Part 1: 1991: Code of practice for design
BSI, 1991

13. METFRAME LIMITED
Fire protection data and details

RELEVANT SCI PUBLICATIONS

P089 Design of structures using cold formed steel sections

P125 Building design using cold formed steel sections: Worked examples to BS 5950: Part 5: 1987

P128 Building design using cold formed steel sections: Acoustic insulation

For further information please contact:

The Publications Department
The Steel Construction Institute, Silwood Park, Ascot, Berks. SL5 7QN.
Telephone: 0344 23345 Fax: 0344 22944