'Is UK Building Regulation guidance on service penetrations adequate in relation to combustible wall or floor constructions?'

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'IS UK BUILDING REGULATION GUIDANCE ON SERVICE PENETRATIONS ADEQUATE IN RELATION TO COMBUSTIBLE WALL OR FLOOR CONSTRUCTIONS?'

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ABSTRACT

Technical guidance to the Building Regulations within the countries which make up the United Kingdom (UK) permits services of limited diameter, including plastic waste pipes, to penetrate fire resistant wall or floor constructions without protection other than fire-stopping the annular space around the penetration. Within the UK, Scotland is singular in additionally limiting the number of pipes and the spacing between pipes within a grouping in close proximity. When this guidance was first introduced in Scotland the permissible use of combustible forms of constructions was less common than it is today. Additionally in the intervening period engineered timber products such as timber I-joists, which may comprise thinner section sizes than traditionally sawn joists or studs, have been introduced to the UK construction market. If it is the case that charring of structural members, which comprise timber I-joists, takes place within a construction cavity as a consequence of unprotected service penetrations, then premature local failure could result. Such failure would undermine the fire resistance of the construction, potentially endangering building occupants and also pose a danger to fire-fighters.

Three reduced scale fire resistance tests were carried out upon combustible floor constructions, containing timber I-joists, which were penetrated by unprotected waste pipes. All of the pipe arrangements would be acceptable in terms of building regulation guidance in Northern Ireland, England and Wales; whilst only one of the arrangements would adhere to the Scottish guidance. In all instances temperatures recorded within the construction cavities were indicative of charring of timber members adjacent to the service penetrations.

NOMENCLATURE

List of Acronyms

ABS   Acrylonitrile Butadiene Styrene
LVL   Laminated Veneered Lumber
OSB   Oriented Strand Board
UK   United Kingdom

1.   INTRODUCTION

In many countries, technical guidance relating to building regulation requires that fire resistant construction be used in specific positions in buildings. Concurrently, many European Governments consider the increase in timber utilisation in the construction of buildings as a significant factor in the emission reduction of greenhouse gases [1]. The technical guidance in Scotland currently indicates more areas where combustible fire resistant constructions are permissible than was the case in the past. Often such construction consists of a combustible timber frame clad with gypsum plasterboard.

Functionality dictates that on occasion such construction requires to be penetrated by services such as drainage or waste pipes.

In order that fire or the products of combustion do not penetrate or bypass such fire rated constructions, via drainage or waste pipes, such pipes are commonly fitted with intumescent collars at the point of incursion. Upon heating, these collars expand, sealing any potential route for gases or flames. However, building regulation guidance in the UK permits plastic waste pipes of limited diameter to penetrate such construction without protection, other than fire-stopping the annular space around the pipes. Scotland is singular within the UK in specifying a maximum number of such pipes and a minimum distance between adjacent pipes, within close proximity. Although practically the circumstance of multiple pipe penetrations in close proximity may be unusual, it is nevertheless permissible.

One aspect of timber, and timber board products, behaviour in relation to fire is the formation of a char layer at the surface, a heated zone below the char layer and a relatively unaffected residual section of timber below the heated zone. The dimension of this unaffected residual timber section influences the ability of a timber framed construction to maintain its load-bearing function during a fire. As some engineered timber products, such as timber I-joists, have relatively slender component parts, when directly exposed to fire they may not perform as well as solid sawn timber joists due to charring [2].

If it is the case that flames or hot gases could invade a construction cavity via groups of small diameter pipe penetrations then there is the possibility that the structural performance of timber members within such a cavity could be compromised. This could be exacerbated as a temperature increase within the construction cavity could also affect the other component parts of the construction; both non-combustible materials such as gypsum plasterboard, and combustible materials such as plywood, fibreboard, or particleboard. For example dehydration, shrinkage and cracking of gypsum plasterboard are related, in part, to its temperature. If the gypsum plasterboard protection to such constructions is heated from within the construction cavity, as well as from the fire exposed face, 'fall-off' of the gypsum plasterboard may occur sooner than would be the case if the heating was from one side only. Early failure of the gypsum plasterboard would result in early direct exposure of the structural members to the fire and hence earlier failure of the construction locally would be expected.

2. BUILDING REGULATION GUIDANCE

2.0 PERFORMANCE BASED REGULATION

Currently the building regulations in the countries which comprise the UK are performance based. Rather than a prescription of what must be done, the regulations set functional standards which must be met. This allows a degree of design flexibility. There are however also guidance documents available which prescribe ways of meeting the functional standards. Designers are at liberty to either use such guidance documents or propose alternative solutions which nevertheless meet the functional standard. Commonly building designers do choose to follow the prescriptive guidance. Although, in cases of disagreement, it is ultimately up to the courts to decide if compliance with the building regulations has been achieved, the guidance documents are critically important, offering the most certainty and best defence when claiming compliance [3].

2.1   ENGLAND

The guidance documents to the building regulations in England are 'Approved Document B, Vol. 1 and 2' [4] [5]. In relation to pipe penetrations these set out provisions of acceptable pipe materials and diameters for different situations; depending on both the installation position and whether or not proprietary sealing systems or sleeves are proposed. Where no proprietary sealing system is proposed pipes of any material and of a nominal internal diameter not exceeding 40mm may penetrate fire separating elements. There is no stipulation concerning the number of pipes, other than that they should be as few as possible, nor is there a requirement of a minimum spacing between adjacent pipes. There is a condition that fire-stopping should be provided around the pipe and that the pipe opening should be kept as small as possible.

2.2 WALES

Approved Document B, Vol.1 and 2, is also applicable in Wales, although incorporating some amendments which apply solely to Wales. However in relation to pipe penetrations the guidance is the unchanged.

2.3   NORTHERN IRELAND

'Technical Booklet E' [6] the guidance document to the building regulations in Northern Ireland gives the same guidance as that in 'Approved Document B' with regard to pipe penetrations.

2.4   SCOTLAND

In Scotland the guidance documents to the building regulations are the 'Domestic and Non-Domestic Handbooks' [7] [8]. These notably vary from the guidance in the rest of the UK with

regard to unprotected service penetrations. Whilst there is still an allowance that a pipe with a bore or diameter of not more than 40 mm may penetrate a fire resisting construction, there are additional limits on both the number of such pipes in close proximity and also the distance between these pipes. Not more than four 40 mm diameter pipes are recommended in a grouping and these should be at least 40 mm apart and at least 100 mm from any other pipe. Alternatively there is the provision that more than four 40 mm diameter pipes may be provided as long as they are at least 100 mm apart, implying that any number of such penetrations would be acceptable.

The basis for these allowances in Scotland may be traced to an amendment to the Scottish Building Regulations in 1973. This amendment allowed 38 mm diameter pipes to remain unprotected and limited the number of pipes. Initially the spacing provision was up to three pipes each 38mm apart, or a closely packed group of four pipes were permitted as long as they were 100mm distant from any other pipe. These parameters were amended in 1990 [9] and remain virtually identical at the time of writing.

A limited literature review revealed that these allowances of unprotected service penetrations are not common to North America, Australia or New Zealand.

3.   TIMBER AND BOARD PRODUCTS

When heated to 100°C free moisture contained in timbers cell structure starts to vaporize [10] some evaporating from the surface and some migrating further into the timber and re-condensing [11] [12]. Where the water re-condenses, the moisture content can be up to 30%, approximating the fibre saturation point of some species; a point at which strength and stiffness are both reduced [13].

Between 200 and 450°C timber undergoes thermal degradation known as pyrolysis, when it decomposes to form volatile gases and char [14]. These gases migrate to the surface and react with oxygen, leading to a release of heat. This induces further pyrolysis and combustion reactions [15]. Between 225 and 275°C the gases given off can be ignited by a pilot flame and burn with a visible flame, above 300°C char is formed and between

350-360°C ignition will occur with the presence of a small pilot flame or spark [16]. BS EN 1995-1-2:2004 [17] states that the char line should be taken as the 300°C isotherm.

When and if ignition takes place depends on: the proportion of oxygen and the volatile gases given off and their mixing, whether ignition is automatic or piloted and the mode of heating. Babrauskas [18] found piloted ignition required a temperature of between 210 and 497°C and between 200 and 510 °C for auto ignition.

White and Dietenberger [19] specify OSB as having an ignition temperature of 326°C, whilst Babrauskas [20] specifies 364°C. The ignition temperatures given by Quintere [21] for plywood and particleboard are 390°C and 412°C respectively.

Babrauskas [18] states that panel products such as plywood or particleboard have ignition properties very similar to solid wood.

When heated, the mechanical properties of timber change. BS EN 1995-1-2:2004 [17] indicates a reduction in modulus of elasticity, and a reduction in strength in compression, tension and shear with increased temperature. These reductions in strength and stiffness are at temperatures below that at which charring might be expected.

Char has no strength or stiffness and the heated zone below the char has reduced strength and stiffness, therefore the load-bearing capacity of timber depends on the residual section size of unheated wood. BS EN 1995 1-2:2004 [17] discounts up to a further 7 mm below the char layer when using the 'reduced cross-section' method for the structural analysis of residual strength, to allow for this heated layer.

The temperature and moisture content at any particular point in a timber member will depend on the temperature gradient within the member. This in turn will depend on the heat flux the timber or board is exposed to, the thermal conductivity which will change dependent on moisture migration and the time of exposure.

BS EN 1995-1-2:2004 [17] gives guidance on charring rates of timber, LVL and board products,

but points out that charring rates in a standard fire differ depending on the protection to the timber member. Two different notional charring rates are given for timber and LVL; one accounting for two dimensional heating, the other not. The charring rates given for panels are only for one dimensional heating. It notable that the charring rates given for board products such as OSB and plywood are greater than for solid timber or LVL. There are three conditions considered: surfaces unprotected throughout the time of fire exposure, surfaces initially protected prior to failure of the protection, and initially protected surfaces after the failure of the protection. The charring rates after protection failure are greater than the situation where there was no initial protection, until the char depth reaches 25 mm when the rate of charring reverts to that of an initially unprotected member.

The problem with historical data on charring rates found in the literature, as pointed out by Friquin [16], is the variation in test conditions and methods, wood species and methods of measurement. The charring rates given in BS EN 1995-1-2:2004 [17] relate to exposure to a standard fire.

4. POTENTIAL HEAT TRANSFER

Plastic service pipes can melt and ignite relatively quickly when directly exposed to fire. Where such pipes traverse a fire rated wall or floor, a hole may be left in the fire exposed side of the construction. Choi [22] proposed a number of potential failure modes by which flames or hot gases could travel from the exposed to the unexposed side of such a construction: flame propagation along the pipe surface; the combustion of un-burnt volatile gases emerging from an open pipe end on the unexposed side; or the melting of the pipe on the unexposed face, again releasing volatile gases.

Some plastics melt and char when heated; subsequent pipe deflection can lead to self-sealing of the penetration [23]. However as Choi [22] points out, if a plug of char forms, it may subsequently disintegrate under continuous fire exposure.

If the pipe remained intact on the unexposed face of the construction, with hot gases flowing through it, the pipe temperature would rise. Initially such a rise may exceed limits designed to stop fire spread by conduction, ultimately though the temperature may reach a level suitable for piloted or auto-ignition of the plastic pipe itself. Where plastic pipes pass through cavities in a construction, there is the additional possibility of flames, hot gases and smoke entering these cavities.

One aspect identified as important in relation to the performance of plastic pipe penetrations passing through constructions is whether or not the end on the unexposed face is sealed, for example where a pipe terminates at a water trap. Research indicates that pipes with sealed ends on the unexposed face performed better than those with open ends. Attwood [24] attributed this to a 'cushion of stagnant air' in the pipe when the end is sealed, which limits the temperature rise within.

If a timber framed wall or floor is not penetrated by services the heat transfer in a fire would be first to the surface by radiation and convection from either the flame or the hot products of combustion. Thereafter heat will be transferred through the gypsum plasterboard ceiling or wall lining by conduction. The cavity and structural members will then be heated both by radiation and convection from the rear face of the gypsum plasterboard and heated gases in the construction cavity, and also by conduction where the member comes into contact with the rear of the gypsum plasterboard.

With the addition of unprotected plastic pipe penetrations additional thermal energy may be introduced into the construction cavity.

In the early stages of heating before the pipe distorts or melts, heat transfer from the pipes would be by radiation to the sides of the adjacent structural members, underside of the flooring and rear face of the gypsum plasterboard. Additionally where the gypsum plasterboard and particleboard flooring are in contact with the pipe walls there will be heat transfer by conduction.

If the pipes in the cavity subsequently soften and distort, the ratio of heat transfer mechanisms would change and with it the rate of heat transfer. If there is a gap around the distorted pipe, this

would allow gases from the fire to enter the cavity thereby increasing gas temperatures. This in turn would lead to heating by convection and radiation to the sides of the structural members from the gas in the cavity. Additionally there may be some radiation through such a gap. If this distortion leads to the pipe directly touching the timber member there will also be conduction

Assuming a flow of gas is maintained through the pipes then they will heat up on the outside face by conduction. The exterior face of the pipes would then radiate heat both in the cavity and on the unexposed face of the construction.

5. FIRE TESTS

5.0 TEST SAMPLE DESIGN

Three reduced scale fire resistance tests were conducted on 2 m x 2 m floor samples. The floor samples consisted of 18 mm flooring grade particle board on 195 x 45 mm timber I-joists at 400 mm centres. The I-joists comprised 45 mm x 47 mm softwood flanges at the top and bottom, connected to each other by a 9 mm thick OSB web. The underside of the I-joists was lined with a base layer of 19 mm gypsum wallboard and a further layer of 12.5 mm gypsum wallboard. This specification was identified within an I-joist manufacturers technical manual as one providing 60 minutes fire resistance [25]. In all cases the samples contained both a construction cavity

which was penetrated by plastic waste pipes and a control cavity with no penetrations. Figure 1 shows a section through the construction. The plastic pipes were positioned a nominal 2 mm away from the adjacent structural member. In all cases the plastic pipe material used was ABS. The pipe penetrations were tightly fitted within the apertures in the particle board flooring and gypsum plasterboard. The minimal annular space around the pipe penetrations remaining were then sealed with inert gypsum based plaster filler; this type of fire-stopping material being permissible in the guidance to the Building Regulations.

The time/temperature curve followed during the test was that of a BS 476-20:1987 test; variations from the standard curve during the tests were within the permitted tolerances [26]. As the tests were at a reduced scale it was not possible to load the samples. Monitoring took place via thermocouples positioned on the webs of the timber I-joists adjacent to the pipe penetrations and on the I-joist webs in the control cavities. The control cavity web was measured in each case by a single thermocouple. The test cavity web was measured by two thermocouples in test 2 and three thermocouples in tests 1 and 3. The data presented represents only the control cavity thermocouple measurements and the highest single thermocouple measurement recorded in the test cavity.
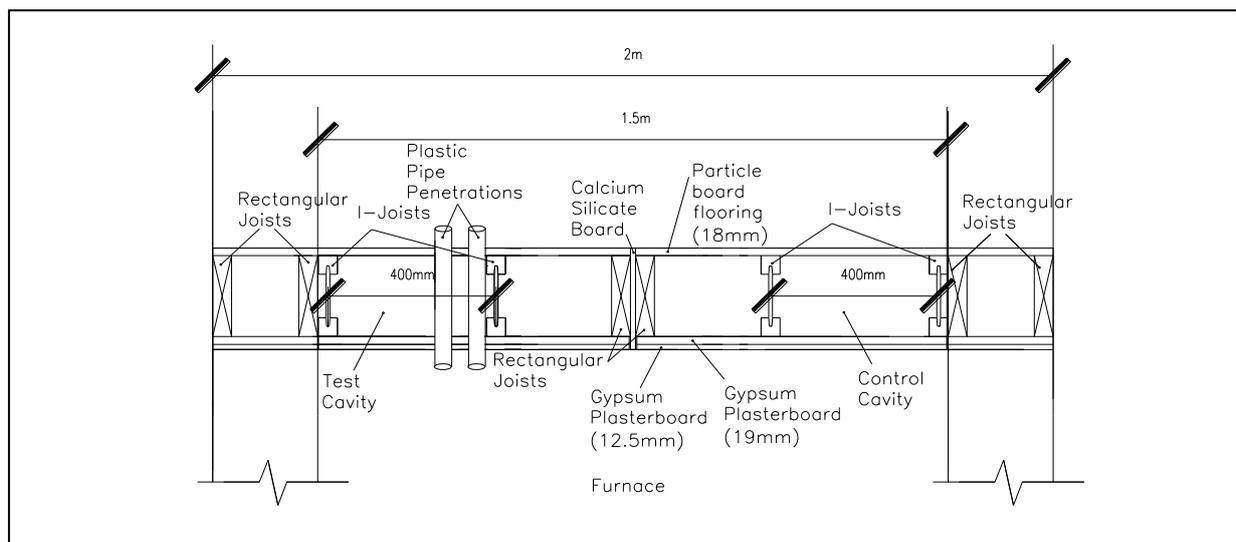

Figure 1: Section through Floor Sample

5.1 FIRE TEST 1

In test 1 the number and spacing of pipe penetrations in the test cavity followed the guidance to the Scottish Building Regulations explicitly: four 40mm diameter pipes each 40 mm apart.

Figure 2 indicates the web temperatures to the I-joist adjacent to the pipe penetrations and the web temperature measured in the control cavity.
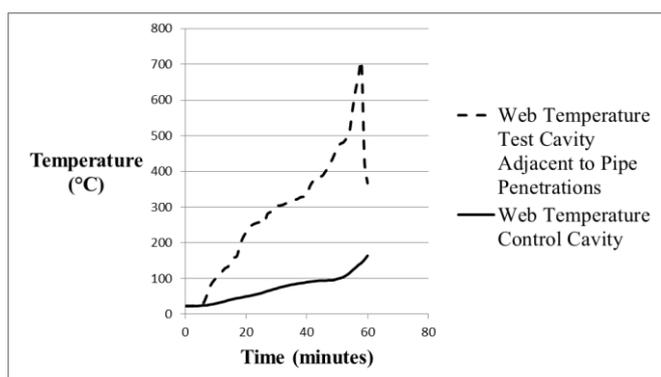

Figure 2: Web Temperatures Test 1

It may be seen from the graph that the web temperature in the cavity without service penetrations exceeds 100°C between 50-51 minutes and therefore would have been subject to some moisture migration. The maximum temperature of 164°C was reached by the end of the 60 minute test period. Therefore the temperatures associated with pyrolysis, ignition or charring was not reached.

By contrast, the thermocouple to the web immediately adjacent to the pipe penetrations in the test cavity exceeded 100°C after 10 minutes indicating the start of moisture migration. It subsequently reached 200 °C at 18-19 minutes; indicative of pyrolysis. 250°C was reached at 22 minutes, potentially conducive to ignition in a glowing mode. 300°C was reached at 29-30 minutes indicative of charring and at the bottom of the range identified for piloted direct flaming ignition. The top of this range for piloted flaming combustion ignition, 365°C, was reached at 41-42 minutes.

It was also observed that flaming combustion of the pipes themselves took place on the unexposed face of the floor construction outwith the furnace, prior to test termination.

5.2 FIRE TEST 2

The second test varied from the building regulation guidance in Scotland in that an additional pipe penetration was introduced; five 40mm diameter pipes each 40 mm apart. This would follow the guidance for the rest of the UK.

Unfortunately the thermocouple to the control cavity I-joist web malfunctioned during this test and therefore a direct comparison between the control and test cavities was not possible. However a post-test examination of the I-joists from the control cavity confirmed that the web, although discoloured, was not charred.

With reference to Figure 3 it may be seen that the web to the I-joist in the test cavity reached 100°C between 4-5 minutes indicating the start of moisture migration; 200°C between 7-8 minutes, indicative of pyrolysis; 250°C between 9-10 minutes, potentially conducive to ignition in a glowing mode; 300°C between 14-15 minutes indicative of charring; and 365°C between 27-28 minutes, the top of the range for piloted flaming combustion ignition.
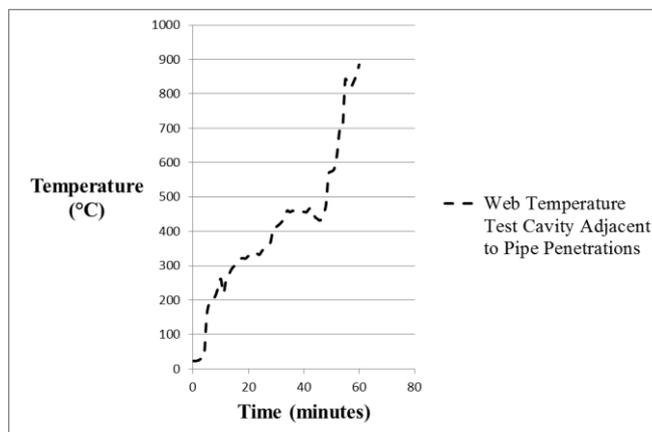

Figure 3: Web Temperature Test 2

As in Test 1 it was observed that that flaming combustion of the pipes themselves took place on the unexposed face of the floor construction outwith the furnace, prior to test termination. This occurred sooner in Test 2 than in Test 1.

5.3 FIRE TESTS 3

The final test contained four 40mm diameter pipes each spaced 20 mm apart. This is at variance with the Scottish guidance to the building regulations

but, as in Test 2, would follow the guidance in the rest of the UK.

The web temperature in the control cavity exceeded 100°C at 45 minutes, indicating the start of moisture movement in the OSB board and exceeded 200°C at 59-60 minutes indicating potentially the start of pyrolysis.
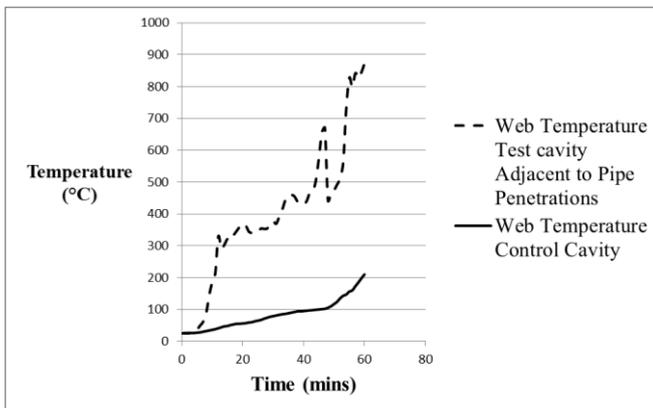

Figure 4: Web Temperatures Test 3

The I-joist web in the test cavity reached 100°C between 8-9 minutes indicating the start of moisture migration; 200°C between 10-11 minutes, indicative of pyrolysis; 250°C between 11-12 minutes, potentially conducive to ignition in a glowing mode; 300°C also between 11-12 minutes indicative of charring and 365°C between 19-20 minutes, the top of the range for piloted flaming combustion ignition.

Again, as in Tests 1 and 2, flaming combustion of the plastic pipe penetrations on the unexposed face outwith the test furnace were observed. This occurred sooner than in either of the two previous tests.

The experiments indicate that in each case web charring and ignition of the timber I-joist in the test cavity took place, whereas no charring or ignition of the web occurred in the control cavities. In all three experiments post-test examination showed that the test cavity web had charred through its entire thickness. It should be pointed out however, that due to the nature of the test furnace arrangement, extinguishment of the floor samples did not take place until approximately four minutes after the furnace was turned off.

Additionally it was evident that in all cases the degree of gypsum plasterboard 'fall-off' was greater to the test cavities than the control cavities.

6.   CONCLUSIONS

To re-iterate; the perceived potential problem with current building regulation guidance in relation to unprotected service penetrations is that these may lead to a rise in temperature within the construction. If the construction contains engineered timber products with relatively modest section sizes, such as I-joists, charring associated with such increases in temperature could prematurely undermine the load-bearing capacity of the construction. Additionally a rise in temperature in the construction cavity could exacerbate the situation by contributing to premature failure of the gypsum plasterboard protection. Consequently the fire resistance of the overall construction could be reduced as compared to an un-penetrated construction.

The rates of charring given in BE EN 1995-1-2:2004 [17] relate to exposure to a standard fire. Prior to 'fall-off' of the gypsum plasterboard protection, it was not possible to estimate the charring rate of the structural member. It was however possible to estimate when charring commenced, and to compare this with the control cavities.

The data indicates that charring could potentially occur earlier in a construction cavity which has groups of pipes penetrating, than a similar cavity without pipe penetrations. Additionally the data also signifies that moisture migration, pyrolysis and ignition are also likely to occur earlier in a penetrated cavity. These facets may be more pertinent in constructions containing structural members with relatively thin section sizes, such as timber I-joists, than those containing traditional rectangular sawn joists or studs.

It is also worthy of note that the time/temperature history for the web temperatures in test 1 indicate better performance than those in tests 2 or 3, suggesting that the limitation on spacing or number of pipe penetrations unique to Scottish Building Regulation guidance is material.

The main limitation of the research discussed here was that the fire tests were at a reduced scale. This is pertinent as the volume of the construction cavity, which is a function of joist depth, span and the joist spacing, will have an effect on the rate at which the void increases in temperature. Additionally at reduced scale it was not possible to load the floor sample and as such the effects of deflection were excluded.

Although these experiments are indicative of a potential problem with building regulation guidance regarding unprotected service penetrations, further fire resistance tests require to be carried out which better represent realistic spans and loadings. These tests should utilise a full sized furnace and include loading of the floor specimens in order to determine whether failure would actually occur.

ACKNOWLEDGEMENTS

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