Fire resistance of hollow core slabs

Experiences from the UK

By

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1. 1999 Natural fire test.
2. 1999 Hollow core fire test.
3. 2005 Fire behaviour of Pre-tensioned floors report
4. UK Practice - Restraint
5. Proposals
6. Recommendations and Conclusions

2 1999 Natural Fire Test.

- In February 1999 BRE undertook a series of tests investigating natural fires.
- The test used hollowcore units as a roof.
- The test was stopped due to explosive spalling of the concrete.
- Units only 2 weeks old and had a high moisture content.
- Uniformed publicity resulted in new test being undertaken.

2 1999 Hollow core Fire Test.

Details of Test

- Two Slab Tests
- Slab A All joints filled. Structural Topping (50 mm A98 Mesh)
- Slab B All Joints Filled. Hooked reinforcing bars to slab joints over supports
- Design fire load of 570 MJ/m^2
- Applied static load of 3.66 kN/m^2

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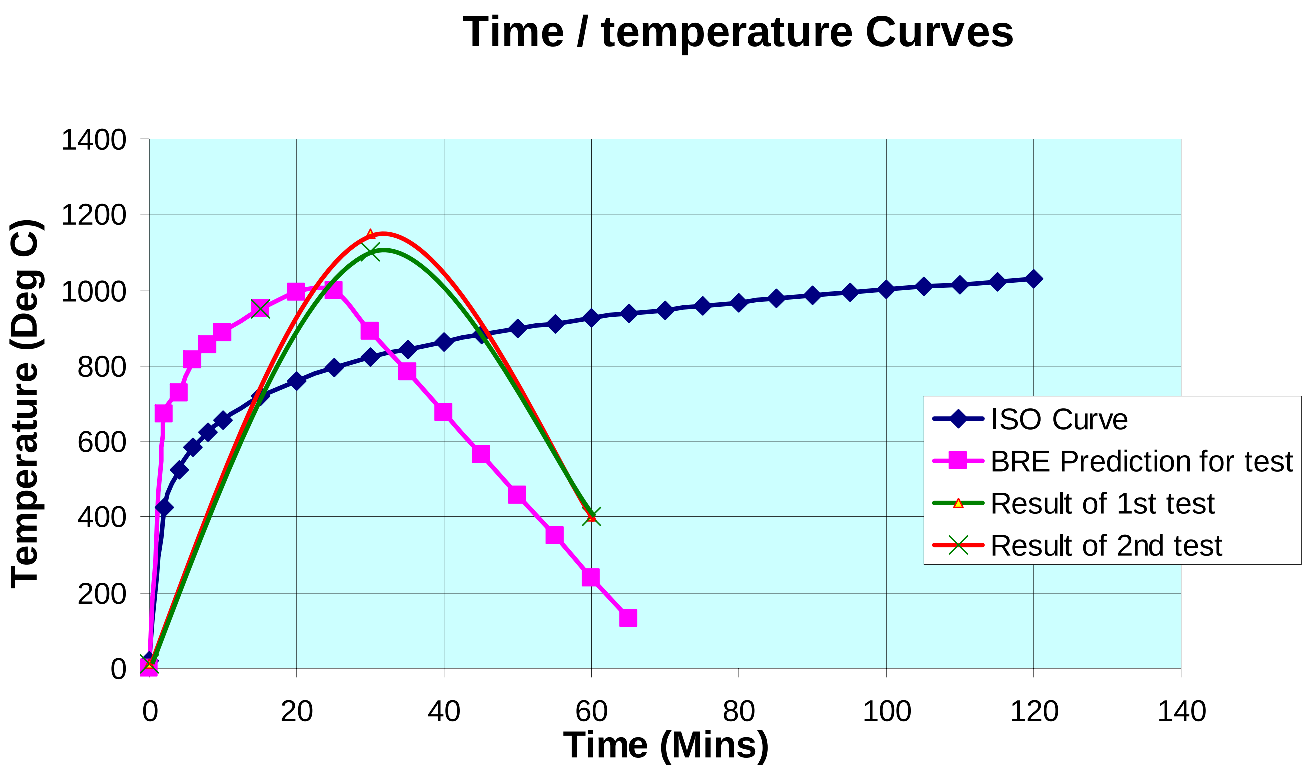
2 1999 Hollow core fire test - results.



3 2005 Fire behaviour of Pre-tensioned floors report

A Summary of report

a) Provides a summary of testing to date.

b) Comments on basis of current design guidance for prestressed units.

c) Comments on the modes of failure and discussion on the failure modes (Spalling failures, premature shear failures).

d) Current UK Practice

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a) Summary of testing reviewed

- UK Tests
- USA Tests
- Danish Tests
- Belgium Tests
- Dutch Tests
- Finnish Tests
- Italian Tests

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a) Summary of Testing :- UK testing 1950 -

- No systematic research/testing,
- All tests incorporated plaster protection or screed/topping finish. Limited value beneficial to fire resistance.
- Common forms of floor units not been fully tested
- Designers within UK relied heavily on generic guidance given in BS8110
- Tests results not widely available due to sponsor,
- Tests terminated when fire performance achieved (1hr)
- More recent tests as discussed briefly before,

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a) Summary of Testing:- US testing

- Prior 1962 – 50 + standard fire tests on pretensioned and post tensioned elements,
- Air entrainment, solid slab units only,
- 1958 – 62 5 Tests + 6 further tests
    - Effect of restraint pronounced effect on resistance
    - Value of restraint is never achieved in real buildings
    - Full restraint likely to cause explosive spalling,
    - No restraint failure governed by temp of prestressed wires
- 1966 PCA Tests - 11 No tests
    - Tests performed well
    - Argued no shear failure
    - No spalling, air entrainment

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a) Summary of Testing:- Danish testing 1998 - 2005

- Shear tests on hollowcore slabs,
- 2005 tests conclusion hollowcore acceptable for 1 hour fire provided displacement force < 75% cold shear capacity,
- 1998 tests premature failure due to shear failure,
- Wires at 150 degrees at failure, potential loss of bond, material not at elevated temperatures,

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a) Summary of Testing:- Belgium testing

- 1971 3 Tests – shear failure observed between 29 and 36 min. (end condition)
- 1980 Tests – topping and end beam, 76 – 126min fire resistance bending failure
- 1990 Tests – topping and end beam and end sleeves bending failure between 182 and 194 min
- More recent tests 83 – 120min fire resistance No failure in shear when floor adequately tied. And acts as a coherent floor system,
- Lead to recommendations for fire testing hollowcore units

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a) Summary of Testing:- Dutch Investigation

- Theoretical and experimental study 1998 – 2004 by "Fellinger"
- 25 Tests conducted, incorporating 2 ribs of hollowcore,
- Designed to fail in shear and anchorage (does not reflect real buildings)
- Used to develop FE model for further investigation into shear & anchorage
- Shear failure not related to temp of strands
- Shear must be considered in design
- States that axial restraint should not be relied upon??
- States placing bars in cores over support does not increase fire resistance?? But axial restraint is increased??

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a) Summary of Testing:- Finnish testing

- Discussed later when comparing code guidance
- 38 No. tests
- 27 tests showed no failure mode,
    - 9 failed due to spalling, due to high covers to reinforcement,
    - Other modes, shear, bond, slip, integrity or combination thereof.

3 2005 Fire behaviour of Pre-tensioned floors report

a) Summary of Testing:- Italian testing

- 1985 – 1990 5 No tests
- Fire resistance 120 – 180min
- Compared EC2 and BS8110. Correlated well to observed test results.

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b) Comments on BS 8110 and EC2 guidelines

UK design guidance given in BS8110, Parts 1 and 2

- Min thickness, Table 4.4, $t_e = h \text{ x } \xi + t_f$ cover,
- Covers based upon prestressed tendons retaining 50% of ambient strength at 450 degree C. Too high and Unconservative.
- No spalling requirement for prestressed slabs of 2hr spec or less. Cover 40 –50mm,
- No check on shear, anchorage / debonding,

Eurocode EN1992-1-2 (simplest design approach),

- Axis distance specified in Table 5.8 increased by up to 15mm for prestressed wire / tendons. cl 5.2(5) CEB/FIP and PCA recommendations,
- Tables 5.8 conservative based on 70% load level, unlikely
- Specifies cover so no tendon exceeds 350 degrees C

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b) Comments on BS 8110 and EC2 guidelines

BS8110 *thkness; cover*

1hr – 95mm ; 25mm

2hr – 125mm ;40mm

EC2 *thkness; axis dist.*

1hr = 80mm; 35mm

2hr = 120mm; 55mm

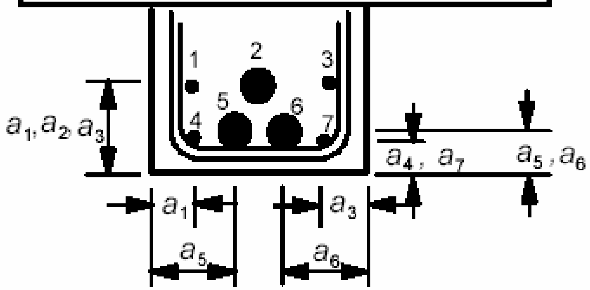

Figure 5.3: Dimensions used to calculate average axis distance a_m

Table 5.8: Minimum dimensions and axis distances for reinforced and prestressed concrete simply supported one-way and two-way solid slabs

Standard fire resistance	Minimum dimensions (mm)			
	slab thickness h_s (mm)	axis-distance a		
		one way	two way: $l_y/l_x \le 1,5$	two way: $1,5 < l_y/l_x \le 2$
1	2	3	4	5
REI 30	60	10*	10*	10*
REI 60	80	20	10*	15*
REI 90	100	30	15*	20
REI 120	120	40	20	25
REI 180	150	55	30	40
REI 240	175	65	40	50

l_x and l_y are the spans of a two-way slab (two directions at right angles) where l_y is the longer span.

For prestressed slabs the increase of axis distance according to 5.2(5) should be noted.

The axis distance a in Column 4 and 5 for two way slabs relate to slabs supported at all four edges. Otherwise, they should be treated as one-way spanning slab.

* Normally the cover required by EN 1992-1-1 will control.

EC2 Guidelines

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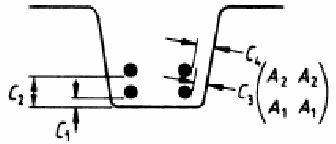
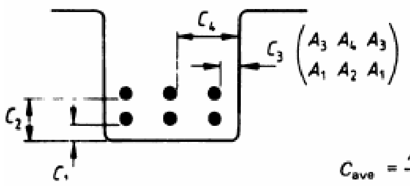
b) Comments on BS 8110 and EC2 guidelines



$$C_{ave} = \frac{2A_1 \times \begin{pmatrix}\text{lesser of}\\ C_1 \text{ or } C_3\end{pmatrix} + 2A_2 \times \begin{pmatrix}\text{lesser of}\\ C_2 \text{ or } C_4\end{pmatrix}}{2A_1 + 2A_2}$$



$$C_{ave} = \frac{A_2C_1 + 2A_1 \begin{pmatrix}\text{lesser of}\\ C_1 \text{ or } C_3\end{pmatrix} + 2A_3 \begin{pmatrix}\text{lesser of}\\ C_2 \text{ or } C_3\end{pmatrix} + A_4 \begin{pmatrix}\text{lesser of}\\ C_2 \text{ or } C_4\end{pmatrix}}{2(A_1 + A_3) + A_2 + A_4}$$

BS8110 Guidelines

Nature of construction and materials		Minimum dimensions excluding any combustible finish for a fire resistance of:					
		0.5 h	1 h	1.5 h	2 h	3 h	4 h
		mm	mm	mm	mm	mm	mm
Reinforced concrete (simply supported):							
dense concrete	Thickness	75	95	110	125	150	170
	Cover[a]	15	20	25	35	45	55
lightweight concrete	Thickness	70	90	105	115	135	150
	Cover[a]	15	15	20	25	35	45
Reinforced concrete (continuous):							
dense concrete	Thickness	75	95	110	125	150	170
	Cover[a]	15	20	20	25	35	45
lightweight concrete	Thickness	70	90	105	115	135	150
	Cover[a]	15	15	20	20	25	35
Prestressed concrete (simply supported):							
dense concrete	Thickness	75	95	110	125	150	170
	Cover[a]	20	25	30	40	55	65
lightweight concrete	Thickness	70	90	105	115	135	150
	Cover[a]	20	20	30	35	45	60
Prestressed concrete (continuous):							
dense concrete	Thickness	75	95	110	125	150	170
	Cover[a]	20	20	25	35	45	55
lightweight concrete	Thickness	70	90	105	115	135	150
	Cover[a]	20	20	25	30	35	45

[a] Cover is expressed here as cover to main reinforcement (see 4.2.3). For practical purposes cover is expressed as nominal cover to all reinforcement and these tabulated values need to be decreased accordingly.

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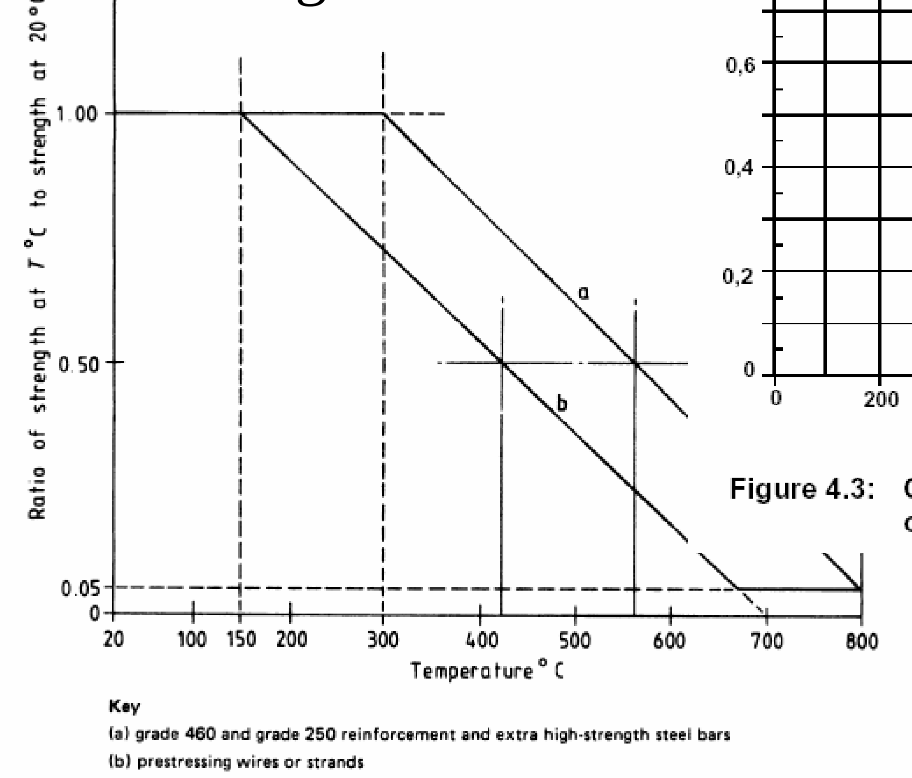
b) Comments on BS 8110 and EC2 guidelines

BS Design Curve



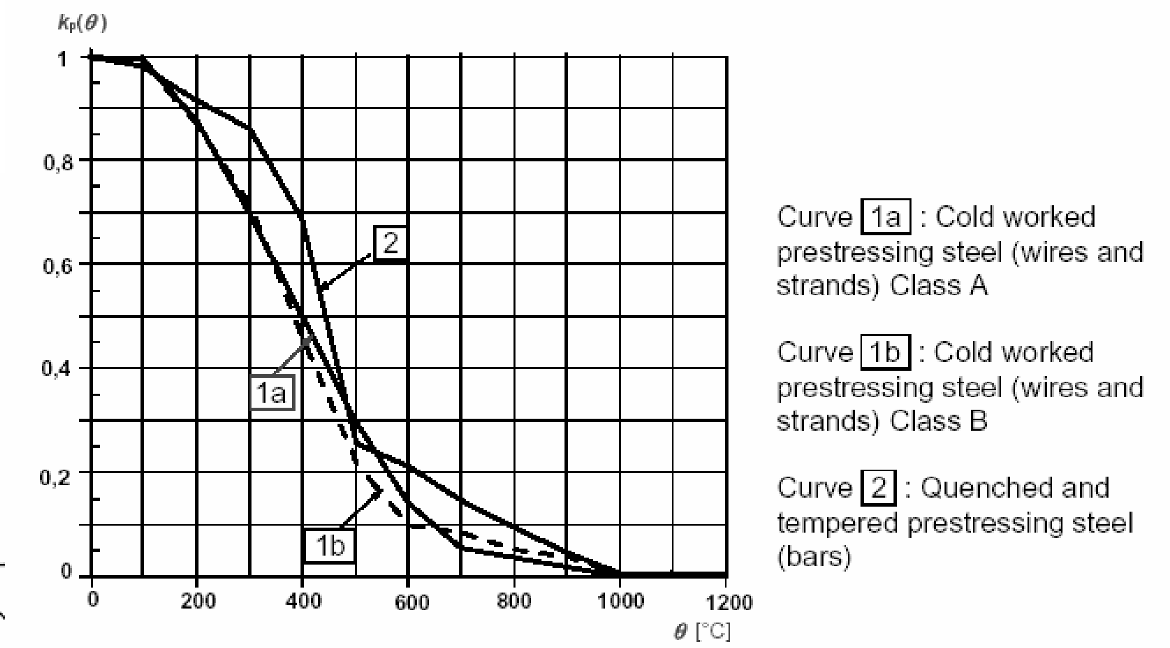


Figure 4.3: Coefficient $k_p(\theta)$ allowing for decrease of characteristic strength (βf_{pk}) of prestressing steel

EC Design Curve

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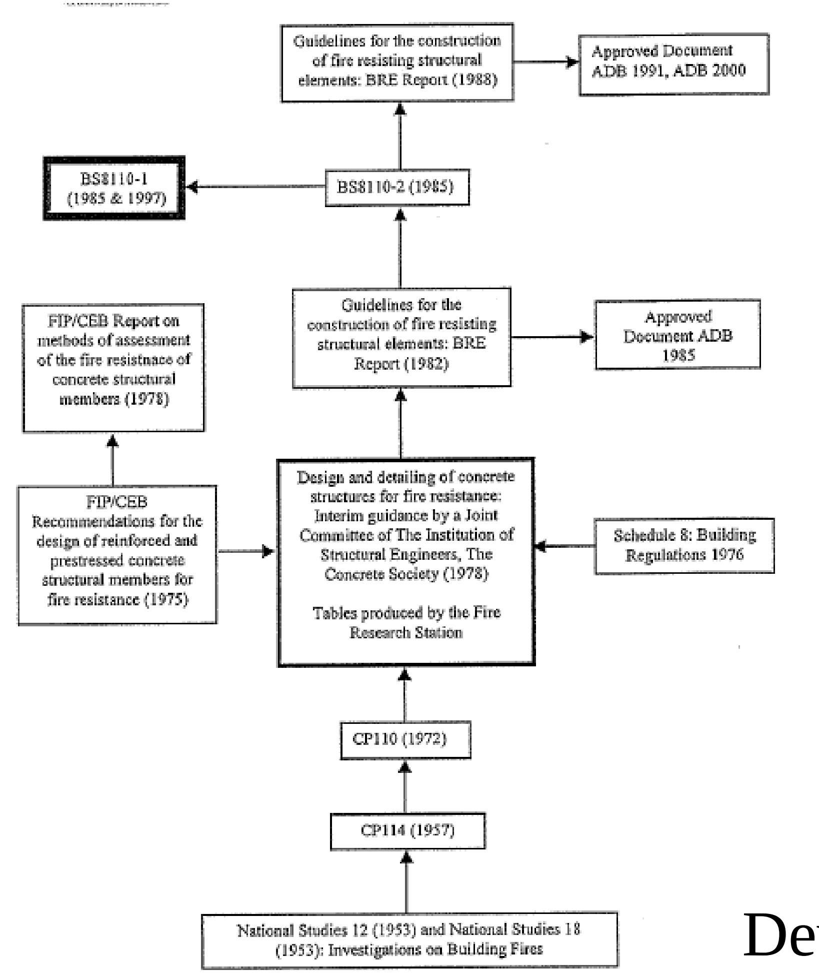
b) Comments on BS 8110 and EC2 guidelines



Comparison between Codes

- 38 Finnish Tests
- 22 cases BS8110 was un-conservative
- 14 cases EN1992-1-2 was un-conservative
- EC2 is more conservative due to larger covers/axis distance
- Status of both codes a concern
- Italian Tests, Code guidance was conservative.

Development of BS8110

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c) Comments on Failure modes

- A number of test units have failed premature, attributable to support conditions,
- Van Acker states that premature shear failure does not occur in practice, floor acts as a coherent diaphragm,
- not all tying is carried out in the UK and some EU countries, Author - Current construction practices, raises concern, Shear failure not been reported in practice in real buildings,
- Peripheral ties and anchorage help, to be determined, axial restraint provided by support helps,
- general agreement that axial restraint improves fire resistance,
- Poor prediction by BS and EC2,

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c) Comments on Failure modes

- Failures, author states that the issue of shear failure has gone un-noticed in the UK industry,
- Inconsistencies between Van Acker and Fellinger work
- Previous research that design guides are based do not mention spalling as a problem,
- Recommendations investigating problem areas,
- Air entraining in tests on fire performance, guidelines based upon 6%, manufacturers do not use anywhere near 6% air entrainment
- High strength concrete, inherently more brittle,

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d) Recommendations from report

- Investigate level of Axial and notional restraint to ensure shear failure does not occur, in particular where no peripheral tie or tying arrangements are provided
- Shear investigation under Natural and Standard fires,
- Use of air entraining agents to be investigated,
- Maximum and minimum concrete strengths specified to ensure inherently brittle and high strength concretes are not specified,
- Investigate the benefits of axial restraint in relation to spalling

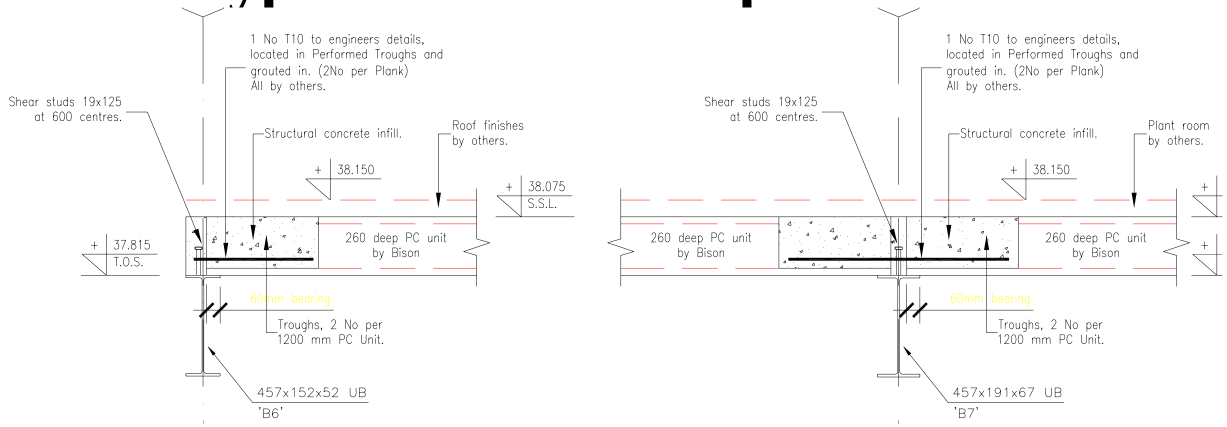
4 UK Practice – Restraint

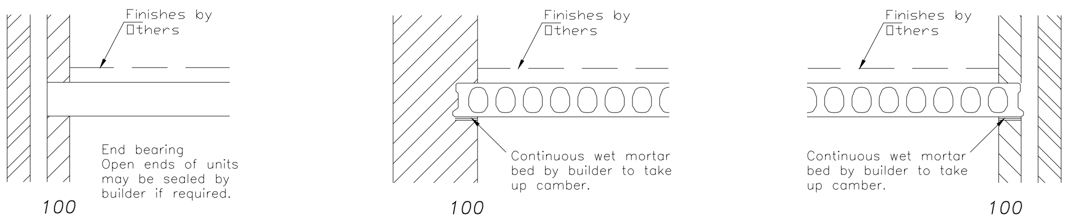
•**Masonry** :- Floors built in walls if Class 2A construction, tied if Class 2B or higher. Provides acceptable construction, modular arrangement, friction and shear between units and walls provide restraint to thermal expansion. Hence prevents premature shear failure,

•**Steel** :-Class 2A construction, slabs bears on to steel, it is possible steel provides restraint if steel expansion is not greater than concrete unit expansion, even for protected steel expansion could still be greater, thus no restraint and premature shear failure,

•**Steel** :- Class 2B or higher requirement to tie slab to steel, therefore restraint provided.

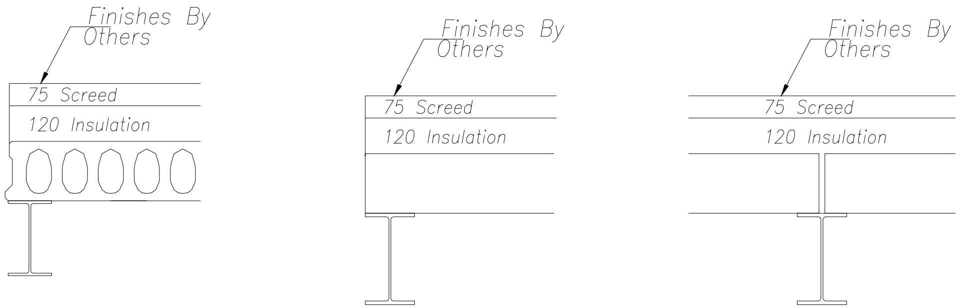
4 Typical Details that provide thermal restraint





UK Practice:-

Prior to Dec 04, NO consideration for tying in buildings under 5 storey



Typical Details that provide No thermal restraint

5 Test Proposals

- Natural Fire Test, Compartment Fire, (3No. 6m bays x 7m span), Fire Load to be confirmed,
- Masonry Test not required, opinion provides fire resistance,
- No tie between steel and hollowcore slab, hence no restraint, Class 2A construction on steelwork, worst case.
- Walls built in to restrain Steel Columns,
- 100% dead load to be applied, incl. 1.0 kN/m2 Partitions, 1.8kN/m2 Finishes, Service 0.15 kN/m2
- Imposed load on hollowcore unit 2.5 kN/2, 33% of live load to be applied,

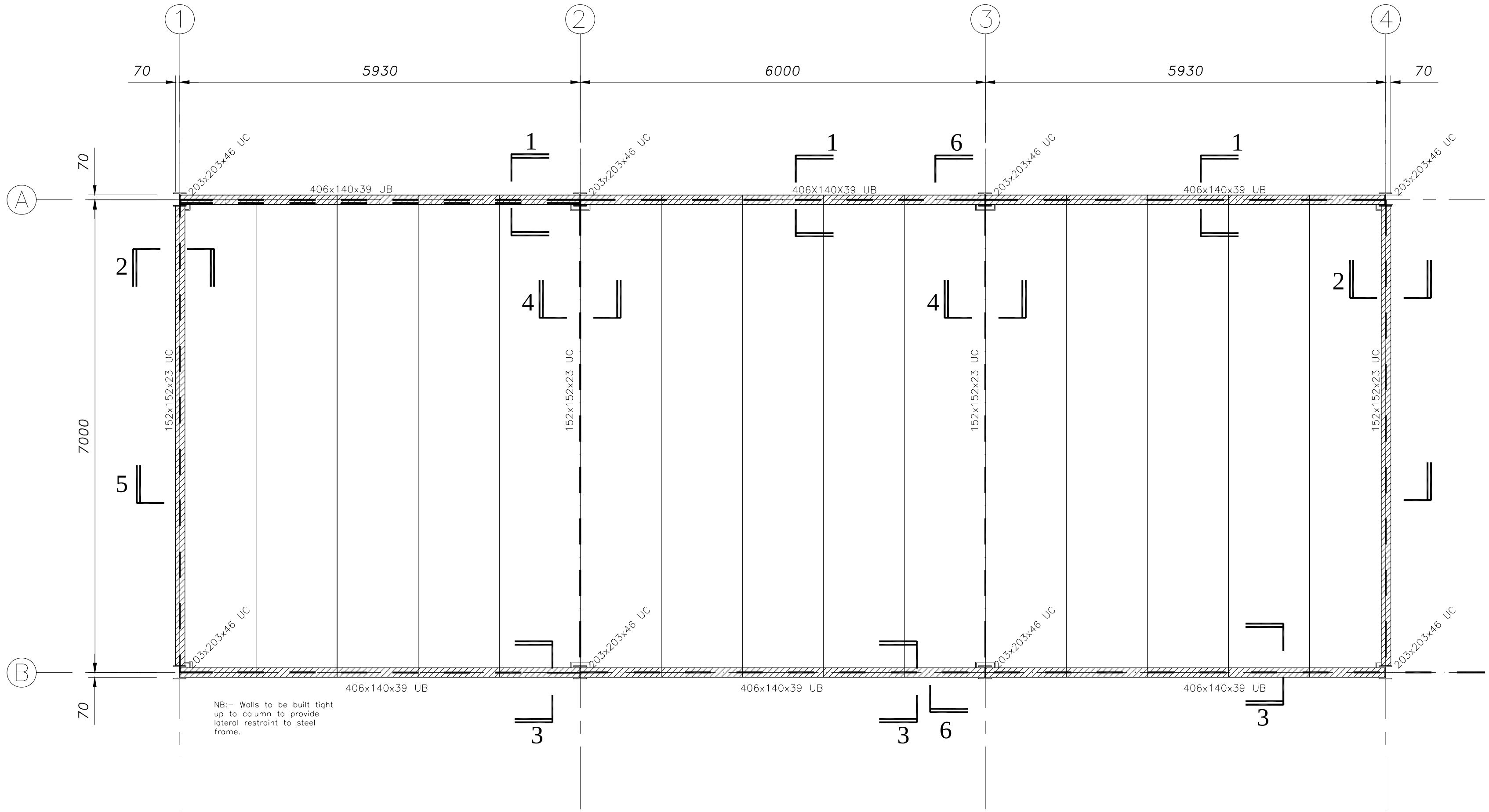
5 Test Proposals

- 1 Hour Fire board protection to steel beam and column elements, by Knauf or similar
- Testing to achieve 1 Hour fire performance on hollowcore,
- Finite Element investigation to extrapolate fire data to imposed of 4.0 kN/m2
- Ventilated Opening, size to be confirmed after design assessment,
- Moisture content to be limited 2.5% by volume, prevent spalling
- Instrumentation, to be confirmed
  - Thermocouples attached to prestressed tendons, located through hollowcore depth, determine thermal gradient

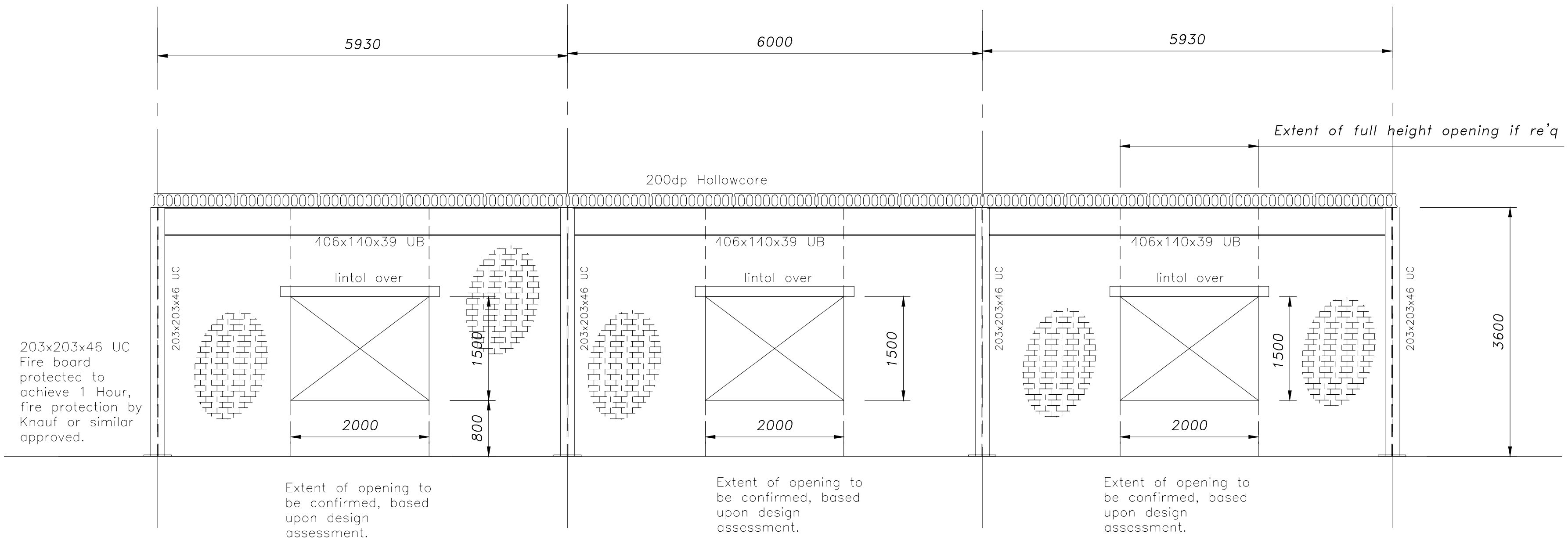
5 Test Proposals

- Instrumentation continued
  - Strain gauges attached to steelwork tie elements and hollowcore elements, t.b.c
  - Displacement gauges, t.b.c
- Aggregate – Limestone and Gravel,
- 200 dp Hollowcore Units,
- Proposed testing to commence summer 2006 - funding

5 Test Proposals



5 Test Proposals



Elevation on Grid Line B

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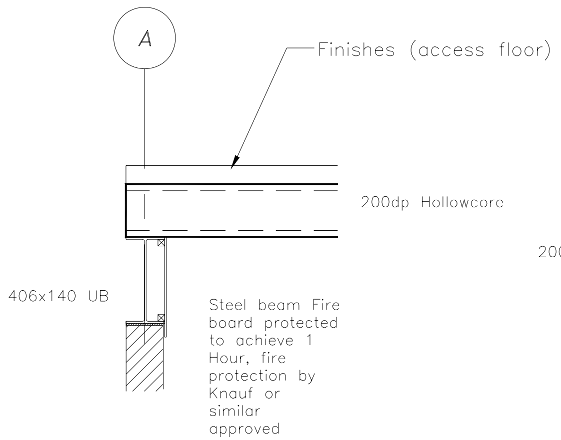
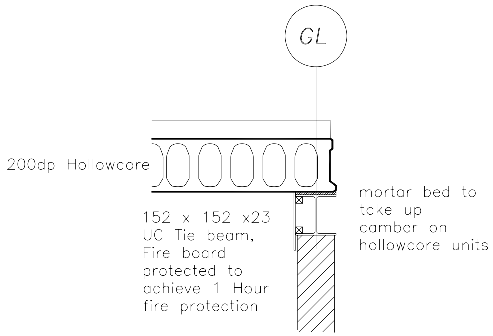
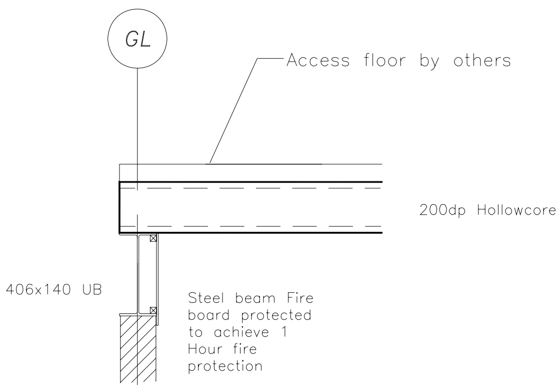
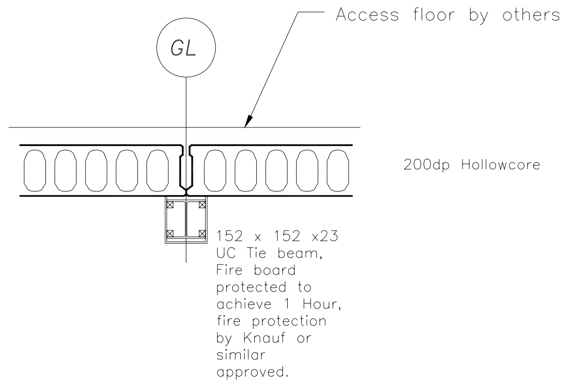
5 Test Proposals









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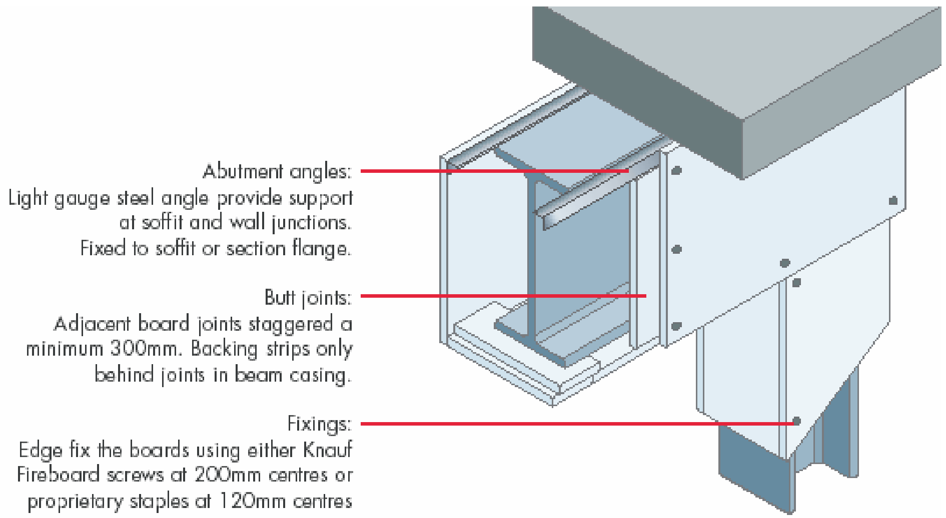
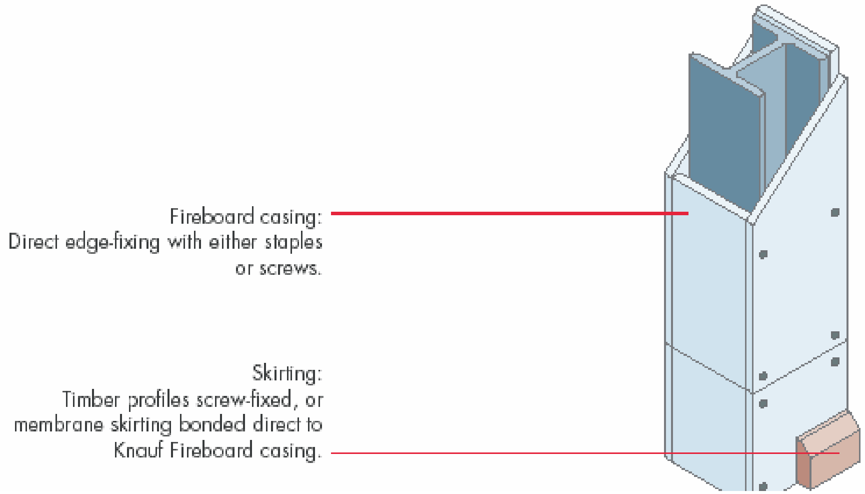
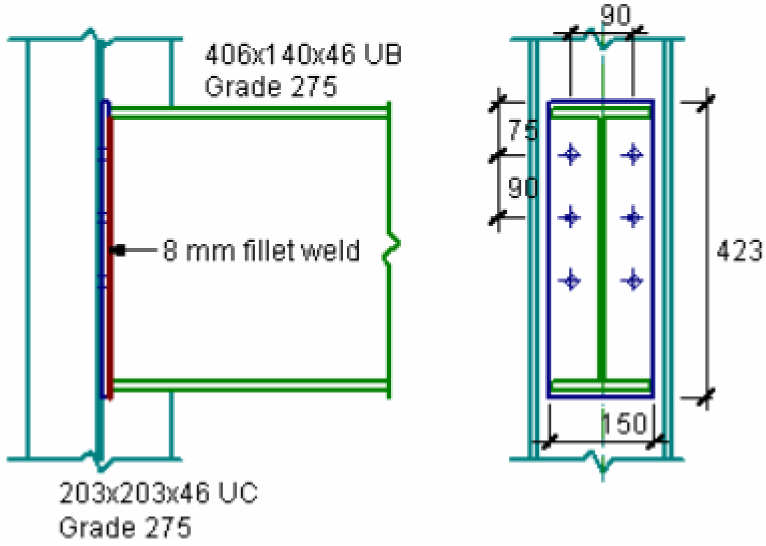
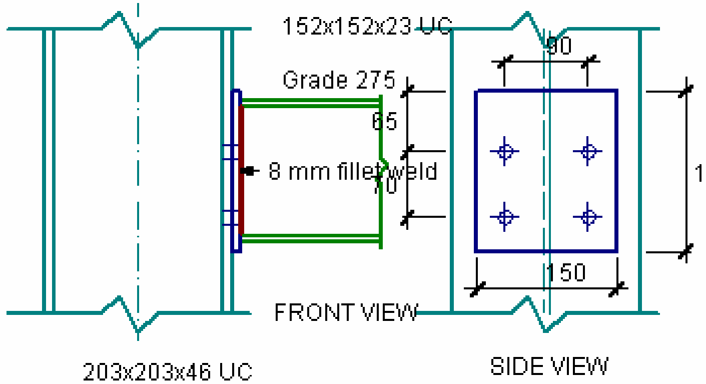
5 Test Proposals









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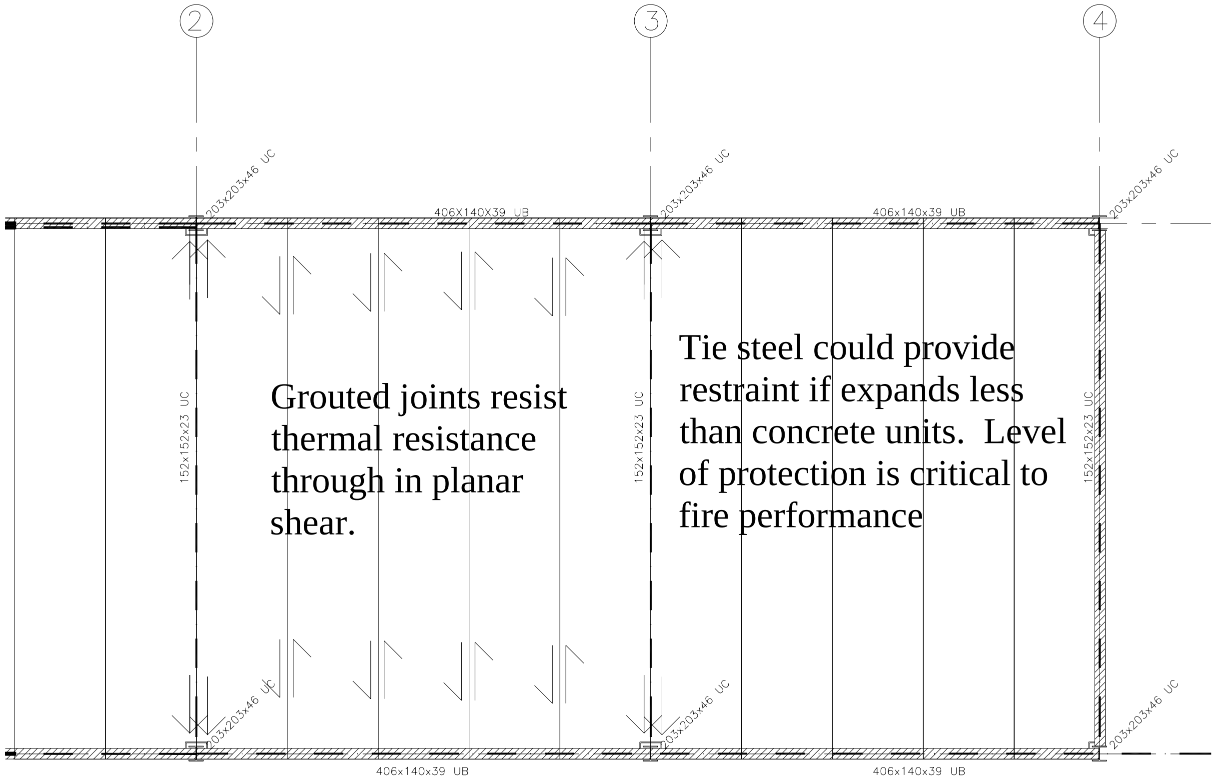
5 Test Proposals – Restraint Mechanism



Grouted joints resist thermal resistance through in planar shear.

Tie steel could provide restraint if expands less than concrete units. Level of protection is critical to fire performance

Thermal expansion is restrained by hollowcore units compressing against column.

6 Recommendations and Conclusions

- UK concerns but wider European problem,
- Testing should validate Hollowcore performance, and UK practices
- Validation of Guidance in Particular EN1992 / BS 8110,