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# Fire resistance of hollow core slabs

# supported on non-fire protected Deltabeams

Prepared for
Peikko Group Oy, Finland
January 2010

# Fire resistance of hollow core slabs supported on non-fire protected Deltabeams

List of content



Enclosures



**Preface**
This report is the property of Peikko Group Oy.
The report is based on the test reports from SP, Borås:

- P802216A
- P802216B
- P802216C
- P802216D

**Introduction**
The goal of the fire tests was to document the ability of Peikko Deltabeam without fire insulation to support hollow core slabs in a floor structure without fire insulation during fire situation.

To meet this goal four test panels and a test setup was planned, with a max utilization of shear and support capacity of the hollow core slab during fire. A typical representation from a series of hollow core slab was chosen to the test: Xtrumax EX27 from Spaencom/Consolis, Denmark, with a characteristic cold shear value $V_{Rk}$ = 159.7 kN pr. 1.2 m wide slab.

The Deltabeams were designed and produced by Peikko and the test panels were assembled and cast together at SP Technical Research Institute of Sweden, Borås.

The capacity of the shear load transfer slab to Deltabeam during 60 minutes of standard fire plus 120 minutes of standard cooling phase was found to be 46 kN/m inclusive dead load of the slab. This value corresponds to 35.0% of the characteristic cold shear value of the tested slab.

The capacity of the shear load transfer slab to Deltabeam during 120 minutes of standard fire plus 248 minutes of standard cooling phase was found to be 39 kN/m inclusive dead load of the slab. This value corresponds to 29.4% of the characteristic cold shear value of the tested slab. The slab has been prepared to resist 120 minutes of fire by increasing the bottom cover on the strands by 15 mm.

The capacity of the shear load transfer slab to Deltabeam during 180 minutes of standard fire without a cooling phase was found to be 26 kN/m inclusive dead load of the slab. This value corresponds to 19.8% of the characteristic cold shear value of the tested slab. The slabs and the Deltabeams were in this test designed to resist 120 minutes of standard fire.

Due to the choice of typical hollow core slab the test results can be assumed to be valid for all normal hollow core slabs supported on Deltabeams. The bearing capacity in the fire situations is given as a fraction of the characteristic bearing capacity in a cold design situation.

***Summary of conclusion:***

***The result from the test showed, that load transfer in the interface between a non-fire insulated Deltabeam and a hollow core slab was fulfilled. The capacity of the load transfer from a typical hollow core slab and a Deltabeam during fire was at least - depending on the fire duration - 35% (REI60+), 29% (REI120+) or 19% (REI180) of the characteristic shear capacity of the slab in a cold design situation. The "+" means that the standard fire included the standard cooling phase.***

**Design team**
To get the most up to date knowledge of the problems due to fire resistance of hollow core slabs as well as composite beams a design working group with participation of the following experts were established:

Jesper Frøbert Jensen, Alectia – specialist in design of concrete element structures
Kristian Hertz, DTU – specialist in fire design of structures
Lars Reimer, Spaencom/Consolis – head of design office at the concrete element factory
Finn Passov, Spaencom/Consolis – design chief at the concrete element factory
Poul Erik Hjort, BEF – director of the union of Danish concrete element factories
Rolf Hilling, SP – specialist in execution of fire test at the SP laboratory
Simo Peltonen, Peikko Group Oy, R&D Manager – specialist in design of Deltabeams
Kjell-Ole Gjestemoen, Peikko Group Oy, director, international operation
Jonas Høg, Peikko Danmark A/S, managing director
Head of the working group:
Carsten Munk Plum, ES-Consult A/S – specialist in design of steel- and composite structures

All participants in the design working group have been contributing to the final design of the test panels and of the test rig. Many problems have been solved during the meetings, and the successful outcome of the fire test was very much a result of the team work.

A grateful thanks to all participants in the design team shall be expressed.

**Test panel**
The test panels for the fire test consisted of a main Deltabeam with a span width of 3915 mm. The span width of the slabs was 2350 mm between the main beam and the two edge beams:

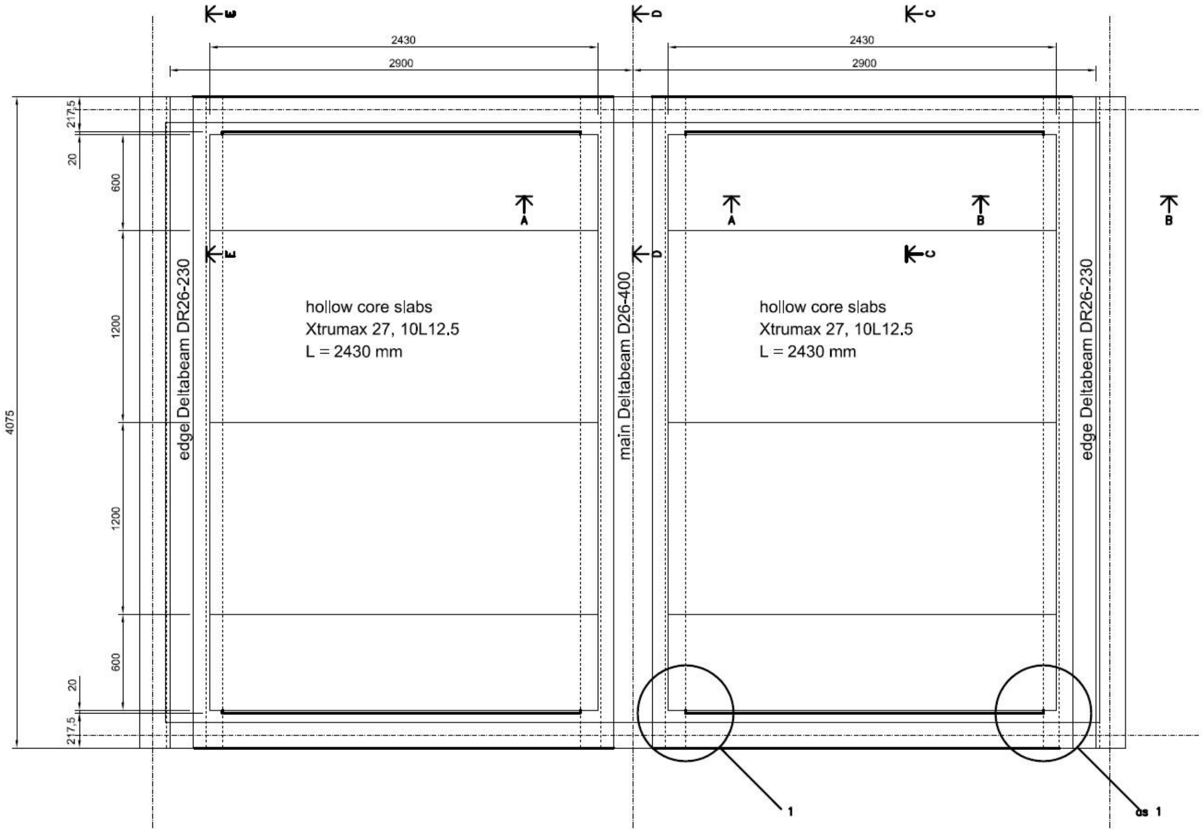



*Fig. 1. Plan of test panel.*

The cross section of the Deltabeam was:

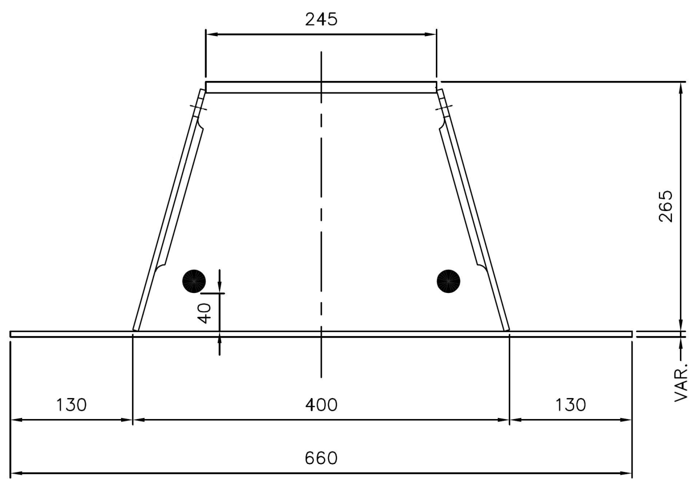



*Fig. 2. Cross section of the main Deltabeams*

The web thickness was 5 mm
The top flange thickness was 15 mm
The bottom flange thickness was 8 mm
The fire reinforcement was 3 pcs. of ø32 for R60 design and 5 pcs. of ø32 for R120 design

The cross section of the edge Deltabeams were:

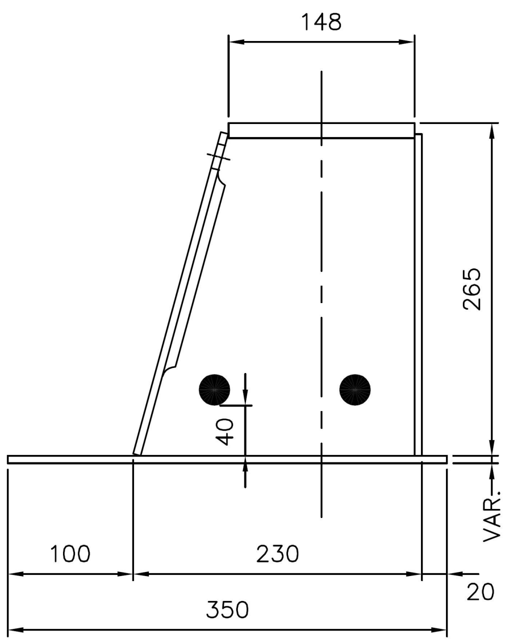



*Fig. 3. The cross section of the edge Deltabeams*

The web thickness was 5 mm
The top flange thickness was 8 mm
The bottom flange thickness was 8 mm
The fire reinforcement was 2 pcs. of ø20 for R60 design and 2 pcs. of ø25 for R120 design

The steel in beam was S355J2+N in accordance with EN 10025-2.
The reinforcement was A500HW in accordance with SFS 1215.

The design and documentation of the bearing capacity of the Deltabeams was carried out by Peikko using the standard software. The degree of utilization of the main Deltabeam and the two edge beams was practically equal in order to obtain unique deflections during the fire tests.

The hollow core slabs were of type Xtrumax EX27. They were designed and fabricated by the supplier – Spaencom/Consolis.

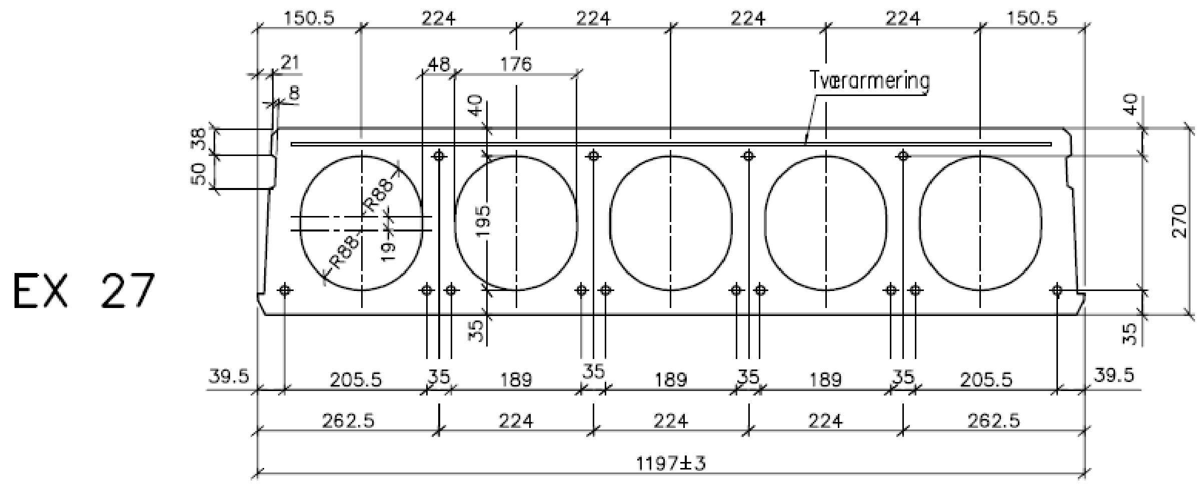



*Fig. 4. The cross section of the hollow core slabs*

The bottom reinforcement was 10 strands L12.5 with an initial prestress of 90 kN each.
The material of the strands was in accordance with EN 10138 with an ultimate strength of 173 kN.
No top reinforcement or cross reinforcement of mild steel was supplied.
The characteristic concrete cylinder strength was $f_{ck}$ = 50 MPa.

The span width of the hollow core slabs in the erection stage was 2350 mm. The end of the slab cores waere cast with a plug depth of 50 mm at the main Deltabeam and a plug depth of 270 mm at the edge Deltabeams. The details at the main Deltabeam were identical to the normal procedure at building sites.

It is essential that the test panel is restrained horizontally in a similar way to a real hollow core slab floor structure. The joint reinforcement was the same as that normally used in hollow core slab deck structures. The transverse reinforcement through the web holes of the main Deltabeam was ø12 in each joint between hollow core slabs in accordance with recommended practice. No longitudinal reinforcement parallel with the Deltabeam was applied. The ends of the Deltabeams were tied together with concrete edge beams, which sole function was to resist longitudinal thermal expansion of the hollow core slabs, see fig. 1 – a model of a real deck structure.

In the corners of the test panel reinforcement between Deltabeams and the concrete edge beams was applied to secure transversal restraining of the test panel so that it would act like a cut out of a real floor structure of hollow core concrete slabs.

The conditioning of the test panels was obtained by storing them in dry climatic conditions to reach a maximum content of humidity - 3% - for the hollow core slabs. The humidity of the interior concrete in the Deltabeams could not reach that level. An estimation of the hmidity of the infill concrete was measured in test cylinders stored in PVC tubes with a 300 mm distance to the free end. The humidity was 6.9 – 8%.

**Choice of hollow core slab**
The market for suppliers of hollow core slabs in Denmark was scanned to find the most typical hollow core slab to be used in the test.

The goal was to find a slab with a representative proportion of "shear carrying" web per meter support of the slab. The data in fig. 5 below was original found in connection with the shear tests of hollow core slabs in fire situation carried out in 2005 by SP, Borås, for the Danish Prefab Concrete Association (Betonelement Foreningen).

The chosen slab Xtrumax EX27 had a shear carrying web of 239 mm/m (mark **o** in fig. 5) and was therefore very typical for the scanned slabs. The characteristic shear capacity of the slab in a cold design situation was 133.1 kN/m (159.7 kN per 1.2 m width of slab).

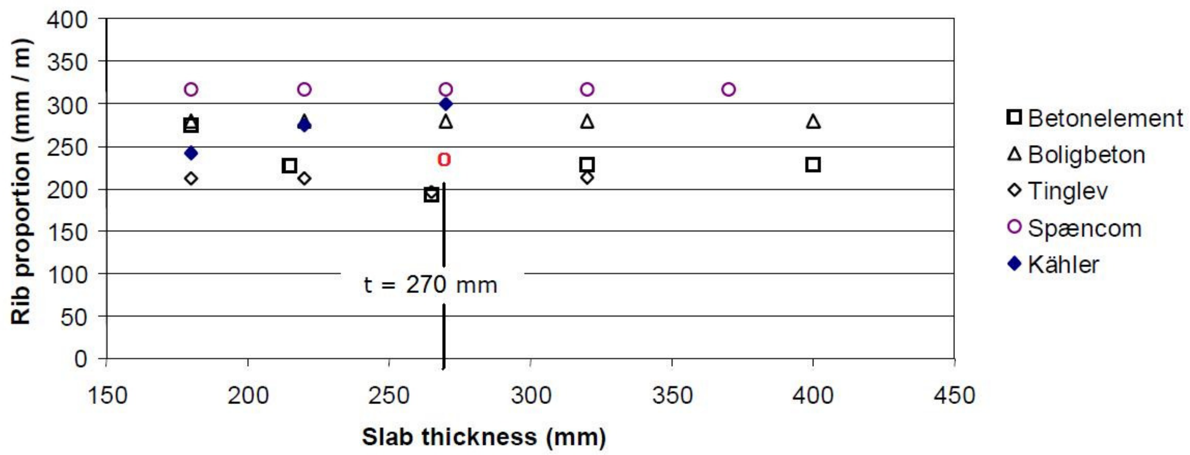



*Fig. 5, The shear web (rib) per meter width of the slab*

**Test loading**
The load application takes place at a distance of 715 mm from the end of the hollow core slab that was supported on the main Deltabeam (see fig. 6). This corresponds to a distance of 675 mm = $2.5 \cdot H_{slab}$ from the theoretical support on the bottom flange.

The piston loading could not be applied directly on the hollow core slabs. In order to simulate a uniform distribution, the load was applied on a 2430 mm long steel plate with a width of 100 mm placed on the surface of the hollow core slabs – see fig. 7.

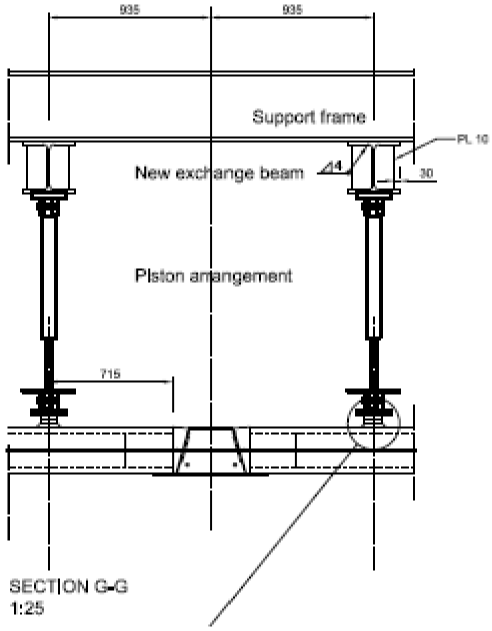



*Fig. 6, Load application on the hollow core slabs*

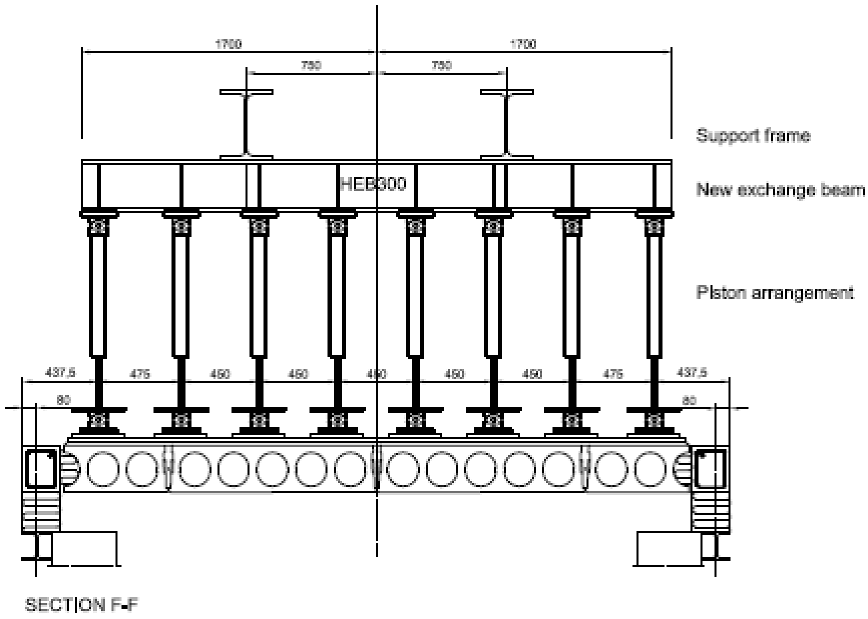



*Fig. 7, Distribution of the load transverse on the hollow core slabs*

*Fig. 8, Deflection of the load distribution plate / transversal deflection of the test panel*

The realistic behavior of the distribution plate is shown in fig. 8, where it can be seen that the plate follows the upper surface of the slab.

An overview of the test arrangements including the loadings is show in fig. 9.

*Fig. 9, Test arrangement*

**The applied loading in each of the 4 tests**

The **first test** 27th October 2009 was carried out using 60 minutes of standard fire and 120 minutes of standard cooling phase. The loading on the hollow core slab applied by the pistons were:

48.0 kN/m

This was applied through 8 pieces of pistons placed by a distance of 450mm. Load from each piston was:

21.6 kN

The mutual reaction between the slab (from one side) and the Deltabeam was calculated to be 38.7 kN/m using a span width of 2350 mm of the slab between the theoretically supports (assumed 80 mm wide) on the bottom flanges of the Deltabeams plus the dead load from the 2430 mm slab elements including the joint casting.

The resulting total load on the main Deltabeam has been calculated to:

76.9 kN/m

The calculated resulting moment and max shear (~reaction) for the main beam was:

M = 158.7 kNm

V = 156.6 kN

The resulting load on the edge Deltabeams has been calculated to:

18.4 kN/m

The calculated resulting moment and max shear (~reaction) for the edge Deltabeams was:

M = 38.6 kNm

V = 39.9 kN

The **second test** 4th November 2009 was carried out using 60 minutes of standard fire and 120 minutes of standard cooling phase. The loading on the hollow core slab applied by the pistons were:

$1.2 \cdot 21.6 = 25.9$ kN

This corresponds to a distributed loading:

$1.2 \cdot 48 = 57.6$ kN/m

The mutual reaction between slab and Deltabeam was calculated to be 46 kN/m using a span width of 2350 mm of the slab between the theoretically supports on the bottom flanges of the Deltabeams.
The calculated resulting moment and max shear (~reaction) for the main beam was:

M = 185.2 kNm
V = 181.7 kN

The calculated resulting moment and max shear (~reaction) for the edge beam was:

M = 43.6 kNm
V = 44.6 kN

The **third test** 11th November 2009 was carried out using 120 minutes of standard fire and 248 minutes of standard cooling phase. The loading on the hollow core slab applied by the pistons was the same as in the first test.

The **forth test** 18th November 2009 was carried out using 180 minutes of standard fire and no cooling phase. The loading on the hollow core slab applied by the pistons were:

13.5 kN

This corresponds to a distributed loading:

30.0 kN/m

The mutual reaction between slab and Deltabeam was calculated to be 17 kN/m using a span width of 2350 mm of the slab between the theoretically supports on the bottom flanges of the Deltabeams.
The calculated resulting moment and max shear (~reaction) for the main beam was:

M = 185.2 kNm
V = 181.7 kN

The calculated resulting moment and max shear (~reaction) for the edge beam was:

M = 43.6 kNm
V = 44.6 kN

**Test procedures**

The test panel was placed on the supporting structure, which was outside the furnace. The Deltabeams were supported on roller bearings to allow free expansion in the span direction of the beams and angular deflection of the beams. In the transversal direction, the movement of the edge Deltabeams away from the main Deltabeam – due to expansion, was possible because the relative movement between the panel and the test furnace was not prevented and sliding in the steel-steel interface could occur. In this direction an elastic hindrance of the expansion in order to model a real slab structure was required.

The test loading was reached minimum 15 minutes before the fire test started.

The test loading was kept constant during both the heating and the cooling phases, in other words, throughout the test.

**Test measurements**

The test panel was produced with cast in-situ instrumentation to measure temperature and stress in the relevant spots of the test panel. The placement of each temperature cell and strain gauge was measured carefully prior to the casting of the joints and the interior of the Deltabeam.

There was also placed devices to measure the pull in of the strands in the hollow core slabs. The measurement was on the top of a wire placed in a small tube of steel cast into the transversal joint of the slab and fitted to the free end of the strand of the hollow core slab. The wire must not be fixed to the strand as welding was not allowed on the strands. Hence a carefully tightening of the tube to the end of the slab was carried out.

Furthermore, temperature and deflection measurements were installed on the upper side of the test panel prior to the fire test.

**Test results**

All four tests were successful. The test panels did not fail, as they maintained their load bearing capacity during the entire test period, and they also preserved integrity and insulation capacity.

The interaction between the hollow core slabs and the Deltabeam was also preserved. And the force transmission from slab to Deltabeam occurred with no local bending deformation of the bottom flange of the Deltabeam – see fig. 10.

*Fig. 10, Bottom flange of the main Deltabeam after 180 minutes of standard fire*

The temperature measured below the bottom of the test panel – see fig. 10 – indicated the furnace temperature during the four fires see fig. 11. In the figure it can also be seen that it was not possible to follow the standard cooling phase when the temperature reached about 300˚C. It was not possible to cool the interior of the furnace quicker than the speed shown.

The test of the panel was stopped after the standard time required for a normal cooling phase. At this time the test loading was released. The heat input during the actual test was a little more than the prescribed amount. It can therefore be concluded that the actual test slightly exceeded the requirements of a standard fire test with cooling phase.

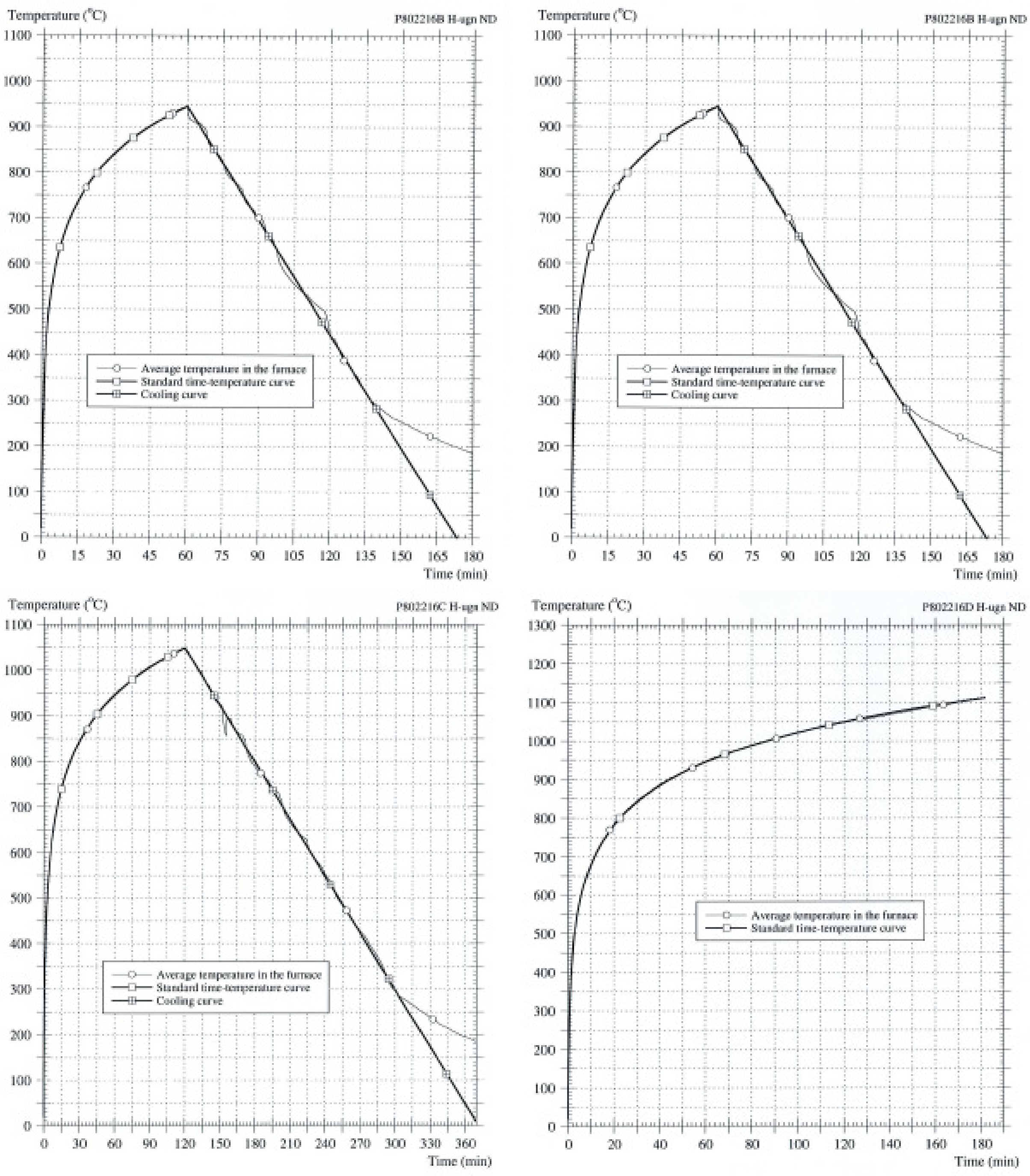



*Fig. 11, Temperature in furnace during the 4 fire tests*

The deflection of the test panel was measured during the fire tests – see figure 12.

At the initial loading, before the start of the fire, the measurement included the deformation of the loading frame of the test rig. After that the loading was kept constant and the measured deflections were only the actual deformation of the test panel during the fire.

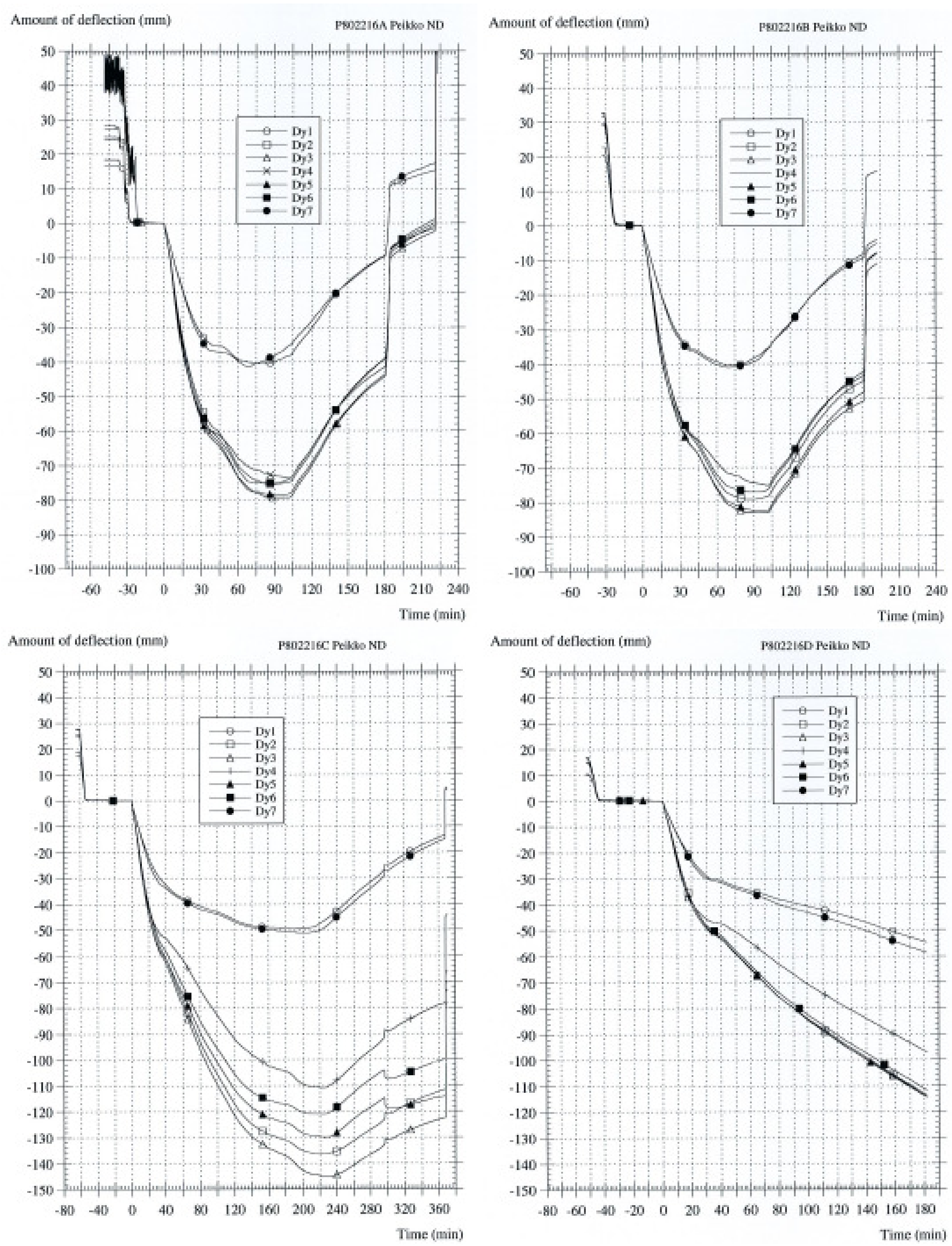



*Fig. 12, Deflection measurements.*

*D1, D7 were on the middle of the edge Deltabeam*
*D2, D6 were on the middle of the span of the hollow core slab*
*D3, D5 were on the middle of the applied loading*
*D4 was on the midle of the main Deltabeam*

The loading from the pistons was measured by placing a loading cell below a reference piston identical to the 16 other pistons and being in the same hydraulic circuit. The actual loading on the test panel was controlled by measuring the load from the reference piston. The loading can be seen in fig. 13.

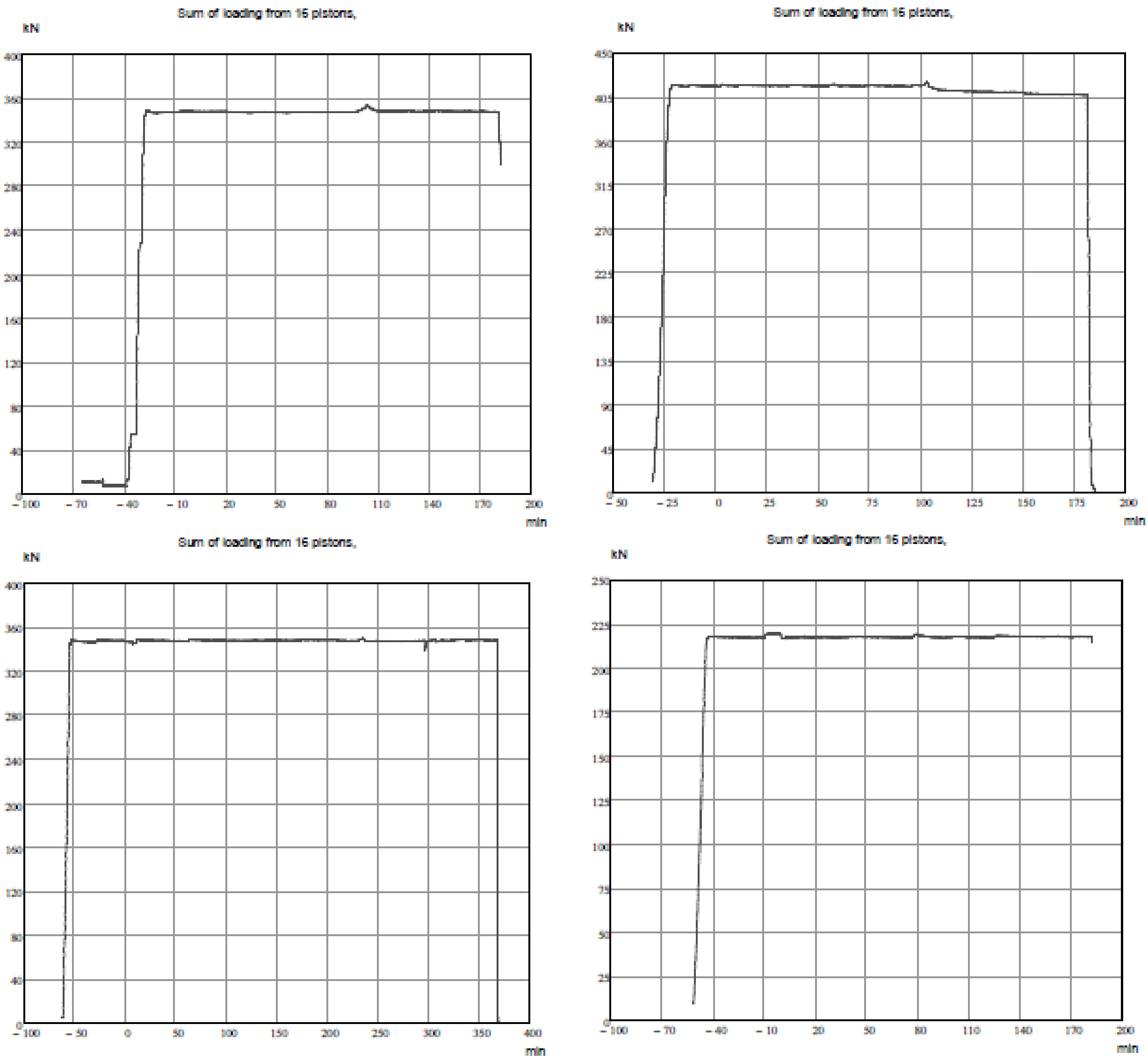



*Fig. 13, Sum of the piston loading on the test panel*

**Concluding remarks**

The Deltabeam was able to carry the load from the hollow core slab during the four fire tests.

The transfer of load from the hollow core slab to the Deltabeam did not happen through the support of the slab on the bottom flange of the Deltabeam, as the bending capacity of the bottom flange in all the tests was practically zero due to the high temperatures of the bottom flange ~ furnace temperature.

The load transfer must therefore rely on the compression of the slab to the inclined web of the Deltabeam – a bow action – plus friction along the web surface. The compression arises from tension in the joint reinforcement between the hollow core slabs and possibly also from the hindrance of the expansion of the slab structure.

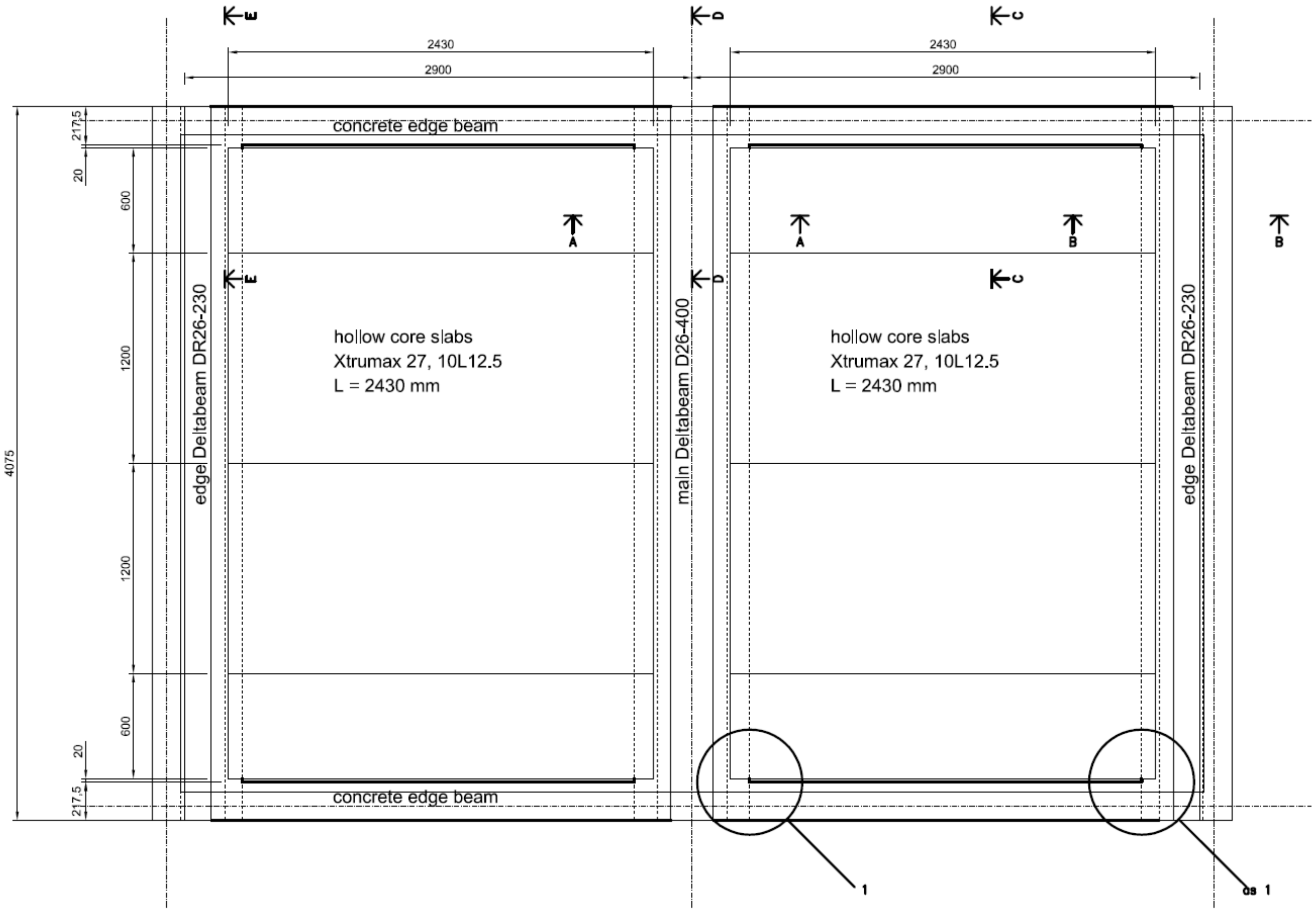
A small fraction of the load transfer might also come from the concrete cast through the web holes. This behavior is most likely to occur in the case of smaller Deltabeams than the D26-type used in the tests as the web holes are placed in the upper and more cracked region for the higher beams.

The applied load in the fire tests corresponds to uniformly distributed design load situations on slab structures with 7.2 m or 9.6 m span as shown in the following table:

| *Span of 270 mm slab* | *R60 + cooling* | *R120 + cooling* | *R180* |
|---|---|---|---|
| 7.2 m | 16.0 $kN/m^2$ | 10.7 $kN/m^2$ | 8.3 $kN/m^2$ |
| 9.6 m | 12.0 $kN/m^2$ | 8.1 $kN/m^2$ | 6.2 $kN/m^2$ |

*Table 1, Uniform design loads in the fire situations (incl. dead load of the slab).*

Due to the choice of typical hollow core slab, the test results can be assumed valid for all normal hollow core slabs supported on Deltabeams. The bearing capacity of the load transfer from a hollow core slab to the Deltabeam in fire situations is given as a fraction of the characteristic bearing capacity in a cold design situation.




PLAN
1:25

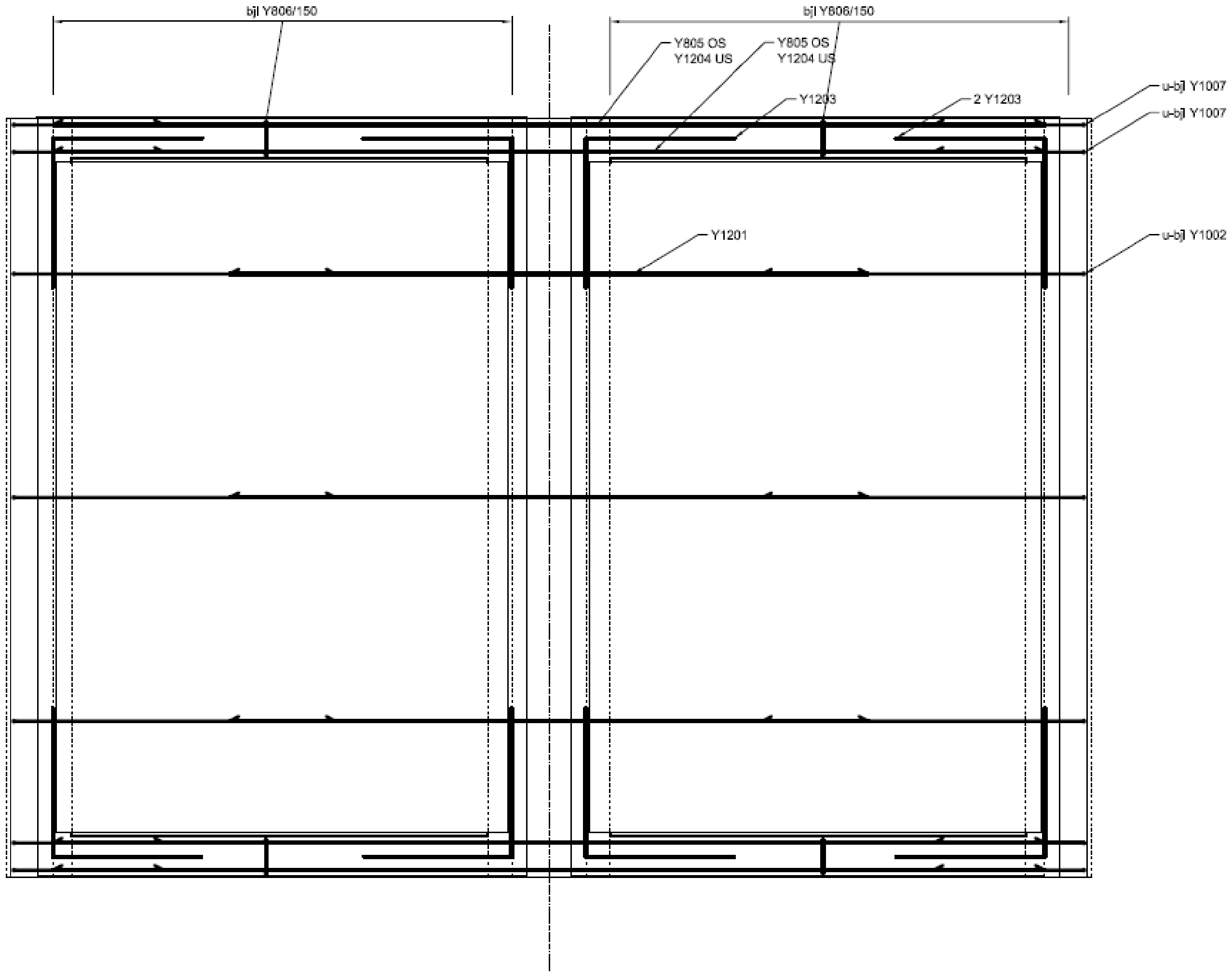
NOTE:
Measurements in mm
Concrete: Passive environmental class, fck = 25 MPa,
Reinforcement: Class A, fy = 500 MPa
Designation: Ydnn
d is diameter of bar
nn is number of bar

PEIKKO Fire test with DELTABEAM
Un-insulated bottom flange supporting hollow core slab

PLAN of testpanel

Drawing no. 01

ES-Consult date: 2010-01-11




PLAN
1:25

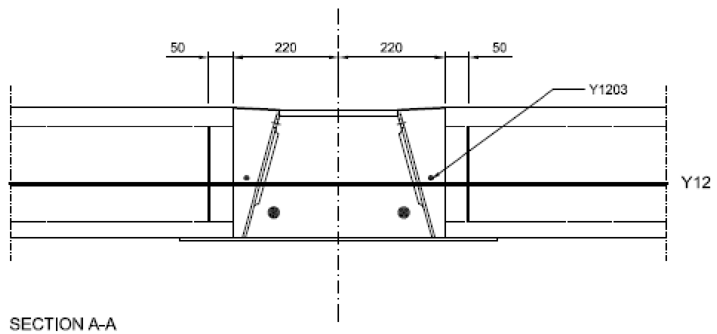
NOTE:
See drawing 01

PEIKKO Fire test with DELTABEAM
Un-insulated bottom flange supporting hollow core slab

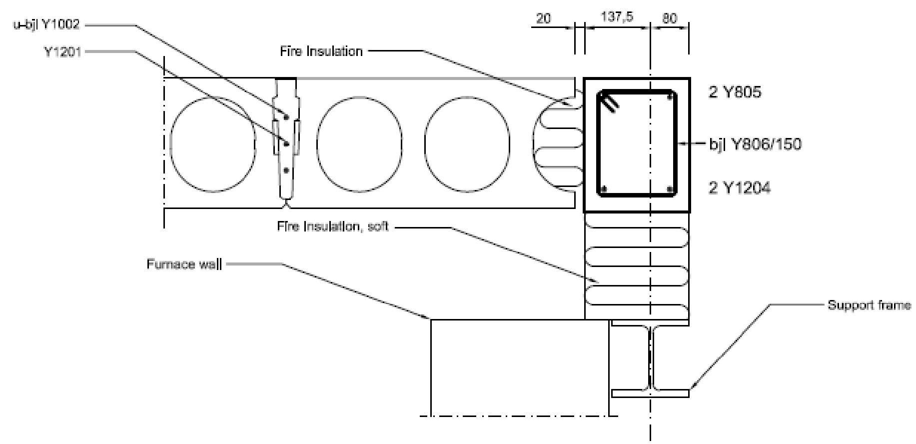
PLAN of testpanel with reinforcement

Drawing no. 04

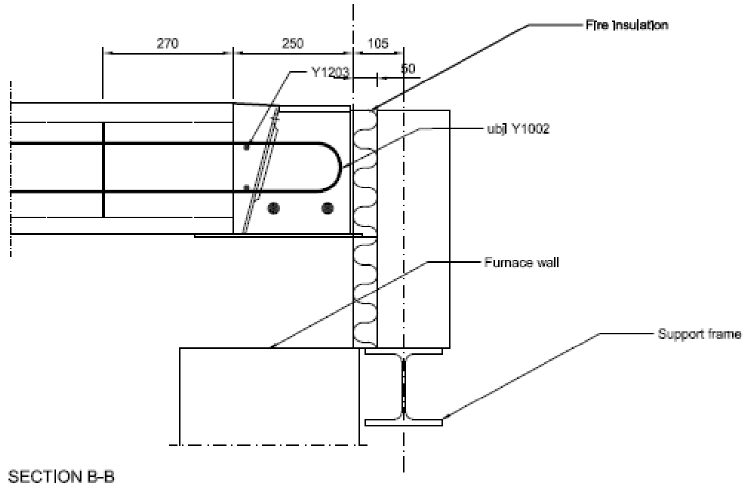
ES-Consult date: 2009-01-07




SECTION A-A
1:10




SECTION C-C
1:10



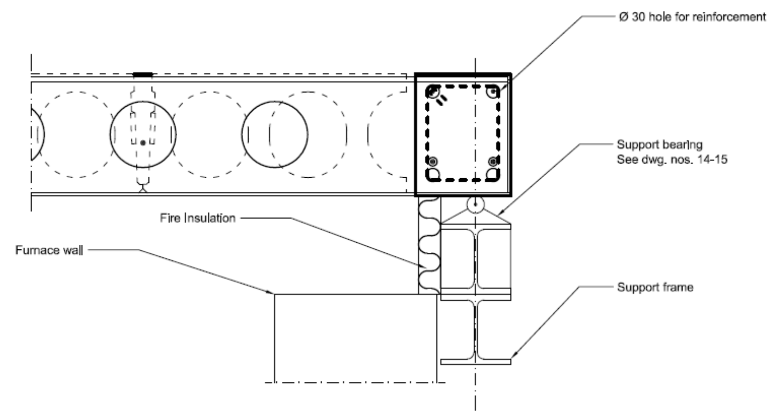

SECTION B-B
1:10

PEIKKO Fire test with DELTABEAM
Un-insulated bottom flange supporting hollow core slab

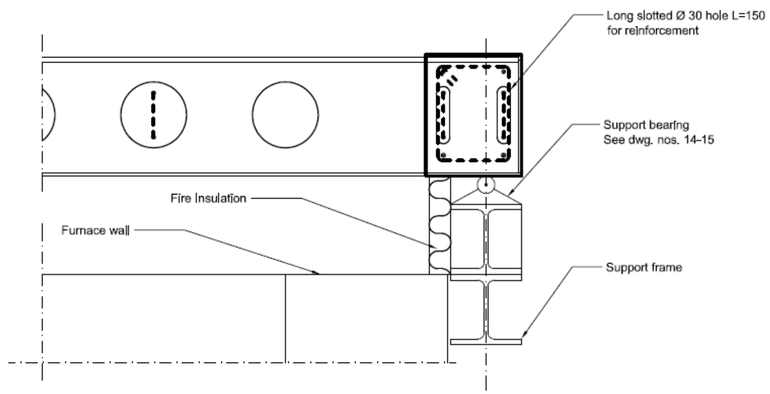
SECTIONS and DETAILS

Drawing no. 11

ES-Consult date: 2009-03-04




SECTION D-D
1:10




SECTION E-E
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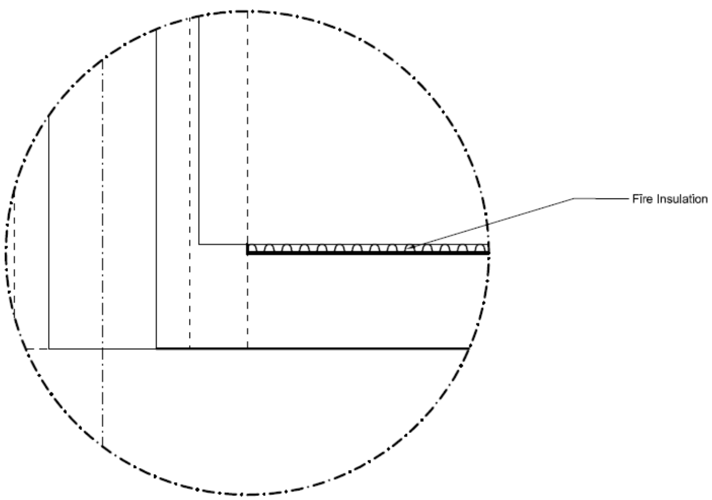


DETAIL 1
1:10

PEIKKO Fire test with DELTABEAM
Un insulated bottom flange supporting hollow core slab

SECTIONS and DETAILS

Drawing no. 12

ES-Consult date: 2010-01-06