

Fire test Deltabeam-Hollow-core slab

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



Peikko Group implemented in November 2009 an extensive four-phase fire-test series for the Deltabeam-hollow-core structure at the fire laboratory of SP Technical Research Institute in Borås, Sweden. The test proved the uniqueness of Deltabeam particularly when used together with hollow-core floor slabs.

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Introduction

The goal of the four fire tests was to document the ability of Peikko Deltabeam without fire insulation to support hollow-core slabs during a fire situation. The result from the test showed that load transfer in the interface between a hollow-core slab and a non-fire insulated Deltabeam was fulfilled. The capacity of load transfer from a typical hollow-core slab and a typical 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.

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 as shown in **figure 1**. The cross sections of the Deltabeams and the hollow-core slabs are shown in **figures 2, 3, and 4**.

The design and documentation of the bearing capacity of the Deltabeam was carried out by Peikko. 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 steel in the beams was S355J2+N in accordance with EN 10025-2. Fire reinforcement in the beams was A500HW in accordance with SFS 1215.

The hollow-core slabs were of type Xtrumax EX27. They were designed and fabricated by the supplier Spaencom/Consolis. The characteristic concrete cylinder strength for the design 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 were cast with a plug depth of 50 mm at the main Deltabeam and

a plug depth of 270 mm at the edge Deltabeams. The detail at the main Deltabeam was 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 $\varnothing 12$ 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 – 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. The humidity 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 m(eter) support of the slab. The collected data originally published by the Danish Prefab Concrete Association in 2005 is shown in **figure 5**. The chosen slab Xtrumax EX27 had a shear carrying web of 239 mm/m (mark "o" in figure 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.

Figure 5 Shear web (rib) per m slab

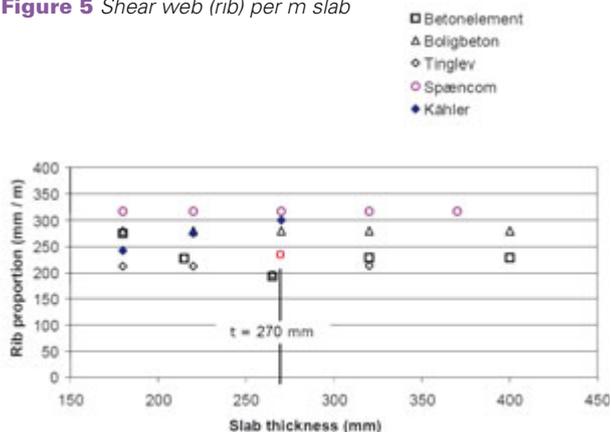


Figure 1 Plan of the test panel

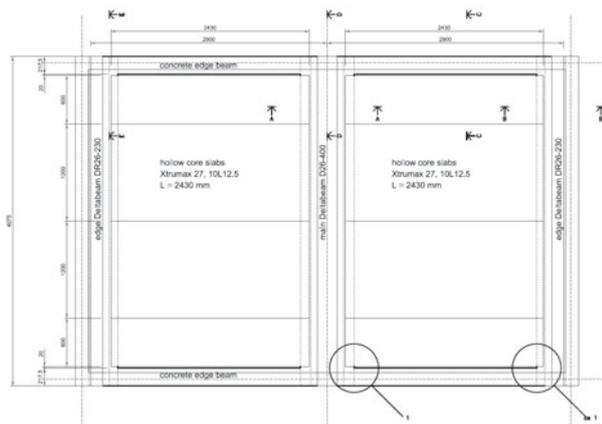


Figure 2 Cross section of main Deltabeam

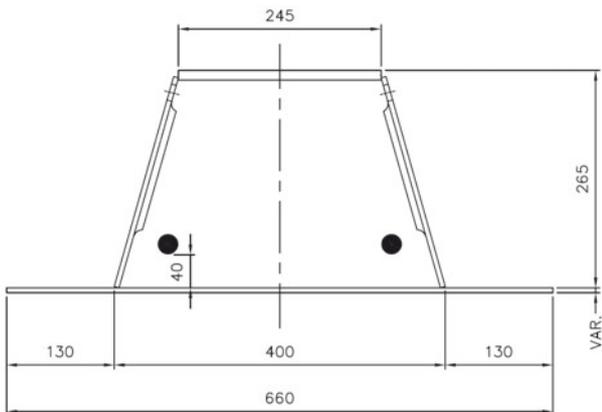


Figure 3 Cross section of edge Deltabeam

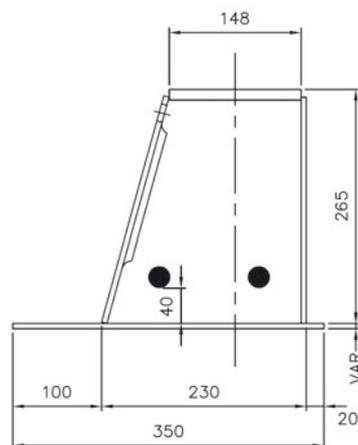
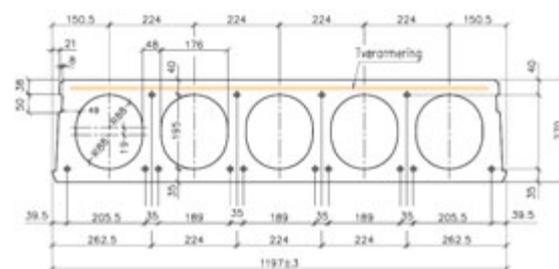


Figure 4 Cross section of hollow core slab



No top reinforcement or cross reinforcement of mild steel was supplied.

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 **figure 6**). This corresponds to a distance of $675 \text{ mm} = 2,5 \cdot H_{\text{slab}}$ 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 placed on the surface of the hollow core slabs – see **figure 7**.

The realistic behavior of the distribution plate is shown in **figure 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 shown in **figure 9**.

The applied loading in each of the four tests

The first test was carried out with a 60 minutes standard fire and 120 minutes of standard cooling phase. The loading on the hollow core slab applied by the pistons was $48,0 \text{ kN/m}$.

The mutual reaction between the slab (from one side) and the Deltabeam was calculated to be $38,7 \text{ kN/m}$ using a span width of 2350 mm of the slab between the theoretical 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 second test was carried out with a 60 minutes standard fire and 120 minutes of standard cooling phase. The loading on the hollow-core slab applied by the pistons was $57,6 \text{ kN/m}$.

The interactive reaction between the slab from one side and the Deltabeam was calculated to be 46 kN/m using a span width of 2350 mm of the slab between the theoretical supports on the bottom flanges of the Deltabeams.

The third test was carried out with a 120 minutes standard fire and 247 minutes of standard cooling phase. The loading on the hollow-core slab applied by the pistons is the same as in the first test.

The fourth test was carried out with a 180 minutes standard fire and no cooling phase. The loading on the hollow core slab applied by the pistons was $30,0 \text{ kN/m}$.

The interactive reaction between the slab from one side and the Deltabeam was calculated to be 26 kN/m using a span width of 2350 mm of the slab between the theoretical supports on the bottom flanges of the Deltabeams.

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 the expansion was possible because the relative movement between the specimen and the furnace frame 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.

Figure 6 Load application on the hollow core slabs

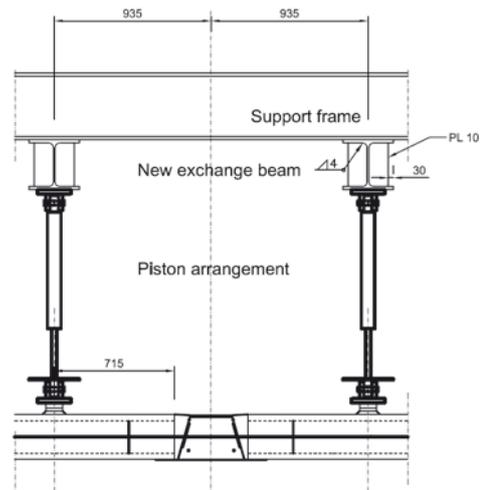


Figure 7 Distribution of the load transverse on the hollow core slabs

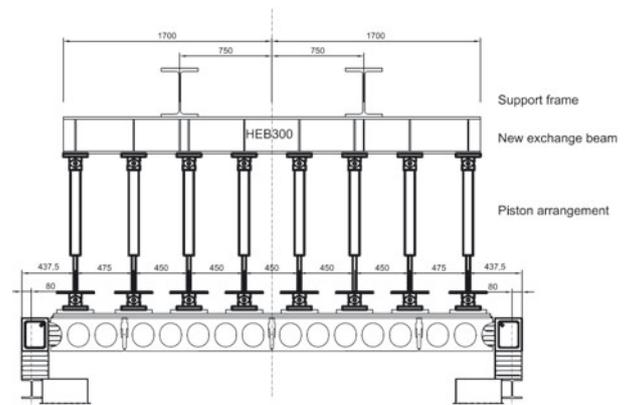


Figure 8 Deflection of the load distribution plate / transversal deflection of the test panel



Figure 9 Test arrangement



The full test loading was reached within a minimum of 15 minutes before the fire test started.

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

Test measurements

The test panel was produced with cast-in-situ instrumentation to measure temperatures 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.

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

Test results

All four tests were successful. The specimens did not fail, but maintained their load bearing capacity during the entire

test period, and they also preserved integrity and insulation capacity during the fire tests.

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

The temperature measured below the bottom of the test panel – see figure 10 – indicated the furnace temperature during the four fires; see **figure 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. In practice it was not possible to cool the interior of the furnace quicker than the speed shown.

The fire test 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.

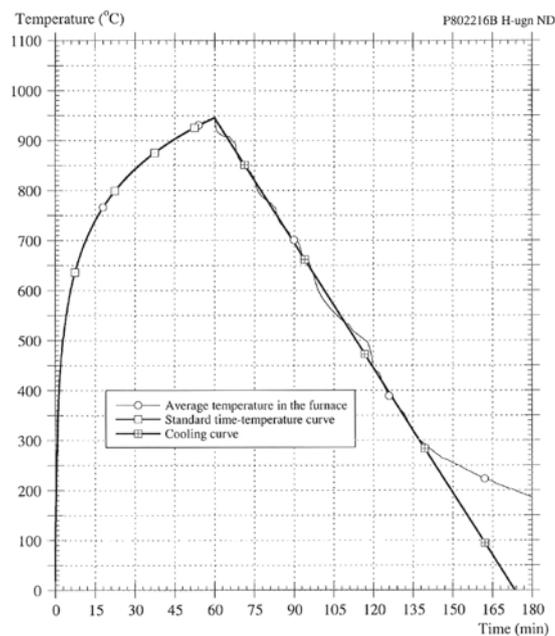
The deflection of the test panel was measured during the fire tests – see **figure 12**.

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 induced by the fire. The maximum fire induced deflection for the 60 minutes test was 82 mm for the slab and 75 mm for the Deltabeam.

Figure 10 Bottom of the main Deltabeam after 180 minutes of standard fire

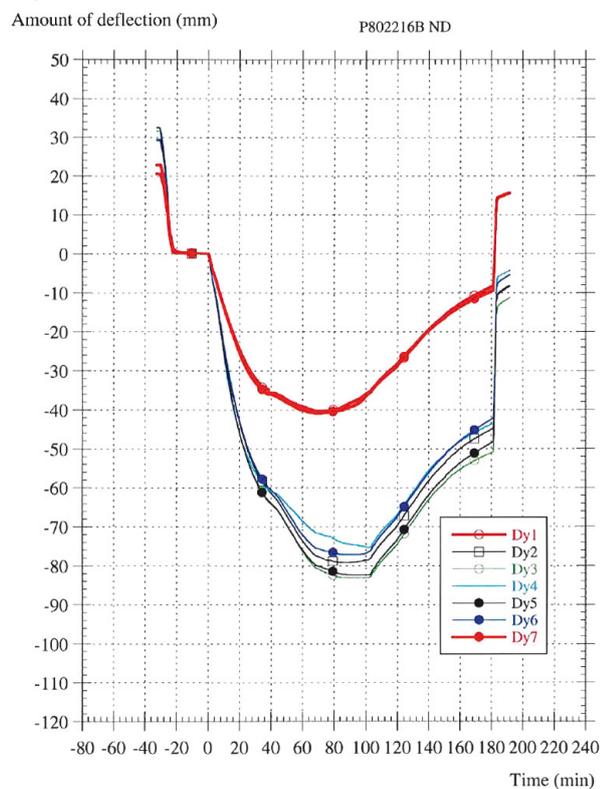


Figure 11 Temperature in furnace. 60 minutes fire test with cooling phase



Average temperature in the furnace in relation to the standard time-temperature curve and the time-temperature curve in the cooling phase

Figure 12 Measured deflections



Dy1, Dy7: Middle of edge Deltabeam
 Dy2, Dy6: Middle of hollow core slabs
 Dy3, Dy5: Middle of applied load
 Dy4: Middle of main Deltabeam

The corresponding values for the 120 minutes test were 145 mm and 110 mm respectively.

Concluding remarks

The Deltabeam was able to carry the load from the hollow-core slab during all 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 fire tests was practically zero due to the high temperatures.

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 expansion of the slab structure.

The applied load in the fire tests corresponds to uniformly distributed load situations on slab structures with 7,2 m or 9,6 m span as shown in the following table:

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

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

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 shear bearing capacity in a cold situation.

