Steel-fibre-only reinforced concrete in free suspended elevated slabs

As outlined in Concrete Society Technical Report 63[1], over the last 15 years the total replacement of all traditional reinforcement by steel fibres has become completely routine in applications such as industrial and commercial suspended slabs on piles. More recently, the structural use of steel-fibre-only reinforcement at a high dosage rate has been developed as the sole method of reinforcement for fully elevated suspended slabs, which span from 5m to 8m in each direction.

Xavier Destrée, ArcelorMittal Bissen, Bissen, Luxembourg

This novel solution, called TAB-Slab, has been patented by ArcelorMittal Bissen. To date, 65 multi-storey buildings have been completed incorporating TAB-Slab solutions where each level consists of a steel-fibre-only reinforced concrete flat slab spanning from column to column without drop panels and beams. However, TAB-Slabs include anti-progressive collapse (APC) reinforcement running from column to column in the *x* and *y* directions.

Two full-scale slabs were tested at Bissen (2004) and Tallinn (2007) to investigate the structural behaviour during the elastic and plastic phases of structural SFRC in elevated slab applications[2].

Figure 1: Placing a TAB-Slab concrete at LKS site in Mondragon (Spain).

Mix design

The concrete[3] is typically C30–37, with a minimum 350kg/m³ CEM I or III; water: cement ratio <0.50, a 0–16mm aggregate grading; and with 70kg/m³ of HE+1/60 steel fibres (1475MPa drawn wire hooked end, 1mm diameter and 60mm long) or 100kg/m³ of TABIX 1.3/50 steel fibres (850MPa drawn wire undulated fibre, 1.3mm diameter and 50mm long). The result is a F6 flowing concrete that is pumpable and does not need any poker vibration during installation (Figure 1), leading to significant time and cost savings.

Full-scale testing

The square flat slabs tested in Bissen and Tallinn consisted of three spans in each direction (6m × 6m × 0.20m thick; and 5m × 5m × 0.18m thick respectively). The slabs were simply supported on 300mm × 300mm columns.

First a uniformly distributed load (UDL) of 3–6kN/m² was imposed in both checkerboard and orthogonal row patterns as shown in Figure 2. The slab remained fully elastic with deflections <5mm with no significant increase after seven days under load.

Figure 2: Checker board loading pattern of the Bissen test slab.

Point loads were then imposed on the centre, edge and corner spans to load the slab to ultimate, see Figure 3.

Figure 4 shows a load vs deflection plot from the Tallinn test. The load was increased to 340kN and then removed before reloading to ultimate. The first crack appeared at 125kN and 4mm deflection. The maximum load reached was 600kN, with cracking only on the bottom of the slab.

A load of 240kN was needed to cause a deflection of 10mm (span/500), almost three times the calculated value. The global safety factor of the TAB-Slab was 600/80 = 7.5 when maximum service and ultimate loads were compared. As shown in Figure 5, this very high safety factor results from the extreme ductility of the slab. Thousands of micro-cracks of 0.1–0.3mm form around the supports, then later join to form larger macro-cracks of up to 3.5mm at 480kN so that a yield line pattern forms to reach the ultimate load of 600kN or more.

Design method

The design method involves both elastic and plastic calculations to check the serviceability and the ultimate capacity[3,4]. At service-

Figure 3: Point loading of the corner span of the Tallinn test slab.

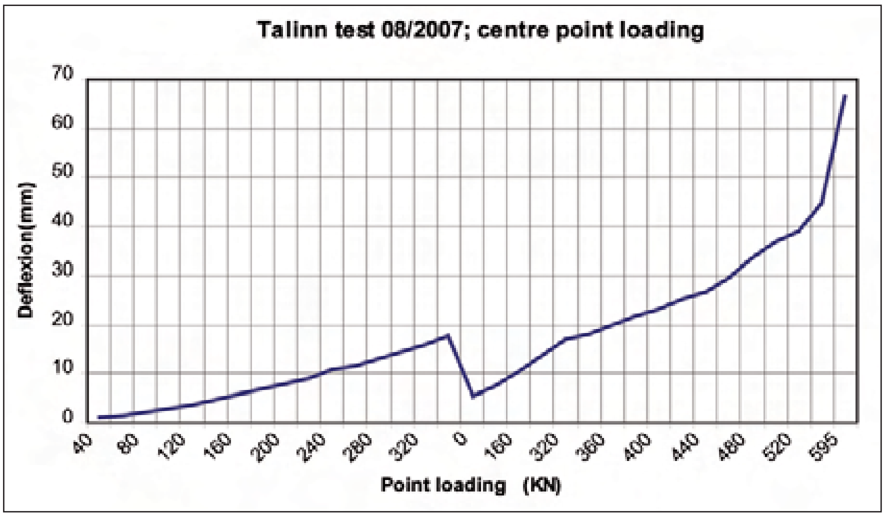

Figure 4: Load vs deflection for the Tallinn slab.

ability, under unfactored load, the maximum bending stress using traditional elastic analysis methods is limited to 5MPa so that the slab does not crack.

At ultimate, Johansen yield line method is used, as justified by the full-scale testing. The internal equilibrium of rotation along a yield line is such that:

$$M_L = 0.45 \times f_{tu} \times h^2$$

where f_{tu} is the plastic tensile strength of the cracked section, determined from round indeterminate slabs under point loading as shown in Figure 6.

The equilibrium of rotation of one circular sector between two adjacent yield lines(3) gives:

$$P_{ultimate} = 2\pi M_L$$

Table 1 (opposite page) gives back-calculated values of f_{tu} as a function of dosage rates and types of fibre(4). A long-term factor is already included as the whole scatter of results is taken into account.

The design approach is described in References 3 and 4.

Deflections

Deflections are negligible in most cases since the span to depth ratio is always smaller than 30 and that the maximum service bending stress is limited to 5MPa. The maximum long-term deflection of TAB-Slab is in most cases less than span/1000.

Punching

Numerous punching tests have been carried on 200mm-thick slabs with no failures occurring even under a point load of 600kN. Failure only occurred, at a stress of 3.2MPa, when 60% of the slab along the critical perimeter at the very edge of the slab had been removed.

Typical examples of completed TAB-Slabs

Among the 65 TAB-slabs completed so far, there are examples of multi-storey residential buildings, multi-storey offices, commercial buildings such as superstores and shopping malls, schools, detached and semi-detached houses, industrial plants, parking garage slabs and roof slabs.

Ditton Nams shopping mall in Daugavspils (Latvia)

This project is an extension of a shopping mall. The ground-level slab is a fully suspended elevated flat slab 42.5m × 24m up to 7m clear span. A 250mm TAB-Slab has been installed as shown in Figure 8. After completion, the slab was loaded up to the maximum service load of 7kN/m^2, typical for a superstore where full pallets of food and non-food products are frequent. The maximum deflection recorded was 1.9mm, far less than predicted by the finite-element software.

LKS office building, Mondragon (Spain)

This building, with five suspended levels, includes more than 4000m^2 of offices for a structural engineering firm. The column grid is up to 8.30m × 8.30m and the loading 4–8kN/m^2.The 280mm-thick TAB Slabs are flat plates with 100kg/m^3 of TABIX 1.3/50 steel fibres as the only reinforcement. Four APC 20mm-diameter reinforcing bars are needed in each span. Around the staircases and lift shafts some additional bottom reinforcing has been provided. Cantilever balcony reinforcement includes a top mesh above the supports for safety reasons, in case an accidental cold joint forms during pouring.

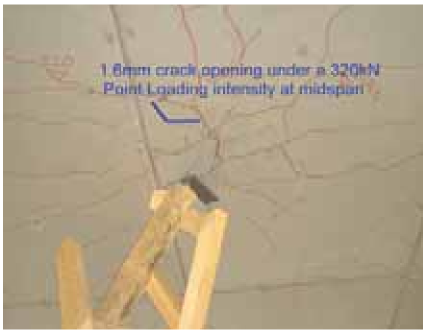

Figure 5: View of the cracking pattern of the Tallinn test slab under a 320kN point load, equivalent to four times the service load.

Figure 6: Round slab test set-up (left) and typical fan pattern cracking (right).

Table 1 – Values of f_{tu} from round slab tests

Fibre type and dosage	f_{tu} (MPa)	Diameter and thickness
70kg/m³ TABIX + 1/60	2.30	1500mm × 150mm
100kg/m³ TABIX13/50	2.30	1500mm × 150mm

forms during pouring. The steel fibres alone provide the hogging moment. The whole TAB-Slab project has been controlled by the Polytechnic University of Bilbao.

Sixteen-storey Rocca Tower in Tallinn (Estonia)

Each floor is of about 550m² and has a curved triangular shape as shown in Figure 10. Columns or walls are up to 7m apart. The slab is 210mm thick and includes 100kg/m³ TABIX13/50 as the only reinforcement.

Traditional double fabric reinforcement has been retained between the lift shafts in order to ensure that horizontal forces are transmitted under all circumstances. Here the APC reinforcement consisted of five T20mm bars running in both directions between the supporting columns or walls. The TAB-Slab concrete was easily pumped up to the highest level. Each level was poured continuously without joints. Construction was quite rapid at a rate of one TAB-Slab floor per week for most of the project. ■

References:

1. THE CONCRETE SOCIETY. *Guidance for the design of steel-fibre-reinforced concrete.* Technical Report 63, The Concrete Society, Camberley, 2007.
2. DESTRÉE, X. Free suspended elevated slabs of steel fibre reinforced concrete: full-scale test results and design, *Proceedings Seventh RILEM Symposium on fibre reinforced concrete*, Chennai, India, pp.941–950.
3. DESTRÉE, X. Structural application of steel fibres as only reinforcing in free suspended elevated slabs: conditions, design, examples, *Proceedings Sixth RILEM Symposium on fibre reinforced concrete*, Varenna, Italy, pp.1073–1082.
4. SORANAKOM, C, MOBASHER, B and DESTRÉE, X. Elevated slabs with steel fibre reinforced concrete: numerical simulation of FRC round panel tests and full-scale elevated slabs, *Deflection and stiffness issues in FRC and thin structural elements,* ACI SP-248, pp.31– 40.

Figure 7: Punching test with 50% of the critical perimeter removed.

Figure 8: A 250mm TAB Slab being poured at Ditton Nams shopping mall project (Daugavspils, Latvia). APC bottom reinforcement from column to column is visible.

Figure 9: LKS office building with TAB-Slab pouring in progress; APC reinforcement is also visible.

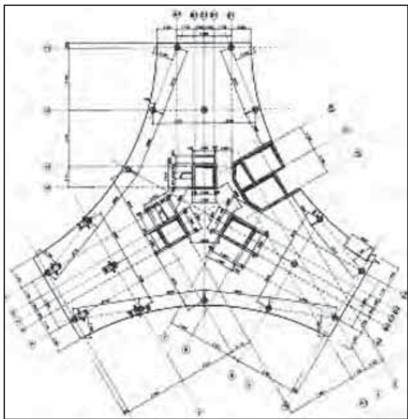

Figure 10 left: Typical floor of the Rocca Tower.

Figure 11 left: Typical floor preparation before pouring and showing APC bottom reinforcement running from column to column.

Figure 12 right: Rocca Tower – TAB-Slabs and concrete frame partially completed.