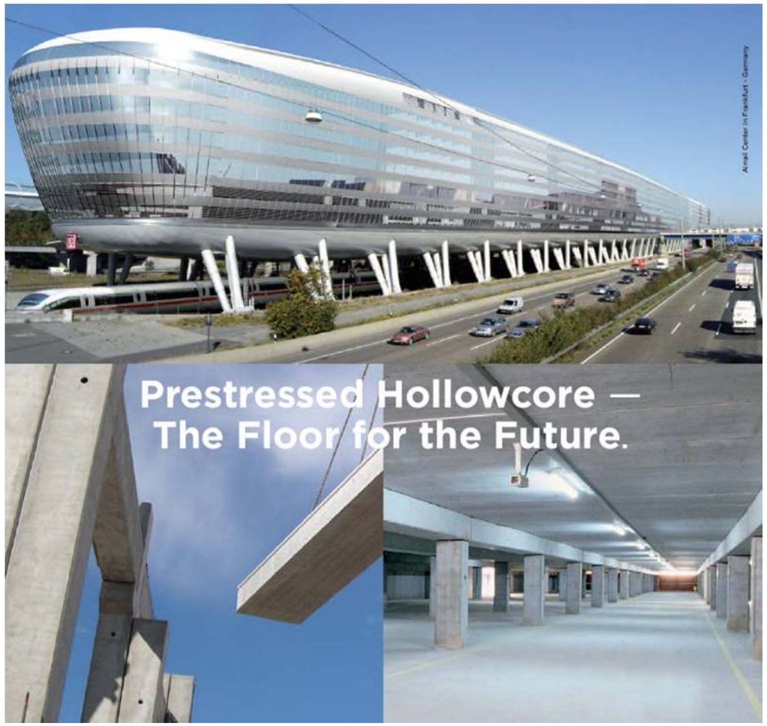
INTERNATIONAL PRESTRESSED HOLLOWCORE ASSOCIATION

Transversal load distribution

and

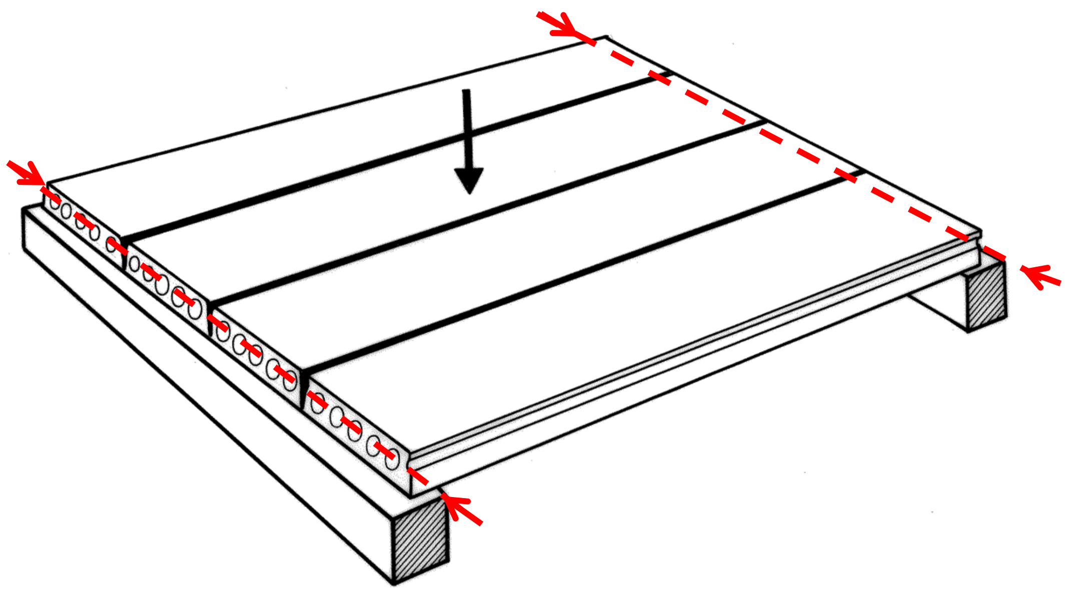
Large openings

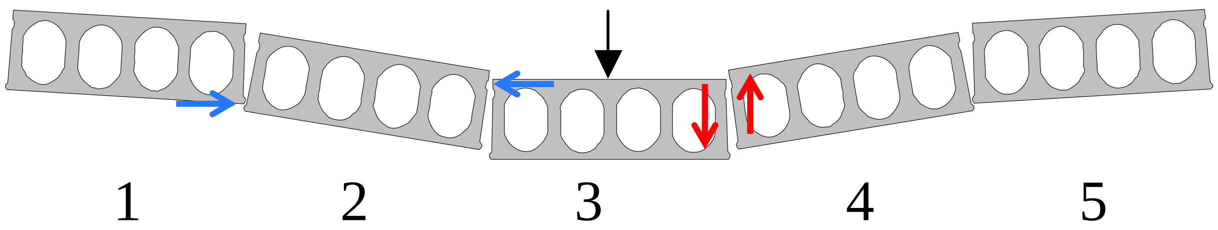


Arnold Van Acker

Transverse load distribution

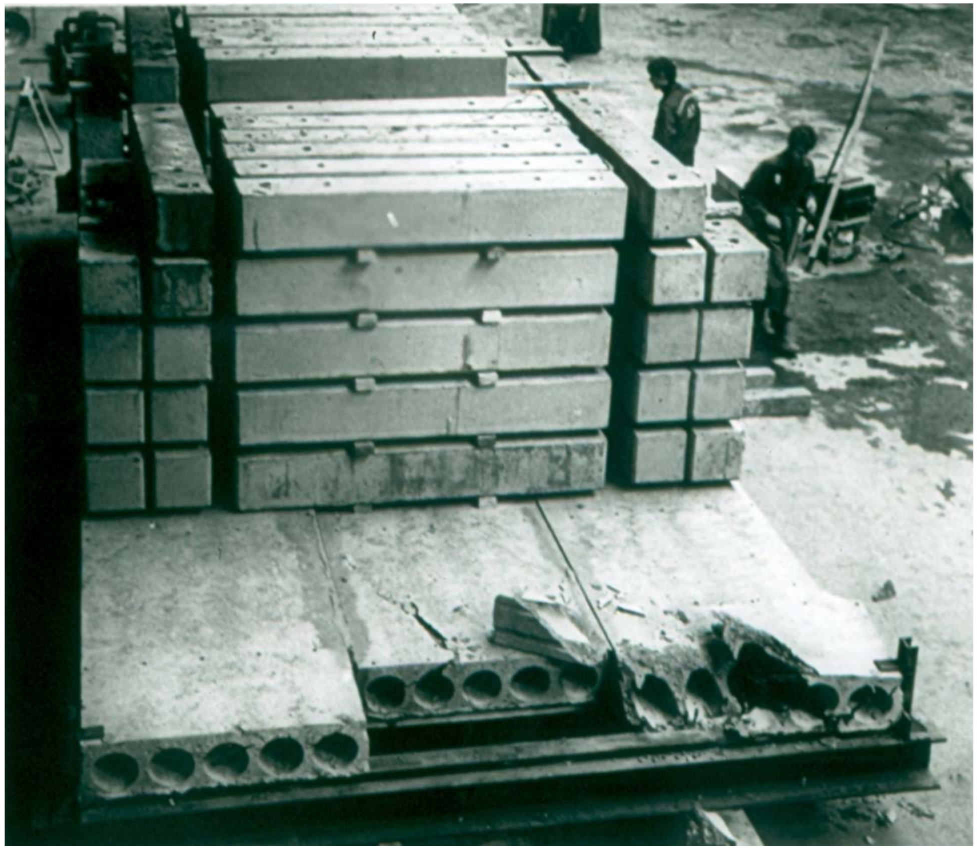
- Principle





Historical review

- Test KG Bernander Strängbetong (1970 ?)



Background guidelines EN 1168

- Research programme FEBE Belgium
  - Load distribution tests University LLN
    - Concentrated load at the floor centre
    - Concentrated load at the floor edge
  - Analytical analysis Somers - AVA

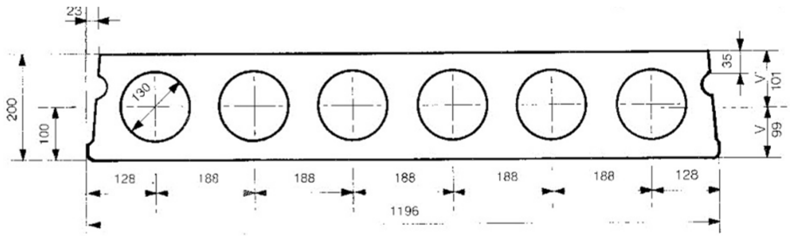
Load distribution tests (1977)

- Test programme

a) Load test single floor unit
  - Failure at 86,25 kN, deflection 370 mm

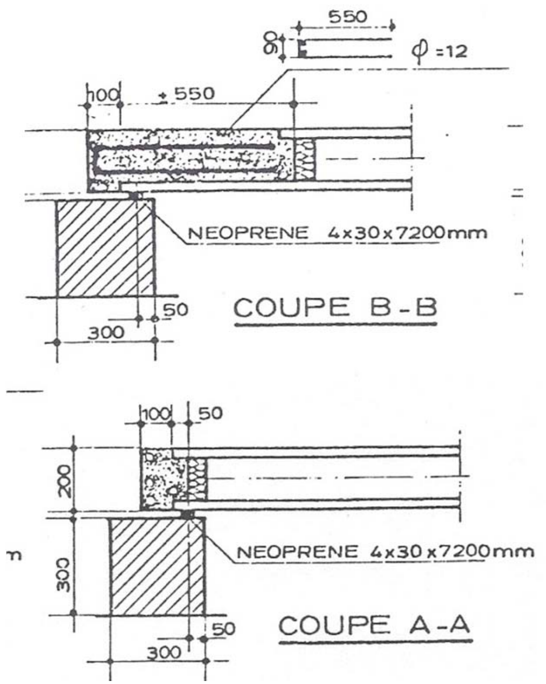
b) Load at the floor centre
  - Deflection under static load up to 64 kN
  - Dynamic tests : 200.000 load cycles between 32 and 48 kN
  - Loading up to failure

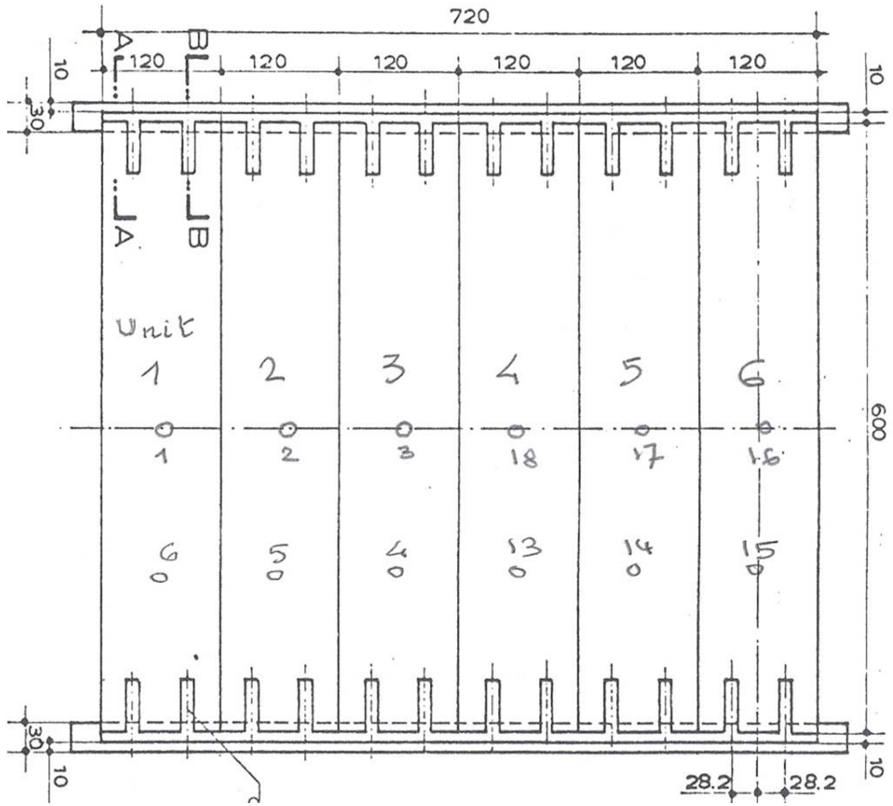
c) Load at the floor edge
  - Deflection under static load up to 64 kN



Load distribution tests

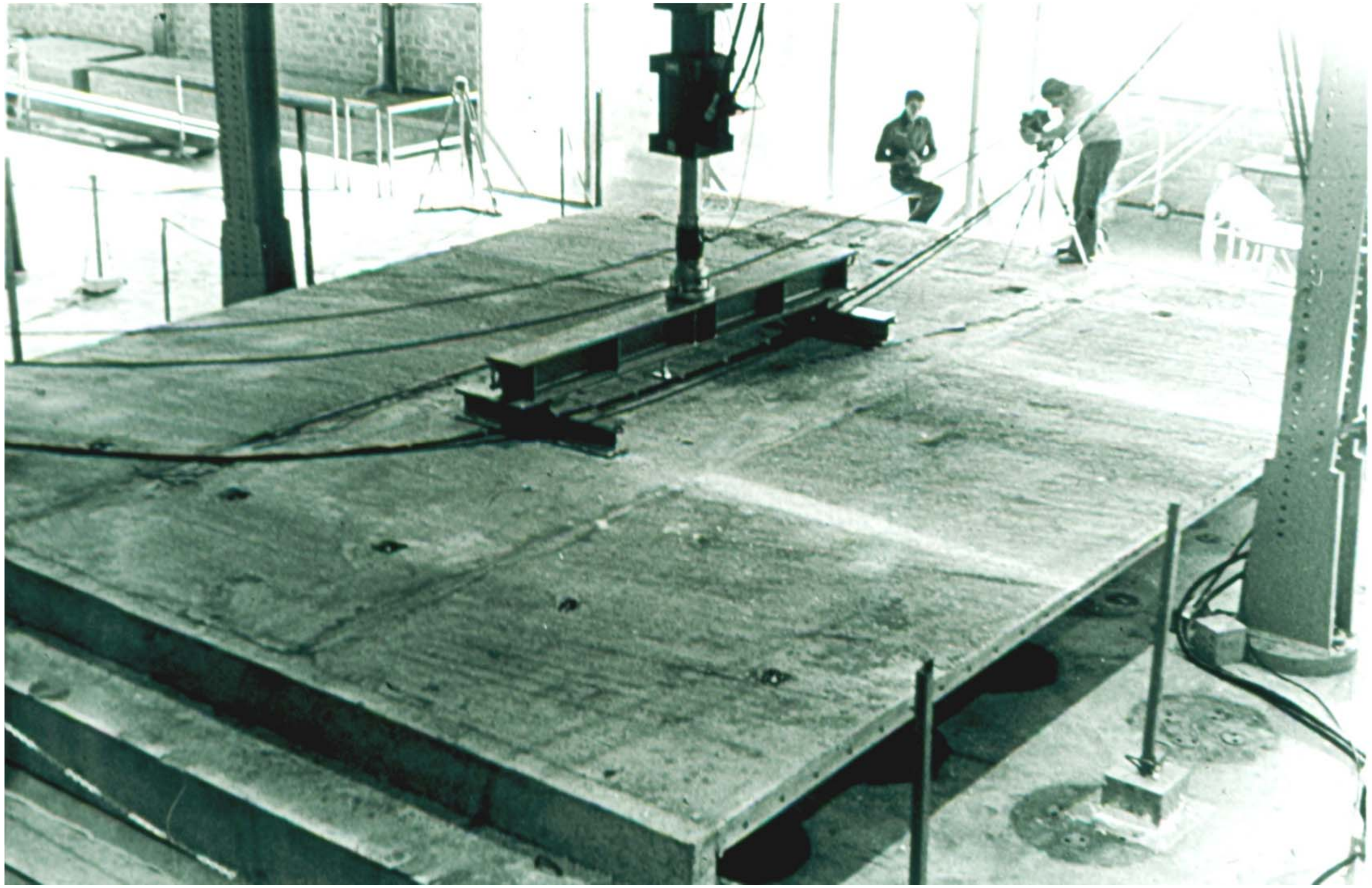
- Test set-up University LLN Belgium





Test floor composed of 6 HC slabs of 200 mm thickness and 6,00 m span

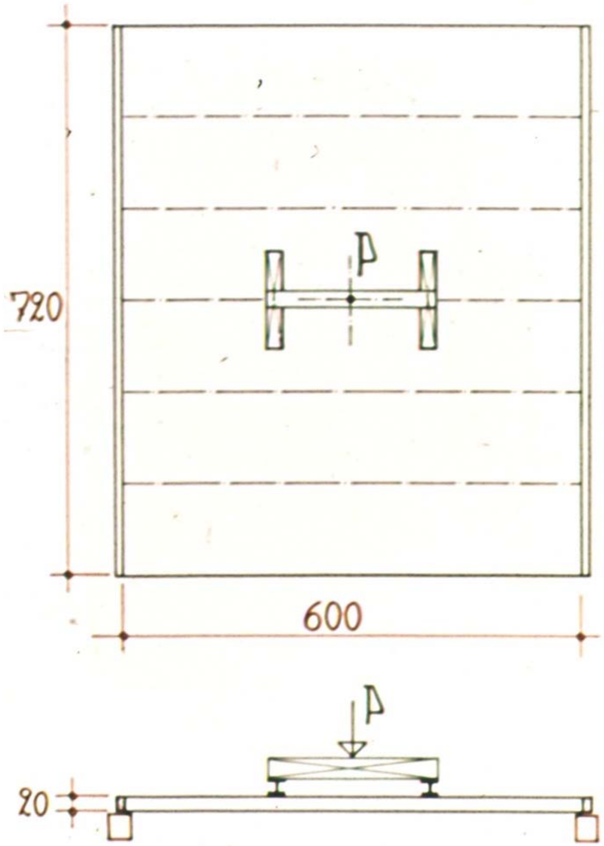
Load distribution tests

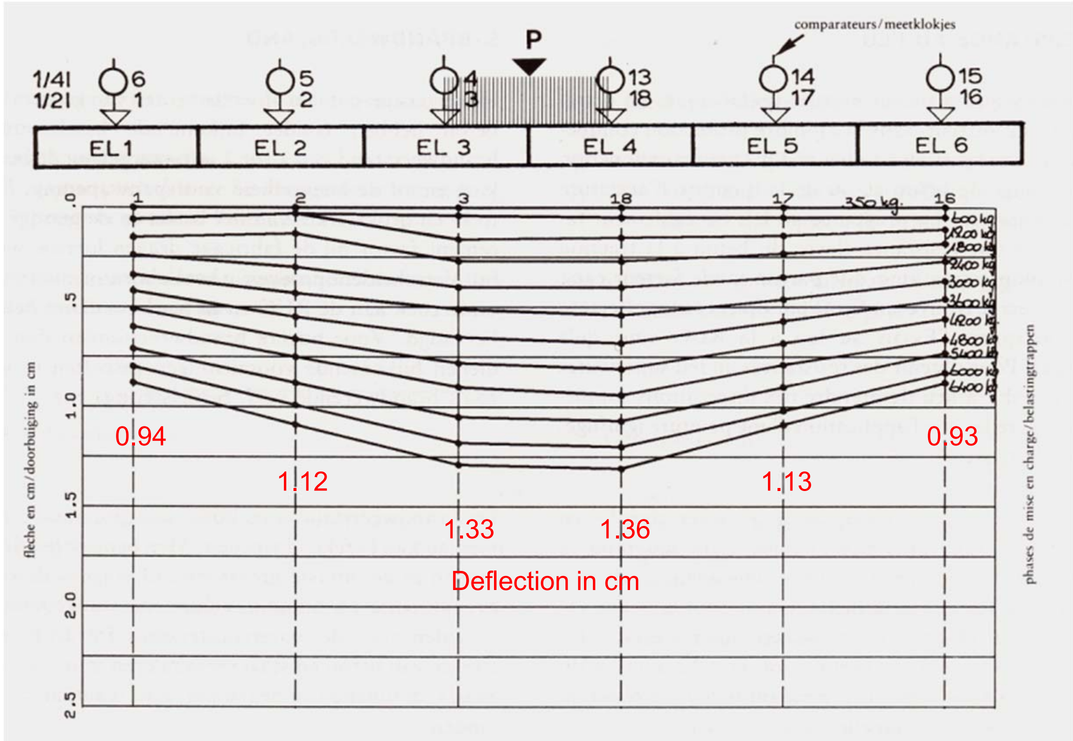


Example of similar test set-up for ribbed floors

Load at the floor center

- Static test

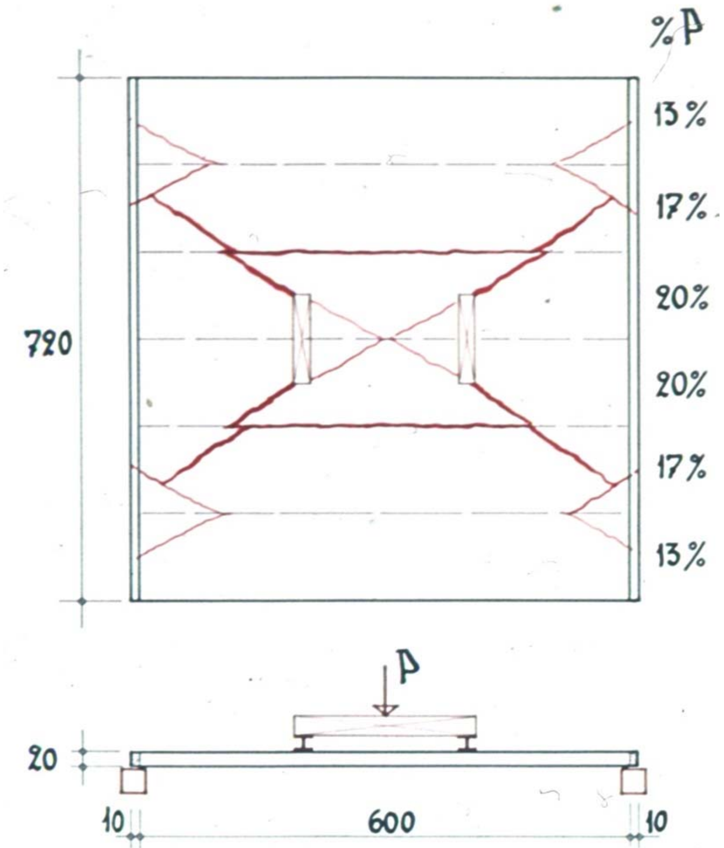




Step by step increase of load up to 64 kN

Load at the floor center

- Loading till failure

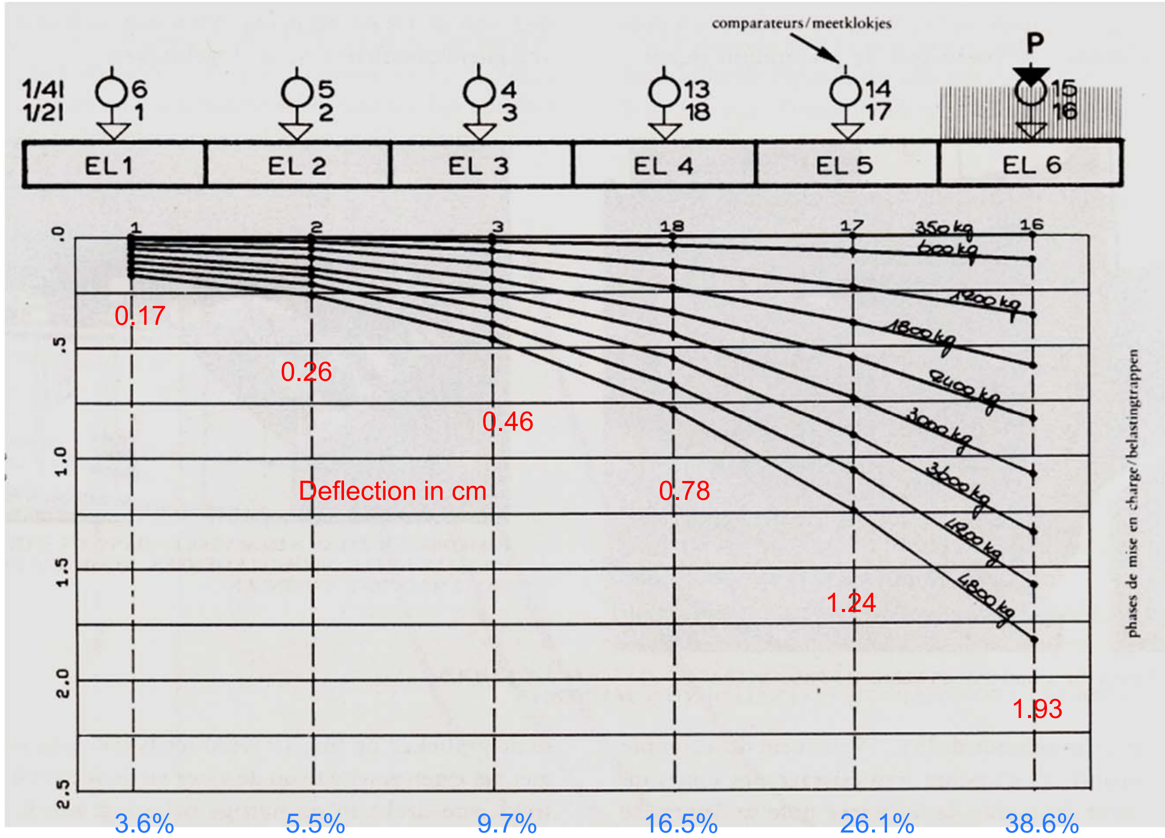


Load (kN)	Deflection mm
3.50	0
92.00	2
128.00	3
156.00	4
191.75	5
225.60	6
255.00	7
280.00	8
300.00	9
310.00	10
337.50	failure

Load steps and deflection at the floor centre in mm

Load at the floor edge

- Static test up to 48 kN



Load distribution in % of total concentrated load

Calculation programme (1982)

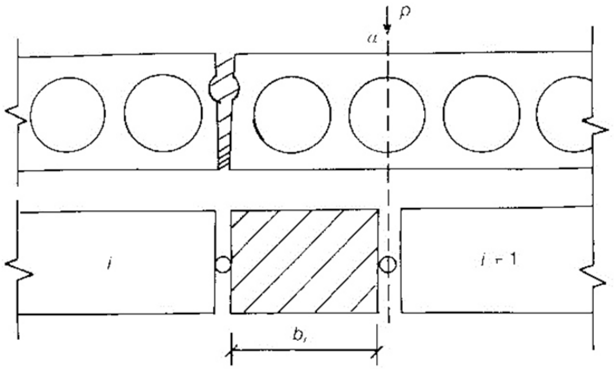
- Calculation model based on Fourrier analysis

General assumptions

The distribution is calculated on the basis of the theory of isotropic slabs assuming the compatibility condition of the longitudinal and transversal deflection of the floor elements at their joints. It is also assumed that the longitudinal joints behave in the manner of longitudinal hinges, i.e. they cannot transmit bending moments, but only shear forces.

A mathematical calculation based on Fourrier analysis has been carried out for the general case of a floor composed of an unlimited number of floor elements of various widths, one of them carrying a concentrated loading.

The theory has been applied on a system of five floor slabs, connected by hinged joints. The loaded element is laterally supported by the adjacent slabs through the joints. Between the two hinges, tensile stresses will occur at the bottom of the loaded slab unit. They are maximum at the place of the linear load, and equal to zero at the joints. At the ULS, the slab is assumed to be cracked right through at the location of the linear load, or at the nearest core. It is further assumed that the crack cannot transmit any bending moment, but only shear forces, just as for the longitudinal joints between the elements.



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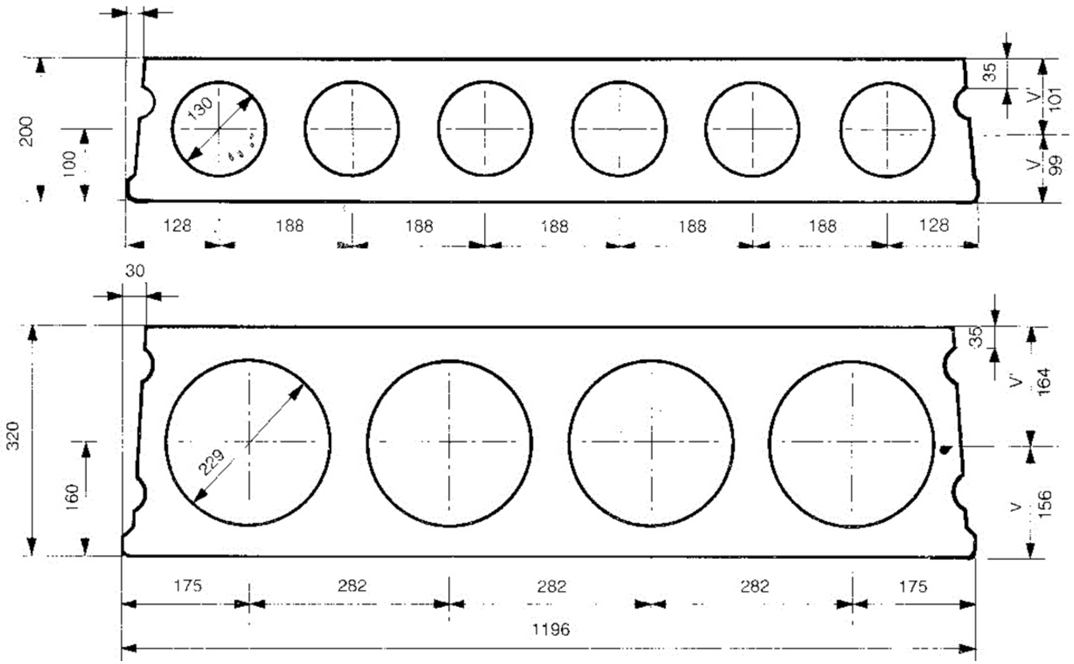
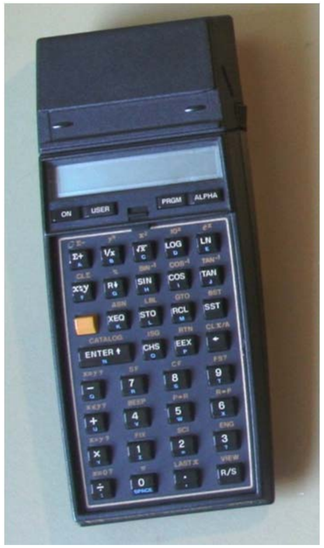
Practical calculations

- Software programme (ERGON)
- More than 100 calculations on HP pocket calculator
  - HC 150, 200, 265 and 320
  - Various span lengths
  - 20 minutes for each calculation





Comparison with test results

- Concentrated loading at the edge floor unit

Floor of 6 units						
Test results for P = 1,5 x service load	38,17	26,65	16,84	9,59	5,33	3,41
Calculation results without crack in the loaded unit	36,56	26,10	15,76	9,82	5,68	5,16

Floor of 5 units					
Calculation results without crack in the loaded unit	37,04	26,58	16,56	11,10	8,71
Calculation results with crack in the loaded unit	39,17	25,69	16,00	10,73	8,41

Load distribution in % of linear concentrated load

Comparison with test results

- Concentrated line load at the second floor unit

Floor of 6 units						
Test results for P = 2,0 x service load	26,26	24,63	19,73	13,50	9,35	6,53
Calculation results without crack in the loaded unit	26,05	25,75	20,69	12,53	8,40	6,58

Floor of 5 units					
Calculation results without crack in the loaded unit	26,58	27,02	21,13	14,16	11,10
Calculation results with crack in the loaded unit	25,89	29,32	20,39	13,67	10,72

Load distribution in % of linear concentrated load

Comparison with test results

- Concentrated loading at the third or central floor unit

Floor of 6 units						
Test results for P = 2,0 x service load	17,34	19,69	20,78	17,97	13,59	10,62
Calculation results without crack in the loaded unit	15,76	20,11	23,02	18,76	12,53	9,82

Floor of 5 units					
Calculation results without crack in the loaded unit	12,56	21,13	24,62	21,13	12,56
Calculation results with crack in the loaded unit	16,04	20,46	27,00	20,46	16,04

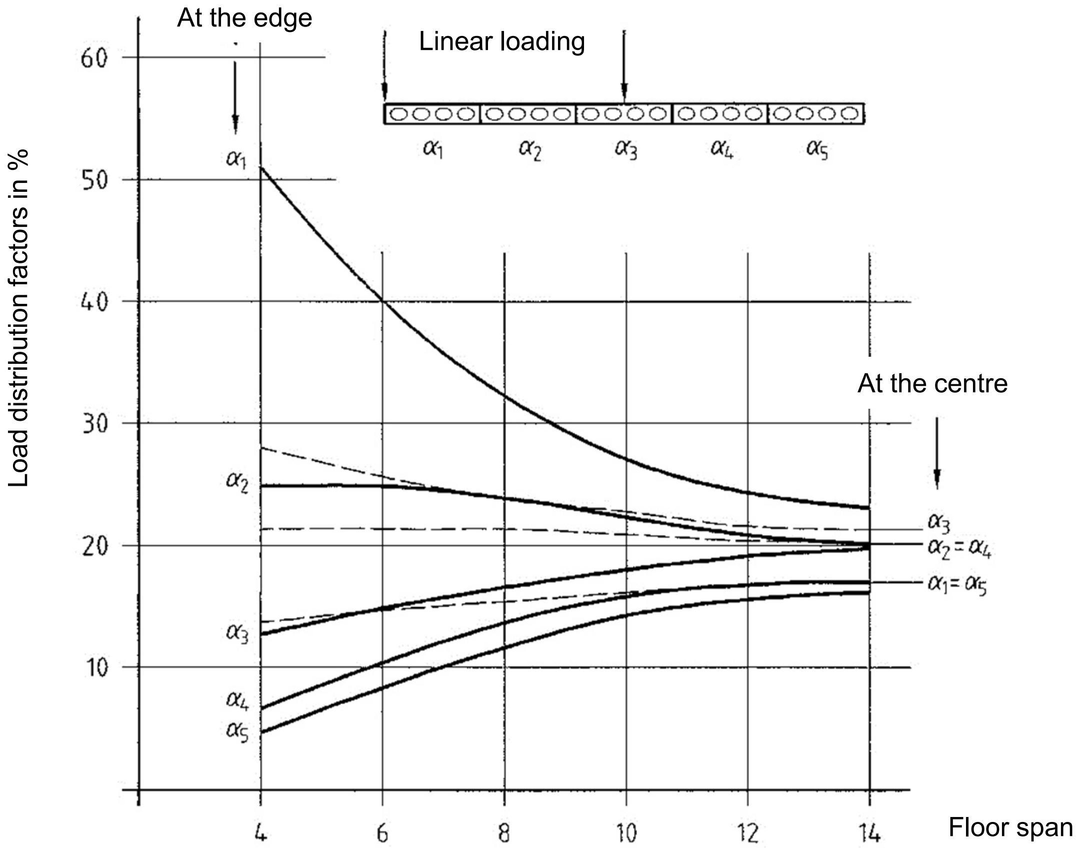
Comparison with test results

- Concentrated loading across the central joint

Floor of 6 units						
Test results for P = 0,9 x service load	13,01	15,45	20,33	19,92	17,89	13,41
Test results for P = 2,0 x service load	13,98	16,24	19,45	20,58	16,56	13,18
Test results for P = 2,6 x service load	13,64	16,08	19,98	20,34	16,57	13,40
Calculation results without crack in the units	11,97	15,26	22,70	22,70	15,26	11,97

Load distribution curves

- Curves published in FIP Recommendations 1988



An additional safety margin of 25% has been applied on the directly loaded unit

Load distribution factors for linear loads (without topping)

Tests on 400 mm slabs, VTT Finland (1991)

- Test programme

a) Two tests on 400 mm HC floors without topping
   - Four HC slabs of 6.00 m span
   - Six HC slabs of 12.00 m span
   - 5 loading cycles with service load located at L/6
   - Loading at floor centre up to failure

b) Load at the floor edge
   - 5 loading cycles with service load located at L/6
   - Loading at floor centre up to failure

c) Measurements: deflection + support reaction

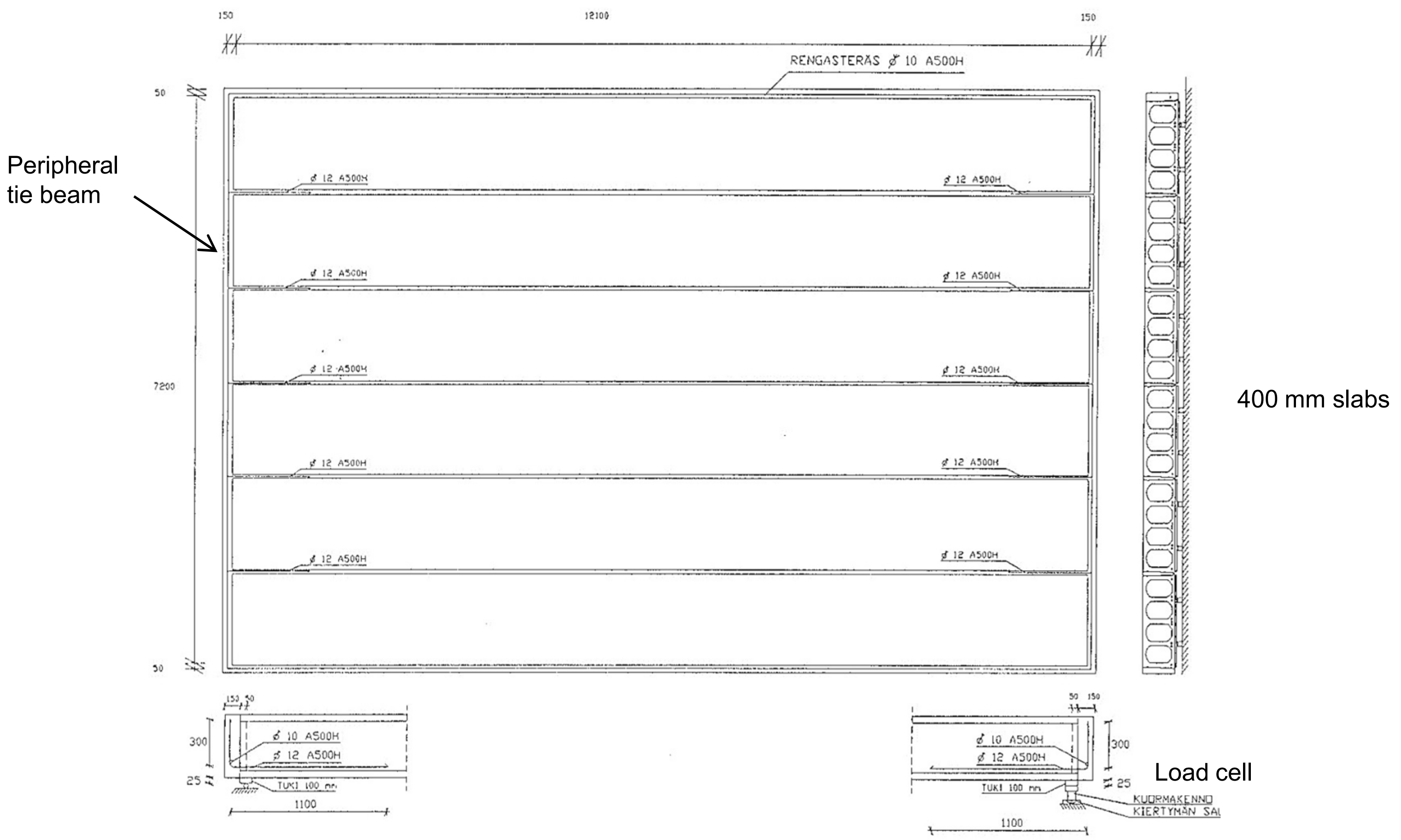
d) Comparison with FIP curves

(including additional safety of 25% on the most loaded unit)

Study sponsored by IPHA, Partek Concrete, Finnmap and Lohja Betonila
Presented at IECA conference 1991 in Paris

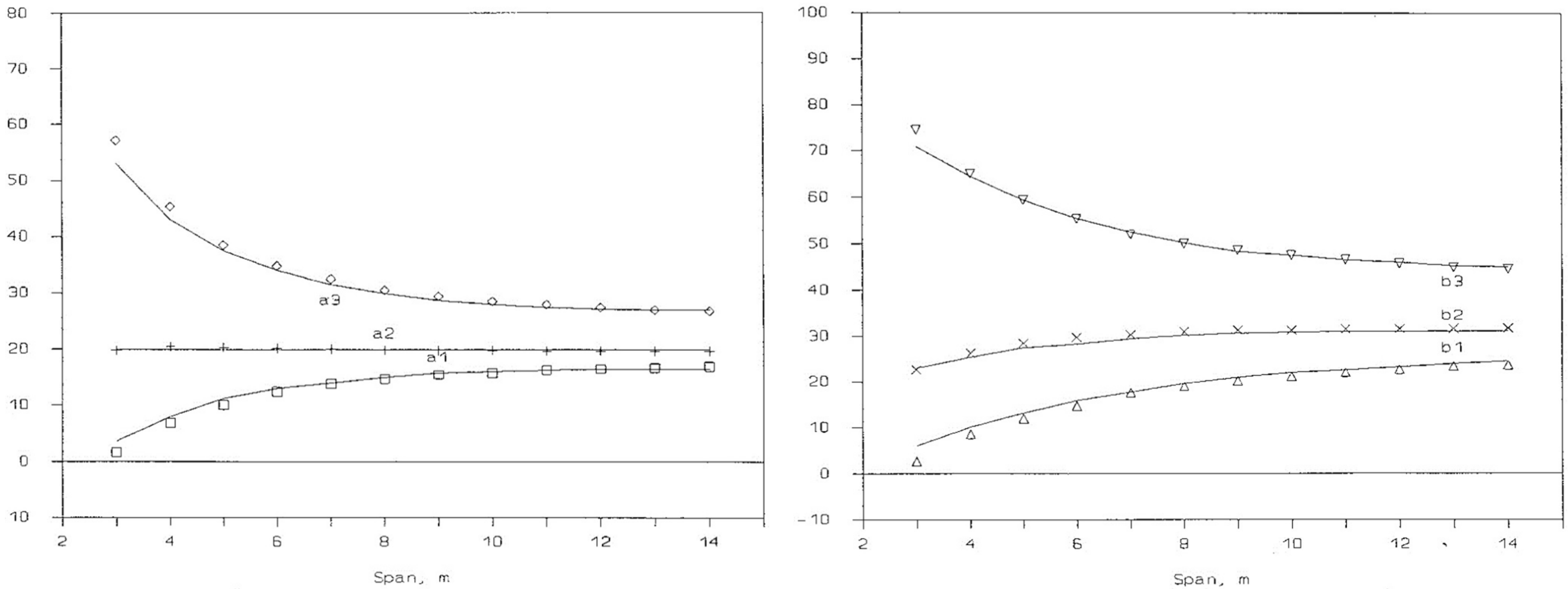
Tests at VTT

- Test set-up floor 12 m span



Load distribution factors

- Comparison with FIP curves



Legend: continuous line: FIP

+ / △ / ▽ : VTT

Bending moment distribution factors

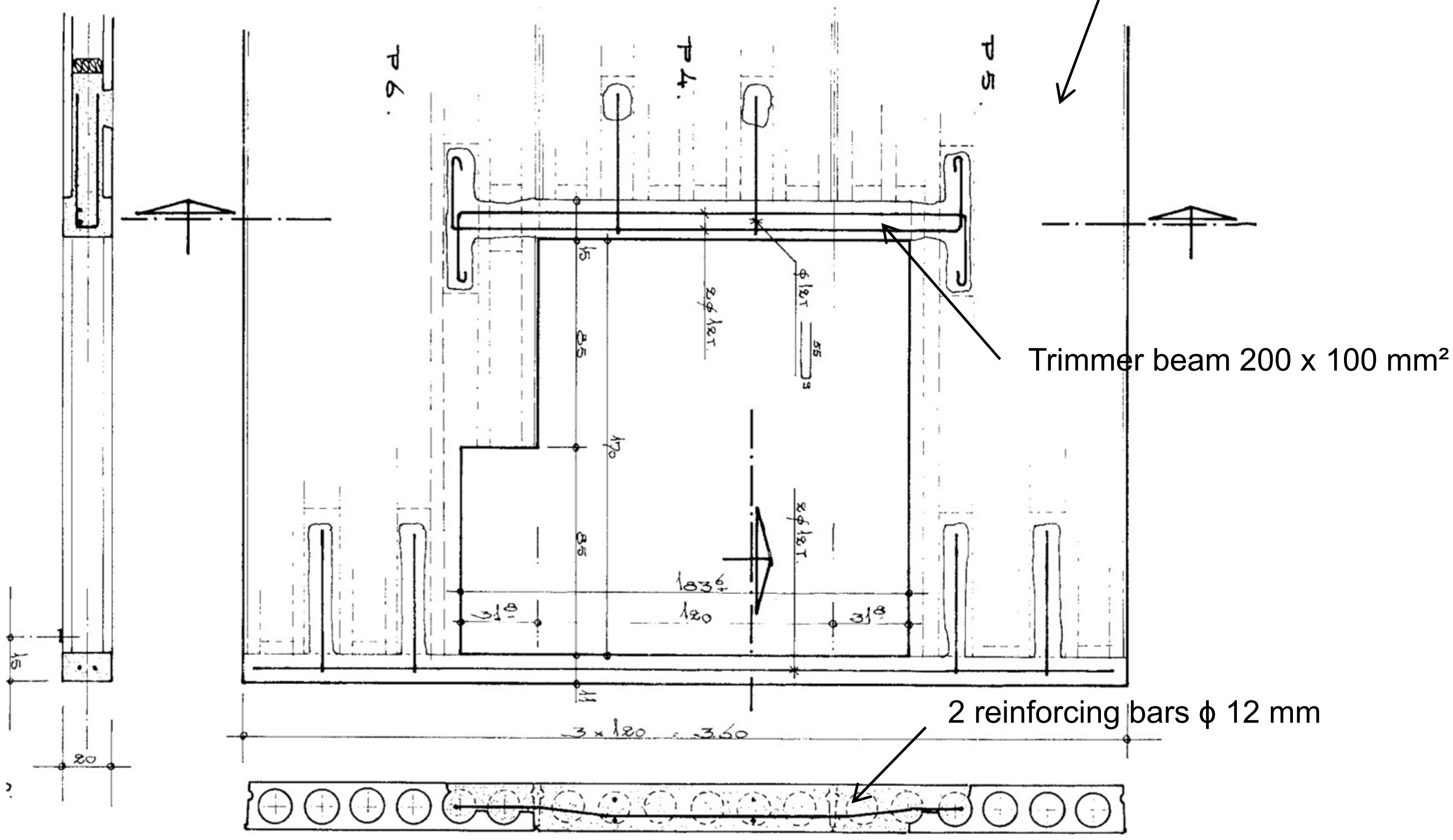
Large floor openings

- Tests carried out at CBR laboratory, Belgium (1976)

Three test were carried out on floor slabs of 3,60 m x 8,00 m surface with a large opening in the supporting zone.

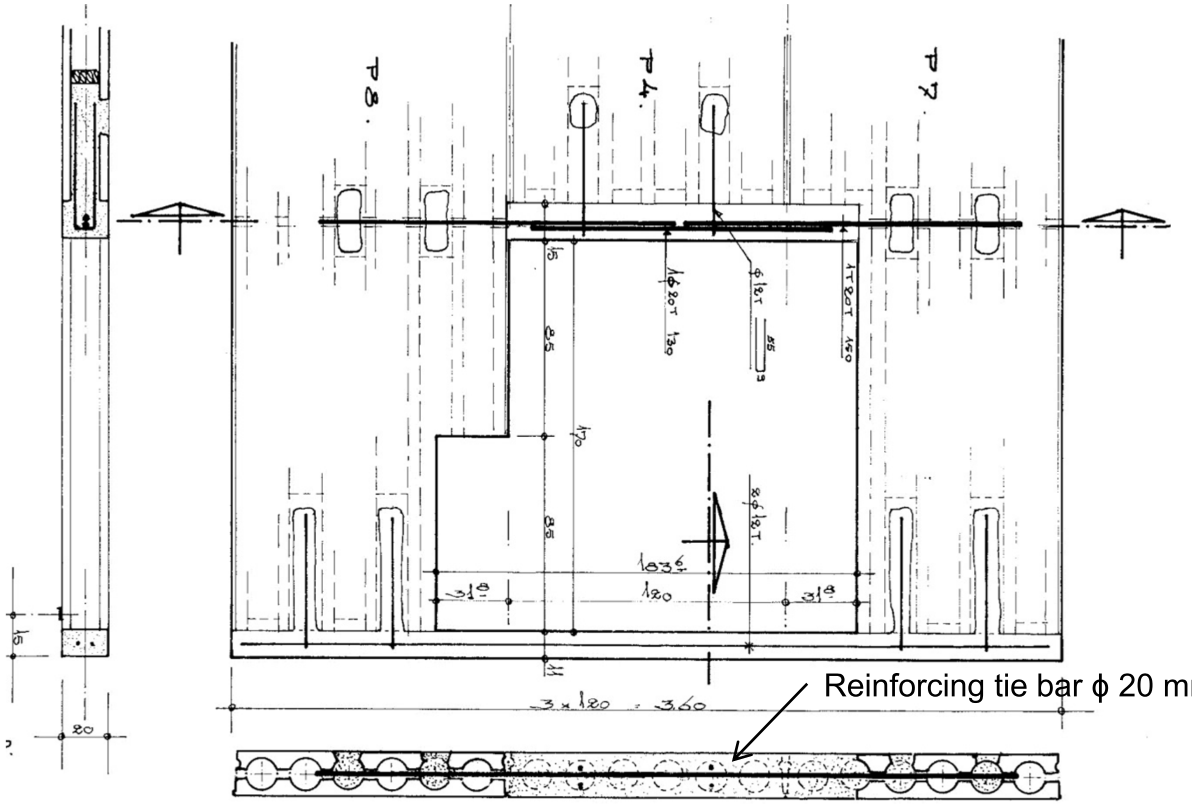
- Test N° 1: Opening 1,80 m x 1,70 m, trimmer beam in reinforced concrete, anchored in the two adjoining units
- Test N° 2: Opening 1,80 m x 1,70 m, trimmer beam in reinforced concrete, anchored in the two adjoining units by means of tensile bars ϕ 20
- Test N° 3: Opening 1,20 m x 1,20 m, steel trimmer beam, welded to steel plates anchored in the two adjacent slab units

Test N° 1



Opening 1,80 m x 1,70 m, trimmer beam in reinforced concreter anchored in the two adjacent units

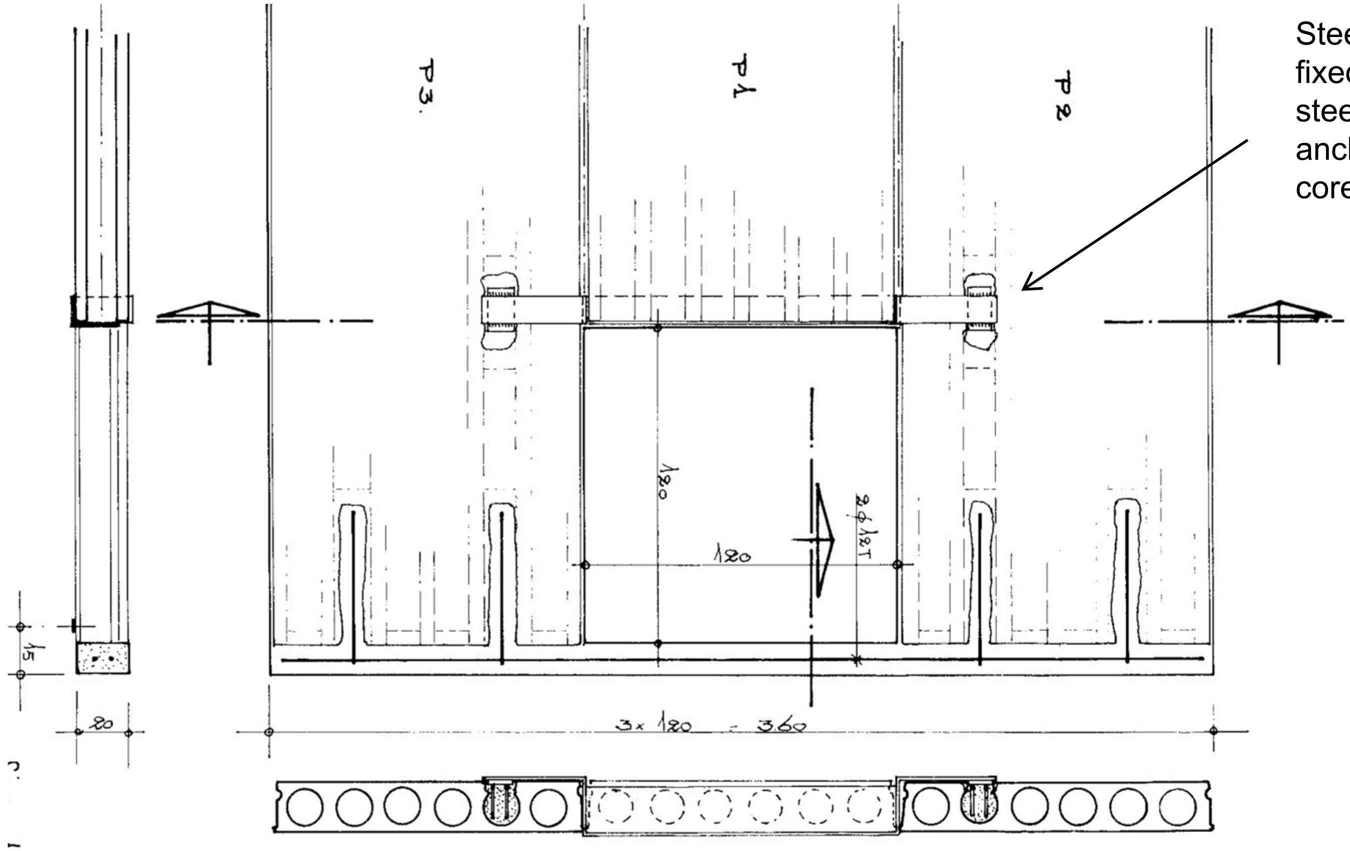
Test N° 2



Opening 1,80 m x 1,70 m, trimmer beam in reinforced concreter anchored in the two adjacent units by means of a tensile bar ϕ 20

Test N° 3

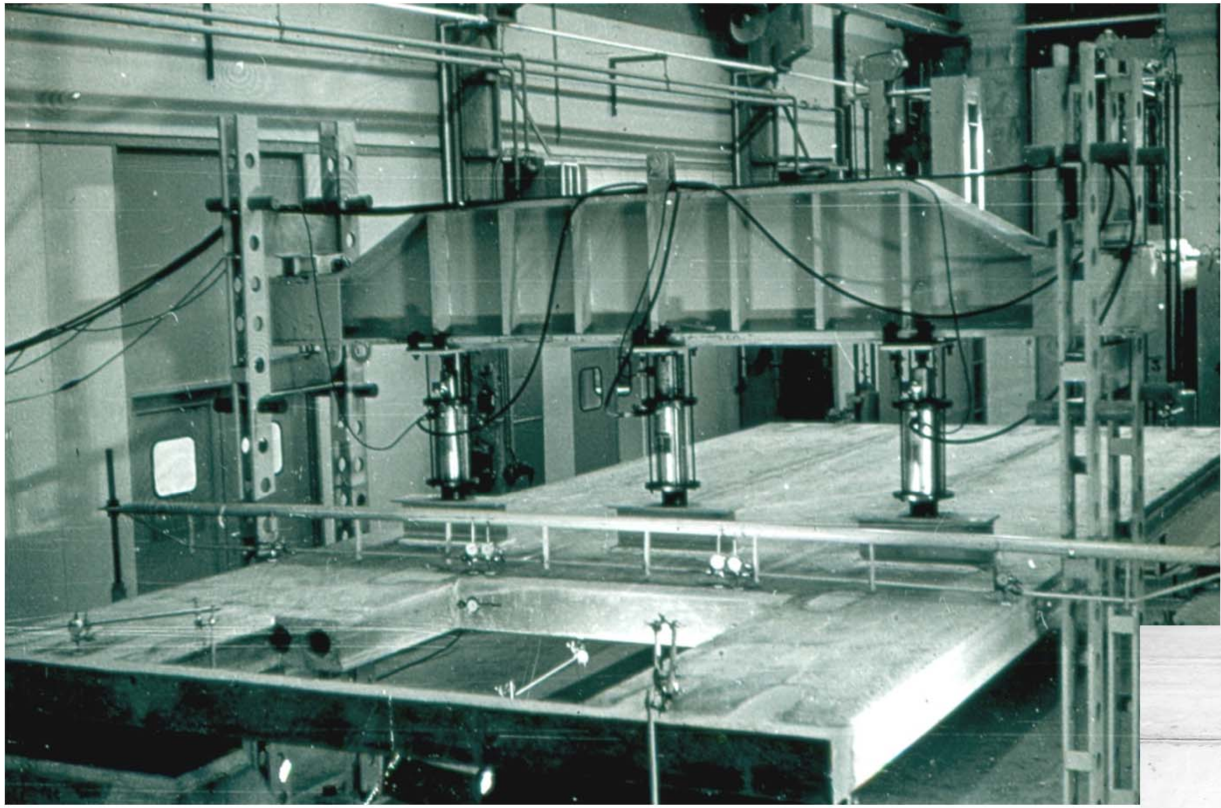
Trimmer beam composed of vertical plate 180 x 8 x 1206 mm,
welded to a horizontal folded plate 100 x 6 mm

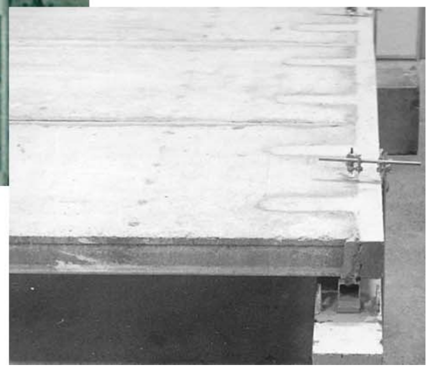


Steel trimmer beam fixed by welding to steel plates anchored in filled cores

Opening 1,20 m x 1,20 m, steel trimmer beam, welded to supports
anchored in the two adjacent slab units

Test set-up



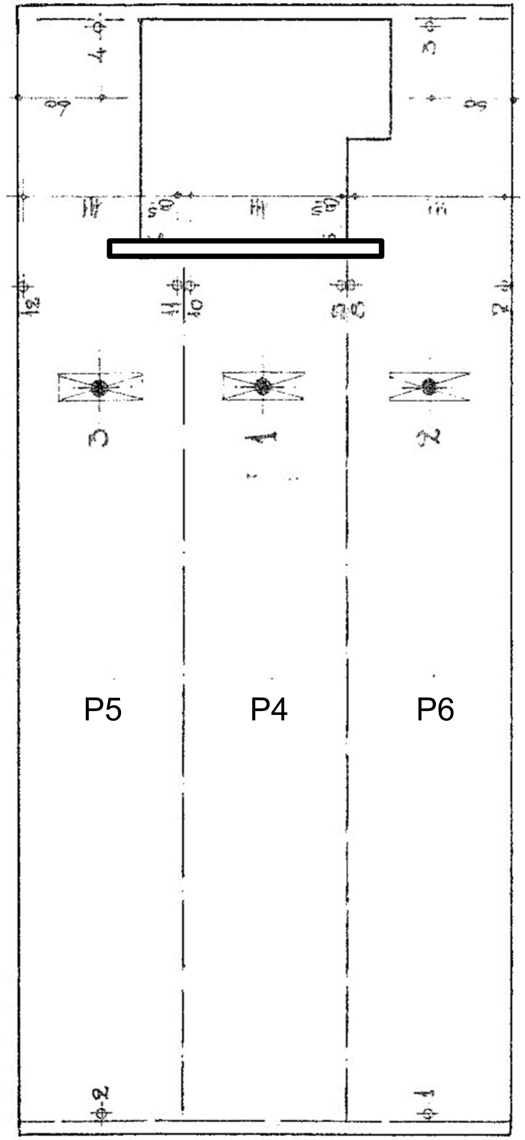


Test N° 1 with opening 1,80 m x 1,70 m and trimmer beam
in reinforced concreter anchored in the two adjacent units

Test N° 1

- Loading steps

Load (kN)		Observations
Lateral units	Central unit	
0	0	Start
15.5	15.5	Maximum service load
15.5	37.0	Theoretical cracking load for the whole floor
15.5	44.0	
15.5	60.00	First crack at the corner of slab n° 5
15.5	± 80.00	Transversal cracks from opening corner to slab edges
15.5	88.00	Longitudinal cracks in the outer slabs starting from the anchor zones of the trimmer beam in slab n° 6
		Failure in the anchorage of the trimmer beam in slab N° 6.



Test N° 1

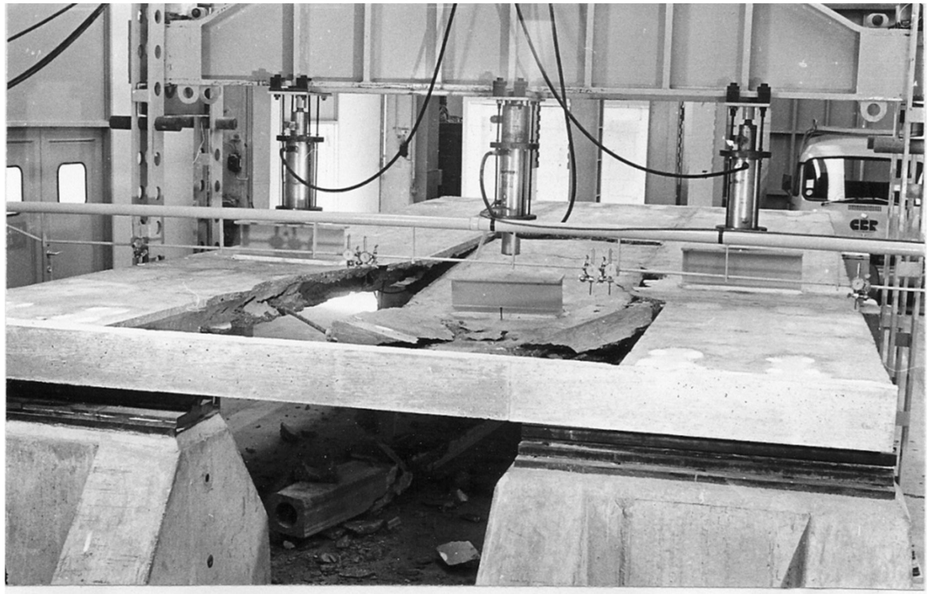
- Failure pattern

- Failure for 88 kN jack force on central slab.
- Maximum allowable imposed floor loading: 5.60 kN/m²
- Corresponding load on trimmer beam: 5.60 kN/m² + 3.25 kN/m² self weight = ½ (8.85 kN/m² x 1,80 x 5,33) = 42.5 kN

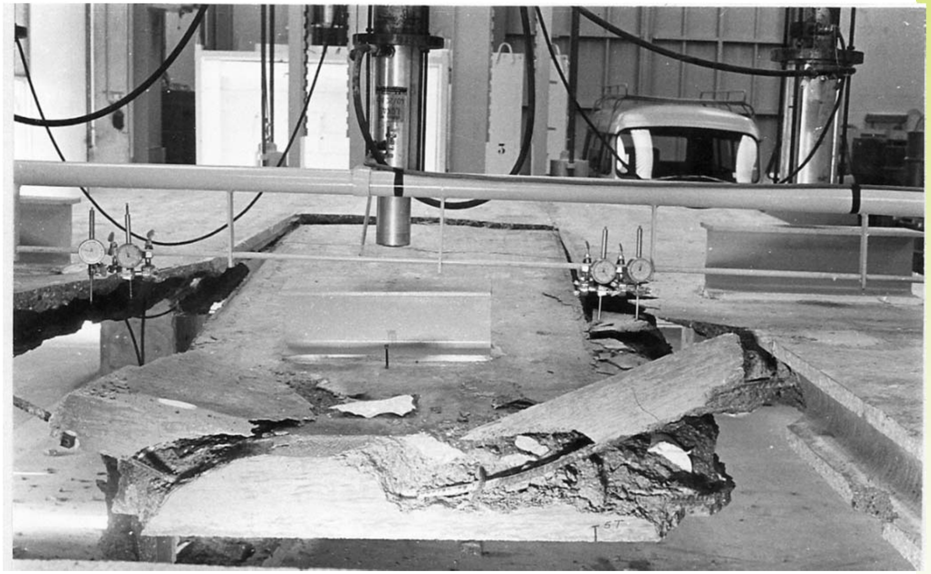
Test N° 1 with opening 1,80 m x 1,70 m and trimmer beam
in reinforced concreter anchored in the two adjacent units

Test N° 2

- Failure pattern



Bending failure load whole floor = 96 kN on central slab.



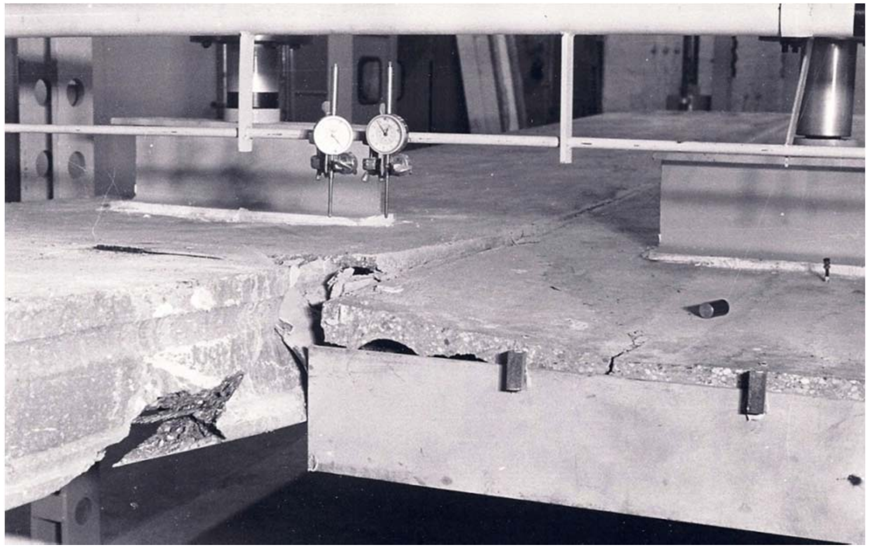
Opening 1,80 m x 1,70 m, trimmer beam in reinforced concreter anchored in the two adjacent units by means of a tensile bar ϕ 20

Test N° 6

- Loading steps

Load (kN)		Observations
Lateral units	Central unit	
0	0	Start
41.00	44.00	Small cracks at the corners of the opening e = 4 to 6/100 mm
43.00	37.00	Service load edge slabs
43.00	50.00	Crack opening 10/100 mm
43.00	53.00	Cracking load edge slabs
43.00	60.00	Several transversal cracks starting from trimmer beam
43.00	80.00	Numerous transversal cracks; no deformation of trimmer beam
43.00	110.00	Deformation of trimmer beam
43.00	120.00	Crushing of exterior void under support of trimmer beam
43.00	127.00	The anchorages of the trimmer beam in the supporting slabs are gradually being pulled out. The trimmer beam is heavily deformed and carries hardly the middle slab unit. The latter ones still caries the jack load as a cantilevering slab.
43.00	137.00	The central slabs gets broken under negative moment. The anchorages of the trimmer beam are completely extracted, but the central unit is not really collapsing. The failure mode is very slow.

Test N° 3



Bending failure load whole floor = 13,7 t on central slab.
Maximum allowable imposed floor loading: 560 kg/m²
Corresponding load on trimmer beam: 560 kg/m² + 325 kg/m² self weight is: ½ (885 kg/m² x 1,20 x 5,33) = 2,83 t

Opening 1,20 m x 1,20 m, steel trimmer beam, welded to supports anchored in the two adjacent slab units

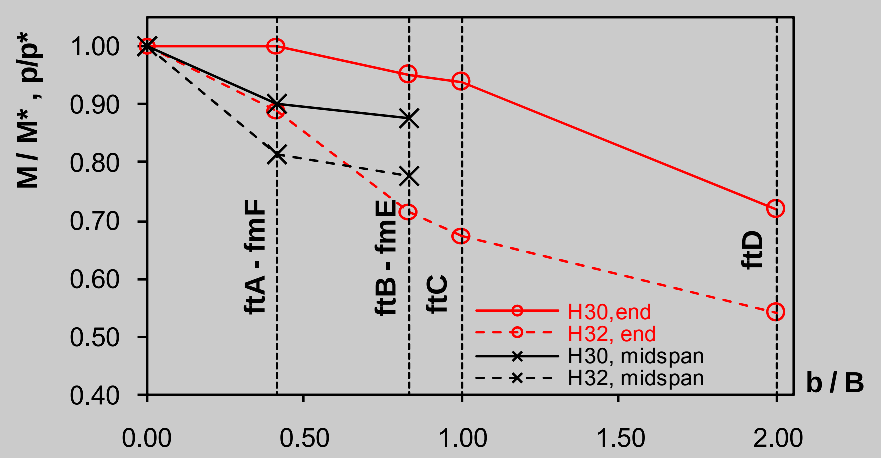
Conclusions

- In all tests, the joints have transmitted a considerable part of the load. This was demonstrate by the equal deformation of each slab unit near the load.
- The initial cracks in tests 1 and 2 started from the corner of the opening in the edge slabs, and not at the support of the trimmer beam.
- At failure, the joints were broken over a length going from 0,8m to 1,5 m
- The bearing capacity of the trimmer beam construction is more than the double of the acting load for tests 1 and 2, and about 4,8 times higher in test 3.

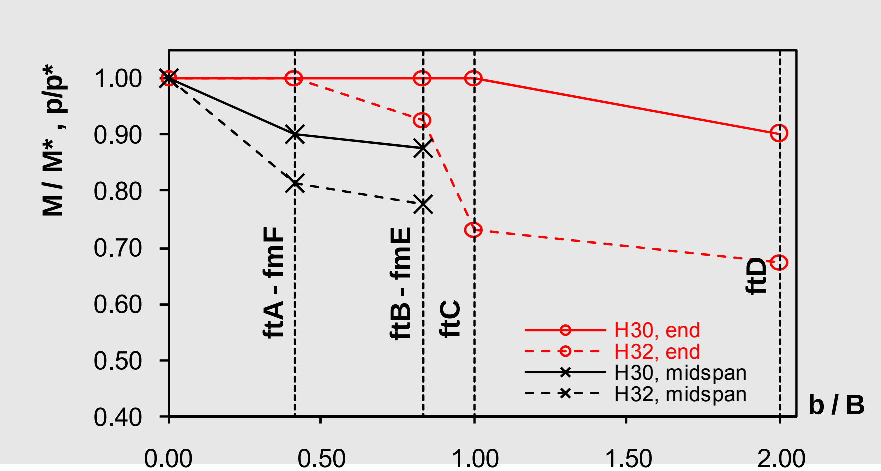
Parametric study on HC floors with large openings
Example of design charts

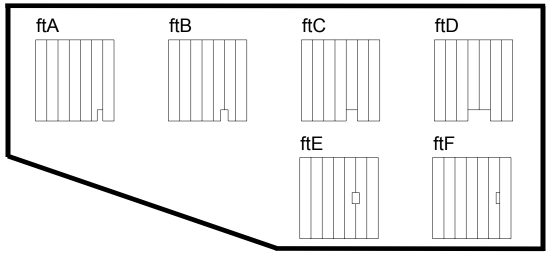
H30-H32 untopped floors, H/L = 1/35, imposed service load 10 kN/m²

Without concrete fillings

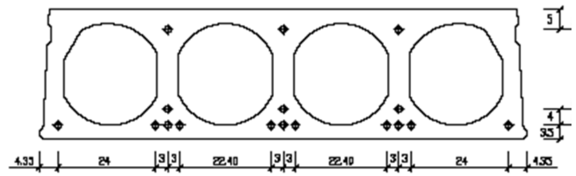


With concrete fillings





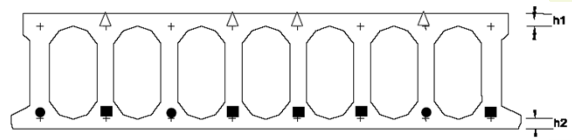
H32



$A_{p,sup}$ = 279 mm²
$A_{p,inf}$ = 1302 mm²

$M_{rd,H32}$ = 424.79 kNm

H30



$A_{p,sup}$ = 84.84 mm²
$A_{p,inf}$ = 974 mm²

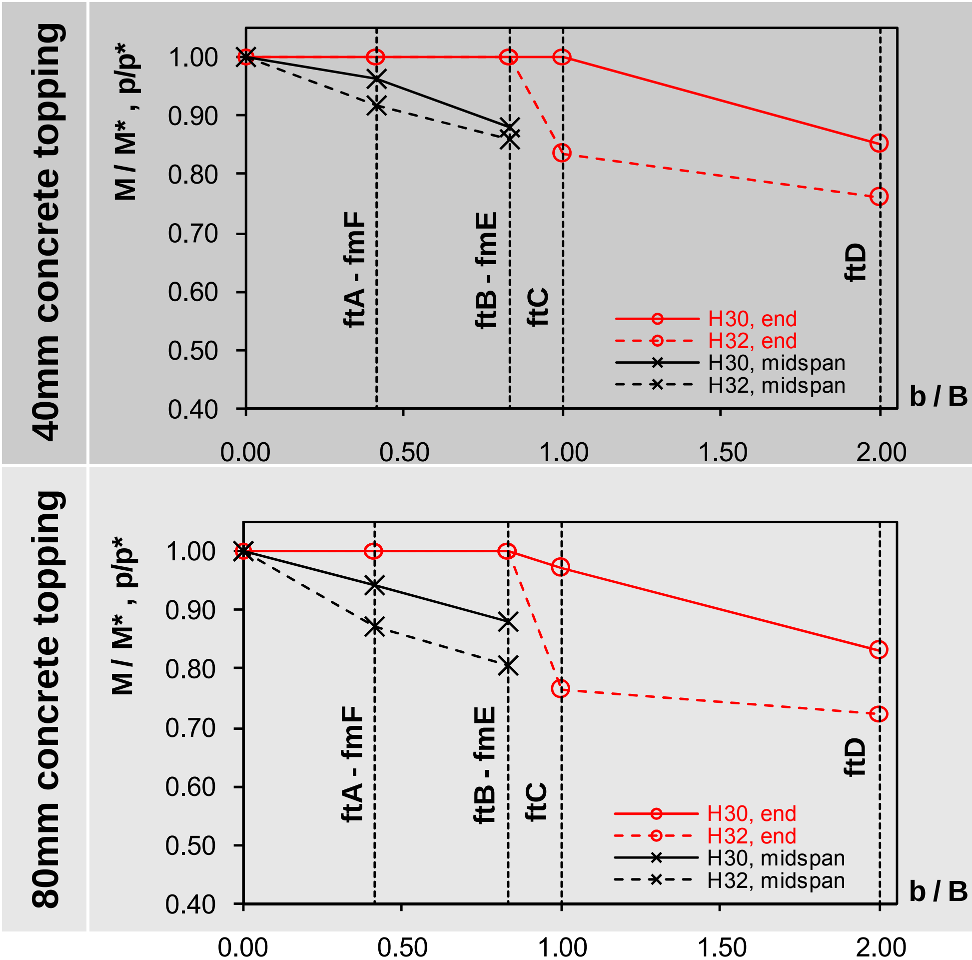
$M_{rd,H30}$ = 382.61 kNm

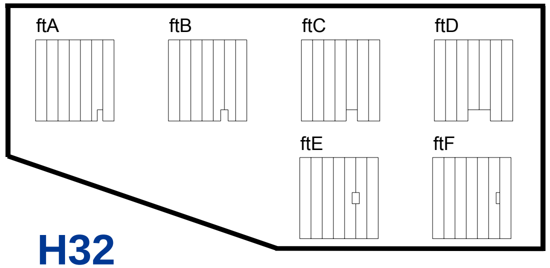
Parametric study on HC floors with large openings
Example of design charts

DICATeA – University of Parma & ASSAP Research Program

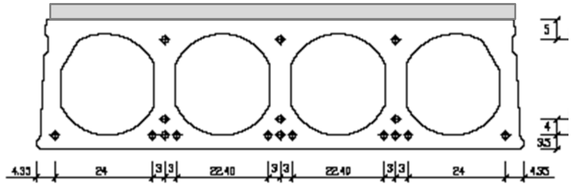
"Parametric numerical study on HC floors with large openings for the development of design charts"

H30-H32 topped floors, H/L = 1/35, imposed service load 10 kN/m²





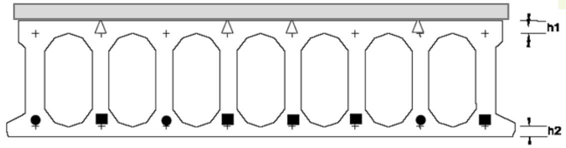
H32



$A_{p,sup}$ = 279 mm²
$A_{p,inf}$ = 1302 mm²

$M_{rd,H32+4}$ = 507.88 kNm
$M_{rd,H32+8}$ = 575.63 kNm

H30



$A_{p,sup}$ = 84.84 mm²
$A_{p,inf}$ = 974 mm²

$M_{rd,H30+4}$ = 404.67 kNm
$M_{rd,H30+8}$ = 471.38 kNm

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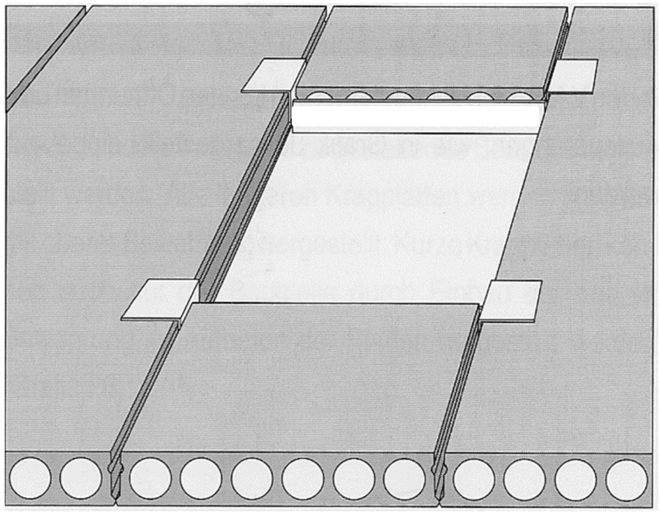
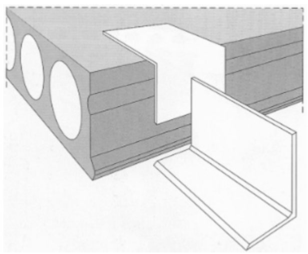
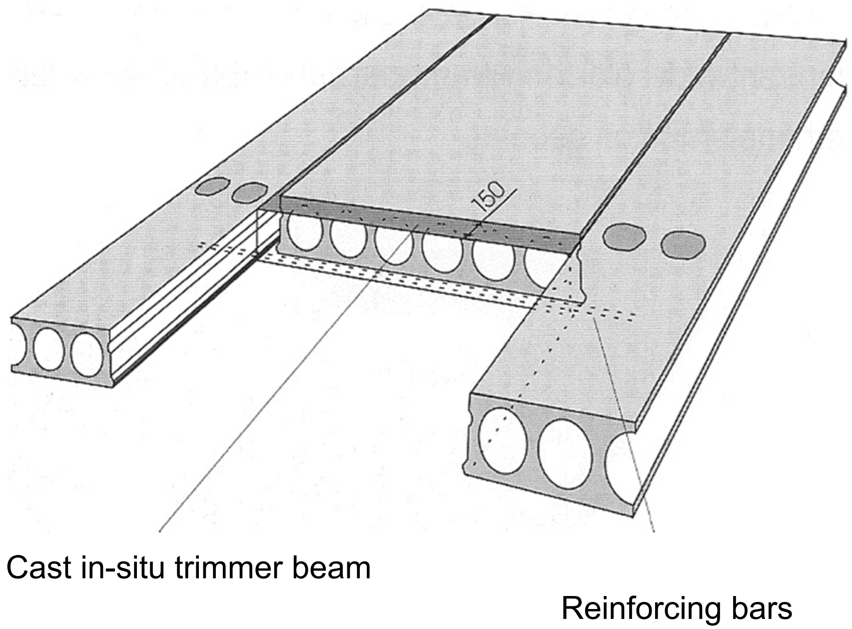
Detailing

- Type solutions





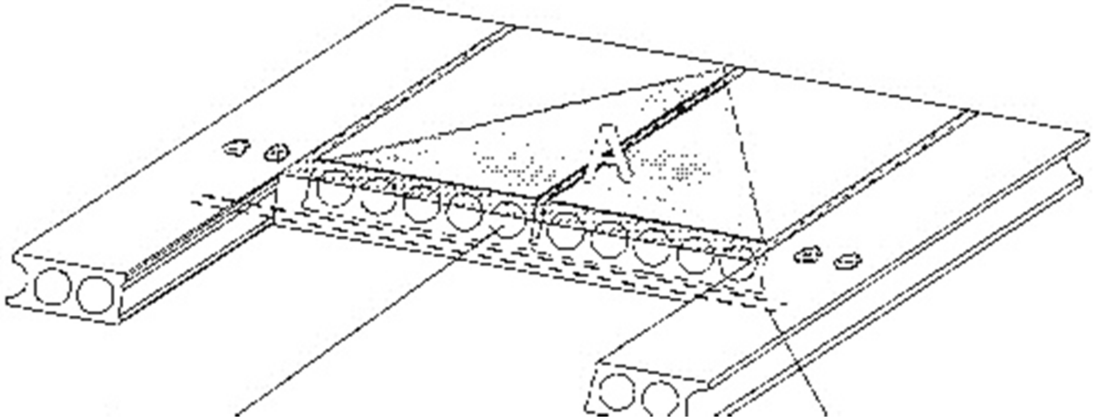
Steel trimmer beam

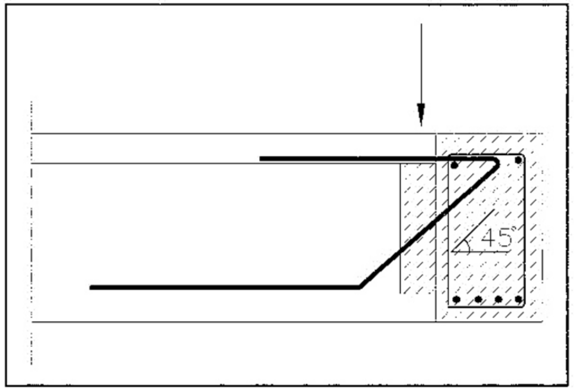


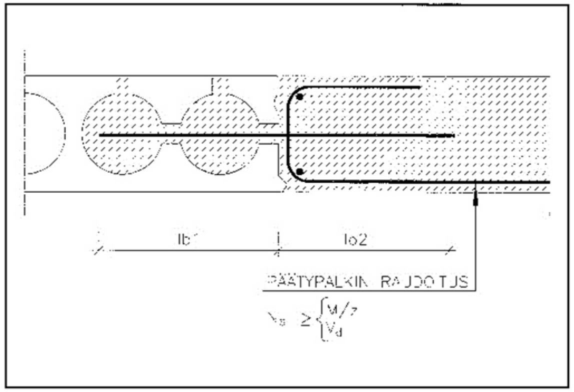
Concrete trimmer beam

Detailing

- Parma Betonila Finland

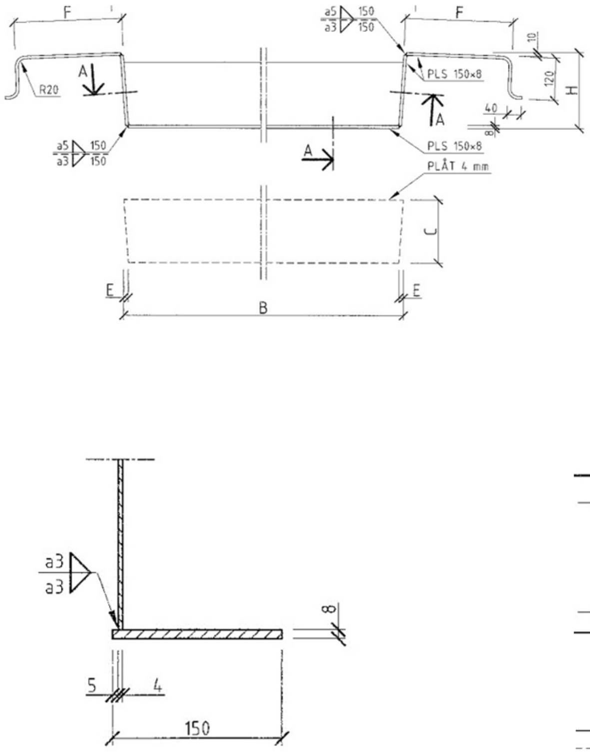


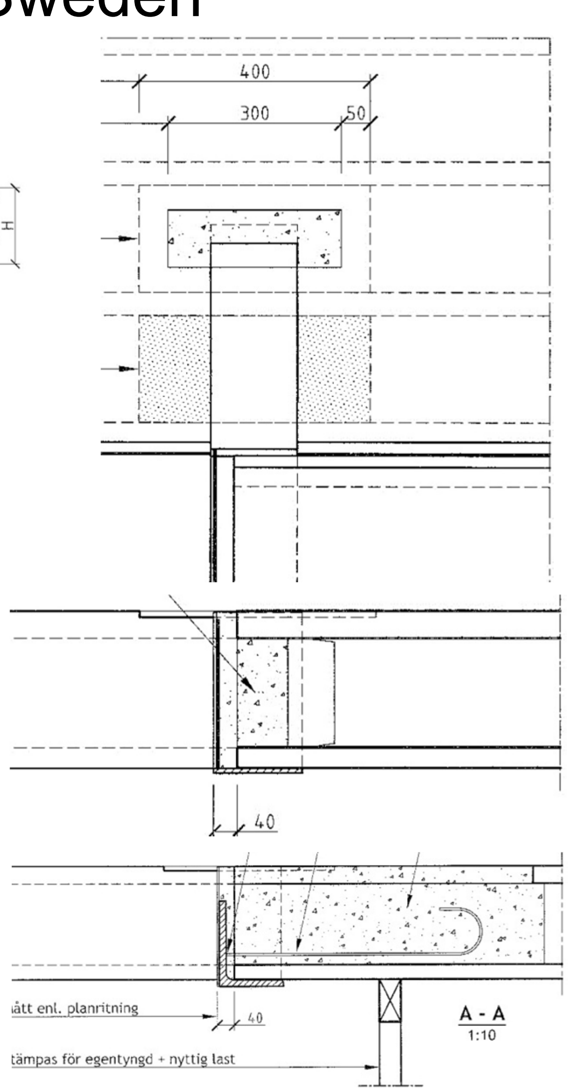


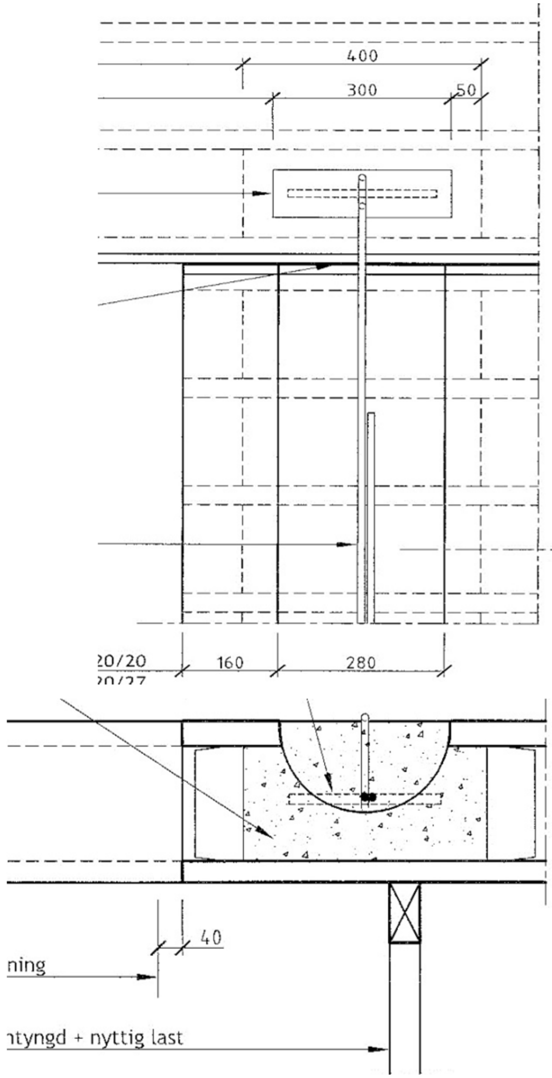


Detailing

- Strängbetong Sweden







Detailing

- Large opening with steel frame

HC 240 x 600 + 50 mm topping

Opening of 3.60 m x 3.60 m in HC floor of 10.00 m span