REPORT ON LOAD TESTS ON RVK 100 - UNITS

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REPORT FROM TESTS OF RVK-UNITS

CONCLUSIONS
The anchorage of the reinforcement is the deciding factor for the load carrying capacity of the RVK-units.

The tests have revealed that it is relevant to establish a minimum slab thickness in order to utilize the full capacity of the RVK100-unit.

Altered reinforcement pattern in 200 mm slabs (test series B) did improve the load carrying capacity. The low failure load in test A1 is probably due to the short distance from the corners and the shape of the reinforcement. If test A1 is disregarded, the mean failure load for test series A is 98,9 kN; the standard deviation is 8,9 kN; and the characteristic load is 76,6 kN. This is still less than the characteristic load for test series B (92,4 kN).

The results from test series B do not support of the hypothesis that the units closest to the corners have reduced capacity, while the results in test series A and C indicates that the hypothesis is correct. The altered arrangement of the reinforcement in test series B may be the reason. For safety reasons it is considered prudent to establish a minimum distance from the RVK-unit to the corner of the slab.

For the slabs of 265 mm depth, the mean failure load for test series C is 141,1 kN, and the characteristic failure load is 108,9 kN when all results are considered. The tests where the support was on two units have a lower mean failure load of 130,6 kN, but the characteristic failure load is 122,2 kN. This is due to the small scatter in the last case.

For the evaluation of the results a normal statistical method has been used:
Characteristic value = (Mean value) – w × (Standard deviation)
w = coefficient according to table on page 10

With a large number of tests it can be assumed that the characteristic failure load would be about the average of the results of the two samples of the population used above. This is due to a smaller value for w, and without any increase in the scatter the standard deviation will be smaller. The average characteristic failure load is (108,9 + 122,2) / 2 = 115 kN.

(A documentation of this assumption is on page 11, where it is shown that the characteristic failure load of all the tests on 200 mm slabs is 77,1 kN. This is close to the average results of test series A and B = (58,3 + 92,4) / 2 = 75,4 kN.

The very poor result of test A1, where the reinforcement was bent back under the RVK-units, has a heavy impact on the calculations. If test A1 is disregarded, the average characteristic failure load would be (76,6 + 92,4) / 2 = 84,5 kN.)

Consequently the “material factor”, defined as the ratio of characteristic failure load and the design ultimate load, will be 115 / 100 = 1,15. This is considered satisfactory.

The maximum service limit state load will be about 100 / 1,4 = 70 kN. Examining the condition of the test specimens at this load level reveals that the crack development at this stage is insignificant.

Using the same argument for the 200 mm slabs, the ultimate limit state load should in this case be limited to about [(92,4 + 101,2) / 2] / 1,15 = 84,1 kN, provided the arrangement of the reinforcement are as in test series B. It seems appropriate to select 80 kN, because the slimmer slab is more sensitive to small deviations in the placement of the reinforcement.

The corresponding service limit state load is about 80 / 1,4 = 57 kN. Examining the condition of the test specimens (except tests A1 and A2) at this load level reveals that the crack development at this stage is insignificant.

Similarly, with traditional arrangement of the reinforcement, the ultimate limit state load should in this case be limited to about [(58,3 + 76,6) / 2] / 1,15 = 58,6 kN

RECOMMENDATIONS:

The RVK100-units should preferably be placed at least 300 mm from the edge of the slab.
If the RVK-unit must be placed closer to the edge, the absolute minimum distance is 200 mm. In that case the reinforcement in the front of the RVK-unit must be over the RVK-unit (under the RVK-unit in the back), bent down (or up) parallel to the face of the slab, and anchored with fairly long ends perpendicular to the face of the slab. (The reinforcement model is shown in figure 3.) The capacity shall be reduced to 80 kN.

For slabs of depth less than 265 mm the capacity of RVK100-units shall be reduced to 80 kN.
The reinforcement in the front of the RVK-unit must be over the RVK-unit (under the RVK-unit in the back), bent down (or up) parallel to the face of the slab, and anchored with fairly long ends perpendicular to the face of the slab (see figure 3). The reinforcement shape where the reinforcement is bent back under the RVK-units (see figure 1), must be avoided.

When traditional reinforcement with the anchoring ends of the stirrups parallel to the face of the slab is used in slabs of depths less than 265 mm, the capacity of the RVK100-unit shall be reduced to 60 kN.
The reinforcement shape where the reinforcement is bent back under the RVK-units (see figure 1), must be avoided.

BACKGROUND

A request from one of Spenncon's licensees for use of RVK-units in very slim slabs, prompted a discussion about how the reinforcement ought to be arranged when using the RVK-units in slabs of small depths, and what the minimum depth of slabs should be. The standard slab depth for use with RVK100 is 265 mm. The RVK100 will always have 70 mm of concrete cover above the unit, and the depth of the unit is 60 mm. After extensive calculations that yielded no firm conclusions, it was decided to test the standard RVK100 in slabs of 200 mm depth, which must be considered the minimum slab depth for this unit, in order to leave sufficient room for the reinforcement. It was decided to use the standard reinforcement pattern around the units. The reinforcement is shown in figure 1. The test specimens were 1200 × 3300 mm. These dimensions made it possible to carry out the tests in the test rig designed for full scale testing of hollow core slabs. The two specimens were identical, and had three RVK-units in each end, in the hope of getting six test results from each slab.

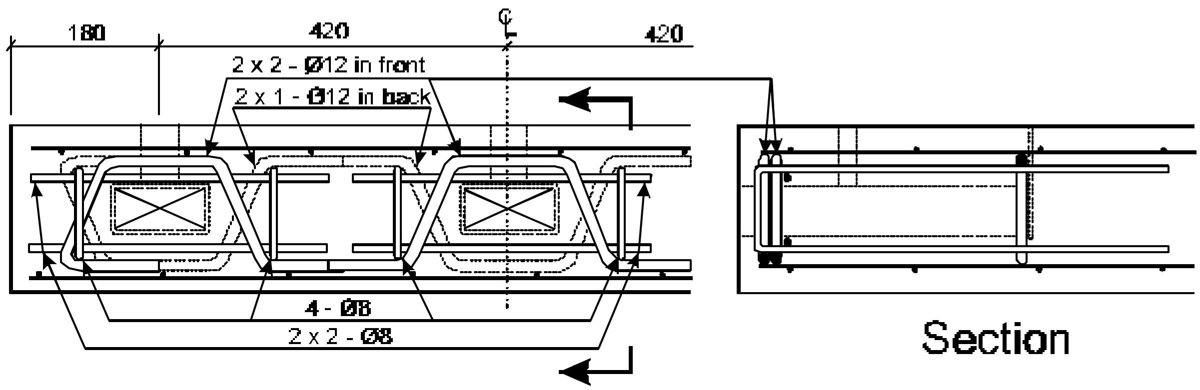


Figure 1. Reinforcement arrangement for test slabs A.

TEST GEOMETRY

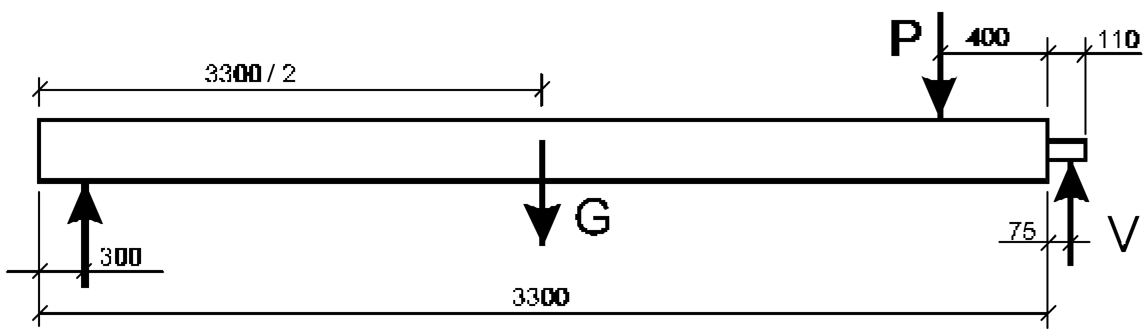


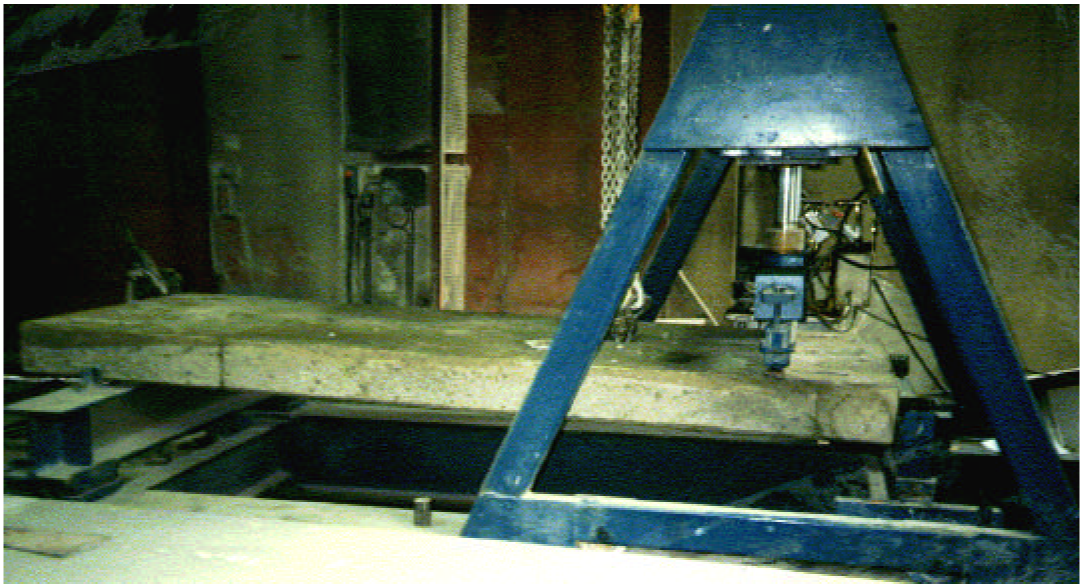
Figure 2. Test geometry.

V = support reaction
P = load from the hydraulic jacks = 4,97 kN for a gage reading on the test rig R = 1 bar.
G = weight of the test specimen

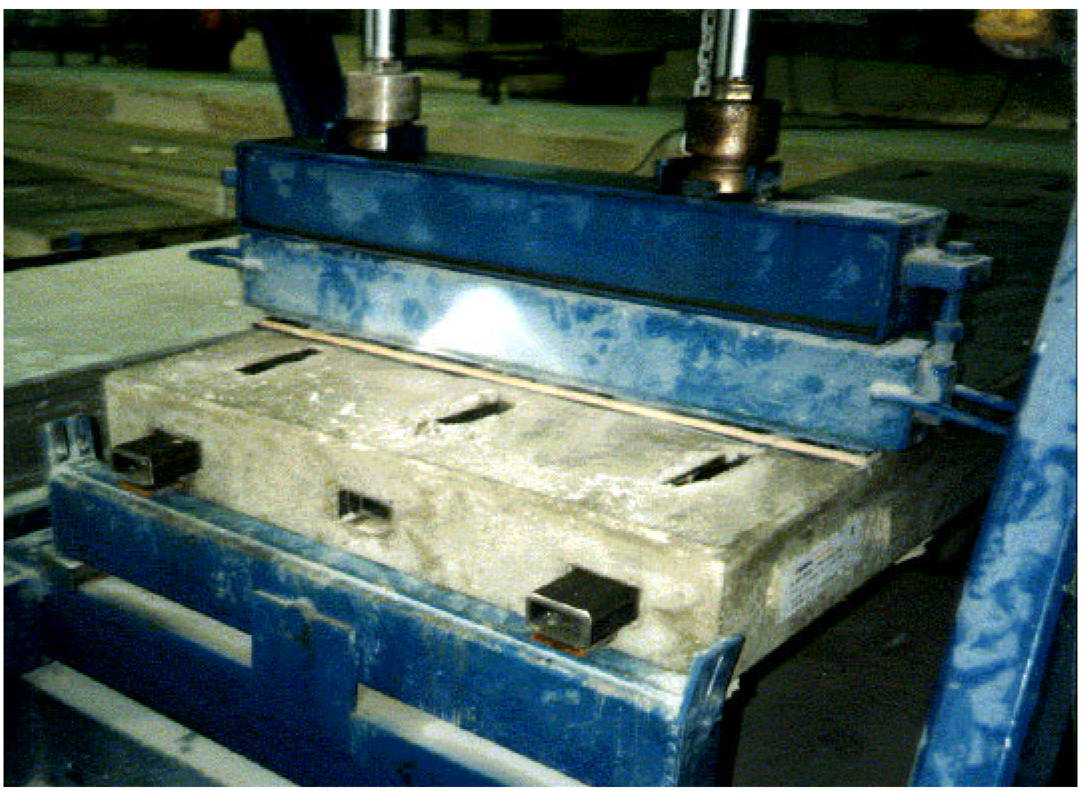
$V \times (3300 - 300 + 75) = G \times [(3300/2) - 300] + P \times (3300 - 300 - 400)$
$V = 0{,}439 \times G + 0{,}8455 \times P$ (V, G and P in kN)
$V = 0{,}439 \times G + 4{,}20 \times R$
(V and G in kN, R in bar hydraulic pressure read on the gage on the machine)

THE FIRST TESTS

Two test specimens were cast on January 26 and 27, respectively. The normal concrete grade for landings is C45. These slabs were cast in C55 in order to cut down on the required time for curing. After about two weeks of curing it was decided to carry out the tests on February 9. The test setup is shown in pictures 1 and 2.

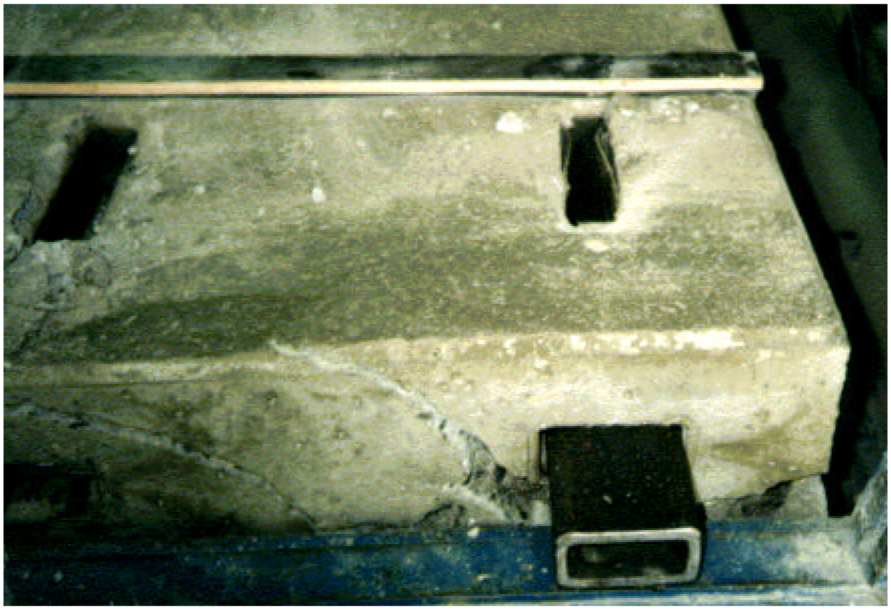


Picture 1. General view of test setup.



Picture 2. Arrangement at the end to be tested.

The first slab to be tested was the one cast on January 27. In the first test of this slab (test A1), the slab was supported on the two outermost RVK-units. The anchorage of the reinforcement closest the face of the slab failed at about 75% of the calculated ultimate load for the RVK-units (100 kN). The end of the slab after failure is shown in picture 3.



Picture 3. Test A1 after failure.

A similar test was started at the other end of the slab (test A2), but when the exact same failure pattern seemed to develop, the test was stopped at about 55% of the calculated ultimate load, in order not to damage the end of the slab completely. The support of the slab was now changed to be only on the RVK-unit in the center of the slab. Starting the load application again (test A3), this unit had a gradual increase in crack widths until collapse at 135% of the calculated ultimate load. However, at about 90% of the calculated ultimate load the crack widths were so large that it for all practical purposes had to be considered a failure at that point.

CONCLUSIONS AFTER THE FIRST TESTS

It was obvious that the supports did not perform quite as expected, so it was decided not to test the second slab at this time, but rather to go in the “think tank” for a while.

An examination of the failure patterns revealed that it was not the RVK-unit itself that failed, but rather the anchorage of the reinforcement passing over the RVK-unit, closest to the face of the slab. This implied that there should be limitations to the minimum slab depths in order to utilize the full capacity of the RVK-units. Furthermore, cracks would appear rather quickly at the top corners of the RVK-unit, extending upwards and outwards, while new cracks would develop from the bottom corners of the RVK-unit immediately before failure. These cracks would be approximately parallel to the cracks above.

The reinforcement around the RVK-units in the test specimens was made of many small pieces in order to try to make each RVK-unit behave independent of the others. This obviously did not work, and had the disadvantage of poorer anchorage due to lack of continuity.

The test on one RVK-unit alone (test A3) suggested a somewhat better result than the test with two supporting RVK-units (test A1). This was probably because in test A1 the bars over the RVK-units were bent back under the unit (see figure 1), which caused the whole slab to split in the corner. Consequently there should be a minimum distance from the edge of the slab to the RVK-unit in order to facilitate a satisfactory arrangement of the reinforcement.

One encouraging observation was that the failures had been ductile, with no sudden collapse. The slab had signaled impending failure with large deformations.

It was decided that further tests were required, and it was decided to make two identical slabs of depth 200 mm with what hopefully would be improved arrangement of the reinforcement, and two identical slabs of the standard depth of 265 mm with traditional reinforcement. All four slabs had two RVK-units in one end, and one in the center at the other end.

THE SECOND TEST SERIES

The two slabs of 200 mm depth were cast on March 6 and March 9. The reinforcement is shown in figure 3 and pictures 4 and 5.

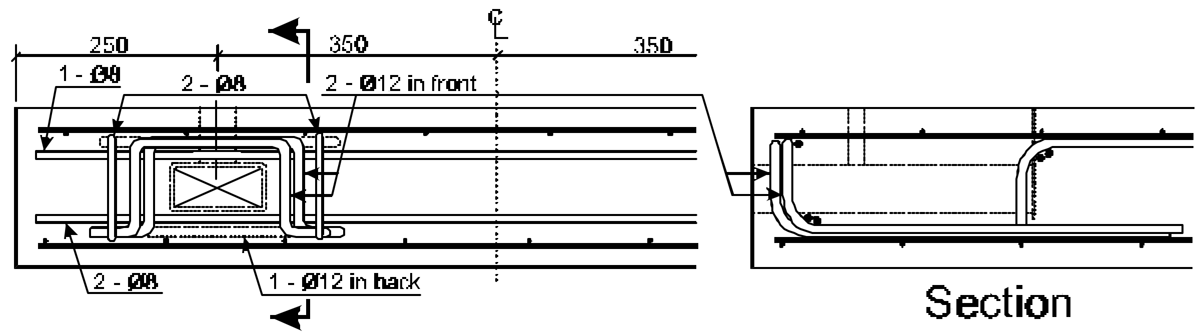
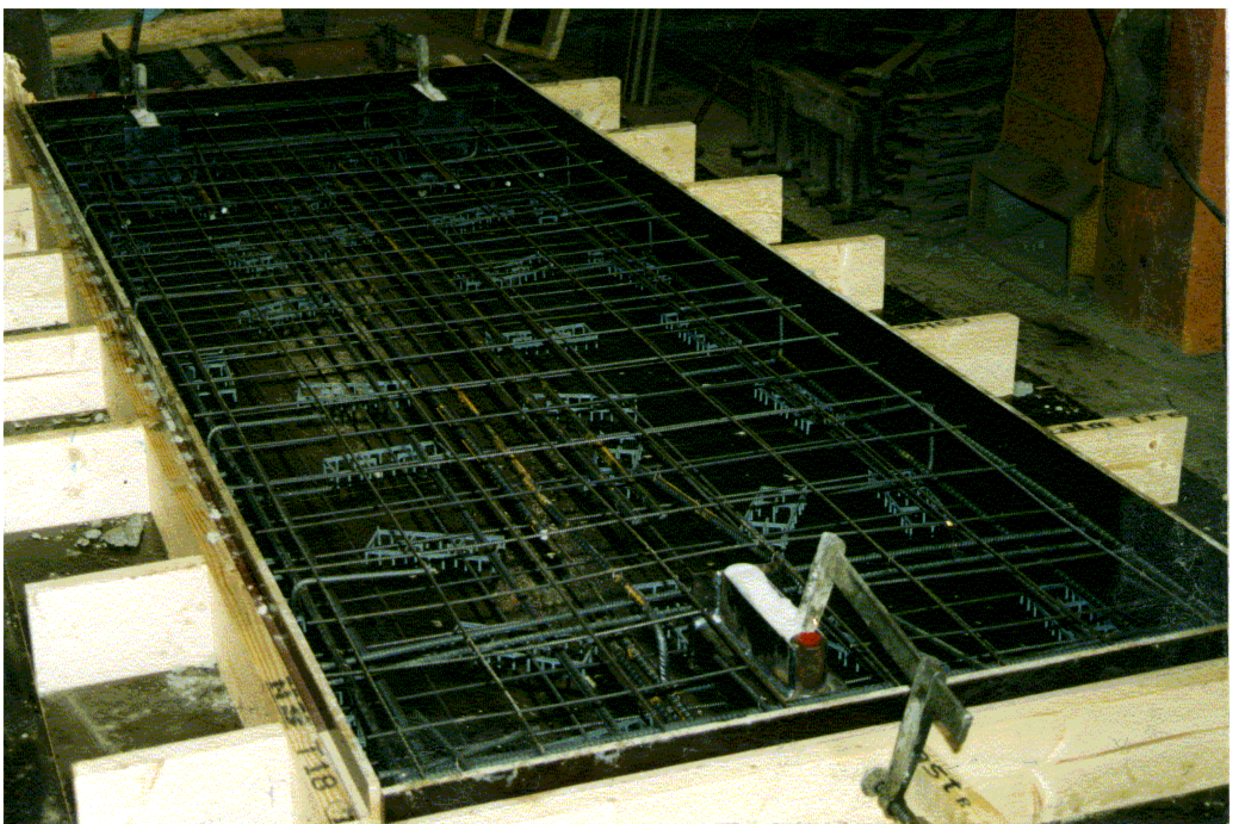
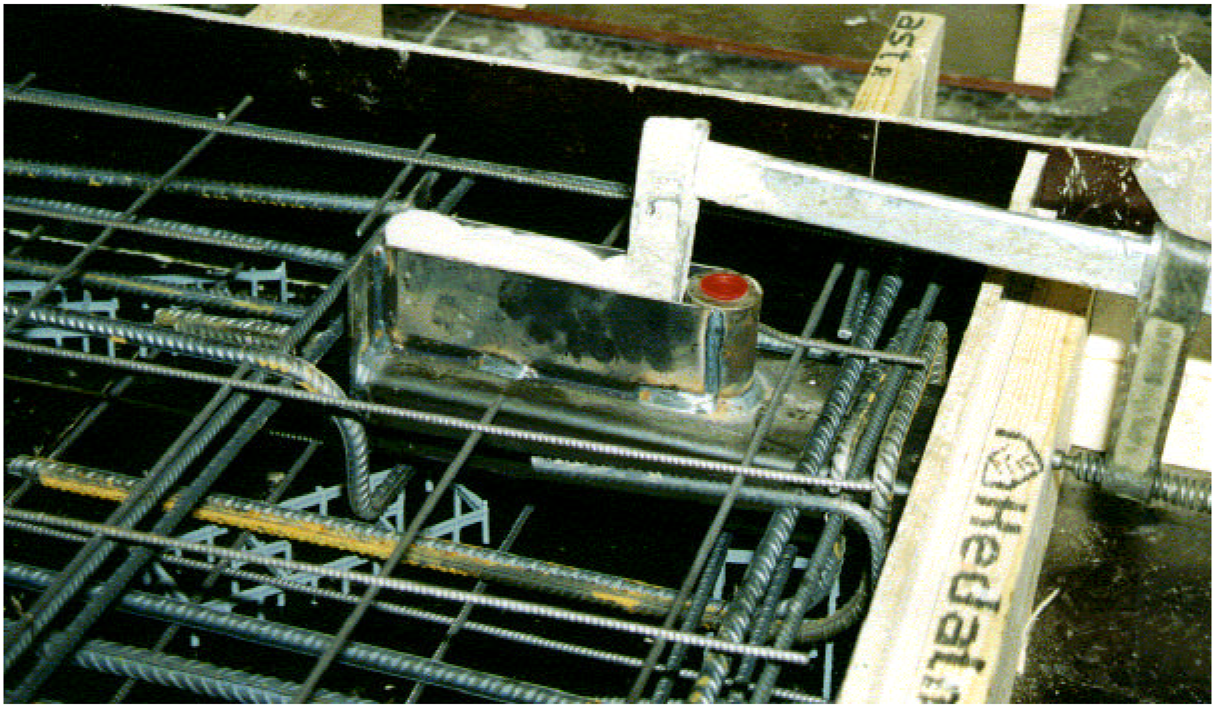


Figure 3. Reinforcement arrangement for test slabs B.



Picture 4. Overview of reinforcement in slab B.



Picture 5. Reinforcement arrangement for test slabs B.

The two specimens of 265 mm depth were cast on March 10 and march 11. The reinforcement is shown in figure 4 and picture 6.

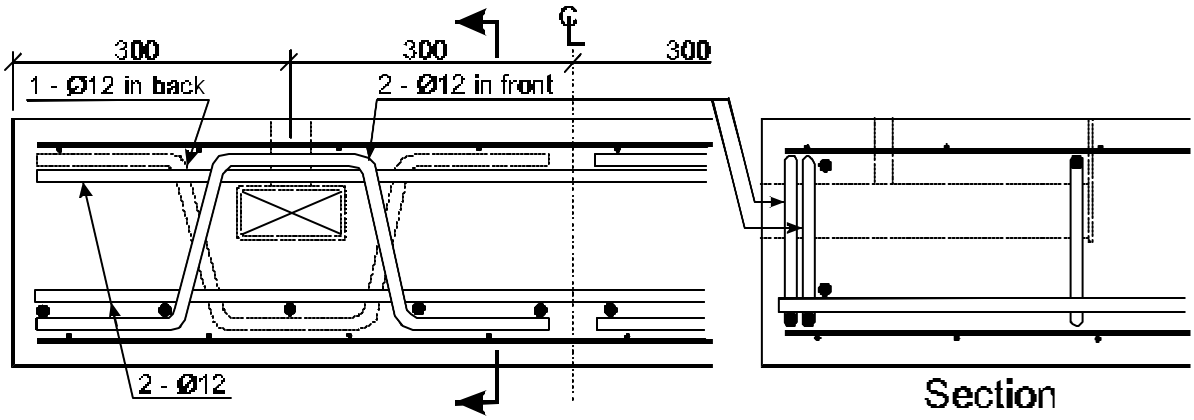
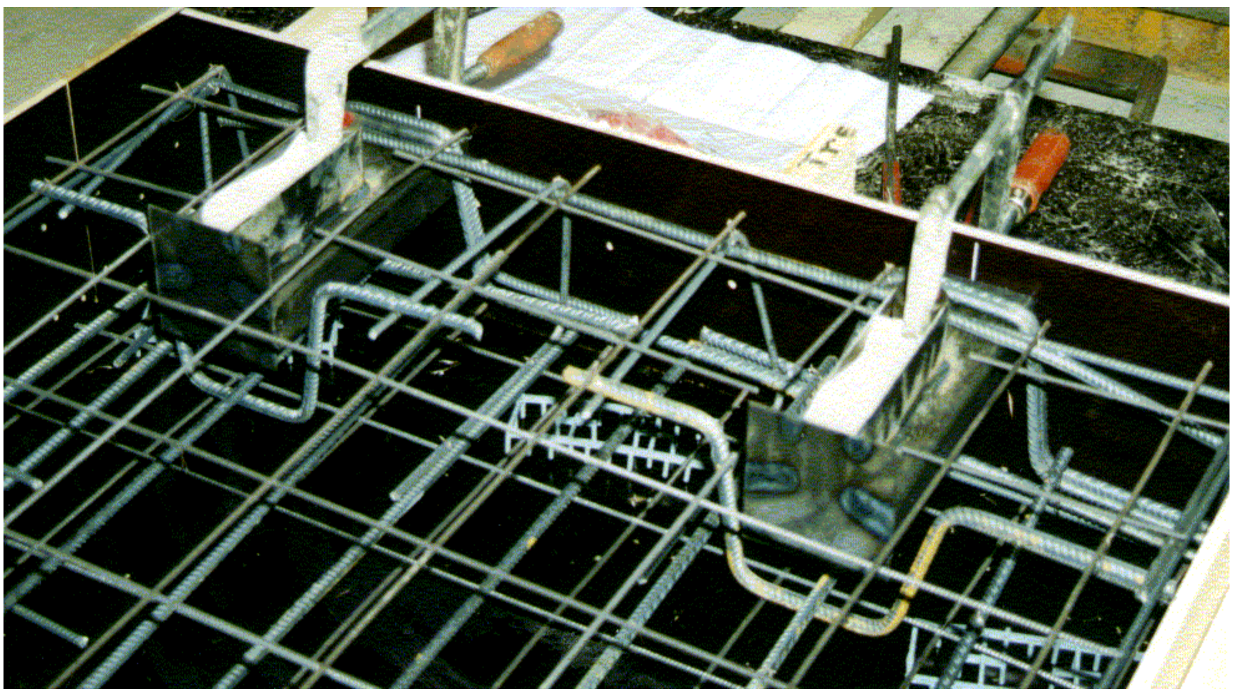


Figure 4. Reinforcement arrangement for test slabs C.



Picture 6. Reinforcement arrangement for test slabs C.

All tests were carried out on March 25, and the slab cast on January 26 was also tested the same evening. Altogether 10 tests were carried out, yielding results for two RVK-units in 200 mm slabs with traditional reinforcement (the remaining of test series A), six RVK-units in 200 mm slabs with improved reinforcement (test series B), and six RVK-units in 265 mm slabs with traditonal reinforcement (test series C).

TEST RESULTS

Test specimens A and B: G = 19,8 kN
Test specimens C: G = 26,2 kN

Summary:

Test no.	Slab depth (mm)	Age at testing (days)	Concrete grade at testing	No. of units on support	Gage at failure (bar)	Failure load, each unit (kN)	Comments
A1	200	13	≈ C60*	2	33	73,6	The failure came after approx. 3 min. when the hydraulic pressure was kept at 33 bar.
A2	200	13	≈ C60*	2	23		Test interrupted before failure.
A3	200	13	≈ C60*	1	≈ 20	92,7	Large cracks at 20 bar, collapse at 29,6 bar.
A4	200	58	≈ C75*	1	23,9	109,1	The hydraulic pressure was kept at 23 bar for approx. 5 min.
A5	200	58	≈ C75*	1	20,5	94,8	
B1	200	19	C58,8**	1	21,0	96,9	The pressure was increased to 21,8 bar before collapse.
B2	200	19	C58,8**	2	46,9	102,8	
B3	200	16	C65,1**	1	20,1	93,1	At 16,7 bar it was observed that the element had caught the center hinge on the support beam. The element was unloaded and released before the test was continued.
B4	200	16	C65,1**	2	48,5	106,2	
C1	265	15	C58,1**	1	34,3	155,6	Very little crack development before 15 bar. Hardly any change in the cracks before 21,5 bar.
C2	265	15	C58,1**	2	57,4	126,3	The first crack appeared at 22 bar. The first crack at the top surface appeared at 52,8 bar.
C3	265	14	C58,3**	1	37,4	168,6	Cracks developed at one side rather early due to skewed support of the RVK -unit
C4	265	14	C58,3**	2	61,5	134,9	

* Estimated from the established grade/time relationship for this concrete.
** Determined with extra 100 mm cubes crushed on the day of the tests.

Evaluation of the failure loads.

The statistical formulas are as follows:

$$V_m = \Sigma V / n$$
$$s = \sqrt{\{[n \times \Sigma V^2 - (\Sigma V)^2] / [n \times (n - 1)]\}}$$
$$V_c = V_m - w \times s$$

V_m = mean failure load
V = test result
n = number of tests
s = standard deviation
V_c = characteristic failure load
w = coefficient

The coefficient w depends on the number of tests as follows:

Number of tests	3	4 - 5	6 - 10	11 - 20	> 20
w	2,5	2,0	1,7	1,5	1,4

Test series A		Test series B				Test series C					
A1 =	73,6	B1 =	96,9		96,9	C1 =	155,6		155,6	A1 =	73,6
A1 =	73,6	B2 =	102,8	102,8		C2 =	126,3	126,3		A1 =	73,6
A3 =	92,7	B2 =	102,8	102,8		C2 =	126,3	126,3		A3 =	92,7
A4 =	109,1	B3 =	93,1		93,1	C3 =	168,6		168,6	A4 =	109,1
A5 =	94,8	B4 =	106,2	106,2		C4 =	134,9	134,9		A5 =	94,8
		B4 =	106,2	106,2		C4 =	134,9	134,9		B1 =	96,9
Mean value	88,8		101,3	104,5	95,0		141,1	130,6	162,1	B2 =	102,8
Standard deviation	15,2		5,3	2,0			18,9	5,0		B2 =	102,8
Characteristic value	58,3		92,4	101,2			108,9	122,2		B3 =	93,1
										B4 =	106,2
										B4 =	106,2
										Mean value	95,6
										Standard deviation	12,3
										Characteristic value	77,1

Detailed test observations.

Test A1

Cast 27.1.98, tested 9.2.98, supported on two RVK-units.

Gage reading	Load per RVK-unit	Observations	Reference
15	35,8	Cracks extending from the top corners of the RVK on one unit.	
25	56,8	Cracks extending from the top corners of the RVK on both units.	
28	63,1	Crack widths increasing, crack lengths practically unchanged.	
33	73,6	Concrete layer over one of the units started to lift. After about three minutes without any change in the load, the concrete layer was lifted off.	

Test A2

Cast 27.1.98, tested 9.2.98, supported on two RVK-units.

Gage reading	Load per RVK-unit	Observations	Reference
10	25,6	No cracks.	
15	35,8	Small crack on one side.	
20	46,3	Existing cracks increased, cracks started to develop at the other RVK.	
23	52,6	Major increase in the cracks. Test stopped.	

Test A3

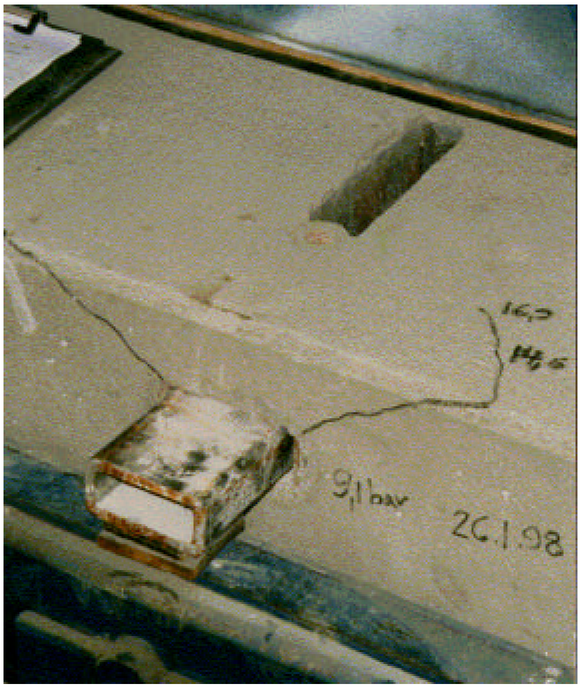
Cast 27.1.98, tested 9.2.98, supported on one RVK-unit.

Gage reading	Load per RVK-unit	Observations	Reference
7,3	39,4	A small crack started to develop at one of the corners of the RVK.	
10,0	50,7	Cracks from both corners of the RVK.	
12,4	60,8	Crack width increasing.	
14,1	67,9	Crack width approximately 0,5 mm.	
17,0	80,1	Small deflection in the outer tube.	
20,0	92,7	Crack width so large that it has to be considered a failure.	
21,0	96,9	Cracks extending on the top surface.	
21,6	99,4	No significant changes, crack width approximately 2,5 mm.	
29,6	133,0	The slab was left at this load for approximately one minute before it failed.	

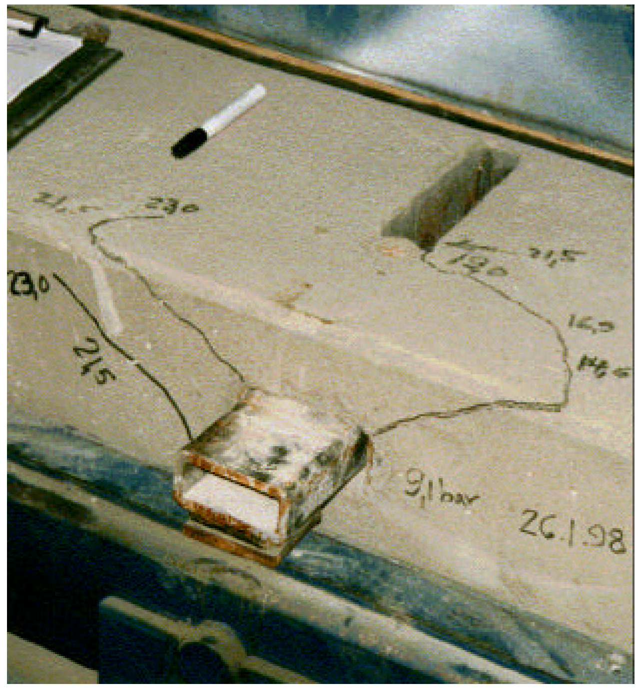
Test A4

Cast 26.1.98, tested 25.3.98, supported on one RVK-unit.

Gage reading	Load per RVK-unit	Observations	Reference
9,1	46,9	Small cracks extending from the top corners of the RVK.	
12,3	60,4	Small increase in crack width, cracks start to extend on the top surface.	
16,9	79,7	No significant changes.	Picture 7
23,0	105,3	Left at this load level for about three minutes, nothing happened.	Picture 8
23,9	109,1	Failure.	Picture 9



Picture 7. Test A4 at 80 kN.



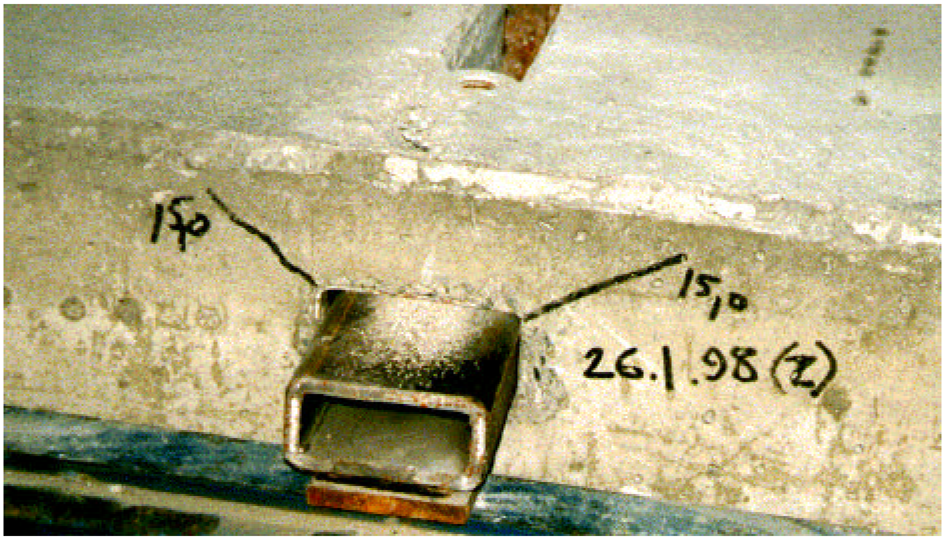
Picture 8. Test A4 at 105 kN.

Picture 9. Test A4 after failure.

Test A5

Cast 26.1.98, tested 25.3.98, supported on one RVK-unit.

Gage reading	Load per RVK-unit	Observations	Reference
9,0	46,5	Small cracks extending from the top corners of the RVK.	
11,0	54,9	Small increase in crack width, but not much in crack length.	
15,0	71,7	Small increase in crack width, but not much in crack length.	Picture 10
18,0	84,3	Increase in crack width, cracks no extending on the top surface.	
20,5	94,8	Cracks developed from the bottom corners of the RVK, failure.	

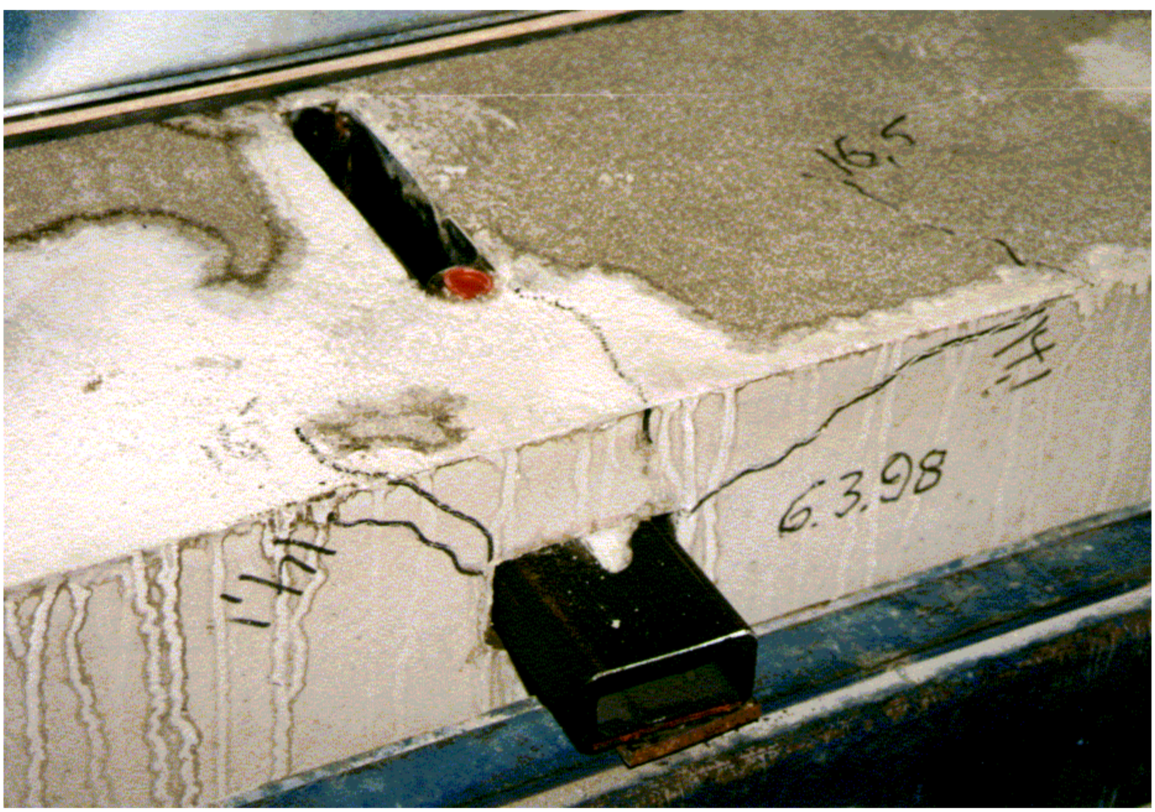


Picture 10. Test A5 at 72 kN.

Test B1

Cast 6.3.98, tested 25.3.98, supported on one RVK-unit.

Gage reading	Load per RVK-unit	Observations	Reference
9,5	48,6	Small crack from one top corner of the RVK.	
14,0	67,5	Crack increases.	
16,5	78,0	Cracks extending on the top surface.	Picture 11
19,0	88,5	Increase in the crack lengths on the top surface. Crack width approximately 2,5 mm at the vertical face of the slab.	
21,0	96,9	Crack width so large that it has to be considered a failure.	
21,8	100,3	Collapse.	



Picture 11. Test B1 at 78 kN.

Test B2
Cast 6.3.98, tested 25.3.98, supported on two RVK-units.

Gage reading	Load per RVK-unit	Observations	Reference
14,0	33,7	Start of crack development.	
28,0	63,1	Crack above one of the RVK's.	Picture 12
33,0	73,6	Insignificant increase of the cracks.	
38,0	84,1	Significant increase of the cracks.	Picture 13
43,0	94,6	The top layer of concrete starts to lift at one side. Increase in crack width, but not much in crack length.	
46,9	102,8	Failure.	

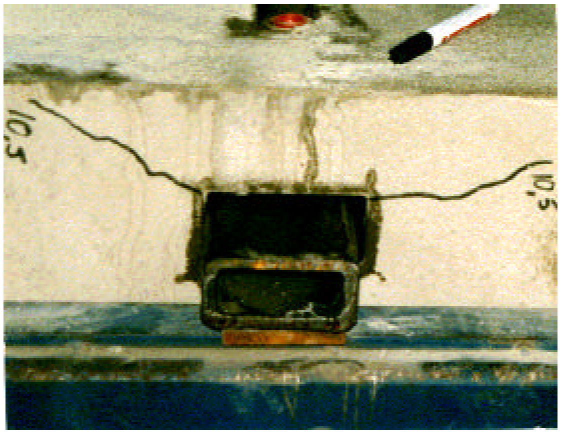

Picture 12. Test B2 at 63 kN.


Picture 13. Test B2 at 84 kN.

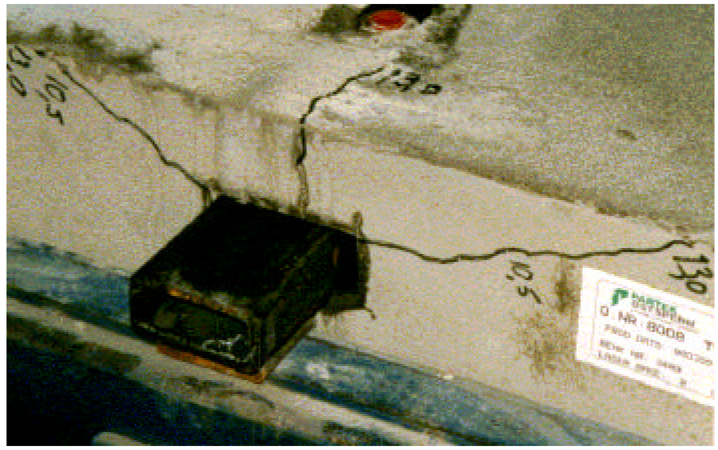
Test B3
Cast 9.3.98, tested 25.3.98, supported on one RVK-unit.

Gage reading	Load per RVK-unit	Observations	Reference
10,4	52,4	Start of crack development.	Picture 14
13,0	63,3	A small crack also directly above the RVK.	Picture 15
15,3	73,0	No changes.	
16,7	78,8	Increase in crack width.	
16,7	78,8	Noticed that the slab itself had caught on the center hinge of the support beam of the test rig. Unloaded the element, and moved the support beam to free the slab. Applied the load again at a steady, slow rate.	

20,1	93,1	Failure.	



Picture 14. Test B3 at 52 kN.

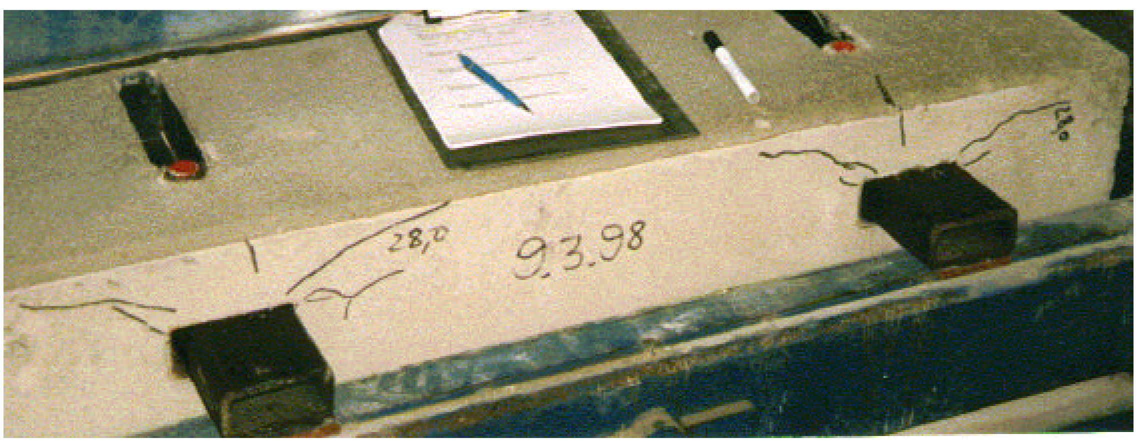


Picture 15. Test B3 at 63 kN.

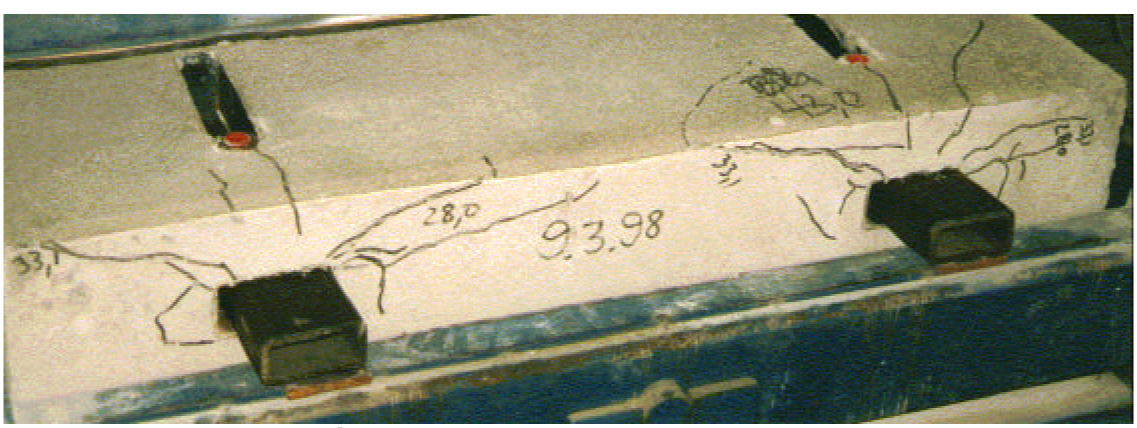
Test B4

Cast 9.3.98, tested 25.3.98, supported on two RVK-units.

Gage reading	Load per RVK-unit	Observations	Reference
20,2	46,8	Cracks had developed from the top corners and directly above the RVK's.	
28,0	63,1	Insignificant crack increase.	Picture 16
33,0	73,6	Slight crack increase.	
38,0	84,1	Significant crack increase.	
43,0	94,6	Top concrete layer starts to lift at one side.	Picture 17
48,5	106,2	Failure.	



Picture 16. Test B4 at 63 kN.



Picture 17. Test B4 at 95 kN.

Test C1

Cast 10.3.98, tested 25.3.98, supported on one RVK-unit.

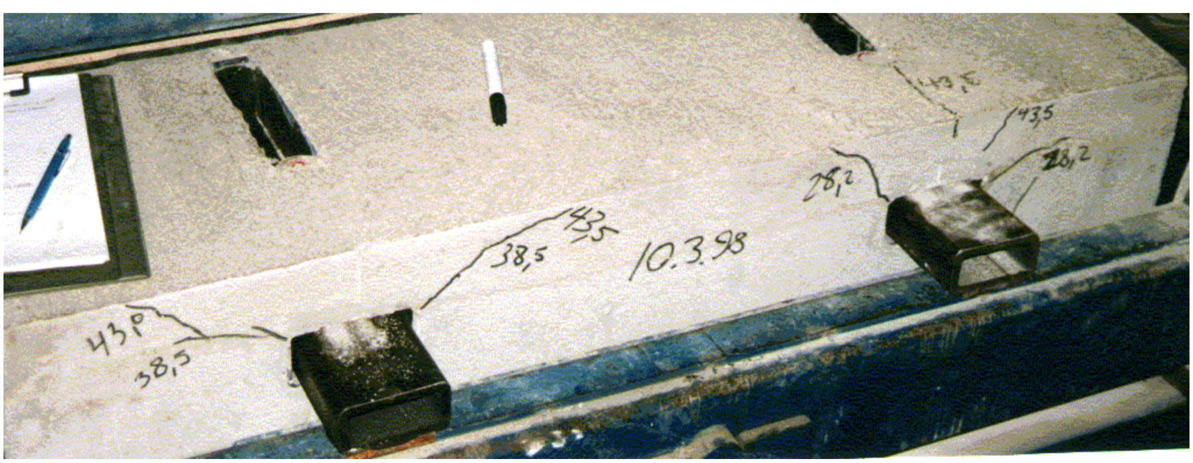
Gage reading	Load per RVK-unit	Observations	Reference
14,4	72,0	Cracks had developed from the top corners of the RVK. On one side the cracks extended in on the top surface.	
16,5	80,8	Insignificant crack increase.	
19,0	91,3	Insignificant crack increase.	
21,5	101,8	Cracks extending on the top surface on both sides.	Picture 18
34,3	155,6	Lifting of the top layer of concrete, failure.	

Picture 18. Test C1 at 102 kN. Notice shims at the support.

Test C2

Cast 10.3.98, tested 25.3.98, supported on two RVK-units.

Gage reading	Load per RVK-unit	Observations	Reference
22,0	52,0	Start of crack development.	
33,0	75,1	Insignificant crack increase.	
38,0	85,6	Insignificant crack increase.	
43,0	96,1	Insignificant crack increase.	Picture 19
52,8	116,6	Cracks extending on the top surface.	
57,4	126,3	Failure.	

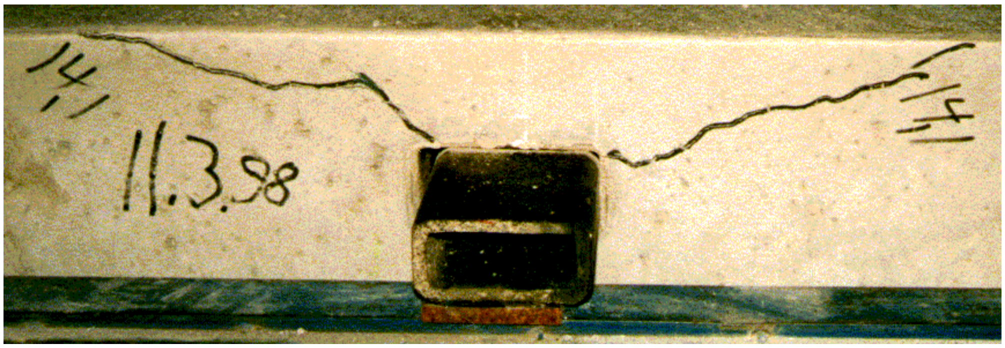


Picture 19. Test C2 at 96 kN.

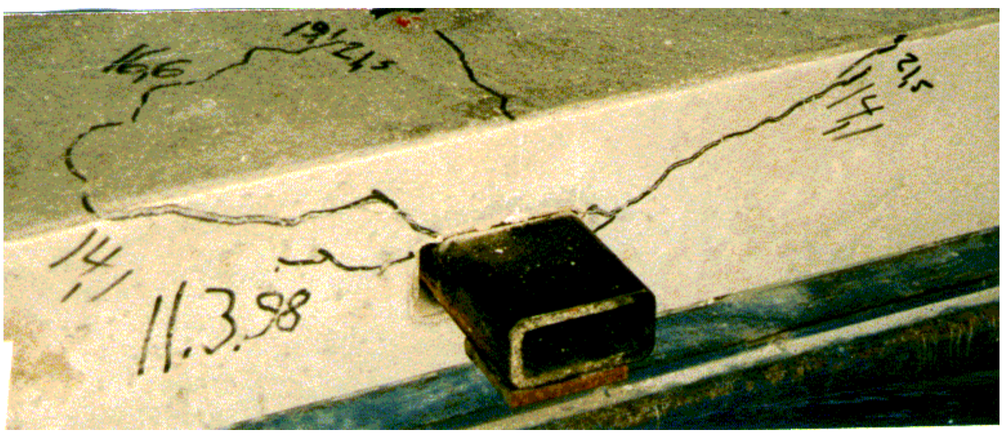
Test C3

Cast 11.3.98, tested 25.3.98, supported on one RVK-unit.

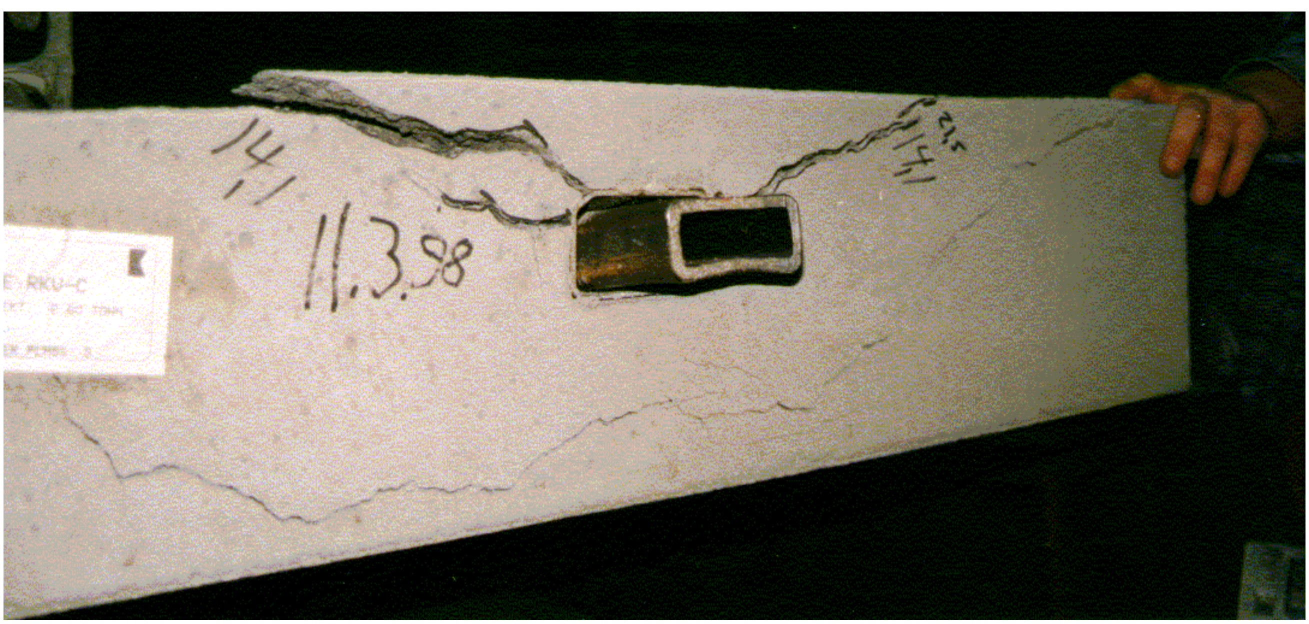
Gage reading	Load per RVK-unit	Observations	Reference
14,0	70,3	Crack widths 0,5 to 1,0 mm. Unsymmetrical support.	Picture 20
16,5	80,8	Cracks extending on the top surface on one side.	
19,0	91,3	Crack increase.	
21,5	101,8	No new cracks.	Picture 21
29,0	133,3	Cracks extending on the top surface on both sides.	
37,4	168,6	Failure.	Picture 22



Picture 20. Test C3 at 70 kN. Notice eccentric support.



Picture 21. Test C3 at 102 kN.



Picture 22. Test C3 after failure. Notice crack starting at the anchorage level of the front stirrups.

Test C4

Cast 11.3.98, tested 25.3.98, supported on two RVK-units.

Gage reading	Load per RVK-unit	Observations	Reference
18,8	45,2	Start of crack development at one of the RVK's,	
26,4	61,2	Crack development directly above the other RVK.	
34,0	77,2	Crack width 0,8 mm on one side and 0,3 mm on the other.	
38,4	86,4	Slight crack increase.	
43,0	96,1	Crack width increased to 1,5 mm on one side and 0,8 mm on the other.	Picture 23
61,5	134,9	Failure.	Picture 24

Picture 23. Test C4 at 96 kN.

Picture 24. Test C4 at 135 kN (failure).

REPORT ON LOAD TESTS ON RVK 40 - UNITS

CONTENT: **Page**

Hønefoss, June 1998.

Sven Alexander

CONCLUSIONS

The tests have documented that the governing parameter for the load carrying capacity is the anchorage of the front reinforcement. Due to the shape of the stirrups in the front the behavior of the connection was very ductile – actually real failure was never achieved in the tests. Consequently criteria had to be established to define the limits to be considered.

The service load limit was defined as the load at which the deformations became unacceptable for use in practice.

Failure was defined as the load at which the deformations started to increase considerably for small increments in the load – see figure 3.

The safety against unacceptable deformations is approximately 1,5, depending to a certain extent upon the ratio between live load and dead load as well as the load factors.

The factor of safety against failure as defined above is approximately 2,3, depending to a certain extent upon the ratio between live load and dead load as well as the load factors.

The tests have documented that the calculation model for the reinforcement shown in Memo 23 is correct.

The recommended reinforcement model as shown in Memo 26 gives the best anchorage for the reinforcement.

The RVK units used in the tests were designed for an ultimate load capacity of 50 kN. However, since the anchorage of the reinforcement made it reasonable to limit the ultimate load to 40 kN, the unit was redesigned. The calculations are shown in the document “Calc-RVK40.doc”.
The validity of the calculation model is documented because the same calculation model was used for the design of RVK100, and in all the tests done on with RVK100 the failure was also here always the anchorage of the reinforcement – with two exceptions:
In test A1 there was a local buckling of the thin steel plate used to form the opening in the concrete, as visible in picture 3 in the report on the RVK100 tests.
In test C3 there was a local deformation of the inner tube at the support, as visible in picture 22 in the report on the RVK100 tests.

BACKGROUND

A request from one of Spenncon's licensees for use of RVK-units in very slim slabs, prompted a discussion about how the reinforcement ought to be arranged when using the RVK-units in slabs of small depths, and what the minimum depth of slabs should be. The standard slab depth for use with RVK100 is 265 mm, and the customer wanted to use RVK in slabs with a depth of 150 mm. Based on the results of the tests of RVK 100 in slabs with 265 and 200 mm depth with different reinforcement patterns (see separate report), RVK 40 was developed on paper. To document the calculations and reinforcement model the RVK 40 units were tested. This report contains the results of these tests.

TEST SPECIMENS

Two specimens were produced, with two RVK 40 in one end and one in the other. This way it was expected to achieve six test results. The slabs were 1200 mm wide and 3300 mm long, with a thickness of 150 mm.

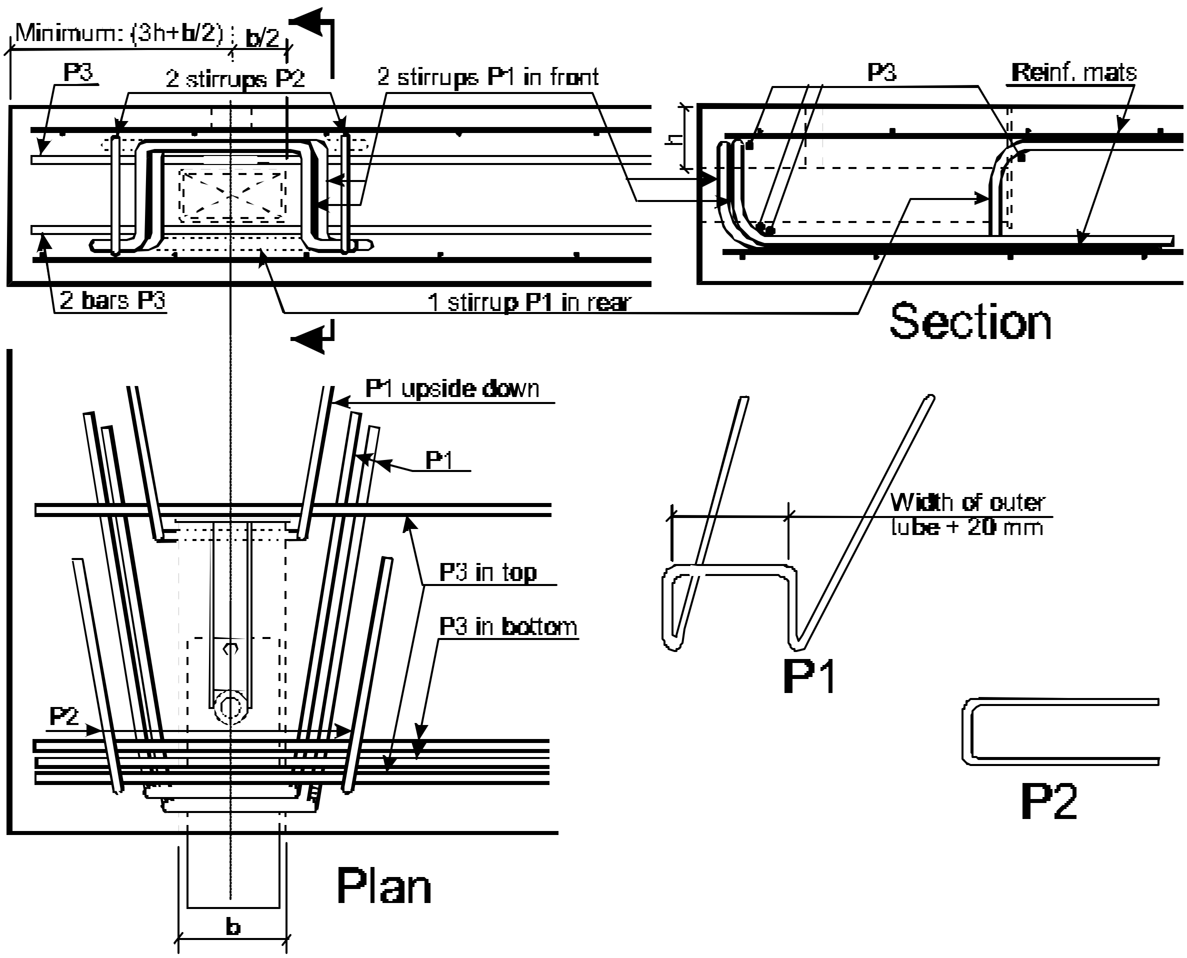
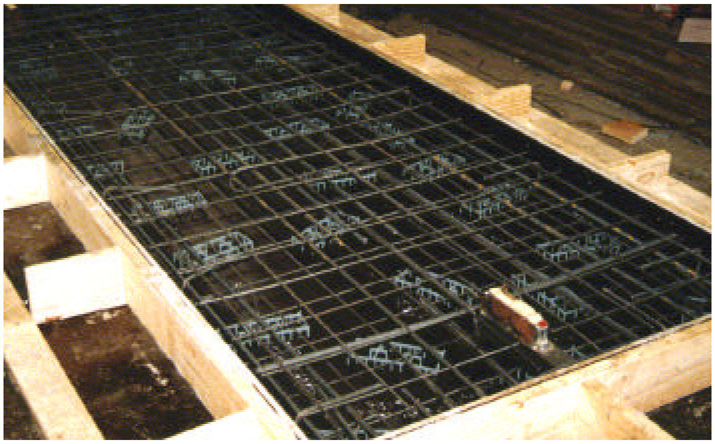


Figure 1. Reinforcement for the RVK 40 units.

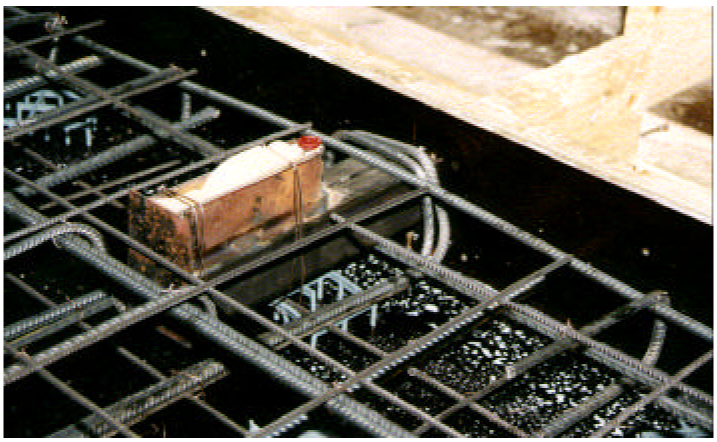
The proposed minimum edge distance would be (3h+b/2) = 3×50+80/2 = 190 mm. In the tests 250 mm were used to make sure that a too small edge distance would not influence the results. The cracks pattern could also document this minimum requirement.

The diameters of all bars P1, P2 and P3 were 8 mm, with a yield strength of 500MPa.

The reinforcement mesh has a steel area of 131 mm^2/m.



Picture 1. Main reinforcement in the test slab.



Picture 2. Reinforcement in the end with one unit.

Picture 3. Reinforcement in the end with two units.

The test specimens were cast on the 11th and 12th of May 1998, and tested on the 19th and 20th of May and the 11th of June.

TEST GEOMETRY

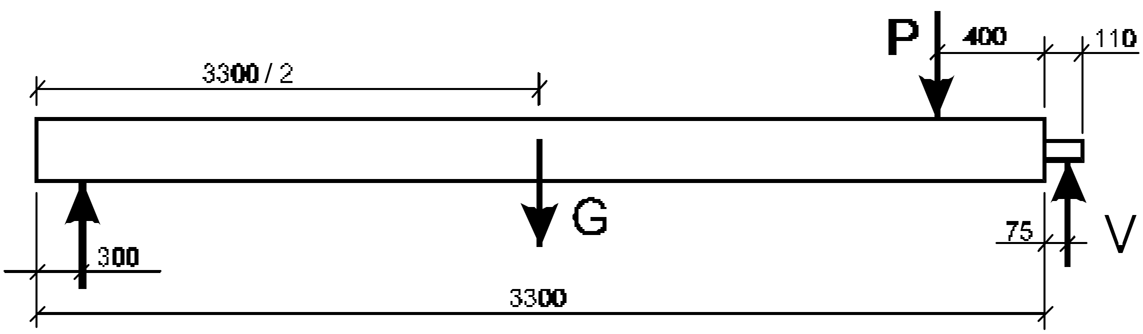
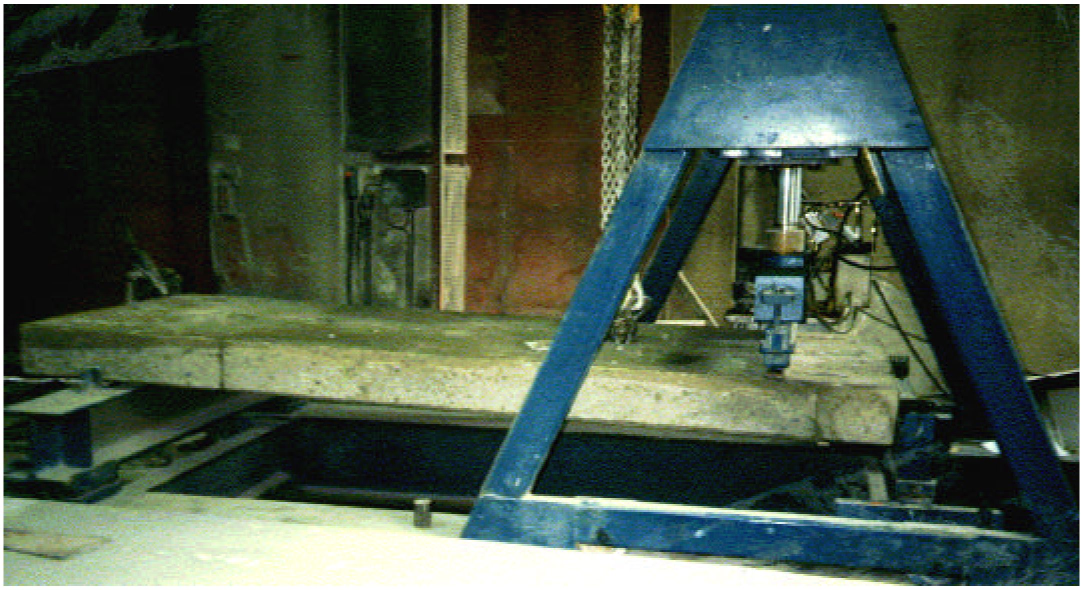


Figure 2. Test geometry.

V = support reaction
P = load from the hydraulic jacks = 4,97 kN for a gage reading on the test rig R = 1 bar.
G = weight of the test specimen = 14,9 kN

$V \times (3300 - 300 + 75) = G \times [(3300/2) - 300] + P \times (3300 - 300 - 400)$
$V = 0{,}439 \times G + 0{,}8455 \times P$ (V, G and P in kN)
$V = 6{,}5 + 4{,}20 \times R$ (V in kN, R in bar hydraulic pressure read on the gage on the machine)



Picture 4. General view of test setup.

TEST RESULTS

Both specimens had a concrete strength of 56 MPa at the time of testing in May. Both specimens were then 8 days old at the time of testing. For the test in June (test D4) the age was 30 days. No cubes were crushed at this time, but from the established grade/time relationship for this concrete the strength was estimated to be 65 MPa.

All tests showed a ductile behavior, with large deformations a any real failure as a collapse of the support system. *Failure is the load level at which the deformations increased considerab increments of the load. Service load is defined as the load wh deformations became unacceptable.* See figure 3.

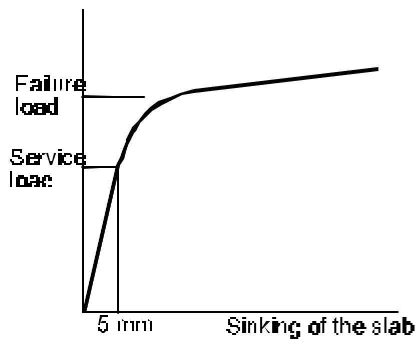


Figure 3. Definitions of service limit and failure loads.

Summary:

Test no.	No. of units on support	Gage reading at failure (bar)	Failure load, each unit (kN)	Service load (kN)	Comments
D1	1	14,9	69,2	50,3	At 14,9 bar (69,2 kN) the slab had sunk 7 mm. The load was left for about 5 minutes, without any increase of the deformations.
D2	2	32,2	70,9	45,3	At 22,5 bar (50,6 kN) a large crack developed downward from one of the RVK's. At 32,2 bar (70,9 kN) the deformations increased with insignificant load increase.
D3	1	16,6	76,3	49,4	At service load limit the crack width was about 2 mm, while the sinking of the slab was 3 mm.
D4	2	32,7	72,0	45,3	A large crack (4 mm) appeared at the left unit at 14,3 bar (33,3 kN). This crack kept increasing until failure, at service load it was 8 mm.

Evaluation of the test results.

The statistical formulas are as follows:

$$V_m = \Sigma V / n$$

$$s = \sqrt{\{[n \times \Sigma V^2 - (\Sigma V)^2] / [n \times (n - 1)]\}}$$

$$V_c = V_m - w \times s$$

V_m = mean load
V = test result
n = number of tests
s = standard deviation
V_c = characteristic load
w = coefficient

The coefficient w depends on the number of tests as follows:

Number of tests	3	4 - 5	6 - 10	11 - 20	> 20
w	2,5	2,0	1,7	1,5	1,4

Test number	Service load	Failure load
D1	50,3	69,2
D2	45,3	70,9
D2	45,3	70,9
D3	49,4	76,3
D4	45,3	72,0
D4	45,3	72,0
Mean value	46,8	71,9
Standard deviation	2,4	2,4
Characteristic value	42,8	67,8

Statistical evaluation of the test results.

Defining the average load factor γ_{avg} as follows:

$$\gamma_{avg} = (\gamma_{LL} \times LL + \gamma_{DL} \times DL) / (LL + DL)$$

LL and DL is total live load and total dead load, respectively.

The recommended ultimate limit state load on this RVK unit is 40 kN.

Assuming an average load factor γ_{avg} of 1,4:

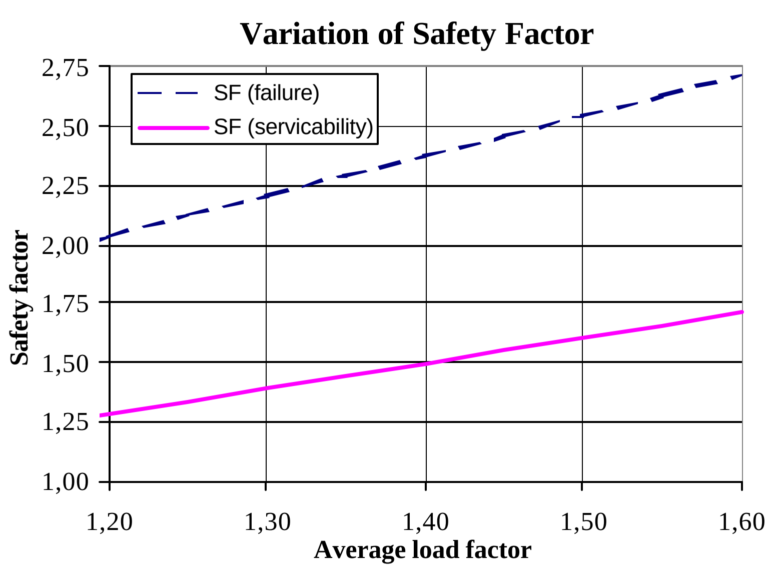
Safety coefficient = (67,8/40) × 1,4 = 2,37

Safety against unacceptable deformations = (42,8/40) × 1,4 = 1,50

If the average load factor γ_{avg} is 1,35:

Safety coefficient = (67,8/40) × 1,35 = 2,29

Safety against unacceptable deformations = (42,8/40) × 1,35 = 1,44



Detailed test observations.

Test D1

Cast 11.5.98, tested 19.5.98, supported on one RVK 40.

Cube tests: 56,0; 56,7 and 55,3 MPa. Average 56,0 MPa.

Gage reading (bar)	Load per RVK unit (kN)	Observations	Reference
4,6	25,9	Cracks of width 0,3 and 0,4 mm at the front surface, extending from the top corners of the unit towards the top, inclination about 3:1.	Figure 4
6,0	31,8	One crack was visible on the top surface of the slab, extending 40 mm in from the front surface.	Figure 4
8,0	40,2	Cracks continued to develop to widths of 1,8 and 1,0 mm. The crack on the top surface was now extending 130 mm.	
10,4	50,3	The concrete above the unit had lifted 2 mm. Several new small cracks had developed at the front surface.	
14,9	69,2	The concrete above the unit had lifted 7 mm. The cracks at the front surface were about 8 mm. No increase in deformations when the load was left on for about 5 minutes.	

Test D2

Cast 11.5.98, tested 19.5.98, supported on two RVK 40.

Cube tests: 56,0; 56,7 and 55,3 MPa. Average 56,0 MPa.

Gage reading (bar)	Load per RVK unit (kN)	Observations	Reference
5,4	14,6	Cracks of width about 0,7 at the front surface above the right unit, otherwise as for the first stage of test D1.	Figure 4
12,2	28,9	Small cracks (0,2 mm) had developed on the front surface by the left unit, increased crack width (2,8 mm) for the right unit. No visible cracks on the top surface.	
16,0	36,9	Cracks visible on the top surface by the right unit.	
20,0	45,3	The concrete above the unit on the right side had lifted 4 mm, on the left side 3 mm.	
22,5	50,6	A crack (0,2 mm) developed at the front surface by the left unit, extending left and downward from the lower left hand corner of the unit.	
32,2	70,9	The concrete above the right unit had lifted about 10 mm.	
		Continued running the hydraulic pump – the deformations increased with negligible increase in the pressure. Ran the pump until the jacks were extended to their maximum. The damage was severe, but the load carrying capacity was still intact.	Picture 5

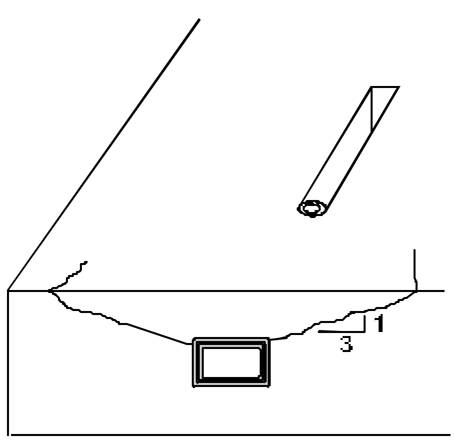


Figure 4. Typical crack pattern.

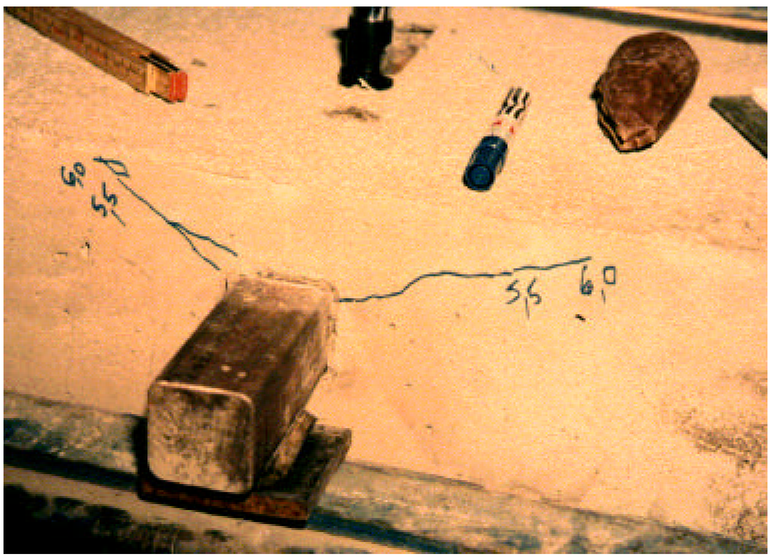
Picture 5. The right unit in test D2 when the test was discontinued and the debris removed.

Test D3

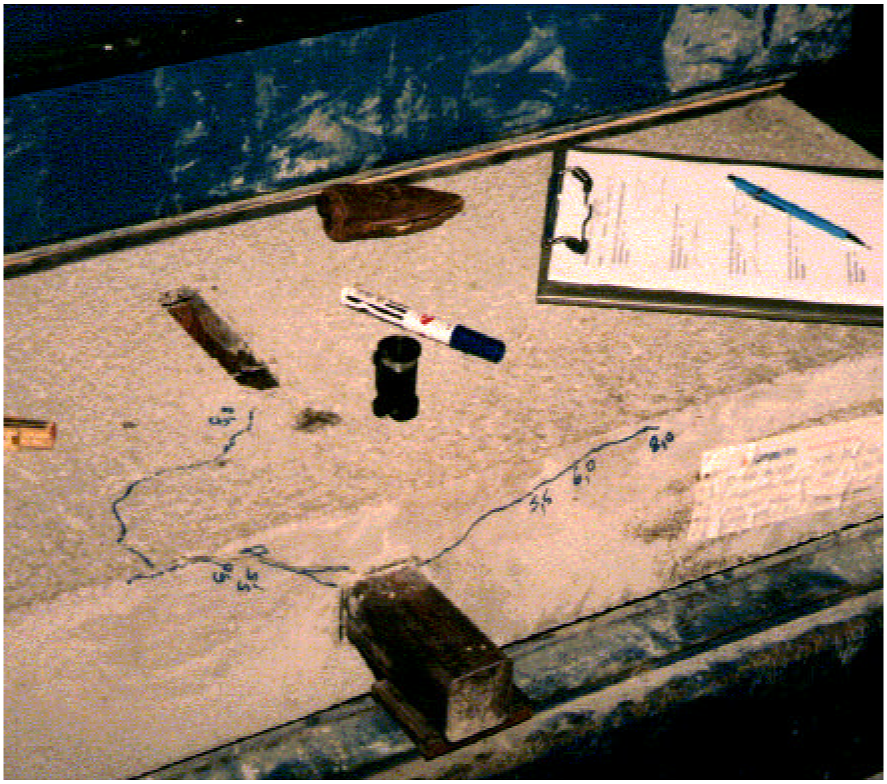
Cast 12.5.98, tested 20.5.98, supported on one RVK 40.

Cube tests: 56,0; 56,7 and 56,0 MPa. Average 56,2 MPa.

Gage reading (bar)	Load per RVK unit (kN)	Observations	Reference
5,5	29,7	Crack width less than 0,1 mm at the front surface.	
6,0	31,8	Slight increase in crack width.	Picture 6
8,0	40,2	Crack width 1,5 and 1,0 mm at the front surface. One crack was extending 45 mm along the top surface on one side, but the vertical deformations were negligible.	Picture 7
10,2	49,4	Crack width at the front surface increased to 2,0 mm on both sides. One crack was extending 130 mm on the top surface.	
16,6	76,3	Failure load.	



Picture 6. Test D3 at 31,7 kN.



Picture 7. Test D3 at 40,2 kN.

Test D4

Cast 12.5.98, tested 11.6.98, supported on two RVK 40.

Concrete grade ≈ 65 MPa.

Gage reading (bar)	Load per RVK unit (kN)	Observations	Reference
0	0	Small cracks (0,3 mm) were visible at the front surface, extending downward at about 45 ^{o} from the lower corners of both units.	Figure 5
2,9	9,4	A small vertical crack developed on the front surface directly above the right unit. The crack was not visible on the top surface.	Picture 8
6,0	15,9	Small cracks.	
12,2	28,9	Increased crack lengths, insignificant increase of crack width.	Picture 8
14,3	33,3	Crack width at the front surface increased to 4 mm on the left side of the left unit. All other crack widths less than 1 mm.	
20,0	45,3	Crack width at the front surface increased to 8 mm on the left side of the left unit. All other crack widths practically unchanged. The vertical crack at the front surface above the right unit now became visible at the top surface.	Picture 9
26,3	58,5	Insignificant changes in the cracks.	
32,7	72,0	Failure load.	
32,7	72,0	The load was kept constant for about 5 minutes. The sinking of the slab increased at an even rate.	Picture 10

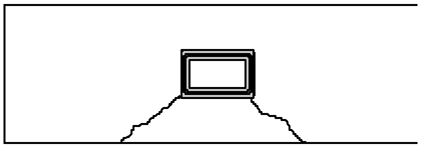
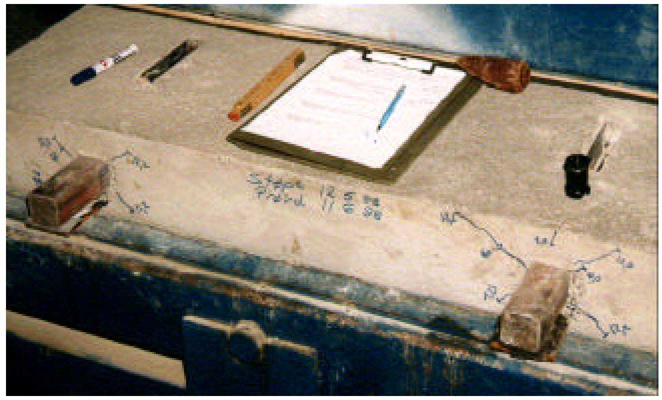


Figure 5. Cracks in the slab before start of test D4.



Picture 8. Test D4 at 28,9 kN.

Picture 9. Test D4 at 45,3 kN.

Picture 10. Test D4 after 5 minutes with 72,0 kN.

Picture 11. The extremely skilled test personnel examining test D3 after failure.