TEST REPORT

Load tests of the beam unit of BCC 250

SB-Produksjon, Åndalsnes

CONTENT **Page**

CONCLUSION

During the development of BCC 250 extensive calculations and analysis of the force pattern in the steel units as well as in the reinforcement and concrete has been carried out. In addition various welding methods for the production of then units has been tried and evaluated. To document the calculation model and production method a test series for the beam unit has been carried out.

As expected, the tests documented that the stirrups at the face of the unit are the weak link. Under the supposition that these stirrups always will have their "open" end at the bottom of the beam the failure will always be ductile with clear development of cracks before failure. However – even with relatively poor anchorage of the stirrups in the top of the beam – the characteristic failure load was higher than the theoretical failure load.

The tests show that the design model predicts a correct failure mode for BCC 250. The design and production method gives the required level of safety in the steel unit itself.

It was decided to define a crack width of 0,6 mm (= 0,024 ≈ 3/128 inches) as failure. The tests show that the reinforcement at the face of the unit does not provide sufficient level of safety according to NS 3473 or EC 2 based on this definition.

Therefore it is recommended to increase the reinforcement at the face of the unit to achieve a sufficiently high characteristic load when the crack width reaches 0,6 mm. The chosen reinforcement is 7-Ø12 stirrups. (The cross-section of Ø12 reinforcement is 113 mm^2, and the steel quality has a yield strength is 500 MPa.)

Under this assumption it can be concluded that BCC 250 has a theoretical failure load of 250 kN with the required level of safety.

This design model is also used for BCC 450, which is a larger version with identical execution. Under the qualification of an increase of about 75 % of the calculated amount of stirrups at the face of the unit, any testing of the BCC 450 unit is not considered necessary, when designed for an ultimate limit state load of 450 kN.

Report from load tests of BCC 250.
Commissioned by SB-Produksjon, Åndalsnes.

BACKGROUND

SB-Produksjon owns the patent for BSF joint units for the connection between precast columns and beams. The need for simplification and improvement of the production of the units as well as the reinforcement used in connection with the units has been felt for some time. This applies especially to the reinforcement at the beam ends.

In addition also certain other improvements have been carried out. Therefore BCC has patent pending as a separate invention.

Extensive calculations have been carried out to find a simple execution of a unit that should have an ultimate limit state capacity of 250 kN. After some time the execution shown in figure 1 was selected.

The design of the column unit was simple without any doubts about the calculation model. For the beam unit the force pattern and reinforcment layout was more uncertain, and it was decided to carry out a test series.

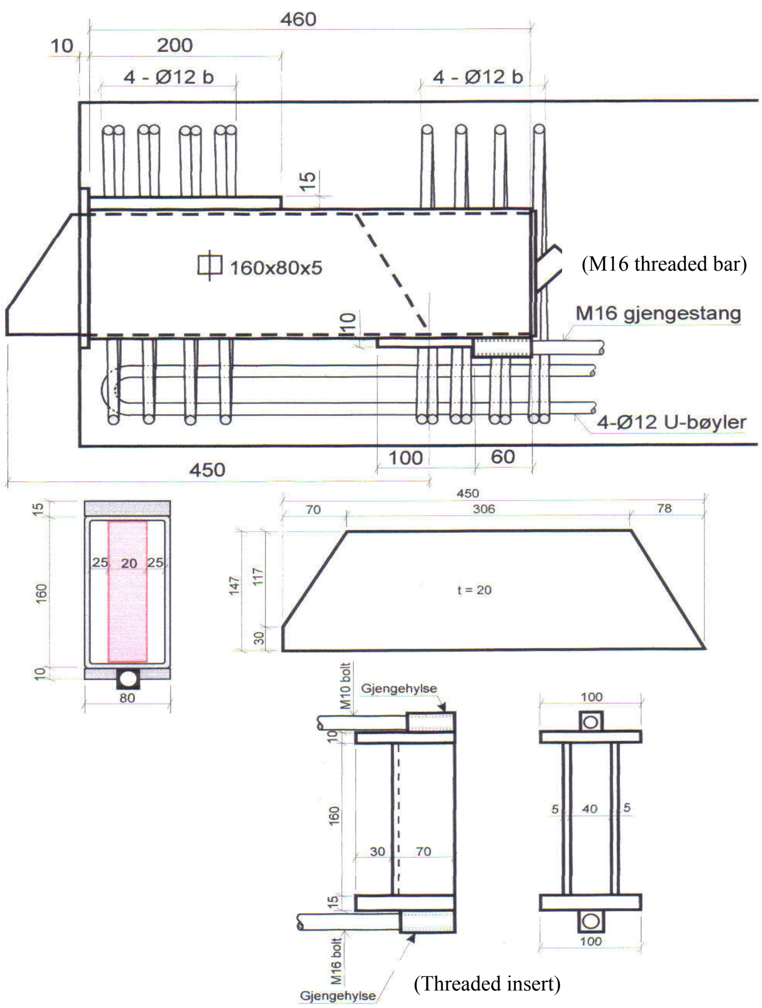

Figure 1. Execution of BCC 250.

TEST SETUP

It was decided that the test should be carried out at Spenncon AS Hønefoss in the test rig used for full scale testing of hollow core slabs. The maximum distance between the supports is 6000 mm (≈ 20 feet). The beams should have an overhang in the unloaded end to make sure that this end would not be damaged during the test. Hence one beam would yield two test results. The test geometry is shown in figure 2.

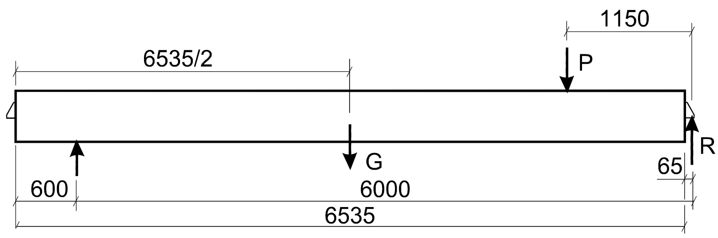

Figure 2. Test geometry.

R = support reaction
G = weight of the beam
P = load applied with two hydraulic cylinders

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$$R = [P \times (6{,}00 - 1{,}15) + 0{,}5 \times G \times (6{,}00 - 0{,}60 - 0{,}065)] / 6{,}00$$
$$= 0{,}808 \times P + 0{,}445 \times G$$

$$G = 0{,}3 \times 0{,}5 \times 6{,}535 \times 25$$
$$= 24{,}5 \text{ kN}$$

1 bar on the cylinders manometer corresponds to $P = 4{,}97$ kN

This means:
$R = 4{,}016 \times P + 11$ kN
(P i bar)

Theoretical ultimate load for R is 250 kN, which corresponds to a manometer pressure of about 60 bar. It was decided that the tests should be terminated for R ≈ 300 kN (P ≈ 72 bar), which is 20% over theoretical ultimate load.

Figure 3. The test rig.

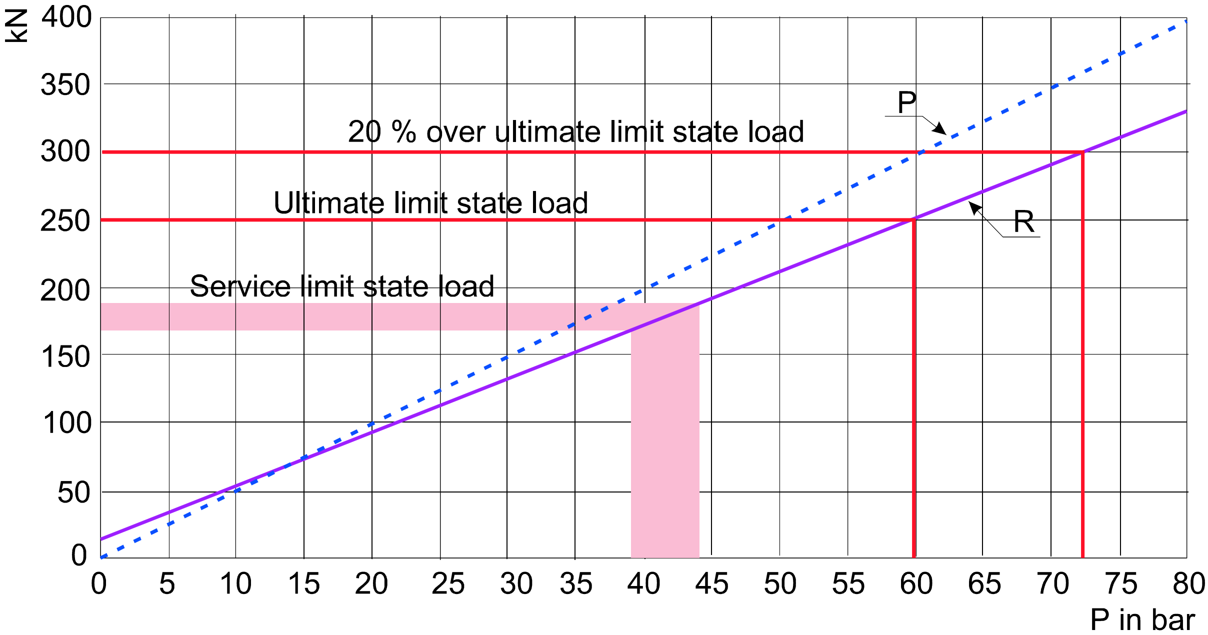

Figure 4. The relationship between P in bar and P and R in kN.

Report from load tests of BCC 250.
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TEST BEAMS

Two test beams with dimensions 300×500 mm were produced. To ensure that the test beams did not become the weak link, the main reinforcement and shear reinforcement was designed for P ≈ 110 bar ≈ 550 kN, which corresponds to R ≈ 450 kN. The stirrups in connection with the BCC unit was designed for R = 250 kN.

The concrete grade was B45 as defined in NS 3473, which corresponds to C45/55 in the CEN system. The beams were produced by Spenncon AS Trøndelag in Verdal on March 14. and 15.

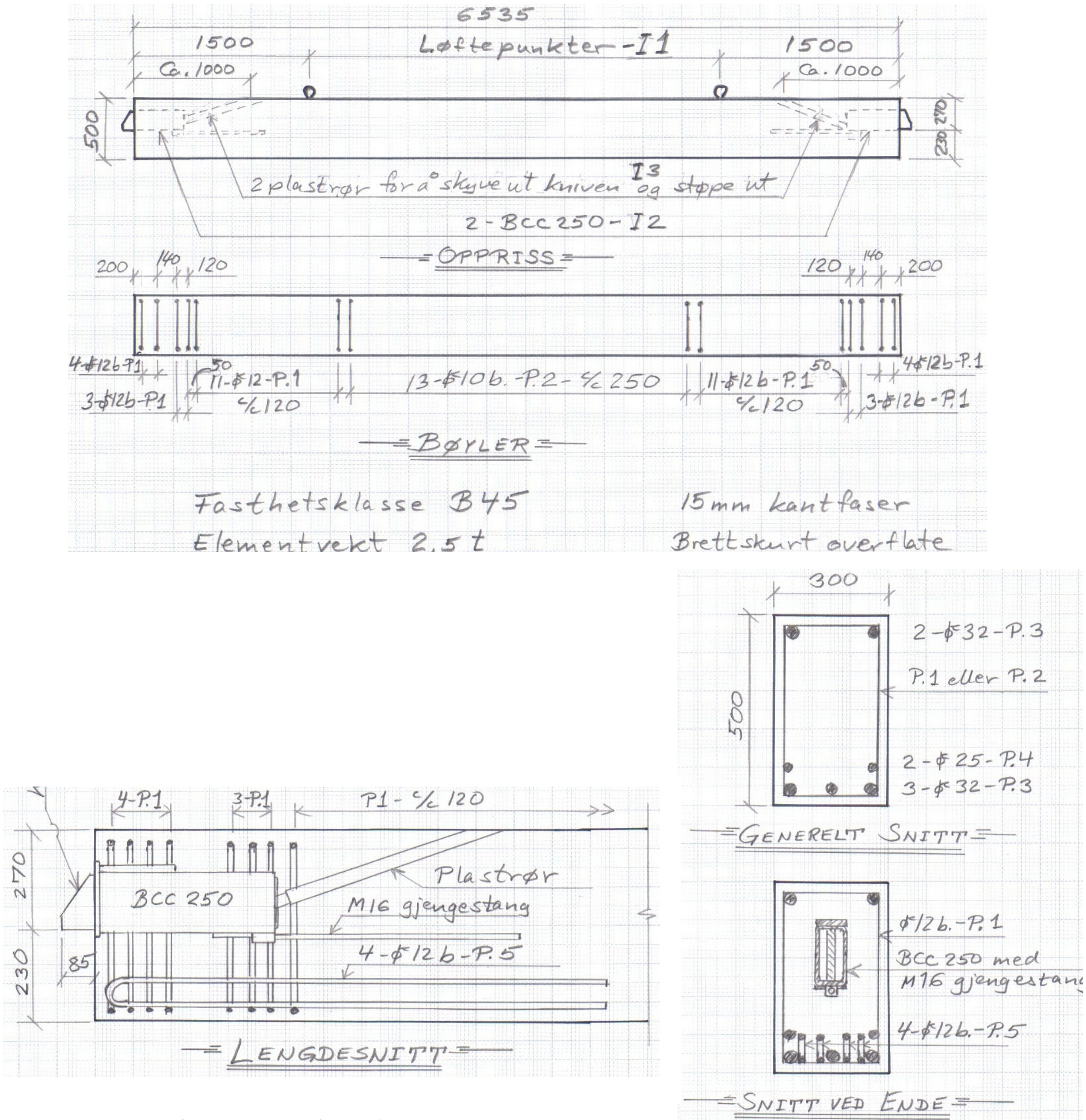


Figure 5. Reinforcement of test beams.

Figure 6. The reinforcement cage in the test beams.

The beams were tested on March 31, so the age was 16 and 17 days at the time of testing.

A rough check with Smith-hammer suggested that the concrete strength was in the order of 30 to 40 MPa. Furthermore, based on the maturity curve for this concrete it may be assumed that the concrete grade was in the order of B35 to B40 at the time of testing.

The BCC units were grouted with Nonset 120 AF early in the morning at the same day the tests took place.

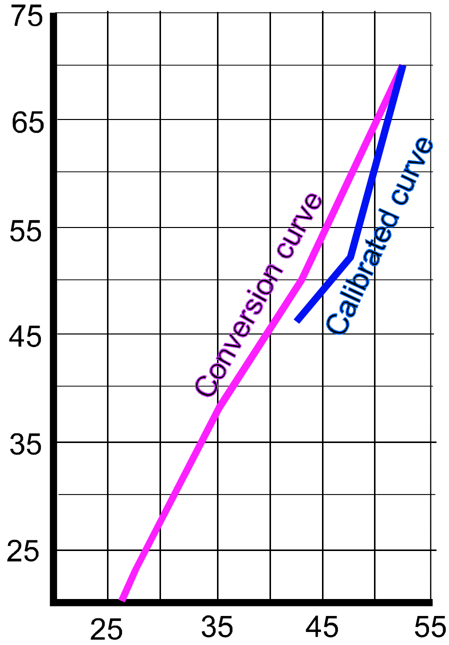


Figure 7. Conversion curve for the Smith-hammer.

TEST RESULTS AND OBSERVATIONS

Beam end marked 1:

Manometer reading P (bar)	Support reaction R kN	lb	Observations	Reference
30	131	288	First visible crack.	
40	172	378	Slight expansion of the crack. Crack width < 0,15 mm.	Figure 8.
60	252	554	Further crack development. Crack width ≈ 0,25 mm.	Figure 9.
70	292	642	Further crack development. Crack width ≈ 0,35 mm. Shear and bending cracks in the beam.	Figure 10.
78	324	713	Crack width ≈ 0,60 mm. Test terminated. After load release the crack width went back to about. 0,2 mm.	

Figure 8. Test 1 at R ≈ 170 kN

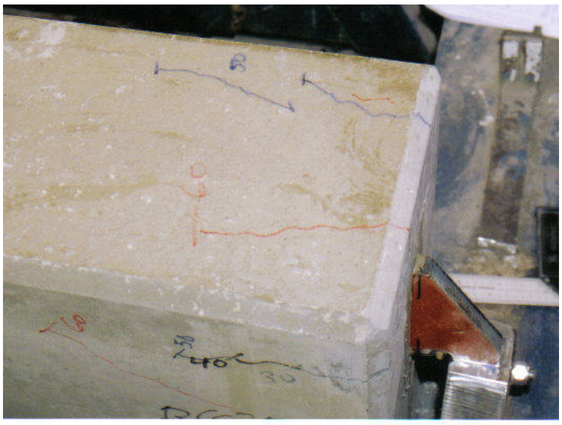


Figure 9. Test 1 at R ≈ 250 kN.

Figure 10. Test 1 at R ≈ 300 kN.

Beam end marked 2:

Manometer reading P (bar)	Support reaction R kN	lb	Observations	Reference
40	172	378	First visible crack. Crack width < 0,10 mm.	
50	212	466	Slight expansion of the crack. Crack width < 0,15 mm.	Figure 11.
60	252	554	Further crack development. Crack width ≈ 0,25 mm. Shear cracks in the beam.	
80	332	730	Further crack development. Crack width ≈ 0,45 mm.	Figure 12.
90	372	818	Crack width ≈ 0,80 mm. Test terminated.	Figure 13.

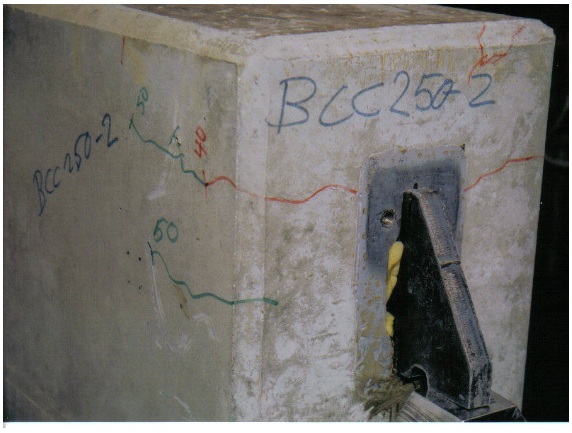


Figure 11. Test 2 at R ≈ 210 kN.

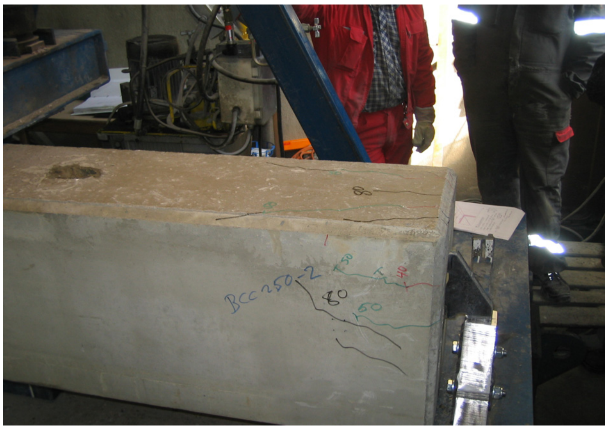


Figure 12. Test 2 at R ≈ 330 kN.

Figure 13. Test 2 at R ≈ 370 kN.

Beam end marked 3:

There was an uncertainty whether the grouting with Nonset 120 AF had been quite successful.

Manometer reading P (bar)	Support reaction R		Observations	Reference
	kN	lb		
40	172	378	First visible crack. Crack width < 0,10 mm.	
50	212	466	Slight expansion of the crack. Crack width < 0,15 mm.	
72	300	660	Further crack development. Crack width ≈ 0,35 mm. Shear cracks in the beam.	Figure 14.
85	352	774	Violent bang, the concrete over the stirrups burst off – test terminated. All the stirrups had the ”open” side up – as also can be seen on figure 6.	Figure 15 and 16.

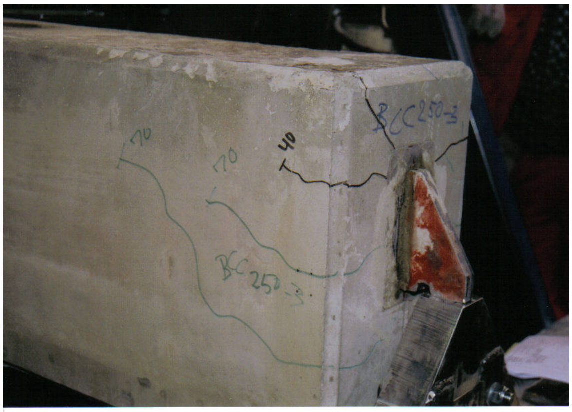


Figure 14. Test 3 at R ≈ 300 kN.

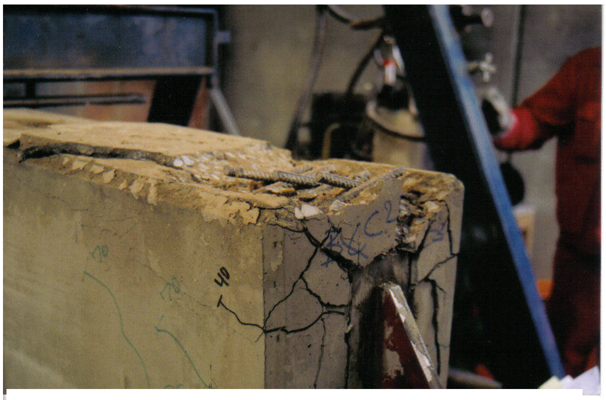


Figure 15. The end of test 3 after brittle failure at R ≈ 350 kN.

Figure 16. Top of stirrups after brittle failure at R ≈ 350 kN.

The failure was caused by bending stresses perpendicular to the longitudinal axis of the beam at the beam end. Since all the stirrups had the lap splice of the legs at the top of the beam (the plan was that every second stirrup should have been upside-down), the horizontal part of the stirrup had poor anchorage for transverse stresses. The anchorage capacity to the concrete was exceeded, and it was the spot weld between the two legs of the stirrup (see figure 6) that provided the tensile capacity. At the instance when this spot weld failed due to these tensile stresses, the stirrups straightened out, and a trapezoidal shaped concrete block was blown off over the BCC beam unit. This can be clearly seen in figure 15, which shows that the beam does not have any transverse expansion. This type of brittle failure can be prevented by placing the stirrups ”upside-down”. The reason that this particular test failed in such a way is probably caused by the somewhat uncertain quality of the grouting of the rectangular tube resulting in more concentrated loads against the concrete above the rectangular tube.

Beam end marked 4:

Manometer reading P (bar)	Support reaction R		Observations	Reference
	kN	lb		
40	172	378	First visible crack. Crack width < 0,10 mm.	Figure 17.
50	212	466	Slight expansion of the crack. Crack width ≈ 0,20 mm.	
60	252	554	Further crack development. Crack width ≈ 0,25 mm. Shear cracks in the beam.	
75	312	686	Crack width ≈ 0,6 mm.	Figure 18, 19 and 20.
85	352	774	Further crack development. Crack width ≈ 0,8 mm.	
89	368	810	Crack width ≈ 1 mm. Test terminated.	

Figure 17. Test 4 at R ≈ 170 kN.

Figure 18. Test 4 at R ≈ 310 kN.

Figure 19. Test 4 at R ≈ 310 kN

Figure 20. Test 4 at R ≈ 310 kN.

EVALUATION OF THE TEST RESULTS

Up to a support reaction of 350 kN all the tests had about the same crack development. At this load test number 3 had a brittle failure.

All tests had approximately linear crack development up to about 275 kN. After that the curves gradually changed direction, and the crack development became faster.

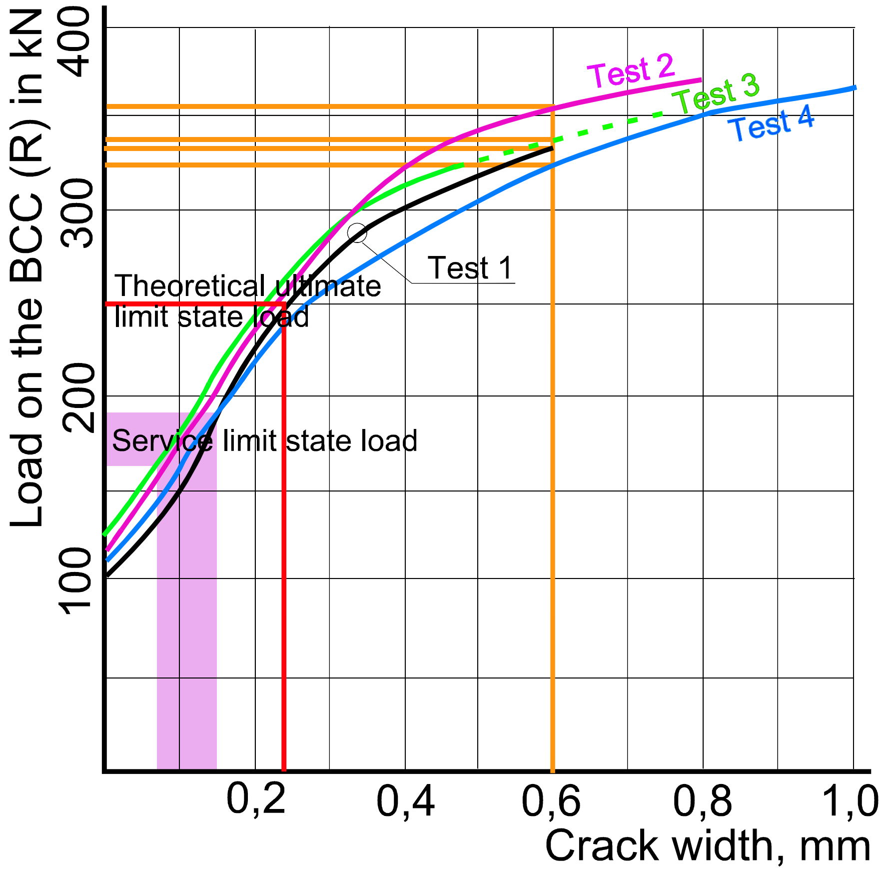


Figure 21. Crack development during testing.

Due to the lack of a clear failure load for three of the four tests, it was decided to define a crack width of 0,6 mm (3/128 inches) as failure.

This leads to the following table:

Test no.	Failure load R (kN)
1	333
2	356
3	338
4	322

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 value of the load
V = test result
n = number of tests
s = standard deviation
V_c = characteristic load
w = koefficient

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

$V_m = (333+356+338+322) / 4 = 1349 / 4 = 337,25$ kN
$s = \sqrt{\{[4 \times (333^2+356^2+338^2+322^2) - (1349)^2] / [4 \times (4-1)]\}}$
$= \sqrt{[(4 \times 455553 - 1819801) / 12]} = \sqrt{200,9} = 14,17$
$V_c = 337,25 - 2,0 \times 14,17 = 309$ kN

This corresponds to a ”material coefficient” of 309/250 = 1,23.
The material coefficient for reinforced concrete in the ultimate limit state is 1,4 in NS 3473 and 1,5 in EC 2. However, in EC 2 this is a “boxed” value, subject to be changed in national annexes.

Figure 21 also shows that within normal service limit state loads the maximum crack width will be less than 0,15 mm (0,0059 < 1/128 inches), which is considered as a visually acceptable crack width both for professionals and laymen.

The fact that the cracks almost closed after load release documents that the stresses in the reinforcement still was below the elastic limit.

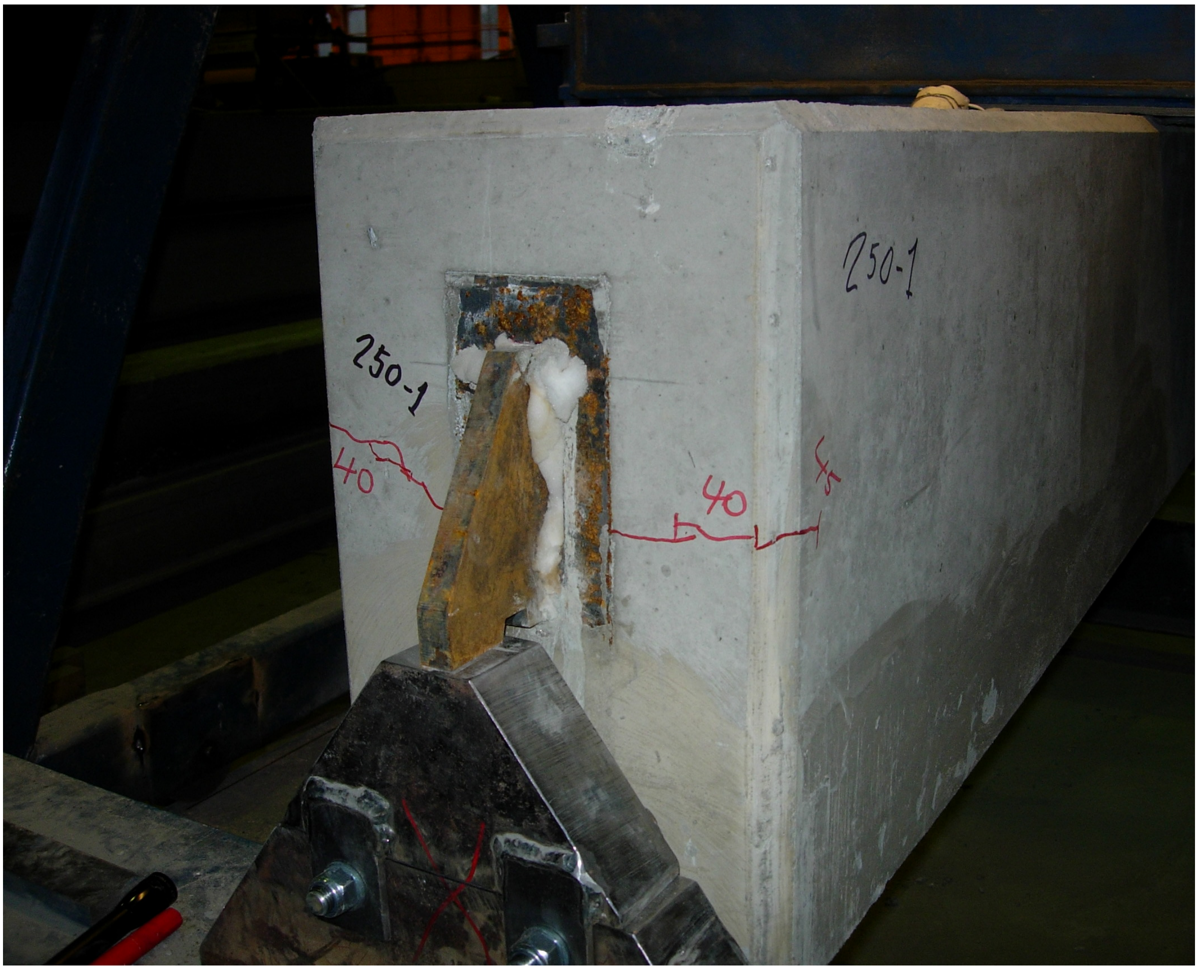
However, the crack development should be limited so that a crack width of 0,6 mm (defined as failure) is reached at a characteristic load of about 250×1,4 = 350 kN. Hence the mean value of the test results must be about 350+2×14 ≈ 375 kN. Because the reinforcement is in the elastic range, the crack width will be proportional to the applied load and inversely proportional with the cross sectional area of the reinforcement.

The tests that are carried out shows that test loads of 375 kN is reached for a crack width of approximately 1,0 mm with the reinforcement provided (see figure 20). Consequently the amount of reinforcement must be increased with a factor of 1,0/0,6 = 1,67. The reinforcement was 4-Ø12 = 4×113 = 452 mm^2. The reinforcement should therefore be increased to 452×1,67 = 755 mm^2, which corresponds to 755/113 = 6,7 ≈ 7-Ø12.

The results of the calculations show a requirement for 430 mm^2 for this reinforcement, which must be increased to approximately 755 mm^2 to limit the crack width. This is an increase of about 75 %. The chosen reinforcement (7-Ø12) is an increase of 84 % compared to calculated reinforcement.

ADDITIONAL REPORT

Supplementary tests of the BCC 250 beam unit



SB-Produksjon, Åndalsnes

CONTENT **Side**

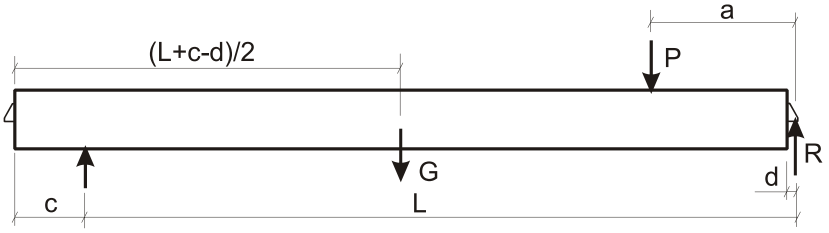
CONCLUSION

Using the theoretically calculated area of stirrups in the front of the beam units and stirrup arrangement as shown in figures 3 and 4 the BCC 250 unit will at a support load of 250 kN (ultimate limit state load) have the required level of safety according to NS 3473 (the Norwegian concrete design standard). The crack widths will not be offensive.

BACKGROUND

Based on the tests carried out 31.3.2005, the test report dated 20.5.2005 recommends an increase of the amount of reinforcement in the front of the unit relative to theoretically calculated area of stirrups. This was necessary to achieve sufficiently high characteristic load when the crack width was 0,6 mm. Chosen reinforcement was 7-Ø12 stirrups – which is an increase of 75 % compared to calculated reinforcement area.

A closer analysis of the fracture models observed in the tests triggered the idea that a slight change of the reinforcement pattern could make this increase unnecessary. Therefore a beam with cross-section 300×500 mm was produced. The beam had BCC 250 in both ends and a reinforcement pattern as shown in figure 4. The beam should be tested exactly the same way as described in test report dated 20.5.2005. The test geometry is shown in figure 1.



Figur 1. Prøvegeometri.

R = Support load
P = load applied with two hydraulic cylinders
G = dead load of the beam = 0,3 × 0,5 × 6,5 × 25 = 24,4 kN

Beam length = 6500 mm
L = 6000 mm
d = 65 mm
c = 6500 + 65 – 6000 = 565 mm
a = 1150 mm

$R = [P \times (6{,}00 - 1{,}15) + 24{,}4 \times (6{,}5 / 2 - 0{,}565)] / 6{,}00$
$= 0{,}808 \times P + 11$ kN
1 bar on the manometer of the cylinders corresponds to P = 4,97 kN
Consequently: $R = 4{,}016 \times P + 11$ kN (P in bar)

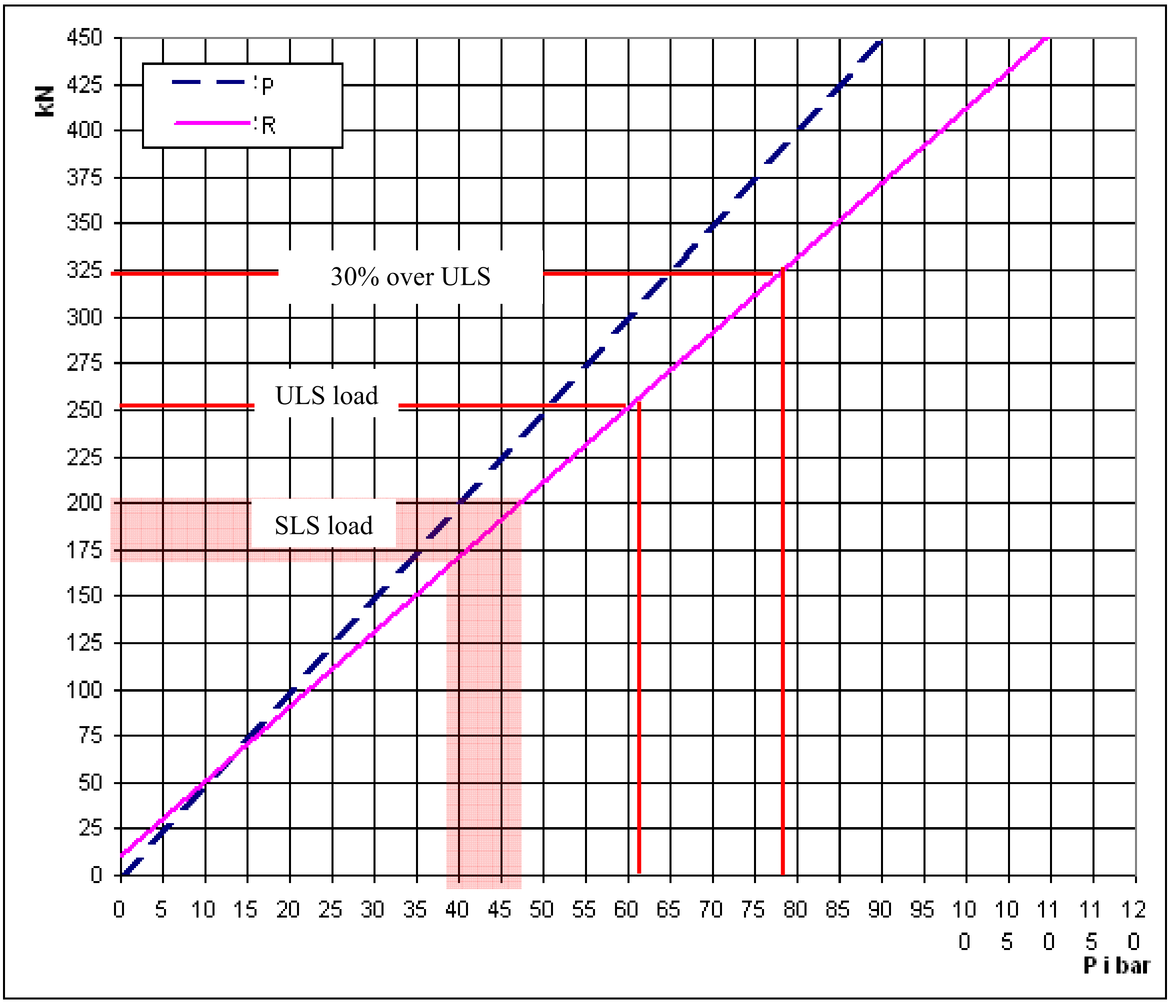


Figure 2. The relationship between P in bar and P and R in kN.

THE TEST BEAM

A test beam with dimensions 300×500 mm was produced. To make sure that the test beams did not become the weak link, the main reinforcement and shear reinforcement was designed for P ≈ 110 bar ≈ 550 kN, which corresponds to R ≈ 450 kN. The stirrups in connection with the BCC unit was designed for R = 250 kN.

The concrete grade was B45 as defined in NS 3473, which corresponds to C45/55 in the CEN system. The beams were produced by Spenncon AS Trøndelag in Verdal on 20.10.2005. The beam was tested on 24.11.2005, so the age was 35 days at the time of testing. The BCC units were grouted with Nonset 120 AF the day before the test.

Testing with Smith-hammer yielded the following results:
42-38-40-48-44-42-40-42-44-46, mean value 43 MPa.
Production data for the test beam is shown in figures 3, 4 and 5.

Report from supplementary tests of BCC 250.
Commissioned by SB-Produksjon, Åndalsnes.

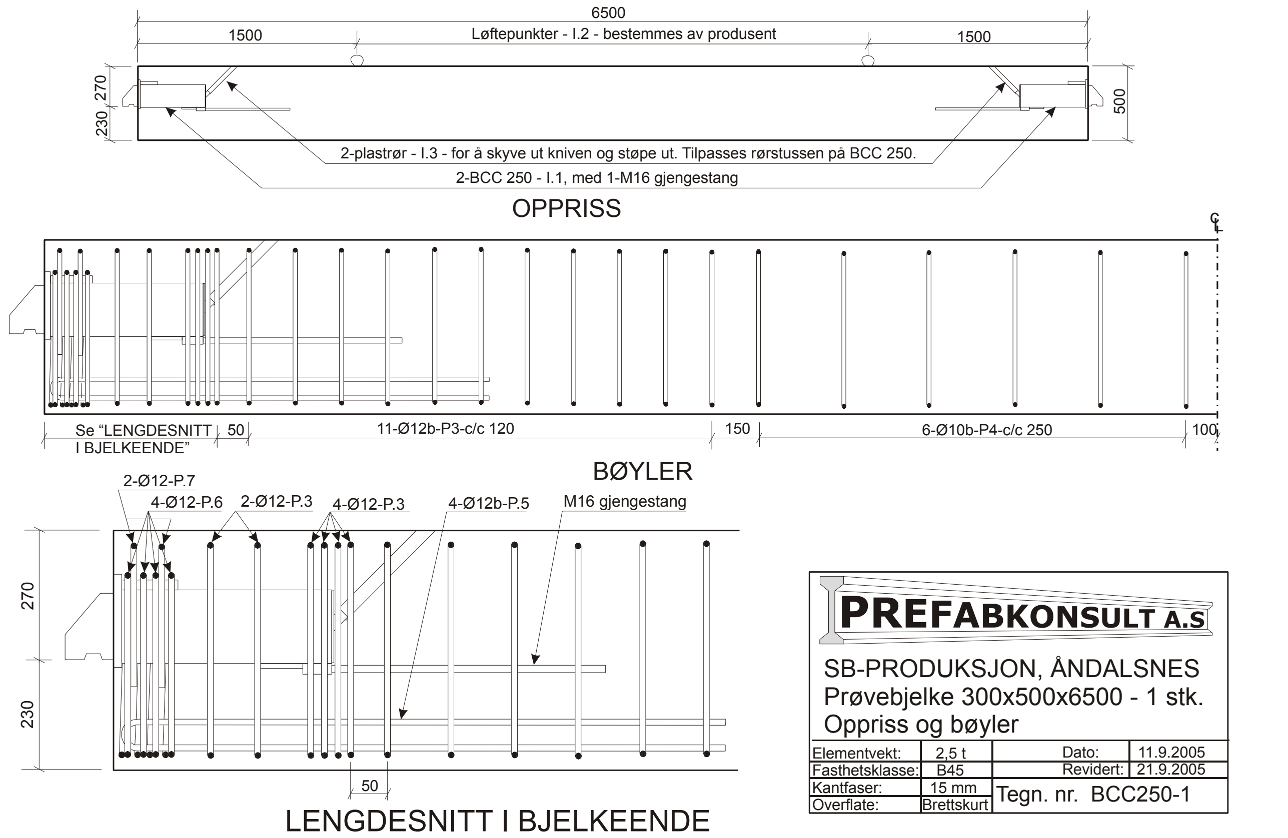


Figure 3. Side views of the test beam.

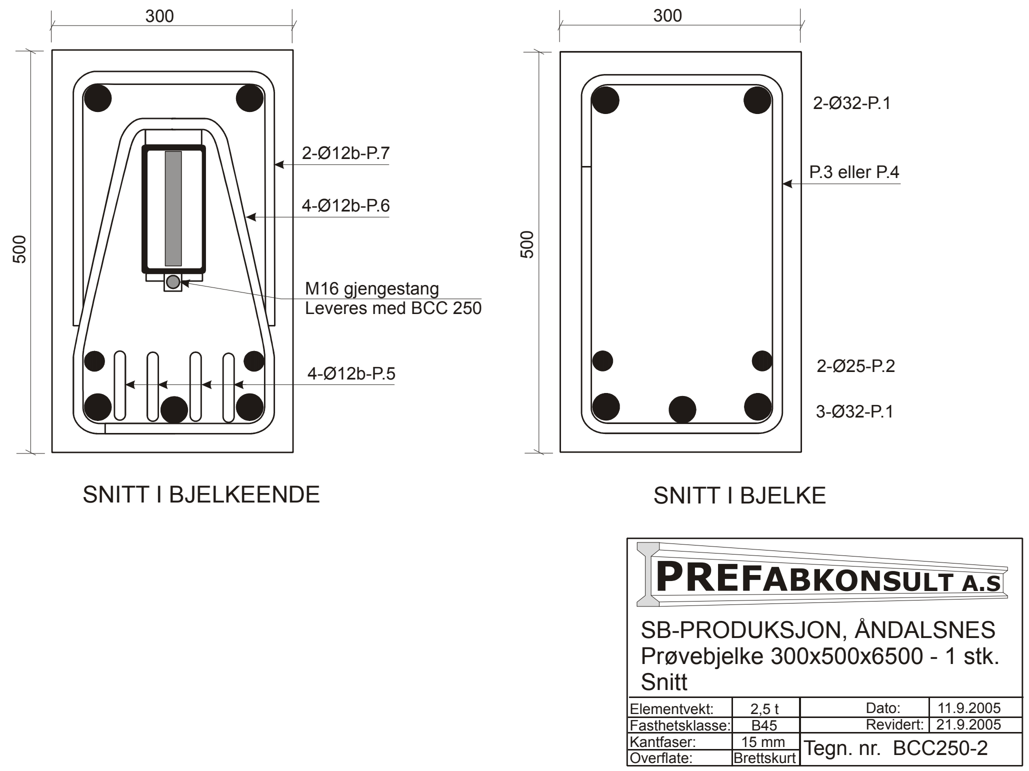


Figure 4. Sections of the test beam.

Report from supplementary tests of BCC 250.
Commissioned by SB-Produksjon, Åndalsnes.

Pos.	Diam.	Kappl.	Ant. pr. element	Bøying	Kval.
P.1	32	6460	5	6460	B500C
P.2	25	5400	1	6000	B500C
P.3	12	1700	34	200, 250, 450, 450, 250	B500C
P.4	10	1700	12	200, 250, 450, 450, 250	B500C
P.5	12	2600	8	1250, 70, 1250	B500C
P.6	12	750	8	75, 100, 75, 395, 290, 105, 200, 105, 200	B500C
P.7	12	850	4	250, 300	B500C
Innst. gods	Gjenstand			Beskrivelse	
I.1	BCC 250		2	Skjult konolløsning med bruddgrensekapasitet 250 kN. Leveres med 1-M16 gjengestang, L=600,	
I.2	Løfteanker		2	Beskrives av produsent (Deha?)	
I.3	Plastrør		2	Innvendig diameter ca. 45 mm, tilpasses utvendig diameter på rørstussen i enden av BCC 250. Lengde ca. 160 mm.	

Should have been 2. Was corrected during production.

PREFABKONSULT A.S

SB-PRODUKSJON, ÅNDALSNES
Prøvebjelker 300x500x6500 - 1 stk.
Bøyeliste og materialliste

Elementvekt:	2,5 t	Dato:	14.9.2005
Fasthetsklasse:	B45	Revidert:	19.9.2005
Kantfaser:	15 mm	Tegn. nr. BCC250-3	
Overflate:	Brettskurt		

Figure 5. List of materials for the test beam.

TEST RESULT AND OBSERVATIONS.

Beam end marked 1:

Manometer reading P (bar)	Support reaction R (kN)	Observations	Reference
40	172	No visible cracks	
45	192	A few visible cracks, crack width < 0,10 mm	Picture on front page
55	232	A few visible cracks, crack width < 0,10 mm	
61,2	257	Slight crack development. Crack width < 0,15 mm	Ultimate limit state load
79,8	331	The beam has developed some bending and shear cracks. Crack width < 0,15 mm	
92	380	Cracks above the beam unit. Crack width < 0,15 mm	Figure 6
100,7	415	Crack width ≈ 0,25 mm	
106,2	438	Crack width ≈ 0,30 mm	Figure 7
109,3	450	Fracture of the knife.	Figure 8

Figure 6. Beam end at R = 380 kN

Figure 7. Beam end at R = 438 kN

Figure 8. Fracture of the knife.

The result was so convincing that the opposite end of the beam was not tested.

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