HIGH STRENGTH CONCRETE BEAMS

Carl Johan Bernhardt, Professor,
Division of Concrete Structures,
The Norwegian Institute of Technology,
The University of Trondheim, Norway

Carl Christian Fynboe, MSCE, Researcher,
Cement and Concrete Research Institute,
SINTEF, Trondheim, Norway

ABSTRACT

Static load tests have been carried out on 27-150 x 200 x 2850 mm high strength concrete beams (f_{ck} = 100 to 125 MPa). Three of these beams were subjected to a constant long-term applied load where the remaining beams were subjected to short term loading. Comparisons have been made with the present Norwegian Concrete Code.

Key words: high-strength concrete, bending and shear, long-term loading.

1. INTRODUCTION

During the last 5 to 10 years High Strength Concrete (HSC) has been used in an increasing number of cases, especially in connection with Offshore Structures.

In this field the development of practice has bypassed the code-regulations.

In order to give a sound basis for calculations several Norwegian firms and institutions /1/ have contributed to a study of the behaviour of HSC in structural components such as beams, columns etc.

The technology of hardened HSC is included in the research project and this holds for concrete with ordinary aggregate as well as with light-weight aggregate of different types.

The project is at present on-going at FCB (Cement and Concrete Research Institute, The Norwegian Institute of Technology) Trondheim.

Some of the results have been published earlier /2/.

In this paper test results will be reported for beams in HSC with ordinary aggregate. The test included beams with cube strength up to 125 MPa and in some cases the beams were held under a rather high constant load for several weeks.

A simple analysis of the results is presented in the form of a comparison with specified capacities according to the Norwegian Concrete Code. [4].

The test results may be of some value for those working with Code revision.

2. AN EXPERIMENTAL INVESTIGATION OF HSC-BEAMS

2.1 Test specimens and test set-up

A total number of 27 reinforced beams made of high strength concrete have been tested after this scheme:

No of beams	Age at testing Days	Cube strength MPa	Type of test
19	~ 28	~100	Short term
5	~570	~125	Short term
3	~570	~125	Long term

The dimensions of the beams were 150 x 200 x 2850 (b x h x l). The arrangements of reinforcement and the placement of the loads during testing are shown in Fig. 2.1.

The yield strengths of the different types of reinforcement are given in table 2.1:

Table 2.1	Yield strength (f_{sy})
Ks 40S (d = 8mm)	: f_{sy} = 427 MPa
Ks 50 (d = 16mm)	: f_{sy} = 511 MPa
Ks 50 (d = 20mm)	: f_{sy} = 510 MPa

The 19 beams which were tested after 28 days were held under moist cover together with the test cubes until the day before testing.

The remaining 8 beams were uncovered after 28 days and placed out of doors together with the test cubes until the date of testing.

The test rig is shown in Fig. 2.2. Corrections are made for the weight of the beams. In the following tables P_u gives the jack-load at failure, V_u gives the maximum shear force and M_u gives the maximum bending moment.

Throughout testing the following parameters were measured:

1) Deflection at midspan and at loaded points.

2) Concrete compression strain at midspan with 2 PL 60 Strain Gages glued to the concrete surface (Fig. 2.3).

3) Extensometer readings of 14 points along the surface of the cross-section (Fig. 2.3) at midspan.

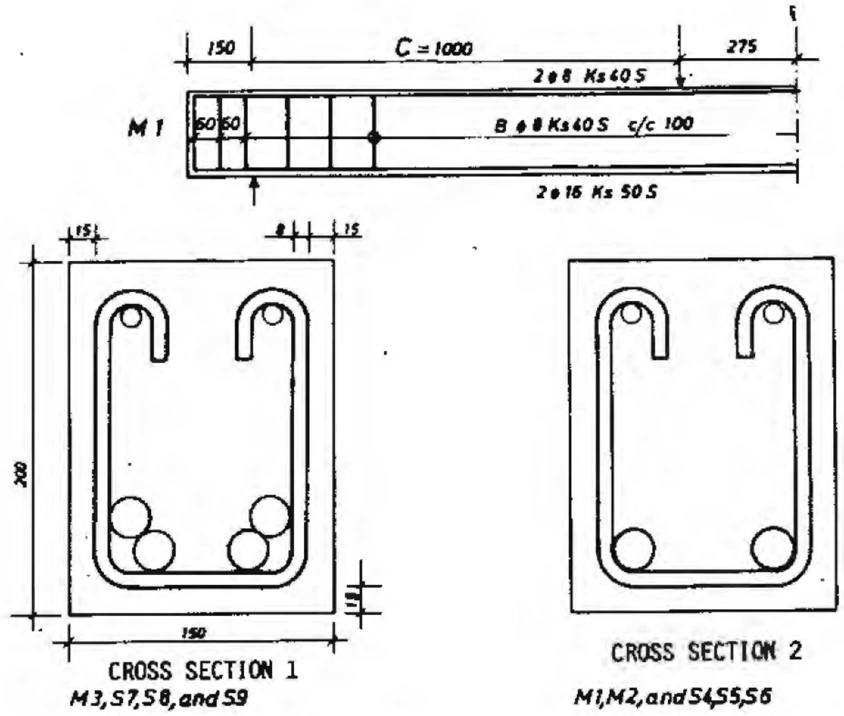


Fig. 2.1 Cross section of beams with reinforcement and typical arrangement of loads. (Cfr Table 2.2 and 2.3 for further specifications).

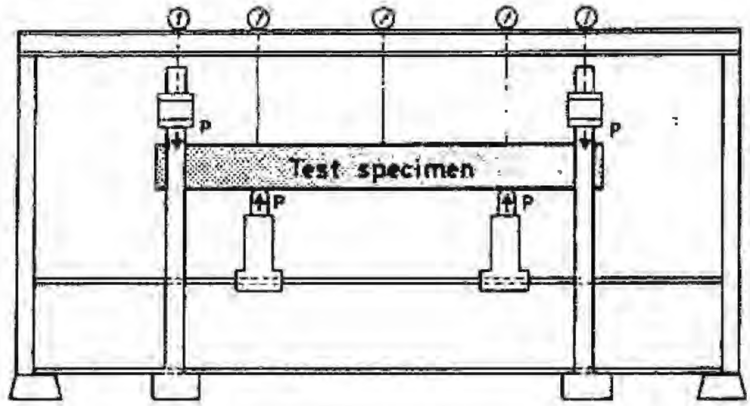
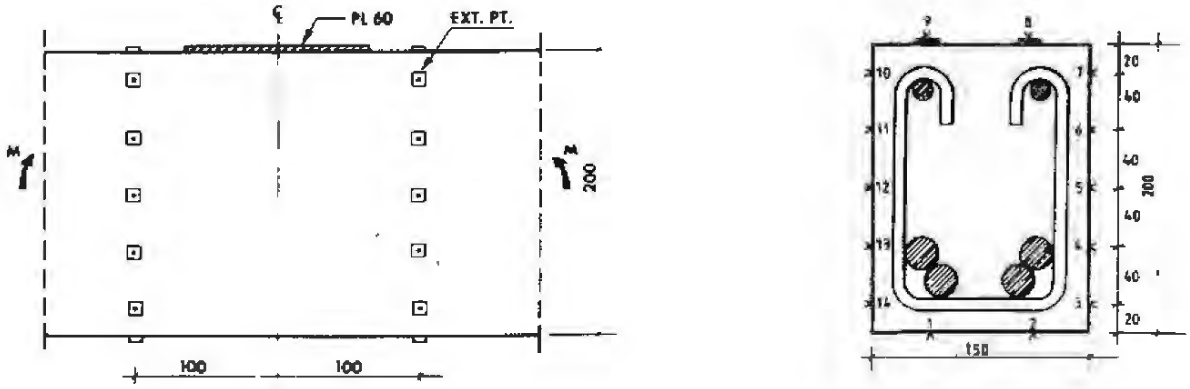


Fig. 2.2 Test rig.



Longitudinal section. Midspan

Cross section Midspan

Fig. 2.3 Set-up of extensometer readings of Strain Gages.

2.2 Test results

Table 2.2 gives the most important data and test results for beams with failure in flexure. For the main part the analysis has been carried out as a comparison between the relative values of test results versus design values according to the Norwegian Code, NS 3473 [4]. For flexure the ultimate state is defined by 1) A limited compression strain ε_c = 3,5 o/oo of the concrete or 2) A limited tension strain $\varepsilon_c = \varepsilon_{sy}$ + 5 o/oo in the steel. The design value is determined from the stress/strain diagrams of the two materials as shown in Fig. 2.4.

The limit stress f_c in the concrete is defined by the code to

$f_c = \gamma_m\ (0{,}4f_{ck}+6)$ MPa for strengths from f_{ck}*)=35 MPa to f_{ck}=65MPa.

In most cases the material coefficient γ_m is set to 1.25 for both materials.

The design value M_d has been calculated for the 16 beams in Table 2.2 by taking f_{ck} as the cube strength at the date of beam testing and by using the f_c-formula, regardless of the limitation f_{ck} = 65 MPa.

The relative values M_u/M_d will indicate the general safety level for failure in flexure, and this is found to be between 1.29 and 1.52 for the 16 beams with varied parameters, e.g. concrete quality (98 MPa - 126 MPa), age and reinforcement.

Of special interest are the results for the beams exposed to "Long Term" - loading. Fig. 2.5 shows the concrete strain through the load history of beam S8C, starting with 7 days with a load of 623 kN (0.72 x P_u). After 1 days "resting" the load was increased to 81.9 kN (0.95 x P_u) and held for 36 days. After unloading and reloading to failure the value of P_u was found to be 86,4 kN, which gives a general safety level as high as 1.37.

Fig. 2.6 shows the development of strains and deflection during the load history of the same beam. The load histories of the beams S5C and S7C are somewhat similar; the total time of loading being 94 days for S5C and 7 days for S7C.

In table 2.2 are shown the values of deflection, f_u, at ultimate load and the ductility index f_u/f_{el} is given for the different beams.

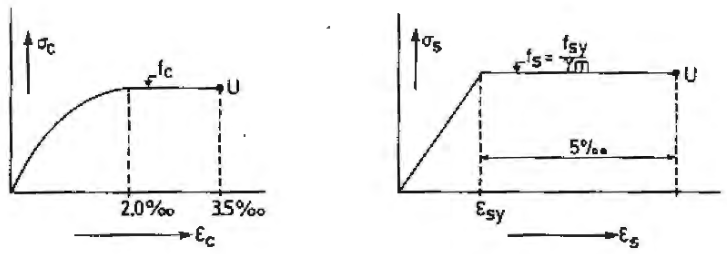


Fig. 2.4 Assumed stress/strain relations for ultimate state calculations of design value of bending moment (M_d) according to Norwegian Code NS 3473.

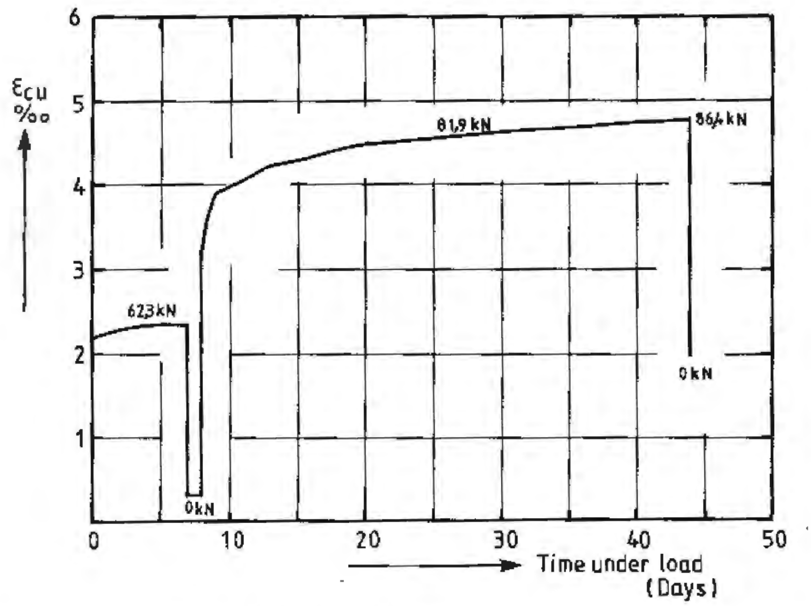


Fig. 2.5 Concrete Strain development through load history of Beam S8C.

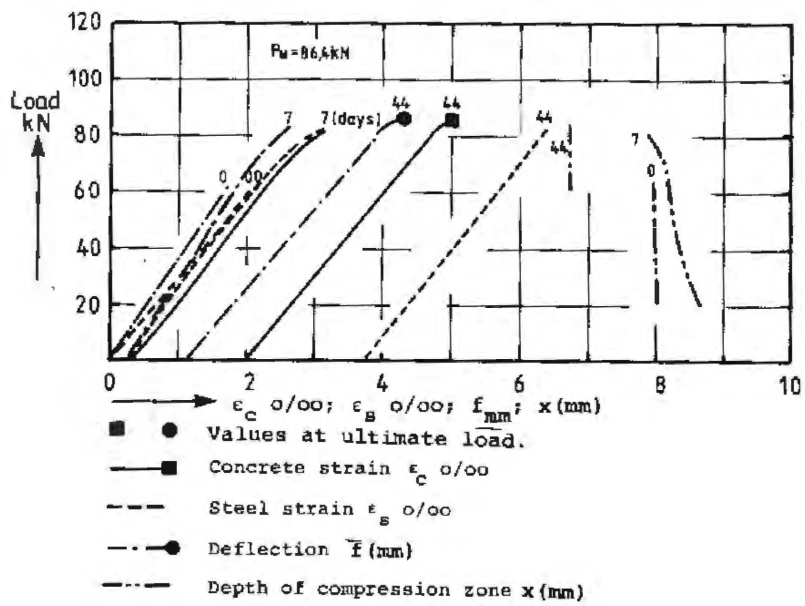


Table 2.2 Beams with Failure in Bending.

Beam No	Age at testing Days	Cube strength MPa	A_s mm^2	A_{sv} mm^2/m	c m	P_u kN	ε_{cu} o/oo	f_u mm	f_{el} mm	M_u kNm	M_d kNm	f_u/f_{el}	M_u/M_d	Type of test
M1A	28	98	402	1.01	1.0	33.7	4.3	-	16.2	33.1	24.8	-	1.33	Short term
M1B	28	98	402	1.01	1.0	32.5	3.4	55.1	17.2	31.9	24.8	3.20	1.29	- " -
M1C	570	124	402	1.01	1.0	35.0	3.1	49.9	19.9	34.4	24.5	2.51	1.40	- " -
M2A	29	98	628	1.01	1.0	50.0	3.2	49.9	19.9	49.4	36.5	2.51	1.35	Short term
M2B	29	98	628	1.01	1.0	51.3	3.8	46.9	19.3	50.7	35.8	2.43	1.41	- " -
M2C	570	127	628	1.01	1.0	56.0	3.4	49.0	19.0	55.4	36.6	2.58	1.52	- " -
M3A	30	98	1256	1.68	1.0	82.5	3.5	28.2	20.8	81.9	54.0	1.36	1.52	Short term
M3B	30	98	1256	1.68	1.0	80.5	3.8	28.7	20.8	79.9	55.0	1.38	1.45	- " -
M3C	570	124	1256	1.68	1.0	89.0	3.6	28.5	22.0	88.4	69.8	1.30	1.39	- " -
S4A	28	104	628	1.01	0.4	130	-	42.5	18.5	57.1	37.9	2.30	1.51	Short term
S4B	28	104	628	1.01	0.4	128	-	64.0	19.8	51.7	37.2	3.23	1.39	- " -
S4C	565	126	628	1.01	1.0	57.5	3.6	69.5	21.5	50.9	36.7	3.23	1.39	- " -
S5B	28	104	628	0.67	0.4	127	-	68.5	20.5	50.5	36.1	3.34	1.40	Short term
S5C	>570	126	628	0.67	1.0	53.7	4.0	50.1	18.0	53.1	36.5	2.78	1.45	Long term
S7C	>570	123	1256	1.01	1.0	86.5	4.5	41.0	20.0	85.9	62.8	2.05	1.37	Long term
S8C	>570	123	1256	0.67	1.0	86.4	4.9	42.4	20.0	85.8	62.8	2.12	11.37	Long term

A_s tensile reinforcement

A_{sv} amount of stirrups

c shear span

P_u ultimate jack load

ε_{cu} ultimate concrete compression

f_u deflection at ultimate load

f_{el} deflection at limit of elasticity

M_u ultimate bending moment

Data and test results for 11 beams failing in shear are given in Table 2.3.

The beams in Series S6 were made without stirrups. Accordingly the results from these 3 beams show a rather large deviation. The lowest value of P_u, that is P_u = 94.4 kN, should be taken as the most significant value from the 3 beams. The two higher P_u values (114.4 kN and 122.4 kN) may well depend on a not reliable arch- effect.

The same is the case for the 3 beams in series S9 and the lowest capacity P_u = 63.5 kN should be taken as the most significant value.

The results from the shear tests may be analyzed by comparing the ultimate shear capacities, V_u, with formal design values based on some assumptions of design stresses and limitations. As the code regulations in this field differs rather much from country to country, a further analysis is discarded here.

Table 2.3 Beams with Failure in Shear.

Beam No	Age at testing Days	Cube strength MPa	A_s mm^2	A_{sv} mm^2/m	c m	P_u kN	M_u kNm	V_u kN
S5A	28	104	628	0.67	0.4	110	43.7	109.4
S6A	29	104	628	0	0.4	95	37.7	94.4
S6B	29	104	628	0	0.4	123	48.9	122.4
S6C	29	104	628	0	0.4	115	45.7	114.4
S7A	30	104	1256	1.01	0.55	140	76.6	139.5
S7B	30	104	1256	1.01	0.55	150	82.1	149.5
S8A	30	104	1256	0.67	0.55	125	68.4	124.5
S8B	30	104	1256	0.67	0.55	135	73.9	134.5
S9A	30	104	1256	0	0.55	80	43.6	79.5
S9B	30	104	1256	0	0.55	64	34.8	63.5
S9C	570	123	1256	0	0.55	68	37.6	67.5

3. CONCLUSIONS

The general safety level for bending failures as defined in section 2.2 was found to be between 1,29 and 1,52 for the HSC-beams. For beams of ordinary concrete quality we find very near the same safety level. This indicates that the mechanism of bending failure is represented in the code regulations [4] fairly well also for HSC concrete up to f_{ck} 0 125 MPa.

The safety level has here been based on the Norwegian Code, with a linear extrapolation for HSC concrete. It may be assumed that similar procedure based on code regulations from other countries will give the same trend.

It is indicated, within the limitation of the tests, that "Long Term" loading does not reduce the flexural capacity in a severe way.

The shear tests comprised several parameters, A_s, A_{sv} and the shear span (c). It can be stated from the test results that these parameters influence the shear capacities for HSC-beams in a similar way as for ordinary concrete. In this way the referred pilot tests may be of special value when planning further tests.

REFERENCES

/1/ Norwegian Contractors, Den Norske Stats Oljeselskap (STATOIL) A/S, F. Selmer A/S, NORCEM A/S.

/2/ Hoff, A., Høiseth, K., and Håverstad, T.A.: Testing of High Strength Leightweight Aggregate Concrete Elements, Nordic Concrete Research 1984.

/3/ Einstabland, T., Helland, s.: Høyfast Betong (High Strength Concrete), Norsk Betongdag 1983.

/4/ NS 3473 - Norwegian Code - Concrete Construction.