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Autor: Maage, Magne / Helland, Steinar

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Quality Inspection of Concrete Bridges and Wharfs in Norway

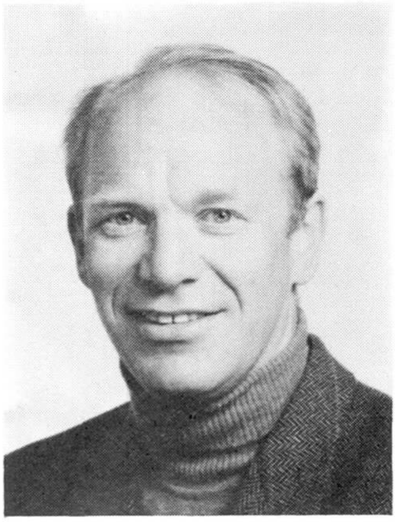
Auscultation de ponts et quais en béton en Norvège

Qualitätsuntersuchungen von Betonbrücken und Werften in Norwegen

Magne MAAGE
Dr. eng.
Selmer Furuholmen Anlegg a.s.
Oslo, Norway

Magne Maage, born 1944, received his dr. eng. degree at the Norwegian Institute of Technology. He has served as a lecturer in building materials at the Norwegian Inst. of Technology, as Dep. head at the Cement and Concrete Res. Inst. in Norway and as a specialist in concrete technology for the contractor Selmer Furuholmen Anlegg a.s.

Steinar HELLAND
Civil Engineer
Selmer Furuholmen Anlegg a.s.
Oslo, Norway



Steinar Helland, born 1947, received his civil engineering degree at the Norwegian Institute of Technology. He has served in different positions with the contractor Selmer Furuholmen Anlegg a.s. and is now head of the Concrete Technology Group.

SUMMARY

Results from the quality inspection of 35 bridges and 27 wharfs in Norway, varying in age and location, are reported. The results may be used as a basis for improvement of quality assurance, better design and detailing, changing of specifications and planning of maintenance and rehabilitation.

RÉSUMÉ

Les résultats de l'auscultation de 35 ponts et 27 quais d'âges et d'emplacements divers en Norvège sont présentés. Ils peuvent servir de base à l'amélioration de la qualité, à de meilleurs projets et détails constructifs ainsi qu'à l'adaptation des prescriptions et de la planification de l'entretien et de la remise en état.

ZUSAMMENFASSUNG

Die Resultate von Qualitätsuntersuchungen an 35 Brücken und 27 Werften verschiedenen Alters und Standortes in Norwegen werden vorgestellt. Sie können als Basis zur Verbesserung der Qualitätssicherung, des Entwurfsund der Konstruktionsdetails sowie zur Anpassung von Ausschreibungen und zur Plannung von Unterhaltung und Instandsetzung verwendet werden.

1. INTRODUCTION

Concrete bridges and wharves have been built for more than 80 years in different locations and exposed to different environments in Norway. The structures have been built according to existing codes and standards. The main purpose with the quality inspection has been to look for deterioration and analyse the reasons. The information will be used to improve the quality of future structures by introducing better quality assurance systems, by better design and detailing and by changing codes and specifications. For existing structures the information may be used for planning maintenance and rehabilitation.

2. TEST PROGRAM

2.1 Inspection

The inspection at the structure included a general visual survey to give an overall condition, a more detailed examination of deteriorated areas, a half cell surface potential mapping for detecting the corrosion situation of the rebar and, rebar cover measurements using a covermeter. From different locations at the structures, cores were drilled for further examination and testing in the laboratory.

2.2 Laboratory testing

The laboratory testing of cylinder cores included measurement of compressive strength, capillary adsorption, carbonation depths and chloride content. Capillary adsorption is of more present interest than water permeability. Carbonation was measured by the phenolpthalein method and chloride content by the Quantab test.

3. RESULTS

3.1 Bridges

Bridges from two areas in Norway have been inspected. In the western county of Hordaland, the survey included 20 bridges built in the period from 1930 to 1975 and located in the environmental zones outward and inner coast, inner fjord and inland. Most of the bridges were located in the costal zone. In the eastern county of Telemark, 15 bridges built in the period from 1940 to 1975 were inspected. The bridges were located in the environmental zones inner fjord, inland and higher inland. Some interesting information is shown in Table 1. More detailed information is given in /1 and 2/.

3.2 Wharves

27 wharves along the Norwegian coast, most of them in the northern part of Norway, have been inspected. The wharves were built in the period from 1920 to 1984. Some interesting information is shown in Table 2. More detailed information is given in /3 and 4/.

4. DISCUSSION

In spite of the relatively high number of structures, the variables are so many that a detailed discussion is impossible. More general

Table 1. Test results from bridges

No	Location 1)	Building-period	Strength (MPa)	Carb min/max (mm)	Max Cl⁻ close to surface (% of concr)
1	H - OC	1930-39	41	0/ 8	0.05
2	H - IC		39	0/15	0.07
3	H - OC		64	1/15	0.22
4	H - I	1940-49	28	10/32	0.15
5	H - IC		56	2/32	0.08
6	H - IC		33	2/30	0.14
7	T - I		32	3/ 7	0.08
8	T - I		47	1/10	0.06
9	T - HI		40	0/22	0.04
10	H - IF	1950-59	41	2/13	0.18
11	H - IC		69	0/ 0	0.05
12	H - OC		90	0/ 2	0.19
13	H - OC		72	0/ 8	0.20
14	H - I		23	0/ 8	0.11
15	T - IF		37	8/10	0.02
16	T - IF		40	4/22	0.07
17	T - HI		71	0/ 4	0.18
18	H - IF	1960-69	61	0/ 8	0.11
19	H - OC		27	0/16	0.05
20	H - OC		55	0/ 0	0.13
21	H - IC		24	12/31	0.05
22	H - OC		50	0/ 1	0.27
23	T - IF		46	3/20	0.08
24	T - IF		45	4/ 7	0.09
25	T - I		45	0/ 5	0.12
26	T - HI		44	0/ 4	0.06
27	T - HI		46	8/ 8	0.17
28	T - HI		49	0/ 3	0.07
29	H - IF	1970-79	54	3/ 4	-
30	H - OC		73	2/ 6	0.05
31	H - OC		33	0/15	0.06
32	H - OC		77	0/ 1	0.07
33	T - IF		48	0/ 5	0.03
34	T - I		64	0/ 9	0.14
35	T - I		42	8/ 9	0.02

1) H - Hordaland
T - Telemark
OC - Outward coast
IC - Inner coast
IF - Inner fjord
I - Inland
HI - Higher inland

Table 2. Test results from wharves

No	Building-period	Strength (MPa)	Max Cl⁻ close to surface (% of concr)
1	1920-29	-	-
2	1930-39	-	0.19
3	1950-59	55	0.52
4		52	0.13
5	1960-69	57	0.14
6		47	0.21
7		38	0.12
8		45	0.20
9		44	0.06
10		58	0.10
11		53	0.47
12		-	-
13		-	-
14		-	-
15		65	0.28
16		-	0.23
17	1970-79	50	0.36
18		46	0.10
19		55	0.23
20		70	0.18
21		51	0.40
22		53	0.10
23		44	0.44
24	1980-82	50	0.27
25		53	0.31
26		59	0.48
27		45	0.13

trends, however, are of great interest.

4.1 Bridges

The general deterioration problem of the bridges is reinforcement corrosion due to high chloride content. Carbonation and frost deterioration were og minor importance.

The compressive strength was in the majority of the structures higher than specified. However, as shown in Table 1, the strength values varied quite a lot.

The environmental zone seems to have a consistant effect on chloride penetration. The most severe environment is outward coast (OC), diminishing towards the inland. However, in some cases the bridge slab in inland bridges has a high chloride content due to summer salting in order to reduce dust on gravel roads. Also high chloride content, probably due to the use of accelerators during construction, have been found.

Carbonation rate is found to be highest in the inner cost zone. Bridges built in the period 1940-49 have the highest carbonation depts due to lack of cement during and after the second world war. This resulted in a higher w/c-ratio and a poorer quality. The correlation between carbonation dephts and concrete quality was as expected.

The concrete cover was found to vary quite a lot. In most of the bridges, the measured cover was satisfactory with respect to existing code during construstion. However, it is clear that specified cover has been too low. In the new Norwegian code, the specified cover in the actual environmental class is increased to 40 mm and 50 mm in the splash zone. This seems to be enough when combined with increased demand on concrete composition (reduced w/c-ratio to 0.45) and improved quality control.

The visual inspection revealed some common weak details in the structures. The most common was insufficient drainage systems from the top of the bridges. Drainage pipes with diameter 75 mm or lower were filled with scrap and blocked. Lack of protruding pipes under the bridges resulted in local high water content with freezing deterioration and mis-colouring. Reinforcement corrosion was most commonly found along the rim of the bridge slab sides. Insufficient concrete compaction had in many structures resulted in washing out of the hardened concrete, leaving white areas of lime. In structural details like sharp edges, the risk of deterioration was found to be very high. Also the fixing of steel railing to the bridge slab was found to be weak points where corrosion and concrete scaling were common. It is reasonable that freezing also may be a reason for the deterioration in such local areas.

4.2 Wharves

The main deterioration problem in concrete wharves is also reinforcement corrosion, first of all due to chloride ingress. The wharf slabs were commonly more deteriorated than beams and columns. Generally, the most deteriorated part of the slab was the inner part underneath due to splashing sea water. Therefore, the orientation of the wharves compared to the main wind direction is of importance. Heavy sea water splashing resulted in high chloride content and low electrical resistivity in the concrete, an ideal situation for rebar corrosion. Rebar corrosion was also found as a result of damage due to ship collision. This is not a material but may be a structural problem. Wharves should be designed so that the risk of damage due to ship collision is reduced or so that such structural parts may be replaced.

The compressive strengths were in most cases higher than specified, but the variation was relatively high as shown in Table 2.

Frost damage is a smaller problem than expected in spite of the fact that air entrainment is used in very few structures, especially in structures built before the middle of the fifties. The reason may be that the frost load is low due to the fact that the minimum temperature is relatively high close to the unfrozen sea water. Frost damages were located to special details like drainage pipes with insufficient protruding, along the lower rim where dripping noses were insufficient and along railroad tracks where deicing salts had been used.

Carbonation is found to be no problem in wharves. The reason seems to be a combination of a moist environment and a relatively high concrete quality.

The measured concrete cover varied a lot and the minimum values were frequently lower than specified. In general, the measured cover were lower in the bottom of soffit slabs than in beams and columns. This is in correlation with the most severe deterioration in the wharf slabs.

Cracks due to different reasons were observed in the majority of the wharves. The most common reason seems to be plastic and drying shrinkage, thermic cracking, deformation of the base and overloading compared to design specification.

The criteria for designing and detailing have primarily been based on strength requirements. From a durability point of view, this is normally not sufficient. The reasons for deterioration are mostly due to environmental and not to static loads. Important keywords are detailing like water drainage, location/direction of the wharf in the environment, concrete quality and good workmanship.

In some of the newer structures, silica fume has been used. The number of wharves and exposure times are too limited to draw conclusions, however, based on numerous research reports it is expected that the use of silica fume will reduce the ingress of chlorides considerably.

5. CONCLUSIONS

35 bridges and 27 wharves in Norway have been inspected and tested the last few years. From the results it can be concluded that during design, more attention has to be paid to durability, environmental loads and detailing.

Concrete cover was in most cases too low. In the new Norwegian code, the specified cover is increased to 40 mm and 50 mm in the splash zone for the actual environmental class. This seems to be sufficient in most cases when combined with the specified increased material quality. The new Norwegian code specifies a w/c-ratio lower than 0.45 in the actual environmental class. When carbonation is the limiting factor, this is sufficient requirements. However, regarding chloride penetration, the w/c-ratio should not exeed 0.40 which also is specified in the new design code from the Norwegian Public Road Administration. This specification is also recommended for wharves. In a planned submerged floating tube for public trafic across a fjord in Norway, the specifications may be even stronger.

A combination of a blended cement and silica fume as well as entrained air is recommended, especially where the structure is exposed to saline water.

Quality assurance and quality control both during design and construction are of great importance in order to achieve a satisfactory result.

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