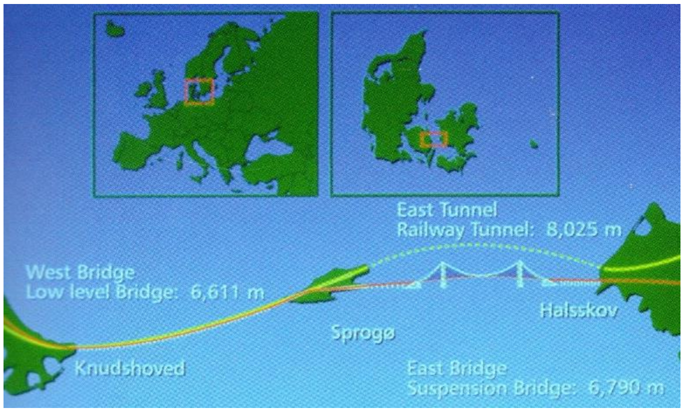
NDTitans in action

Case 5.3 Production control of the cover layer at The Great Belt Link project, Denmark



The Great Belt Fixed Link runs between the Danish islands of Sjælland and Fyn (eastern and western Denmark). The 18 km long project consists of three structures: a road suspension bridge and a railway tunnel between Sjælland and the small island Sprogø located in the middle of the Great Belt, and a box girder bridge for both road and rail traffic between Sprogø and Fyn. The "Great Belt Bridge" (Danish: “Storebæltsbroen”) commonly refers to the suspension bridge, officially known as the East Bridge, which has one of the world's longest main span (1.6 km). The construction work took place between 1988 and 1998 and because of its size and importance, implied that aspects of durability were studied in an unprecedented scale in Denmark to keep the risk level at a minimum for a 100-year service life design period. One important objective was therefore to specify the requirements to prevent deterioration from alkali-silica reactions, frost attack, and reinforcement corrosion due to chloride ingress.

Both concrete strength and durability are influenced by the curing conditions. Inspection of potential compressive strength with companion well cured lab specimens, however, gives no guarantee of safety against failure of the concrete structure or quality of the cover layer, therefore, it was of major importance to specified that, in addition, the achieved characteristic compressive strength at the cover layer was controlled using in-situ testing with LOK and CAPO tests.

The decision rule for acceptance was: $\{f_c\} \geq 0.8\, k_n\, f_{ck}$, where $\{f_c\}$ is the mean value of the strengths measured, and k_n is a factor that depends on the number of tests and the coefficient of variation.

In-situ strength testing had never before been used for production tests in Denmark, but on the Great Belt Link LOK-test inserts were used for all structures (in average 1 test for every 25 m^3) except the slip-formed caisson walls (West Bridge) and the tunnel lining segments, where CAPO-test rings were inserted at the time of testing.

The general correlation shown in the next page, recommended by Germann Instruments and based on data from international research and construction projects, was used for the East tunnel and East bridge as it matched reasonable well with the actual correlations obtained (dotted lines). However, during full-scale trial castings for the West Bridge, it was realized that the in-situ CAPO strengths determined by the general correlation were significantly lower than the LOK strengths. The obtained values also indicated a potential risk of rejections, so it was decided to carry out a correlation test for the actual West Bridge concrete. For this purpose, several 400 x 200 x 200 mm blocks were prepared with four LOK-test inserts (air curing outside the lab) After each 4, 7, 28 and 56 maturity days, six blocks were tested with LOK and CAPO along with 18 lab cylinders for standard strength tests. The West Bridge correlations found and used for the project are shown with the blue and green solid lines.

The main characteristics of the concrete mixes tested with LOK or CAPO were:

Structure	East Tunnel	East Bridge		West Bridge	
Concrete ID	A1 a)	A	B	A	B b)
28-day f'_c, MPa c)	76	56	53	58	57
w/c	0.33	0.34	0.37	0.34	0.36
Fly ash, %	10	12	13	10	17
Microsilica, %	5	5	5	5	5
Density, kg/m^3	2,485	2,340	2,348	2,323	2,280
D_{max}, mm	16	25	25	32	32
Air content, %	0.8	1.4	1	6	6
Superplast. kg/m^3	1.8	7.6	6	8.8	5.7

a) *segments* b) *caissons* c) *from standard cylinders*

The structures were subdivided into inspection sections, each of which was accepted or rejected after the statistical evaluation. The main quantities and number of required strength tests for one of the inspection sections in the West Bridge are presented in the following figure.

Ref.: Extracts from Concrete Technology, A/S Storebæltsforbindelsen, Copenhagen, Denmark, 1999

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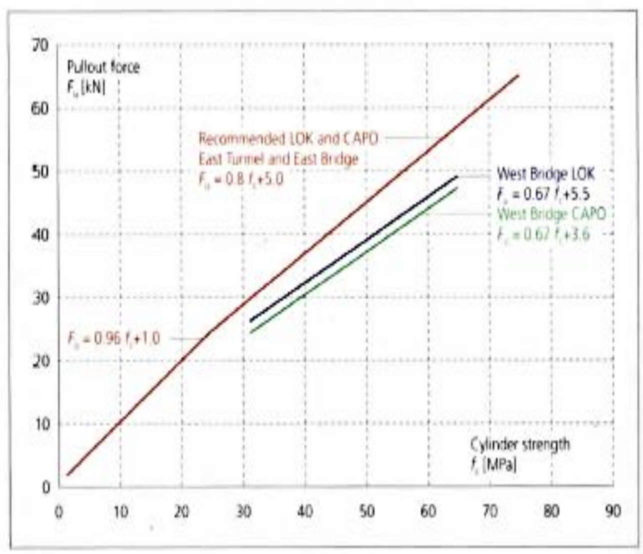
NOTE: Slip forming on the West Bridge caissons caused cracking in the cover layer. Cathodic protection was later applied on all the caissons to achieve a service life of > 1,000 year, according to the consulting engineers. **See case 5.4**

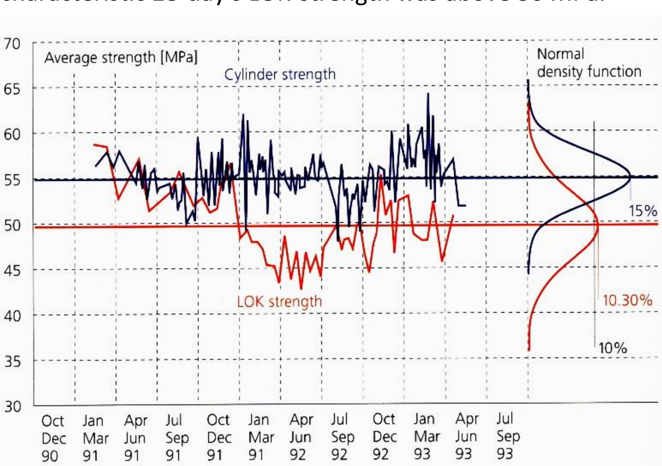
Fig. 5.3-3 Recommended correlation (red) between LOK-test and CAPO-test pull-out forces and 150mm diameter x 300mm long standard test cylinder compressive strength. This correlation was used for the East Tunnel and East Bridge whereas separate correlation relationships (blue and green) were established for the West Bridge



CAPO-test on the caissons of the West Bridge

Figures per inspection section in the West Bridge			
	Concrete, m^3	No. of LOK/CAPO tests	No. of test cylinders
Caissons (walls)	2,500 - 2,900	100 - 116	50 - 58
Pier shafts	700 - 1,200	28 - 48	14 - 36
Road girder	2,300	92	46
Rail girders	1,700	84	34

As an example of production testing, the West Bridge rail girder inspection sections were tested by LOK-test inserts. In the beginning, the cylinder and in-situ strengths were almost identical until November 1991. From then on, the LOK-strength was about 10% lower because of poorer concrete, but the concrete cover complied with the requirements if the characteristic 28-day's LOK-strength was above 36 MPa.



The final results of the comprehensive statistical evaluation of the major part of the project shows the differences between the strength and coefficient of variation, CV, obtained under lab conditions (cylinders) and under in-situ conditions, which in turn, evidence how important the control of transport, casting, compaction, and curing is in order to maintain a proper level of quality of the cover layer. Without quantitative monitoring the cover layer, the works would have run in blind.

		28-d LOK/CAPO strength, $f_{L/C}$		28-d cylinder strength, f_c		Ratio
Structure / Concrete ID		Avg., MPa	CV, %	Avg., MPa	CV, %	$\frac{f_{L/C}}{f_c}$
East Tunnel	A1	58.2 ^{C}	16.3	76.4	6.0	0.78
East Bridge	A	55.4 ^{L}	11.6	55.8	7.6	0.99
	B	51.8 ^{L}	13.3	53.0	6.9	0.98
West Bridge	A	53.7 ^{L}	9.7	57.6	4.9	0.93
	B	50.1 ^{L}	7.7	55.4	5.1	0.90
	200	51.9 ^{C}	19.5	57.4	4.9	0.90

Well-planned pretesting and trial castings for the actual work methods, and prior certified training of the workforce, was a key aspect. Training and technical follow-up during all this Danish iconic project was made by **NDTitan Claus Germann Petersen**

Ref.: Extracts from Concrete Technology, A/S Storebæltsforbindelsen, Copenhagen, Denmark, 1999