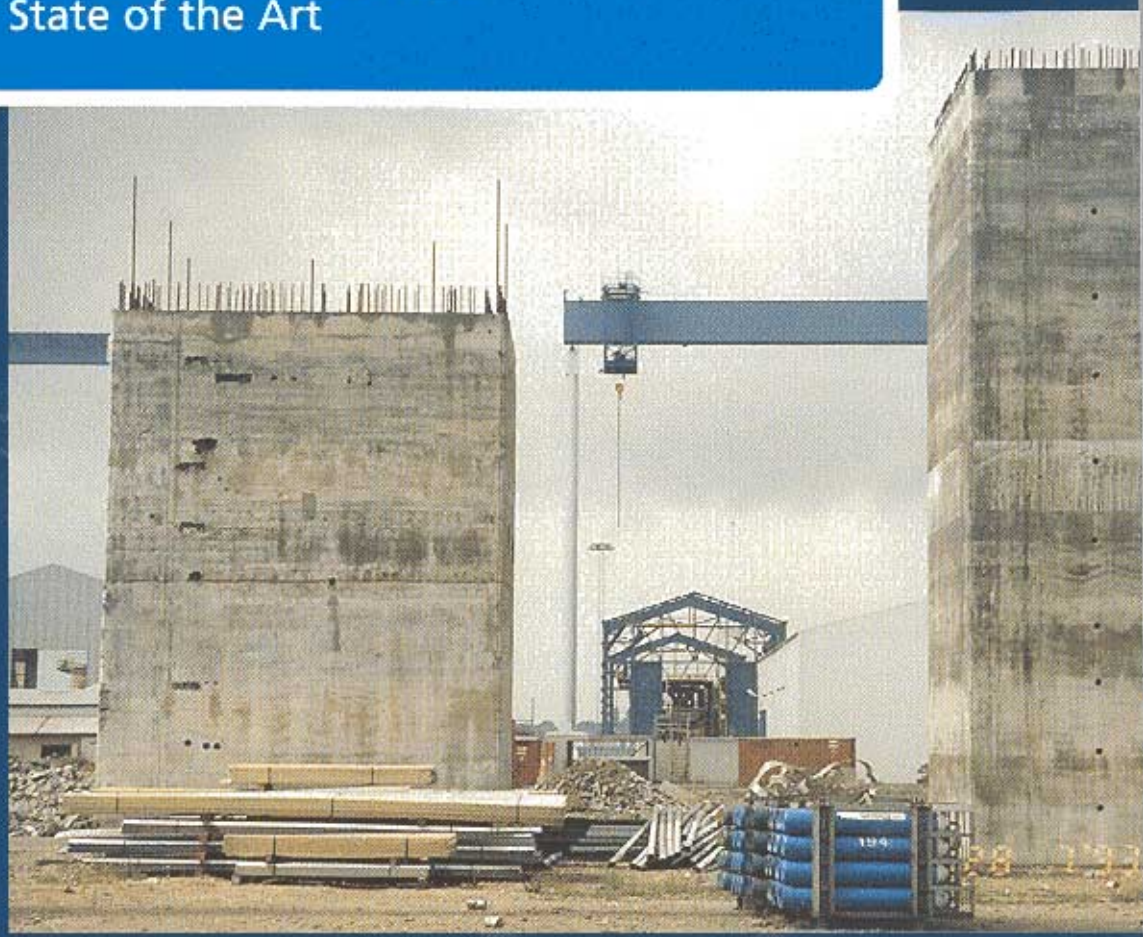
HETEK

Guide for Trial Castings
State of the Art



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REPORT No 40: Guide for trial castings - state of the art

The following comments were recieved from the Øresund Consortium after editing had been completed:

In sections 2 (Summary and conclusion) and Section 4 (Requirements for trial castings), there are references to an ØSK document with the title "Construction Requirements for The Øresund Link, abbreviated to ØSK, Øresundskonsortiet, 1995". This document does not exist.

Specific contract documents, e.g. "Contract No.1 - Tunnel Construction Requirements, Volumen 2 - Materials July 1995" exist, but these are confidential and cannot be made available on request or published.

In Table 1 of Section 4.2 (Concrete composition), a note 5 should be added under ØSK concrete composition, with the following text: "Note 5) For A -PC concrete for the tunnel".

In Table 2 of Section 4.3 (Design properties), a note 7 should be added under ØSK concrete, with the following text: "Note 7) In addition, comprehensive pretesting of hardening and hardening properties is required ".

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IRRD Information

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Abstract	This report forms a part of the Danish Road Directorate's research programme called High Performance Concrete - The Contractor's Technology (abbreviated to HETEK). HETEK is divided into eight parts where part no. 7 concerns Trial Castings. Prior to the casting of concrete structures a pre-testing shall be carried out. The pre-testing may be performed by trial castings or by investigations of existing results obtained with the concrete in question. This development programme is primarily about pre-testing performed by Trial Casting. The extent of such trial castings and the acceptance criteria related hereto varies. This state of the Art report describes the level of Trial casting connected to different codes of practise, standards and specifications which have been used during the last decade. In addition the results of a significant number of Trial Castings have been evaluated in collaboration with the involved contractors and supervision engineers.
Front page photo	The front page photo shows the trial casting specimens, which were cast as a part of the pretesting for the slip form casting of the Great Belt West Bridge Caissons. The height was 8 m, length and width 4 x 4 m and the thickness of the walls 0,3 m.

Contents

0. Preface

This programme regarding trial castings is part of the Danish Road Directorate's research programme, High performance Concrete - The Contractor's Technology (in Danish: Højkvalitetsbeton - Entreprenørens Teknologi abbreviated to HETEK).

High Performance Concrete is concrete with a service life in excess of 100 years in an aggressive environment.

The research programme includes investigations regarding the contractor's design of high performance concrete and execution of the concrete work with reference to obtain the requested service life of 100 years.

The research programme is divided into eight parts within the following subjects:

- chloride penetration
- frost resistance
- autogenous shrinkage
- control of early-age cracking
- compaction
- curing (evaporation protection)
- trial casting
- repair of defects

The Danish Road Directorate has invited tenders for this research programme which primarily is financed by the Danish Ministry for Business and Industry - The Commission of Development Contracts.

This programme regarding trial castings is performed by a consortium consisting of:

The Danish Concrete Institute represented by

- Find Meyer (Head of the programme)
- Carl de Fontenay
- Ulla Kjær
- Torben Wegmann

The Danish Technological Institute represented by the Concrete Centre

- Christian Munch-Petersen

Unicon Beton represented by

- Freddie Larsen
- Ib Jensen
- Lasse Toft

Jens Frandsen, 4K-Beton has participated as consultant.

The programme is divided in the following five phases:

Phase 1 State of the Art
Phase 2 Guide for pre-testing of concrete and wxecution, Graduation
Phase 3 Test Panels and Exposure Places
Phase 4 Incorporation of results from other HETEK research programmes
Phase 5 Final Report and Guide

This is the State of the Art Report.

The work has been reviewed by Reidar Kompen, The Norwegian Road Directorate, who is a member of the technical committee associated with HETEK.

April 1996

Find Meyer
Christian Munch-Petersen
Freddie Larsen
Jens Frandsen
Steering Committee of the HETEK-Trial Casting project

1. Introduction

Prior to the casting of concrete structures some investigations must be carried out. The aim of such investigations is to ensure that the concrete, which is to be used, complies with the required quality.
The investigations may be performed by trial castings or by reviewing existing results obtained with the concrete in question.

This development programme is primarily about pre-testing performed by trial casting.

It appears that in practise it is difficult to decide to which extent production methods related to a specific project should be tested by trial casting to ensure compliant production castings.

It also appears difficult for clients, consultants and perhaps more important for contractors to set up relevant objective criteria for a successful trial casting.

The programme is carried out in five phases. The first phase is a state of the art analysis concerning trial castings and acceptance criteria related hereto.

This state of the art report is based on studies of specifications primarily for Danish civil works carried out with concrete in aggressive environmental class.

In addition the results of a significant number of Trial castings have been evaluated.

2. Summary and conclusion

Based on codes, standards and specifications which have been used in the latest decade, the report states how pre-testing may be classified at 3 different levels.

The 3 levels are defined as:

Pre-testing, Level 1:	Pre-testing without trial casting.
Pre-testing, Level 2:	Pre-testing by trial casting of minor plain concrete test specimens of 0.1-1.0 m^3.
Pre-testing, Level 3:	Pre-testing by trial casting of larger reinforced concrete specimens. The shape and reinforcement reflect the construction in question and the casting is carried out using the actual planned production methods.

The codes, standards and specifications which have been analysed and the related pre-testing levels are:

DS 411, Level 1:	Dansk Ingeniørforenings code of practice for the structural use of concrete - Dansk Standard DS 411. 3. Edition 1984. - 3. Issue 1988 and 4. Issue 1991.
BBB, Level 2:	Basic Concrete Specification for Building Structures, BBB, published by The National Building Agency 1988 with later revisions.
AAB, Level 2:	Tender and Construction precepts, Concrete Bridges, Ordinary Work Specification - abbreviated to AAB. The Danish Road Directorate 1985 with revisions 1989 and 1994.
NVB, Level 2:	The Norwegian Road Directorate. Special work specifications for Aursundbrua and similar larger bridge structures.
SBF, Level 3:	Ordinary and Special work specifications for the Great Belt projects - abbreviated to SBF. A/S Storebæltsforbindelsen 1988. The work specifications are based on AAB (85) but enlarged i.a. concerning required extent of trial castings.

ASØ,	Level 3:	Guidance in selection of concrete for the land based structures to the Øresund Link - abbreviated to ASØ. A/S Øresundsforbindelsen 1994. The Guide is based on AAB (89) but enlarged i.a. concerning required extent of trial castings.
ØSK,	Level 3:	Construction Requirements for The Øresund Link - abbreviated to ØSK, Øresundskonsortiet 1995.

It should be emphasized that DS 411, BBB, AAB and ASØ are basis documents for the special work specifications, SAB. The requirements in the SAB may therefore be tightened.

Results from a significant number of trial castings at level 2 and 3 have been investigated in collaboration with the involved contractors, concrete suppliers and supervision engineers.

A preliminary evaluation of the results indicate that a more differentiated graduation is needed to meet the contractor's demands concerning pre-testing of specific production methods such as e.g. vibration need.

The report recommends a more detailed investigation of the significant amount of information with the aim of establishing a further graduation of trial castings, whilst also taking into account the expenses involved.

3. Pre-testing by trial Casting

As already mentioned some investigations must be made prior to the casting of concrete structures. Such investigations are known as pre-testings.

Pre-testings may be subdivided into the following main groups:

3.1 Concrete constituents
3.2 Concrete composition
3.3 Design properties
3.4 Production properties

The design properties are defined as the properties, which are important for the use of the structure - e.g. strength, elasticity and durability.

The production properties are defined as the properties, which have to be taken into consideration during the production in order to ensure compliance with design properties.

This report is primarily concerned with the examination by trial casting of design - and production properties.

The requirements to the concrete constituents and composition are related to the design properties.

The contractor's choice or limitations of choices can however affect the production properties. The concrete constituents and composition are therefore described in separate sections.

3.1 Concrete constituents

The purpose of investigations concerning the concrete constituents is to ensure that they are pure and without components which may lead to reduced durability. Production properties should also be taken into account.

Requirements to the minimum extent of these investigations are usually defined by the client's consulting engineers.

Pre-testing is usually performed without trial casting.

3.2 Concrete composition

The concrete composition has direct influence on the design properties e.g. through the w/c-ratio. The limits for the composition are therefore usually defined by the client's consulting engineers.

Extreme requirement e.g. to low w/c-ratio may lead to reduced production properties. In such cases it may be necessary to change the production methods. Alternatively the required limits may be changed in such a way that the production can be carried out as planned. [The Danish Concrete Institute 1993 and 1995].

Pre-testing of concrete composition is performed by demonstrating that the actual mix is constituated within the required limits.
Pre-testing is carried out based on the concrete mix design, with or without trial casting.

3.3 Design Properties

Investigations of the design properties may include strength, elasticity and durability. The durability tests may comprise:

- w/c-ratio
- Petrographical analysis
- Frost resistance based on air content and specific surface
- Frost resistance based on frost/thaw-testing
- Resistance against chloride ingression

The client is in principle mainly interested in compliance with design properties in the finished concrete work. Production testing is however usually demanded only for major civil work structures. Strength testing is generally based on cast cylinders.

To ensure compliance with design properties in the finished concrete work the contractor must perform pre-testing.

The minimum extent of such pre-testing is often specified by the client's consulting engineers.

The extent of pre-testing of design properties can be at different levels:

Level 1: Pre-testing without trial casting

Level 2: Pre-testing by trial casting of minor plain concrete specimens 0.1-1.0 m^3.

Level 3: Pre-testing by trial casting of larger reinforced concrete specimens. The shape and reinforcement reflect the construction in question and the casting is carried out using the actual planned production methods.

3.4 Production properties

The concrete production properties are i.a.:

- Mixing and transportation
- Change of consistency
- Stickiness
- Change of air content
- Pumpability
- Bleeding
- Vibration need
- Crust formation
- Setting time
- Heat development
- Strength development

The production properties are of decisive importance for the contractor's production planning. The minimum extent of pre-testing is often specified by the client's consulting engineers. The extent may be divided into the same levels as the pre-testing of design properties.

4. Requirements to trial castings

A number of codes and specifications has been the basis for execution of Danish civil work structures during the last decade. These and similar specifications for Norwegian civil work structures are:

DS 411: Dansk Ingeniørforening's code of practice for the structural use of concrete - Dansk Standard DS 411.
3. Edition 1984. - 3. Issue 1988 and 4. Issue 1991.

BBB: Basic Concrete Specification for Building Structures, BBB, published by The National Building Agency 1988 with later revisions.

AAB: Tender and Construction Precepts, Concrete Bridges, Ordinary Work Specification - abbreviated to AAB. The Danish Road Directorate 1985 with revisions 1989 and 1994.

NVB: The Norwegian Road Directorate. Special Work Specifications for Aursundbrua and similar larger civil work structures.

SBF: Ordinary and Special Work Specifications for the Great Belt projects - abbreviated to SBF.
A/S Storebæltsforbindelsen 1988.
The work specifications are based on AAB (85) but enlarged i.a. concerning required extent of trial castings.

ASØ: Guidance in selection of concrete for the landbased structures to the Øresund Link - abbreviated to ASØ.
A/S Øresundsforbindelsen 1994.
The Guide is based on AAB (89) but enlarged i.a. concerning required extent of trial castings.

ØSK: Construction Requirements for The Øresund Link, abbreviated to ØSK, Øresundskonsortiet 1995.

It should be emphasized that DS 411, BBB, AAB and ASØ are basis documents for the special work specifications, SAB. The requirements in the SAB may therefore be tightened.

The specifications mentioned have been analysed with the aim of determining the level for requirements to pre-testing. The results are shown in Table 3.

The division of levels of pre-testing is:

Pre-testing, Level 1:	Pre-testing without trial casting
Pre-testing, Level 2:	Pre-testing by trial casting of minor plain concrete test specimens 0.1-1.0 m^3.
Pre-testing, Level 3:	Pre-testing by trial casting of larger reinforced concrete specimens. The shape and reinforcement reflect the construction in question and the casting is carried out using the actual planned production methods.

The analyses are performed for each of the main groups:

4.1 Concrete constituents
4.2 Concrete composition
4.3 Design properties
4.4 Production properties

4.1 Concrete constituents

The levels of pre-testing for each of the specifications are stated Table 3.

4.2 Concrete composition

The levels of pre-testing for each of the specifications are stated Table 3.
In addition selected requirements to the concrete composition are investigated.

Table 1 shows the requirements to powder and water content for each of the specifications.

Concrete composition	DS411	BBB	AAB[2)]	NVB	SBF	ASØ[3)]	ØSK
w/c-ratio, max.	0,50	0,45	0,40	0,40	0,35	0,42	0,40
Water content, max.	-	-	-	-	135	-	-
Cement content, C min. kg/m³	-	-	300	-	300	270	275
Flyash content, FA, min. %	-	-	-	-	10	10[1)]	-
Flyash content, max. %	-	-	20	-	-	20	15
Microsilica content MS, min. %	-	-	-	-	4[4)]	3[1)]	-
Microsilica content, max. %	10	10	6	-	8	6	5
FA + MS content, max. %	35	35	25	-	25	25	-
C + FA + MS content min. kg/m³	-	-	-	340	-	-	340

Table 1: Typical requirements to powder- and water content. Aggressive environmental class.
Note 1) Either FA or MS or both must be used.
Note 2) Valid for concrete type C ref. AAB (94)
Note 3) Valid for environmental class SA
Note 4) For the East Bridge the requirement was 5%

It appears from Table 1 that the Great Belt specifications, SBF have several requirements to the powder and water content. The contractor's possibilities for selection of the concrete composition were therefore limited. The developed concrete mixes had reduced production properties. As a consequence some of the production methods had to be changed, but this was not always revealed during the trial casting (see chapter 5).

The extent of requirements was reduced for the later specifications ASØ and ØSK, thus giving the contractor greater possibilities to adjust the concrete composition to the selected production methods.

4.3 Design properties

The level of pre-testing for each of the specifications is given Table 3.
In addition the extent of testing of the hardened concrete is investigated. The result can be seen in Table 2.

Design Properties Hardened concrete	DS411	BBB	AAB	NVB	SBF	ASØ	ØSK
Compressive 28 days strength	+	+	+	+	+	+	+
Splitting tensile 28 days strength					+	+	+
E-modulus, 28 days				+		+	+
Petrographical analysis		+[1)]	+		+	+	(+)[3)]
Air content and specific surface		+	+		+	+	(+)[3)]
Frost resistance				(+)[5)]			+
Chloride ingress				(+)[6)]	(+)[2)]	+	(+)[4)]

Table 2 Requirements to testing of design properties.

Note 1) The requirement is omitted in the supplement to BBB
Note 2) The requirement was only valid for the East Tunnel
Note 3) No specific requirement to the results except for min. air content
Note 4) No specific requirement to the results
Note 5) To be tested only if the requirement to air content in fresh concrete is exceeded
Note 6) Test method for water penetration ISO/DIS 7031

Test methods and requirements to obtained results from the pre-testing are not identical.

It can be seen in Table 2 that more extensive testing is required for the major civil work structures SBF, ASØ and ØSK.

The acceptance criteria for pre-testing performed by trial casting are i.a. that the requirements to the design properties are fulfilled. Acceptance is therefore more difficult the more extensive and stringent the requirements are.

Acceptance is usually more difficult at level 3 than level 2 because, compared with testing at level 2, actual circumstances (geometry, reinforcement and production methods) at level 3 may have a negative effect on the test results on the design properties.

On the other hand the probability for compliant production castings is higher when the pretesting is carried out at level 3.

4.4 Production properties

The level of pre-testing for each of the specifications is stated Table 3.

Pre-testing Level		DS 411	BBB	AAB	NVB	SBF	ASØ	ØSK	Of interest for	
4.1 Constituents	1	+							The client and the contractor	
	2		+	+	+					
	3					+	+	+		
4.2 Composition	1	+							The client and the contractor	
	2		+	+	+					
	3					+	+	+		
4.3 Design properties	1								The client	
	2	(+)[1]	+	+	+					
	3					+	+	+		
4.4 Production properties	1	+							The concrete supplier	The contractor
	2		+	(+)[2]	+					
	3					+	+	+	The casting team	

Table 3 Requirement for pre-testing level 1, 2 and 3 for the specifications used during the latest decade

Note 1) The requirement is based on cast cylinders
Note 2) AAB assume that casting technique and equipment is tested by trial casting ref. AAB (94) cl. 8.5.5. This is however not described in detail.

It appears from Table 3 that:

- Civil work structures designed in accordance with DS 411 are pre-tested at the lowest level 1.

- Civil work structures designed in accordance with BBB, AAB and NVB are pre-tested at the medium level 2. It should be emphasized that BBB and AAB are basis documents for the special work specifications, SAB. The requirements in the SAB may therefore be more demanding.

- The major civil work structures designed by A/S Storebæltsforbindelsen, A/S Øresundsforbindelsen and Øresundskonsortiet are all pre-tested at the highest level 3.

Table 3 indicates also who (the client, the contractor or the concrete supplier) has the greatest interest in the performance of the pre-testing.

5. Results from selected trial casting

In order to evaluate to which extent pre-testing by trial casting has served its purpose a number of civil works structures have been investigated. The investigations are carried out by interviewing contractors, concrete suppliers and supervision engineers who participated in the execution of the concrete works. The civil works structures are:

- The Guldborg Sund Tunnel between Lolland and Falster, Denmark. The tunnel was executed in 1985-1987 in accordance with concrete specifications based on AAB. The main concrete works consisted of two tunnel elements, each 230 m long, cast in ordinary reinforced concrete.
  The total quantities were:
  - approx. 25,000 m^3 concrete
  - approx. 2,500 t reinforcement

  The pre-testing was performed at level 2.

- The Great Belt Link, East Tunnel between Sprogø and Zeeland, Denmark. The tunnel was executed in 1990-1995 in accordance with the SBF specifications. The main concrete works consisted of prefabricated segments used for the bored tunnel lining and cut & cover cast in situ.
  The total quantities were:
  - approx. 200,000 m^3 concrete
  - approx. 20,000 t reinforcement

  The pre-testing was performed at level 3.

- The Great Belt Link, Western Bridge between Sprogø and Funen, Denmark. The bridge was executed in 1991-1994 in accordance with the SBF specifications. The Western bridge is a combined road- and railway bridge 6.6 km long. The bridge was built of prefabricated concrete elements.
  The total quantities were:
  - approx. 480,000 m^3 concrete
  - approx. 80,000 t reinforcement
  - approx. 12,000 t prestressing steel

  The pre-testing was performed at level 3.

- Road bridge structures at Rødkærsbro near Viborg, Jutland, Denmark. The concrete specifications were based on AAB. The execution of the bridges was part of another development programme, HUA-2 [Find Meyer 1995]. For some of the structures the concrete composition was specified in accordance with SBF, for other structures as ASØ or AAB. In this way it was possible to investigate relationships between production properties and construction methods. Pre-testing was performed at level 2, but extended by testing of

production properties i.a. stickiness and vibration need.

The structures, which were built in 1995-1996, included the following 6 bridges:

- The Brandstrupvej Bridge consisting of a prestressed bridge deck and columns of ordinary reinforced concrete. The total quantities were:
  - approx. 450 m³ concrete
  - approx. 50 t reinforcement
  - approx. 4 t prestressing steel

- The Kjellerup East Bridge consisting of a prestressed bridge deck and columns of ordinary reinforced concrete. The total quantities were:
  - approx. 600 m³ concrete
  - approx. 66 t reinforcement
  - approx. 6 t prestressing steel

- The Højbjerg Møllevej Bridge consisting of a prestressed bridge deck and columns of ordinary reinforced concrete. The total quantities were:
  - approx. 680 m³ concrete
  - approx. 74 t reinforcement
  - approx. 6 t prestressed steel

- The Struer-Langå Railway Bridge constructed of ordinary reinforced concrete.
  The total quantities were:
  - approx. 600 m³ concrete
  - approx. 70 t reinforcement

- The Bjerrevej Bridge constructed of ordinary reinforced concrete.
  The total quantities were:
  - approx. 870 m³ concrete
  - approx. 104 t reinforcement

- The Kjellerup West Bridge consisting of an ordinary reinforced bridge slab supported by sheetpile walls. One half of the bridge slab was cast with a concrete mix within the SBF specifications (w/c-ratio = 0.35). The concrete mix for the other half was within the AAB specifications (w/c-ratio = 0.45). The bridge was subject to comprehensive investigations of the relationships between composition, production properties and production methods [Find Meyer 1995].
  The total quantities were:
  - approx. 180 m³ concrete
  - approx. 23 t reinforcement

- Shelters, Aalborg airport, Jutland, Denmark. The hangars/shelters, cast in ordinary reinforced concrete, were executed in 1987-1990 in accordance with the BBB.
  The total quantities were:
  - approx. 41,000 m³ concrete
  - approx. 720 t reinforcement

  The pre-testing was performed at level 2 except for the floor structure which was tested by a 3 m³ trial casting at level 3.

- The Gadholtvej Arch Bridge between Sæby and Frederikshavn, Jutland, Denmark built in high strength concrete and ordinary reinforcement. The requirements to the high strength concrete were different from the AAB and therefore additional trial castings were carried out. One of the trial castings consisted of a foundation slab which was a part of the final structure. The other trial casting, which was also performed at level 3, consisted of representative arch- and column parts.
  The total quantities were:
  - approx. 710 m³ concrete
  - approx. 86 t reinforcement

- The Assentoft Bridge, Djursland, Denmark, built in 1995. The bridge deck was prestressed and the concrete specifications were based on AAB. The pre-testing was performed at level 2. In addition, the workability was investigated during casting of the first foundation slab.
  The total quantities were:
  - approx. 320 m³ concrete
  - approx. 40 t reinforcement
  - approx. 4 t prestressing steel

5.1 Civil works pre-tested at level 3

The contractor, the supervision engineer and the concrete supplier for the three civil work structures with pre-testing carried out at level 3 have all been questioned as to whether the trial castings served their purpose; i.e. if difficulties in execution were clarified prior to production castings. The answers are shown Table 4.

Level 3	Contractor	Supervision engineer	Concrete supplier
East Tunnel segments	Satisfactory	Satisfactory	Satisfactory
East tunnel Cut & Cover	Less satisfactory	Less satisfactory	Satisfactory
West Bridge Caissons	Less satisfactory	Less satisfactory	Satisfactory
West Bridge Road Girders	Less satisfactory	Less satisfactory	Satisfactory
Arch Bridge High strength concrete	Satisfactory	Satisfactory	Satisfactory

Table 4 Pre-testing at level 3. The contractor's, the supervision engineer's and the concrete supplier's opinion on the benefit of trial castings.

The typical reason for being less satisfied is that the production castings still showed defects, in spite of trial castings which were caried out on 15 m^3 representative test specimens.

Not all circumstances concerning casting rate and vibration need were settled prior to slip form casting the first West Bridge caisson, even though the trial castings were larger than 15 m^3. Furthermore the production properties were reduced due to stickiness and crust formation [The Danish Concrete Institute 1995]. As a consequence mechanical trowelling of the girder deck surfaces had to be given up.

It can be concluded that in three out of five cases where the trial castings were carried out on 15 m^3 representative test specimens, these trials have still not met the expectations in full. Investigations of all design properties and production methods on large test specimens are time consuming, and in some cases the information about the difficulties which may arise during production are not clarified.

This is the contractor's and the supervision engineer's opinion, while the concrete suppliers in all five cases have been satisfied with the results of the trial castings.

Judging by the results on the major civil work structures some additional testing concerning production properties i.e. vibration need appears to be needed. Such testing carried out on minor test specimens may reduce the risk of casting defects, but of course they cannot eliminate defects.

5.2 Civil works pretested at level 2

For the remaining 9 civil work structures the pre-testings were carried out at level 2. The contractors, the supervision engineers and the concrete suppliers were questioned as to whether the trial castings served their purpose or if extended testing concerning production methods would have improved the production castings. The answers are shown in Table 5.

Level 2	Contractor	Supervision engineer	Concrete supplier
The Guldborg Sund Tunnel	Less satisfactory	Less satisfactory	Satisfactory
The Brandstrup-vej Bridge	Satisfactory	Satisfactory	Satisfactory
The Kjellerup East Bridge	Satisfactory	Satisfactory	Satisfactory
The Højbjerg Møllevej Bridge	Satisfactory	Satisfactory	Satisfactory
The Struer-Langå Railway Bridge	Satisfactory	Satisfactory	Satisfactory
The Bjerrevej Bridge	Satisfactory	Satisfactory	Satisfactory
The Kjellerup West Bridge	Satisfactory	Satisfactory	Satisfactory
Shelters, Aalborg Airport	Satisfactory	Satisfactory	Satisfactory
The Assentoft Bridge	Satisfactory	Satisfactory	Satisfactory

Table 5 Pre-testing at level 2. The contractor's, the supervision engineer's and the concrete supplier's opinion on the benefit of trial castings.

It can be concluded that in 8 out of 9 cases the contractor's and the supervision engineer's opinion is that the trial castings were sufficient, as the level of defects in production castings was acceptable. The concrete suppliers are in all 9 cases satisfied with the trial castings.

It should be emphasized that in 6 of these 8 cases (the road bridge structures at Rødkærsbro) the trial casting was extented by additional investigations on i.e. vibration need [Mette Geiker 1995]. The two remaining projects were also

investigated by additional trial either on the first production casting (foundation slab Assentoft) or by trial casting of a relatively simple floor structure (shelters).

Regarding the Guldborg Sund Tunnel, which is significantly larger than the road bridges, some setting cracks occurred during production of the bottom- and roof slabs. Both the contractor and the site supervision are of the opinion that the trial casting carried out at level 2 could not reveal these problems. Perhaps a level 3 trial casting could have avoided the production defects.

Mechanical trowelling of the same structural parts (bottom- and roof slab) was given up because of cracking.
Based on the information in section 5.1, it is however questionable as to whether the problems concerning mechanical trowelling could have been revealed by a trial casting at level 3 - unless this was of a significant area.
Testing of the production properties which may lead to difficult mechanical trowelling are described in "Guide in use of High Performance concrete for exposed civil work structures" - in Danish: Anvisning i brug af højkvalitetsbeton til udsatte anlægskonstruktioner. [Dansk Betoninstitut A/S 1995].

The results above indicate a demand for a more differentiated graduation by which major civil work structures (Guldborg Sund tunnel) in marine environment are pre-tested at level 3 with supplementary tests on vibration need.
For the minor landbased civil work structures it seems to be adequate to pre-test at level 2, possibly extended by additional vibration trials.

5.3 Recommendations for further investigations

Based on the preliminary overall evaluation of the results from 12 trial castings, it is recommended to differentiate further between the three pre-testing levels defined in this report.

The levels could for instance be:

Level A:	As level 1
Level B:	As level 2
Level C:	As level 2 extended by trials on production methods i.e. vibration time.
Level D:	As level 3
Level E:	As level 3 extended by trials on vibration time and insertion distance for poker vibration.

The exact definition of these levels, and in which cases each of the levels should be used, must be decided by further analysis of the information made available through the interviews with contractors, supervision engineers and concrete suppliers.

Furthermore it should be decided when and to which extent pre-testing by trial casting may be substituted by:

- The concrete supplier's documentation
- Additional testing of production properties carried out by the concrete supplier
- Additional testing of specific production methods carried out by the contractor
- Special investigations carried out on final production castings, i.e. foundation slabs where minor defects are less important.

Most of the civil work structures which will be carried out in the future in Denmark are significantly smaller than the major bridge and tunnel structures dealt with in this report. Consequently the graduation of pre-testing levels of such minor and medium size structures should be given high priority.

An upgrading will involve additional expenses compared with the existing trial castings; an aspect which should also be clarified.

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