Impact-echo testing for evaluating de-bonding of composite slabs prior to measuring the adhesion strength by pull-off in bonded areas

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Claus Germann Petersen
IN-SITU TEST A/S
Emdrupvej 102
DK-2400 Copenhagen
Denmark

Abstract

The impact-echo is a non-destructive test method that offer quick classifying of de-bonded areas from bonded of composite structures. However, impact-echo cannot measure the adhesion strength between two layers, ref. (1).

Intrusive testing by the pull-off technique is, so far, the only method for measurement of the actual adhesion strength. The method leaves coring holes in the structure and takes time, about 15-20 minutes per test.

The testing case illustrate the combined use of impact-echo and pull-off testing. A survey is first made with the impact-echo to classify the areas in bonded and not-bonded, after which a limited number of pull-off tests is made in the bonded areas.

The system used for impact-echo was the DOCter Impact-Echo Test System with the VIKING software, and for pull-off the BOND-TEST. Cores were extracted by the CORECASE. The systems are described in ref (2).

1. Background and purpose of testing

The 250 mm thick concrete slabs of a wastewater plant outside Copenhagen, Denmark, fig.1, were overlaid with a special concrete, "Stabilo", to ensure proper drainage in case of water spillage. A bonding agent was applied to the 250 mm parent slab prior to applying the Stabilo overlay.

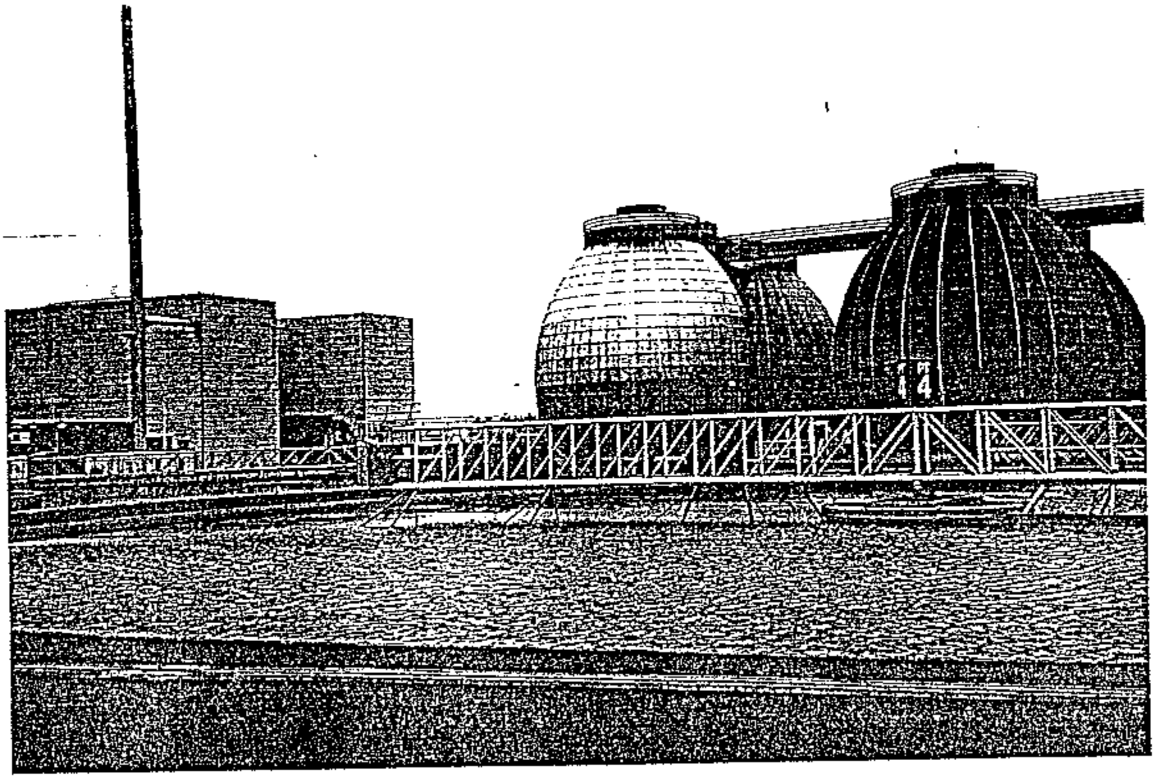


Fig.1. The Waste Water Plant outside Copenhagen, Denmark

The drawings indicated a thickness of the overlay ranging from 70 mm closest to the drainage's to 150 mm at the highest points. The overlay had two layers of 10 mm diameter reinforcement, the deepest placed 25 mm from the parent concrete slab and the other layer positioned 30 mm higher.

Four slab sections were tested. The test results reported in the following are from the 900 m^2 basement section.

The adhesion strength was specified to be 1.60 MPa (230 PSI), in average.

2. Initial impact-echo testing

2.1 Wave speed

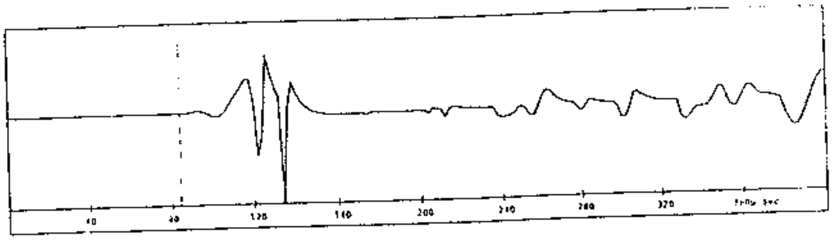
The concrete wave speed was first measured on the surface using two transducers placed 300 mm apart. The wave speed measurements for the basement section are shown in fig.2, 3, 4 and 5.

Fig.2. Wave speed record #1

VIKING P-WAVE SPEED DETAILS FOR RECORD wsp1

Structure Name:	comp.slab		
Grid ID:		CURSOR AT TRANSDUCER1:	84 μ Sec
Grid Size:	15 X 20	CURSOR AT TRANSDUCER2:	162 μ Sec
File:	c:\viking\avedore	CURSOR TO CURSOR:	78 μ Sec
Record Number:	301	CONVERSION FACTOR:	0.96
Date Of Testing:	10-28-1999	WAVE SPEED:	3694 m/s
Tested By:	cgp		
Instrument ID:	3345		
Comments:			

WAVE FORM TRANSDUCER #1



WAVE FORM TRANSDUCER #2

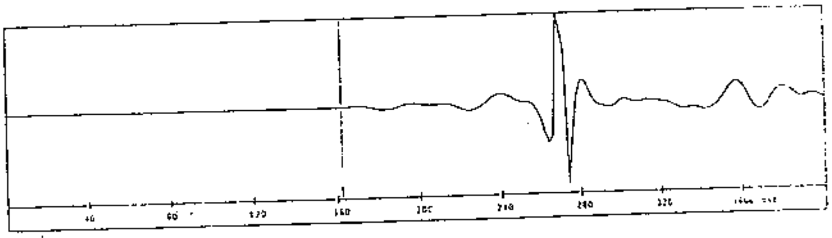
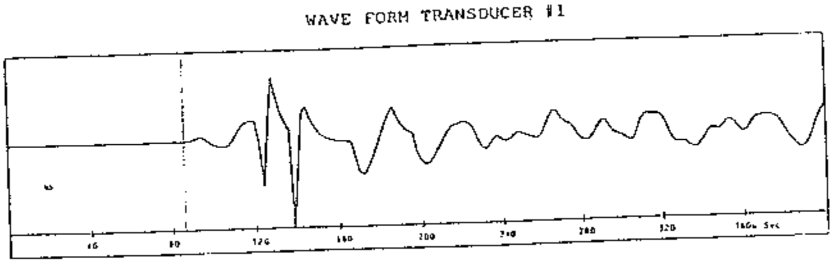


Fig.3. Wave speed record #2

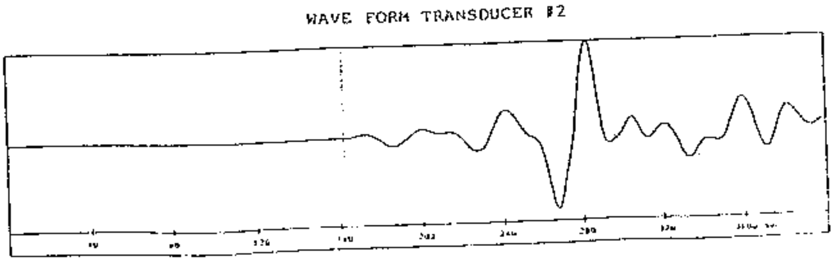
VIKING P-WAVE SPEED DETAILS FOR RECORD wsp2

Structure Name:	comp.slab		
Grid ID:		CURSOR AT TRANSDUCER1:	86 μ Sec
Grid Size:	15 X 20	CURSOR AT TRANSDUCER2:	162 μ Sec
File:	c:\viking\avedore	CURSOR TO CURSOR:	76 μ Sec
Record Number:	302	CONVERSION FACTOR:	0.96
Date Of Testing:	10-28-1999	WAVE SPEED:	3790 m/s
Tested By:	cgp		
Instrument ID:	3345		
Comments:			

WAVE FORM TRANSDUCER #1



WAVE FORM TRANSDUCER #2



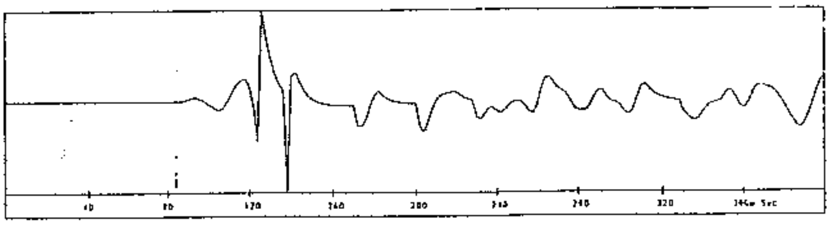
VIKING P-WAVE SPEED DETAILS FOR RECORD wsp3

Structure Name: comp.slab
Grid ID:
Grid Size: 15 X 20
File: c:\viking\avedore
Record Number: 303
Date Of Testing: 10-28-1999
Tested By: cgp
Instrument ID: 3345
Comments:

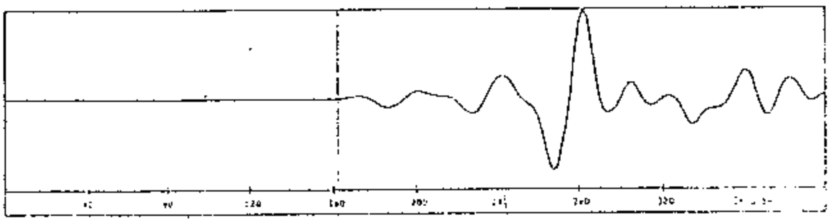
CURSOR AT TRANSDUCER1: 84 µ Sec
CURSOR AT TRANSDUCER2: 162 µ Sec
CURSOR TO CURSOR: 78 µ Sec
CONVERSION FACTOR: 0.96
WAVE SPEED: 3694 m/s

Fig.4. Wave speed record #3

WAVE FORM TRANSDUCER #1



WAVE FORM TRANSDUCER #2



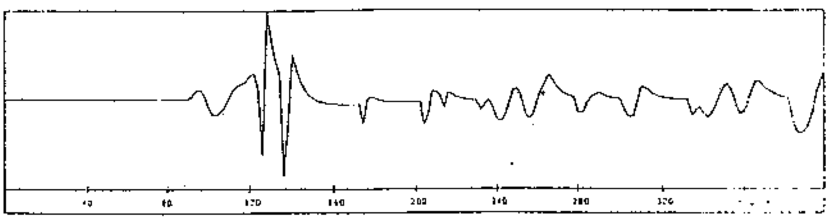
VIKING P-WAVE SPEED DETAILS FOR RECORD wsp4

Structure Name: comp.slab
Grid ID:
Grid Size: 15 X 20
File: c:\viking\avedore
Record Number: 304
Date Of Testing: 10-28-1999
Tested By: cgp
Instrument ID: 3345
Comments:

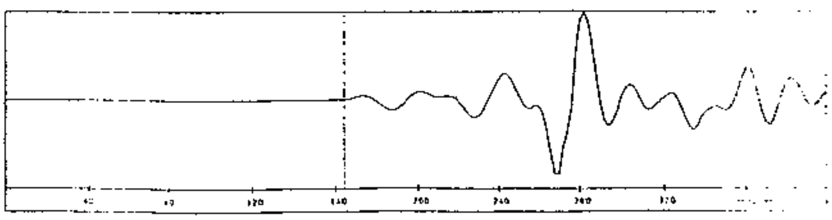
CURSOR AT TRANSDUCER1: 88 µ Sec
CURSOR AT TRANSDUCER2: 164 µ Sec
CURSOR TO CURSOR: 76 µ Sec
CONVERSION FACTOR: 0.96
WAVE SPEED: 3790 m/s

Fig.5. Wave speed record #4

WAVE FORM TRANSDUCER #1



WAVE FORM TRANSDUCER #2



The average wave speed measured was 3742 m/s, with a maximum variation of ±50 m/s.

2.2 Cross-section, acoustic impedance(s), expected frequencies and selection of impactors

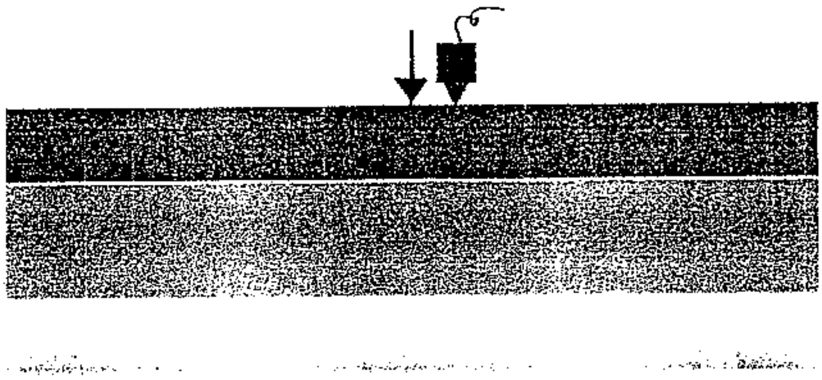


Fig. 6. Cross-section of the basement slab

For an **air interface** (de-bonding) between the two concrete layers reflection of the P-wave will take place at a frequency of

$$f = C_p / 2T \qquad (1)$$

For a thickness of 70 mm the expected frequency is f = (3742 m/s)/140 mm = 27 kHz and for a thickness of 150 mm f = (3742 m/s)/300 mm = 13 kHz.

For a **bonded area** the P-wave will travel through the two concrete layers and be partly reflected at the concrete – earth fill interface. As the acoustic impedance difference of the materials at this interface is 6-8 times, with the acoustic impedance of the earth fill being the smallest, equation (1) applies as well for calculating this expected frequency.

For a thickness of 330 mm, and assuming an average wave speed of the concrete of 3742 m/s, the expected solid frequency is f = (3742 m/s)/660 mm = 6 kHz, and for a thickness of 400 mm f = (3742 m/s)/800 mm = 5 kHz.

The primary impactor chosen was the 12 mm impactor, generating a maximum useful frequency to about 10-12 kHz. Should the 5-6 kHz solid frequency not be present in the frequency spectrum a 5 mm impactor was used subsequently, generating a maximum useful frequency to about 35 kHz.

Frequencies from reinforcement are of no interest for the analysis using this procedure.

2.3 Test grid and impact-echo test results

A test grid of 300 test points (15 x 30) was laid out with an internal distance of 1.7 meter x 1.7 meter between the test points and tested with the Mark IV transducer unit mounted the Spider.

Fig. 6 and fig. 7 shows examples of impact-echo signals indicating a solid bonded slab.

Fig. 8 and fig. 9 show results found at a de-bonded area. Compare the frequencies to the expected.

VIKING DETAILS FOR RECORD I1

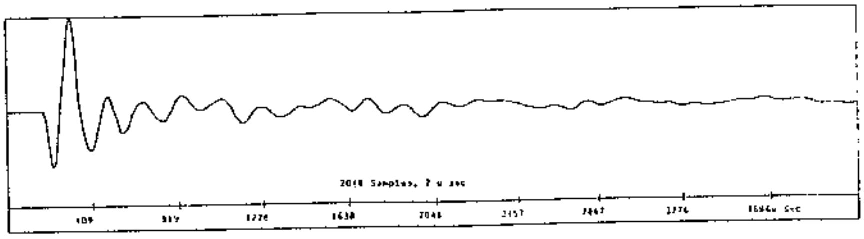
Structure Name:	comp.slab
Grid ID:	
Grid Size:	15 X 20
File:	c:\viking\avedore
Record Number:	9
Date Of Testing:	10-28-1999
Tested By:	cgp
Instrument ID:	3345
Comments:	10

CALIBRATED VALUES
Wave Speed: 3742 m/s
Thickness: 330 mm.
Frequency: 5.67 kHz

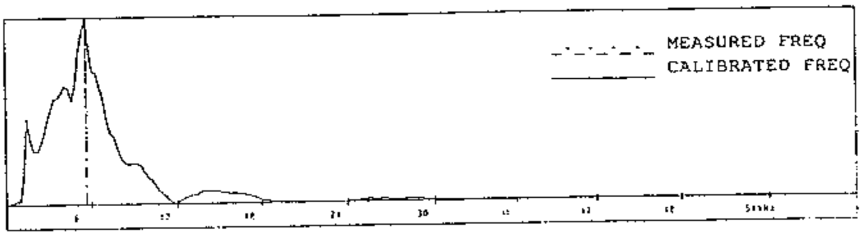
MEASURED VALUES
Frequency: 5.62 kHz
Thickness: 333 mm.

Fig.7
Impact-echo signal showing a bonded overlay

WAVE FORM



FREQUENCY SPECTRUM



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VIKING DETAILS FOR RECORD I2

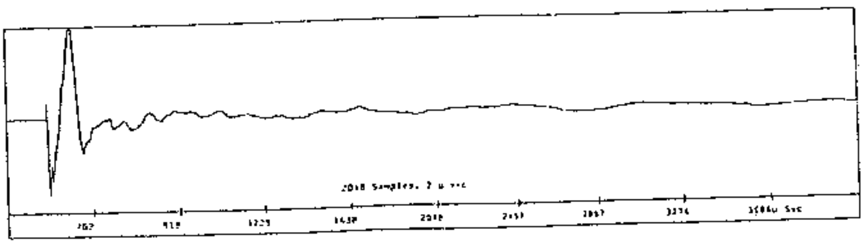
Structure Name:	comp.slab
Grid ID:	
Grid Size:	15 X 20
File:	c:\viking\avedore
Record Number:	22
Date Of Testing:	10-28-1999
Tested By:	cgp
Instrument ID:	3345
Comments:	2

CALIBRATED VALUES
Wave Speed: 3742 m/s
Thickness: 330 mm.
Frequency: 5.67 kHz

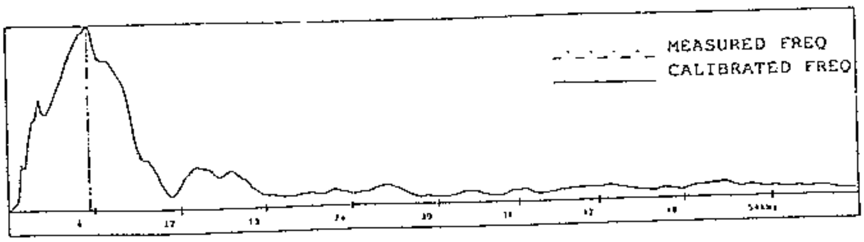
MEASURED VALUES
Frequency: 5.62 kHz
Thickness: 333 mm.

Fig. 8.
Impact-echo signal showing a bonded overlay

WAVE FORM



FREQUENCY SPECTRUM



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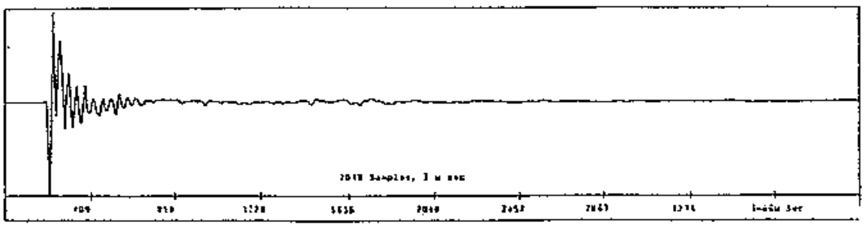
VIKING DETAILS FOR RECORD 01

Structure Name: comp.slab
Grid ID:
Grid Size: 15 X 20
File: c:\viking\avedore
Record Number: 15
Date Of Testing: 10-28-1999
Tested By: cgp
Instrument ID: 3345
Comments: 10 plus 30 cm

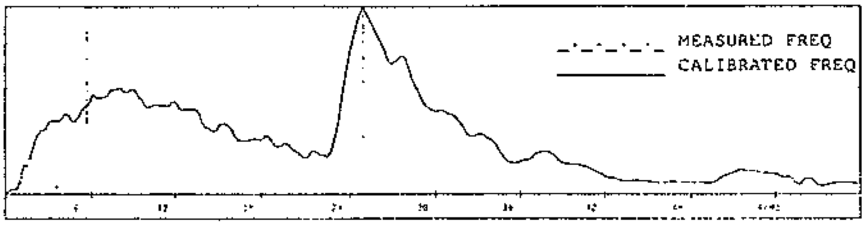
CALIBRATED VALUES
Wave Speed: 3742 m/s
Thickness: 330 mm.
Frequency: 5.67 kHz
MEASURED VALUES
Frequency: 24.90 kHz
Thickness: 75 mm.

Fig. 9
Impact-echo signal showing de-bonding at 75 mm depth

WAVE FORM



FREQUENCY SPECTRUM



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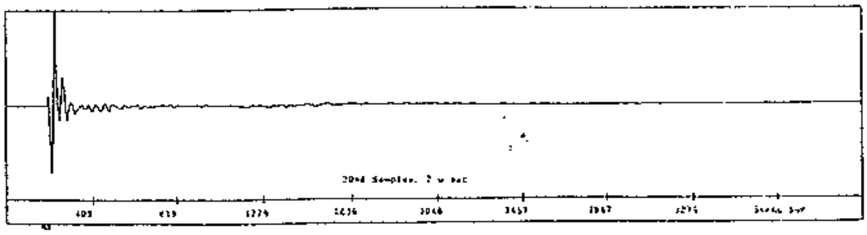
VIKING DETAILS FOR RECORD 02

Structure Name: comp.slab
Grid ID:
Grid Size: 15 X 20
File: c:\viking\avedore
Record Number: 16
Date Of Testing: 10-28-1999
Tested By: cgp
Instrument ID: 3345
Comments:

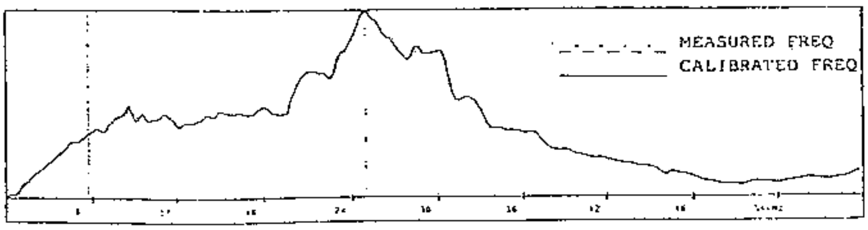
CALIBRATED VALUES
Wave Speed: 3742 m/s
Thickness: 330 mm.
Frequency: 5.67 kHz
MEASURED VALUES
Frequency: 24.90 kHz
Thickness: 75 mm.

Fig.10.
Impact-echo signal showing de-bonding at 75 mm depth

WAVE FORM



FREQUENCY SPECTRUM



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2.4 Confirmation of the impact-echo findings

Coring with the 75 mm Corecase was made in the area found to be de-bonded.

Fig. 11 illustrates one such core drilled out. When coring through the interface took place, the core came loose. The de-bonding was caused partly by the bottom reinforcement of the overlay resting against the 250 mm slab, and partly by poor consolidation of the overlaid concrete.

The depth of the de-bonded interface was measured to be 72-76 mm. Compare this measure to the depth estimated by impact-echo of 75 mm.

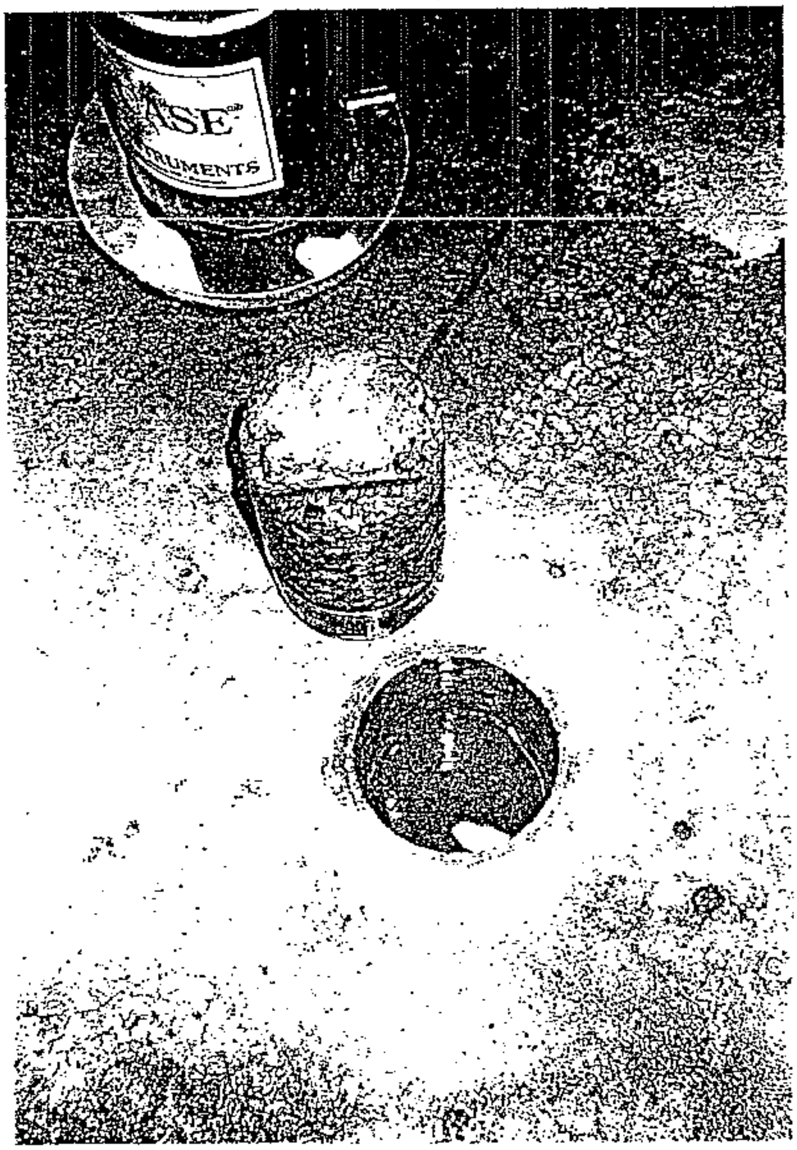

Fig 11. Core showing de-bonding at the air interface detected by impact-echo

Coring made in an area evaluated as bonded by impact-echo showed the interface to be bonded as expected, fig. 12.

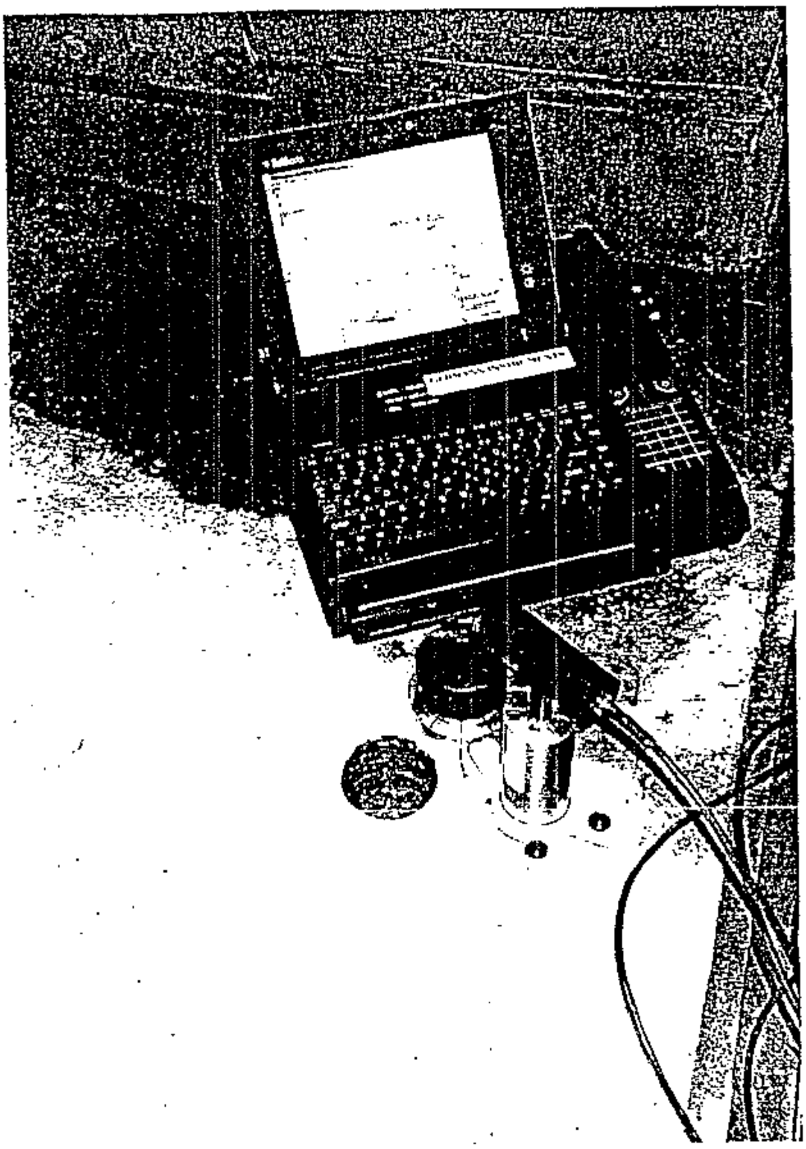

Fig.12. A bonded area tested with impact-echo

3. Pull-off testing

The test results from nine pull-off tests in the solid section of the basement slab are shown in the table below.

Test No.	Drill depth (mm)	Failure position	Depth of failure (mm)	Tensile strength (MPa)
1	190 mm	Substr./bonding agent	120 mm	0.89
2	190 mm	Substrate	140 mm	2.25
3	150 mm	Substr./bonding agent	80 mm	0.78
4	150 mm	Substr./bonding agent	110 mm	0.69
5	150 mm	Substr./bonding agent	105 mm	0.64
6	90 mm	Substr./bonding agent	75 mm	1.00
7	90 mm	Substr./bonding agent	65 mm	0.85
8	90 mm	Substr./bonding agent	45 mm	0.87
9	90 mm	Substr./bonding agent	50 mm	1.01

Table 1. Nine pull-off results from testing of the basement section. The average adhesion strength is 1.07 MPa.

Pull-off failures are illustrated in fig. 13 and 14 below.

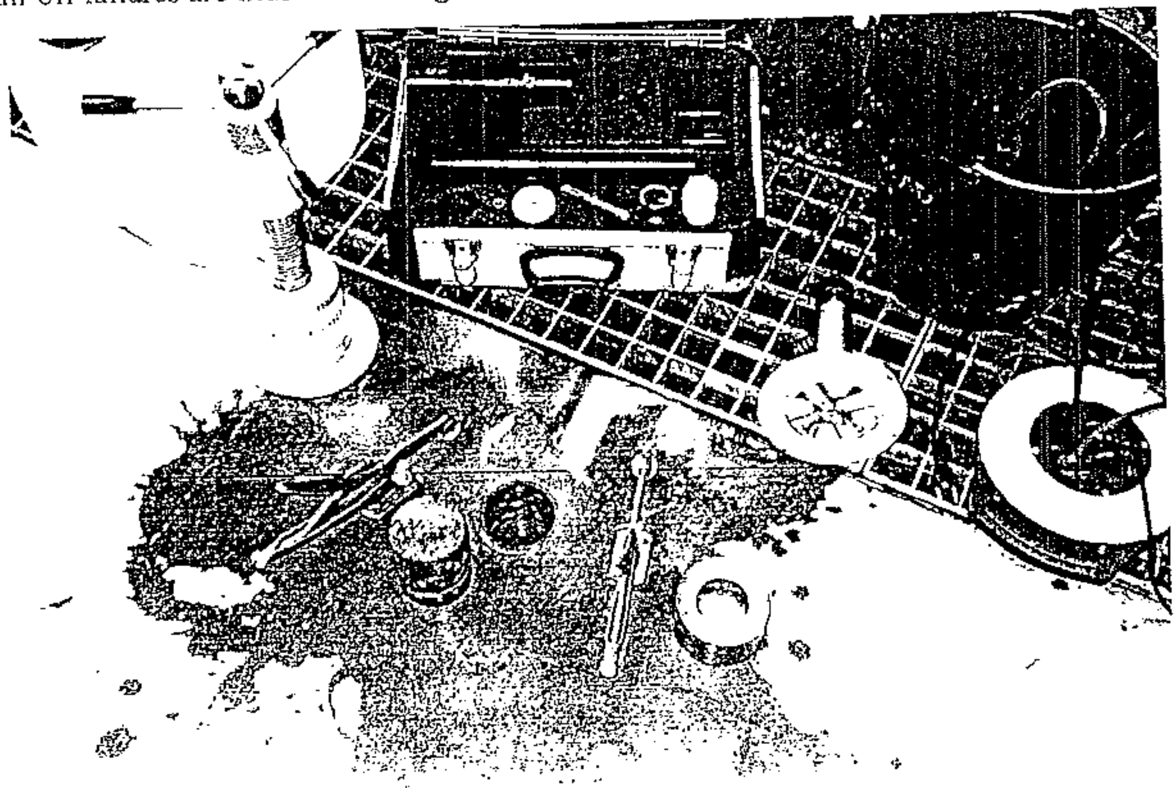

Fig.13. Completed pull-off test. The diameter of the partial drilled core is 75 mm

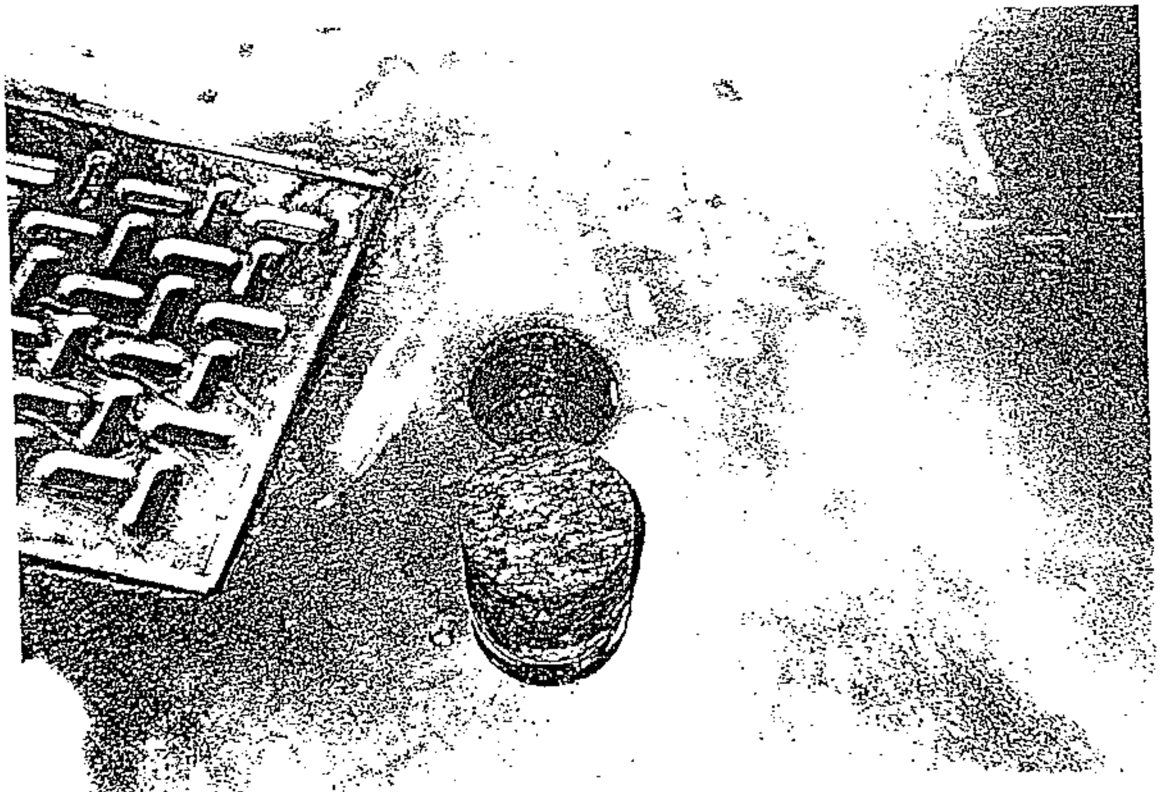

Fig.14. Pull-off failure indicating an adhesion strength of 1.01 MPa (test # 9)

4. Conclusions

4.1 Impact-echo classified successfully bonded and de-bonded areas of a composite basement slab. The impact-echo results were confirmed by coring.

4.2 To evaluate the adhesion strength in bonded areas, intrusive testing with the pull-off test was performed.

4.3 Pull-off tests made in the bonded areas of the slab indicated an adhesion strength of 1.07 MPa, in average. All tests but one, out of the nine performed, failed between the bonding agent and the substrate. The age was 14 days at 20°C at the time of testing.

4.4 The specified adhesion strength was 1.60 Mpa.

4.5 Re-testing was decided at a later age to observe if the adhesion strength will increase with increasing maturity.

4.6 Repair of the de-bonded area has not yet been decided.

5. References

(1) Lin. J.-M. & Sansalone, M.: "Impact-echo studies of interfacial bond quality in concrete", Report No. 95-4, May 1995, Structural Engineering, School of Civil and Environmental Engineering, Cornell University, Ithaca, New York, USA

(2) Germann Instruments A/S: "In-situ test systems for durability, inspection and repair of Reinforced concrete structures", catalog IST-98, Germann Instruments A/S, Emdrupvej 102, DK-2400 Copenhagen, Denmark