INJECTION QUALITY OF STEEL CABLE DUCTS EVALUATED BY NDT

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ABSTRACT

Injection of steel cable ducts is important for preventing corrosion on the tensioned strands as well as for stress transfer from the strands to the structural concrete.

The paper gives experience obtained from Non-Destructive Testing (NDT) of the grouting quality of steel cable ducts, partly from practical on-site testing and partly from a controlled specimen using reflection of shear waves (low frequency ultrasound 3D tomography) and from P-waves (Impact-Echo).

The conclusion is that voided and fully injected steel ducts can be evaluated by the two NDT systems, provided the testing engineers have sufficient understanding and training in operation of the systems.

KEYWORDS: NDT, ultrasound, 3D-tomography, impact-echo, injection quality, cable

1.Introduction

During construction of post-tensioned structures, steel cable ducts (fig. 1) are inserted with strands and tensioned (fig. 2) after the concrete member has achieved sufficient strength. Subsequently, pressure injection of the mortar takes place from tubes connected to the ducts until the duct has been fully filled with mortar.

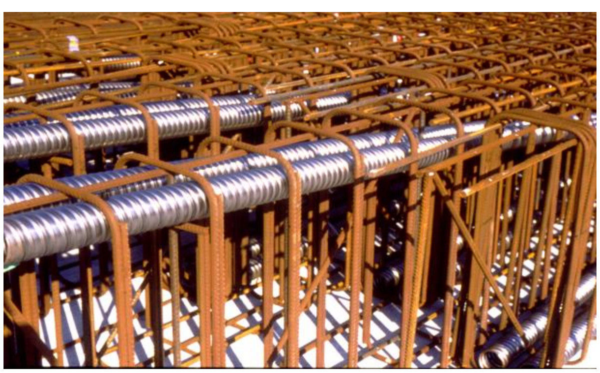

Fig.1 Example of ducts with inserted strands

Fig.2. Post-tensioned strands

The steel ducts, usually about 100 mm in diameter, are inserted typically with 10-12 twisted strands, ea. 15 mm in diameter.

The mortar has to encapsulate the strands (fig.3) to prevent corrosion of the strands (fig.3) and to ensure stress transfer from the strands to the structural concrete member. The examples are from a post-tensioned bridge beam in Finland constructed in 1971, ref. (1).

Fig.3 Sound strands in well injected duct

Fig.4 Corroded strands in empty steel duct

Consequently, testing for voiding of the mortar in steel cable ducts is essential, not only at a later stage of a structures life, but also at the beginning for quality assurance.

2. NDT methods

To avoid destructive invasive testing, selected NDT methods have been used in the past, and are increasingly being used on-site. They are low frequency ultrasound and impact-echo, both sonic systems.

In this paper experience is given with the two systems tested out on a controlled slab containing voided and fully injected steel cable ducts containing 10 twisted strands.

The NDT systems are the MIRA 3D-Tomographer and the DOCter Impact-Echo.

2.1 Low frequency ultrasound tomographer

Shear waves are emitted into the concrete and reflected against materials with another acoustic impedance, using an antenna with an array of dry point contact transducers arranged in a 4×12 matrix. The transducer array permits many pitch-catch, time-of-flight measurements to be made in a short period of time.

The antenna captures the raw data and creates in a laptop with special visualization software a 3-D color image of the reflecting interfaces within the element.

Fig.5. 3D Tomographer testing in progress for cable duct injection

2.2 Impact-Echo

A short-duration stress pulse is introduced into the member by mechanical impact. The generated P-wave will be reflected from interfaces with another acoustic impedance, return to surface, travels into the member again, etc. Thus the P-wave undergoes multiple reflections. A sensitive transducer next to the impact point picks up the surface displacement due to the successive arrival of the P-wave. The recorded waveform of surface displacement has a periodic pattern that is related to the depth of the reflection surface.

Fig.6. Impact-echo testing of pulp tanks for cold joints

Other examples of the use of impact-echo

Testing of the thickness of concrete liner inside a steel riser column in a refinery, Sweden

Tunnel lining thickness, Germany

Delaminations in sour pipes, Denmark

Depth of surface opening cracks in a fire damaged slab, Germany

Collapsed beams to be tested for injection of cable ducts, UK

Testing of tightness of highway slab joints, Holland

Testing for injection of ducts, Denmark

3.Test specimen

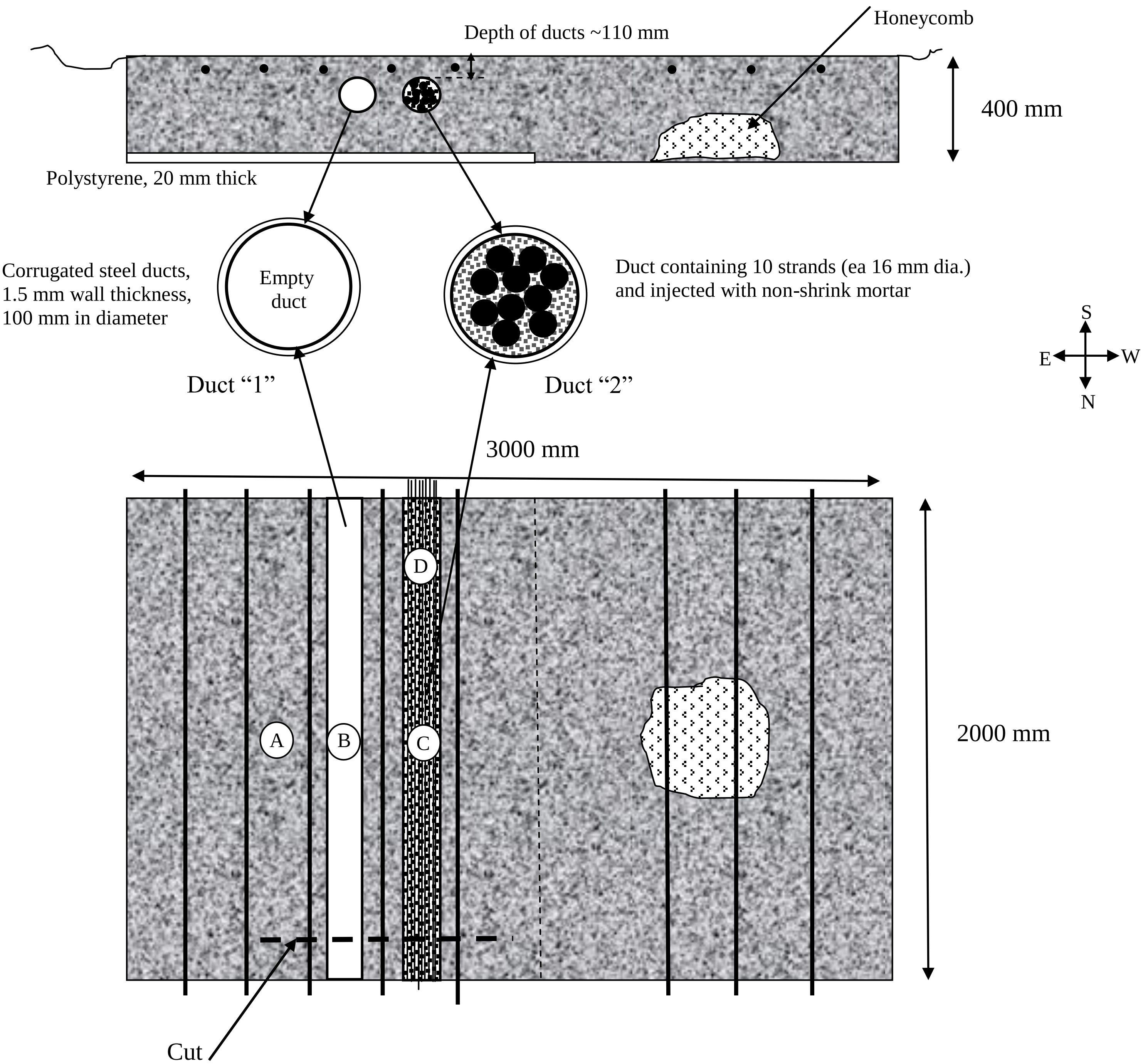

Fig.7 The test specimen

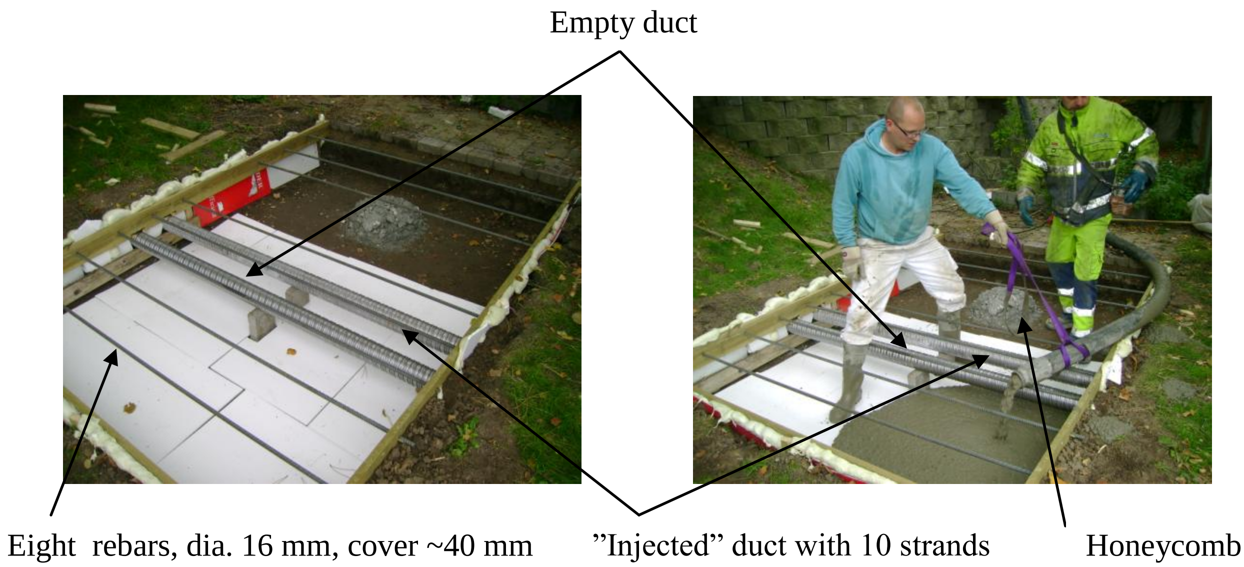

Fig.8 The test specimen shown before and during casting using SCC

2. Manufacturing and placing of the injected duct with ten strands

The 2 meter long corrugated steel duct was kept in a locked vertical position with the bottom resting firmly against a watertight polystyrene plate. BASF MASTERFLOW 9500 (with an autogenous shrinkage of - 0.1 $^{0}/_{00}$ after 6 days) was mixed in smaller portions and poured into the duct containing three strands, initially. At a mortar level of 20 cm from the bottom another strand was pushed into the duct, more mortar was poured to a level of 40 cm, another strand was pushed in, etc., etc., until all ten strands were positioned in the duct surrounded by mortar to the top. Constantly during casting, the duct was excited side wards with a rubber hammer with gentle hammer strokes in an attempt to ensure total embedment of the strands in the mortar. At the upper end of the duct, about 20 cm from the top, the mixer broke down, and another less efficient mixer had to be used.

The cable duct was kept in the same vertical position for 30 days and then placed carefully in the specimen´s formwork. The upper end of the duct was positioned at the face of the formwork containing the red plate, in the “south” direction.

3. Testing

Testing of the ducts was made with the MIRA ultrasound and DOCter Impact-Echo for defects in the ducts.

Prior to the testing the steel (reinforcements and cable ducts) in the specimen was located with GPR (Ground Penetrating Radar) and CoverMaster as shown in appendix 1.

3.1 MIRA ultrasound

Testing was made in two scan lines above the ducts with 250 mm distance between the scan lines and in steps of 100 mm, fig. 9, going from South to North face on the 2 meter wide plate.

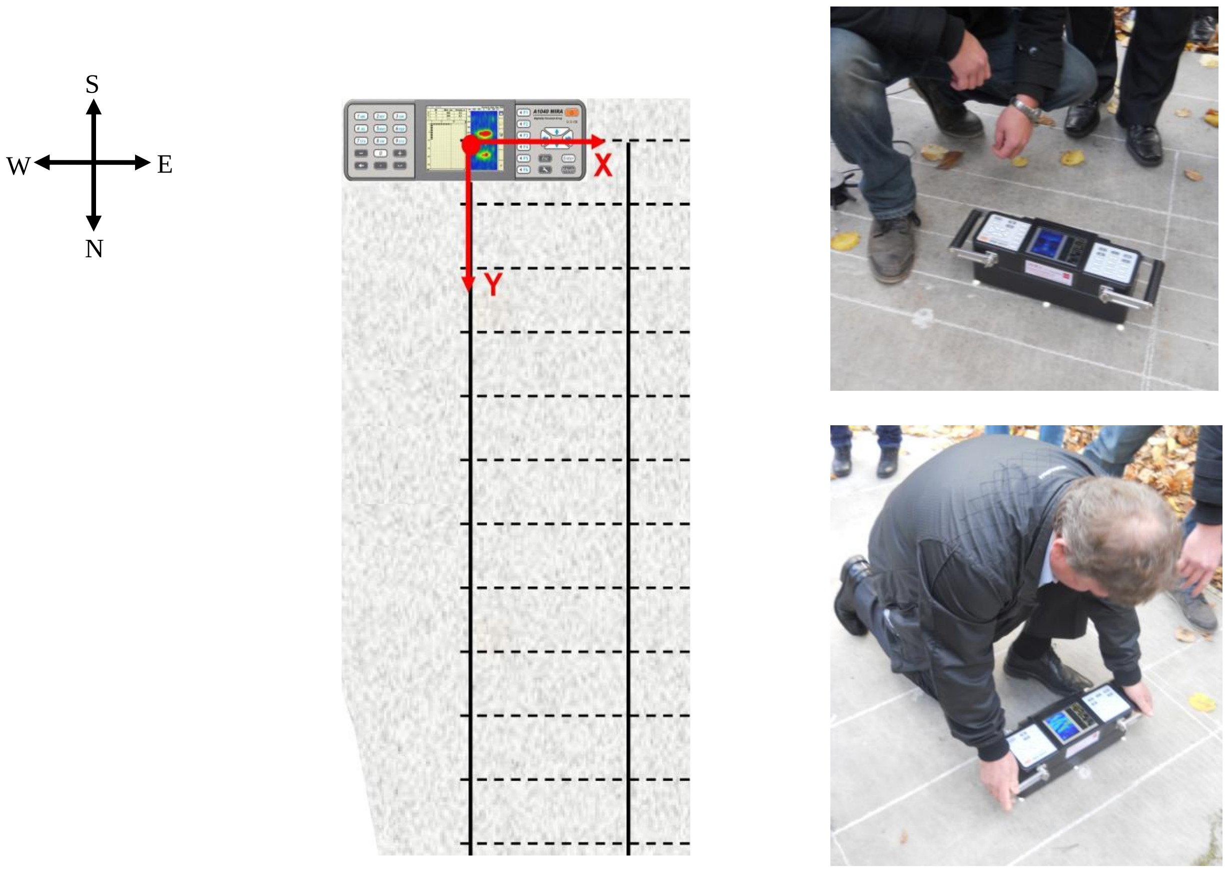

Fig.9 MIRA testing above the cable ducts in steps of 100 mm (Y-direction) in two scan lines, 250 mm apart (X-direction)

After transferring the records into the IdealViewer software of the MIRA laptop the illustrations are readily available as shown in the figures 4 – 8.

The settings of the MIRA were:

Operating frequency: 25 kHz
Color option: MIRA
Color gain: 7 dB
Analog gain: 30 dB

3-D color illustration of the volume around the ducts:

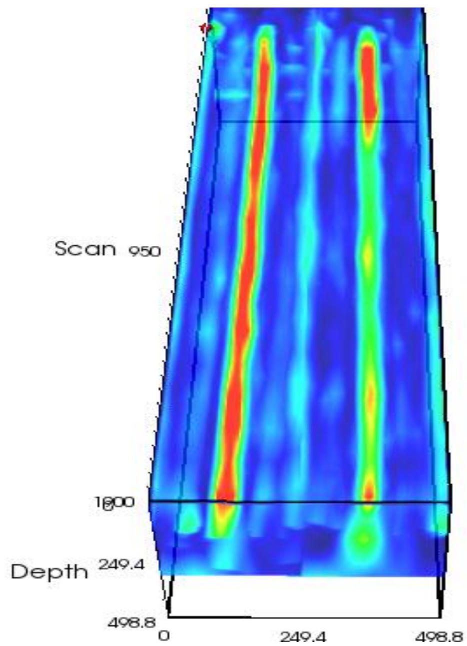

Fig.10. 3D-color illustration of the volume tested in the vicinity of the ducts.
The back wall reflection has been removed for clarification of the ducts condition

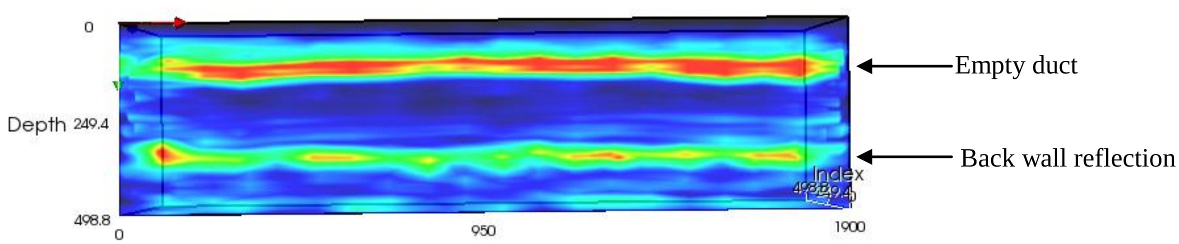

Fig.11. D-scan of the reflection from the empty duct

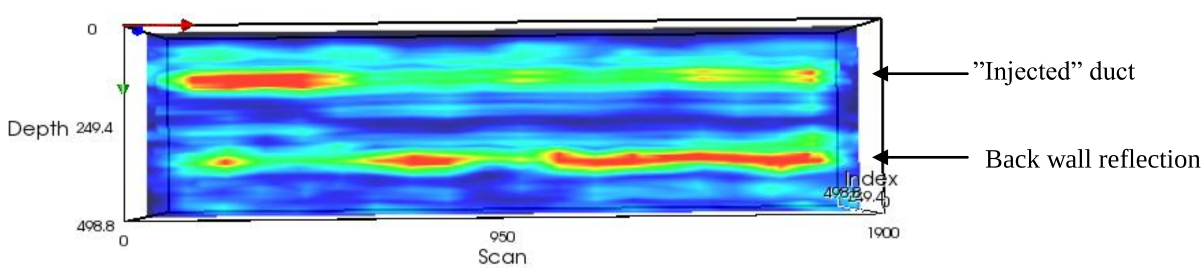

Fig.12. D-scan of the reflection from the "injected" duct

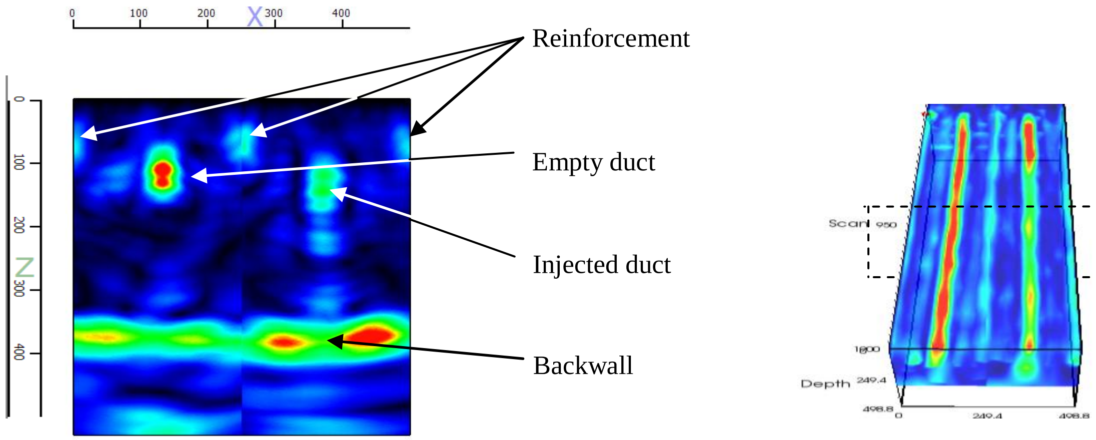

Fig. 13. B-Scan 1200 mm from south edge

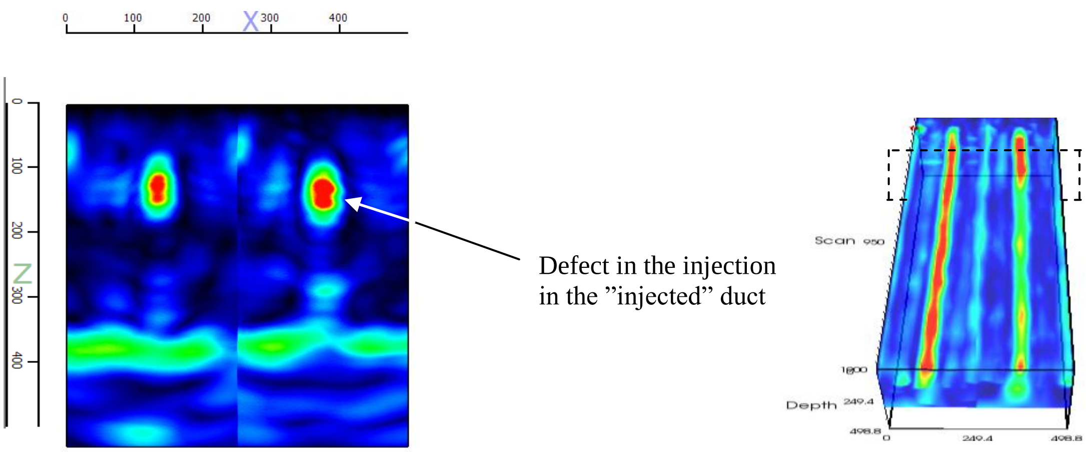

Fig.14. B-Scan 150 mm from south edge

As will be seen from the figures, the “injected” duct is in fact not fully injected. Starting from the south face of the specimen and extending about 30 cm into the duct, the red reflection indicates air in the duct.

3.2 DOCter Impact-Echo

To cross-check the results obtained by the MIRA, the DOCter Impact-Echo was applied in selected test points, Fig.7:

1. Point A, solid
2. Point B, empty cable duct
3. Point C, fully injected duct
4. Point D, poorly injected duct

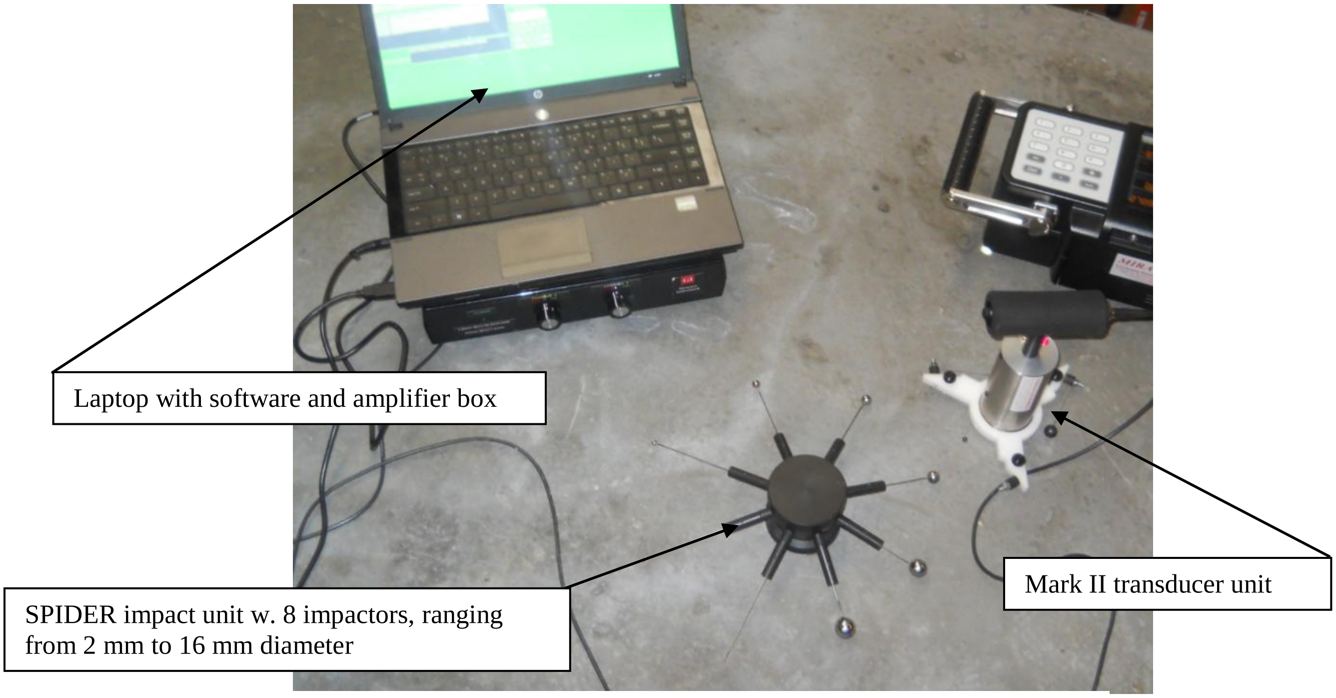

Fig. 15. DOCter Impach-Echo test system shown together with the MIRA

3,2.1 Point A, **Solid**

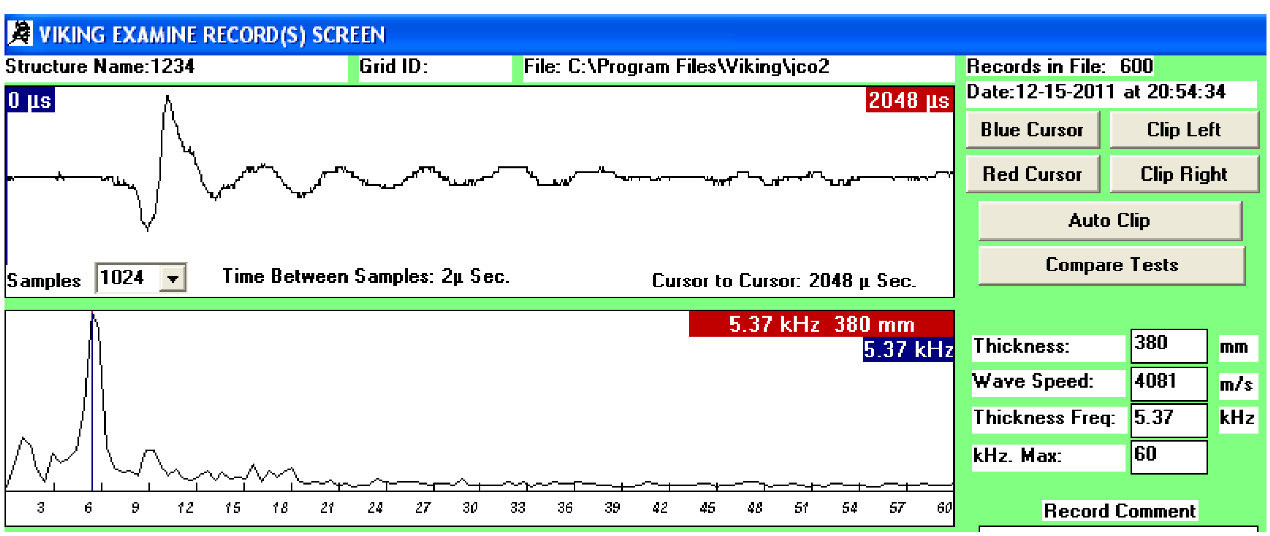

*Fig.16. Solid signal. For the measured frequency of 5.37 kHz and an estimated thickness of 380 mm the P-wave speed is 4081 m/s. Note that the estimated frequency of 5.37 kHz (blue box) coincides with the measured frequency (red box) related to 380 mm thickness after the calibration has been done. The red cursor in the frequency spectrum is hidden behind the blue cursor. The frequency is 4081 m/s (**2** x 380 mm) = 5,37 kHz, following the general impact-echo equation for air / concrete / air.*

3.2.2 Point B, **Empty Duct**

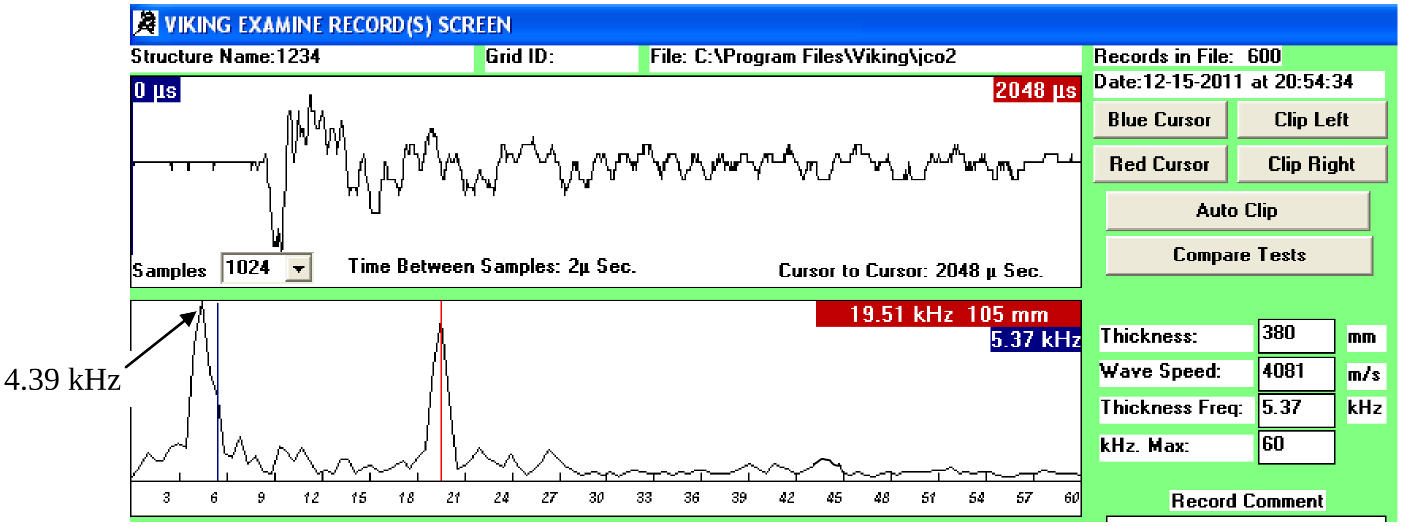

Fig.17. The 5.37 kHz solid frequency in fig.16 has dropped to 4.39 kHz, meaning that the travel path of the P-wave is: (4081 m/s / (2 x 4.39 kHz))=464 mm, 84 mm longer than 380 mm. Consequently, the P-wave has to run around a reflection surface, which may be the empty cable duct. At the same time a frequency peak at 19.51 kHz shows up, where the red cursor is positioned. This frequency relates to a depth to the reflection surface of 105 mm, the depth of the empty cable duct.

3.2.3 Point C, **Fully Injected Duct**

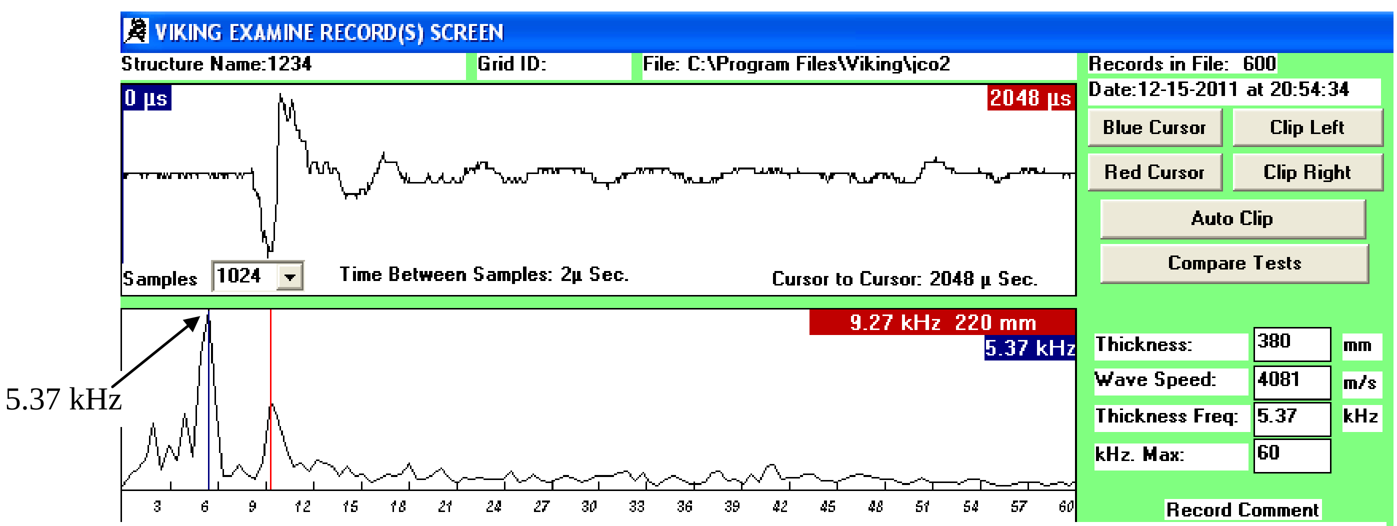

*Fig.18. The 5.37 kHz frequency is the same as the solid frequency in fig. 16 indicating a P-wave travel path of 380 mm. This can only happen if the duct with the strands is fully injected with no air intrusions, provided the testing is made over the duct. To make sure this is the case, there has to be an additional reflection from the strands inside the injected duct. This reflection shows up at 9.27 kHz, equivalent to a depth to the steel strands at 4081 m/s / (**4** x 9.27 kHz) = 110 mm (half of the 220 mm indicated in the red box), the impact-echo equation for air / concrete / steel. An 8 mm impactor was used. To enhance the 9.27 kHz peak a 5 mm impactor was subsequently used, fig. 19.*

5.37 kHz

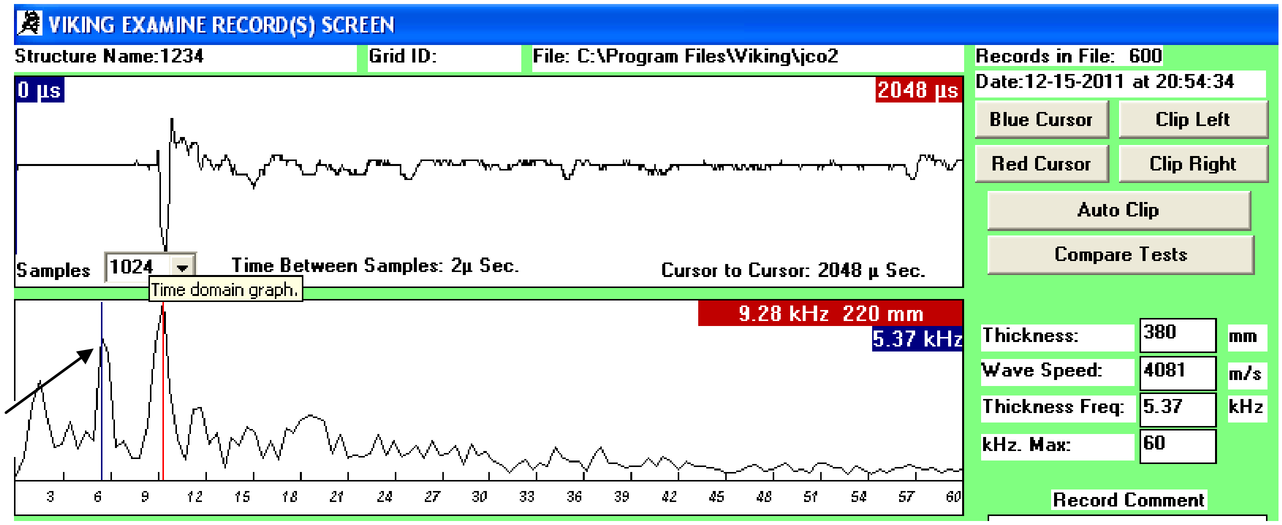

*Fig.19. Enhancement of the signal in fig. 18. A 5 mm impactor is used with a smaller contact time producing a higher maximum useful frequency. The main conclusion is the same: As the solid frequency of 5.37 kHz in fig. 10 is unchanged the P-wave runs directly through the duct with no obstruction from air interfaces inside the duct. In addition, a more pronounced frequency peak at 9.28 kHz is exhibited, producing a depth to the steel strands inside the cable duct of 4081 m/s / (**4** x 9.27 kHz) = 110 mm, following the impact-echo equation for air / concrete /steel.*

3.2.4 Point D, **Poorly Injected Duct**

4.60 kHz

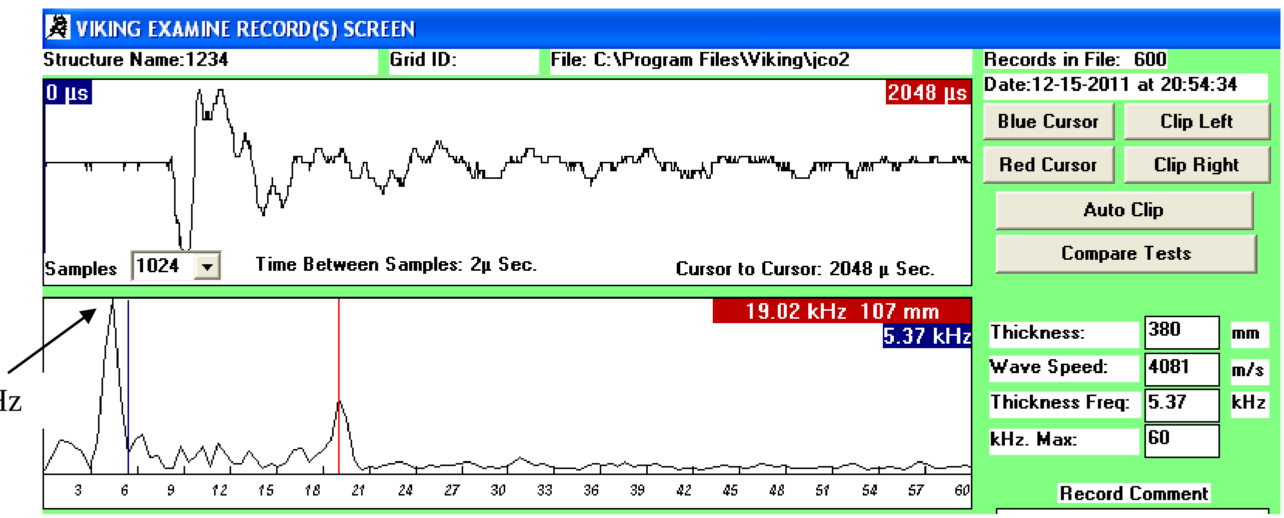

Fig.20. The P-wave has a travel path of more than 380 mm as the frequency has dropped from 5.37 kHz to 4.60 kHz. This can only happen if there is air in the duct. The air interface is positioned at a depth of 107 mm. The duct is poorly injected.

4.Openings in the slab for verification

A cut at the end part of the slab was made, position as shown in figure 7.

Figure 21. End cut in the slab for illustration of the empty duct and the injected duct with the 10 strands

Similarly, cuts were made at the D position figure 7, and a “poorly” injected cable duct was found with smaller air inclusions colored black in the photo below. Despite the air inclusions the strands are fully protected by the grout.

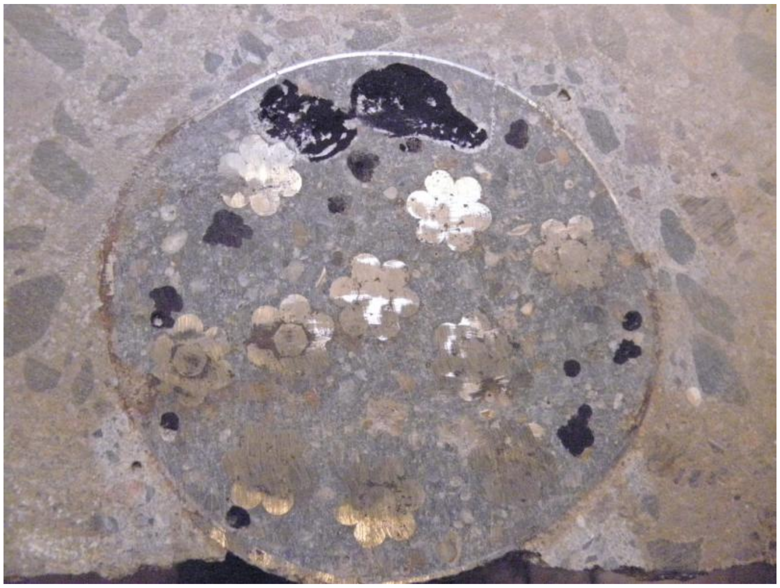

Fig.22. Cut at the D position in figure 7. The air bubbles found are enhanced by black marking. The corresponding impact-echo signal is shown in fig. 20.

5.Conclusions

4.1 Both the MIRA and the DOCter Impact-echo can detect steel cable ducts not injected. For the DOCter the frequency designated as the "solid frequency" will drop and another frequency will come up in the amplitude spectrum related to the depth of the reflection surface.

4.2 Partly injected steel cable ducts can also be detected with both the MIRA and the DOCter. Care should, however, be exercised in the interpretation. In spite of the presence of voids in the injection material the strands may be fully protected and well bonded to the injection material. Only opening will reveal the actual condition of such a partially injected steel cable duct.

4.3 Fully injected steel cable ducts will for detection with the MIRA require proper adjustment of the colors, while for the DOCter Impact-Echo reflection from the strands will take place following the equation $f = Cp / 4 \times T$ with no drop in the "solid frequency".

4.4 For practical testing with the DOCter Impact-Echo it is important to test in the longitudinal direction of the duct. Prior to testing, the duct(s) have to be located e.g. by GPR or MIRA. During testing make sure the reflection frequency occur from either the strands in the duct, fig. 18 and 19, with no drop in the solid frequency (solid signal) or from a void in the duct, fig. 17 and 20 with a drop in the solid frequency (voided signal)

6,References

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