IMPROPER FILLED DUCTS DETECTED
BY ULTRASOUND REFLECTION

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Abstract

Results of investigations performed at specimens prepared by BAM, Berlin, BASt, Bergisch-Gladbach and Darmstadt Technical University, which contain partially filled tendon ducts are presented. These specimens differ in the used concrete mixture and in the content of ordinary reinforcement. The measurements were taken utilising the pin contact shear wave ultrasound transducer array A1220 which is manufactured by MSIA Spectrum, Moscow. It is the aim of the investigations to check the capability of the applied technique to find areas of the ducts which are unfilled with grout. Therefore statistical techniques evaluating the amplitude of the back scattered ultrasonic signals are applied. These techniques were developed and tested in former investigations.

1. Introduction

Using post tensioned simply supported and continuous beams has been the dominating technique of bridge building during the last fifty years. The basic idea is to produce compressive stress within a beam by prestressing cables anchored at both ends of the beam. The cables are guided by ducts which are embedded in the reinforced concrete beam. A bond between the cable and the beam is performed by filling the remaining volume of the duct with mortar after the application of tensile stress into the cable.

The requirements a prestressing cable material has to fulfil are different from those applicable to ordinary reinforcement. The yielding point is significantly higher and the relaxation is lower than the corresponding values of ordinary reinforcement. Fulfilment of these requirements leads to a material, which is sensible to certain types of corrosion. This sensibility doesn't play a role as long as corrosion protection is guaranteed by a basic concrete environment, i.e. the grout also provides the corrosion protection of the embedded cable. It was found that the proper filling of the ducts was not achieved in some structures. Hence the risk of some failure introduced by the corrosion of the unprotected cables is increased remarkably. As a consequence the risk for the stability of the structure itself also increases. It is obvious, that such a risk will become more serious over the lifetime of the building. It is impossible to perform an area covering inspection based on destructive methods. There is a need for non-destructive techniques on a reasonable cost level with sufficient accuracy indicating areas of improper filling under practical circumstances.

The actual technique fulfilling almost always the criteria of sufficient accuracy is the application of X-rays but the method needs accessibility from both sides of the structure. Inspection areas are relatively small and the need for sufficient radiation protection is often a severe problem. So this technique is barely applied.

2. Ultrasonic Inspection Techniques

Concrete is an extremely inhomogeneous medium, causing a large amount of backscattering for elastic waves, which leads to "grain noise". The relationships of grain noise and detectability for longitudinal waves are reported in detail in [1, 2]. As reported in [3], ultrasonic devices utilising shear waves like the A1220 [4] offer advantages with respect to back scattering in the direction of the receiver. In addition there is no need of application of a coupling agent like it is well known if standard transducers are used. Shear waves can be applied to concrete surfaces by point contacts, moving parallel to the concrete surface. As long as there is a transfer of forces parallel to the surfaces there is no need for a coupling agent. The development of such transducers must be regarded as the most significant impact over the last ten years on ultrasonic testing of concrete structures.
Signal processing techniques developed by several research institutes like spatial averaging [5], amplitude statistics [6, 7, 8] or the addition all types of available preinformation should now be proven whether these can also improve the results gained by ultrasonic tests utilising shear waves. It is shown here that the amplitude statistics of reflections originated from unfilled ducts differ from filled ones.

3. Preinformation

The situation that nothing is known about the structure under test may be excluded. As soon as pictures can be composed, even if they only consist of one thousand pixels, a large number of information can easily be included in the interpretation of results. In the case of the inspection of ducts some of these nearly trivial information might be:

- The approximate position of the duct in all three co-ordinates maybe taken almost always out of the documentation of the structure.
- The fact, that a duct is a lengthy object going all along the structure from one anchoring point to the other is obvious.
- There is no doubt, that a duct will have a minimum bend radius because of its bending stiffness.
- The position of rebars may also be documented or provided by accompanying measurements.

It is self-evident that exactly this leads to a tool to judge and understand the results of an ultrasound inspection. In the following sections examples will be given. It is shown in [9] that there is a significant difference in the quality of the basic A-scan depending on the relative position of the transducer to the ordinary reinforcement. Crossing points of rebars proved to be obstacles for the waves to penetrate the concrete volume. In practical applications there will be a certain difference in the quality between certain areas of the image. The application of the statistical approach presented here follows the basic ideas presented in [8]. Detailed information about this matter can be found in [6, 7, 10, 11, 12].

4. Investigations

As a first step the objective of the detection of ducts was formulated and proven by taking the available pre-information into account. In the next step the detection of areas which are not filled with grout was investigated. It was found that the amplitude distribution is an indicator for unfilled ducts. In contrast to [6] a simpler statistical approach was chosen because the amount of data which made up a sample was remarkably lower.

The specimens under investigation in the first attempts had been concrete blocks of different maximum aggregate size and drilled holes with a diameter of 80 mm. Consequently the next steps for investigation had been structures with different types reinforcement and ducts with well controlled areas of improper filling. Corresponding specimens are available at the Federal Institute for Materials Research and Testing (BAM) in Berlin, the Federal Highway Research Institute (BASt) in Bergisch-Gladbach and the Technical University of Darmstadt. These specimens are carefully produced and the conformity with the documentation was proven by X-ray investigations.

5. Experimental Results

5.1 Procedure and Statistical Interpretation

A standard measurement provides 40 (x-direction) x 24 (y-direction) x 128 (z-direction) = 0.123 megavoxel data points, where z is the direction of depth. The physical volume of each voxel depends on the step width in x and y-direction and on the depth of the specimen. A reasonable physical voxel volume for a concrete slab of 50 cm thickness and x, y-steps of 2 cm is 1.6 cm^3. The results of measuring are presented in layers parallel to the accessible surface as C-Pictures. All reflecting structures i.e. rebars, ducts - in the observed case - and the backwall should contribute to the picture in the corresponding depth. Dark areas in the pictures indicate high intensity of reflected waves, light areas indicate low intensity. The interpretation of results can be separated roughly in two steps: finding out the position of reflecting objects and the explanation of different intensities within an identified object. In fact these two steps can't be separated perfectly in most practical cases localising a scatterer already means taking into account the differences of intensity. That means, different to the optical image of a structure like a duct, there will be a surrounding of the object under observation whose intensity level is not much lower than that of the object.

Major scatterers in a concrete volume will produce shadowed areas on the backwall because there is a reduced intensity of the incident waves. These shadowed areas must correspond to reflecting areas in planes parallel to the accessible surface. If both statements are found to be true, the existence of a scattering structure - here a duct - can be assumed strongly. Differences in the reflectivity of the structure indicate differences in density and/or Young's modulus of the scatterer. Those differences in the case of ducts must be a consequence of proper or improper filling with grout. A comparison of the sketches indicating the positions of improper filling and the corresponding ultrasound pictures shows a remarkable consistence. This consistence is obviously not strongly influenced by the reinforcement of the two specimens under consideration.

Statistical methods are the most reliable mean to provide proper distinguishing between background and scatterer of interest. A first simple check for the applicability of the strategy is the comparison of the intensity distribution of different characteristic areas of the pictures presented above. A significant difference of the mean values of the Gaussian distributions representing the background, the well grouted and the improper grouted duct is the first requirement for the applicability statistic methods of interpretation and especially for the definition of a reasonable threshold to separate the different intensities. Based on this threshold the probability of false alarm can be defined [6]. The investigations presented in the following are clarifying the procedure.

5.2 Investigations at BAM

with a metal duct diameter 85 mm. Maximum aggregate size is 8 mm the concrete has a strength category B45 using cement HOZ35L. The measured area of the specimen is free

duct, inten

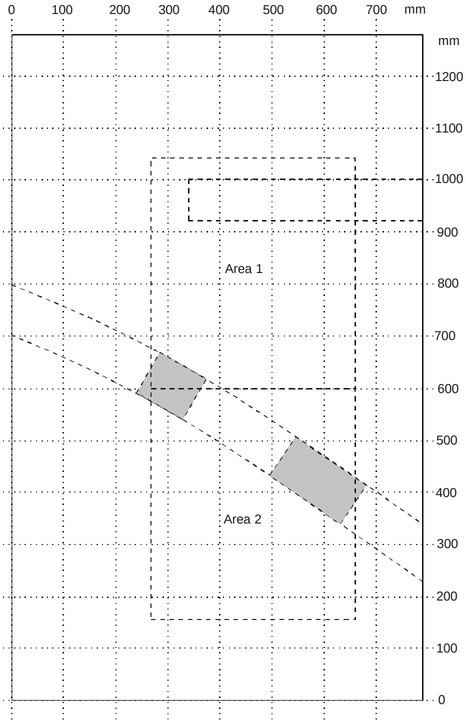

Figure 1: Test specimen BAM

Figures 2 and 3 are presenting C-Pictures of the specimen of BAM. Area 1 and 2 are combined in both pictures.

Figure 2 clearly shows the reflection of the duct and of the drilled hole. The differences of the grey values in the range of the duct point to distinctions of the filling. The drilled hole in the upper part of the picture is indicated. The upper surface of the hole is not perfectly parallel to the inspected surface. Stepping upward in z-direction proves this assumption. Dark areas are representing the improper filled zones of the duct. In figure 3 the dark areas are belonging to the back wall and the bright areas to the duct and the drilled hole. Those bright areas are reasoned by the shadowing effect of the duct and the hole. Beside that there are scattering obstacles which are not indicated in figure 2 producing also shadowed areas on the backwall.

The areas associated to the surrounding concrete, the filled and unfilled ducts are investigated separately. The amplitudes of the pixels that make up an area are regarded as different samples and it is assumed that the amplitudes are Gaussian distribute. Figure 4 shows these distributions. A threshold crossing the point of intersection between the distributions “filled” and “improperly filled” is introduced.

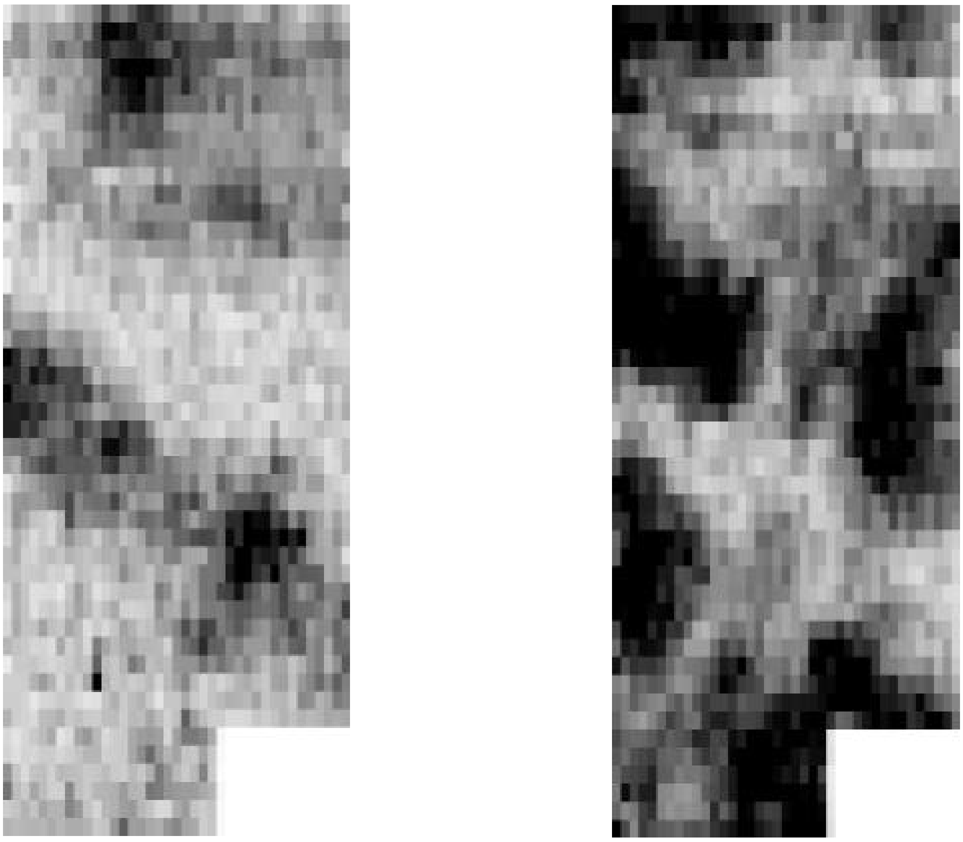

Figure 2 and 3: C-Pictures in a depth *z* = 337 mm and *z* = 500 mm (back wall)

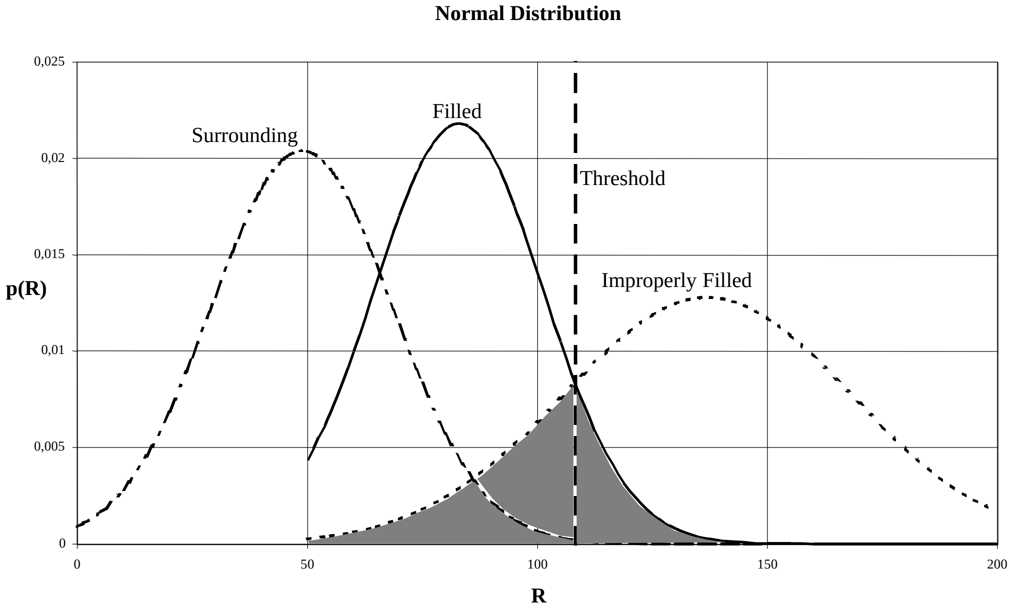

Figure 4: Gaussian distribution (BAM specimen, area 2, z = 337 mm)

Following the underlying distributions figures 5 and 6 are the transformed results by applying the threshold between "Filled" and "Surrounding" (figure 5) and between "Improperly Filled" and "Filled" (figure 6). It is clearly visible that the remaining pixels correspond to the areas of interest.

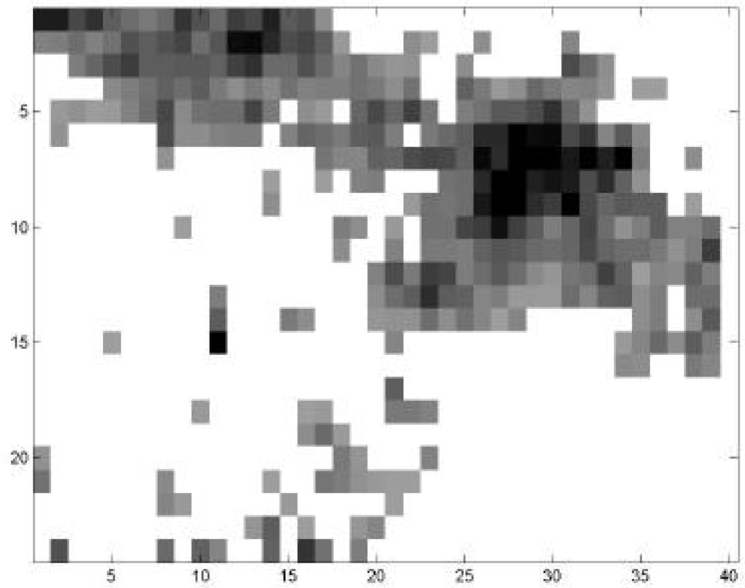

Figure 5: Transformed C-Picture of area 2 threshold between filled duct and surrounding

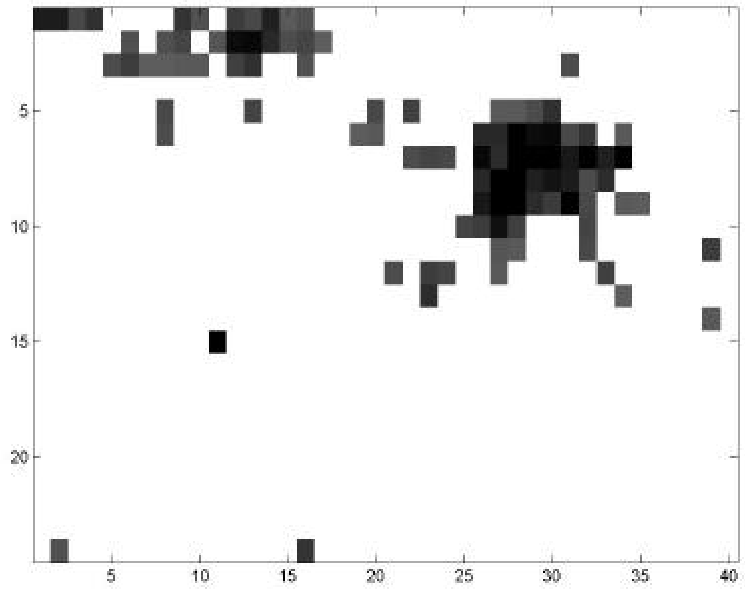

Figure 6: Transformed C-Picture of area 2 threshold between filled and improper filled duct

5.3 Investigations at BASt

The test specimen of BASt, as displayed in figure 7, has a volume of 2.0 x 1.5 x 0.68 m³ with two metal ducts diameter 85 mm. Maximum aggregate size is 16 mm the concrete has a strength category B45 using cement CEM III/A 42,5. The specimen is divided in two halves of the kind of mesh reinforcement; area 1 (left) mesh size is 50 x 50 mm on both sides, area 2 (right) mesh size is 75 x 75 mm on both sides. The diameter of the rebars is 12 mm. The improper filled areas in the ducts are made by plastic flaps (PE) and around the first duct are two artificial honeycombs.

Figures 8 to 10 are displaying the result of measurement and interpretation following the argumentation of section 5.1. The sequence of figures equals that of section 5.2.

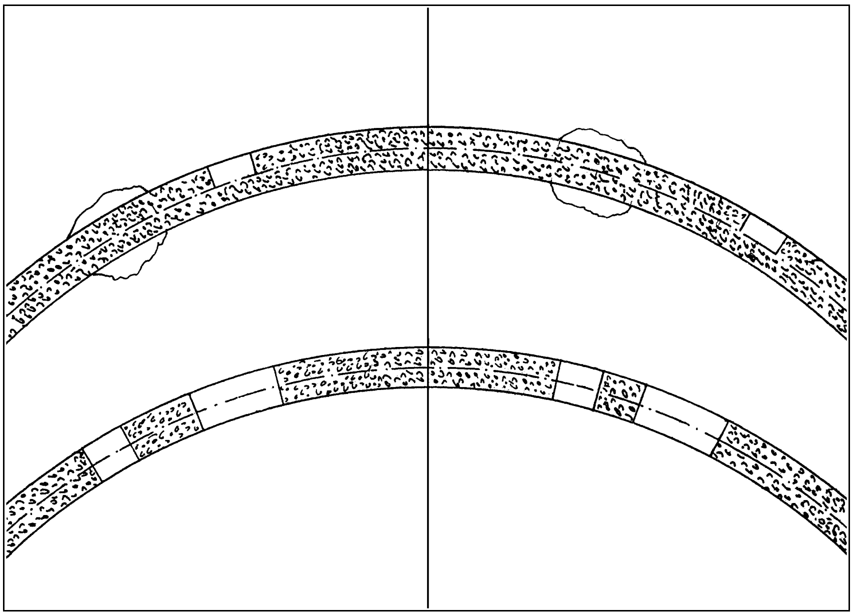

Figure 7: Test specimen BASt

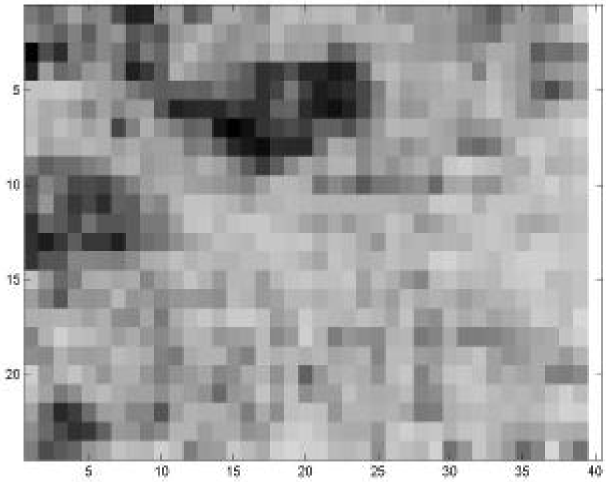

Figure 8: C-Picture of BASt specimen, left area, depth z = 287 mm

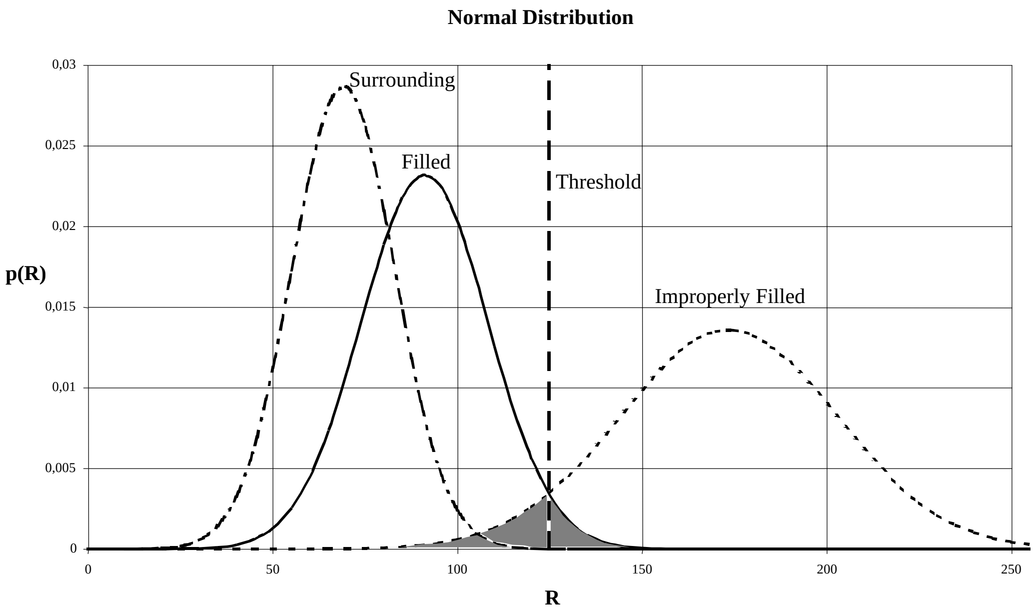

Figure 9: Gaussian distribution (BASt specimen, left area, z = 287 mm)

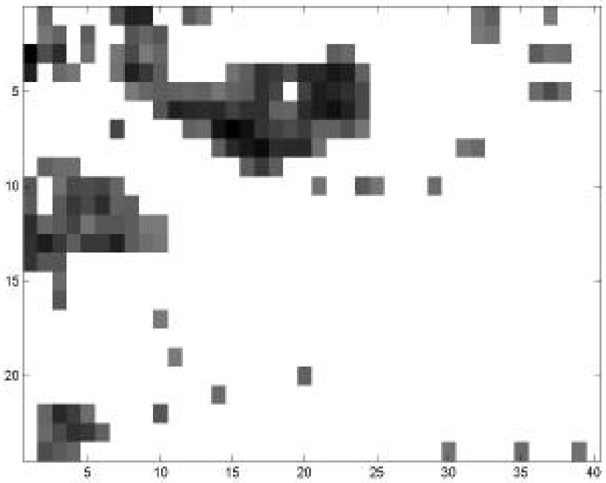

Figure 10: Transformed C-Picture of the left area, threshold between filled and improper filled duct

5.4 Investigations at Darmstadt University of Technology

The specimen at Darmstadt University of Technology contains an unbowed duct in the depth of 285 mm but no regular reinforcement was build in. It consists of concrete possessing a compression strength of 25 MPa/mm², grading curve between A and B and a maximum aggregate size of 16 mm. Following the argumentation and sequence of figures of the former sections the results of the investigations are documented in the next figures [13].

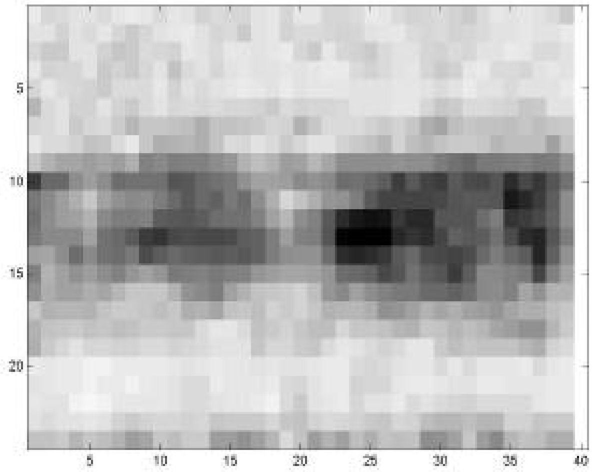

Figure 11: C-Picture of TUD specimen, duct located horizontally in the middle of the image, depth z = 293 mm

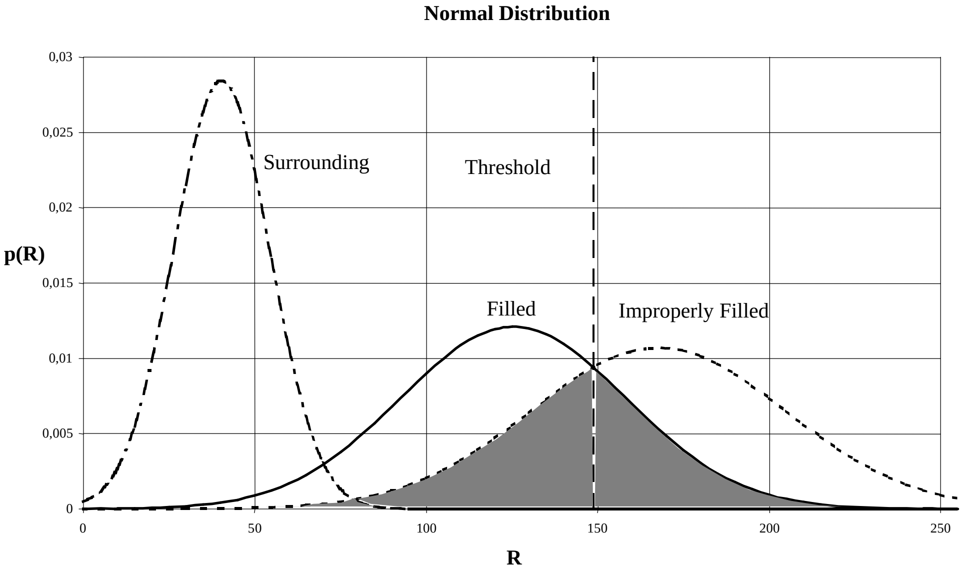

Figure 12: Gaussian distribution (TUD specimen, depth z = 293 mm)

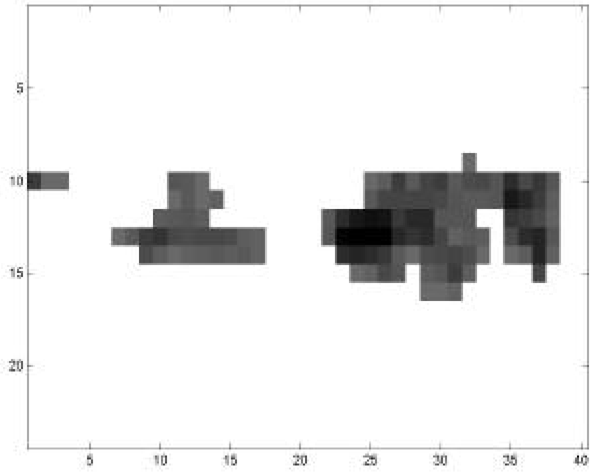

Figure 13: Transformed C-Picture, threshold between filled and improper filled duct

6. Conclusion

The differences in the reflectivity of filled and unfilled ducts embedded in concrete with up to a thickness of 70 cm with different percentages and arrangements of ordinary reinforcement proved to be detectable by shear wave reflection technique. Statistical evaluation of amplitudes obtained by the measurements indicate that it can be distinguished between plain concrete, filled and unfilled duct. Refining these observations by introduction of other better suited probability density functions in the sense of [6] and estimating the thresholds by means of improved techniques [7, 10, 12] will be the next step of our research work.

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