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MEASUREMENT OF ASPHALT CONCRETE BASE THICKNESS USING ULTRASONIC PULSE ECHO

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Abstract. This paper deals with the description and use of one of the up-to-date NDT method, the ultrasonic pulse echo, to determine the thickness of an asphalt concrete model. In the article, the authors explain the principle of the method and the limits of its use. Furthermore, attention is also paid to the influence of the shape and design of the back wall of the tested elements and the speed of propagation of ultrasonic waves. The research is part of a larger work, defect analysis and implementation of Whitetopping technology in the Czech Republic.

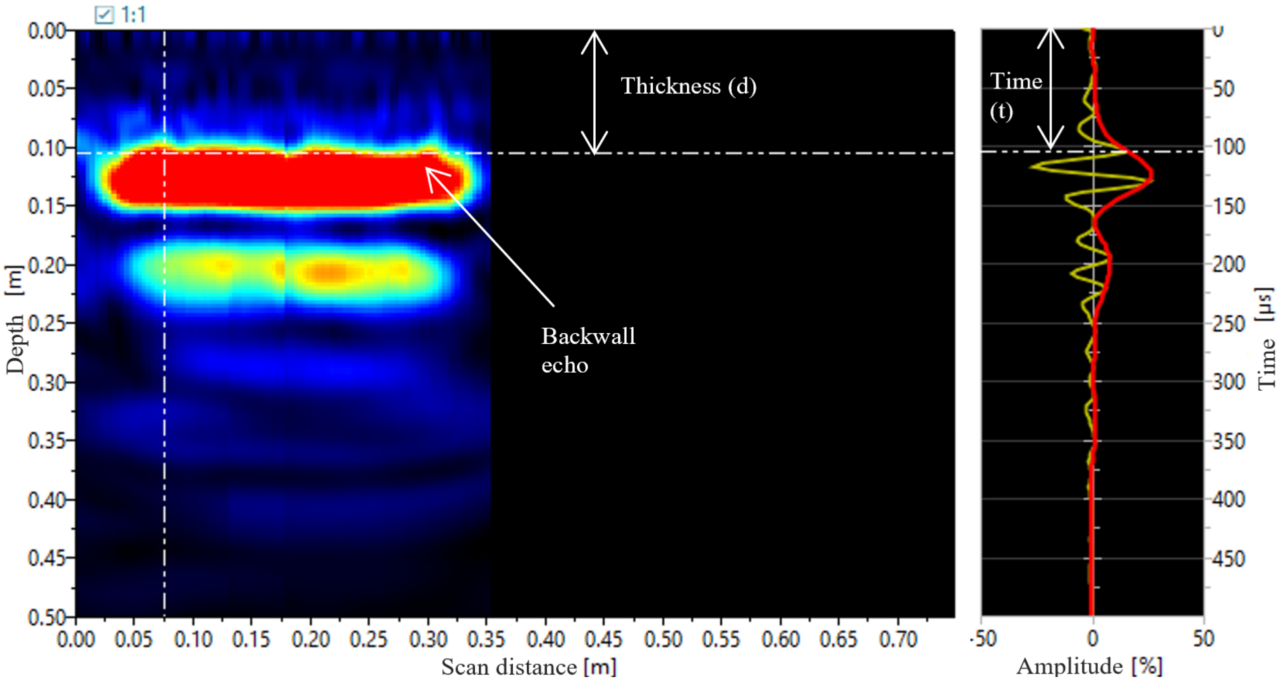
Keywords: Asphalt, thickness, whitetopping, non-destructive testing (NDT), ultrasonic pulse echo.

1. Introduction

Asphalt concrete plays a very important role in the construction industry today. With the development of road transport of goods, services, etc. there was also a need to improve the design and implementation of roadways and parking areas. It is for these reasons that asphalt concrete, i.e. a mixture of aggregate and asphalt binder, began to be used in the past. However, with the increasing intensity of traffic, it is necessary to further adjust and improve these mixtures, especially with regard to their durability and economy. The topic that the authors deal with in this paper is part of a larger research. This research deals with sustainability and the correct implementation of so-called Whitetopping. Even though the Whitetopping technology is relatively old and in some countries such as the USA, Sweden, etc. commonly used, its development in the Czech Republic has only now come to fruition. Whitetopping is a method of rehabilitation of roadways, roads, parking areas, etc. The implementation consists of applying a thin layer of high-strength concrete to the existing ACP layer, which creates a composite material with new properties. The thickness of the Whitetopping layer is from 100 to 200 mm. It is the connection of these two layers and their interaction that is essential for the proper functionality of the new composite. The use of this method is especially suitable in places with a high intensity of heavy freight traffic, such as highways, parking lots next to highways, etc. [1, 2] With the development of Whitetopping implementations in the Czech Republic, there are also requirements for verification of the quality of execution and condition. As already mentioned, for the correct implementation of this remediation method, the connection of the Whitetopping layer with the underlying asphalt concrete is essential. In order to be able to assess this, it is first necessary to have an overview of the underlying layer, its thickness, whether the devices can detect and measure it. Based on the previous experience of the authors, the ultrasonic pulse echo method was chosen for these measurements, which is very suitable for measuring the thickness of the structure, possibly delaminations and cracks. [3, 4]

2. Methodology and principle of UPE

The pulse echo Pundit 250 Array (nowadays called Pundit PD8050) was evaluated as the most suitable device for these measurements, as it is used in construction practice for a similar issue (measurement of the thickness and properties of cement concrete). The principle of UPE consists in sending short beams of damped mechanical oscillation into the material. This oscillation is created in the exciter, which regularly and repeatedly sends electrical impulses, and the sensor then detects them. In the case of UPE, only one probe is used, which fulfills both functions and is therefore an exciter and a sensor at the same time. When the probe (piezoelectric) is applied to the surface of the structure, it first functions as an exciter sending a mechanical signal to the structure, then it switches to the sensing mode, when it receives the signal reflected from the opposite surface of the structure or an obstacle and changes it into an electrical image. The image transformed in this way is displayed on the device screen as a so-called "echo". Ultrasonic waves propagate with certain materials and are reflected at the interface of the environment, such as delamination, cracks, plastic or metal objects, etc. Air and plastic objects are excellent insulators for ultrasound. When using UPE, the signal transit time through the examined element is determined as the time that elapses between the sending of an ultrasonic wave into the environment, the subsequent reflection of the wave from a distant surface (or defects) and the recording of the reflected echo at the point of sending



(a). B-scan (b). A-scan

Figure 1. B-scan and A-scan measurements of model thickness.

Device	Length [mm]	Width [mm]	Height [mm]	Back Of Model
Model No. 1	505	305	102	Straight, smooth
Model No. 2	505	305	110	With compacted macadam

Table 1. Description of asphalt concrete models.

the signal. Modern devices can display the observed time on their screens as an A-scan graph, which captures the deviations of the impulse as a function of time (Figure 1). First, the initial impulse is recorded on the screen, then the impulse of the defect inside the environment (echo of the defect) or the echo of the back wall. [4, 5]

The thickness of the structure, or the depth of the detected defect, can be determined from the exact time the ultrasound passes through the examined environment. Given the known speed of propagation of ultrasonic waves through the environment under investigation and the time t, which indicates the time between sending and recording the reflected signal from the back wall, the depth of the defect can be determined as d:

$$d = \frac{v\,t}{2}. \qquad (1)$$

Similarly, the thickness of any defects or defects inside the examined structure can be determined [6]. Measurements on the models took place in the premises of BUT FAST. An ultrasonic pulsed echo Pundit 250 Array was used. For the purpose of measurement, 2 asphalt concrete models were created simulating common asphalt concrete base layers.

Model No. 1 (see Figure 2) is made of ACP asphalt concrete with an aggregate grain of up to 16 mm. The model is flat on both the top and bottom surfaces, well compacted. The model simulates the underlying layers, on which remediation in the form of Whitetopping is normally applied. For description of dimensions see Table 1.

Model No. 2 (see Figure 3) is also made of ACP asphalt concrete with an aggregate grain of up to 16 mm. In the second model, macadam fraction 63 mm was vibrated on the bottom side, so the surface of the bottom side is not flat. This model is intended to simulate a base when, during the realization of the base layer, asphalt concrete was thickened into a macadam gravel bed. For description of dimensions see Table 1.

For the sake of systematicity and clarity of measurement, the same measurement grids were drawn on both models. Lines in the x-axis direction were marked with numbers A-I, lines marked with Roman numerals I-V run in the y-axis direction. The lines are marked with a grid of 50×50 mm. A grid of 50 mm was chosen with regard to the required measurement detail. Due to the size of the UPE matrix probe (210 mm), the overlap of the individual B-scans was chosen to be

(a). Upper surface (b). Lower surface (c). Side view

Figure 2. Photo of model No. 1.

(a). Upper surface (b). Lower surface (c). Side view

Figure 3. Photo of model No. 2.

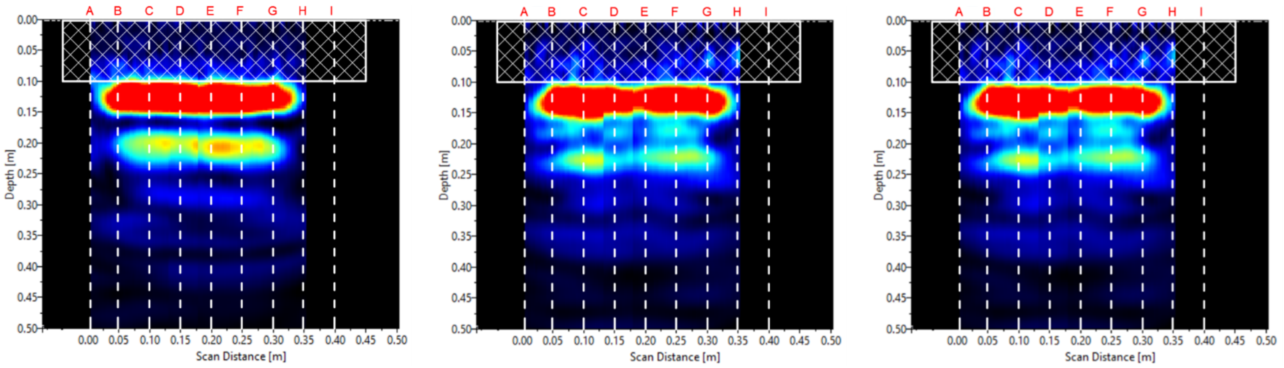
Device	**Pulse Velocity [m/s]**	**Pulse Voltage [V]**	**Receiver Gain [dB]**	**Bandwidth [kHz]**
Model No. 1	2 002	150	50	40
Model No. 2	2 001	150	50	40

Table 2. Default settings of Pundit 250 Array [5].

160 mm. Measurements were always made as close as 50 mm from the edge of the model to avoid distortion by edge effects. Before the actual measurement, the surface speed of the shear wave was determined by measuring at 8 places evenly over the entire area of model No. 1 and No. 2. As already explained, the determination of this speed is very important for the correct calculation of the thickness of the examined element. Device settings before measurement on individual models, see Table 2.

3. Results and comparison of measurements on models

With the device's default settings according to Table 2, measurements were made on both models. The models were measured parallel to the x and y axes, i.e. in lines I-IV and A-I. Such measurement of the model with a step of 50 mm proved to be sufficiently detailed for the purpose of measuring the thickness of the element. Scans of individual lines II-IV are shown in Figure 4, where part (a) is a measurement in line

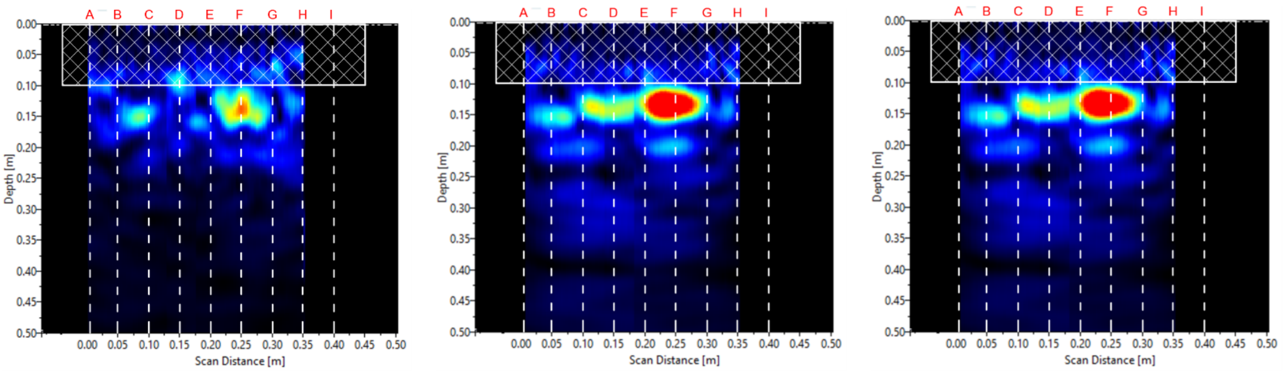


(a). Line II (b). Line III (c). Line IV

Figure 4. Scans taken in lines II-IV on model No. 1.

Line	B [mm]	C [mm]	D [mm]	E [mm]	F [mm]	G [mm]	Average [mm]	Deviation [mm]	Deviation [%]
II	103	103	104	104	105	102	103.5	1.5	1.4
III	105	105	105	103	105	104	104.5	2.5	2.4
IV	105	106	105	107	104	105	105.3	3.3	3.2

Table 3. Results of thickness measurement in selected lines II-IV and points B – G on model No. 1.



(a). Line II (b). Line III (c). Line IV

Figure 5. Scans taken in lines II-IV on model No. 2.

II, part (b) is a measurement in line III, and part (c) is a measurement in line IV. Lines I and V were not measured due to possible edge effects that could distort the measurements.

At each point B–G of the given line, the measured thickness of the element was subtracted in the evaluation program. A total of 18 values were therefore measured on model No. 1. Subsequently, the average thickness of the measured line was determined and the deviation of the measured and real thickness of the model in the given line was calculated. The measurement results are shown in Table 3.

Measurements were made in the same way on model No. 2. Figure 5 again shows scans of lines II-IV, where part (a) is a measurement in line II, part (b) is a measurement in line III and part (c) is a measurement in line IV.

The evaluation of the thickness measurement was carried out in the same way as on model No. 1. On model No. 2, however, it was possible to determine only 9 element thickness values, as the backwall echo was not well or completely visible in the rest of the measurement, so it was not possible to determine the thickness. The authors deal with the justification of this phenomenon in the following chapter. The measurement results are shown in Table 4.

The average asphalt concrete thickness of Model No. 1 was determined to be 104.4 mm using the Pundit 250 Array probe, which is approximately 2.4 mm (+2.34 % deviation) more than the actual thickness of 102.0 mm. The largest difference between the measured and actual thickness was measured in line IV, namely 3.3 mm (deviation +3.2 %). For model No. 2, the average thickness was determined to be 111.2 mm,

Line	B [mm]	C [mm]	D [mm]	E [mm]	F [mm]	G [mm]	Average [mm]	Deviation [mm]	Deviation [%]
II	-	-	-	113	-	-	113.0	3.0	2.7
III	-	109	112	113	109	-	110.8	0.8	0.7
IV	-	111	114	111	109	-	111.3	1.3	1.1

Table 4. Results of thickness measurement in selected lines II-IV and points B – G on model No. 2.

which is approximately 1.2 mm (+1.09 % deviation) more than the actual thickness of 110.0 mm. The largest difference between the measured and actual thickness was measured in line II, namely 3.0 mm (deviation +2.7 %). However, this measurement must be taken with a grain of salt, since, as already mentioned, it was not possible to determine the thickness in certain places.

4. Conclusion

Measuring the thickness of the investigated element using an ultrasonic pulse echo is dependent on many factors. In this work, the authors were mainly concerned with the influence of the shape of the back wall. From the previous works of the authors and other researchers dealing with this issue, it was clear that the shape of the back wall will certainly have its importance. To verify this thesis, the authors created 2 models simulating the real performance of the asphalt base layer in situ. When measuring on these models, it was confirmed that the detection of the back wall of the element depends on its shape. If the back wall is straight (model no. 1), the ultrasonic waves are reflected from it, pass through the element back at such an angle that the probe is able to detect them. In the case of uneven, vibrating into the underlying macadam, or an inclined back wall, the slope of which is greater than 40 degrees (inclusive), the ultrasonic waves are either scattered or reflected beyond the reach of the probe. This also corresponds with research conducted by other authors, e.g. the company Proceq SA [7]. This is especially important for understanding the principle and limits of ultrasound pulse echo measurements. The aforementioned is also clearly visible from the comparison of measurement results on both models Figure 4 and Figure 5. In Figure 4 are beautifully visible strong echoes of the back wall of model No. 1 at a depth of 102 to 107 mm. While in Figure 5 showing the measurement on model No. 2, the echoes of the back wall are clearly visible only on a few scans (places where the underlying macadam did not vibrate). In the rest of the measurements, they are either very weak or completely invisible. Table 3 and Table 4 also correspond well with these results, in which the thicknesses of the models at individual measurement points are subtracted and the deviations from the reference thicknesses of the models are subsequently determined from them. According to the authors, of these measurements, only the measurements on model No. 1 can be considered completely conclusive. The average deviations found when measuring the thicknesses of the models were set at +2.34 % for model No. 1 and +1.09 % for model No. 2, which are excellent values. It is clear that the ultrasonic pulse echo Pundit 250 Array is a relatively accurate and suitable device for measuring the thickness of the structure and possible delaminations, in the case of correct device settings and knowledge of the factors influencing the measurement, which was the reason for this research. The authors follow up on these findings in further research into the control and implementation of Whitetopping technology.

Acknowledgements

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