UNIVERSITY OF PARDUBICE

JAN PERNER TRANSPORT FACULTY

NONDESTRUCTIVE DIAGNOSTICS OF ROAD PAVEMENT STRUCTURES BY GROUND PENETRATING RADAR

DOCTORAL DISSERTATION

(Annotation)

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Contents

1 Introduction to the issue

Identifying road pavement quality after its construction and putting in use, and identifying degradation processes which appear in the road structure during its load by traffic are the basic prerequisites for timely measures which shall lead to the optimum use of financial sources used for their construction, maintenance, and repairs. Faults, which are hidden in the road pavement on its acceptance or within its warranty period, always lead to increased costs on the maintenance and repairs in the future. These costs are paid from public budgets instead of being dealt with within complaint procedure and required from a construction company.

Unless found in time, the faults caused by degradation processes in the road pavement during its use by traffic lead to the propagation of problems into structural changes in the pavement. In such case, the road administrator only reacts once the pavement faults are obvious, which means significantly increased costs on maintenance and repairs.

Non-destructive diagnostics of pavements is one of the tools which are able to identify the condition and development hidden imperfections in the pavement. The only non-destructive structural device which is used within the system of road management is a Falling Weight Deflectometer – FWD, see ČSN 73 6192. This device can help to identify local deformation characteristics of the road pavement, but only the faults which appear at the place of testing can be found. Moreover, the interpretation of the found faults in this case is just indirect.

The dissertation focuses on the use of georadar (GPR) as a tool for non-destructive diagnostics of road pavements. In contrast to FWD and if placed on a mobile base, cart or vehicle, GPR is able to identify structural changes in road pavement within the line of its path, therefore, its function is not limited just to the detection of discreet results from the local measurement. However, georadar is not an acknowledged device which could be used in road construction, since no specific regulations and interpretation methods for measured results for individual applications are specified for this device.

2 Current state of knowledge

Georadar is among the devices which are applied in many human activities. Road construction is an example of such activity. The research within this dissertation is only focused on one application out of the field – non-destructive identification of the positions of dowels and tie bars in concrete pavements by georadar, while focusing on finding the accuracy limits to identify accurate positions of these reinforcement elements.

The research of literature and effective standards and regulations shows that it is necessary to prepare materials for different application of georadar to achieve their correct and effective use. An example of such application is the determination of the position of dowels and tie bars in concrete road pavements by georadar. The existing publications mention this issue only partially, when evaluating laboratory measurement results (Shaw, 2005; Chang, 2009; He, 2009; Rao, 2009 a Lai, 2011). Only one comparison measurement which is related to the application of the determination of reinforcement element positions has been published. This measurement was focused on construction layer thickness of concrete road pavements (Edwards a Mason, 2011). In contrast to test by drill cores, errors in the thickness differences when determining concrete road pavement thickness reached the value of 272 mm and the relative error for thickness determination ranged between 6 % and 83 %, despite using the existing georadar devices with the calibration methods for the verification of the measured results.

Standards and regulations show table values of EM signal propagation speed and relative permittivity for different materials. However, specifically for road construction materials, such as concrete and asphalt, they differ significantly and the ranges between them are large, particularly due to the saturation of material by water (concrete relative permittivity is shown in tables with the range of 4 to 20 and the speed of EM signal propagation within the range of 67 to 150 mm/ns). Selecting the table value when evaluating the data, a person may make an error in vertical direction in centimetres.

When localizing dowels and tie bars in concrete road pavement, the accuracies are specified in a German regulation (B 10, 2008) and in technical specifications of the Ministry of Transport (TP 233, 2011). The German accuracy limit of determined thickness for the dowels localization is 10 %, including the effects of concrete moisture on the position determination. In the Czech Republic (TP 233, 2011), calibration must be performed and the accuracy of the determination of dowels is expected up to 10 mm. However, there had been no comparison in situ measurement which would have confirmed this fact, therefore, the limit of 10 mm needs to be considered only for an illustration.

I believe that, in relation to national and European research projects, it is possible to reach effective evaluations and results for individual applications, either in cooperation, by knowledge exchange, implementation of comparison measurements, or by laboratory experiments, and definitely with the implementation to practice. Within the dissertation, a number of laboratory experiments, in situ measurements and comparison measurements were made to find the accuracy limit of the determination of accurate position of dowels and tie bars.

3 Aim of the dissertation

The dissertation aims to set conditions for using georadar as a non-destructive device in road diagnostics for determination of positions of dowels and tie bars in concrete road pavements. The potential of georadar will be tested in the planned areas:

- detection of reinforcement displacement in concrete slabs and determination of the localization accuracy
- detection and finding accuracy for determination of concrete pavement thickness
- detection of the interface of concrete pavement and the excessive water content in construction layers of pavement.

4 Methods and devices

4.1 Assumptions

The approach to the issue in question was based on the assumption that in order to find the accuracy limit of the determination of dowel or tie bar accurate position by georadar, it is necessary to know their real position. Such identified pairs of values of both quantities will be measured in the same concrete pavement material and under the same conditions. This assumption was reached by georadar measurements on laboratory produced samples from materials which are used for the construction of concrete road pavements. Furthermore, georadar measurement was performed in situ (on a construction site, or on testing segments) verifying the correct depth/thickness or position. The methodology of measuring by georadar was based on the existing foreign standards and regulations.

To achieve the designed aim, a device purchased from an American company GSSI was used. This device used a cart for local measurement – model 615 (Fig. 1) with the combination of antennas 1.6 GHz and 2.6 GHz and a control unit SIR 20. Power supply was provided by a stable power supply unit, antennas were connected to the control unit SIR 20 with coaxial cables.

Fig. 1 *Georadar equipment – hand cart (model 615)*

On the basis of research and for the measurements in situ, a mobile device was designed and assembled for the measurement of the position of dowels and tie bars (specified below). Software Radan 6.6 by the device manufacturer, GSSI company, was used for the evaluation of the measured data.

Laboratory concrete slabs were made for the preparation of laboratory experiments. Methods and devices for the preparation of the mixture, production of wooden boarding, mixing the mixture, preparation and testing of laboratory concrete samples, compacting the concrete mixture, and forming the concrete slabs were provided by accredited laboratories of the transport infrastructure and the environment in Tišnov in accordance with respective standards, which are designed for this purpose.

The results of the determination of dowels and tie bars positions were evaluated by statistical quantities.

Important quantities for the characterization of individual materials are permittivity, conductivity, and permeability, while permittivity is crucial for the needs of the road material measurements. For the needs of georadar measurements, the properties of road construction materials are most commonly distinguished on the basis of their relative permittivity, which is sometimes considered as dielectric constant, or dielectric value respectively. Relative permittivity expresses the ration of permittivity of a given material and permittivity of vacuum. Relative permittivity of material is based on the propagation speed of electromagnetic signal. Based on the collected EM signal propagation speeds through individual layers of the tested structure, this value is converted into thickness (depth). The correct determination of this speed is very important, since it is a key factor for the accuracy of this method.

4.2 Relationship of laboratory measurements and in situ measurements

Laboratory experiments were performed gradually following their continuous results. The collected complex set of measurement results from many experiments was used as material for related in situ and comparison measurements for the production of the mobile cart.

4.3 Laboratory determination of EM signal propagation speed, dielectric constant and evaluation by calibration methods CMP and WARR

The determination of EM signal propagation speed was performed in laboratory with the same device, and changes in the results when combining different settings of input quantities were monitored.

The monitored input quantities were:

- used frequency of a dipole antenna,
- position of transmitter and receiver towards the line of antenna movement,
- thickness of laboratory concrete slabs,
- moisture of subgrade material.

Typical recording of this measurement with its description is shown in Fig. 2.

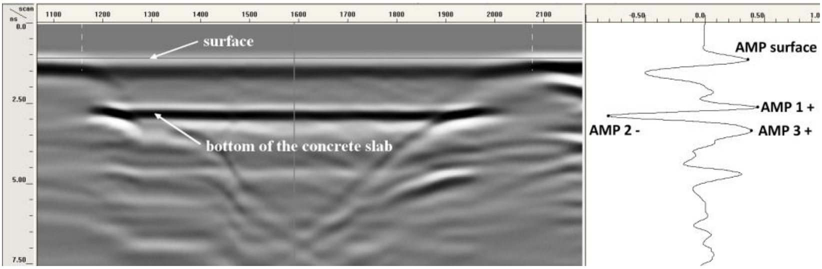

Fig. 2 *Sample example of a radargram from a measurement of EM signal propagation speed through concrete slab: thickness 100 mm, antenna 1.6 GHz*

On the basis of the real measured thicknesses, the determined propagation speed was evaluated by the methods CMP and WARR. GPR measurement was performed with the measurement step of 1 cm. Furthermore, modelling of EM signal propagation speed in concrete slab was made in Excel and the times of propagations of EM signal were calculated. The results of the modelling and the collected values by georadar were compared between each other and the relationship between the times of EM signal propagation from the surface and bottom of the concrete slab were monitored. Continuous laboratory results are evaluated in detail in the dissertation.

4.4 Determination of the interface of concrete slab with the road subgrade layer

In order to determine the interface of concrete slab with the subgrade layer, the results from the experiment of EM signal propagation speed and from the determination of dielectric constant on testing laboratory samples were used. The subgrade layer of aggregates was intentionally moisturized. Based on the collected EM signal propagation speeds through subgrade layer, this value is converted into thickness (depth). A metal lamella was placed at the surface and bottom of the examined subgrade layer for a clear identification in radargram. Subsequently, the values of reflective coefficient at the interface of layers were calculated and compared with the determined amplitude polarity of layer interface meeting the theoretical assumptions. This way the correct identification of layer interfaces in georadar records was verified.

4.5 Determination of reinforcement element position by georadar

The determination of dowels and tie bars position was performed in laboratory by the same device and changes in results under the same combination of different settings of input quantities were monitored.

The monitored input quantities were:

- dipole antenna frequency,
- sampling scale – number of impulses per metre
- reinforcement diameter
- centre to centre horizontal distance of reinforcement
- reinforcement depth
- horizontal and vertical displacement of reinforcement.

A recording with a measurement with description is shown in Fig. 3.

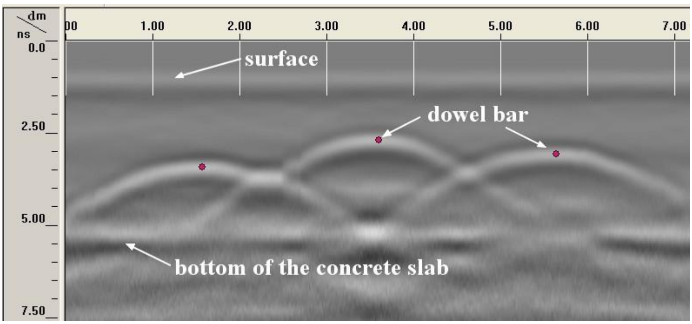

***Fig. 3** Radargram example from measuring three built-in dowels in concrete slab of 240 mm thickness*

Higher resolution of slab outlines, slab bottom, and reinforcements was reached by an antenna 2.6 GHz. Significant differences of displaying dowels and tie bars were not found during the evaluation. With the axis distance of reinforcement of 50 and 75 mm, total or partial merger of both reinforcement elements into one occurred during the evaluation. With the axis distance of 100 mm, the reinforcement distances were already determined with high accuracy. It was verified that with the sampling of 200 scans, the same results were obtained as with the sampling of 2000 scans, and the deviations in vertical as well as horizontal direction were comparable. High accuracy to determine the depth of reinforcement was reached.

Laboratory experiment results showed that it is necessary to pay particular attention to the correct localization of antenna for the measurement, so that the highest possible accuracy is maintained. Furthermore, it was found that during the measurement a distortion occurs close to the ends of dowels (the hyperbola is less visible and the measurement accuracy is reduced).

4.6 Design and construction of a mobile device for in situ measurement

In the past, the measurement of dowels and tie bars positions by georadar was performed by moving antenna on the joint and subsequently the evaluation of the measured data was made. Then, the measurement in two positions parallel to the joint was made, which allowed higher accuracy of the determination of the reinforcement elements positions. Two independent antenna rides were in sequence.

In order to increase the accuracy of determined positions and reduce the measurement time, a special cart was constructed. It uses two antennas during one ride – CDV mobile device (Fig. 4), which contains two antennas with the medium frequency 1.6 or 2.6 GHz.

Antennas can be placed in a plastic box with different distances from each other, or different positions. The simultaneous use of two antennas of the same type and frequency provides higher accuracy of determining the displacement of dowels and tie bars, rather than using just a single antenna and performing the measurement individually.

The mobile device of CDV is also equipped with a stable power supply unit, two wheels bearing its own weight and a small suspended wheel with a localization device. The suspended wheel evenly copies the concrete road pavement surface, therefore, the wheel is not lifted up.

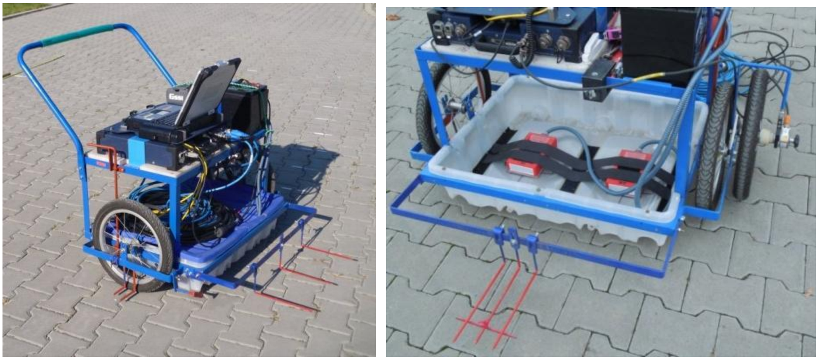

Fig. 4 *Mobile device for measuring dowels and tie bars positions with two antennas 1.6 GHz and a positioning device*

Transversal or longitudinal joint is measured in three profiles distant from each other based on the setting of the front forks of the measuring cart. The distance of the profiles is determined with the use of a built-in element (the most common current setting of forks is +/- 50 mm for the measurement of transversal joints and +/- 75 mm for the measurement of longitudinal joints. When evaluating, we obtain maximum of 6 points for the determination of dowel position. These points are integrated into a three dimensional linear regression with the known position of the measured points from the joint.

The accuracy in the horizontal direction is further increased with the se of a system of fixed beginning and fixed end. The cart contains position indicators which provide accurate localization of the measured signal. When evaluating, these indicators help to linearly adjust inaccuracies occurring at the georadar (e.g. inaccurate calibration of the measuring device, surface unevenness, etc.). The distances between joints are measured with a measuring tape.

In order to determine the electromagnetic signal propagation speed in concrete pavement slab (calibration in vertical direction), it is necessary top know at least some of these distances:

- depth of a dowel in the spot where the measurement was performed found by test drilling core,

- project or measured position of dowels placed in pre-drilled openings after a one-day concrete casting, or inserted in the boarding at the end of a one-day concrete casting (influenced by the accuracy of boarding on the construction site and the method of storage out of the construction), or inserted with the use of tubes into the fresh concrete at the end of a one-day concrete casting (influenced by dowels placement by a finisher),
- slab thickness at the test core at the spot where the measurement was performed by georadar, without reinforcement, and without cracks and joints which may affect the measurement results (less accurate method – we work with a double thickness and an inaccuracy for determination of the slab thickness),
- expected depth of dowel placed in the joint into a reinforcement cage (problematic accuracy placement and sufficient fixation of the cage and dowel).

4.7 Comparison measurement of reinforcement position by georadar and other non-destructive devices

Similarly to other devices, regular function verification of georadar individual components and the whole system should be performed. For these purposes, it is ideal to establish a testing segment/slab with a different layer composition or with in-built objects from different materials in different positions.

Regarding the above mentioned, no requirements are specified in this matter, and each georadar system provider needs to ensure this activity themselves, or arranges that with a GPR manufacturer or another organization. Another option is to get involved in comparison (harmonization) measurements, which are sometimes organized. Repeatability and reproducibility of the measured results are evaluated within these measurements.

4.7.1 Comparison measurements on motorway D1

The first simplified comparison measurement by georadar in the Czech Republic within the measurement of dowels positions in motorway concrete pavement, which was organized by the Czech Roads and Motorway Directory.

The measurements were performed by georadar by three different companies. The aim was to verify the accuracy of this method for the determination of these elements positions. The calibration of the signal propagation in concrete was selected by each company according to their experience, since there was no clearly given known depth distance, according to which the EM signal propagation speed could be calibrated for each device. The measurement results of three selected dowels positions were compared to their real positions found by drilling cores.

4.7.2 Comparison measurements in Pelhrimov

The second dowel position measurement was performed in the premises of Strabag company in Pelhrimov. The total length of the segment was 8 metres. The dowels were installed in the whole segment by a finisher.

Two companies measuring with georadar participated n the measurement. Georadar measurement for CDV was performed by a mobile cart with the measurement step of 0.003 metres. Direction forks of the measuring cart were set to the value of 50 mm. The calibration of the measuring wheel distance and the calibration of EM signal propagation speed were performed on the spot by the CMP method.

After the collection of the results from georadar, a destructive measurement to determine the position was made, so that a beam containing 30 dowels was cut out and removed from the concrete slab. The removed beam fell into several pieces, thus it was impossible to determine horizontal positions of dowels with sufficient accuracy. However, the depths of dowels on the beam side walls at the distance of 200 mm from the transversal joint on both sides were measured with reliable accuracy.

The accuracy results have not been published, not even in a form of a report. It was promised that the results should be published in a journal article.

4.7.3 Comparison measurement by NDT method on a testing segment in Stare Mesto

A testing segment of approx 28 m of length in the premises of Skanska, a.s. company was built to verify the correct measurement of dowels and tie bar positions. The reinforcement elements were placed in holes drilled in the right half of the concrete road pavement

(Fig. 5) with different displacement and shift towards the required (central) position. The real position of elements was accurately measured by an accredited laboratory before the concrete application over the left half of the concrete road pavement. On the tested segment, the deviations of individual reinforcement elements were selected as very extreme, in relation to positions on the real construction.

Fig. 5 *View of the testing segment with in-built tie bars and top view on dowels*

The georadar measurement by two companies and the measurement by MIT-Scan device were performed 14 days after the concrete casting. Our georadar measurement was performed by a mobile device. The height of concrete was manually measured in the middle of the testing joint. On the basis of this information, georadar measurement was to be performed above this place and the calibration was to be made (determination of electromagnetic signal propagation speed through the concrete slab).

Within this comparison measurement, the results of reinforcement elements positions found by georadar and MIT-Scan device were compared.

The aim of the comparison measurement was to find the accuracy of individual measurement devices. The following parameters were monitored at the evaluation:

- depth of dowels and tie bars in the joint,
- vertical differences of dowel and tie bar ends,
- horizontal differences of dowel and tie bar ends,
- longitudinal displacement of dowels and tie bars.

4.7.4 Tests of load transfer on joints by a FWD deflectometer and determination of dowel positions by georadar on two testing segments

In 2012, 2 testing road segments were selected. On these road segments, measurements of load transfer on joints were performed by FWD deflectometer. The measurements of dowel positions were by georadar were also performed on these segments.

Fig. 6 *Application of non-destructive methods for evaluation of dowels and tie bars positions on testing segments*

The interaction of slabs is considered as the ratio of geophone D3 slumping (on unloaded slab edge at the distance of 300 mm from the centre of the loading slab) and D2 geophone (on loaded slab edge at the distance of 200 mm from the centre of the loading slab) occurring at the test by FWD deflectometer.

Transversal joints of three slabs were measured on a testing road segment of R1 – Prague ring road, and transversal joints of sic slabs were measured on a testing motorway segment D1 before Kromeriz.

The measurement by georadar was performed by a mobile cart with the measuring step of 0.003 metres. Direction forks of the measuring cart were set to the value of 50 mm. The calibration of the measuring wheel distance was made on the spot.

4.8 Measurements of dowel and tie bar positions in situ

When measuring with the use of two-channel cart in situ, a number of different anomalies in the position of the in-built reinforcement, which are described below, were identified. In the first place, it is necessary to realize that for good interpretation, the georadar measurement needs to be performed at least two days after the concrete road pavement casting, otherwise the radargram is poorly readable (Fig. 7 in the top right part).

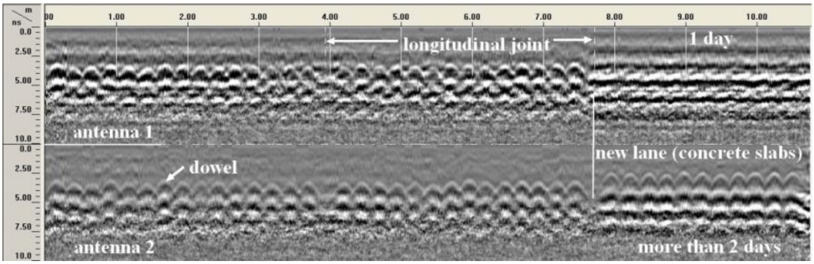

Fig. 7 *Radargram of dowels positions measurement in concrete road pavement transversal joint by a mobile device*

It is possible that the contraction joint, which is cut into compacted concrete a creates individual road pavement slabs, is not in the correct position above the dowels and tie bars, and thus the standard requirements for the maximum allowed reinforcement displacement along its longitudinal axis in relation to the joint are not met. This case is demonstrated in Fig. 8, showing the joint was not cut straight above the dowels which was displayed in the recording from the measurement. Some dowel ends were only caught partially and some not at all.

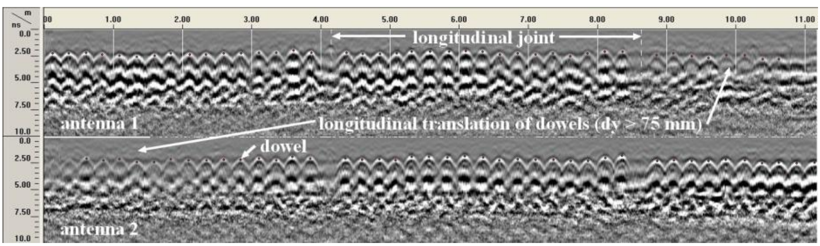

Fig. 8 *Radargram of dowels positions measurement in concrete road pavement transversal joint by a mobile device – longitudinal displacement of dowels*

Other possible anomalies in the positions of dowels and tie bars regarding the contraction joints are shown in Fig. 9 and 10; it particularly concerns the variability of the reinforcement position in the joint. Pushing of dowels by tie bars down at the place of transversal and longitudinal joints, anomalies caused by the use of steel cages for the reinforcement fixation in a required position, missing and redundant reinforcement, etc. are shown in the dissertation.

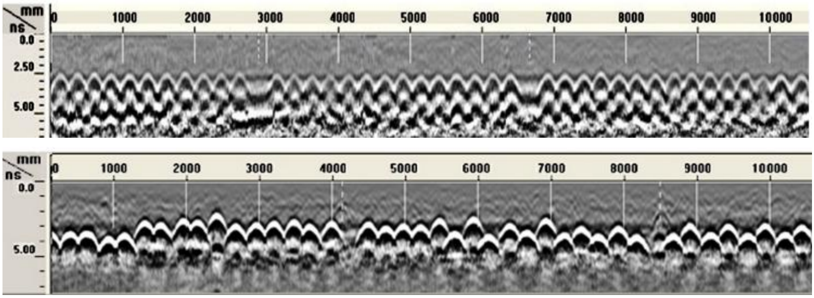

Fig. 9 *Radargram of dowels positions measurement in concrete road pavement transversal joint – variability of dowel positions*

Construction transverse joints, a special type of joints, should be in significantly better condition regarding the position of the built-in reinforcement than the contraction joints, thanks to the use of more accurate technologies of dowel and tie bar placement. However, even there may occur anomalies caused by bending or displacement of wooden boarding, which is used for the last transversal joint at the end of a one-day concrete casting or with the use of segmented boarding, which is not applied in then same level.

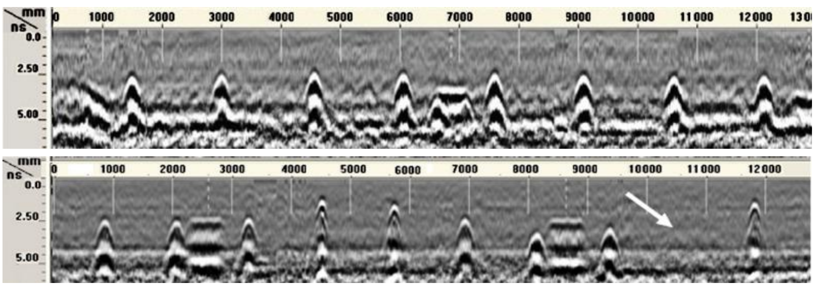

Fig. 10 *Radargram of dowels positions measurement in concrete road pavement transversal joint – variability of tie bar positions*

The highest accuracy for dowels and tie bars is reached when they are placed in the construction transverse joint by drilling them in young, but compacted concrete.

5 Measurement results

Overall results of EM signal propagation speed and relative permittivity of concrete elements found by laboratory experiments, comparison measurements, and in situ measurements by georadar are shown in Table 1. Table also shows the method of the determination of the monitored propagation speed. Table 2 shows limits of accuracy of determination of dowel or tie bar position while using georadar.

Tab. 1 *Overall results of EM signal propagation speed and relative permittivity of all performed measurements*

Set of measurements	Number of measure ments	Method	Propagation speed [m/ns]	Relative permittivity
concrete slab (CS) THK. 100 mm	24x530	TD	0.114	6.91
CS THK. 150 mm	24x465	TD	0.114	6.94
concrete slab (CS) THK. 150 mm	6x5	CMP/ WARR	0.113	7.03
CS THK. 240 mm	34x965	TD	0.105	8.19
TS Pelhrimov	24x2	HV	0.094	10.10
TS Pelhrimov	1x2	CMP	0.101	8.86
TS Stare Mesto	1x3	JV	0.101	8.81
TS Kromeriz	75x2	PHV	0.099	9.07
TS Prague	53x2	PHV	0.099	9.07
motorway segment (MS) No. 1	2x40	PS	0.100	8.90
MS No. 2	2x2	JV-V	0.100	8.92
MS No. 3	4x43	PS	0.097	9.44
MS No. 4	3x2	JV	0.097	9.47
MS No. 5	2x42	PS	0.095	9.93
MS No. 6	2x38	PS	0.091	10.80
MS No. 7	2x10	HV	0.085	12.52
MS No. 8	1x2	JV	0.100	8.92
MS No. 9	4x43	PS	0.097	9.46

TD …known thickness of laboratory concrete slab
CMP/WARR …auto-calibration method
HV …direct measurement of dowel/tie bar depths
JV …test drilling cores
JV-V …test drilling cores by dowel
PHV …expected reinforcement depth
PS …known position of reinforcement in construction trans. joint

Tab. 2 *Overall results of performed measurements of dowel positions*

	Measurement parameter	**Number of measurements**	**Differences of GPR from real ones [mm]:**		
			max.	**aver.**	**sm. odch.**
laboratory concrete slab THK. 240 mm	depth of dowels:	21	**4**	**1**	**1**
	horizontal position:	21	**7**	**2**	**2**
	placement depth of dowels: 105-140 mm				
	horizontal distance of GPR overrun: 550 mm				
testing segment Pelhřimov - concrete slab THK. 250 mm	depth of dowels:	60	**4**	**0**	**2**
	vertical differences of dowel ends:	30	**6**	**1**	**3**
	placement depth of dowels: 106-153 mm				
	horizontal distance of GPR overrun: 8000 mm				
	vertical differences of dowel ends: 0-23 mm				
testing segment Staré Město concrete pavement THK. 300 mm	depth of dowels:	42	**12**	**3**	**3**
	depth of tie bars:	11	**9**	**5**	**2**
	vertical differences of dowel ends:	42	**16**	**8**	**3**
	vertical differences of tie bar ends:	11	**23**	**9**	**7**
	horizontal differences of dowel ends:	42	**20**	**9**	**5**
	horizontal differences of tie bar ends:	11	**24**	**8**	**8**
	placement depth of dowels: 98-153 mm				
	placement depth of tie bars: 110-148 mm				
	horizontal distance of GPR overrun: 28000 mm				
	vert. differences of dowel ends: 0-80 mm, tie ends: 0-122 mm				

High accuracy was reached during laboratory measurements thanks to known constant thickness of the slab produced from homogeneous concrete and to the fact that the measurements were performed in distance of max. 1 m.

High accuracy was also reached during comparison measurements and in situ measurements, even though the reinforcement elements were built-in in extreme positions which are defective during constructions of motorways with concrete pavements.

6 Result discussion

Laboratory measurement results proved high accuracy of determination of dowel and tie bar positions. Furthermore, it was verified that the measurement accuracy decreases when measuring at the dowel bar ends. The comparison measurement results also reached high accuracy, even for extreme positions of dowels and tie bars. It is generally expected that these results are possible to be reached on real constructions as well. The in-situ tests presented possible anomalies caused by different reasons during concrete road pavement installation and ways to identify these anomalies and their causes by georadar. The results from the set of measurements by a cart with two antennas with the central frequency of 1.6 GHz implied the conclusions that, when determining dowel and tie bar positions in situ, accuracy of +/- 15 mm in horizontal direction (at the end of the length 11.5 m) and +/- 10 mm in vertical direction (for pavement thickness of 300 mm) can be reached. In the measurement results, the overview is shown of all measured EM signal propagation speeds and relative permittivities which are crucial for the accuracy of the determination of dowel and tie bar positions in vertical direction by georadar and are based on the correct determination of concrete road pavement and subgrade layer.

In laboratory and in situ measurements of the interface of concrete slab and subgrade layer by georadar the change in amplitude polarity (EM signal propagated through an environment with higher relative permittivity to an environment with lower relative permittivity) was found.

In the comparison experiments and in situ measurements, above what is the contents of the dissertation, the results of other non-destructive measurements which measured the same parameter as georadar (MIT-Scan, GPR of another company), or were combined with georadar (deflectometer FWD), were evaluated.

7 Conclusion

The presented dissertation opened the issue of research in the field of georadar application in road diagnostics. Limits of accuracy of the determination of dowel or tie bar positions were found, methodology to perform measurements and evaluate the positions of dowels was designed, a device which is able to perform non-destructive measurements of dowel positions was designed and produced.

The research results have an effect on the existing as well as the prepared regulations concerning the non-destructive diagnostics of roads by georadar.

The research results were continuously published n journals and conferences.

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10 Abstract

The research presented in this dissertation is focused on finding the accuracy limit of determining an accurate position of dowels and tie bars when using a ground penetrating radar (GPR), so that potentially risky spots where an inaccurately laid reinforcement element may sooner or later cause a fault in concrete pavement could be identified.

Dowels and tie bars in concrete pavement joints, particularly in motorway pavements, are to guarantee the interaction of the neighbouring slabs, so that there would be no vertical displacement towards each other. The reinforcement elements are usually laid in the future joints in concrete pavements by machines, but the technology of laying and subsequent compacting of concrete mixture may cause such displacement of a reinforcement element that its final position in hardened concrete is out of standard values.

The research conducted within this dissertation forms a single complex with a research project in Centrum dopravního výzkumu, v. v. i. (Transport Research Centre), which is focused on the extent of incorrect laying of reinforcement elements on the quality of complete work and on mechanisms which are applied. The work also confronts the use of georadar in the diagnostics of road pavements with other methods (particularly with MIT Scan method), verifies the results with test core holes and shows possible combinations with FWD deflectometer (falling weight deflectometer).

Based on the results of this dissertation in combination with results of the above mentioned CDV project, it will be possible, during acceptance tests of new and reconstructed motorway segments, to reliably identify spots where problems can be expected due to hidden faults, i.e. an incorrectly laid reinforcement element.