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The practice of geo-radar research in the Republic of Kazakhstan

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Abstract: The article considers the issues of applying ground penetrating radar (GPR) technologies for engineering purposes concerning subsurface research. It describes the field of application of GPR research during road construction and operation and the advantages and disadvantages of this type of engineering survey. It presents comparative data on the accuracy (inaccuracy) of existing GPR control methods applied to determine the thickness of the monolithic pavement layers in Europe, CIS, and the USA. The main provisions of the GPR survey procedure are described, including four main stages: the analysis of initial materials of surveyed section and equipment preparation; GPR survey; geological verification; processing and interpreting of radargrams; and the preparation of a report. Geophysical works were performed using the geo-radar of the OKO series as part of the road measuring complex DVK-05 on the section of the Astana-Petropavlovsk A-1 highway with cement concrete pavement and on the section of the R-12 "Kokshetau - Atbasar" with asphalt pavement. The example of a radargram and the core sample of a cement concrete pavement taken during geological verification of the thickness of a monolithic layer is presented. Graphs of variation in the thickness of pavement layers by radargrams of longitudinal passages in the indicated road sections with the assumptions about the nature of the heterogeneity of the obtained values are given. The obtained results on the thickness of monolithic layers (cement concrete and asphalt concrete) were assessed on the criteria of quantitative deviation from the required standard value. Recommendations were provided to address positive deviations in the thickness of monolithic pavement layers at various stages of the road survey.

Keywords: geo-radar, ground penetrating radar, methodology of field studies, radargram, the thickness of monolithic layers, cement concrete pavement, asphalt pavement

1. Introduction

GPR (ground penetrating radar) technologies have existed for many years, but only during the last 30-40 years have they received significant development concerning subsurface research. Georadars have found their application in engineering geology,

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industrial and civil construction, archeology, and road construction. They are also used for other particular purposes, for example, ensuring the environment (detection of leaks from oil pipelines, burial sites of hazardous wastes) and law enforcement (detection of smuggling, hidden premises, and people searching in the avalanches) [1–13].

The demand for geo-radar research in road practice for diagnostic purposes is due to its versatility and high efficiency. The main trends in geo-radar usage in road activity are as follows:

- assessment of the thickness of the pavement layers and the thickness of the soil layers of the subgrade, as well as the evaluation of their uniformity (quality of compaction and moisture; acceptance of work and assessment of operational changes) [3,6,10–17],
- evaluation of defects in pavement and subgrade layers (voids, zones of decompacted soils and water infiltration, zones of waterlogged soils, etc.),
- assessment of the content of water and clay in the layers of pavement and the ground of the subgrade (determination of the depth of the groundwater level, the depth of freezing and thawing of soils, as well as changes in their moisture content, the depth of groundwater) [6,9,13,16],
- inspection of concrete elements and structures [4,10,11,12,18].

Despite the wide enough scope, we can say that there is a certain lack of understanding of the information obtained in the process of GPR research and its correct interpretation to obtain the real characteristics of the studied object. The method of ground-penetrating radar research is specialized since it depends on the technical aspects of the equipment used, the qualifications of the specialists conducting the survey and interpretation of the data, and the interpretation methods used. Nevertheless, even now, GPR control can successfully complement the existing traditional methods of assessing the conformity of road characteristics, for example, the thickness of the upper layers of the road surface and uniformity in the thickness of the layers of the road pavement, followed by certification by sampling.

This article presents the data of a ground-penetrating radar survey of five sections of the republican highways of Kazakhstan, carried out as part of the stage "Implementation of ground-penetrating radar quality control of road construction works" under contract No. 44 dated 09/12/2018 with the Roads Committee of the Republic of Kazakhstan.

2. Accuracy (inaccuracy) of the existing techniques

One of the critical issues in assessing the thickness of the structural layers of road pavements using the GPR method is the accuracy (inaccuracy) of the data obtained. Currently, the European Union does not have a sufficiently developed regulatory framework, both at the national and the pan-European level, in terms of applying ground-penetrating radar studies to assess the thickness of road pavements of highways [10, 19].

Comparative studies carried out in the Czech Republic and France to determine the accuracy of the national methods used [10] showed that when choosing the thickness of asphalt concrete on the bridge structure, the difference ranged from 3 mm to 15 mm, or 1-9% of the layer thickness, outside the bridge structure - 10 -18 mm (3-5%). In another, a higher value of inaccuracy in determining the coating thickness on bridge structures is indicated - 6-7% [12].

In work [11] on the results of a ground-penetrating radar survey of 17 sections of roads with asphalt concrete pavement with different service lives (from newly introduced to 20 years), it is indicated that the inaccuracy in determining the thickness increases with the age of the pavement. In this case, the inaccuracy in determining the thickness of monolithic asphalt concrete layers is 4.4% to 5.8%. For hard coatings, the inaccuracy is lower: no more than 3%.

According to [15], with a monolithic layer thickness of at least 40 mm, the inaccuracy is no more than 5 mm, and in [3], for example, it is indicated that the accuracy varies from 2% to 10% depending on the thickness of the layers.

Methods presented in [13,14,17] indicate that the inaccuracy in determining the thickness of GPR surveys may not exceed 5%. It should be noted that the methodology of works described in this article is based mainly on these methods.

On the other hand, the normative requirements of the PR RK 218-35-2016 "Instructions for quality control and acceptance of works during the construction and repair of highways," can be taken as target indicators of accuracy (inaccuracy). The deviation from the design values of the thickness of the asphalt concrete pavement should not exceed 5 mm. At the same time, 10% of the determination results may have deviations from the design values from 10 mm to 15 mm, the rest up to ± 5 mm. For cement-concrete pavements, the deviations from design values are 5 mm (10% of measurements may have deviations of 15 mm).

Thus, this work aims to test the methodological approaches [13, 14, 17] to assess the conformity of the thickness of the upper layers of the road pavement utilizing GPR studies of selected sections of Kazakhstan's highways republican significance.

3. Implementation technique and results of ground penetrating radar research

The following road sections were selected as objects of study at this stage of work:

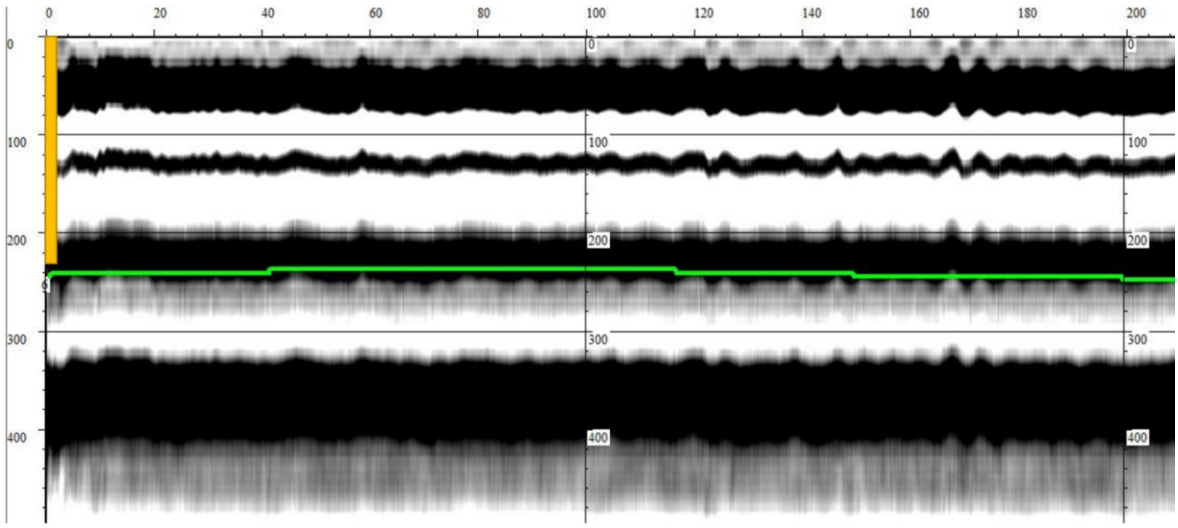
- A-1 "Astana-Petropavlovsk" (I technical category), km 233,000 - km 242,483 (coating - cement concrete),
- R-12 "Kokshetau - Atbasar" (III technical category), km 70,000 - km 80,000 (asphalt concrete).

When performing geophysical work, geo-radars of the "OKO" series were used as a part of the DVK-05 measuring road complex. The GPR survey included the following sequential operations:

- the analysis of source materials of the surveyed area and preparation of equipment,
- conducting geo-radar surveys,
- geological verification,
- processing and interpretation of radarograms and preparation of the report.

In analyzing the raw materials, technical documentation was studied regarding the requirements for the thickness of the structural layers of the road pavement.

When conducting GPR surveys, the radarogram files were recorded longitudinally in the surveyed areas (Fig. 1). Geological verification – a sampling of pavement layers materials. Cores were taken at a distance of 1 m from the edge in the alignment of the GPR passage. The samples were photographed in the process of coring (Fig. 2).



1 – the coring site (240 mm); 2 – the sole of the certified layer of cement concrete (242 mm)
Fig. 1. The example of a radarogram obtained in a national road A-1 «Astana – Petropavlovsk» (km 233-km 234)

Fig. 2. An example of cores taken on the A-1 «Astana – Petropavlovsk» highway km 233

When processing radarograms, the interference was eliminated from the external sources, checking the correspondence of the length of the profiles to the actual distance traveled, as well as setting parameters such as signal amplification, contrast, brightness, and scale to bring the wave profile into the most readable form.

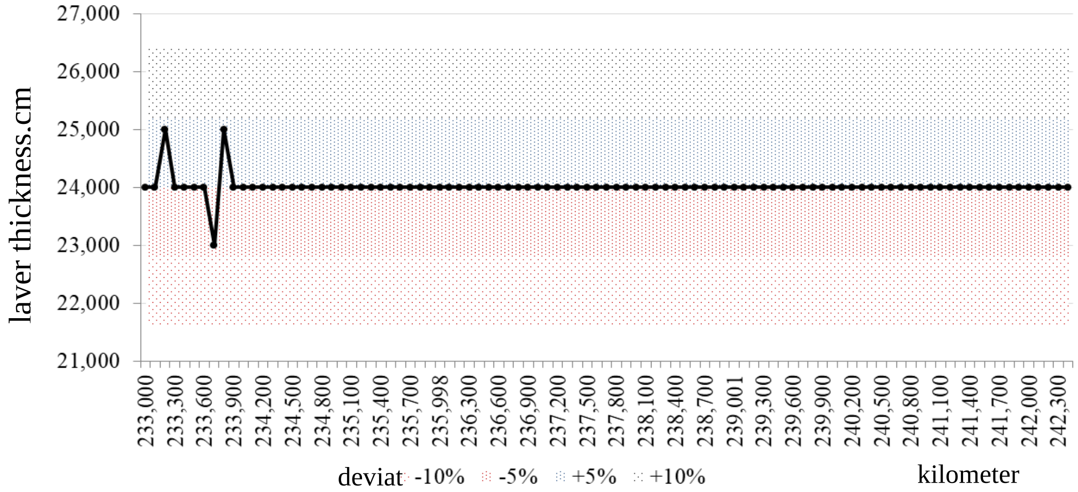


Fig. 3. Graph of changes in the thickness of pavement layers (cement concrete) according to the radarogram of the longitudinal passage A-1 «Astana-Petropavlovsk», km 233,000-km 242,300 (forward direction)

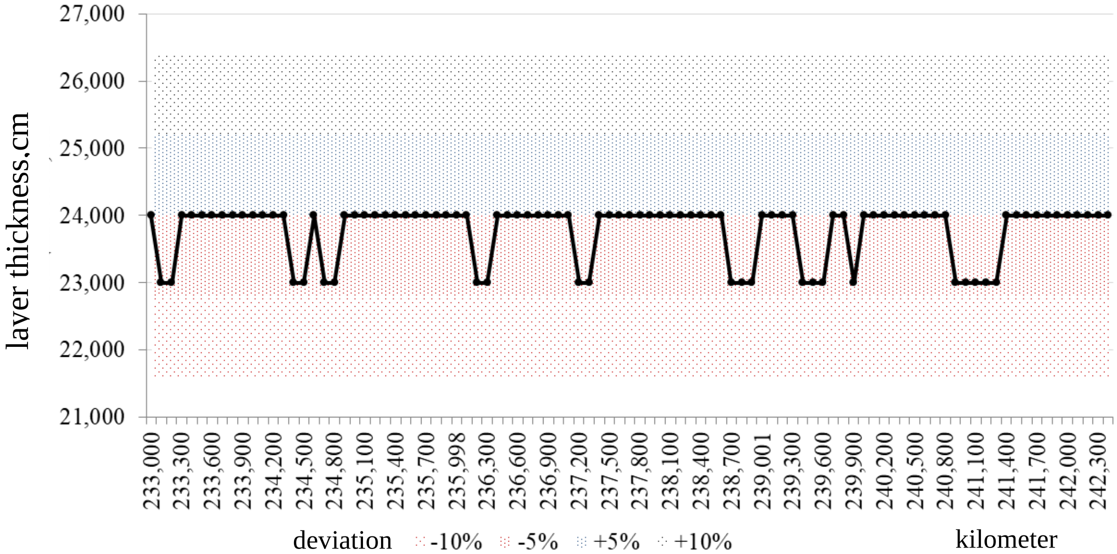


Fig. 4. Graph of thickness changes of pavement layers (cement concrete) according to the radarogram of the longitudinal passage A-1 «Astana-Petropavlovsk», km 233,000-km 242,300 (backward direction)

Interpretation of radarograms was carried out in manual, semi-automatic, and automatic modes. Interpretation consists of mapping the reflective boundaries of different layers, calculating the thickness of layers, and highlighting areas of inhomogeneity in the properties of materials and soils. Figures 3 and 4 show graphs of changes in the thickness of the upper layer of the cement concrete coating according to the radarogram of the longitudinal passage A-1 "Astana-Petropavlovsk" in the forward and reverse directions, respectively.

According to the data obtained, in the forward direction, 3% of the values deviate up to ± 5%, and the rest correspond to the required values. In the opposite direction, 23% of the values deviate up to -5% and the rest meet the requirements. In this case, we can talk about compliance with the needs of the thickness of the cement-concrete pavement and the high homogeneity of the obtained values, which is caused by the high quality of the preparatory work provided by the technology of such coatings.

Figures 5 and 6 show graphs of changes in the thickness of the upper layers of asphalt concrete pavement according to the radarogram of the longitudinal passage R-12 "Kokshetau – Atbasar" in the forward and reverse directions, respectively.

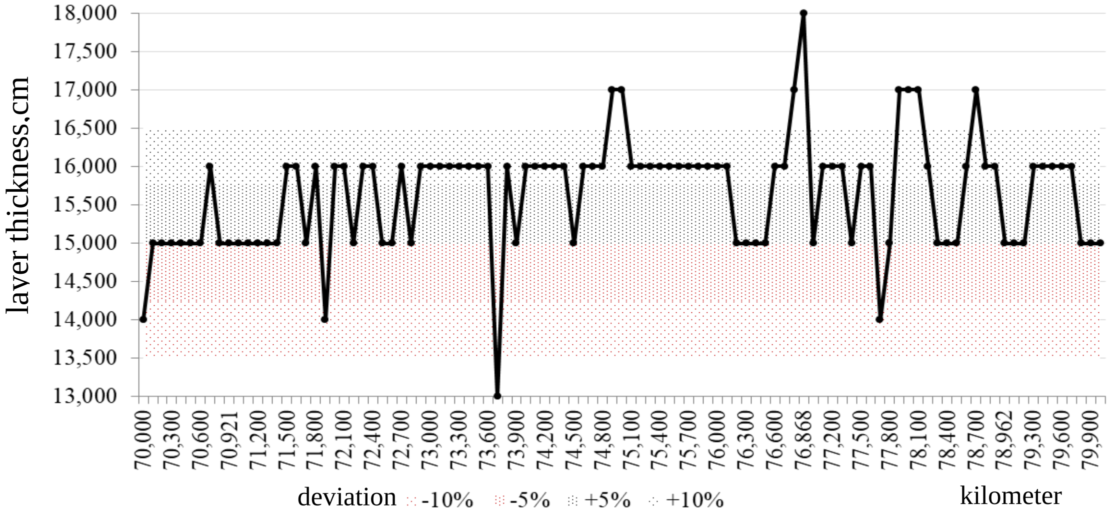


Fig. 5. Graph of changes in the thickness of pavement layers (asphalt concrete) according to the radarogram of the longitudinal passage R-12 «Kokshetau-Atbasar», km 70,000-km 80,000 (forward direction)

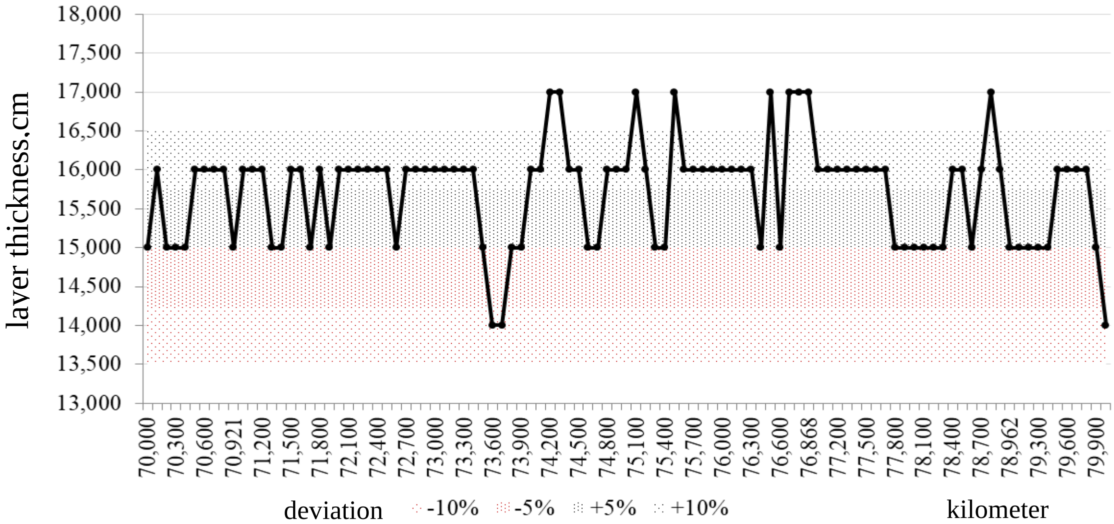


Fig. 6. Graph of changes in the thickness of pavement layers (asphalt concrete) according to the radarogram of the longitudinal passage R-12 «Kokshetau – Atbasar», km 70,000-km 80,000 (backward direction)

According to the data obtained in the opposite direction, 59% of the values deviate up to ± 10% (56% up to + 10%), and 9% differ from the required value by more than + 10%. In the forward direction, 57% of the values have a deviation of no more than ± 10% (of which 54% is upward), and 9% differ from the required value by more than ± 10% (of which 8% is upward). In this case, the high inhomogeneity of the values is presumably caused by the quality of the arrangement of the separate layers preceding the laying of asphalt concrete layers. At the same time, although the excess thickness of the layer package relative to the required value is mainly observed, from the point of view of the existing regulatory requirements, this section of the road does not meet the requirements.

Based on the results obtained, it can be recommended, for example, not to consider positive deviations when deciding on compliance but to calculate only the percentage of negative deviations (except for artificial structures). In addition, the issue of changing the permissible deviations for the stage of monitoring and diagnosing highways should be considered.

Tabl. 1. Total number of measurements

Road name	Total number of measurements	% of measurements deviation		
		0 %	5 %	10 %
A-1 «Astana-Petropavlovsk» km 233,000-km 242,300 (forward direction)	105	97,2	2,8	–
A-1 «Astana-Petropavlovsk», km 233,000-km 242,300 (backward direction)	101	78,2	21,8	–
R-12 «Kokshetau-Atbasar», km 70,000-km 80,000 (forward direction)	109	33,1	58,8	8,2
R-12 «Kokshetau – Atbasar», km 70,000-km 80,000 (backward direction)	107	29,9	58,9	11,2

4. Conclusion

The article presents the results of practical testing of the method of ground-penetrating radar survey to determine the thickness of the upper monolithic layers of the road pavement on the selected sections of the republican significance highways of Kazakhstan. The conformity of the obtained thicknesses was assessed according to the criterion of deviation from the required value using graphs of changes in the thickness of the pavement layers according to radarograms of longitudinal passages in the indicated areas with asphalt concrete and cement concrete coating.

When determining the thickness of the cement-concrete pavement, values were obtained with a higher homogeneity than that of a batch of asphalt-concrete layers. It was assumed that this was due to technological differences in preparing the underlying layers. At the same time, you can also recommend considering the positive deviations when deciding on compliance and limiting the percentage of negative deviations.

In the future, it is planned to continue work on the introduction of geo-radar control on the roads of the Republic of Kazakhstan, not only to assess the thickness of monolithic layers of road pavements but also to solve a broader range of tasks and, thus, increase the durability of road structures by justifying management decisions based on this modern non-destructive testing method.

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