International Journal of GEOMATE, Sept. 2023, Vol. 25, Issue 109, pp.189-196
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.109.m2320
Geotechnique, Construction Materials and Environment

RESULTS OF EXPERIMENTAL GEORADAR SURVEYS OF RAILWAY SECTIONS

*Zhanar Oralbekova[1], Gulnur Tyulepberdinova[2], Gulnur Gaziz[3], Aigul Adamova[4] and Bakytgerey Sholpanbaev[5]

[1]Department of Computer and Software Engineering, L.N. Gumilyov Eurasian National University, Republic of Kazakhstan, [1]School of Science and Engineering, University of Dundee, United Kingdom, [2]Department of Artificial Intelligence and Big Data, Al-Farabi Kazakh National University, Republic of Kazakhstan, [3]Department of Computer Science, Al-Farabi Kazakh National University, Republic of Kazakhstan, [4]Department of Computer Engineering, Astana IT University, Republic of Kazakhstan, [5]Institute of Mathematics, Physics and Informatics, Abai Kazakh National Pedagogical University, Republic of Kazakhstan

*Corresponding Author, Received: 28 March 2023, Revised:26 April 2023, Accepted: 6 July 2023

ABSTRACT: The aim of the study is to evaluate the effectiveness of using georadar sounding as a high-speed method for monitoring the condition of subsurface layers of railway infrastructure facilities and identifying zones of abnormal structure in the embankment and underlying soil, which could worsen the bearing properties of the soil at the base of the railway track, and develop specific measures to eliminate soil defects. The methodology of the study involved conducting georadar surveys using Loza geophysical complex and antennas with 100 cm, lateral steps of 50 cm and 20 cm, and a depth of sounding up to 256 ns to profile the embankments of new and old railway tracks and transverse georadar profiles through problem areas. Abnormal violations of the railway embankment structure were detected through georadar survey, revealing local heterogeneities due to insufficient and uneven compaction, while the main part of the embankment and the bedrock at its base remain unaffected. The practical significance of this research is that it provides important information about the structural integrity of railway embankments, which can be used by railway engineers to identify potential problems and make necessary repairs, thus improving the safety and efficiency of railway transportation.

Keywords: Railway track, Embankment, Metre antenna, Bedrock, Rails.

1. INTRODUCTION

A safe train track design requires modern engineering solutions and high-quality repairs. Adequate financial resources are necessary to support these efforts, which should aim for maximum technical and economic benefits [1]. Accurate diagnostics and stabilization measures are crucial for addressing railway defects and deformations. However, visual inspection and well-drilling surveys often lack the necessary accuracy for assessing subsurface conditions [2].

Systematic monitoring of the condition of railway infrastructure facilities by high-speed methods would allow for identifying deformations at the early stages of their formation, monitoring their development, and analysing weather and seasonal changes in the physical and mechanical properties of track structural elements [3, 4].

Of particular importance in the examination of hydraulic structures is the assessment of the condition of reinforced concrete elements of the base [5]. It is known that voids behind reinforced concrete elements of underground hydraulic structures formed during their construction and operation are serious defects that prevent the normal operation of structures [6, 7]. The results of methodical georadar studies conducted on the sections of the Charsk – Ust-Kamenogorsk railway line in the East Kazakhstan region have shown the high efficiency of the georadar sounding method for assessing voids in the soil of the embankment under the concrete slabs of the slope. The purpose of using the georadar method to investigate the path is to identify the "pressure points", which often lead to damage to the upper structure of the path. Errors of this scale are often associated with local changes in soil moisture and density in the gravel underlayer and subsoil. Of the modern diagnostic methods, the georadiolocation method primarily meets these requirements [8].

The object of the study is the sections of the Charsk – Ust-Kamenogorsk railway in the East Kazakhstan region with a length of 2 km:

1. A section of the existing railway track with a length of 2 km (from 15 to 17 km) to identify the causes of problems in the underlying layers.
2. A section of the railway track under construction with a length of 2 km (back from 17 to 15 km) to identify the causes of problems in the underlying layers.
3. Transverse measurements in three different problem areas to clarify the identified causes of problems in the underlying layers [9].

Survey tasks:

– Geophysical survey of the structure of the embankment of the railway track and the underlying soil at the base of the embankment on the section of the Charsk – Ust-Kamenogorsk railway (from 15 to 17 km);

– Detection of zones of abnormal structure of the embankment and underlying soil (zones of decompression, subsidence, local moisture), which could worsen the bearing properties of the soil at the base of the embankment of the railway track.

2. RESEARCH SIGNIFICANCE

The results of the georadar survey provide a fairly complete indication of the condition of the upper section of the track and allow planning specific measures for the timely elimination of soil defects. Kazakh and international experience show that the georadiolocation method is an intensively developing and promising method that significantly improves the efficiency of diagnostics of the technical condition of hydraulic and transport structures. Therefore, it can be predicted that the demand for GPR technologies for measuring these structures will steadily grow.

3. MATERIALS AND METHODS

Profile georadar survey along the embankment of the new and old railway tracks. The survey step is 50 cm (one measurement between the sleepers), and the scan is 256 nsec. Transverse georadar profiles through the embankments of the new and old railway tracks in places of visible violations of the embankment structure [10-15]. A georadar system comprises a transducer or antenna that emits and receives signals and a control unit that generates signals. The antenna is usually placed on the ground and manually moved or attached to a vehicle while the control unit records the reflected signals. By analyzing the signals, georadar produces a subsurface picture with distinctive patterns revealing various materials and structures [16-19]. This technique finds use in utility mapping, environmental assessments, and archaeology surveys. The depth and resolution of georadar depend on variables such as signal frequency, soil or rock type, and the size and shape of the detected object. It can typically detect objects at depths ranging from a few millimetres to several meters.

The work was carried out by the Loza geophysical complex, antennas – 100 cm, a lateral step – 50 cm and 20 cm, a depth of sounding – up to 256 ns. The main measurement mode is the registration of the waveform of the signal on a logarithmic scale. 1st dimension "A". A section of the existing railway track with a length of 2 km. The survey was carried out in one direction along the edge of the railway track. The profile length is 2 kilometers. There were objects along the railway track:

1. Double pipes for animals to cross paths.
2. Kilometer reserve (additional rail along the tracks).
3. Interval control sensor.
4. Integrated control system (ICS) (Fig. 1).

Fig.1 The first measurement along the railway

The acceleration sensor complex includes: digital radio data channel equipment; integrated in the MPC-I radio interlocking center; active/passive track transceivers (ATR). A locomotive component consisting of:

- on-board locomotive computer (LTC),
- satellite navigation system (SNS) receiver,
- the PPR reader,
- doller radar (DR),
- track and speed sensor (TPS),
- display and data input unit.

Acceleration sensors use the radio interlocking centre to collect train location data and provide real-time information on the current railway section conditions, including data from station interlocking systems [20,21]. This enables every train within the interlocking centre's jurisdiction to receive continuous updates, such as allowable speed, braking distance, and control signals, including emergency braking.

The BCS system is responsible for constantly tracking the location and speed of the locomotive, sending this data to the radio interlock centre via a digital radio channel. The driver's control panel displays information regarding the allowable and current speeds. When the current speed exceeds the allowable speed, the train's automatic brakes are triggered. In real-time, the braking curve is calculated based on the train's actual location, its parameters, and the distance to the intended braking point.

2nd dimension "B", "C". A section of the railway track is under construction with a length of 2 km. The survey was carried out in one direction along the edge of the railway track. "B" – measurements of the track with rails. "B" – measurements of the track without rails, along the embankment. The profile length is 2 kilometres. There were objects along the railway track:

1. Double pipes for animals to cross paths.
2. Kilometre reserve (additional rail along the tracks).
4. Interval control sensor.
5. Integrated control system (Fig. 2) [16,17].

Fig.2 The second dimension along the railway under construction

3rd dimension "R". Transverse measurements in three different problem areas to clarify the identified causes of problems in the underlying layers (Fig. 3):

Fig.3 The third transverse dimension of the railway

1. The measurements were carried out from the beginning of the measurements of the existing railway at 1500 metres. A green line is given in Fig. 4. Measurements were also carried out with a metre antenna in 50 cm increments. From the curb to the rails – 6 m., between the rails of the new and old railways – 8 m. The total length is 21 m.

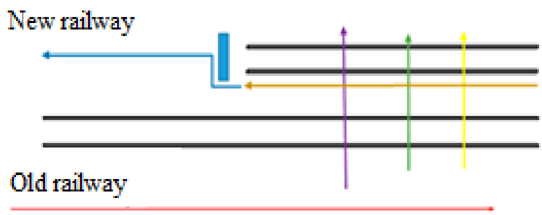

Fig.4 Measurement plan

2. The measurements were carried out from the beginning of the measurements of the existing railway at 1400 metres. A purple line is given in Fig. 4. Measurements were also carried out with a metre antenna in 20 cm increments. From the curb to the rails – 9.2 m, between the rails of the new and old railways – 6.3 m. The total length is 23.3 m.

3. RESULTS AND DISCUSSIONS

No anomalous disturbances in the structure of the embankment are recorded at the site "A" 0-250 metres. The structural layers of the embankment have a uniform structure and uniform compaction. An abnormally disturbed soil structure is recorded (1) on the section of the profile 20-40 metres and 55-75 metres at a depth of up to 3 metres at the base of the embankment of the railway track, indicating a local decompression of the soil at the base of the embankment. At depths of 3-5 metres, a normal undisturbed structure of the bedrock is recorded (Fig. 5).

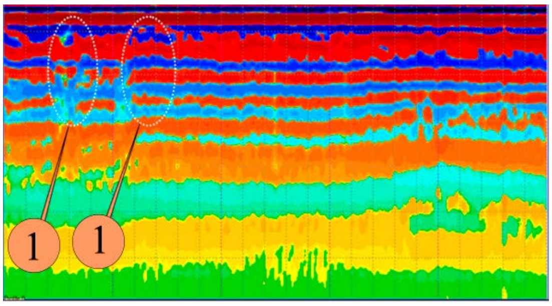

Fig.5 The first measurement by georadar of site "A" from 0 to 250 m

At the site "A" 250-500 metres, the structural layers of the embankment have a uniform structure and uniform compaction. The bedrock at the base of the embankment at depths of 3-5 metres has a normal undisturbed natural structure. The bearing capacity of the soil at the base of the railway embankment is not violated (Fig. 6).

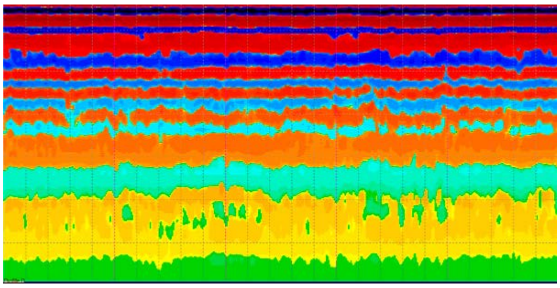

Fig.6 The first measurement by georadar of site "A" from 250 m to 500 m

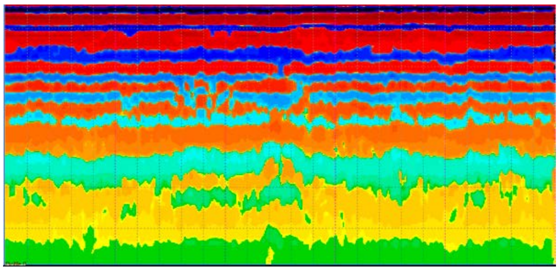

Fig.7 The first measurement by georadar of site "A" from 500 m to 750 m

Site "A" 500-750m shows no anomalous disturbances in the embankment structure, with uniform structural layers and compaction. The bedrock at 3-5m depth has a normal, undisturbed structure, with no violation of the soil's bearing capacity (Fig. 7). The same uniformity in structure and compaction is observed at the site "A" 750-1000m and site "A" 1000-1250m, with normal, undisturbed bedrock structure and no violation of soil bearing capacity at 3-5m depth (Fig. 8 and Fig. 9).

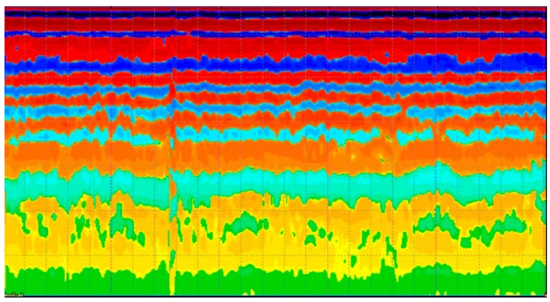

Fig.8 The first measurement by georadar of site "A" from 750 m to 1000 m

No anomalous disturbances were detected in the embankment structure at site "A" between 1250-1500 metres, except for thickening at 1450-1465 metres (2). The embankment's structural layers have uniform structure and compaction. However, a disturbed soil structure was found at the base of the embankment at 1390-1465 metres (1), indicating localized decompression (Fig. 10).

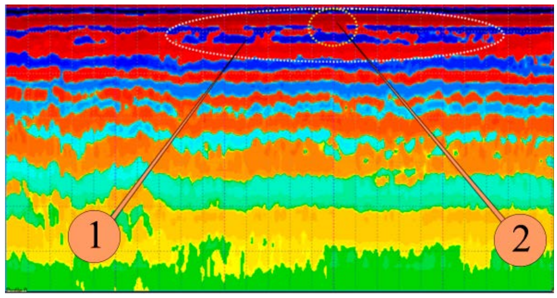

Fig.9 The first measurement by georadar of site "A" from 1000 m to 1250 m

No disturbances were observed in the embankment structure at the site "A" between 1500-1750 metres, except for thickening at 1650-1670 metres. However, a disturbed soil structure was found at the base of the embankment at 1500-1515 metres, indicating localized decompression. The bedrock's bearing capacity within 3-5 metres of the embankment soil is intact (Fig. 11).

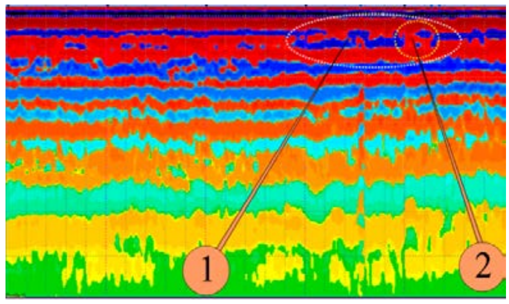

Fig.10 The first measurement by georadar of site "A" from 1250 m to 1500 m

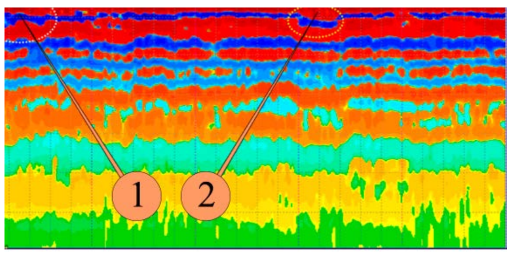

Fig.11 The first measurement of site "A" from 1500 m to 1750 m

At site "A" 1750-2000m, embankment layers have uniform structure and compaction. Anomalous disturbed soil structure (1) was found at the base of the embankment on the 1760-1800m section. Bedrock at 3-5m depth is normal and undisturbed, with no effect on soil bearing capacity (Fig. 12).

At site "B" 0-250 metres, in the array of structural layers of the embankment, there are local inhomogeneities (3) (decompression) with horizontal dimensions up to 10-15 metres. Such anomalies are recorded in sections of the profile 70-75 m, 95-112 m, 195-208 m, and 212-226 m at a depth of 1-1.2 metres. The nature of the radio pattern of anomalies indicates a local decompression of the soil at the base of the embankment (Fig. 13).

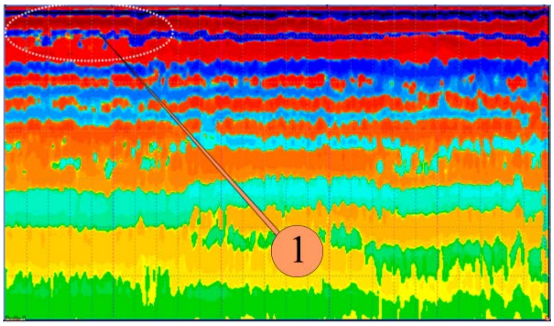

Fig.12 The first measurement by georadar of site "A" from 1750 m to 2000 m

At site "B" 250-500 metres, there are local inhomogeneities in the embankment array (3). Such anomalies are recorded in sections of the profile 255 m, 285 m, 315 m, 325 m at a depth of 1-1.2 metres. At a site of 290-380 metres, the stratification of the structural horizons of the body of the embankment (4) is recorded. At depths of 3-5 metres, a normal, undisturbed structure of the bedrock is recorded (Fig. 14).

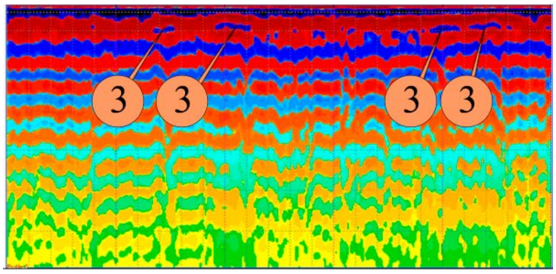

Fig.13 The second measurement of site "B" by georadar – (0-250 metres on the opposite side)

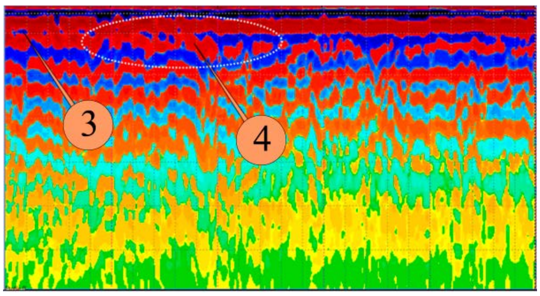

Fig.14 The second measurement of site "B" by georadar – (250-500 metres on the opposite side)

Site "B" 500-750m shows significant stratification of embankment structural horizons at 520-650m. Normal, undisturbed bedrock structure was found at 3-5m depth (Fig. 15). At site "B" 750-900m, heterogeneity and stratification of structural horizons were found at 770-900m in the embankment array (4). At depths of 3-5 metres, a normal, undisturbed structure of the bedrock is recorded (Fig. 16). At the site "C-1" 0-250 metres, starting from the 150-metre mark, elements of heterogeneity and stratification of the structural horizons in the embankment array (4). The nature and structure of the radio pattern of anomalies indicate uneven compaction of the soil layers. At depths of 3-5 metres, a normal structure of the bedrock is recorded (Fig.17).

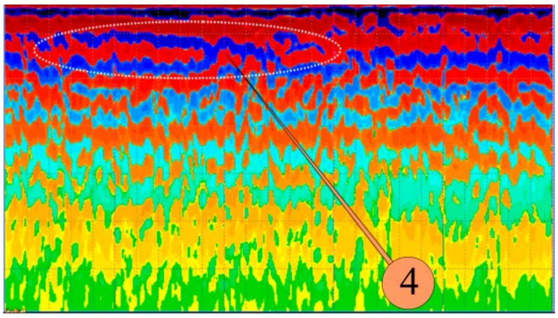

Fig.15 The second measurement of site "B" by georadar – (500-750 metres on the opposite side)

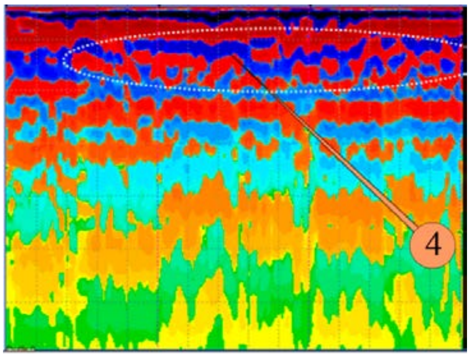

Fig.16 The second measurement of site "B" by georadar – (750-900 metres on the opposite side)

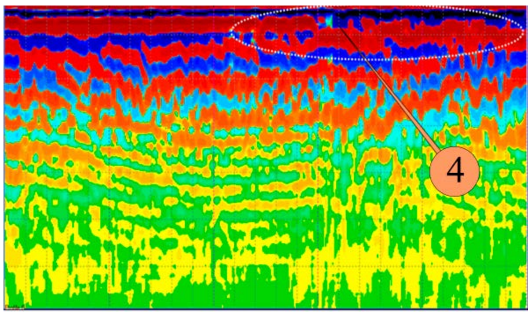

Fig.17 The second measurement of site "C-1" by georadar – (0-250 metres on the opposite side)

Site "C-2" 250-500m has no significant embankment anomalies. Heterogeneity of structural horizons was found at 150-330m, indicating uneven soil layer compaction at the base of the embankment.

Normal, undisturbed bedrock structure was found at 3-5m depth (Fig. 18).

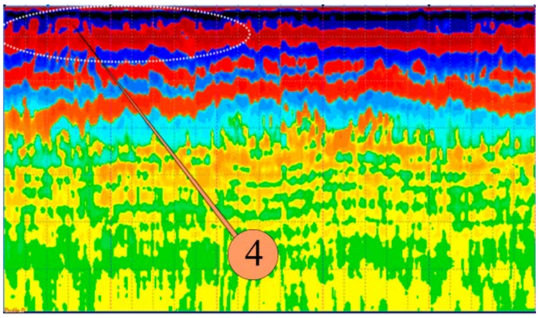

Fig.18 The second measurement of site "C-2" by georadar – (250-500 metres on the opposite side)

At the site "C-3" 500-750 metres, starting from the 150-metre mark, noticeable elements of heterogeneity and stratification of the structural horizons are registered in the bulk of the embankment (4). The nature and structure of the radio pattern of anomalies indicate uneven compaction of the soil layers at the base of the embankment. At depths of 3-5 metres, a normal, undisturbed structure of the bedrock is recorded (Fig. 19).

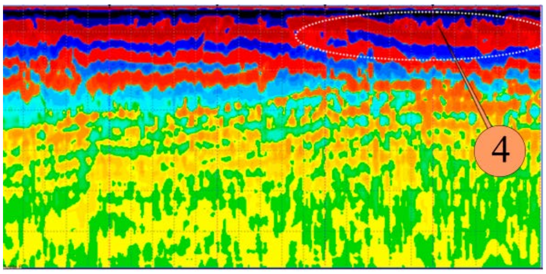

Fig.19 The second measurement of site "C-3" by georadar – (500-750 metres on the opposite side)

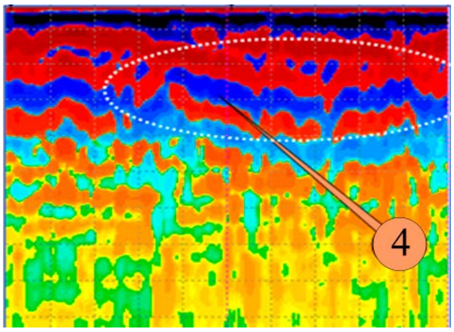

Fig.20 The second measurement of site "C-4" by georadar – (750-850 metres on the opposite side)

Site "C-4" 750-850m shows heterogeneity and stratification of structural horizons from 785m mark in the embankment, with uneven soil layer compaction at the base. Normal, undisturbed bedrock structure was found at 3-5m depth (Fig. 20).

At site "R-1" (marker 1500+75m), the old embankment (1) has a compacted "core" (5) with less compacted material in upper layers. The new embankment (2) has uniformly compacted layers with minor heterogeneity (6). Bedrock at 3-5m depth is undisturbed (Fig. 21).

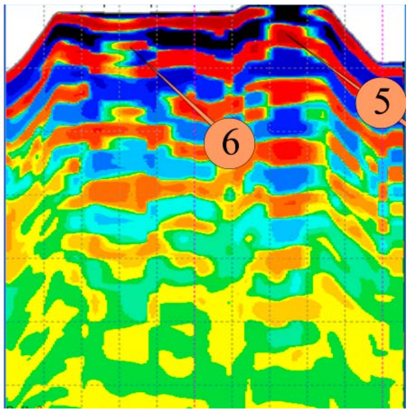

Fig.21 The third measurement by georadar of site "R-1" – (transverse profile on the survey marker 1500 +75 m)

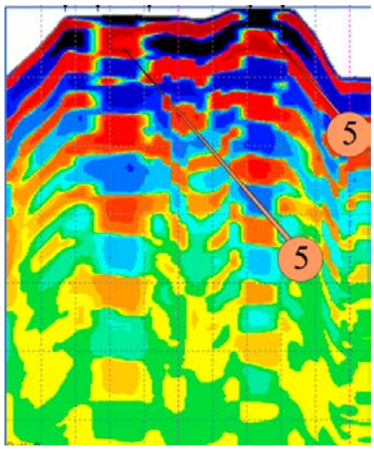

Fig.22 The third measurement by georadar of site "R-2" – (transverse profile on the 1500 m survey marker)

At site "R-2", as shown in Fig. 22, the cross-section profile (survey marker 1500 m) reflects the structure of the embankment and the base of the embankment in the cross-section, taking into account the relief of the embankment. The right part of the embankment (1) is the existing old railway. The left part of the embankment (2) is the newly constructed embankment of a new railway under construction. A massive compacted "core" (5) is registered in the embankment array of the old railway. In the upper layers of the embankment 0-0.5 metres, a less compacted part of the embankment located in the inter-rail space of the old railway is registered.

Table 1 Results of the georadar survey

Track	Abnormalities	Sections
Old	Disturbed soil structure at a depth of 1-1.2 metres	20-40 m, 55-75 m, 1080-1220 m, 1390-1465 m, 1500-1515 m, 1760-1800 m
Old	Local thickening of the embankment array	1080-1220 m, 1450-1465 m, 1650-1670 m
New	Local heterogeneities in the array of structural layers of the embankment with horizontal dimensions up to 10-15 metres (decompression)	70-75 m, 95-112 m, 195-208 m, 212-226 m, 255 m, 285 m, 315 m, 325 m
New	Local stratification of the structural horizons of the body of the embankment	"B" - 290-380 m, 520-650 m, 770-900 m; "C" - 150-250 m, 250-330 m, 630-750 m, 770-850 m
Cross-sections	Massive compacted "core" (5) in the embankment array of the old railway	Survey markers 1500 + 75 m, 1500, 1400
Cross-sections	Less compacted part (6) located in the inter-rail space is registered in the upper layer of 0-0.5 metres	Survey markers 1500 + 75 m, 1500, 1400

The left part of the new embankment consists of uniformly compacted structural layers and a massive compacted "core" (5). At depths of 3-5 metres, a normal, undisturbed structure of the bedrock is recorded. As shown in Fig. 23, at site "R-3", the transverse profile (survey marker 1400 m) reflects the structure of the embankment and the base of the embankment in cross-section, taking into account the relief of the embankment. The right part of the embankment (1) is the existing old railway. The left section of the embankment (2) is newly constructed for a new railway, while a massive compacted "core" (5) is present in the old railway's embankment.

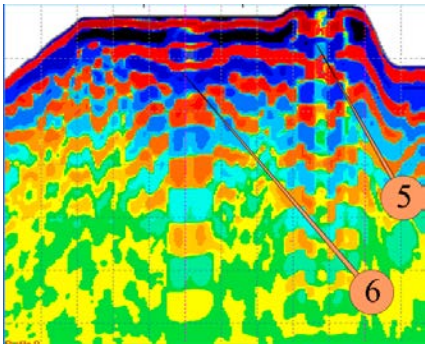

Fig.23 The third measurement by the georadar of site "R-3" – (transverse profile on the 1400 m survey marker).

A less compacted area is detected in the upper layers of the 0-0.5 metre embankment, located in the inter-rail space. The new embankment's left section (6) has uniformly compacted structural layers with minor heterogeneity. Bedrock at depths of 3-5 metres has a normal structure. As a result of the georadar survey, abnormal violations of the structure of the railway embankment were revealed (Table 1).

4. CONCLUSION

All identified anomalies represent local heterogeneities associated with insufficient and uneven compaction of the embankment array. The main part of the embankment has no anomalous disturbances in the structure of the embankment array. The structural layers of the embankment have a uniform structure and uniform compaction. The bedrock at the base of the embankment at depths of 3-5 metres has a normal undisturbed natural structure. The bearing capacity of the soil at the base of the railway embankment is not violated.

The uniqueness of this work lies in the use of georadar technology to conduct a survey of a railway embankment. This is a non-invasive method that can provide detailed information about the subsurface structure of the embankment, which is important for assessing its stability and safety. The study identified specific anomalies in the embankment structure that could affect its bearing capacity and provided recommendations for addressing these issues.

5. REFERENCES

[1] Baibatsha A.B., and Muszynski A., Geological-geophysical prospecting indicators of the arganaty district predictive blocks (Eastern Balkhash). News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, Vol. 2, No. 440, 2020, pp. 31-39.

[2] Bolatbek K., Ivanov S.I, Gordienko M.G, and Menshutina N.V., Mathematical modeling of aerogel structures, including with embedded carbon nanotubes. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, Vol. 3, No. BOOK 6, 2016, pp. 69-76.

[3] Kornet M.M., Brazhko O.A., Zavhorodniy M.P., Tkach V.V., Kruglyak O.S., Ivanushko Y.G., de Oliveira S.C., and Yagodynets P.I., Electrochemical determination of antioxidant activity of new 4-thiosubstituted quinoline derivatives with potential radioprotecting properties. Biointerface Research in Applied Chemistry, Vol. 11, No. 2, 2021, pp. 9148-56.

[4] Bondarenko I.N., Galich A.V., Slipchenko N.I., and Troitski S.I., Cone-shaped resonator the high-order mode oscillation trasducers. CriMiCo 2012 - 2012 22nd International

Crimean Conference Microwave and Telecommunication Technology, Conference Proceedings, Vol. 1, 2012, pp. 565-567.

[5] Prentkovskis O., Beljatynskij A., Juodvalkiene E., and Prentkovskiene R., A study of the deflections of metal road guardrail post. Baltic Journal of Road and Bridge Engineering, Vol. 5, No. 2, 2010, pp. 104-109.

[6] Bondarenko I.N., and Lavrinovich A.A., Investigation of the thin-film high-temperature superconductivity coplanar line. Telecommunications and Radio Engineering (English translation of Elektrosvyaz and Radiotekhnika), Vol. 66, No. 7, 2007, pp. 597-605.

[7] Onishchenko A., Stolyarova L., and Bieliatynskyi A., Evaluation of the durability of asphalt concrete on polymer modified bitumen. E3S Web of Conferences, Vol. 157, 2020, art. 06005.

[8] Barabanshchikov Y., Belkina T., Muratova A., and Bieliatynskyi A., Heat liberation of barium cements as a background of their application in mass concrete structures. Solid State Phenomena, Vol. 871, 2016, pp. 9-15.

[9] Oralbekova Zh.O., Tyulepberdinova G.A., Gaziz G.G., Adamova A.D., and Sholpanbaev B.B., The use of radar technologies in the hydraulic engineering in seismic zones. Journal of Applied Engineering Science, Vol. 19, No. 4, 2021, pp. 1040-1048.

[10] Baibatsha, A., Geotectonics and geodynamics of paleozoic structures from the perspective of plume tectonics: A case of Kazakhstan. International Journal of GEOMATE, Vol. 17, No. 71, 2020, pp. 194-202.

[11] Koval Y.M., Kutsova V.Z., Kotova T.V., and Kovzel M.A., Forecast and control of structure and properties of ultra-low-carbon steels. Metallofizika i Noveishie Tekhnologii, Vol. 43, No. 6, 2021, pp. 753-768.

[12] Kulyk K., Borysenko M., Kulik T., Mikhalovska L., Alexander J.D., and Palianytsia B., Chemisorption and thermally induced transformations of polydimethylsiloxane on the surface of nanoscale silica and ceria/silica. Polymer Degradation and Stability, Vol. 120, 2015, pp. 203-211.

[13] Francisco A., Paixao A., Varandas J.N., and Fortunato E., Short soil-binder columns in railway track reinforcement: Three-dimensional numerical studies considering the train-track interaction. Computers and Geotechnics, Vol. 98, 2018, pp. 8-16.

[14] Yenkebayeva A., Lukpanov R., Yenkebayev S., and Tsygulyov D., Comparative analysis of design solutions of a reinforced railroad embankment using various calculation methods, GEOMATE Journal, Vol. 21, No. 87, 2021, pp. 58-63.

[15] Baibatsha A.B., Kembayev M.K., Mamanov E.Z., and Shaiyakhmet T.K., Remote sensing techniques for identification of mineral deposit. Periodico Tche Quimica, Vol. 17, No. 36, 2020, 1038-1051.

[16] Kulyk K., Ishchenko V., Palyanytsya B., Khylya V., Borysenko M., and Kulyk T., A TPD ‐ MS study of the interaction of coumarins and their heterocyclic derivatives with a surface of fumed silica and nanosized oxides CeO2/SiO2, TiO2/SiO2, Al2O3/SiO2. Journal of Mass Spectrometry, Vol. 45, No. 7, 2010, pp. 750-761.

[17] Atmojo P.S., Sachro S.S., Edhisono S., and Hadihardaja I.K., Simulation of the effectiveness of the scouring prevention structure at the external rail ballast using physical model, GEOMATE Journal, Vol. 15, No. 47, 2021, pp. 178-185.

[18] Khussain B., Brodskiy A., Sass A., Rakhmetova K., Yaskevich V., Grigor’eva V., Ishmukhamedov A., Shapovalov A., Shlygina I., Tungatarova S., and Khussain A., Synthesis of Vanadium-Containing Catalytically Active Phases for Exhaust Gas Neutralizers of Motor Vehicles and Industrial Enterprises. Catalysts, Vol. 12, No. 8, 2022, art. 842.

[19] Tkach V.V., Kushnir M.V., de Oliveira S.C., Zavhorodnii M.P., Brazhko O.A., Kornet M.M., Luganska O.V., Kopiika V.V., Ivanushko Y.G., Mytchenok M.P., Ahafonova O.V., Yagodynets´ P.I., Kormosh Z.O., and Dos Reis L.V., The theoretical description for a sucralose electrochemical cathodical determination over a 9-9´-diacridyl-modified electrode. Orbital, Vol. 13, No. 3, 2021, pp. 219-222.

[20] Kutsova V.Z., Kovzel M.A., Grebeneva A.V., Ratnikova I.V., and Velichko O.A., The influence of alloying elements on structure formation, phase composition and properties of chromium-manganese iron in the cast state. Metallurgical and Mining Industry, Vol. 7, No. 9, 2015, pp. 1090-1095.

[21] Bolatbek K., Shlygina I.A, Brodskiy A.R, Ivanov S.I, and Gordienko M.G., Quantum-chemical research methods of geometrical and electronic structure of silicon dioxide aerogels. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, Vol. 3, No. BOOK 6, 2016, pp. 135-142.