# QUALITY CONTROL OF MINERAL LAYER THICKNESSES IN FOUNDATION WORKS

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**Abstract:** The installation of defined thicknesses of mineral layers in the superstructure of roads and railway tracks is closely related to the achievable bearing capacity and the long-term performance of the total structure. To be able to measure the project-specified layer thickness without delaying the construction progress, radar detectable geotextiles have been developed as quality control system, which consist of a geotextile separation and filtration layer and specially designed reflector strips, which have to be applied in defined widths and distances across the geotextile.

After installation of the mineral layer, a Georadar detection system is used, which is sending out electromagnetic impulses that are transmitted into the subgrade. The metallic strips on the geotextile reflect the impulse of the radar in the transition zone between existing subgrade and the overlying installed mineral layer, which finally allows the measurement of the actual installed thickness and quantity of fill material. The radar detectable geotextile is offering an effective and reliable quality control device to the investor at very low costs, compared to the total costs of the project. The application of such radar detectable geotextiles will be described in the paper on the basis of the rehabilitation of the railway track between the city of Bucharest and Constanta in Romania in 2007.

**Keywords:** needle punched geotextile, innovative-geosynthetics, quality control, railway, road, infrastructure projects

## NECESSITY OF NON-DESTRUCTIVE THICKNESS MEASUREMENT IN ROAD CONSTRUCTION

The layer thickness of unbounded base courses (UBC) in road construction is predominantly ascertained by determining the height of the formation level and the base course surface at several points. The thickness of the base course results from the difference in height of both levels. It is assumed that the height of the formation does not change due to the subsequent application and compaction of the UBC. In reality, however, even compaction of the UBC material frequently leads to settlement of the subgrade/roadbed and/or to the intrusion of aggregate particles from the UBC into the subgrade/roadbed due to the limited bearing capacity of the subgrade/roadbed and possibly the lack of filtration stability between the UBC material and the soil of the subgrade/roadbed (Floss 2007, Koehler et al. 2006). Their thickness even cannot be determined precisely when layer thicknesses are measured by creating shallow trial pits in the UBC because it is not possible to define a precise layer boundary between the granular UBC material and the subgrade/roadbed. This can lead to ambiguities when charging for construction work.

In the long term, due to the uneven layer thickness of the unbound base course(s) and the non-uniform bearing capacity of their surface, settlement can be expected which, in the course of the road's service life, appears as deformation (longitudinal and lateral unevenness) at the road surface, thus impairing the servicability of the roadway.

If there is inadequate filtration stability between the UBC material to be applied to the formation and the soil of the subgrade/roadbed, the occurrence of erosion at the layer boundary can be prevented by placing a geotextile on the formation. The geotextile must be dimensioned with regard to its mechanical and hydraulic filtration efficiency. Selection is also based on application demands, according to the necessary geotextile robustness class (FGSV 2005, Koehler 2007). The geotextile assumes the separation and filtration function in the formation level, not only under construction but also during the service life of the traffic area superstructure.

Layer thickness measurements using "Ground Penetration Radar" (GPR, frequently called "georadar") are often performed for the purpose of capturing inventory data for the repair management of road infrastructure, not only in the acceptance of construction work but primarily also to determine the stratigraphic sequence of existing traffic area superstructures (Foerster et al. 2001). In cases where the structural conditions and water content of the UBC and the subgrade/roadbed, and hence the dielectric constant, of both layers do not differ considerably, the formation level is not clearly discernible on the measured radargrams, which means that the thickness of the UBC or the whole superstructure cannot be measured reliably. This is the reason for the demand for the precise fixed mark on the formation level as the reference level for a non-destructive measurement of layer thicknesses, using georadar.

## GEOTEXTILE WITH REFLECTOR STRIPS (RDG) TO IDENTIFY THE FORMATION LEVEL

The described task of creating a fixed mark of the formation level for georadar measurements was the catalyst for a joint development between the companies GBM Wiebe Gleisbaumaschinen and NAUE GmbH & Co. KG, manufacturer of geosynthetics. The outcome of this development is a mechanically bonded geotextile onto which aluminium strips with a width of 5cm to 20cm (depending on requirements) are attached across the roll width at intervals of 2m to 5m in longitudinal direction of the roll. This geotextile is called a "Radar Detectable Geotextile" (RDG).

**Figure 1.** Mechanically bonded geotextile with aluminium reflector strips (RDG)

The reflector strips that are installed transverse to the longitudinal direction are detected as anthropogenic obstacles when scanning the traffic area superstructure using the Georadar method; they are shown as hyperbolas in the radargrams, enabling the formation level to be identified precisely. Due to the separation and filtration function of the geotextile, the base course material and the subgrade/roadbed material are prevented from mixing, thus ensuring the permanent frost resistance of the superstructure by inhibiting hydraulically caused erosion at the layer boundary. RDGs are applied in the same manner as conventional separation and filtration geotextiles; the reflector strips do not affect the installation procedure.

The catalyst for the development of the RDG was the need to be able to clearly detect the formation level for construction supervision in railway track construction. Above all, the dimensions, course and quality of the ballast beneath the track system and the issue of ballast mixing with the material of the formation protection layer (FPL) were to be investigated and documented by means of a track survey using Georadar methods.

## APPLICATION IN RAILWAY TRACK CONSTRUCTION - DEFINED DETECTION OF LAYER BOUNDARIES WITH REFERENCE TO THE "RADAR DETECTABLE GEOTEXTILE (RDG)"

The GeoRail method has been used since 1990 by national and international railroad network operators for pre-exploration purposes ("rough diagnosis“) and quality control (Haszio 2007, Niessen 2000, Niessen 2002, Niessen 2004). The company GBM Wiebe Gleisbaumaschinen GmbH investigates an average of approx. 1,500 kilometres of railway track per year using the GeoRail method. A vehicle equipped with the necessary devices can be seen in Figure 2. Measurements are taken at 80 km/h with a longitudinal resolution of 5cm (20 georadar scans per metre for all three profiles). The scale generated is 1:500.

**Figure 2.** Control vehicle with GeoRail measuring system

The measured data captured by using the georadar method deliver information that is as precise as possible to ensure customers can make further use of it for the tasks of the railroad network operator. Although routinely performed GeoRail measurements provide the precise detection of layer boundaries, their course and quality, and although data evaluation and interpretation specialists are able to clearly identify these layers, the signatures in the radargrams are not apparent to laymen. This is why work on visualisation options oriented towards DIN 4023 has been carried out in recent years. Radargrams can then be read by civil engineers and geotechnicians (see Figure 3).

Figure 3 portrays the final product of a GeoRail track survey. All details are presented synchronously and continuously on the monitor. All data is stored in a database to enable changes to the data inventory to be automatically incorporated into the 2D display.

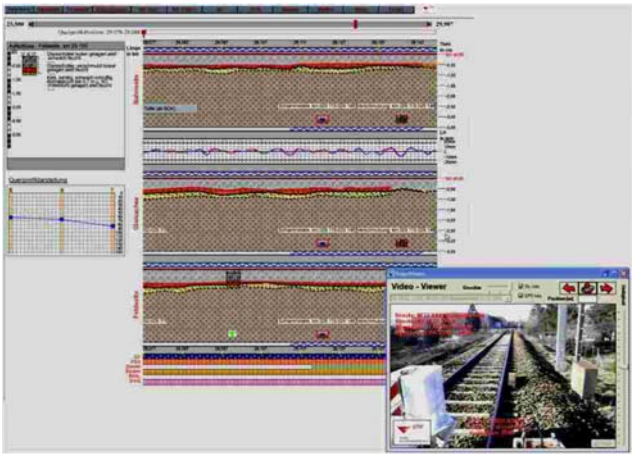

**Figure 3.** 2-D display of three measured profiles with video, exposures, cross profile and longitudinal track heights

Using the tools shown above, high-quality radar data that can be evaluated and displayed. The layer thicknesses and transverse gradient can be read directly from the radargrams. Even small-scale defects are easily discernible. In case of doubt, several calibration exposures have to be performed.

The radargram example in Figure 4 shows an approx. 70m long rehabilitation section. The design of the superstructure is a ballasted track with a formation protection layer (FPL) arranged beneath the ballast. The rail side and exteriors are portrayed. The exteriors of a double track are the sides facing away from the track axis; they adjoin the neighbouring terrain. The rail sides make contact in the track axis. In the case of single tracks, the exterior is always on the right side with ascending chainage.

The gradient is immediately discernible from both radargrams as well as the minor disturbance on the rail side (red arrow). The layer boundaries appear slightly blurred on the field side. This is due to a mixed zone, which has a thickness of a few centimetres. Effluent water transports fine-grained material along the gradient towards the exterior and covers the actual bottom edge of the ballast. In the region of the layer boundary between the formation protection layer and the subgrade (lower edge of FPL), FPL material mixes with the in-situ subgrade.

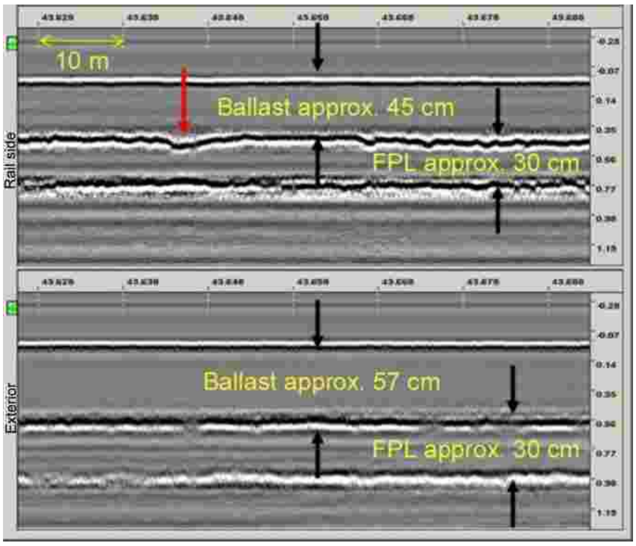

**Figure 4.** Track and field side of a newly constructed track; the red arrow designates a damaged spot

However, radargram signatures cannot clearly be attributed to existing objects and layer boundaries. Ideally, the layer boundaries to be detected should create signatures that are not expected there. For this reason, a geotextile with applied reflector strips (RDG) across the direction of traffic is incorporated into the layer boundary between the formation protection layer and the subgrade. The 20cm wide strips are placed at 5m intervals. Both the layer boundaries and the reflector strips are detected when scanning the railway track. Their signatures clearly represent the bottom edge of the FPL. Figure 5 shows a measured section with such reflector strips. Small hyperbolas are created when crossing the strips; the peaks clearly represent the position of the RDG. Their regular occurrence ensures clearness. If the peaks of the hyperbolas are connected along the identifiable layer boundary, their actual course is obtained. Since metals act as total reflectors for radar signals, the reflector strips are even easily identifiable in regions where there is mixing with water or other materials.

In the radargram example in Figure 5, two parallel radargrams (track axis + exterior) are depicted. A geotextile with reflector strips was installed in the track axis (RDG trial sample). Due to mixing with water, the bottom edge of the FPL is virtually indiscernible but the hyperbolas in the track axis are very clear: the peaks of the hyperbolas represent the layer boundary onto which the RDG was installed (reflector strips lie on the terrestrial body).

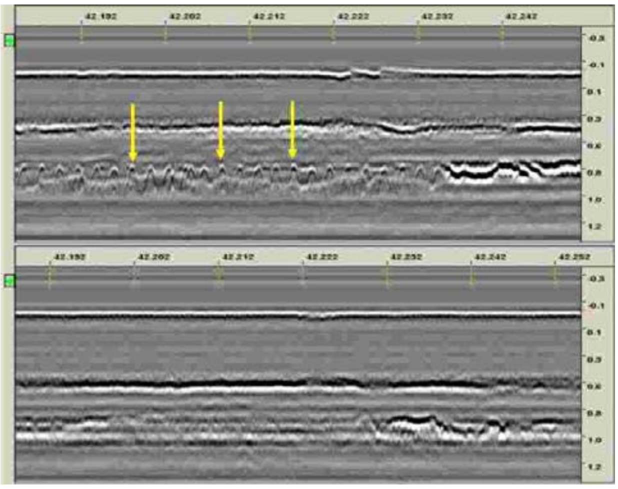

**Figure 5.** Radargram identifying the bottom edge of the formation protection layer (yellow arrows) based on the reflector strips applied to the geotextile

## APPLICATION OF THE RDG IN A TEST FIELD FOR TRAFFIC AREA SUPERSTRUCTURES

### Construction of the traffic area superstructures

Within the scope of construction works at the campus of Lippe and Hoexter University of Applied Sciences in Detmold, Germany, the outside facilities, among other things, were reconstructed. A car park with an area of $30m^2$ was designed as a "test field for water-permeable traffic area superstructures", according to specifications by the subject area "Earthwork and Road Construction". The superstructure consists of a uniform 0/32mm gravel base course with a regular thickness of 40cm and six different road surfaces. These included four water-permeable paved surfaces, a conventional concrete paving stone surface and an asphalt pavement made of water-permeable asphalt.

The silty soil that was available as the subgrade had an inadequate bearing capacity ($E_{v2} \approx 35MPa$). For this reason, plans were made to place a separation/filtration geotextile and a geogrid on the formation as base course reinforcement. The mechanically bonded geotextile with reflector strips (mass per unit area: $250g/m^2$, GRK 4; see Figure 1) developed by the companies NAUE and GBM Wiebe was used as the separation/filtration geotextile (see Figure 6).

**Figure 6.** Covering of RDG and geogrid with the (reddish coloured) gravel base course material

### Measuring the superstructure thickness using georadar

After completion of the traffic area superstructures, georadar measurements were performed on the test field by the company GBM Wiebe with the aim of determining the superstructure thickness. The measurements were carried out along five parallel lines with 1,000MHz antennae, whereby all of the surface course designs and reflector strips were crossed. Immediately after completion of the measurement, three shallow trial pits were created along one of the measurement lines, whereby the complete superstructure (paving stones, bedding layer and gravel base course) was dug up down to the geotextile on the formation. The superstructure thickness measured at the first trial pit was used by the company GBM Wiebe as a reference value for the calibration; the two remaining measured values of the superstructure thickness acted as control values for the georadar measurement.

**Table 1.** Comparison of the total thickness of the superstructure determined by excavation and by georadar measurement

| **Trial pit** | | **Superstructure thickness [cm]** | |
|---|---|---|---|
| **No** | **Road surface course** | **From trial pit** | **From georadar measurement** |
| 1 | Conventional rectangular paving stones on gravel chippings bedding layer | 53.0 | -<br>(calibration point) |
| 2 | Drainage concrete rectangular paving stones on gravel chippings bedding layer | 68.5 | 68.0 |
| 3 | Drainage paving stones on gravel chippings bedding layer | 59.0 | 59.0 |

**Figure 7.** Georadar measurement by the company GBM Wiebe

As immediately apparent from the radargrams following the georadar measurement (Figure 8), the reflector strips applied to the formation are clearly identifiable. The various superstructure designs are also represented in the radargrams with partially specific signatures. It is also apparent that the superstructure thickness is extremely variable, which is due to the uneven thickness of the gravel base course. Although the formation was extracted evenly, settlement of the subgrade has obviously occurred in places, due to the application of the gravel base course, which was levelled out by applying additional base course material.

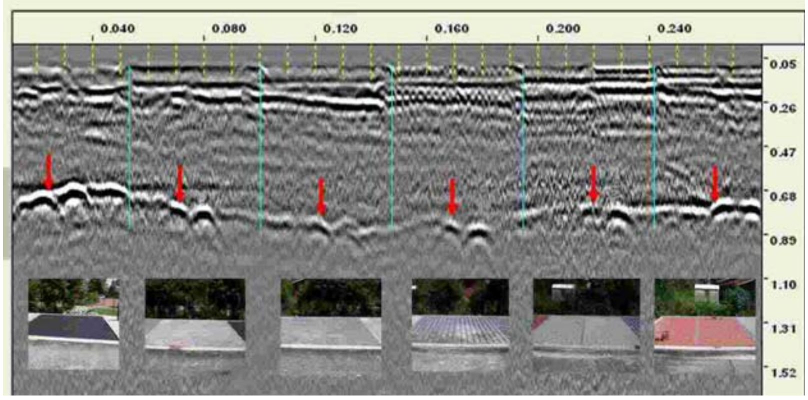

**Figure 8.** Test field radargram (red arrows mark the RDG reflector strips; the distance between the markers, entered as yellow dotted lines, is 1 m)

The results of the trial pits, with measured superstructure thicknesses of between 53cm and 68.5cm, confirm the uneven superstructure thickness that was already discernible from the radargrams. The superstructure thickness derived from the radargrams corresponded almost exactly, with a deviation of 0.5cm; to the values determined at trial pit site 2 and 3 (Table 1).

## USE OF RELIABLE LAYER THICKNESS INFORMATION FOR CONSTRUCTION SUPERVISION AND INFRASTRUCTURE MANAGEMENT OF ROADS

Georadar measurements for the non-destructive determination of the layer thicknesses of traffic area superstructures in relation to an RDG in the formation level can – depending on the time of implementation – serve a number of purposes:

### Construction supervision

As shown by results of georadar measurements at the test field of Lippe and Hoexter University of Applied Sciences, settlement of the subgrade/roadbed during the application of road superstructure layers can lead to a low or non-uniform bearing capacity. The formation then no longer reveals an even course, as usually assumed. The occurring settlement is predominantly levelled out by applying additional base course material. When construction works are charged by the square measure [m²], the contractor is usually not compensated for the additional installation of base course fill material. If, on the other hand, the base course material is charged according to the delivered and installed mass [t], this service is compensated, even if the unexpected higher mass of installed material often leads to discrepancies between the customer and the contractor. The example shown above therefore highlights the necessity to place an RDG onto the formation and to perform georadar measurements with the aim of determining a more precise construction mass and bill of cost for construction works. As a side-effect, the base course material is also prevented from drifting into the subgrade/roadbed, since the filtration stability between the base course material and the soil of the subgrade/roadbed can be guaranteed with the use of a geotextile.

Georadar measurements in relation to the RDG in the formation level should also be used to determine the stratigraphic sequence following repair and rehabilitation work. If work is carried out in civil engineering or in combined civil engineering and structural engineering applications, the previously existing layers remain in fluctuant thickness in the construction, meaning that fluctuations in the new stratigraphic sequence can be documented by measurements.

### Infrastructure management

If no construction files are available, in the context of infrastructure management, inventory data for traffic area superstructures can also be generated using georadar measurements. An RDG applied at the formation level increases the reliability of the layer thickness measurement for unbound base courses. The determined layer thickness fluctuations are of considerable importance to the prediction of the expected development of irregularities in the road surface. The generated inventory data, which are stored in the road database, are of vital importance to determining values for road infrastructure.

In order to support maintenance planning, georadar measurements should be used to identify weak spots, such as at the boundary of homogeneous sections or when stipulating maintenance work. The procedure necessary for this has been tried and tested several times. Its reliability can be increased yet further by referencing a defined formation level using RDGs.

## CASE HISTORY

### Rehabilitation of Railway Line Bucharest-Constanta, Romania

The railway section Bucharest - Constanta is the main railway route in Romania, both for international and national traffic. It links the capital Bucharest to the city of Constanta, which is the main port at the Black Sea as well as the main tourism, entertainment and health resort of Romania. The Bucharest-Constanta line is part of the "Pan-European Corridor IV railway line", connecting Germany and Turkey. The overall objective of the rehabilitation of the railway section Bucharest- Constanta is an upgrading of the railway line to EU standards. The project refers to an existing double tracked line, which will completely be rehabilitated with the help of EU-ISPA Programme funding, Romanian Government funds and a loan granted through the Japan Bank for International Cooperation (JBIC). The total railway track is subdivided into three sections and has a total length of approx. 225 km. The existing subgrade in the area of the railway track consists of a mix of granular soil (old ballast, sand, gravel & stones) and fine grained material (loess). It provides insufficient bearing capacity for the planned railway superstructure.

The design of the railway superstructure was technically oriented towards standards defined by the German Federal Railway Authority (EBA). On top of the FPL (0-63 mm) a static deformation modulus of $E_{V2} = 80$ MPa (according to DIN 18134) was specified. The design of the superstructure is based on maximum speeds for freight trains of 120 km/h and for passenger traffic of 160 km/h. A typical cross section of the railway superstructure is given in Figure 9.

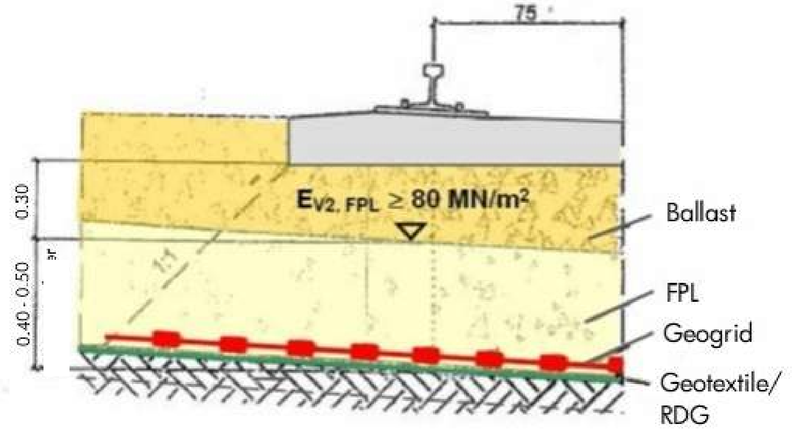

**Figure 9.** Standard Cross Section of Railway Superstructure

Between the city of Fundulea and Feteşti (approx. 100 km long section) the project specification asked for a system that enabled the measurement of the installed thicknesses of the individual layers (FPL & Ballast) installed on top of the formation. The use of a radar detectable geotextile (RDG) fulfilled this requirement. Using the RDG it is possible to measure exactly the in-situ layer thicknesses of the installed FPL and ballast without delaying the construction works, as the monitoring will take place after the complete system has been installed already.

In Figure 10 the installation of the FPL and the ballast on top of the RDG and the laid and welded geogrid (Secugrid® 40/40 Q1) is shown.

**Figure 10.** Installation of FPL on RDG and geogrid

Carried out load plate tests proved that the use of a laid and welded Secugrid® geogrid together with the needle punched Secutex® geotextile/RDG underneath the FPL resulted in an additional safety potential for the railway track, as the minimum required project specific deformation modulus of $E_{V2} = 80$ MPa had been exceeded by more than 60 % of all carried out load plate tests.

The combination of the used geogrid reinforcement together with a separation and filtration geotextile/RDG improve the serviceability and further allow an ongoing monitoring of the performance of the rehabilitated railway section.

## SUMMARY

The layer thickness of unbounded base courses (UBC) in road construction is predominantly determined by the difference between the height of the base course surface and the height of the formation. Both stratified surfaces are assumed to be level. In reality, however, settlement of the formation frequently occurs during application of the base course, which is levelled out by applying addition base course material. The course of the layer boundaries in the

superstructure and also the course of the formation after construction of the traffic area superstructure can be determined non-destructively with the use of georadar measurements. However, it is often impossible to clearly identify the formation level from the results of previously performed georadar measurements. A newly developed geotextile with integrated reflector strips (so-called "Radar Detectable Geotextiles, RDG"), placed on top of the formation generates clear boundaries of the formation level in the radargrams.

In railway track construction, RDGs are already being used to prevent formation protection layer material from mixing with the soil of the subgrade/roadbed beneath it. Within the scope of systematic pre-exploration with the GeoRail method, the reflector strips serve the purpose of clearly identifying the formation level in the recorded radargrams. The thicknesses of the formation protection layer (FPL) and the ballast layer beneath the track system can then be determined precisely. Layer inhomogeneities can be identified likewise.

The RDG that has already been used and tested in railway track construction was applied at the formation level in traffic area superstructures of road construction for the first time in a test field of the Lippe and Hoexter University of Applied Sciences. The georadar measurements show, that the course of the formation beneath the completed superstructure can be clearly identified using radargrams. Settlements in the formation level, which occur during the installation of the first base course layer and that leads to the installation of additional base course material, can be identified. The identification and documentation of the formation level and the surfaces of superstructure layers by georadar measurements can hence lead in future not only to an improvement of the determination of construction dimensions, but can also increase the reliability of inventory data for the purpose of infrastructure management. Due to the reflector strips of the RDG as a fixed mark on the formation level, it is possible to clearly identify the formation in the radargrams as a reference level.

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